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Sara Paiva
Editor

Mobile Solutions and Their Usefulness in Everyday Life

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Mobile Solutions and Their Usefulness in Everyday Life

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Editor
Sara Paiva
Applied Research Centre for Digital
Transformation - ARC4DigiT
Polytechnic Institute of Viana do Castelo
Viana do Castelo, Portugal

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Part I
IoT Applications

Chapter 1
Integrated Mobile Solutions in an Internet-of-Things Development Model

Issam Damaj and Safaa Kasbah

Abstract The Internet-of-Things (IoT) is a revolutionary technology that is rapidly changing the world. IoT systems strive to provide automated solutions for almost every life aspect; traditional devices are becoming connected, ubiquitous, pervasive, wireless, context-aware, smart, and controlled through mobile solutions, to name but a few. IoT devices can now be found in our apartments, places of work, cars, buildings, and in almost every aspect of life. In this investigation, we propose an IoT system Development Model (IDM). The proposed IDM enables the development of IoT systems from concept to prototyping. The model comprises concept refinement pyramids, decision trees, realistic constraint lists, architecture and organization diagrams, communication interface patterns, use cases, and menus of analysis metrics and evaluation indicators. The investigation confirms that the proposed model enjoys several properties, such as clarity, conciseness, thoroughness, and productivity. The model is deployed for a variety of systems that belong to heterogeneous areas of application; the model is proven to be effective in application and successful in integrating mobile solutions. This chapter includes the presentation of the IDM sub-models, reasoning about their usefulness, and technical developments of several systems. The chapter includes thorough discussions, analysis of the model usability and application, and in-depth evaluations.

I. Damaj (✉)
Electrical and Computer Engineering Department, American University of Kuwait, Salmiya, Kuwait
e-mail: idamaj@auk.edu.kw

S. Kasbah
Computer Science and Mathematics Department, Lebanese American University, Beirut, Lebanon
e-mail: safaa.kasbah@lau.edu.lb

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1.1 Introduction

The quest for automating places of living, work, and services has ever existed. The aim of all times has been to reduce the amount of labor, saving energy, saving materials, improving quality of life, increasing security, enhancing safety, and more. In the old times, ancient societies had float-valve regulators, water clocks, oil lamps, water tanks, water dispensers, etc. The mechanical revolution brought us the much-needed locks, switches, pumps, shading devices, etc. The electrical revolution introduced relays, switches, programmable controllers, and more. Recently, embedded systems such as microcontrollers and programmable devices enabled the automation of an almost infinite list of gadgets, equipment, vehicles, tools, etc. In the 1990s, carrying out a home automation project means the sole responsibility to fabricate all interfacing, port expansion, and bus cards. In addition, the development should include all the soft interfaces. Although the electronic designs were somewhat available, easy to reach and off-the-shelf purchases were almost nonexistent.

At present, a wide range of plug-and-play computer interfacing kits are made available by a variety of providers, such as the Arduino Project, Phidgets, Raspberry Pi, Handy Kit, and National Instruments (NI) systems, to name a few. The richness of present-day interfacing gadgets comes from its ability of integration within ubiquitous and pervasive computing environments that can be controlled through effective, flexible, and easy-to-use mobile solutions. Indeed, the integration of mobile systems and embedded systems, within Internet-of-Things (IoT) applications, enables the development of powerful devices and applications that contribute to people's well-being.

In this chapter, an abstract IoT system Development Model (IDM) is presented. The model comprises concept refinement pyramids, decision trees, realistic constraint lists, architecture and organization diagrams, communication interfaces, use cases, and menus of analysis metrics and evaluation indicators (EIs). The proposed IDM integrates hardware and software subsystems, and their interfaces. The hardware subsystem includes processors, sensors, interfacing boards, etc. Although the IDM partly adopts sub-models that are common in software engineering, it provides a unique integration and enables effective development, application, presentation, and evaluation. The software subsystem comprises core applications, drivers, databases, etc., all developed for mobile applications or interfaces. The research objectives of the work presented in this chapter are as follows:

- Develop a model that enables the design, implementation, analysis, evaluation, and presentation of an IoT system. The proposed model integrates hardware, software, and mobile solutions. The proposed model aims at being clear, concise, visual, easy to use, and effective in application.
- Develop sub-models that can capture the concept, functional requirements, and nonfunctional requirements of an IoT system. The sub-models are tools that aid the capturing and representation of system functions, technologies, architecture and organization, and system interactions.

- Integrate hardware and software systems in development.
- Integrate mobile solutions in development.
- Integrate the main realistic constraints and analysis metrics in development.
- Integrate evaluation indicators in development.
- Target academic users within the context of computer engineering and science.
- Target industrial users.
- Evaluate the model usability and effectiveness in application by developing a variety of IoT systems. All the developed systems adopt the proposed model and a Capstone Design Project (CDP) setup in an undergraduate program on Computer Engineering.

The IDM is used to create and represent several IoT systems. The developed systems include AgriSys, NFC Wallet, and RECON [1–3]. The systems enjoy several creative features including the successful integration of mobile solutions. AgriSys is an agriculture system that deals with desert-specific challenges, such as dust, infertile soil, wind, low humidity, and the extreme variations in temperatures. NFC Wallet develops a universal card machine that enables the use of highly secure wearable bracelets to completely replace one's cards and keys in payments and secure access. In addition, RECON is a long-distance delivery and monitoring drone controlled at one's fingertips using a smart device over the Internet. Indeed, all the proposed IoT systems are ubiquitous, integrate mobile solutions, and contribute to people's well-being.

This chapter is organized such that Sect. 1.2 presents related work. Section 1.3 presents the development model. In addition, Sect. 1.4 presents sample applications, while Sect. 1.5 thoroughly analyzes and evaluates the proposed model. Section 1.6 concludes the chapter and sets the grounds for future work.

1.2 Related Work

IoT is a collection of various technologies that work together in tandem. Numerous attempts have been made to realize an IoT framework that distills the technological complexities of the IoT into single multilayered system architecture. Yet, there is no single consensus on the best development model for IoT. Different reference models have been proposed, for each IoT layer, by different researchers. While a group of researchers consider the development of reference architectures can lead to a faster and exponential increase of IoT-related solutions, other groups believe that the real impact of IoT will be felt in realizing a development model at either the application or the communication level. However, an Integrated Development Environment (IDE) that captures architectural, behavioral, and communicational aspect of IoT will ultimately take IoT to the next level. In the following subsections, we explore existing IoT development models, devices, and enabling services.

1.2.1 IoT Development Models

A complete suite of tools spanning both hardware and software is presented in [4], namely, Michigan's IoT Toolkit. This toolkit has five components: a gateway, four hardware building blocks, multiple sensor platforms, an indoor localization system, and software for connecting users and devices. To address the pitfalls of current applications (limited to specific devices, protocols, etc.), Michigan's IoT provides a layered interoperable system that offers support for moving single-device, cloud-centric applications and toward richer applications that incorporate multiple data streams, human interaction, cloud processing, location awareness, multiple communication protocols, historical data, access control, and on-demand user interfaces under variable external lighting conditions. In [5], Fuller et al. presented a graphical system design approach that includes hardware abstraction, a heterogeneous multiprocessing environment, and different models of computation.

The emergence of a common reference model for the IoT domain and the identification of reference architectures can lead to a faster and more focused development of IoT solutions. In [6], an Architecture Reference Model (ARM) is developed. ARM attempts at standardizing the implementation of IoT systems based on an integrated, common approach and an accessible, reference architecture. ARM sustains the interoperability of solutions at the communication level, service level, and across various platforms. Also, ARM enables the users to derive use-case and application-specific architectures. In [7], the authors introduced and discussed two reference architectures, the ARM [6] and the architecture proposed by WSO2 [8]. By analyzing the characteristics of these architectures, the authors intend to shed light on important issues that will take the research on reference architectures to a higher level. The two proposals were analyzed in terms of their support for addressing the main requirements of IoT systems.

In [9], the authors proposed a cloud-based development environment focused on building Wireless Sensor Network (WSN) applications for IoT, called COMFIT. COMFIT enables the users to develop IoT applications with a simple web interface that requires only a browser. The user's computer is not responsible for most of the processing performance since all the compilers and simulators are hosted in the cloud. COMFIT is composed of two modules. The first module is the App Development Module, which is a Model Driven Architecture infrastructure; it is responsible for providing the application developers with the proper abstraction to support the different phases of application development lifecycle (design, validation, deployment, maintenance, etc.). The second module is the App Management and Execution Module; it is responsible for providing the functionality of uploading the generated code to the remote server hosted in the cloud. In [10], the authors proposed four design patterns (Problem, Context, Motivation Forces, and Solution Details) enabling IoT architects to construct edge applications. The defined patterns are reusable, inter-related, and well structured, providing efficient and reliable solutions to recurring problems discovered by IoT system architects.

In [11], a model-driven methodology for the design and development of smart IoT-based systems is presented. Inspired from the human nervous system and cognitive abilities, a set of autonomic and cognitive design patterns is presented, requirements while taking into consideration big data and scalability management, to incrementally refine the system functional and nonfunctional requirements. A cognitive monitoring system for managing the patient health based on heterogeneous wearables is developed to demonstrate the efficiency of the proposed patterns.

In [12], the authors proposed an IoT domain model based on recent available applications from real world. Their model is derived from the extraction of the concepts and the associations that represent the applications in IoT. Concepts can be "Traditional Internet" concepts (computational service, storage service, end user application, etc.) or "Thing" concepts (EOI, resource, action, device, sensor driver, etc.). Associations represent the relationship between the concepts (observe, produce, run-on, host, etc.). Three IoT applications, shared book reviews, smart plants, and room HVAC maintenance, were successfully modeled using the proposed domain model.

1.2.2 IoT Devices and Enabling Services

IoT devices need mechanisms to connect to the Internet to communicate with other devices and to supporting servers. The communication between IoT devices is mainly wireless because they are generally installed at geographically dispersed locations. The leading communication technologies used in the IoT world are Wi-Fi, Bluetooth, ZigBee, NFC, 2G/3G/4G cellular, and other proprietary protocols for wireless networks. Depending on the application, factors such as range, data requirements, security and power demands and battery life will dictate the choice of one or a combination of technologies.

Today, the most common hardware platforms used by IoT system designers are Arduino, Raspberry Pi, Phidgets, National Instruments, to name but a few. The deciding factor in choosing among these devices can come down to precision, speed, ease of programming. Each has differences in language used, ease of use, cost, and reliability. Arduino is an open-source electronics platform or board and the software used to program it [13]. Some Arduino boards have built-in Wi-Fi and Ethernet capability, plus Linux processors to support more complex functionality. The Arduino boards are programmed through USB-to-serial adapters. The LabVIEW Interface for Arduino (LIFA) Toolkit is a FREE download that allows developers to acquire data from the Arduino microcontroller and process it in the LabVIEW Graphical Programming environment. The advantage of Arduino specifically, and part of what makes it so popular when compared to other development boards, is that there is a standard connector scheme that allows shields to be attached. Shields enable connections to motors, cameras, displays, sensors, etc. and are usually necessary in prototypes. The design can be stand-alone, and all the codes can reside on the device, allowing for a cost-effective and portable design. Arduino makes several different boards, each with different capabilities. Arduino Uno is the simplest and most popular board that contains everything needed to support the microcontroller. LillyPad Arduino is a wearable e-textile technology designed with large connecting pads. It can be sewn to fabric and connected to power supplies, sensors, and actuators with conductive thread.

Phidgets are USB sensors and controllers that connect computers to the real world [14]. Phidgets offer a wide range of language support, which includes an API for C#, C++, Java, Python, Visual Basic, Ruby, LabVIEW, Max/MSP, and more. Example codes for Phidgets, and for most products in several languages, are readily available and can easily be adapted for any project. Phidgets are computer dependent, needing to be connected to a computer to run the application code. Communication with Phidgets can be done in the same language as the source code for the application being developed. This allows users to draw on existing libraries and extensions for any given language without having to develop a bridge between these different environments. Several prototypes have attached Phidgets to a Raspberry Pi, which runs the application, allowing for a fairly cost-effective and portable design. The most popular Phidget boards are pH Phidget, Sonar Phidget, and Phidget RFID Board USB.

Raspberry Pi is a small-size Linux computer; it is fully functional to the point where it can run desktop applications [15]. Raspberry Pi can be programmed in standard languages like Python and comes with it already installed. Raspberry Pi has multiprocessing capability and can run more than one application at a time. It can easily drive video displays and USB devices, like keyboards and mice, but is harder to wire up to sensors. Debugging is easy on Raspberry Pi, with more advanced tools available and the ability to run Python interactively.

National Instruments' (NIs') products are intended for engineers and scientists needing to measure and control in areas that require a high degree of precision and accuracy [16]. They provide an integrated hardware and software platform with a graphical system design that abstracts complexity. NI offers the RIO family of FPGA-based deployment targets and the CompactDAQ data acquisition controllers and chassis.

On the software side, several commercial, and open-source, IDEs and services are available for IoT systems. Indeed, the available software solutions and services effectively enable mobile services. NI hardware is programmed using LabVIEW software exclusively. LabVIEW is an IDE that has been designed specifically for engineers and scientists building measurement and control systems. LabVIEW is used to program NI systems; however, currently, LabVIEW can support a wide range of devices such as Arduino and Phidgets. Systems created using LabVIEW can be published and hosted on a webserver and can be accessed online using PCs, laptops, tablets, etc.

Many online services are available for supporting the development of IoT systems. Web hosts support users with online systems for storing information, images, videos, or any content accessible via the web. For example, GoDaddy.com is a private web hosting company that provides domain registration, hosting, and other e-business services. Arduino IDE is an online platform that enables the users to write the code, access tutorials, configure boards, and share the projects. The code is saved to a Cloud, always backed up, and is accessible from any device. Arduino IDE automatically recognizes any Arduino board connected to the PC and configures itself accordingly. Moreover, MobiOne is an advanced cross-platform mobile software development environment for creating both iOS and Android applications, as well as optimized mobile web apps. MobiOne runs on Windows system and provides a drag-and-drop interface for creating multi-page applications. MobiOne programming model is based on the web programming model and uses HTML, CSS, and JavaScript for customization [17].

Other services include Amazon Web Services (AWS) IoT; it is a platform that collects and analyzes data from internet-connected devices and sensors and connects that data to AWS cloud applications [18]. AWS Mobile is a platform that provides a range of services that help in the development of mobile apps. AWS Mobile includes a variety of tools, including tools to track application analytics, manage end-user access and storage, set up push notifications, deliver content, and build back-end services. Furthermore, Google Cloud IoT is a set of fully managed and integrated services (Cloud IoT Core, Google BigQuery, Cloud Machine Learning Engine, and Google Data Studio) that allow to easily and securely connect, manage, and ingest IoT data from distributed devices at a large scale, process and analyze data in real time, implement operational changes, and take actions as needed [19].

1.3 The Internet-of-Things Development Model

The proposed IoT Development Model (IDM) enables system development by providing sub-models that can capture the concept, functional requirements, and nonfunctional requirements. Moreover, IDM sub-models are tools that aid the capturing and representation of system functions, technologies, architecture and organization, system interactions, main realistic constraints, analysis metrics, and evaluation indicators. IDM comprises Concept Refinement Pyramid (CRP), Decision Trees (DTs), Architecture and Organization Diagram (AOD), Communication Interfaces (CIs), Use Case Diagrams (UCDs), Realistic Constraint List (RCL), Menu of Analysis Metrics (MAMs), and Evaluation Indicators Graph (EIG). The CRP is a pyramid that refines the system top-level concept to Functions and Technologies. Usually, the CRP is of three levels. Each level is described with short statements. The top of the CRP is the concept that must be defined using a title. The purpose of the CRP is to provide an illustration of the system concept, design, and implementation highlights. The highlights of the Functions and Technologies levels address issues that comprise system currency, novelty, design functions, implementation technologies, adherence to professional ethics, and attention to global, economic, environmental, and societal factors.

DTs, UCDs, and AODs are refinements of the functional requirements of the system. A DT is a multi-leaf-node tree that illustrates alternate design or implementation options at the Function or Technology levels. DTs show design and implementation alternatives and options. One of the DT nodes is selected as the designer choice. Evaluation characteristics are included in the tree nodes to justify the selection. Moreover, the IDM adopts the UCDs of UML to depict the system interactions. UCDs include actors that interact with the different system functionalities, such as managing, using, extending, and including. Besides, UCDs specify the events of a system and their flows.

The AOD is the core of the IDM; it depicts the architecture and organizational structure of the system. Moreover, it shows the communication of the different technologies, subsystems, and platforms employed. The presented AOD can adopt three variations of the Communication Interface (CI). The first CI model relies on services hosted by a third-party Internet provider. Here, the interfacing device and the user fully communicate through the third-party providers, such as a webserver, database server, and application server. The second CI model comprises a server-based interface with a dedicated Internet Protocol (IP) address. In this model, the user communicates with the server hosted on the processing system. The third CI model enables a direct communication between the user and the processing system when the user and the device are at the same location. For the three proposed variations, the user communicates with the system using a mobile solution that can be an application or a web interface using a browser.

RCL, MAMs, and EIG are refinements of the nonfunctional requirements of the system. An RCL is a list that highlights the realistic constraints of the system. Realistic constraints can be tight; they are, usually, critical requirements during system development. The clear identification of the system constraints, using the RCL, highlights their importance, enables their adequate satisfaction, and presents them in a self-contained diagram. MAMs are of two types, namely, general and application specific. General metrics are common to all systems developed based on the IDM; however, application-specific metrics are concerned only with the developed system. MAMs enable the evaluation of the robustness, thoroughness, and adequacy of the system and its chosen metrics.

The Evaluation Indicator (EI) is a combination of a set of Key Indicators (KIs) that aid the evaluation of the developed system based mostly on IDM components. The identification and clear understanding of the evaluation KIs enable the early integration of their requirements in the design and implementation stages. Usually, such KIs are specified in project evaluation criteria whether in academia, industry, competitions, etc. [20].

The EIG adopts a holistic approach in evaluation. The evaluation scale of each KI is holistic and range from 1 to 5, where 5 is the highest score. The EI is the arithmetic average score of all KIs. In addition, analytic approaches can be adopted with minimal tuning to the EIG scale [20, 21]. Table 1.1 presents the EI key indicators and their mapping onto the IDM components. A typical development procedure using the IDM is to identify the system concept; review the EIG KIs; survey the literature to identify and properly acknowledge closely related work; identify the main system features; identify global, economic, environmental, and societal factors; develop the CRP; develop the RCL; use DTs to identify functions and implementation technology; develop AOD, UCD, and MAM; implement the

Table 1.1 Evaluation indicators and their mapping onto IDM components

EI Key indicators [IDM]
(a) Currency and novelty **[CRP]**
(b) Design **[CRP, AOD, UCD, DTs]**
(c) Alternate design options **[DTs]**
(d) Implementation technology **[CRP, AOD, UCD, DTs]**
(e) Alternate implementation technologies **[DTs]**
(f) Identification, mastering, and use of hardware/software tools **[DTs]**
(g) Consideration and adequacy of standards and realistic constraints **[RCL]**
(h) Robustness, thoroughness, and adequacy of analysis metrics **[MAMs]**
(i) Adherence to professional practice and code of ethics **[CRP]**
(j) Attention to global, economic, environmental, and societal factors **[CRP]**

system; analyze the system; evaluate the system; and then draw the Final IDM Chart. A sample generic IDM chart is shown in Fig. 1.1.

1.4 Sample Model Application Systems

To present the proposed model, three system applications are presented in the following subsections. The presented systems are AgriSys, NFC Wallet, and RECON. The selected systems belong to different areas of application, namely, agriculture, wearable security systems, and unmanned aerial vehicles. The proposed systems follow the same development patterned that can be captured using the IDM.

1.4.1 AgriSys: A Smart and Ubiquitous Controlled-Environment Agriculture System

AgriSys is a smart Agriculture System that can analyze an agriculture environment and intervene to maintain its adequacy [22–24]. The system deals with general agriculture challenges, such as temperature, humidity, pH, and nutrient support. In addition, the system deals with desert-specific challenges, such as dust, infertile sandy soil, constant wind, very low humidity, and the extreme variations in diurnal and seasonal temperatures. For a reduced controller complexity, the adoption of fuzzy control is considered [1]. The following requirements define the functions of AgriSys:

- Sense temperature

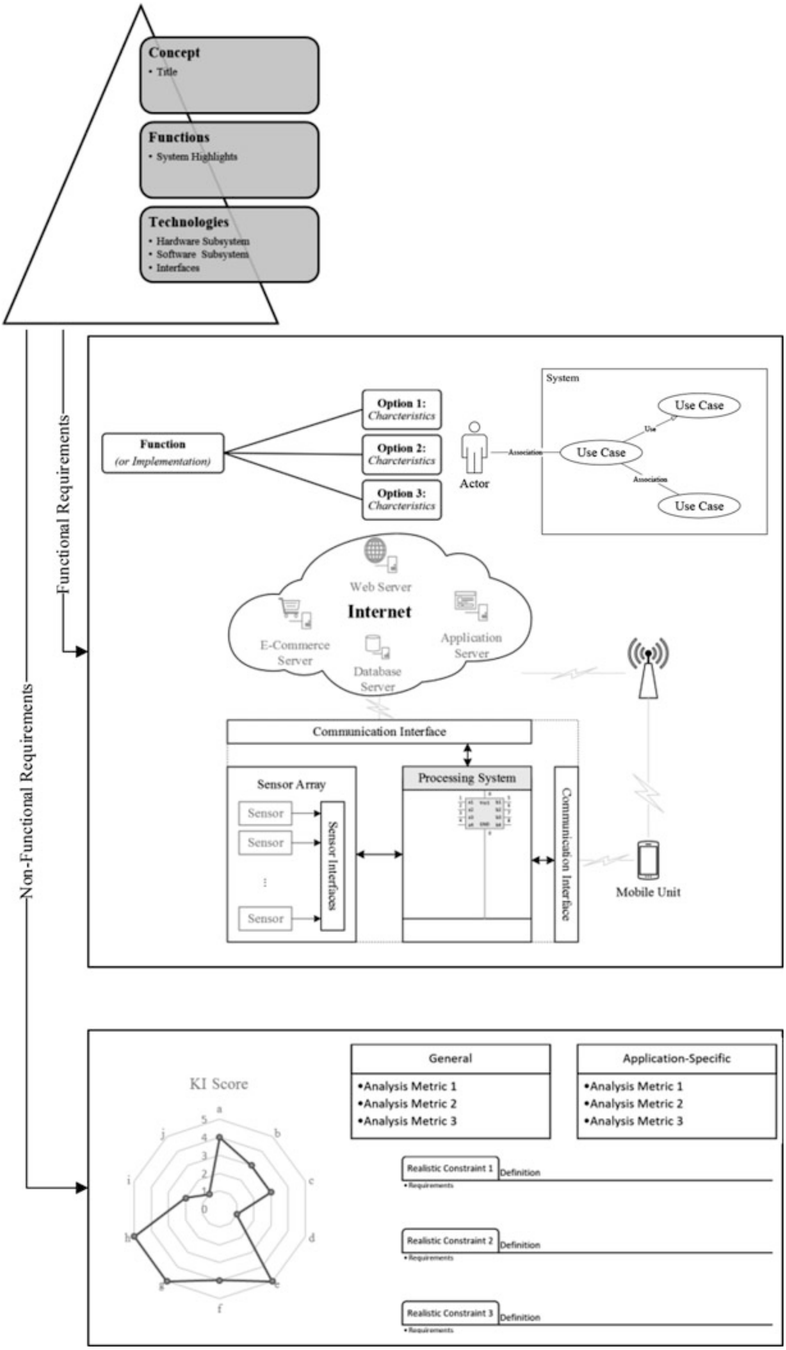

Fig. 1.1 A sample generic IDM Chart that shows all the proposed models. The chart includes generic CRP, AOD, UCD, DT, MAM, RCL, and an assumed EIG

- Sense humidity
- Sense soil moisture
- Sense soil temperature
- Sense the light
- Sense the pH
- Response to sensor readings to control irrigation
- Response to sensor readings to control a fan
- Response to sensor readings to control a shutter

AgriSys is designed to offer low-cost, efficient, and accurate control options. AgriSys is implemented to help saving and reducing the amounts of used water and energy. Indeed, forming cross-disciplinary teams of agriculture specialists and engineer to enable the modernization of agricultural procedures. From an economic point of view, agriculture is the source of livelihood for more than half of world's population; AgriSys increases productivity of farmers at an affordable fixed cost. AgriSys is novel in the sense that it targets extreme weather conditions using a fuzzy controller and enable remote control over the Internet.

AgriSys is implemented using Phidgets interface8/8/8 which connects to a variety of sensors. Moreover, AgriSys system is used to control the temperature, waterfall, and sunlight reaching the plants which is essential for greenhouses system. Phidgets sensors are used for the detection of the required environmental variables such as the humidity, temperature, pH and water level, water and soil temperature, soil moisture, and light. The system also includes a pH or Oxidation–Reduction Potential (ORP) Adapter Interfaces. The interface is to a pH or ORP glass electrode through another connector, the Bayonet Neill-Concelman (BNC) connector, and gives it the data it needs to an input on the Phidgets Interface board. Moreover, the system has a Type-K Stainless Steel Thermocouple with hot and cold junctions. The hot junction is the end that is inserted in the environment of interest, and the cold one is the one used to obtain the readings from the sensor. A pump is needed in both the irrigation and the cooling system to sprinkle water depending on the soil temperature, plant humidity, and the soil moisture sensors.

AgriSys is developed under LabVIEW that comprises a large set of tools for acquisition, monitoring, analysis, and data recording, as well as tools to help debugging code. The complexity and number of used components are reduced with the use of a fuzzy inference system. Using the fuzzy logic library under LabVIEW, the system includes five inputs and different membership functions that also include outputs. AgriSys is deployed on a webserver to enable distant access and monitoring using tablets, computers, smartphones, etc.

In all, AgriSys provides increased productivity, enhanced safety, instant interventions, and an advanced life style. The system is ubiquitous, as it enables distant access. Using a fuzzy controller helped mimicking the behavior of a human operator and added another dimension to the novelty of AgriSys. AgriSys is an addition to the current state-of-art IoT systems.

The IDM components of AgriSys are presented in Figs. 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, and 1.9. In Fig. 1.2, the CRP of AgriSys is presented. In Fig. 1.3, a DT is used

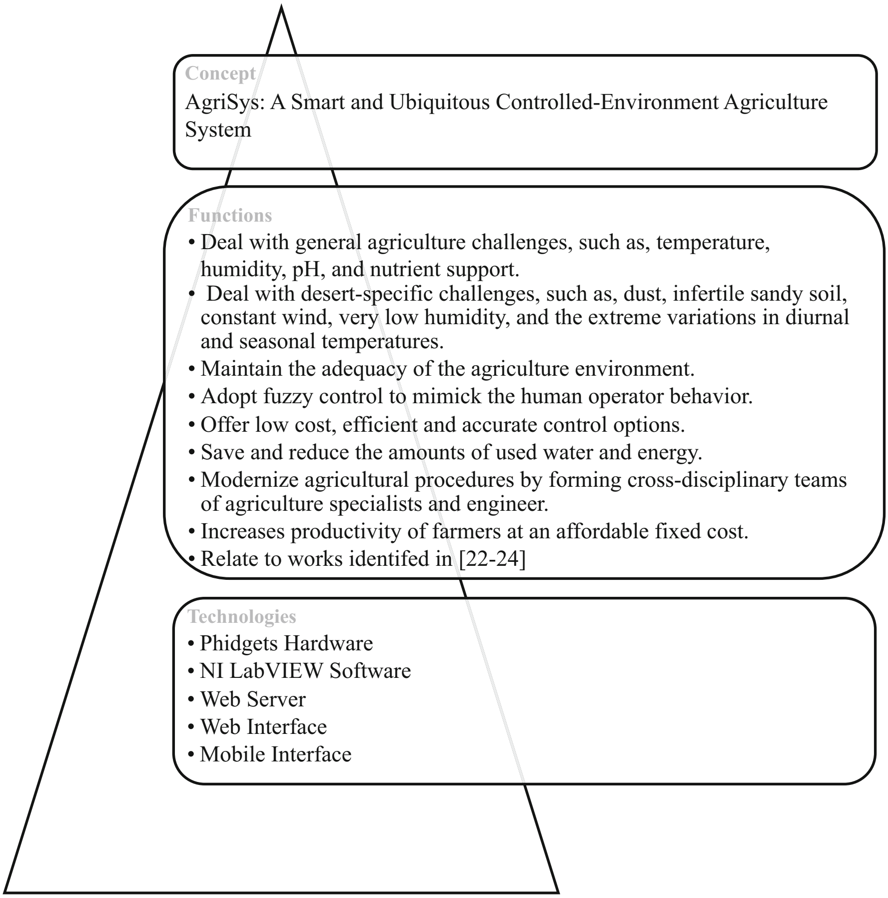

Fig. 1.2 The CRP of AgriSys

to decide what type of system controller to use, while the DT in Fig. 1.4 enables the decision of which hardware and software integration to adopt. Figure 1.5 shows the AOD of AgriSys. The system has a variety of sensors and actuators. The NI Compact-DAQ system is interfaced through a computer or a tablet using a USB port. The computer is configured as a server that runs a published LabVIEW control page with a dedicated IP. The system can be remotely controlled using regular computers or mobile systems through web browsers. The recommended mobile system is a tablet running an MS Windows operating system; this is a requirement to run LabVIEW plugins. A user can control the system from within a Wi-Fi network or using the Internet. Figure 1.6 shows the UCD of AgriSys. In Fig. 1.7, three realistic constraints are listed, besides the corresponding design decision. Figure 1.8 lists the general and application-specific measurement and analysis metrics. Indeed, applying IDM on AgriSys development allows the refinement of the functions,

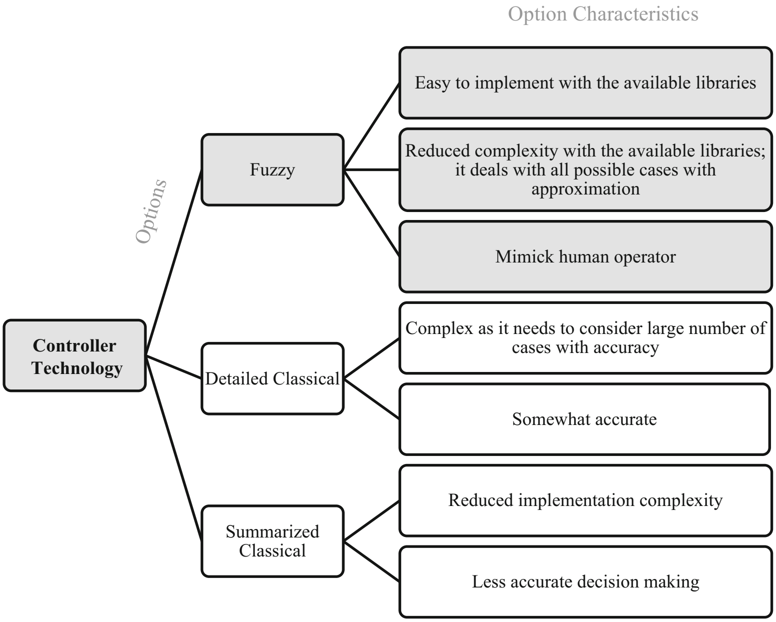

Fig. 1.3 The AgriSys DT of Controller Technology. The decision branch is highlighted

technologies, and decisions realistic constraints identified in the CRP, DTs, and RCL and captured in the AOD. Figure 1.9 shows the EIG of evaluating AgriSys. The evaluation is done by three professionals in the field.

1.4.2 NFC Wallet

NFC Wallet is a ubiquitous and secure system that enables the use of a single customizable and wearable device to replace traditional smart cards [2]. The proposed system is of three main parts, namely, a wearable device, a control web-enabled phone application and a server, and a reader hardware device. The application on the phone is connected to a webserver through which a multitude of tasks can be accomplished. For instance, one can have his/her credit card, debit card, gym card, office card, and university ID card, all stored on one account that has been created on the application. This information is then stored and updated on the webserver, and it is identified by a unique ID on the wearable technology. The wearable technology is a ring with an embedded NFC tag. The presented system enjoys several characteristics including its convenient use, secrecy, robustness, reliability, and scalability, to name a few.

The purpose of the reader is to receive the information from the wearable technology, and then use it to connect to the webserver and provide access. The

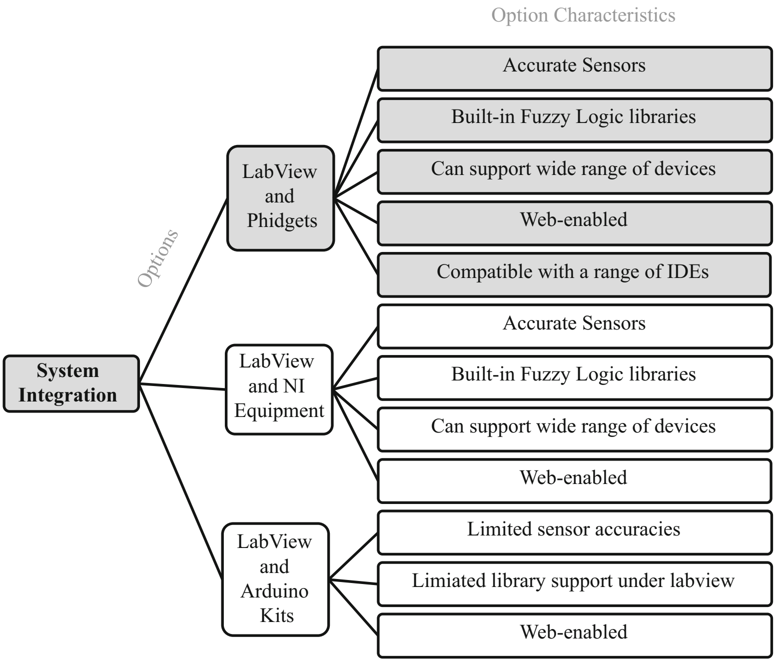

Fig. 1.4 The AgriSys DT of hardware and software system integration. The decision branch is highlighted

reader checks for the account in the webserver's database and enables it depending on its availability. The webserver is supported by a MySQL database. The MySQL database is used to hold users' information, their account information, etc. The database gets all the information from a PHP file, which acts as a mediator.

NFC Wallet is as secured using the AES cryptographic algorithm in the PHP communication layer to ensure the privacy of the data and protect the users' personal information. Two firewall demilitarized zones are created to protect the main server as well as any payment gateways.

The reader contains the following components: Arduino Mega, Ethernet/Wireless Shields, NFC Read/Write Device (RWD), Thermal Printer, TFT Touch Screen, and Electric Door Lock. The reader supports Ethernet or Wi-Fi connections. The AOD of NFC Wallet is depicted in Fig. 1.10. Figure 1.11 shows the UCD of the functional requirements of the web and mobile application GUI. The main two actors are the User and the Admin. Some of these functions are log in, sign up, and manage accounts by adding or removing them. The UCD also shows some of the exceptions that can be handled as extensions to the use cases; such errors include invalid emails, UIDs or e-mail addresses that have already been registered, etc.

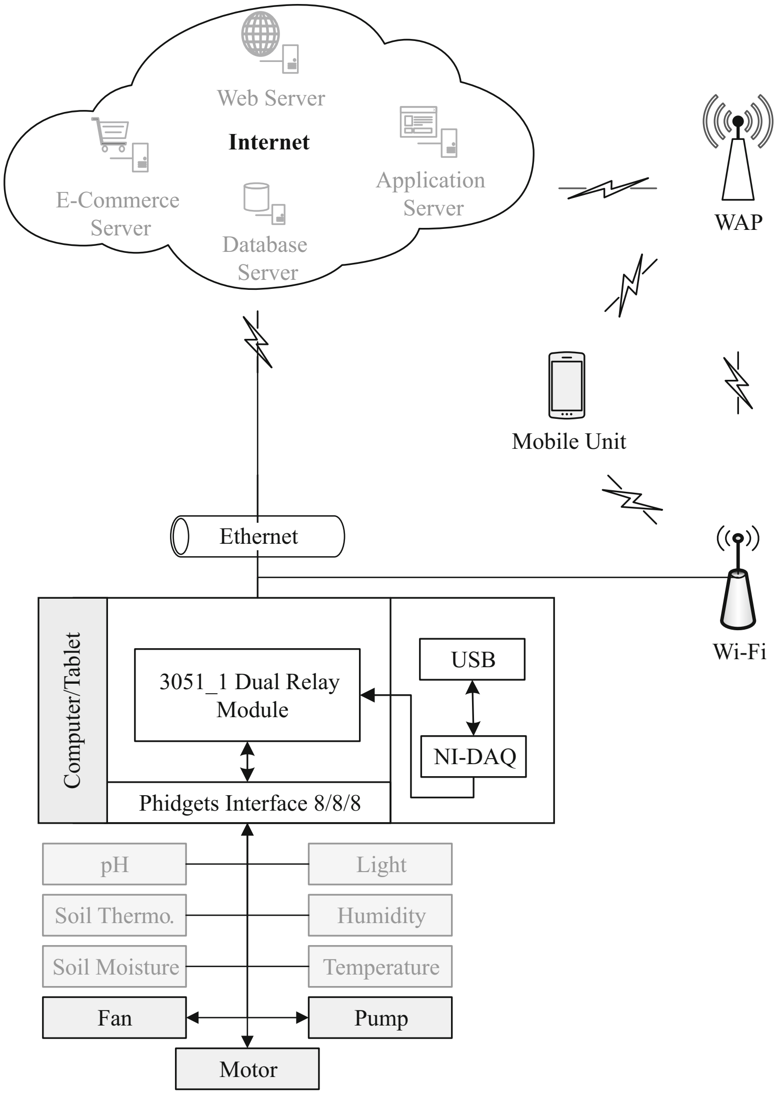

Fig. 1.5 AgriSys AOD

1.4.3 RECON

RECON is an aerial monitoring system that can yield detailed information to help traffic planners, safety managers, and commuters [3]. In addition, RECON provides a "bird's eye view" for traffic surveillance, road conditions, and emergency response to improve overall quality of transportation. Furthermore, RECON is wired with technology features that monitor the safety, security, and activities of their residents

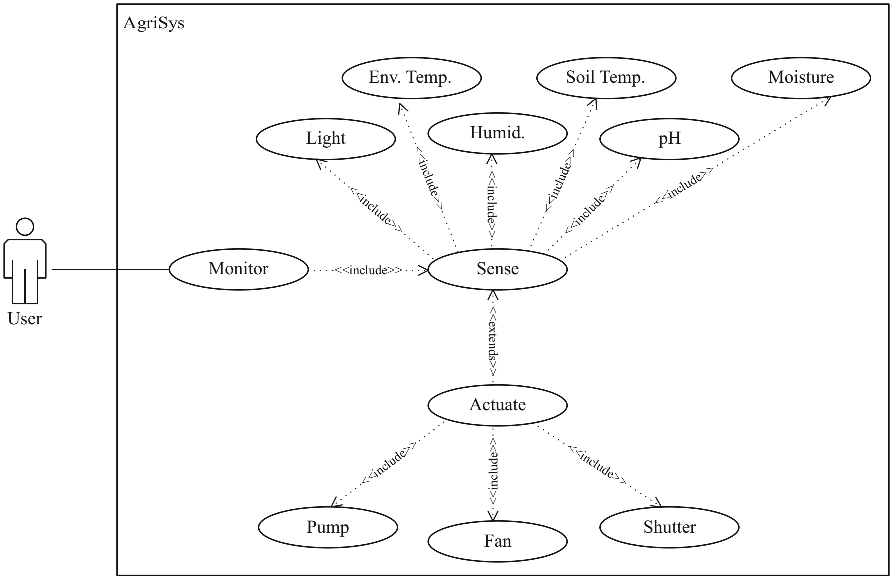

Fig. 1.6 AgriSys UCD

Extreme Weather Conditions Stormy weather in deserts affect temperature, humidity, soil moisture readings, etc.

- Rely on different sensor readings to shut the plant house.
- Possible system expansions include adding distant and close dust sensors, and nutrition sensors

Curved Roof Shape Parts of the plant can suffer greatly from insufficient light due to a curved roof shape

- Design a shutter to regulate the amount of sunlight incident on the plant regardless of the roof shape

Low Market Awareness Farmers usually rely on traditional ways to increase production

- Raise awareness among farmers to show the importance of smart farming applications

Fig. 1.7 AgriSys RCL

to improve overall quality of transportation, search for missing people, and increase independence in technology (search and rescue operations). It can transport goods using various means based on the configuration of the RECON itself. The user can either program a flight path into RECON using a command prompt interface or control the aircraft directly via PC.

RECON system comprises a navigation system, camera, speaker, microphone, sensor areas, delivery arm, centralized control system, and soft interface. RECON is developed under LabVIEW. RECON user can interface with the drone using

General

- Modernity
- Maintainabiliy
- Usability
- User-Interface Adequecy
- Flexibility
- Scalability
- Portability
- Novelty
- Reliability
- Availability
- Dependebility

Application-Specific

- Productivity
- Safety
- Procedure Complexity
- Efficiency
- Affordability
- Accuracy
- Resoponse Time
- Measurement Capability
- Actuation Capability
- Power Consumption

Fig. 1.8 AgriSys MAM

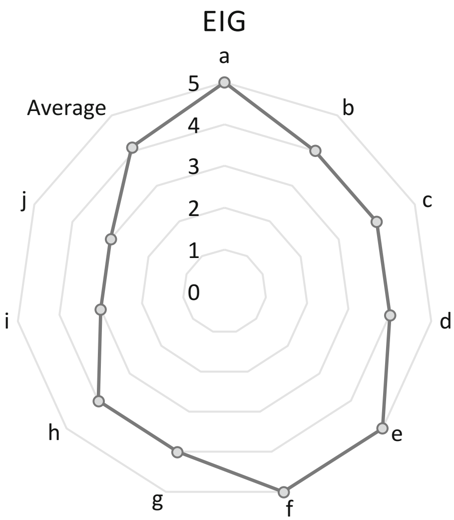

Fig. 1.9 AgriSys EIG showing the scores per KIs (a) through (j)

LabVIEW via a PC, laptop, smartphone, or tablet using standard Wi-Fi networks. A critical part in RECON is replacing a potentiometer with LEDs and photo-resistors to create the same effect by changing the voltage value passing through the LED. Besides, an NI CompactDAQ controls the output voltage, which drives the LED. In addition, RECON is deployed on a webserver to enable distant access and monitoring using tablets, computers, smartphones, etc. The computer is configured as a server that runs a published LabVIEW control page with a dedicated IP. The

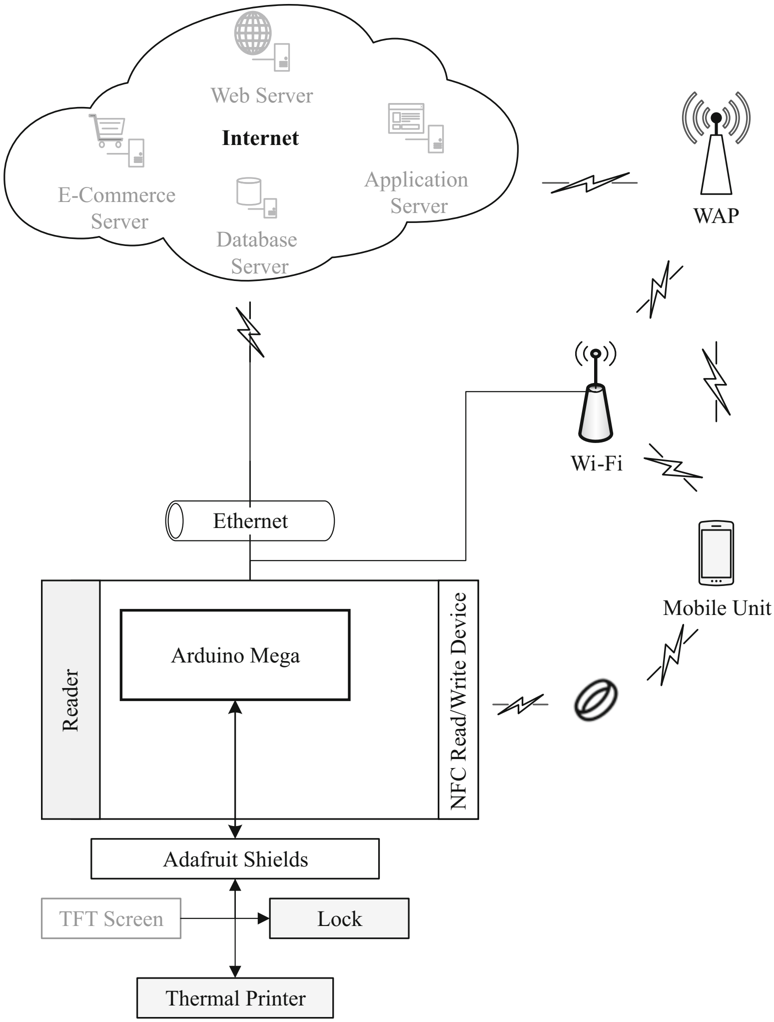

Fig. 1.10 AOD of NFC Wallet

system can be remotely controlled using regular computers or mobile systems through web browsers. The recommended mobile system is a tablet running an MS Windows operating system; this is a requirement to run LabVIEW plugins. A user can control the system from within a Wi-Fi network or using the Internet.

In all, RECON is prepared to intervene by communicating, delivering, and assisting according to its capabilities. RECON touches at several aspects, such as security, by using surveillance system and communication system; safety, by using a nonfossil fuel and gyroscope system; advanced lifestyle, by using remote

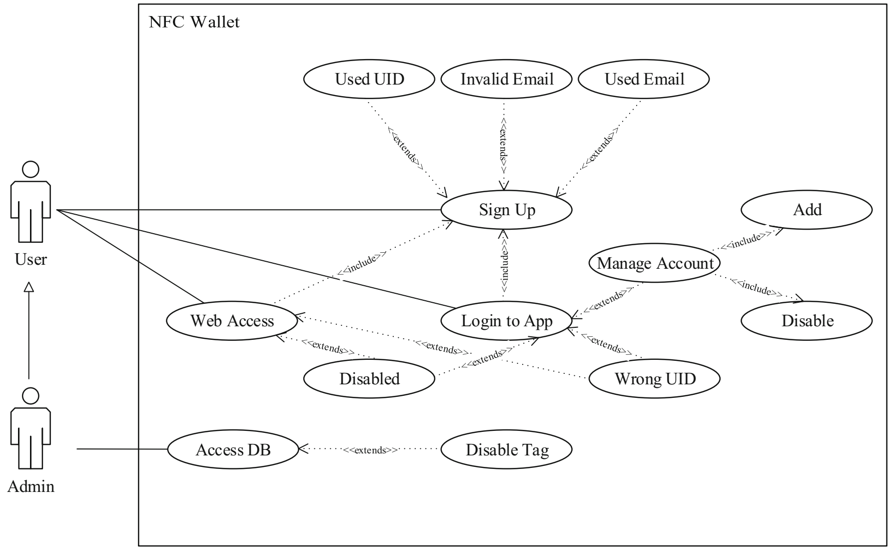

Fig. 1.11 Web and mobile application access UCD of NFC Wallet

control; and real time [25]. In addition, RECON ensures having good stability performance while flying and to get real-time flight telemetry. RECON is capable of self-stabilization, semi-agile flights and includes a framework for assorted add-ons, such as attached cameras or cargo winches. Figures 1.12 and 1.13 present the CRP and AOD of RECON.

1.4.4 Integration of Mobile Solutions

The presented applications benefit from the three Communication Interface (CI) patterns of the IDM. All applications benefit from the first CI model, where they rely on services hosted by a third-party Internet provider. Here, the interfacing device and the user fully communicate through the third-party provider, such as a webserver, database server, and application server. RECON adopts the second CI model that comprises a server-based interface with a dedicated Internet Protocol (IP) address. All the presented systems benefit from the third model that enables a direct communication between the user and the processing system when the user and the device are at the same location. Indeed, in all the presented applications, the user communicates with the system using a mobile solution that can be an application or a web interface using a browser. Figures 1.14 and 1.15 show snapshots of the mobile user interfaces of RECON and NFC Wallet.

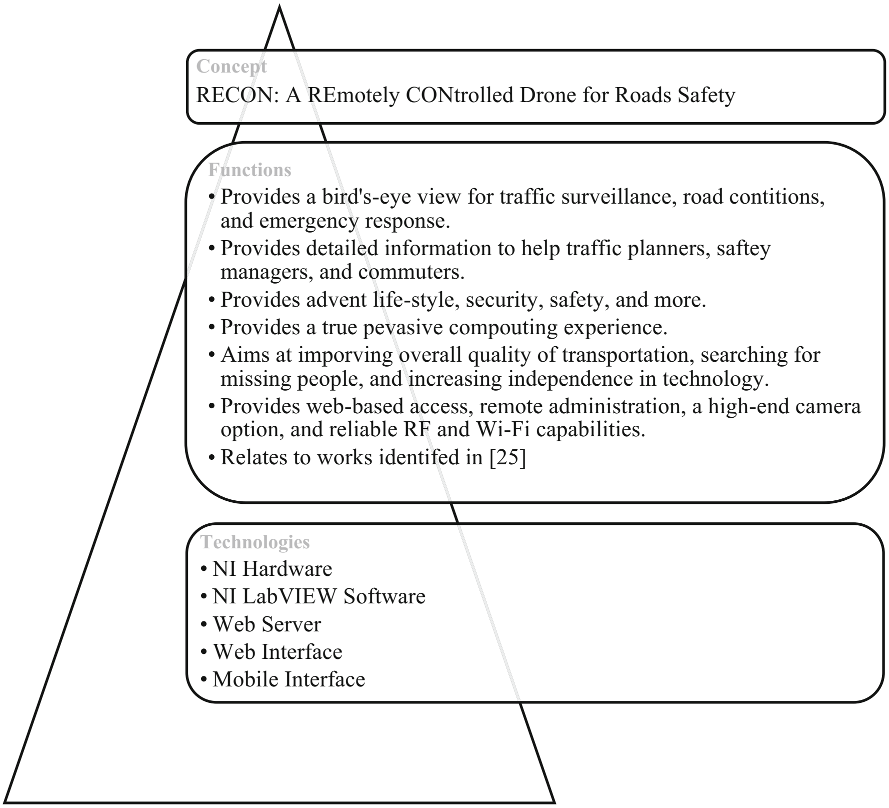

Fig. 1.12 CRP of RECON

1.5 Analysis and Evaluation

The evaluation of the proposed IDM starts by considering the aims, achievements, and advantages of the proposed model. In addition, the model application within higher education is investigated. Moreover, the model effectiveness is evaluated based on a small-scale empirical study. Finally, the section is concluded by presenting the limitations, challenges, and the identified opportunities for future work.

1.5.1 General Evaluation

The proposed IDM is a model that enables the design, implementation, analysis, evaluation, and presentation of an IoT system. IDM aims at providing an easy-

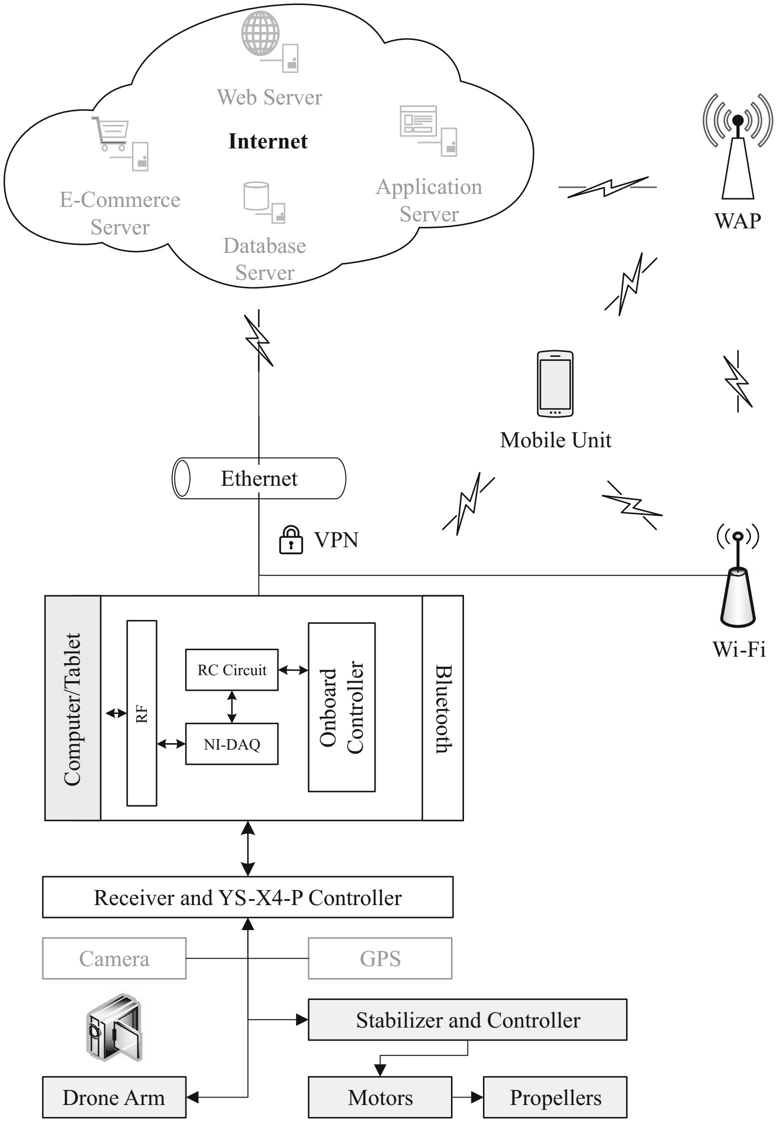

Fig. 1.13 AOD of RECON

to-use, clear, systematic and informal, and effective design tool. The focus of the proposed model is on capturing the system concept and its development through design and implementation. In addition, the model aims at enabling the reasoning about various decisions taken during the development process. The IDM provides an abstract and rich view of the domain; such a view can help people new to the field with understanding the particularities and intricacies of IoT. In addition, the

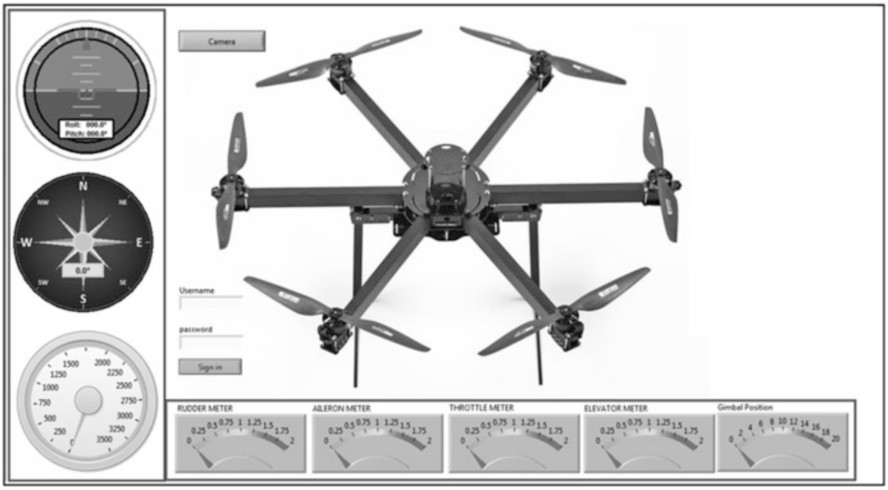

Fig. 1.14 The GUI of RECON and as developed under LabVIEW and published on a webserver

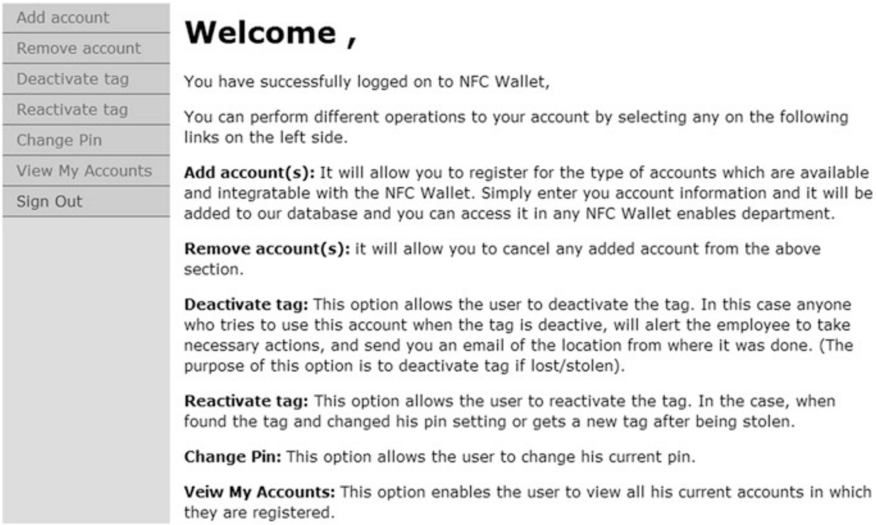

Fig. 1.15 The GUI of NFC Wallet mobile phone compatible webpage

IDM aids in identifying independent, reusable, and off-the-shelf building blocks for IoT systems. The model enables the addressing of realistic constraints and evaluation indicators early in the design process. The model is visual and suitable for presentations at various development stages. The high-level view of IDM is of an added educational value. The proposed model has proven to be useful and highly effective in application.

Several returns are noted for the proposed IDM. Based on the system design team opinions, in a focus group setup, the CRP is found to be of great assistance at the early stage of the project. The CRP can facilitate capturing the candidate project idea descriptions; comparisons among possible alternatives; and with the assistance of the EI Indicators, the selection of one final project idea. The two types of the proposed DTs, namely, the Function and Technology, help in focusing on a few alternatives while clearly specifying the advantages of the specified choices. The AOD template is a reusable design pattern that can be adopted to tailor a context-specific instance. At this point, the UCD assists in specifying the desired system interactions. The RCL, MAMs, and EIG are refinements of the nonfunctional requirements of the system; they allow for the reasoning about, and integration of, such requirements early in the design process. In all, the systems that adopted IDM enjoy the following benefits:

- Facilitated development
- Clear plan setups
- Well-defined development steps
- Increased design productivity
- Reuse of off-the-shelf design models
- Concise and visual presentation

The systems that adopted the IDM possess the following characteristics:

- Pervasive, ubiquitous, and Internet enabled
- Modern
- Have one or more novelty aspects
- Based on well-selected design options
- Based on well-selected implementation options
- Demonstrate mastering and use of hardware and software tools
- Based on robust, thorough, and reliable analysis and evaluation
- Adhere to professional practice and codes of ethics
- Have a clear positive impact on the economy, environment, the society, and more
- Satisfy one or more of the properties of being flexible in functionalities, scalable in terms of number of inputs and outputs, portable across platforms, efficient in performance, affordable as compared to similar systems, efficient in power consumption, etc.

1.5.2 Model Application Setup in Higher Education

The proposed IDM is adopted by 10 Capstone Design Projects (CDPs) [1–3, 26–32], of which development samples are included in this chapter. The CDPs are part of an ABET-Accredited Undergraduate Computer Engineering program. The CDP duration spans over one full academic year. The system developments start by completing the CRP, DTs, RCL, MAMs, then the AOD, and the UCD. The EI Key

Indicators (See Table 1.1) enable the early integration of the evaluation requirements in the design and implementation stages through completing the remaining IDM sub-models. The final product is examined by a team of experts in the field and mainly includes university professors and experts from the industry.

The targeted application setup includes stages that are distributed over two semesters—as follows [20]; the supported steps by the IDM are mapped to the sub-models.

- Semester 1:
  - Problem definition and objectives **[CRP]**
  - Project management
  - Literature survey **[CRP]**
  - Design alternatives and methodology **[DTs]**
  - Design specifications **[AOD, UCD]**
  - Budgeting **[RCL]**
  - Modeling and analysis **[RCL, MAMs, EIG]**
  - Prototyping
  - Documentation **[All Sub-models]**
  - Presentation **[All Sub-models]**
- Semester 2:
  - Implementation **[DTs, AOD, UCD]**
  - Testing and verification
  - Critical appraisal **[RCL, MAMs, EIG]**
  - Documentation **[All Sub-models]**
  - Final product demonstration
  - Presentation **[All Sub-models]**

1.5.3 Model Effectiveness

The effectiveness of the proposed IoT model is evaluated according to four criteria. First, the opinion of members of the design teams as taken during a focus group. The discussion focused on rating several measures that includes clarity, conciseness, ease of use, improving productivity, resolving ambiguity, successful integration of the nonfunctional requirements and evaluation indicators in the design process, and the model adequacy for academic and industrial applications. The rating is based on five scale points that range from *Strongly Disagree* to *Strongly Agree* for the question "To what extent you agree that the IDM achieves the following purpose." The analysis per measure is presented in Table 1.2; the presented responses are the averages of scores. In all, participants strongly agree that the proposed development model is clear, concise, easy to use, and enables effective IoT system design for students.

Table 1.2 The average results of the focus group discussions. The scale points are Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A), and Strongly Agree (SA)

Measure	SD	D	N	A	SA
Clear				×	
Concise				×	
Ease of use					×
Improves productivity					×
Resolves ambiguities					×
Enables the integration of evaluation key indicators			×		
Enables effective system design for students					×
Enables effective system design for professionals				×	

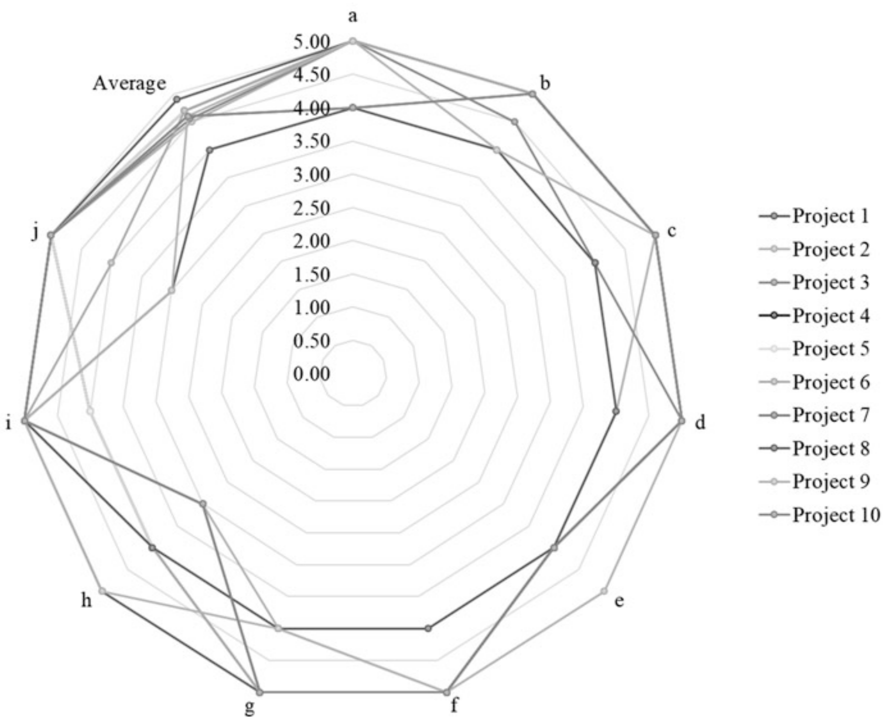

Fig. 1.16 The EIG of ten systems that adopted the IDM

The second criterion for investigating the effectiveness of the proposed model is the level of attained scores of the ten developed systems as examined by a committee of experts. The results show that almost all the developed systems attain scores of 4 and above when mapped onto the EIG. The results are presented in Fig. 1.16.

The ten CDPs that adopt the IDM demonstrate wide acceptance and appearance in exhibitions and competitions (third criterion) and are published as papers in conference proceedings (fourth criterion). The CDPs in [1, 29–31] successfully participated in an Annual Electrical and Computer Engineering Exhibition; [32] received the Student Choice Award, while [30] received the Best Project and Student Choice Awards. The CDPs in [1–3, 30, 32] successfully led to publishing papers in international conference proceedings.

1.5.4 Closely Related Work

Several similarities are identified when comparing ARM [6–8] and COMFIT [9] with the IDM. Both approaches and the IDM are used to enable the creation of IoT systems. The three approaches provide high levels of abstraction to the IoT system development. In addition, the three approaches evaluate the model usability and effectiveness in application. On the other hand, ARM clearly targets the business sector as well as the educational sector. Moreover, ARM provides the generation of architectures for specific systems. The benefit of such a generation includes providing intrinsic interoperability of the derived IoT systems. COMFIT's high abstraction models are tailored to either the application perspective or the network perspective, thus creating a separation between these two concerns. COMFIT's development environment supports code generation, simulations, and code compilation of applications.

Several differences are noted among the three approaches. Unlike ARM and COMFIT, the IDM lacks security mechanisms. Moreover, the IDM doesn't support automated generation or validation options like COMFIT. COMFIT presents a model validation instance that can help the developers to do such verification during design time and using high-level abstraction models. The verification process, included in COMFIT, can verify inconsistencies and errors in the models. The importance of business goals and the system's requirement are better highlighted in ARM and COMFIT than in the IDM. In Table 1.3, a comparison among COMFIT, ARM, and IDM in terms of common requirements [8] and supported aspects is presented. COMFIT is found to be superior over the other approaches by its implementation environment, automatic generation capabilities, and validation support. ARM is superior in its support of security mechanisms. Indeed, IDM is superior in integrating mobile solutions; addressing realistic constraints, analysis metrics, and evaluation key indicators; and being mainly aimed for academia. System concept and functionalities are made clearer and more specific by using the CRP, AOD, and UCDs. Unlike ARM and COMFIT, IDM specifies wide technical particularities of an IoT system—from system concept to prototyping options.

1.5.5 Limitations and Future Work

Through the various evaluations of the IDM effectiveness, and comparisons with similar works, a few limitations are noted. The main limitation of the IDM usability

Table 1.3 Comparison among COMFIT, ARM, and IDM. The symbol "×" means a partial or full support of a requirement or an aspect

Requirement or aspect	COMFIT	ARM	IDM
Interoperability	×	×	×
System development scalability	×	×	×
Security mechanisms support		×	
Coverage of different phases of development life cycle	×	×	×
Automatic generation support	×		
Design support	×	×	×
Implementation environment support	×		
Validation support	×		
Aimed for industry	×	×	
Aimed for academia	×		×
Integration of analysis metrics and evaluation indicators			×
Integration of mobile solutions			×

is that it is mainly education-oriented rather and limited when it comes to large-scale industrial systems. Moreover, the IDM is informal with no supported validation options during the design process. Furthermore, IDM doesn't address business-related goals in the system requirements. During the focus group discussions, it is noted that the IDM enables limited support to software development; in addition, the evaluation key indicators should be further explained using analytic rubrics.

Work in progress and future work include, but are not limited to, expanding the IDM capabilities to target business sector as well as the educational sector. Moreover, improvements include expanding the AOD to include security mechanisms. Future work includes investigating the support of validation during the design time, such as the ability to verify inconsistencies and errors in models and supporting partial automated generations within an IDE.

1.6 Conclusions

The advancement in IoT systems is greatly evident, nowadays, and can be witnessed in almost all aspects of life. The world is becoming closely interconnected through powerful IoT devices that provide true pervasive computing experiences. The aim of this investigation is to present the IDM as an abstract IoT system development model. The IDM comprises several sub-models such as the CRP, DTs, RCLs, AODs, CIs, UCDs, MAMs, and EIG. The proposed IDM integrates hardware and software subsystems and their interfaces; it enables the design, implementation, analysis, and evaluation and presentation of an IoT system. Although the model can be adopted by small-scale industrial systems, the IDM in its current form is mainly intended for academic and small-scale use. The IDM is proven to be clear, concise, productive, and effective in application. A variety of applications adopted the IDM, including AgriSys, NFC Wallet, and RECON. In comparison with similar works, IDM is found to be effective in integrating mobile solutions and addressing realistic constraints, analysis metrics, and evaluation key indicators. Future work includes the creation of an IDE that adopts the IDM, enables automated generations, and supports model validations.

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Chapter 2
The Role of Mobile Edge Computing Towards Assisting IoT with Distributed Intelligence: A SmartLiving Perspective

Hasibur Rahman, Rahim Rahmani, and Theo Kanter

Abstract Internet-of-Things (IoT) promises to impact every aspect of our daily life by connecting and automating everyday objects which bring the notion of SmartLiving. While it is certain that the trend will grow at a rapid speed, at the same time, challenge to alleviate intelligence of things by reaping value from the data requires to be addressed. The intelligence further cannot depend only on the existing cloud-based solutions which edge computing is expected to mitigate by integrating distributed intelligence. An IoT application necessitates applying knowledge with low latency. However, to comply with the vision of autonomic IoT and real-time intelligence, extracting and applying knowledge are necessitated for which this chapter proposes to exploit mobile edge computing (MEC) to further assist distributed intelligence. Therefore, the problem that this chapter addresses is feasibility investigation of MEC to provide intelligence by reasoning contextualised data and, thereby, the role of MEC in distributed intelligence.

2.1 Introduction

Internet-of-Things (IoT) has already started to shape into reality from its hype and promises to incredibly impact every aspect of human life. IoT is expected to drive the future Internet by connecting and automating everyday objects from human body to kitchen and garden appliances, to plants, etc.; thus, it brings the notion of SmartLiving. This has been possible due to the swift advancements in IoT-enabling technologies. More and more such everyday objects are being connected daily and hundreds of billions of things are expected to be connected in the foreseeable future. Research until now mostly focused on architecture and communication aspects of IoT. It is certain that the trend of connecting any possible thing will continue to upsurge; at the same time, IoT necessitates to bring its focus to other aspects such

H. Rahman (✉) · R. Rahmani · T. Kanter
Department of Computer and Systems Sciences (DSV), Stockholm University, Kista, Sweden
e-mail: hasibur@dsv.su.se; rahim@dsv.su.se; kanter@dsv.su.se

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as making sense of data [1]. Making sense of data implies alleviating intelligence of things by reaping value from the data [2]. As an implication of things increase, data generated in IoT becomes massive which has mostly been ignored with respect to analysis, utilisation and providing intelligence [1–3]. It is estimated that about 5% of data is ever analysed [3], while the number could be as low as less than 1% [1]. One of the primary reasons for the low percentage of data utilisation or analysis is that the collected data is raw and does not provide any usefulness [2, 4] which can be mitigated by providing meaning to the raw data, i.e., by contextualisation [2].

Reaping value from data corresponds to enabling instantaneous and informed decision-making. We are moving from a connected world vision to an automated world vision enabled by IoT. Such vision can only be realised by providing intelligence to the connected world. Intelligence, that is, application of knowledge, has so far mostly been limited to cloud-based solutions [2, 5]. In the fast forwarding IoT paradigm, depending only on the cloud-based solutions bring, among other issues, latency and centralised issues [2, 5, 6]. Edge computing is expected to mitigate few of the issues raised by over reliance on the cloud [6, 7]. However, cloud computing cannot be ignored altogether since edge computing as of now is expected to provide solutions based on small dataset, and cloud computing can take care of the bigger datasets. One solution to cater this is to employ a distributed approach such as distributed intelligence-assisted solution [2, 6]. Distributed intelligence-assisted solution implies that application of knowledge is distributed to cloud and edge. An automated, informed and instantaneous IoT application necessitates applying knowledge with low latency and proximity along with the mobility support as envisioned by next-generation 5G IoT vision [3]. Earlier mobile devices such as smartphones and tablets were exploited as gateway to IoT application [8] which further provide system-level intelligence. However, to comply with the vision of autonomic IoT and instantaneous intelligence, extracting and applying knowledge are necessitated for which this chapter proposes to integrate mobile edge computing (MEC) to further assist the distributed intelligence. It is clear that edge computing is capable of enabling real-time knowledge extraction which, however, cannot only be limited to fixed edge devices; therefore, the solution to enable MEC is gaining popularity which is further expected to be driven by 5G [3]. Mobile devices such as a smartphone or a tablet possess sufficient computational capabilities to employ as an IoT gateway [8].

The promise of IoT is going to drastically change the way we live integrating smart applications such as SmartHome, SmartGardening, and SmartHealth in our daily life. Mobile-based solutions are also being employed to complement these applications primarily for accessing data, receiving notifications, local storage, data filtering, etc. [8–11]. A mobile-based solution further can assist in extracting knowledge for IoT applications. Earlier, it was demonstrated that resource-constrained devices can be employed for intelligence at the IoT edge [2]; this chapter presents the feasibility of a mobile edge computing to provide intelligence by reaping value from IoT data. A typical IoT architecture follows three-layer architecture [2, 6, 8, 12], and intelligence has been proposed to be distributed between gateway and cloud layer as shown in Fig. 2.1. Building upon this idea, this chapter further proposes to

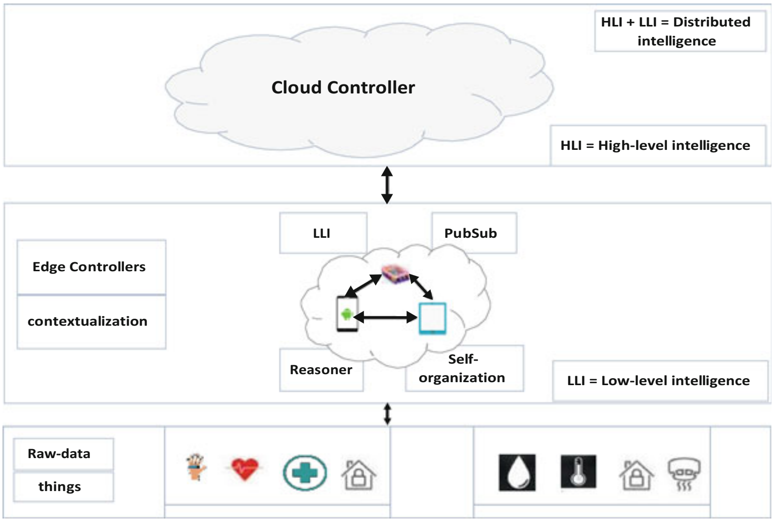

Fig. 2.1 Distributed intelligence-assisted IoT architecture

employ a mobile-based solution to assist in the envisioned distributed intelligence. The chapter specifically looks at the feasibility of a SmartLiving scenario by exploring three IoT applications: SmartHome, SmartHealth and SmartGardening.

2.2 Related Work

When IoT was first coined in 1999, it started with the vision of reducing human labour by collecting data without human intervention [13]. Since then, most research focused on proposing solutions to connect things and collect data. Gateway is usually employed to connect things locally and forward data outside [2, 6, 10, 11, 14]. In [10], reasoning in a SmartHome scenario was demonstrated for providing services where the gateway was employed to provide connectivity, translating protocols for data forwarding, etc. However, the reasoner was employed as a REST API which would store data and feed services to the users on their mobile apps. The approach too followed the existing approach of employing gateway only to connect things and collect data; further, capabilities of mobile device were limited only to a service application which would receive or request services. Recently, there have been few works which propose to add other functionalities to the gateway to improve living by bringing intelligence to the gateway. It was shown in [11] that a mobile phone can be used to control a home system based on human behaviour to reduce costs and save energy. The paper proposed to use a mobile phone as a default gateway whenever connected to the IoT application instead of the fixed gateway to the underlying network the aim of which was to reduce energy and stabilise the gateway further to reduce cost. A gateway controller was employed to manage the migration and synchronisation between the gateways. However, instead of migrating between gateways, combining the gateways' capabilities would better suit today's IoT requirements with respect to distributing computation, providing intelligence, real-time and faster decision-making, computation at the edge, etc. Although the proposal also makes use of user behaviour to dynamically control things in order to make the system intelligent, the intelligence is limited to recommending action to the users. However, intelligence with a mobile edge device can be extended beyond recommendation and enable decision-making, actions and predictions (DAPs) which were earlier demonstrated on an edge device [2, 6].

Rahmani et al. in [8] proposed a SmartGateway for healthcare systems to cater for system-level intelligence such as energy efficiency, scalability, interoperability and reliability issues. The work is one of the first attempts of exploring edge computing with IoT applications with respect to intelligence. It exploited a UT-GATE as the SmartGateway and demonstrated how system-level intelligence can be brought to the edge. The work also proposed lite local data processing but limited to raw data validation and notification service. However, making use of data at the edge is also feasible, which was shown in earlier papers in [2, 6]. It was shown that in addition to data pre-processing, e.g., contextualising IoT data, context-based decision-making, clustering, and reinforcement-based learning were also feasible at the edge of IoT. Although computation on mobile device is expected to be always evolving and improving, it is considered inherently as resource poor [15]. However, the authors envisioned that advanced algorithms such as facial recognition and language translation can be done on mobile devices [15]. They further proposed to use cluster of computers to compensate for the resource poverty of mobile devices and to improve processing power. Their solution was virtual machine based to provide a resource-rich cloudlet closer than a distant cloud the aim of which was to provide low latency, high-bandwidth wireless access. Although the solution resembles the idea of edge computing, that is, computing closer to the things, their solution still brings delay with respect to higher virtual machine launching time.

From this, we can visualise a solution which can use a cluster of resource-constrained devices, e.g., raspberry pies, to perform higher-level data processing and can further be complemented by the mobile devices at the edge. Motivated by future IoT requirement, earlier we proposed to provide distribute intelligence to both edge and cloud computing. The proposal exploited gateway to be explored to provide intelligence based on the small datasets prior to applying advanced data mining techniques to extract knowledge provide insight to the data towards enabling distributed intelligence. Mobile edge computing (MEC) was not explored in the proposal which as mentioned above possess potential to assist in providing intelligence. This chapter would explore the role of MEC to assist IoT with distributed intelligence. The proposal would be targeted at SmartLiving scenario since this holds better application of MEC, as it includes our daily life things. The next section describes the system architecture of the distributed intelligence-assisted IoT.

2.3 System Architecture

The architecture of distributed intelligence-assisted IoT can be used in most of the IoT applications, although the focus of this chapter is limited to a SmartLiving scenario which further includes SmartHome, SmartHealth and SmartGardening applications. Figure 2.1 shows the envisioned distributed intelligence-assisted IoT architecture, which includes collecting data, pre-processing, analysing data and making decisions. The figure illustrates that things are connected to edge controller(s), an IoT gateway that is capable of providing low-level intelligence is defined as an IoT controller in IoT [6], which is responsible for collecting data, organising the things, distributing and reasoning data. Each of these steps is demonstrated below along with distribution of tasks between edge controllers.

Data Collection In an IoT scenario, anything that is identifiable, capable of sensing and/or actuation is regarded as a thing [14]. The thing communicates with gateway via wired or wireless communication medium where the gateway assigns an ID for the thing, if not already assigned. Thereafter, data is collected from the things which can then be disseminated using IoT data protocols such as MQTT, CoAP and DCXP [6]. Once raw data is collected using any of the IoT data protocols, the next task is to process the collected data, which has usually been carried out in the cloud until recently. Few of the local data processing including contextualisation can be carried out closer to the actual things at the edge. Local data processing, e.g., contextualisation, helps providing meaning to the raw data so that services can be provided or insight to the raw data can be inferred [1, 2, 6, 8].

Self-Organisation In the environment that things immerse changes rapidly, where data is frequently communicated and as shown in Fig. 2.1, often, things might be controlled by more than one controller/gateway. The environment evolves over time as a result and this dynamic environment necessitates proper management with no or minimal intervention from outside sources. The configuration, discovery, duplicated identification check, optimising its performance and security of things all these system-level intelligences should be part of any current and future IoT gateway. Depending on the cloud to take care of the system-level intelligence is a thing of past for IoT. A self-organisation approach, therefore, can counter the challenge.

Publish/Subscribe The collected data or the contextualised data, context information, need to be disseminated for further processing and/or for providing services based on the context. There are two actors in this regard, one which is disseminating and the other one which is acquiring the data. This is countered via a Publish/Subscribe (PubSub) model which both DCXP and MQTT protocols can handle. Both these protocols are capable of handling IoT data dissemination challenge and have been tried in IoT scenario earlier [10, 16]. The PubSub model consists of a broker which handles subscription requests and receives published items from the publishers. While mostly cloud has been the prevailing choice for the broker, it was shown in [10] that edge device can be utilised as a PubSub broker. Furthermore, a mobile device can also act as a broker for a PubSub model [17]. The paper further demonstrated the cooperation between the mobile broker and fixed broker. The system architecture portrayed in Fig. 2.1 exploits the similar idea, which advocates the distributed PubSub model via edge controllers. Each of the controllers acts as a broker for the PubSub model.

Reasoner The role of reasoner in IoT is to extract knowledge. Context-aware reasoner enables extracting knowledge based on context [2, 14], which is expected to drive the future IoT. There are many methods to deduce knowledge by means of reasoning, such as naïve Bayes, decision tree, hidden Markov models, ontology-based, rule-based, fuzzy reasoning [14]. Rules and ontology-based reasoning have been the predominant reasoning methods employed in the IoT landscape. Furthermore, rules have been the prevalent choice for reasoning for inferring knowledge at the edge of IoT until recently. However, rules fail to scale well for the ever-increasing number of things as the required number of rules also escalates and at the same time rules fail in uncertain situations. To this end, earlier, we proposed to employ Bayesian reasoning to extract knowledge at the edge [2, 6]. This approach helps in reducing the requirement of the number of rules and is also able to counter the uncertain situations by reasoning based on prior belief.

Distributed Intelligence As mentioned earlier that intelligence in IoT implies application of knowledge. After reasoner enables extracting knowledge, the extracted knowledge needs to be applied. Most of the earlier IoT solutions have proposed to employ cloud to provide such intelligence. However, it was predicted in earlier research that future IoT requires to move on from the central point of control [14]; earlier, it was shown that intelligence can also be distributed [6]. The idea was to employ both edge and cloud computing to provide intelligence based on the collected data where edge would take care of low-level intelligence (LLI) with respect to applying knowledge and high-level intelligence (HLI), e.g., advanced data mining solutions can be applied at the cloud level. Few of these LLIs were earlier discussed in [2, 6]. However, edge-intelligence has been limited to fixed edge devices while mobile devices can also be employed. The next section describes the role of mobile edge computing in the vision of distributed intelligence in the IoT landscape.

2.4 Role of MEC in Distributed Intelligence

In this section, the role of mobile edge computing in aiding IoT with distributed intelligence has been presented. In earlier sections, the importance of distributing intelligence and need for mobile-based edge intelligence were discussed. Table 2.1 shows few of the knowledge that can be provided at the edge of IoT in a SmartLiving scenario. Use of mobile for sensing, i.e., mobile sensing, has been common in IoT, and it was even employed as an IoT gateway which could provide automatic notifications to the users about health [8, 18], home [10], garden, etc. While [18] proposed to use a cloud-like solution to analyse data and use mobile screen to

Table 2.1 Application of knowledge at the edge

Knowledge	Application scenario
Plant growth monitor	SmartGardening
Air/light control	SmartGardening
Automated fertilisation	SmartGardening
Automated harvesting	SmartGardening
Local data analysis	SmartLiving
Prepare food	SmartHome
Turn on/off heating/light	SmartHome
Disease diagnosis	SmartHealth
Request appointment	SamrtHealth
Data learning	SmartLiving

visualise data, in this chapter, it is envisioned that such tasks can be done at the edge by means of edge controllers.

2.4.1 Data Collection and Pre-processing

Data from connected things can be collected both on a mobile device (Mobile Controller-MC) and/or on the fixed edge device (Fixed Controller [FC]). As shown in Fig. 2.1 that, different edge devices together form the edge controller part, each of these devices should be able to handle collected data. MC can collect data from things attached to a human body for SmartHealth scenario and from things related to SmartHome and/or SmartGardening. The first task, after collecting data, for an MC is to add contextual information for which any of the earlier context modelling methods, e.g., key value modelling, W4 diary, can be used and context information can be represented in XML and JSON formats [6, 14]. Figure 2.2 shows an example how raw data can be contextualised to provide meaning to the raw data (Adapted from [1]). It shows how raw data is first contextualised at the second step and the last two steps are obtained via reasoning the context information. Context information includes the actual sensed value and the originator and time. Location (*Where*) is also added but not shown in this particular figure. Context information is filtered before reasoning technique can be applied. This chapter explores the W4 diary context modelling, and context information is represented in JSON formats. Often data from different things is combined into a logical thing; MC can collect different sensor data related to health or home and it would then combine into one single data representation. All these data pre-processing steps are to be taken care by the edge devices including the MC. Moreover, there are certain connected things that communicate with the MC directly via Bluetooth, e.g., as well as via camera. One such example could be pictures taken of a patient or a plant and after pre-processing of the data, it is sent to the FC to find insight to the data—for instance, disease diagnosis of the patient and plant growth, etc.

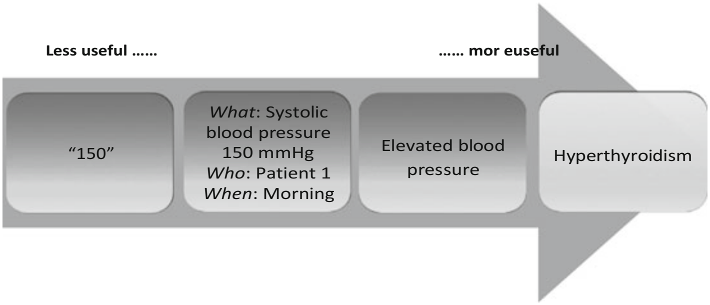

Fig. 2.2 Knowledge extraction from the raw data

Following this, context information should be filtered before a reasoning technique is applied. Often, one sensory data might be required by several applications. For example, a temperature sensor value might be required both SmartHealth and SmartGardening applications. A controller filters the context information and reasons who needs what and when. Earlier, it was shown that MC can also be employed to eliminate noise from the collected data with respect to electric signal as discussed in [8].

2.4.2 *Mobile Edge Reasoning*

As mentioned earlier, reasoning is employed to infer knowledge and mostly rule-based reasoning are used in that respect at the edge in IoT. Bayesian reasoning is a better alternative to rule-based reasoning. The approach was earlier demonstrated in [6] where each context information was given a prior belief and based on the belief of a certain task, a decision or an action was taken. Two simple formulas of sum and product are used in Bayesian machine learning belief calculation as shown in Eq. 3.1. It is the controller's task to determine which context information beliefs are needed to make a decision or take an action. MC can play a vital role in such intelligence. The prior belief that is assigned to each context information is pre-determined, which can be personalised via users' feedback on MC. Users can provide the prior-belief to each of the available context information in his/her SmartLiving application, which can be used to optimise the belief. Moreover, prior belief can be learned from the data and user's interaction with SmartLiving. The learned belief can be sent to users on their mobile devices and asked for confirmation in order to update belief. In a futuristic IoT scenario, distributed edge controllers would be synchronised very quickly, probably within a millisecond, via 5G or very fast Internet speed. Keeping that in mind, we envisage that whichever controller—MC or FC—is able to respond first would respond first and synchronise the other controllers. Therefore, MC should be able to reason the context information. MC should be able to reason context information after filtering for each of the

SmartLiving applications, which can be done by a Multi-Modal Context-Aware reasoNer (MM-CAN) [2]. Based on the outcome of the reasoning, decisions can be made by inferring knowledge.

$$\Pr(A) = \sum_{i=1}^{n} \left(ß_{\mathrm{CI}}{}^{*}ß_{\mathrm{CIV}}\right). \tag{2.1}$$

From Fig. 2.2, it is seen that the third step shows the raw data relates to 'Elevated blood pressure' and it could relate to 'Hyperthyroidism'. Although this can be achieved by using rules, inferring the knowledge of 'Hyperthyroidism' disease based on single data might be misleading. This disease has other symptoms as well.

Therefore, these need to be taken into consideration while applying the knowledge. The mobile device can be helpful to monitor patient's health condition and visualise based on the reasoning on the mobile device's display screen. Some of the reasoned data for visualisation might come from FC, e.g., image classification of analysing disease. Another example in a SmartLiving scenario could be visualising plant growth on the user's mobile device along with portraying what might be contributing to its growth. The MC might then provide intelligence to the user on which actions to take for the plant's smooth growth. It can alert the user if the water is over-used or under-used. The application might be designed that it automatically sprinkles water when certain beliefs are fulfilled, and MC might analyse that one certain context is causing over- or under-watering. It would notify the user that particular context should be included into water sprinkle action, thereby optimising the decision-making. Learning from data is one of the useful roles that MC can play in the future IoT, which is described in the following sub-section (Fig. 2.3).

2.4.3 Mobile Edge Learning

Learning from data is usually done using machine learning techniques without explicitly programming how to learn. In such techniques, the more data an algorithm

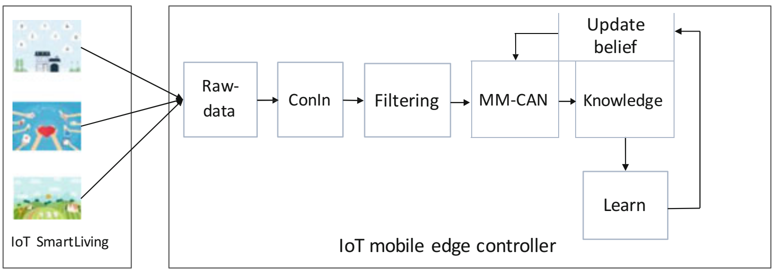

Fig. 2.3 Mobile edge controller roles in SmartLiving

has, the better the performance is. However, while designing an IoT application such as SmartLiving application, even having historical data for that application might not be useful for the optimal performance. SmartLiving corresponds to daily life of individuals, and each individual is different. For example, if the SmartLiving application is to prepare food for its user without his or her intervention, it should take into consideration the context information corresponding to this specific user. For example, when the user usually eats his or her dinner, user's food habits, if the user usually goes to meet a relative on a specific day, if the user has an appointment with someone on a given day, etc. Therefore, the learning algorithm needs to monitor each state of its user and learn from the experiences. Reinforcement learning enables in such vision of learning from experiences [6]. It observes the environment and gives a reward or a penalty based on the outcome. Similarly, this technique can be used in a SmartLiving scenario where the MC observes each state of the user with respect to the connected things. Whenever an action is taken or a decision is made, the MC learns it and gives a reward which is then used to reinforce the belief with a new belief. Once the rewards are collected, depending on the choice or time duration, belief can be learned from the application with the help of the softmax function. Softmax function is useful in providing probabilities of each input and has been used in artificial intelligence. It is mostly used in multiclass classification as well as in deep learning. It can also be used in reinforcement learning to find out the probability of each action as shown in Eq. 3.2 [adapted from 19]. It calculates probability as exponential of the reward of the action divided by sum of all exponential of all actions' rewards and distributes probability to each of the actions based on the reward. The calculated probability is then exploited to update the belief.

$$\Pr\left(a_j\right) = \frac{e^{r(a)}}{\sum_j e^{r(a)}} \tag{2.2}$$

This approach can also be applied to predict any missing value. For example, if a thing that has lost connection or no longer able to provide data, a controller might need to predict the missing value in order to execute an action or make a decision. It is detailed in our previous work [6].

2.5 Discussion

The proposed approach concerns with utilising MEC to assist in distributed intelligence. In our previous work, it was shown how Bayesian reasoning enables to provide decision-making, actions and predictions (DAPs) at the edge with a fixed controller. In this work-in-progress chapter, the feasibility of MEC has been demonstrated on a mobile device. We have employed the same approach as demonstrated in our previous papers [2, 6]. It was earlier shown that Bayesian

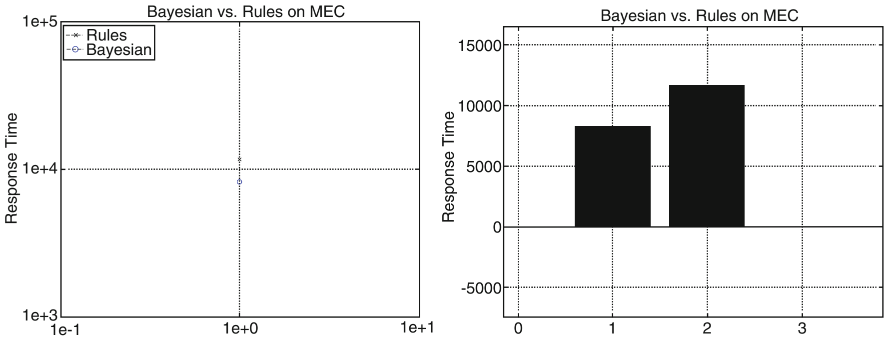

Fig. 2.4 Mobile edge controller roles in SmartLiving

reasoning reduces the number of required rules, which is detailed in [6], along with how each context information is given a belief. For example, the maximum belief of an action is 1 (one), which is then distributed amongst the context information responsible for affecting that action. To illustrate the feasibility, the knowledge extraction that was shown in paper [2] for activating a sprinkler based on Bayesian reasoning has been consulted. Along with the Bayesian reasoning, rule-based reasoning has been utilised to demonstrate the difference and how MEC can be benefitted from Bayesian reasoning over rules based. Figure 2.4 shows performance of both Bayesian and rule-based reasoning performed on Samsung Galaxy (A5). The result clearly shows that Bayesian reasoning provides faster response for activating a sprinkler on MEC. Both the left and right images in Fig. 2.4 show the same result, where y-axis represents the response time in nanoseconds. It shows that rule-based reasoning require about 42% of higher response time compared to Bayesian reasoning for activating the same action. This result particularly could be beneficial in the future IoT where faster response is one of the sought-after performance metrics.

2.6 Conclusions

The true promise of connected things can only benefit us when intelligence of things is extracted in order to automate our surrounding environment by providing instantaneous and informed decisions. By automating our connected daily-life objects allows us to experience a true SmartLiving experience. Cloud computing and rule-based reasoning have been the predominant choice for enabling such experience. Earlier research showed that over reliance on them bring among other issues latency, centralised and scalability issue. Edge computing along with context-aware computing expected to play an integral role in future IoT landscape where artificial intelligence such as reasoning and learning are major challenges, especially at the edge. Mobile edge computing (MEC) can play an important role in reasoning and learning, which is driving current IoT research towards making sense of IoT data. This chapter portrays a solution based on MEC, which can assist in the envisioned distributed intelligence. The chapter laid down the foundation to employ a mobile device as an edge controller. While earlier research demonstrated the feasibility of utilising mobile device as IoT gateway and provide system-level intelligence, we extend the idea to enhance the capabilities a mobile device possesses to provide intelligence based on IoT data. To this end, in this work-in progress research with respect to making sense of data, Bayesian reasoning has been evaluated on the contextualised IoT data using a mobile device. The result suggests that it is feasible to contextualise IoT data and achieve faster response compared to rules on the mobile edge controller. These results contribute towards instantaneous and informed decisions at the edge which can enhance our SmartLiving experience.

The work presented in this chapter can further be extended. The proposed learning approach can be implemented and its feasibility can be investigated. Currently, we are working towards employing deep learning on both fixed edge device (raspberry pi) and mobile device to learn from the IoT data. Its feasibility to improve SmartLiving is one of the future works we are focusing currently, especially diagnosing disease and monitoring plant growth at the edge to improve healthcare and farming. In the future, interoperability and dynamic behaviour between edge controllers, and edge and cloud controller interoperability should be examined. Intelligence and security are the two outstanding issues in the current and future IoT. Therefore, security in IoT needs to be explored from the distributed intelligence perspective.

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Chapter 3
IoT-Based Framework for Crowd Management

Marwa F. Mohamed, Abd El-Rahman Shabayek, and Mahmoud El-Gayyar

Abstract Seasonally, a huge number of people visit public places (e.g., holy places like El-Harm El-Madini El-Harm El-Makki (KSA), railway stations like Mumbai suburban railway (India), or sports events in big stadiums). Crowd management is critical in these situations in order to avoid crowd disasters (e.g., stampede and suffocation). Therefore, there is an urgent need for a framework to manage these crowds in order to save people's lives. This framework shall be smart and efficient in terms of crowd time management and exerted efforts. The proposed framework is based on IoT and supports mobile device interaction through smart applications with a fairly simple interface to suit all ages. The aim is to strongly support administrators controlling and distributing visitors over the given place. The framework consists of three layers: sensor, management, and interface layers. The sensor layer is responsible for crowd data acquisition. The management layer acts as a middleware between sensors and interface layers. It includes web services which are responsible for collecting and analyzing the data coming from the sensors. It then notifies administrators about overcrowded areas to take the suitable decisions. Afterwards, the suitable decision (e.g., close/open doors and roads) will be taken and transferred to the interface layer. The interface layer is formed by user-friendly applications that communicate information between the management layer and the visitors. It provides mobile applications that aim to inform visitors about (1) current opening roads and doors, (2) how to find noncrowded areas, and (3) how to

M. F. Mohamed (✉) · M. El-Gayyar
Computer Science Department, Faculty of Computes and Informatics Suez Canal University, Ismailia, Egypt
e-mail: Marwa_fikry@ci.suez.edu.eg; elgayyar@ci.suez.edu.eg

A. E.-R. Shabayek
Computer Science Department, Faculty of Computes and Informatics Suez Canal University, Ismailia, Egypt

Interdisciplinary Centre for Security, Reliability and Trust (SnT), University of Luxembourg, Luxembourg, UK
e-mail: abdelrahman.shabayek@uni.lu

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locate their groups and friends. The proposed framework provides high availability, reliability, usability, and performance.

3.1 Introduction

The Internet of Things (IoT) is a powerful industrial system of radio-frequency identification (RFID) and wireless (mobile and sensor) devices that have the ability to transfer data over a network without needing human interaction [1]. Mainly, IoT consists of three layers: (1) the sensing layer to gather data from the real world via existing hardware, e.g., sensors and RFID; (2) the network layer to transfer the collected data over wired/wireless network; and (3) the application layer which is responsible for two-way communication between user and systems [2]. IoT applications are rapidly evolving and growing in various fields (e.g., health-care service industry, safer mining production, transportation and logistics, firefighting, and crowd management).

In this chapter, the focus is on crowd management using IoT and smartphone technologies. Examples of crowds that need to be properly managed can be seen in the Kingdom of Saudi Arabia where several millions of pilgrims visit it annually in order to perform the holy rituals of Hajj and Umrah and in Mumbai suburban railway (India) where eight million passengers travel every day in the highest crowded railway in the world [3]. Both cases require a robust crowd management framework (CMF) which is able to manage the huge number of visitors in order to avoid crowd disasters (e.g., stampede and suffocation).

Sensing the crowd by normal sensors and managing it is a challenging problem. Crowd management requires several stages including crowd data acquisition via sensor layers, data transferring via network layers, data analysis for decision-making, and applying crowd control measures via application layer; see Fig. 3.1.

Using different sensor devices, it is possible to gather information about visitors' crowds and determine which areas are overcrowded. This information is then transmitted to the management layer where the administrator can decide to close some doors and roads. The management layer shall be equipped by a smart service that can recommend which doors to be opened/closed to direct the crowd flow. The admins then decide whether to publish this information to the public or not. The visitors receive the publicly available information through a mobile application which informs them about (1) current open roads and doors, (2) how to find noncrowded areas, or (3) how to locate their groups and friends. These services will lead to great save in time and efforts in managing the crowd flow.

The proposed framework shall be highly usable and reliable. In order to increase the user-end application usability, the application provides different languages and a user-friendly GUI. Moreover, the application shall be accessible not only by mobile devices but also by distributed devices throughout the crowded region with a touch screen (and/or visual impairment enabled device) interface for visitors. The collected data shall be reliable, as it is collected from different resources as

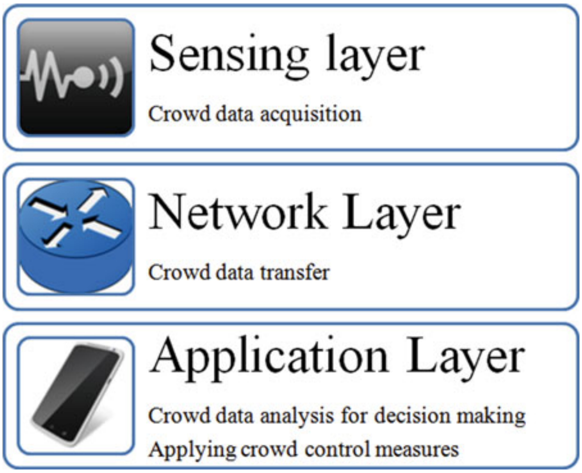


Fig. 3.1 IoT architecture for crowd data management [2]

monochrome cameras, infrared cameras, and RFID tags. The framework shall be always available with high performance. These features are enabled via replicated web services of the middleware layer on various servers. In the case of service failure or overload, the framework adaptively selects another replica to respond to visitor's requests.

The rest of the chapter is organized as follows. Crowd information acquisition and management are covered in Sect. 3.2. Then, a full description of the proposed framework is given in Sect. 3.3. Section 3.4 explains the workflow of the proposed framework, and the case study is discussed in Sect. 3.5. Finally, the conclusion is presented in Sect. 3.6.

3.2 Crowd Information Acquisition and Management

Crowd information acquisition and management can be classified into three main technologies: vision, wireless/radio-frequency (RF), and web/social media data mining [3]. Figure 3.2 summarizes the most recent work for crowd information acquisition and management.

A vision-based technology can estimate the crowd density by analyzing the aggregated real-time images, video, thermal videos, or satellite images. The work in [4–6] introduce a video data analysis-based system for crowd management, which are capable of detecting and tracking visitors [4], estimating the possible route, actively guiding alarm and signal [5], and building crowd energy modeling [6]. The works in [7–9] are using thermal video analysis in order to avoid overcrowding and estimating crowd density at Hajj ritual places. An analysis model was developed by [7] based on an FLIR camera and temperature sensor to detect crowd density. The authors in [8] have added two components to the previous model as visual

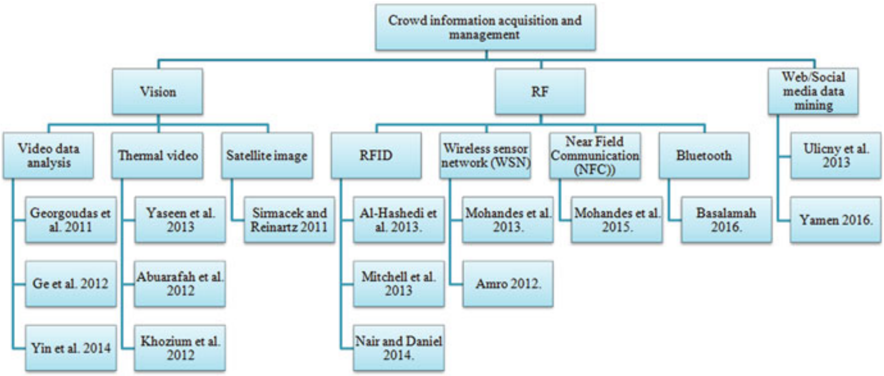


Fig. 3.2 Most recent work for crowd information acquisition and management

camera and light intensity sensor in order to increase the density estimation accuracy. Another framework [10] proposes tracking pedestrians and crowd density estimation depending on the analysis of high-resolution satellite images.

RF-based technologies, e.g., RFID (radio-frequency identification), wireless sensor network (WSN), near-field communication (NFC), and Bluetooth are proposed for data acquisition in crowd management system. The methods in [11–13] use RFID tag in order to identify, track, count, and locate the pilgrims within a certain zone. However, the main drawbacks of RFID technology are that it is less reliable, expensive, and has less memory power [13]. The work in [14] developed a system for estimating crowd density by using Bluetooth technology. The system is composed of three components: a Bluetooth Low Energy (BLE) tag for identifying the pilgrims, a smartphone for counting the BLE, and a web server for crowd data analysis and monitoring. This approach is simple and inexpensive; however, BLE and RFID tags are easily damaged, lost, or mixed with other pilgrims, which may cause inaccurate crowd estimation [15]. The work of [15] uses a mobile phone for identifying and saving important information about the pilgrim, then exchanges this information with doctors or police officers using NFS technologies. The main challenge of using mobile phones for crowd density estimation is that pilgrims may be not carrying a mobile (or wireless devices) and other pilgrims may be carrying multiple mobiles, which can lead to incorrect crowd estimation [3]. Another system tracks and identifies missing pilgrims by using GPS on mobile phones and WSN [16, 17].

Finally, social media and web data mining-based technologies help for crowd management [18, 19]. An application called VIStologys HADRian is developed in [18] for integrating various information sources as social media into a common operational picture (COP) for humanitarian assistance/disaster relief (HADR) operations. An application called “Hajj Mabrour” is developed in [19] to help for crowd management. Under the social media sharing platform, the application (1) tracks visitors via Google Maps, (2) notifies and alerts via SMS and email, and (3) enhances the situational awareness via sharing information. The main challenge of this technology is how to extract critical information from a large amount of data and how to keep the personal privacy during data acquisition.

From the previous work, we can conclude that vision-based approach is recommended for crowd density estimation and RF-based technologies are better for tracking and identifying visitors. Hence, in our framework, a combination of these technologies is proposed to achieve our target to well distribute visitors over crowded areas.

3.3 Crowd Management Framework

This section introduces the crowd management framework (CMF) that aims to redistribute visitors in a crowded area and exploits RFID tags to locate missing children or old people. Mainly, CMF consists of three layers: the sensor layer, the management (middleware) layer, and the interface layer as shown in Fig. 3.3.

The sensor layer includes all sensors to be used for crowd data acquisition and people tracking. The management layer is acting as a middleware between the sensor and the interface layer; it collects data from sensors, analyzes it, and then

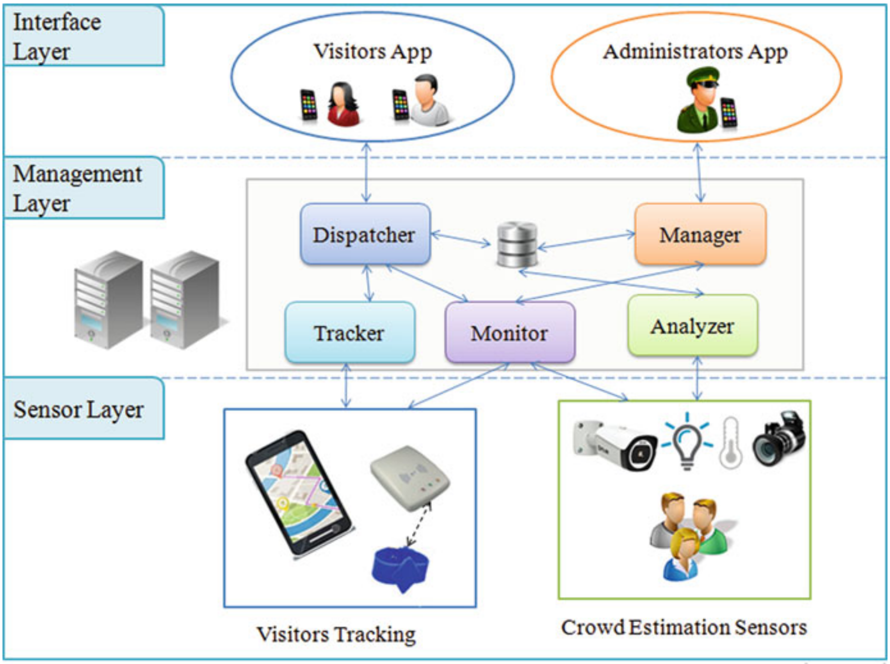


Fig. 3.3 Crowd management framework (CMF) layers

transfers the results to the interface layer. The interface layer is an application which aims to help administrators and visitors to avoid crowd disaster, as it informs pilgrims about (1) current opening roads or doors, (2) how to find noncrowded areas, and (3) how to locate their groups and friends, as we will explain later in detail.

3.3.1 Sensor Layer

Sensors are divided into two categories: crowd density estimation sensors and tracking sensors. Crowd density estimation sensors consist of four components, connected through a computer system, as proposed by [8]: a monochrome visual camera, a low-cost infrared camera, temperature, and light sensors.

Tracking sensors aim to identify and locate the visitors within a certain zone using RFID (in controlled places like El-Haram) and mobile GPS sensors (in uncontrolled places like Mumbai station). RFID will be used to track children and old people. Vulnerable visitors (e.g., children, sick, and old people) will be given wristbands that include RFID tags. These tags contain visitor's information, such as name, age, and nationality. Then, the admin can use RFID readers to retrieve visitors' information from the RFID tags. In addition, Mobile GPS will be used by visitors to share their location when required.

3.3.2 Management Layer

The management layer consists of five components: analyzer, manager, monitor, dispatcher, and tracker:

- *Analyzer* analyzes the data coming from the crowd density sensor using the same analysis model of [8]. It then notifies the manager component about crowded areas and saves it on the database in order to be shared with visitors after administrator's approval.
- *Monitor* is responsible for monitoring crowd estimation and tracking sensors. In the case of malfunctioning, it will notify the manager component about them for maintenance. It is also responsible for monitoring dispatcher service. It will notify the manager component to select another replica in order to reply to visitors' requests (in case of failure) or to balance the load (in case of overloading) [20].
- *Manager* provides a link between other framework components and administrators. It (1) notifies administrators about overcrowded areas, (2) asks for permission to close (doors or roads) and to share this information to the public through the mobile application, (3) asks for permission to locate vulnerable people when required, (4) notifies administrators about sensors required to be

maintained, and (5) selects another dispatcher service replica to respond to visitors requests adaptively, in the case of dispatcher service failure or overload.

- *Dispatcher* provides a link between other framework components and visitors. It is mainly web services invoked by visitors' mobile application. It is responsible to publish information about overcrowded areas, closed doors, and roads on the mobile application. It receives also requests from visitors to search for missing people and forwards them to the manager to accept/refuse it. Acceptance is based on the trusted people circle that will be registered in advance for each user (e.g., family members and the group guide).
- *Tracker* is responsible for tracking RFID tag holders after receiving an order from the manager. It communicates with all RFID readers to search for the requested RFID. It then sends results to the dispatcher in order to forward the search results to the person who placed the request.

3.4 Framework Workflow

The workflow of the suggested framework can be divided into three phases: monitoring, crowd management, and tracking. Monitoring phase is for sensing the failure which may occur to crowd estimation, tracking sensors, and dispatcher services. Crowd management phase is for distributing visitors over a crowded area and avoiding crowd disasters (e.g., stampede and suffocation). Tracking phase is dedicated to locating missing people. The three phases are explained in detail in the following subsections.

3.4.1 Monitoring Phase

The admin adjusts the monitoring component to check in predetermined intervals the availability of crowd sensors, RFID readers, and dispatcher service. If one of the sensors is malfunctioning, the monitor notifies the manager about that sensor failure. Then, the manager notifies the administrators to maintain these sensors. Also, if dispatcher services have failure or are overloaded, the monitor will notify the manager component for selecting another replica to reply to a visitor request (in case of failure) or to balance the load (in case of overloading). Figure 3.4 shows the sequence diagram of monitoring phase.

3.4.2 Crowd Management Phase

The analyzer gathers periodically the crowd data from the crowd sensors. It analyzes the data using the model in [8]. After that, it notifies the manager about overcrowded

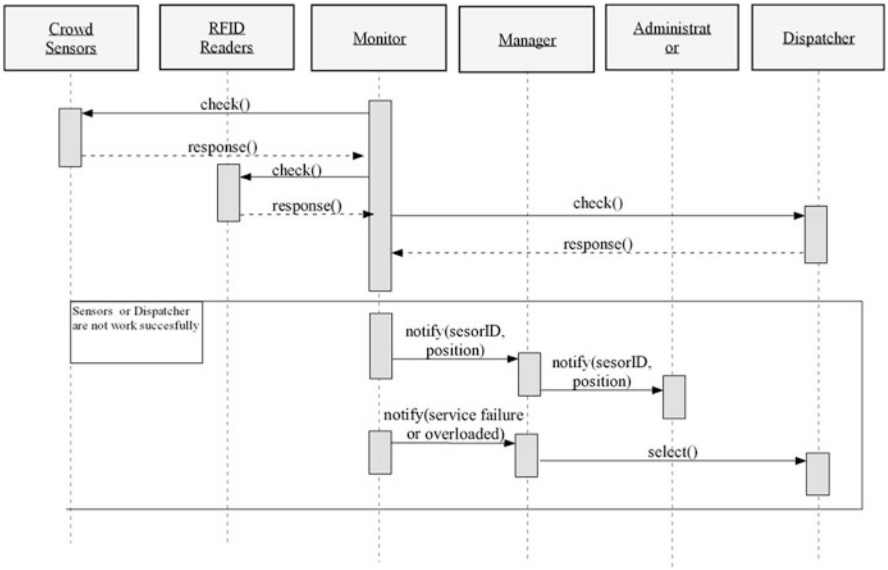


Fig. 3.4 Sequence diagram of monitoring phase

areas and saves it on the database. The manager receives the information from the analyzer. Based on this information, it determines the roads and doors that should be closed. The manager then asks the administrators to confirm publishing this information. Upon acceptance, the manager updates the information privilege on the database to be available for sharing. Then the dispatcher shares this information with the visitor's application. Figure 3.5 views the sequence diagram of crowd management phase.

3.4.3 Tracking Phase

Unlike previous phases, this phase is triggered on demand. The visitor sends a request to locate a missing person. The dispatcher forwards the request to the manager. Then, the manager asks the administrator to confirm this request. After confirmation, the manager sends RFID tag to the tracker to locate the missing person. The tracker asks the RFID readers in the sensor layer. The RFID readers provide response to the tracker on whether the RFID tag has been found or not. After that, the tracker forwards results to both manager and dispatcher in order to inform the administrator and visitor, respectively. Note that if the missing person has a mobile phone with GPS, he/she can share his/her position with friends. Figure 3.6 shows the sequence diagram of tracking phase.

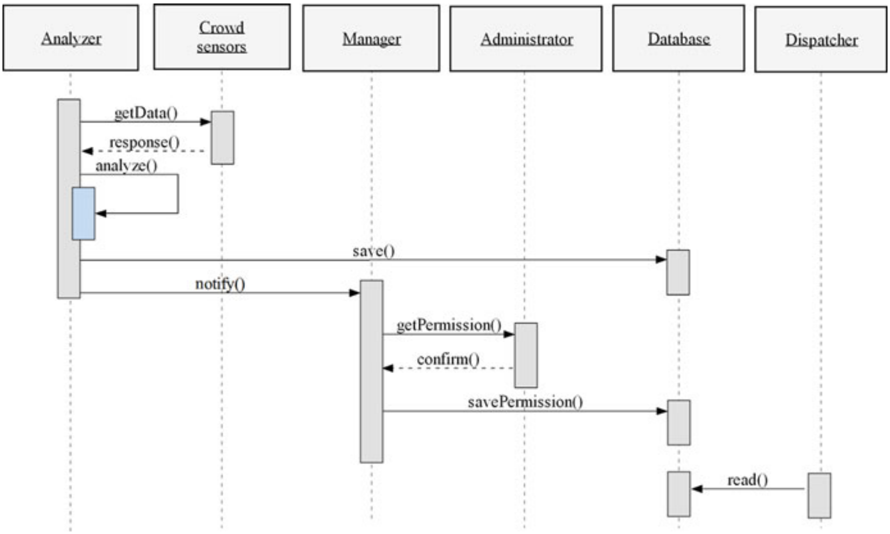


Fig. 3.5 Sequence diagram of crowd management phase

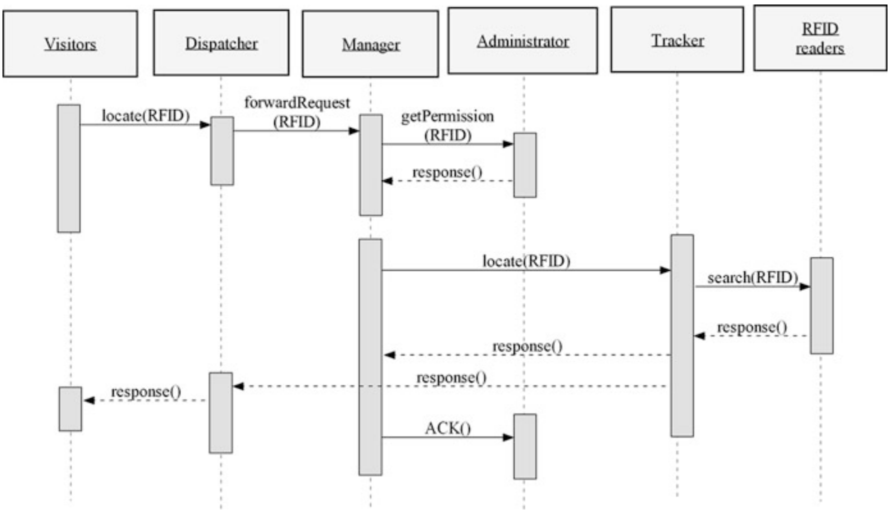


Fig. 3.6 Sequence diagram of tracking phase

3.5 Practical Example: Pilgrim Guide App

In this section, the main features of the Pilgrim Guide application are explained. The application is considered as a practical example of the interface layer in the proposed CMF framework. The Pilgrim Guide application (1) collects the data from sensors and RFID readers, (2) analyzes the collected data, (3) visualizes the collected data in appropriate forms and reports, and (4) periodically checks the performance of the sensor layer.

In the Pilgrim Guide application scenario, RFID tags will be given to pilgrims upon arrival to the Kingdom of Saudi Arabia airport. Also, pilgrims are kindly asked to install the application to help them during the journey. Furthermore, a number of sensors and RFID readers are installed on different ritual places. If the tag is missed, the pilgrim should contact the tour guide or one of the Haram administrators to locate the missed tag. In case the tag can't be found as it may be missed outside the ritual places, a new tag will be provided for the pilgrim. The tag information is secured, as it is only accessible through the readers of Haram administrators.

Figure 3.7 provides a domain model for the Pilgrim Guide application. The aim of the diagram is to introduce the application's objects and relationships between these objects. This diagram could be helpful for business analysts and software developers. Each pilgrim is guided by exactly one tour guide. Pilgrims and tour guides are able to get the current state of the Haram area (crowed or uncrowded) and search for other pilgrims upon the acceptance of Haram administrators. Haram

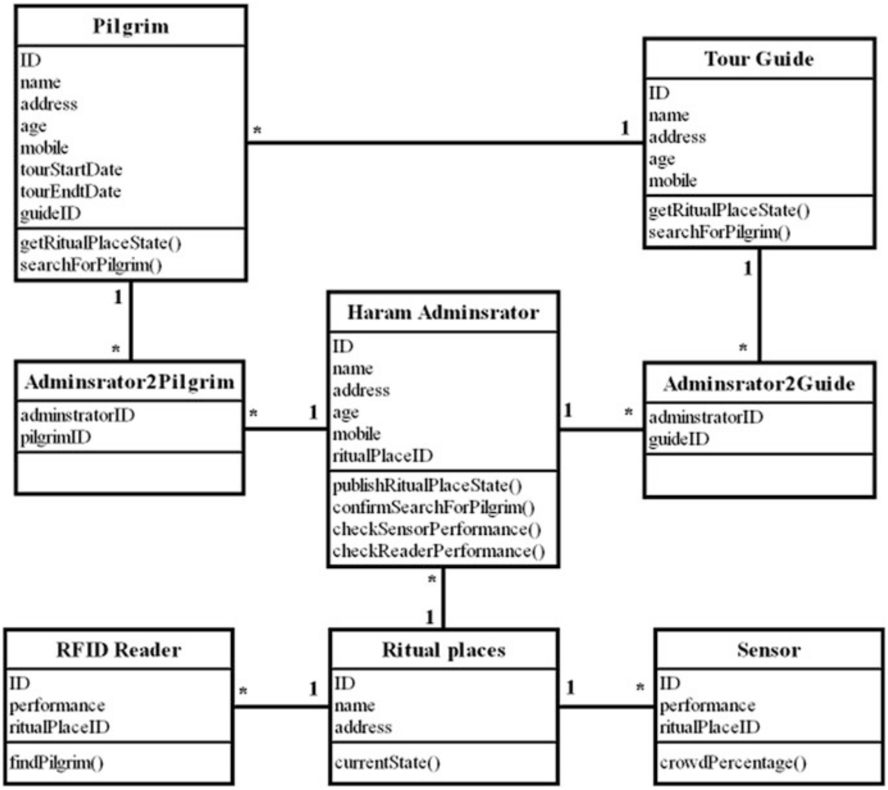


Fig. 3.7 A domain model for the Pilgrim Guide application

administrators are able to confirm the request to search for a missed pilgrim, publish the current state of the ritual places, and check the performance of the sensors and RFID readers. Each ritual place has many administrators for managing the crowd, sensors for determining the crowd percentage, and RFID readers for finding lost pilgrims.

Pilgrim Guide consists of two types of applications: a web-based application for Haram administrators and a mobile one for pilgrims. Both applications are available in different languages (Fig. 3.9a) to increase the application usability. And it requires pilgrims to install the application on their mobiles, register, and login before being able to use the different available features. The following subsections explain these applications interface in detail.

3.5.1 Administration Application

Through the administration application, the admin can explore the Haram map, identify crowded areas, and then accept or reject to close road or door (Fig. 3.8). Also, the admin can send notifications to all pilgrims. Another important feature is the management of pilgrims' requests to track items/people that have RFID tags.

3.5.2 Pilgrim Application

Through the Pilgrim application, the pilgrim can explore the Haram map, identify crowded areas and closed doors (Fig. 3.9b), receive different notifications from Haram administrators (Fig. 3.9c), and store and retrieve different contacts.

The application provides a contact list that contains three different sections as seen in Fig. 3.10; the first section holds a close group (e.g., wife, children, and group

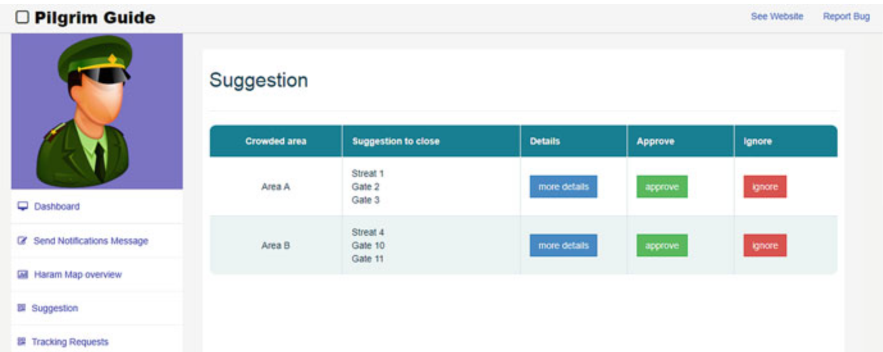


Fig. 3.8 Example of the administration application (suggestion table)

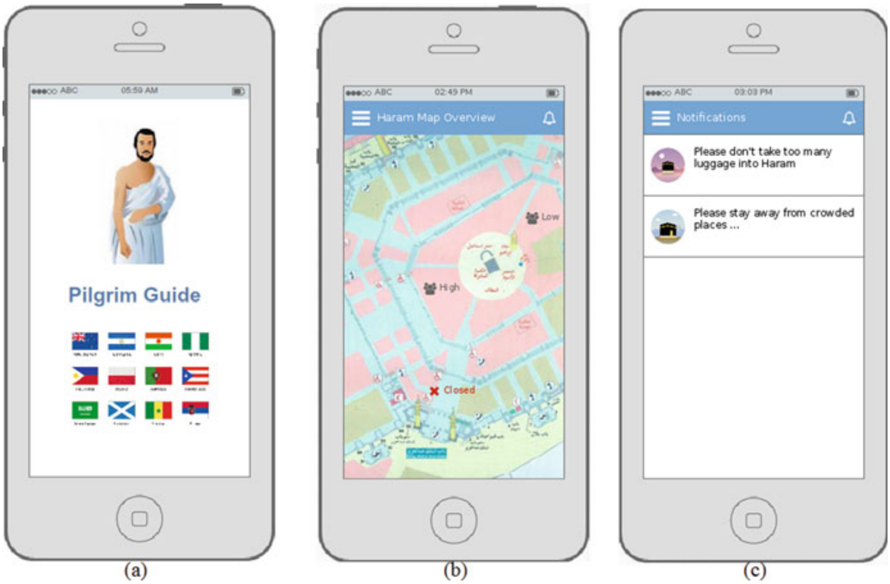
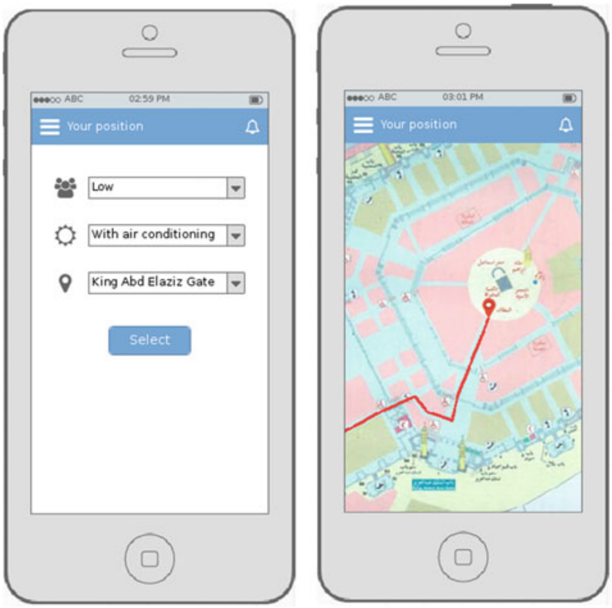


Fig. 3.9 (**a**) Pilgrim Guide application (**b**) Haram map overview (**c**) notification messages

Fig. 3.10 Contact list (**a**) Friends tab (**b**) RFID tab (**c**) General tab



(a) (b)

Fig. 3.11 Select your position (**a**) selection menu (**b**) selection result

coordinator). The second section stores all items that have RFID tags attached to it. Last but not least, the third section provides information about important emergency places (e.g., closest police station or hospital). Through the contact list, the user can send a request to the Haram admin to exactly locate one of his contacts. This feature is very important in case of children or property loss.

Figure 3.11 presents another important feature, that is, the selection of a suitable place inside the Haram. Here, the user can set some conditions including the suitable crowd degrees (low, middle, don't care), air condition (with/without) air-conditional area, and the open preferable road and door to El-Haram; then, the best location is shown on the map with detailed path information.

3.6 Conclusions

In this chapter, a crowd management framework for distributing visitors over a crowded area is introduced. The framework consists of three layers: sensors, management, and interface. Sensors layer aims to track visitors and gather information about visitors' crowds. Management layer aims to analyze the collected data and extract the required information about the visitors upon administrative acceptance. The interface layer provides an application that aims to help administrators and visitors to avoid crowd disasters as it informs them about (1) current opening roads and doors, (2) how to find noncrowded areas, and (3) how to locate their groups and friends. The proposed framework will effectively save time and efforts to help administrators controlling and distributing visitors via low-cost sensors manipulated by smartphone. Also, the proposed framework shall be highly usable, reliable, available, and performance.

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Part II
Mobility and Accessibility

Chapter 4
A Case Study for the Promotion of Urban Mobility for Visually Impaired People

Paulo Faria, Ana Filomena Curralo, and Sara Paiva

Abstract This chapter presents a case study to promote and enhance transport sustainability by providing a mobile app that allows visually impaired people (VIP) to independently use public transportation. This work is a follow-up of a previous case study, and in this chapter, we present new functionalities available in the mobile app, including a careful and detailed layout definition to improve usability. We also present the new tests made in the field with some associates and that allowed us to make important conclusions regarding the usefulness of such an application as well as future directions.

4.1 Introduction

Urban mobility is a key aspect nowadays in almost every city, and the necessity for having concerns about improving urban mobility has several causes. Some might be the growth of the number of people within cities, more roads being built, different and growing number of transports within the city, or the need of people moving within the city several times during the day because of their jobs and personal activities. Urban Mobility Plans are being studied, designed, and continuously improved by cities, so there is an efficient public transport system that promotes accessibility to citizens.

P. Faria (✉) · A. F. Curralo
Instituto Politécnico de Viana do Castelo, Viana do Castelo, Portugal
e-mail: paulofaria@ipvc.pt; anacurralo@estg.ipvc.pt

S. Paiva
Applied Research Centre for Digital Transformation - ARC4DigiT, Polytechnic Institute of Viana do Castelo, Viana do Castelo, Portugal
e-mail: sara.paiva@estg.ipvc.pt

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Sustainability of transports is a related concept that refers to the application of new technologies to minimize the loss of time and improve citizens' satisfaction [1]. Next generations' quality of life, namely, on levels of pollution, should not be compromised by what we are currently doing toward achieving transport sustainability. Some of the actions being promoted by cities around the world include the creation of bicycle paths or fees to enter the center of the city with their own cars, which must be accompanied by a good, working, and efficient transport system.

This thematic has also been important, over the years, for the European Commission (EC) that adopted, in 2009, the Action Plan on Urban Mobility [2] to encourage authorities to define measures to achieve their goals on this field. The same commission published, in 2011, the white paper "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system" [3] that advises cities to develop plans to promote sustainable urban mobility plans. Another initiative dates from December 2013 when the EC adopted the Urban Mobility Package "Together towards competitive and resource-efficient urban mobility" [4].

The application of new technologies to cities represents, in its majority, what is currently called Internet of Things (IoT), which is an emergent reality, gaining more and more momentum. Cities, to be smart, will depend on a wide variety of sensors in almost all types of equipment, places, and objects across cities and the gathered data will allow to improve monitoring and tracking, create alert systems, take preventive actions, etc. In a not very distant future, a smart city will be able to anticipate citizens' problems and provide a better service to them.

On the other hand, mobile solutions are commonly used today for several purposes and domains. The evolution we have been assisting in these last few years regarding technology, processing power, supported sensors, and functionalities made possible the development of a large range of different applications targeting different domains such as tourism, health and care, businesses, transportations, etc.

In fact, mobile solutions can help us in our daily lives simplifying our routines. The relevance and utility of mobile application largely increase when we refer to disabled people, such as visually impaired people (VIP), to whom the benefits of mobile applications are greater than to the rest of the population.

The limitations these people have prevent them, plenty of times, from walking alone in the streets, which is one of the biggest problems VIPs face: mobility. They can only go to places they previously learned with a sighted guide, which means they cannot handle simple tasks available to everyone else without any disability such as going to the City Hall or the Supermarket. Getting lost is a huge problem and asking a person who is nearby can sometimes be the only solution, but of course, there are no guarantees there will always be someone nearby.

Another limitation felt by VIP has to do with public urban transportation, a service most cities provide to their citizens to allow them to reach a given part of the city without using their own car. This service is also very relevant for VIPs, but using these transportations is not always easy and problems come up such as knowing where they are and when to leave the bus. Again, the solution most of the times is to ask someone who is on the bus.

Some of the most adequate technologies to systems to help solve these issues are global positioning system (GPS) or radio frequency identifier (RFID), but there are definitely some trade-offs in both. GPS cannot guarantee an accurate precision and can fail in routes between high buildings. On the other hand, a mobile solution can be relatively cheap when compared to an RFID-based system that requires the streets to be prepared with tags in the sidewalks. The benefit of this solution is that centimeter precision can be achieved.

In this chapter, we present an evolution of a work we first presented in [5] with new functionalities and improvements after the first round of tests has been made. The solution is a mobile application that helps visually impaired people using public transportation in the historical center of a city in the north of Portugal. This chapter includes the feedback from the first version and the new developments made to this new version.

The rest of this chapter is organized as follows: in the next section, we present the problem analysis and a literature review of similar solutions and related work. Next, we present the previous work to contextualize the starting point of the current work we are presenting. The new functionalities are explained in detail in Sect. 4.4, and in the following section, we present the tests made and their evaluation. Finally, we define future directions of this research.

4.2 Problem Analysis and Literature Review

As a consequence of the growing research and development for disabled people, several platforms and systems have emerged in the last few years.

One of such systems is detailed in [6] where the authors present a novel prototype application of a system supporting street navigation and independent, outdoor movement of the blind. The system is capable of finding the route from the indicated source to chosen destination, using a dedicated digital map and a set of various sensors. Subsequently, the system supports the movement of the blind along the found route. The user's position is obtained with the use of differential global positioning system (DGPS) receiver. In order to further improve accuracy, the particle filtering method is used. The system operates on a casual smartphone and communicates with the blind by the touch screen and by the voice messages generated by speech synthesizer.

Nandish et al. present in [7] a research of a navigation system for blind people in order to provide more precise location information. To identify the position and orientation and location of the blind person, the authors rely on global positioning system (GPS) technology, text-to-speech (TTS) program, and Google Maps APIs in order to provide navigation with voices.

Another solution of a navigation scheme has been proposed in [8] where the authors materialized a solution for the blind and low-vision people in order to provide precise location information using Android smartphone. The navigation scheme uses TTS for blindness in order to offer a navigation service through voice and Floyd-Warshall algorithm for suggesting the shortest paths. Also, it uses Google Maps API to show the route information. The proposed scheme, as an independent program, is fairly cheap and it is possible to install onto Android-based smartphone in an easy manner, which allows blind and low-vision people to access the program interactively.

Another solution presented by Dornhofer et al. [9] is motivated by the fact that affordable technologies are not accurate enough to navigate blind persons on a safe trip. The authors defend positioning should be improved by telling the user the surrounding environment. They present a comparison between three different tools to route people (PgRouting, OpenTripPlanner, and OpenSourceRoutingMachine). Finally, they present a prototype for Android to route blind people to a given destination with the following functionalities: allow the user to explore the whole trip on the screen, provide turn instruction by turn instruction, and periodically speak the distance to the next crossing point.

Yet another proposal is discussed in [10] where the authors introduce a system that provides indoor navigation by using Radio Frequency Identifier (RFID), outdoor navigation by using Global Position System (GPS) as well as obstacle detection by using an ultrasonic sensor. The user will give the starting and ending locations, and then this system will give voice instruction to reach at destination by detecting obstacles also. This system can specially be used in big campuses like industries and big institutes where it will act as a guiding map.

Regarding work on IoT, the current literature presents us with many studies regarding the use of IoT to contribute to the creation of smart cities. The domains that can benefit from technology applied to cities are plenty and include smart transport, smart tourism and recreation, smart health, ambient-assisted living, crime prevention and community safety, governance, monitoring and infrastructure, disaster management, environment management, refuse collection and sewer management, smart homes, and smart energy [11]. Picking up on the transport category, Dong et al. present [12] a framework of future Innovative Urban Transport (IUT) to support next-generation urban transport, based on IoT, 4G, Big Data, Cloud Computing, and other novel ICT technologies. The application of IoT to cities allowed for value-added services to be made available for citizens. Another example is presented in [13] which refers to the design of an intelligent urban transportation system in Jamaica based on the Internet of Things. The authors present the motivation and application of this model within the context of the Jamaican and provide the next steps required for evaluating the scaled infrastructure deployments. One other project focuses on solving the problems conductors face in collecting the fare from the passengers [14].

Handte et al. present an interesting study regarding the application of IoT to urban contexts and they present the Urban Bus Navigator [15], an IoT-enabled navigation system for urban bus riders. GHOST is a location-based service, and its goal is to implement an Intelligent Transport System for the public transport which can exploit the geo-referenced information of urban elements along the bus lines, monitoring them in a smart, continuous, and independent way [16]. Finally, another example that can be provided highlights the opportunity to take advantage of emerging technologies, like an open source data platform and its application to the transport domain [1].

4.3 Previous Work

4.3.1 Contextualization and Objectives

As aforementioned, the work presented in this chapter is an evolution of a previous work that was a case study for VIP to use public urban transports within the historical center of Viana do Castelo, a city in the north of Portugal. The development of the mobile application uses a route (Fig. 4.1) that two buses perform during the week from 9:30 to 13:00 and from 14:00 to 18:30. One of the reasons that made us develop a mobile solution from scratch and not use MeoDrive or Google Maps is that they lack significate reference points. Also, we did not want the best route from a given destination to another; we wanted a specific route that can change by a variety of reasons.

The first and main purpose of the mobile application was to help VIPs use their urban transportation. The main difficulty felt by VIP was to know where they should

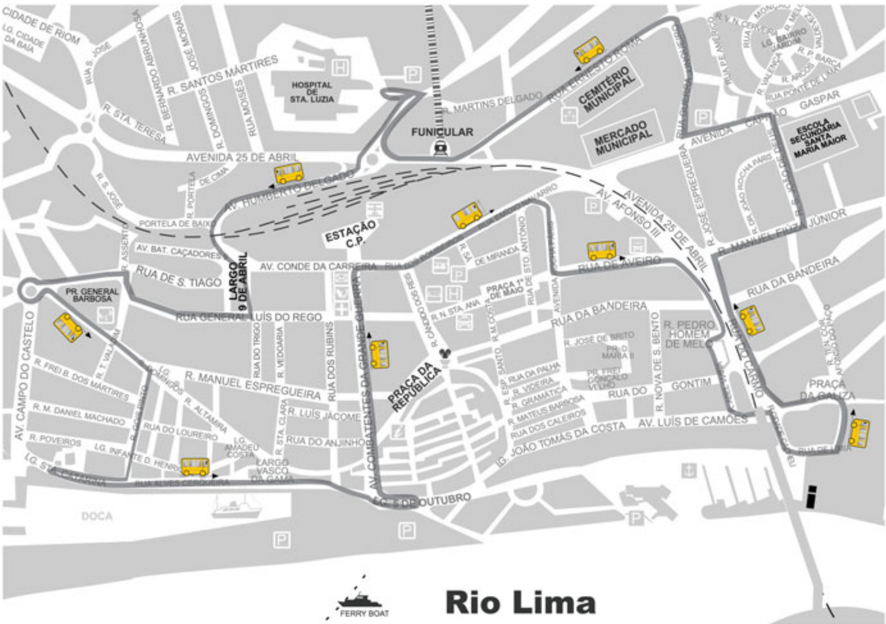

Fig. 4.1 Urban transport route in the city of Viana do Castelo

ring the bell for the driver to stop the bus (this type of urban transportation has no predefined stops; they stop everywhere as long someone rings the bells). After a VIP enters the bus, they easily lose the notion of where they are, and as a consequence, they do not know when to ring the bell to leave. The current and only way to solve this problem is to ask someone to tell them in what street they are or a reference point so they can know if it is already time to ring the bell.

Reference points are the main aspect of the solution, and this was one of the reasons we could not use Google Maps. There are indeed a lot of reference points, but they are too much, and plenty of times they are not relevant because there are little coffee shops that not everyone knows necessarily and, for that reason, cannot be used as a reference point.

Routes can change for several reasons: because it was decided the bus had to go through an additional street or, most likely, because one of the streets in the route is under construction/maintenance. This has conditioned the architecture of the solution requiring a backend to define the routes and support making quick changes to the route. Also, with the routes drawn in a map in the backend, it is easy for the administrative people that will use the backend to guarantee there are enough (and not too much) reference points along each route.

4.3.2 Social Component

With the limitations that are present in the daily lives of blind and partially sighted citizens, it should be noted that part of the technology launched daily nowadays is not directed or may not be thought of with a focus on its use by this public. It is precisely at this point that we focus, and we aim to renew the main ideals in the launch of new technologies. The application we present in this chapter focuses on the bus navigation through the city of Viana do Castelo and assumes an important place in the daily life of these people, providing them with autonomy in one of the tasks of their day to day. In fact, it is quite cumbersome, limiting, and socially exclusive not to be able to ride the bus alone and depend on the person next to us to reach or even ring the bell of the bus. The development of this work allowed all those involved to become aware of a completely unknown reality, which are the difficulties that blind and partially sighted people experience in the most common tasks of everyday life, such as riding a bus, and for people without visual impairment, it is not a problem and we are not even aware that these difficulties exist. Thus, with this work, it was possible to gain this awareness and to experience in the first person what is the reality and difficulties for blind and partially sighted people and to give life to a new version of the application to help them and promote autonomy and social inclusion.

4.3.3 Tests Feedback

The tests made to the first version of this mobile application were performed by several members of the association that worked with us along this project. In its global form, the application works correctly, but some points were mentioned as improvements. One of them is the possibility of the user to obtain additional information regarding a particular place that he passed by. Let us suppose the user just passed by the health center and he wishes to have additional information such as the opening hours or other information. This type of data should be available for the user in a friendly way. Another aspect has to do with the normal behavior of Talkback which is the android accessibility service that helps visually impaired users interact with their smartphones. When the application is in the main screen where a map is shown, what happened in a real scenario was that, if the application did not say anything for a while, the users started clicking on the app/map to see if something was wrong. The normal behavior of Talkback is to stop sending messages in this situation what required that the app was restarted to work again and started sending information to the user again. This situation was asked to be corrected by us, as it caused some confusion to users. Another aspect was that some places used acronyms and were not easily understood. One example is the name Instituto Politécnico de Viana do Castelo that, in the app, was referred to as IPVC. Some other situations existed in some reference points, and this was another aspect to correct.

A major improvement asked by the testers was to add a new functionality that allowed users to say that they left the bus and, from then on, start to receive information regarding nearby points while they were walking. An example can be: "you are now passing by Almeida Coffee Shop."

Finally, an important improvement in this new version is a complete renew of the layout, carefully designed for visually impaired people.

4.3.4 Architecture

The architecture of the solution comprises a mobile application, a visually impaired person in a bus, the global positioning system, GPS, a backend, a set of PHP Web Services, and an MYSQL Database (Fig. 4.2).

The mobile application is used by a VIP in a bus in order to know where he is and when to ring the bell to get out. The mobile application communicates with a GPS to obtain coordinates, so it is possible to obtain the reference points close to where the bus/VIPs are. The reference points are obtained from a web service that communicates with an MYSQL database, where data (routes and reference points) are inserted via a backend.

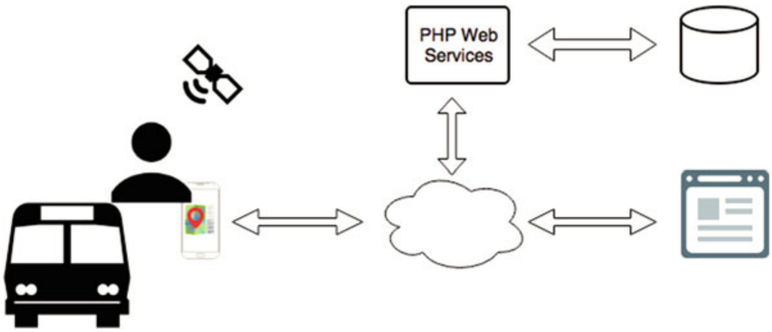

Fig. 4.2 Architecture of the mobile solution for visually impaired pedestrians

4.4 New Features

4.4.1 Layout Reformulation

According to IOS Human Interface Guidelines, layout is a form of communication. Layout defines the visual structure for a user interface. However, it covers more than just user interface elements. It is an essential design element. The app was designed to be perceived as user-friendly by all potential target-users. According to [17], in his work Emotional Design, attractive products work better because when design brings pleasure, mistakes are not so valued.

The arrangement of the different items according to a consistent structure was intended to highlight the different hierarchies in the composition. This will allow users to process the pages visually relying on a user friendly, intuitive layout. In the case of a mobile application design, the layout must consider that this digital tool requires a clear, effective, and simple navigation system. The end user has a goal at the moment of purchase, and according to [18], navigation is one of the most important areas in user experience.

Navigation is a tool composed by different elements such as pagination (previous and next button), links, help texts, etc., which allow the user to move within the application, creating an accessible, objective man-machine interaction. Navigation is constituted by guidelines of structural organization and alignment. It may be considered information architecture, since it allows the easy exploration of the different contents, avoiding feelings of frustration and disappointment from users [18]. In this study, it was fundamental to create an iconographic system adapted to the specific service in question. Hence, easy understanding was most valued, along with intuitive operation by people with visual limitations, to allow quick and accurate perception and action.

The layout of this application was developed taking into account the special needs of the users, blind, and visually impaired users. Subsequently, the design process was open to their special participation, involving interviews and the

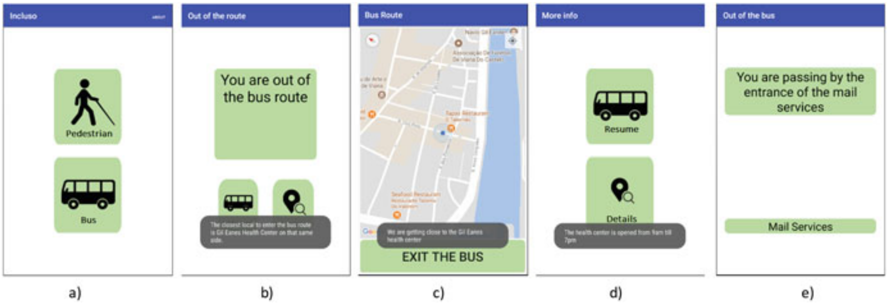

Fig. 4.3 Mobile application screens

collection of suggestions and feedback. Once the application's functionalities were defined, it was necessary to think how this information would be arranged upon the interface. Due to the different functionalities of the application, it was necessary to define a structure that would organize the interface so as to become easy to use. Figure 4.3a represents the first screen where two options are available: one to enter the bus module (the one we will focus on) and another to enter the pedestrian module. This sort of organization has the advantage of making the interface simpler, immediately displaying the functionalities.

In the other screens of this application, a minimalist layout was adopted, with less information. However, it was suggested by visually impaired users that all functions besides the icon (visual image) should contain descriptive text. Therefore, we have adopted a box-type layout (rectangles) with text and icons with their respective description. Concerning typography, a font without serifs was chosen because these require less effort from the eyes when read on screen [19]. Conversely, [20] supports that non-serif fonts are usually used in short reading sections or text to be read quickly. That explains why most mobile applications use non-serif fonts. According to Heather and Roger Graves in "The Strategic Guide to Technical Communication," if fonts are to be read on screen, serif fonts should be used with moderation and only for titles or headings. For long texts, fonts should not be serifs. The typographic family chosen for the display was Helvetica Neue. It coexists harmoniously with the logo and affords good readability to the text, completed with Bold, Regular, and Medium versions.

Regarding the font size, according to IOS Human Interface Guidelines, the most adequate for mobile devices is between 11 and 17 pt. However, in this application, we used 14–17 pt, since our target users are a group with special needs.

Color is also a crucial element in the visual identification of a brand or service, with the strategic objective of identifying and characterizing its recognition by the users. The predominant color used in the construction of the application is green. Green was chosen due to the association with living nature, development, and renovation, making the app more attractive. As a background color, it also allows forming colors across the spectrum of visible colors, and the black along with the shapes provides a good contrast.

Icons are omnipresent in almost all layouts/screens. They are important for visual communication, orientation, exploration, and use of the application. These visual elements have the main purpose of supporting a direct and unequivocal use. Digital icons also referred to as physical or virtual buttons are function holders. They are designed to create the interaction of services and/or products in order to present answers for use and operation. All these elements are accompanied by a sound message. For this app, the chosen icons are simple and easy to understand, with clear-cut intuitive lines, and at the request of future users, they are always accompanied by text, describing their function. All the elements throughout the creation process were verified, validated, and open to suggestions. As aforementioned, this layout was developed with the participation of a panel of visually impaired collaborators.

This layout is adapted to the blind and visually impaired, because it was designed keeping in mind the interaction among all constituents: users, context, message, color, typography, and icons. The singular composition of these elements, and the association with their group, was carefully designed in order to result in an effective, balanced interface.

4.4.2 Mobile Features

The first screen is shown in Fig. 4.3a where two options are available: one to enter the bus module (the one that we will focus on) and another to enter the pedestrian module. When the user clicks the bus module, the current location is obtained and checked if it is near the bus route. If it is not, the user listens to the information "You are out of the bus route" and also, after that message, listens to the closest reference point he should go to in order to take the bus, as shown in Fig. 4.3b. This was one of the main requirements for this new version, and to better explain this functionality, we made a representation in Fig. 4.4.

In Fig. 4.4, we can see three points (A, B, and C) and two reference points (R1 and R2). Points A and B are in a much known street in the city center (Manuel Espregueira Road) and point C is the city plaza. When providing information on the nearest point to catch the bus, we use reference points that are known to the user, but we also have to bear in mind the side of the street. If he is in point A, the closest reference point is R2, which is S. Domingos Church. The message the user will listen to is "The nearest point is S. Domingos Church in the same side of the street." If the user is in point B, which is in the same street of point A, the closest reference point is R1, which is the bank Caixa Geral de Depósitos. This reference point is located in the main avenue of the city – Combatentes Avenue – on the left side of it. So the message sent to the user on point B is "The nearest point is bank Caixa Geral de Depósitos in the same side of the street." Finally, if the user is in point C, the same reference point is recommended (R2), but in this case, the user will catch the bus on the other side of the street relative to the reference point, so the message will be "The nearest point is bank Caixa Geral de Depósitos in the other side of the street."

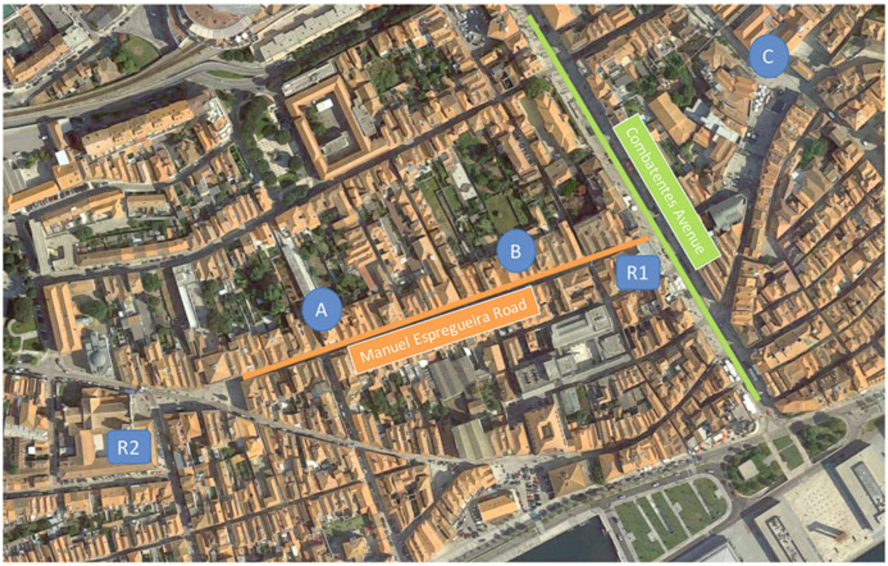

Fig. 4.4 Example of reference points nearby to catch the bus. If the user is in point A, point R2 is recommended; if the user is in point B or C, point R1 is recommended but in different side of the road

In Fig. 4.3b, the user has two buttons. The left one allows him to go back to the bus route. If he is still out of the route, the same screen will persist; otherwise, he will be redirected to the main screen (Fig. 4.3c) that we will cover next. The button on the right in Fig. 4.3b allows the user to listen again to the information of the closest point he should go to catch the bus.

Figure 4.3c shows the main screen of the app that the user will use when inside the bus. Here, he will get information of the next reference point he will face in the bus route. By being located along all routes, the visually impaired user will be able to ring the bell independently whenever he wants to leave the bus. Figures 4.5 and 4.6 show two examples of messages that are shown to the user in different places of the route. The first one is in the beginning of Combatentes Avenue and locates the user regarding a coffee shop on his left so that he can locate himself and know where he is. Figure 4.6 shows a different type of message, as it informs the user of a crosswalk approaching. This is a type of message the VIP working with us asked us to send, as they can need this information to choose this place to leave and cross the street.

In the screen shown in Fig. 4.3c, we have a different behavior if the user clicks the map. This was a problem in the previous version in which the application would stop producing audio information. In this version, if the user clicks the map, we will redirect him to the screen shown in Fig. 4.3d and produce the audio information "You have interrupted the bus route. Please choose an option." And then two options are available to them: the first button allows the user to go back to the

Fig. 4.5 Example of message sent to the user when inside the bus. In this case, the user is informed of a coffee shop to his left

Fig. 4.6 Example of message sent to the user when inside the bus. In this case, the user is informed of a crosswalk approaching so that he can leave here to cross the street

previous screen where there is a map to perform the bus route and the second button shows detailed information of the previous reference point he passed by. Providing additional information was another required feature, so we added it here. If the user is on the bus and passed by a reference point of his interest, he can click the map and then see details about the place. An example of additional information is "The health center is opened from 9 am till 7 pm." After this additional information is presented to the user, the bus route starts again in the screen that has the map and information to locate the user starts again being sent to him.

The final functionality in this version is providing information after the user leaves the bus. That option is available in the button "Leave the bus" of Fig. 4.3c that redirects the user to the screen shown in Fig. 4.3e. Here the user is presented with two types of information: the closest reference point and where he is related to it. An example is "You are in the corner of the entrance to the city hall." As long as the user is walking, he will receive information regarding close reference points along the way.

4.5 Tests and Evaluation

The new version of the application was again tested by members of the association that collaborates with us. Before the tests were performed, a careful and detailed explanation was provided to the people that were going to use the app to perform the tests.

The tests have two goals: assure the user can use the app and the layout is friendly and intuitive; assure the user can really use the app to go to a given destination and independently leave the bus, which is the main purpose of the application. Table 4.1 details the tests we have done.

The tests were made by three associates regarding the use of the app, using three different smartphone models: One plus One 1, Nokia 6, and Samsung Core Prime. Figures 4.7 and 4.8 show some images and scenarios of the tests performed.

The main conclusions after the tests were performed are that the application works very well and serves the main purpose it was developed for. The visually impaired people that made the tests said they preferred to use the app with the inverted colors option activated, as it improves contrast and makes it easier to identify buttons in the screen. The design was referred to as being very functional, intuitive, and easy to understand. Along the route, they are always located in terms of place and also inside the application.

The first time the users opened the application during the tests, they were in the Institution Headquarters (point A in Fig. 4.9) and they were off the route, and they immediately understood these using the information provided by the app. At this point, they chose to listen to the nearest point they should go catch the bus, and they were indicated to go to S. Bento drugstore (point B), and that information was very important to them. At that location, they entered the bus and each of the three associates was given a smartphone to use during the route. All three smartphones were in sync when receiving notification though the Nokia 6 showed some delay.

Along the way, and with the information of reference points, they were always aware of where they were. They were asked to simulate pressing the button to leave for S. Domingos Church (point C) and they successfully identified the place where they should ring the bell. After that, they were asked to leave the bus at Back Caixa Geral de Depósitos (point D) and they successfully rang the bell to leave the bus (see Fig. 4.8).

At this point, they used the pedestrian navigation and were correctly informed of the places they were passing by. Some errors still exist based on the precision the GPS allows and also depending on the equipment.

Table 4.1 Tests performed by visually impaired people to measure the results obtained with the mobile application

Test ID	Description	Action to be performed	Expected result
1	Enter the option “bus”	The user opens the app and click the second button entitled “Bus”	User successfully clicked the option “Bus” and entered the next screen
2	Understand being out of the route	The user chooses the “Bus” button and is out of the route. Listen to the presented audio information	User clearly understood what is happening in the app and that he is out of the route
3	Understand the option “back to the route” when he is out of the route	The user is out of the route and wants to go back to the route. He presses the button “go back to route,” button on the left of screen (Fig. 4.3b)	The user successfully uses this option and goes back to the route
4	Understand the option “catch the bus” when he is out of the route	The user is out of the route and wants to go back to the route. He presses the button “catch the bus,” button on the right of screen (Fig. 4.3b)	The user successfully uses this option and listens to information about the point he should go to catch the bus
5	Understand the main screen of the app that shows a map and audio information	The user is on the route and the app shows a map and starts producing audio information. The user should listen	The user correctly listens and has the feeling of knowing where he is all the way through the route
6	Leave the bus in the right place – Correios	The user should listen to information so he knows when to ring the bell to go to Correios	The user successfully rang the bell at the right moment
7	Leave the bus in the right place – Health Center	The user should listen to information so that he knows when to ring the bell to go to Health Center	The user successfully rang the bell at the right moment

8	Interrupt audio information	The user click the map and he is presented with an audio messaging saying he interrupted the bus route	The user understood what happened and did not get lost in the use of the application
9	Resume audio information	After interrupting audio information, the user uses the option "Resume" to go back to the map and listens to audio information about the route	The user successfully goes back to the map screen
10	Listens to detailed information about a place	After interrupting audio information, the user uses the option "Details" to go back to the map and listens to audio information about the route	The user successfully goes back to the map screen
11	Locate himself inside the app after detailed information is produced	Listen to detailed information about a place	The user knows where he is inside the app after listening to detailed information about a place
12	Leave the bus option	The user wants to leave the bus. He uses the option "Exit the bus" in the map screen	The user successfully left the bus and did not get lost in the app
13	Use the pedestrian information	The user left the bus and listens to information about places he is passing by	The user successfully understands the audio information

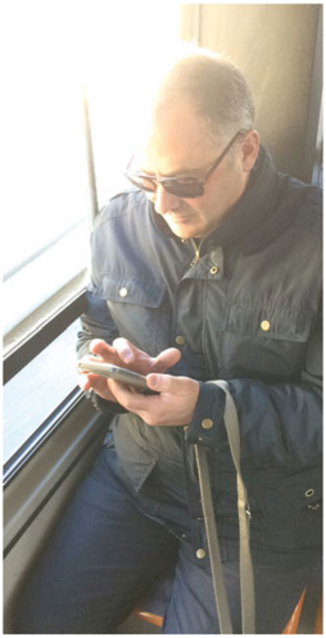

Fig. 4.7 Visually impaired tester inside the bus with the mobile app

4.6 Future Work and Conclusions

In this chapter, we presented the evolution of a previous work regarding the promotion of urban mobility and transport sustainability applied to visually impaired people. We presented the case study that refers to a city in Viana do Castelo, north of Portugal. The prototype consists of a mobile application that helps visually impaired people to successfully and independently use public transportation and be aware of their current location along all bus routes. We presented the improvements made since the previous version that includes new layouts and presented the new tests made with associates of a visually impaired people institution. The results were very satisfactory, as the users successfully made all bus routes being aware of where they were and left the bus in the location they were asked to.

Some future work also came out of the performed tests. The users asked us for a new functionality that allows them to choose the reference points they wish to hear and are important to them. They also would like to have a new button in the main screen that allowed them to hear the last reference point.

Fig. 4.8 Bus where tests were made and associates/testers

Fig. 4.9 Explanation of test scenario

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Chapter 5
Human-Centered Design Components in Spiral Model to Improve Mobility of Older Adults

Jayden Khakurel, Jari Porras, Helinä Melkas, and Ainara Garzo

Abstract As humans grow older, their cognitive needs change more frequently due to distal and proximal life events. Designers and developers need to come up with better designs that integrate older users' needs in a short period of time with more interaction with the users. Therefore, the positioning of human end users in the center of the design itself is not the key to the success of design artifacts while designing applications for older adults to use a smartphone as a promising tool for journey planner while using public transportation. This study analyzed the use of human-centered design (HCD) components, the spiral model, and the design for failure (DfF) approach to improve the interactions between older users and designers/developers in gathering usability needs in the concept stage and during the development of the app with short iterative cycles. To illustrate the importance of the applied approach, a case study with particular focus on older adults is presented.

5.1 Introduction

The proportion of the older age group is growing [1, 2], and it is expected that in upcoming years, many older adults in North America and Europe will travel using their own transportation (i.e., with their own private cars) [3] because of the desire to be autonomous. Ego enhancement, self-esteem, novelty, knowledge seeking, relaxation, socialization, and cultural and historical factors were cited as motivation for travel among older adults [4–6]. However, Rosenbloom and Ståhl (2003) point

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J. Khakurel (✉) · J. Porras · H. Melkas
Lappeenranta University of Technology, Lappeenranta, Finland
e-mail: Jayden.khakurel@lut.fi; jari.porras@lut.fi; helina.melkas@lut.fi

A. Garzo
TECNALIA, Donostia-San Sebastián, Gipuzkoa, Spain
e-mail: ainara.garzo@tecnalia.com

S. Paiva (ed.), *Mobile Solutions and Their Usefulness in Everyday Life*,
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out, “The growing automobility of an aging population poses environmental, safety, mobility, and community design challenges to developed societies” (p. 210). One of the possible ways to reduce the automobility of an aging population is to encourage the use of alternative modes of mobility, such as public transportation; [7–9] point out, “public transport is important to older people’s quality of life, their sense of freedom and independence” (p. 4334). However, journeys via public transportation require travelers to (i) get engaged in a series of high-level activities such as planning, waiting, and moving; (ii) comprehend, manipulate, and process “essential navigation artifacts”; and (iii) accommodate unexpected situations due to system failure or a user’s own error [7]. Such requirements can be a major hurdle for older adults in terms of accessibility, perceptions about safety, and management of the associated informational complexity [10, 11] along with the consequent high cognitive load. Responding to these challenges is possible by meeting the older user’s cognitive and physical access needs through smart technological tools, thereby enabling them to use public transportation.

Among the many existing technologies, smartphones and installed applications can be considered as promising tools that can support the effective use of graphical user interfaces (GUIs), allowing users with visual impairments to customize their phones to suit their particular needs [12]; manage mobility by providing transit information and aiding navigation [13, 14]; and improve the quality of life for older adults [15, 16]. However, in designing for older adults within public transportation information technology (IT) environments, such as real-time transit and navigational information, the requirements are not necessarily the same as those for other categories of the population [11]. A major problem is that stakeholders have little understanding of how to provide better touchscreen interface tools for older users, since the de facto standards of basic operations on touchscreen-based smartphones, which consist of tapping, dragging, and pinching, have only been adopted in the last few years [17]; how to integrate audible, haptic, and visual feedback that is responsive to older users’ physical, cognitive, and mental capacities; and how to design applications for failure caused by the device, the environment, and the user’s own action and supporting technology in a special context; [9, 18] state, “As the system developers target bigger markets from their economic point of view, many products do not address the requirements of specific groups of older people (e.g. those with mobility difficulties)” (p. 4334).

This research attempted to bridge the knowledge gap by undertaking human-centered design (HCD) with the spiral model and the design for failure (DfF) methodological approach within the public transportation information technology (IT) environment using a smartphone application to support older users in managing and improving their mobility. This approach, which was validated by the case study, can help transit stakeholders to understand how smart mobile applications can meet the mobility needs of older adults by identifying and analyzing single probable points of failure based on interacting with older end users during all phases of the design and development process. Accordingly, the objectives of this research were:

- To extend the HCD design approach by using a spiral model and DfF and propose a design process for the development of applications targeted at older adults in an effort to improve HCD's usefulness to application designers and developers. Even though the results are solely based on a web and Android platform, we believe that this design and development approach can be utilized in other application development processes while working with and for older adults to enhance their quality of life.

- To illustrate the usefulness of HCD with a spiral model and DfF approach during the design process with particular focus on older adults, a web platform and smartphone-based application was developed. It lets older adult travelers prepare their personalized journey via public transportation at their convenience and then receive guidance throughout their journey.

Hence, to achieve the objective, this study aimed to answer the following research questions:

RQ1: How does an approach that uses the human-centered iterative design and development activities of application development with a spiral model and design for failure improve the usability needs of older adult users?

RQ2: What types of usability issues related to device characteristics (i.e., hardware and software) were discovered during the case study?

In the following section, we present related work, followed by the case study and our methodology to validate our approach. Following this, we present an interaction analysis framework in line with the case study, followed by the key findings, limitations, and conclusion.

5.2 Background Study

In this section, we describe previous work to understand the impact of aging on access to public transportation; technology; as well as the benefits of HCD, the spiral model, and design for failure that researchers have discussed in recent years.

Regarding the impact of aging on technology and vice versa, [19] investigated the factors that influence the use of user interfaces (UIs) among older users. Zajicek's (2001) study showed that age can impact the interaction between older users and the user interface. Further, Zajicek (2001) found that modalities such as speech interaction are useful for older users with visual impairments. However, such modalities had drawbacks for some older users in trying to follow lengthy output messages. Zajicek (2001) concluded that older users' requirements may vary during the design period due to tiredness, eyestrain, and decreasing abilities over time and designers should take older users' changing abilities into consideration during the design process. [20] attempted to understand how accuracy and performance vary between younger and older users while using the same user interface. The study involved experiments where performance was observed under three instructional sets: accuracy (i.e., users were asked to focus on accuracy only); neutrality (i.e., users were asked to focus on both speed and accuracy), and speed (i.e., users were asked to focus on speed only). They concluded that aging has a significant negative effect on performance and accuracy. [21] performed usability evaluation studies on the user interface of a mobile application targeted at older users. The study produced a set of recommendations regarding navigation, interaction, and the visual design aspects of smartphone application user interfaces.

With respect to the research on the requirements of the needs of older adults in using public transportation, [22] pointed out that due to the impacts of aging, older travelers have a variety of safety, personal security, flexibility, reliability, and comfort concerns about public transit, even if it is physically accessible. [9] conducted a study on the requirements of five different profiles/groups of older people using the public transportation. The study found that easily accessible information provision on public transport was important for all five different profiles/groups of older people but that the required content and delivery of the information varied between groups. [23] conducted a study with a sample of older citizens (75+ years) to understand their perceived travel opportunities. The study concluded that more needs to be done with regard to accessibility and usability of public transit for older people.

5.3 Methodological Approach

To be able to easily access public transportation, older adults will need to know how to manage their tools, locate transit information, and navigate more effectively with minimal cognitive needs. Therefore, when it comes to this target group of users, we believe that it is not enough for stakeholders to decide what older adults will consider an intuitive design. To gather the specific requirements for a user interface and gain its adoption by older users, we considered an approach that uses human-centered design (HCD) with a spiral model presented by Boehm [24] and design for failure to be the foundation of this methodology.

Previous studies have incorporated human-centered design (HCD) to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics and usability knowledge and techniques [25]. Kujala (2003) [26] pointed out that user involvement has positive effects if the user's role is carefully selected, especially during requirements elicitation and user satisfaction. Kujala (2003) stated that "users may not be able to communicate their precise requirements but they are able to explain their goals and how they approach their tasks" (p. 13). Similarly, Uzor et al. (2012) [27] demonstrated the impact of older adults during the design process.

The results of their study showed that by participating in the design process, older users can reveal some of the obstacles that designers may not be familiar with, enabling them to resolve such obstacles in an early stage of the development process. Ferreira et al. (2013) [28] conducted research on lowering the high levels of nonadherence to medication in the older population by using a mobile application that puts the user at the center of the design process. The study concluded that the participation of older users from the initial phase and onward helped to generate

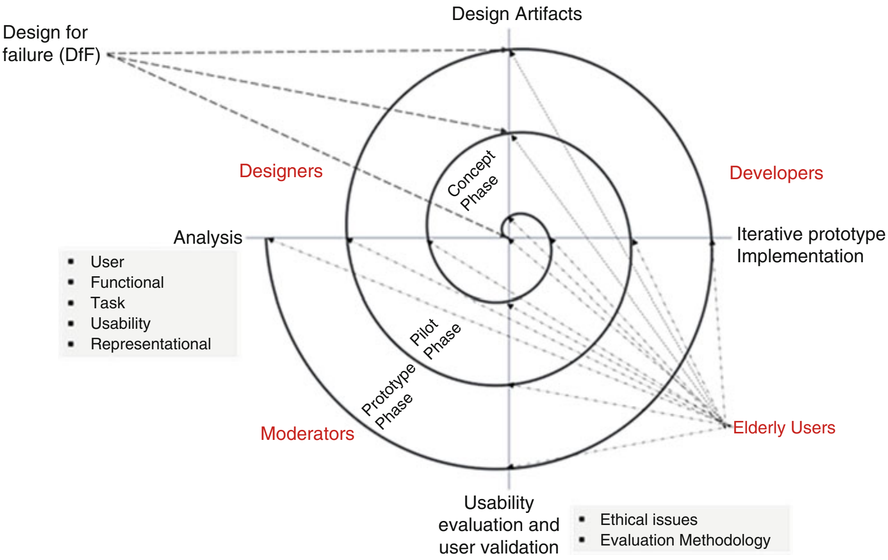

Fig. 5.1 HCD component in a spiral model with a design for failure framework

ideas, enabling the application to be shaped according to the users' needs and capabilities through a continuous process of redesign. However, in the case of older adults, the human-centered design approach has some challenges because older users "may not be able to critique a design until it is far along in the development process, which may be too late to make certain types of changes given time and cost constraints" ([29], p. 8). Such challenges may cause tremendous risks during a project. Thus, to reduce the risk, we adopted a short iterative spiral model (i.e., three distinct phases: the concept phase, the prototype phase, and the pilot phase) and embedded HCD components (i.e., analysis, design artifacts, iterative prototype implementation, and usability evaluation and user validation) (see Fig. 5.1).

Further, technology failures are inevitable during an application's design, development, and implementation because of the complexity of the system. Similarly, human errors while using devices or applications are inevitable because of the need for a high cognitive load to learn new things. Such errors can have adverse effects on older adults' use of a system during public transit. To reduce such adverse effects, we implemented the DfF approach during the design process, which is common in software design. This study applied the DfF framework presented by Carmien (2017), meaning the system should be able to accommodate, which consists of four basic types of failure events: (i) device failure, (ii) environmentally caused failure, (iii) failure due to user action, and (iv) failure due to supporting technology in special contexts.

To help illustrate the concepts discussed and present the results of our study, we now present the proposed "Assistant" web platform and mobile application. [9] point out, "open access data provision in the transport sector has a huge potential

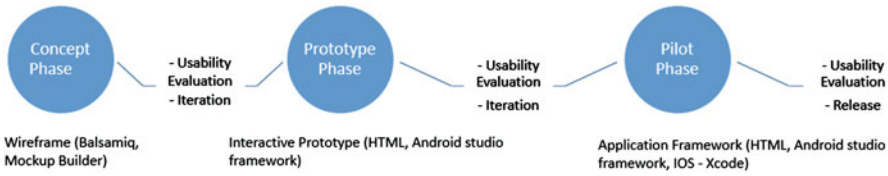

Fig. 5.2 Design iteration process

to encourage dissemination of targeted traveler information using mobile apps with the involvement of the private sector" (p. 4342). Therefore, the aim of this project was to develop a novel personalized and customized public transportation trip planner for older adults with or without disabilities based on the open data. The Assistant provides guidance on transfers when making multi-step journeys and assistance in getting from the vehicle to the final destination. This allows Assistant applications to accommodate expected human errors, increase accessibility, and enable effective error handling. The structure of the Assistant system comprises five main components:

- Web-based route editor platform: The backend maintains a database of public transportation information (i.e., open data) from transit providers and other customized and personalized user information for both primary and secondary users. The Assistant's web interface allows users to create a route on a map, view route calculations, and manage their profiles. Simultaneously, it monitors the users' interactions with the system, checks data for errors, and provides corrective support. Once personalized routes are created, push notification messages are sent to the users' smartphone devices (see Fig. 5.2).
- Mobile Application: The Assistant's mobile application communicates with the server asynchronously over the Internet and retrieves updated maps, schedules, and telematics data.

5.4 Analysis of Methodological Approach

The following section describes how each HCD component was incorporated with respect to the design of the Assistant application for older users within all three distinct phases (concept, pilot, and prototype).

5.4.1 Analysis

A key component of HCD is analysis, which comprises multiple levels: users, functions, tasks, and representations [30]. Rinkus et al. (2005) further explained, "The user analysis level contributes to each of the levels of functional, task, and representational analysis" (p. 5). Since the system is designed for older users, we undertook usability as part of the components of analysis. Therefore, in our approach, the user analysis level consisted of usability, functional, task, and representational level. The following section provides a synopsis of how each requirement in this level was extracted and compiled from the focus groups of older users:

- *User analysis:* The elderly users' needs vary widely based on their physiological and psychological characteristics, which influence the adoption and acceptation of the system. This level focuses on identifying and analyzing the elderly users' physiological and psychological characteristics, which help to design a system that matches their needs, main difficulties, and limitations. Assistant, which is an "on the go" system, consists of two separate users:
  - Primary users: The older users' needs varied widely based on their physiological and psychological characteristics, which influenced the adoption and acceptance of the system. This level focused on identifying and analyzing the older users' physiological and psychological characteristics, which helped to design a system that matched their needs, main difficulties, and limitations.
  - Secondary users: Caregivers and/or relatives who may use different modules of the "on the go" system to support primary users who may or may not have reduced cognitive abilities.
- *Usability analysis:* A system that has older adults as its primary users requires early usability analysis to bridge the gap between users and devices. Usability can be defined as the ability of both primary and secondary users to interact easily with the device and its characteristics (such as physical aspects and software) when used under specified conditions to achieve specific goals [31]. The requirements obtained from a usability analysis must be tangible and can be verified and traced during development [32]. For this purpose, before starting the functional analysis, we asked some older users to answer several questions in order to collect their usability requirements. Based on the collected data and the usability principles provided by Nicolle et al. (1999) [33], ISO/IEC (2001) [36], Parhi et al. (2006) [34], and Creswell (2007) [35], the following system requirements for the Assistant were obtained: it should be simple and user friendly; the user interface (UI) should display only required functionalities; the UI should be personalized based on user preferences due to cognitive abilities; any error, warning, and other messages should be relevant and concise; the UI should be designed with more legible fonts and larger font sizes; the UI should follow all legibility guidelines relating to color contrast, lighting, font size, and so on; the application should have visual and audible instructions and haptic signals; and physical buttons should be utilized rather than touchscreens.
- *Functional analysis* is the process of identifying critical top-level domain structures, goals, and inherent properties of the work domain that are largely independent of implementation [30]. Rinkus et al. (2005) further stated that "it is more abstract than task and representational analyses because it does not

involve details of task processes and representation details" (p. 6). The functional analysis results established the following requirements:

– Route planning (safer and effective ways to plan and compose personalized routes)
– Map accessibility annotation (provide a set of information about the essential accessibility data, such as barriers, bus/metro stops, and public facilities during route planning)
– Waypoint navigation (provide turn-by-turn guidance with waypoints for the personalized routes on smartphone devices during the trip)
– Last kilometer navigation (navigate the user from the last transit stop to the final destination using a map that consists of point-of-view maps and visual waypoint support)
– User preferences (user's personal accessibility needs and preferences are taken into account)
– Error detection and mediation (detects and accommodates human error as well as the failure of system components, e.g., going off track, stolen phone, loss of signal, success or failure of planned routes, etc.)

- *Task analysis:* Task analysis is the process of identifying the procedures and actions to be carried out and the information to be processed to achieve the users' task goals [30]. For the Assistant, we broke down the process into the following steps based on each function, identified during the functional analysis phase: high-level scenario, use case, test case, and tasks.
- *Representational analysis:* A representational analysis, which is based on the representational effect [37], refers to a phenomenon that analyzes the isomorphic restrictions that can have dramatic effects on the user's ability to accomplish the tasks. The form of a representation can influence and sometimes determine what information can be easily perceived, what processes are activated, and what can be derived from the representation [30]. During this process, suitable communication tools (e.g., smartphone devices, computer displays, and customized original component manufacturer devices) with context display interfaces for the given task for the specific set of users can improve the users' experiences overall.

  Because of widespread smartphone device characteristics (i.e., physical aspects and software) in the market, the limitations placed by the smartphone device manufacturers on development platforms, and the users, tasks, usability, and functional requirements, we chose to use an Android-based Samsung smartphone. This smartphone allows users to install customized applications and has a high-resolution display, customizable widget size, fewer limitations in comparison to other OS development platforms, and device connectivity functionalities such as Bluetooth.

5.4.1.1 Summary of User Requirements

The following section summarizes the older users' requirements that need to be taken into consideration on both the mobile and web.

Mobile: In general, the preference was text waypoints; audio of prompts was desired; request to keep smartphone out of the way to diminish the possibility of being stolen was preferred; design should take into account the role of dual glasses; Bluetooth headset was the preferred output device by many; there was a need for clarity on the waypoint page and audible prompts; fonts cannot be small; spoken control of the system was preferred; widget size and appearance were preferred; touchscreen response was preferred; switching between apps was required; and users would like orientation information on the screen.

Web: Scale of the maps and street names must be readable; maps should have the "you are here" indicator; word completion for addresses should be an option; a new terminology should not be used; font size is important; text route instructions should be included; and transfer of data from a web platform to a smartphone is required.

5.4.2 Design Artifacts

Design is essentially a search process to discover an effective solution to a problem [38], not only to provide a better user experience but also to establish the credibility of proposed or existing systems. For our case study, we defined and designed artifacts (i.e., architecture, components, modules, and user interfaces). As this analysis focuses on improving the usability needs of older users, we skipped the technical analysis and focused more on the design analysis to improve their experiences.

During the analysis, it became clear that the user interface acted as a tool for older users to interact with the system and required a particular set of features to meet all the users' cognitive needs. Our first objective was to design a user-friendly interface based on the specified requirements obtained from the analysis to maximize usability and the user's experience. Therefore, early in the design process, interviews and focus groups were held to derive a set of user requirements and different tool kits were utilized (see Fig. 5.2).

Three initial designs were prepared and presented to a focus group of older users to receive their feedback during the concept phase (see Fig. 5.3a). During the first design, online tools "Balsamiq[1]" and "Mockup Builder[2]" were used to create the wireframe. The next iteration of the design cycle was triggered to improve and introduce a new design based on users' feedback after usability evaluation where

[1] https://balsamiq.com/

[2] http://mockupbuilder.com/

a b c

Fig. 5.3 Design iterations. (**a**) Concept phase. (**b**) Prototype phase. (**c**) Pilot phase

HTML was used to create the website and Android studio framework and their libraries were utilized for smartphone application (see Fig. 5.3b). A final application was presented and tested among the older adults (see Fig. 5.3c).

5.4.3 Iterative Prototype Development and Implementation

In the concept phase, the initial stage prototype was implemented using a wireframe (see Fig. 5.4a, b) for both web and smartphone application based on the primary user's requirements, which was useful in outlining the user interface.

During prototype phase, usability protocols were implemented to gather the users' feedback on the mobile device itself. We identified a number of usability issues such as the design and physical shape of the devices in the initial mock-up, even though we followed the usability guidelines stated by Kobayashi et al.

Fig. 5.4 (a) Wireframe (Web). (b) Wireframe (Mobile)

(2011) and gathered usability requirements. After the refinement of the initial mock-up based on the new usability requirements from the users, the first prototype (see Fig. 5.5a, b) was developed, in which system functionalities such as error trapping and remediation were deployed to accommodate human error as well as the failure of system components using HTML, Android Studio framework, and its libraries. This prototype had the ability to (i) recognize path errors, (ii) use the user model to do remediation in case of error, and (iii) capture and do something about the battery running out of power or the loss of the network.

The first prototype of the Assistant smartphone application contained two different views: Navigation and Settings (see Fig. 5.5a, b). For increasing the effectiveness of real-time information delivery systems and acceptability to intervention content without deterring engagement [39], navigation views allowed the user to receive the push notification about "personalized route" generated by either primary or secondary registered user on the web client.

Once the route is accepted, it is shown as a list (see Fig. 5.5b). Further, the application has the ability to identify the users' location, context (i.e., whether the user is walking, user is waiting for a vehicle, or user is on a vehicle), and real-time information from public transportation. For example, if the user misses the destination stop or waypoint or major delays, the application informs the user through a pop-up showing, "*You have missed your bus stop, please get off at the next stop.*" Once the user gets off from the bus stop, the Assistant application automatically recalculates the user's current location and destination and shows the alternative faster route.

The Settings view allows users to change settings for screen brightness, Bluetooth (on/off), volume (increase/decrease), and route planner (on/off). In case of emergency, users were able to call their near ones with call buttons.

After the implementation of the first prototype, we conducted new evaluation studies using three usability methods to gather the usability needs of the primary users. During the evaluation process, a user performed various tasks assigned by the evaluators. As an example, some of the findings from this prototype evaluation concerned the web and mobile user interfaces for the route planning section, such as:

- Textual information which should be put together
- The color of the button background (i.e., red)
- Unnecessary buttons
- A detailed report on how to get from place A to B
- Wanted the AAL system to decide the best routing for them

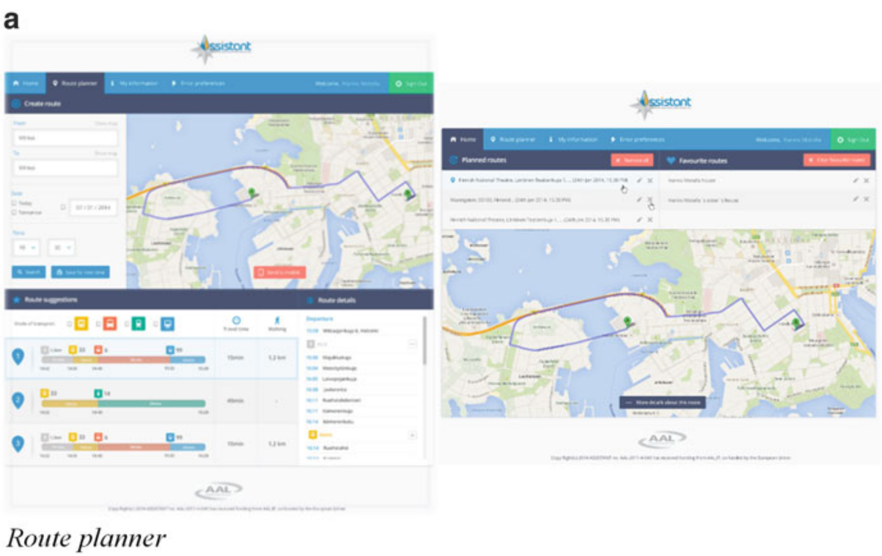

Fig. 5.5 (**a**) First prototype (Web). (**b**) First prototype (Mobile). (**c**) Prototype phase (Mobile)

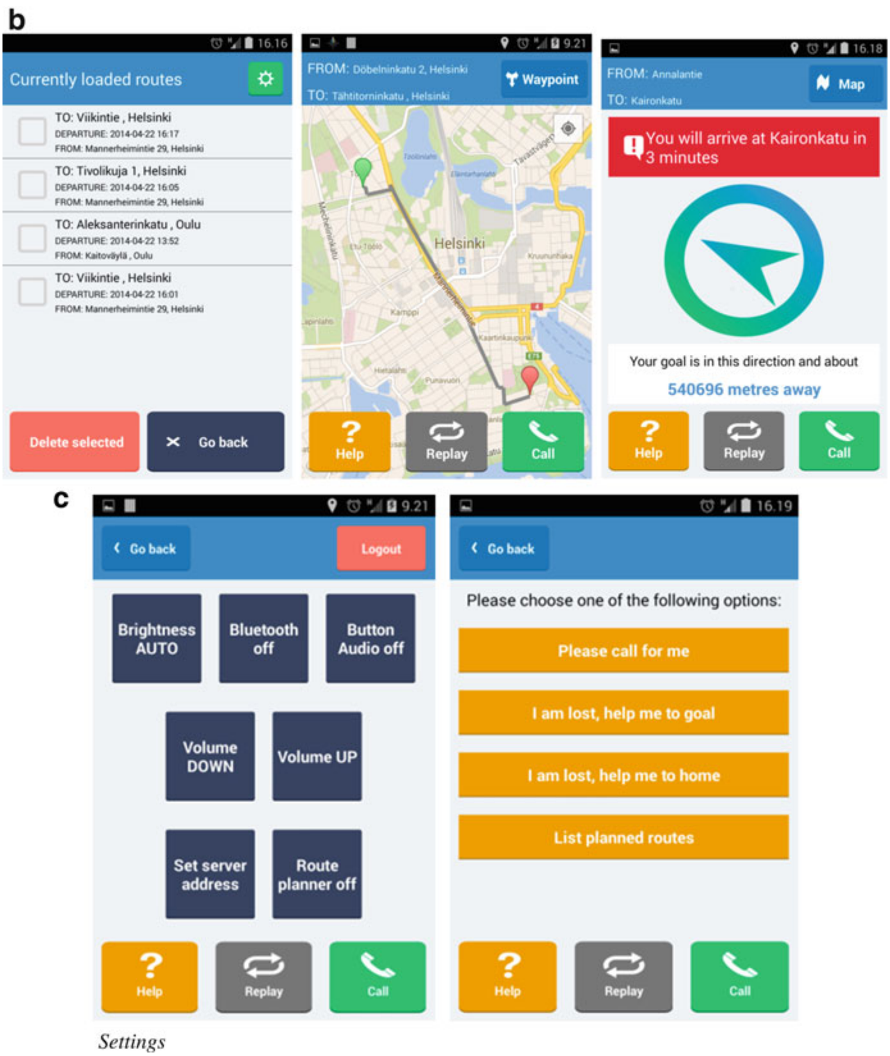

Fig. 5.5 (continued)

To make the Assistant system consistent, user friendly, and usable, we refined the system based on the users' feedback from the evaluation. In the final prototype (see Fig. 5.6a, b), route planner was simplified and removed unnecessary buttons and functionalities of the Assistant system. The application was tested with both primary and secondary users to gather their feedback in real-case scenarios.

5.4.4 Usability Evaluation and User Validation

Usability evaluation methods were employed to get a general overview of the usability issues that were observed during the evaluation process. Usability is measured by the extent to which the intended goals of the use of the overall system are achieved (effectiveness); the resources that have to be expended to achieve the intended goals (efficiency); and the extent to which the user finds the overall system acceptable (satisfaction) [40].

A usability evaluation was performed on the Assistant application to understand how older users experienced each design with their cognitive abilities. To verify the acceptance of the system, older users were recruited to participate in focus

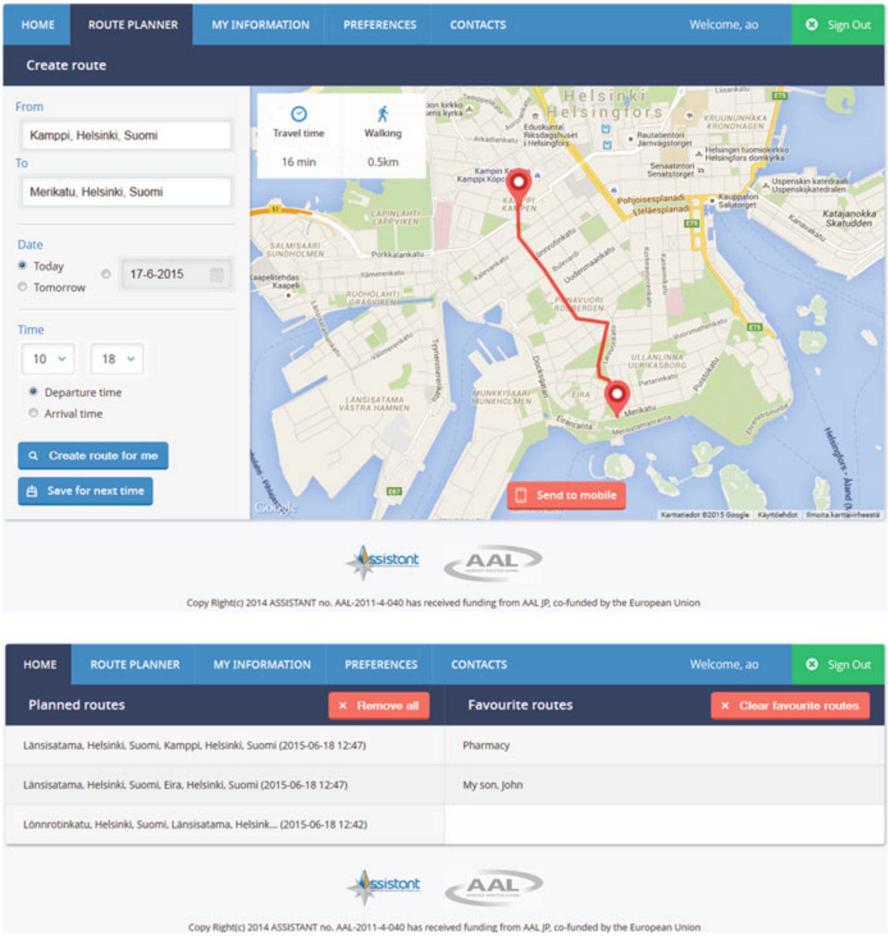

Fig. 5.6 (**a**) Final prototype (Web). (**b**) Final prototype (Mobile)

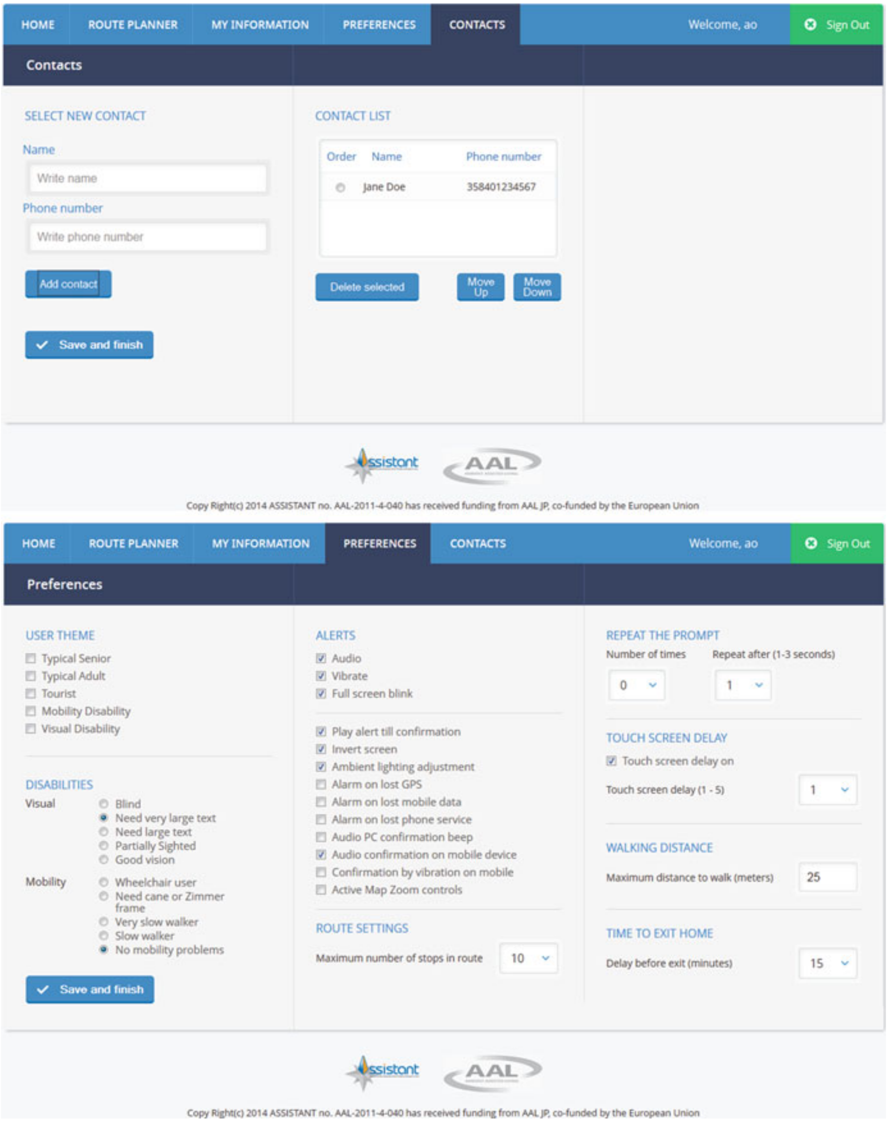

Fig. 5.6 (continued)

Fig. 5.6 (continued)

groups and evaluations were held in different countries: France, Spain, Austria, and Finland (see Table 5.1). Usability evaluation activities were divided into three phases: concept, prototype, and pilot. Out of three usability method classes proposed by [41], two (i.e., inquiry and inspection) were selected to conduct the usability studies. Various methods were applied because it is difficult to gather usability issues by relying on just one set of data from one specific usability method. The

Table 5.1 Summary of the focus groups, evaluation methods, number of participants, and user characteristics from each evaluation phase

Evaluation phase	No. of participants	User characteristics	Country	Evaluation method
1st	4 6 8	1:M, 3:F (65–91/years) 5:M, 1:F 4:M, 4:F	France Spain Austria	Inquiry Inspection
2nd	5 5 5	3:M, 1:F, 81,3/years 3:M, 2:F, 68,4/years 3:M, 2:F, 68,2/years	Finland Austria Spain	Inquiry Inspection
3rd	4 5 5	4:M, 0:F, 65–69, 85+ 1:M, 4:F, 71.4 1:M, 4:F, 69,8	Austria Spain Finland	Inquiry Inspection

method classes included testing, a think-aloud protocol; inspection, a heuristic evaluation; and inquiry, where focus groups, interviews, questionnaires, and diaries were applied.

5.5 Discussion

Generally, younger groups of users have been given more public and scientific attention than older users when it comes to technology and services [42]. In this research, we conducted a case study where we developed a novel personalized and customized public transportation trip planner for older adults with or without disabilities to show that smartphones can be important tools for them to plan trips and use public transportation more easily. Previous researchers have demonstrated that HCD is a good approach for understanding users and improving the functional and nonfunctional requirements of applications (Zimmermann and Grötzbach, 2007) [43]. However, we demonstrated that the HCD design approach is not always applicable when designing an application for a group of older users and requires another framework.

The methodology applied in this study contained four components ((i) analysis, (ii) design, (iii) iterative prototype development and implementation, and (iv) evaluation and user validation) and three phases ((i) concept, (ii) prototype, and (iii) pilot). In the concept phase, initial requirements were gathered from the older users through HCD components. The prototype phase aimed at developing the prototype and improving the design and development based on the feedback from the older users. The pilot phase processed the feedback obtained from the older users during the prototype phase. We explained that interaction is necessary for each phase of the design to enhance usability. Further, the DfF framework approach applied during each iterative cycle of the design and development phase helped the application to detect errors and fix them automatically without any adverse effects on the older users during the user evaluation phase. For example, (i) the system application automatically displays the newer timetable from the public transit system in the case of a missed connection based on the user's location and timetable; (ii) when network coverage is detected as either low or no coverage, the user's caregivers or relatives are notified automatically via the system; and (iii) when the system detects that an older user is walking away from a bus stop, a notification is provided to the user that he or she is going the wrong way and the correct direction is shown. Having components of HCD, a spiral model, and DfF can provide a tangible design within a short period based on older users' characteristics and desires, which can be constantly evaluated during all phases to receive feedback and transform failure caused by either the user or the system into a success.

As an outcome of the analysis, we discovered that despite having older adults' involvement throughout the design process with a short iterative cycle, the user could still encounter usability issues and can have an impact in terms of acceptance. For example, similar multiple usability issues were discovered at the end of the pilot phase in multiple countries with different age groups within that group. Some of these issues were (i) using compass on the Assistant application; (ii) voice commands with unclear pronunciation even though the language was in the native language of the user; (iii) using external devices such as Bluetooth headsets; (iv) inaccurate information about the route; (v) location of the buttons; (vi) calibration of the compass; (vii) size and shape of the device; (viii) battery life; (ix) weak GPS signal; (x) data connectivity; (xi) localization of the text; and (xii) auto-lock/screensaver features on the mobile devices, which stopped the users from interacting with the application during their journey. Further, this study also revealed that intermediate older users with a bit of technological knowledge appeared to have fewer usability issues compared to the novice older users who were new to the smartphone devices, which was inconsistent with the previous study by Arfaa and Wang (2014) [46]. The usability needs varied among the older adults with different user characteristics for design. For example, older adults with vision problems had different needs than those with reduced cognitive abilities. We also found out during the study that an application with too much information increases the cognitive load of older users, lowering user satisfaction.

Figure 5.7 represents the data that were analyzed with regard to the perceived use of the Assistant based on a system usability scale (SUS) during the prototype and pilot phases with the same participants. The results indicate that the usability requirements of the older adults changed over time. Our results are consistent with a previous statement from Zajicek (2001): "Requirements for a particular individual vary from time to time due to tiredness or over use of one of the senses e.g. eye strain, and as we know when people age their abilities tend to decrease over time" (p. 64). Further, our results also showed that there are differences in SUS scores between the three countries where the evaluation was performed. One reason for this is likely to be because of differences (i) in the cultural backgrounds of the older participants, in particular, the users' perceptions of effectiveness, efficiency, and satisfaction [47]. Vatrapu and Perez-Quinones (2006) [48] also established that culture significantly affects usability results and (ii) accessibility of the public transit, in particular, where the application being used was evaluated.

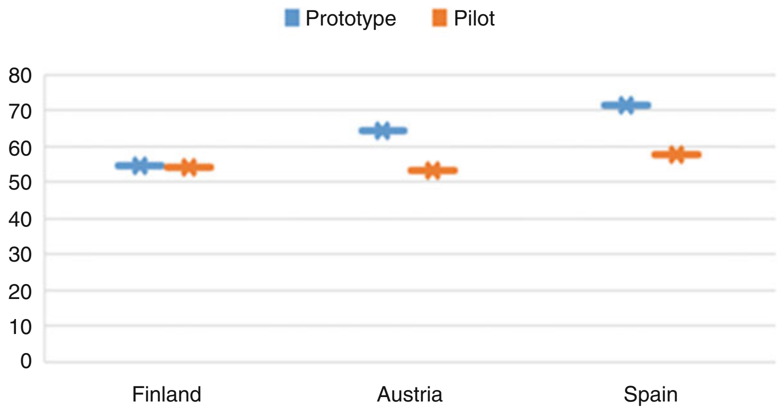

Fig. 5.7 Graphical representation of system usability scale (SUS) between the prototype and pilot phases

For example, the geographic distribution of public transit access, service frequency, transfer distance, and ticketing systems [49] in all three countries is completely different.

Although the SUS scale varied during the prototype and pilot phases, it is noteworthy that the score is still high, which clearly shows that the general perception of the older adults toward the use of the personalized mobile application for public transit was positively high.

First, in the concept phase of the user requirement analysis, the participation of the older adults (65+ years) was quite limited and did not surpass 15%; therefore, potential data bias might exist. However, in the second phase of the project, in both the pilot trials and prototype evaluations, the average age of the older participants was 72.4 years, which could alleviate the prospect of response bias. Second, since all the usability issues collected on the device characteristics (i.e., hardware and software) were based on a single Android-based smartphone device, potential bias might exist regarding the data. Further research with multiple devices is encouraged to gather more usability issues and mitigate the potential data bias.

We also observed that the satisfaction and usability needs of older users vary with aging; therefore, transit stakeholders (including designers and developers who are developing applications based on open data) must design and develop applications for older adults using the approach of HCD components, a spiral model, and DfF with even shorter iterative cycles to come up with better designs that integrate their needs in a shorter period of time than that we have applied in this study.

Certainly, the key findings from this study are beneficial to designers, application developers, researchers, and industries. In fact, the proposed methodology, which we validated with the Assistant platform and older users, can be seen as a methodology that improves design responses to the usability needs of this heterogeneous group of users.

5.6 Conclusion

In this article, we designed the "Assistant," a web platform and smartphone-based application, for older adult travelers to prepare their personalized journey via public transportation at their convenience and then receive guidance throughout their journey. We presented the framework which consists of HCD with a spiral model and DfF approach during the design process with particular focus on older adults. Additionally, we validated the framework through iterative prototype development and usability testing and final implementation within major European cities in Finland, Austria, and Spain. Our study supports that having the involvement of older adults from the beginning of the design process could initiate a better understanding of their user needs, behavior, and acceptance of transit smartphone applications; these results are in line with the previous study of Hwang and Thorn (1999) [44]. Further, such involvement could also help users feel comfortable and develop a high degree of satisfaction, motivation, and enjoyment regarding these applications' usefulness [45] .

In addition, because our study is related to the number of participants and depends on a specific operating system, the generalizability of the results may be limited, and all stakeholders including both public transportation providers and application developers should take any discussed findings as suggestions for accessibility and usability while designing applications for public transportation rather than as conclusive evidence.

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Chapter 6
Maps for Easy Paths (MEP): A Mobile Application for City Accessibility

S. Comai, E. De Bernardi, F. Salice, and A. Vali

Abstract Maps for Easy Paths (MEP) project aims to improve accessibility of our cities, by collecting data of urban barriers and accessible paths using mobile devices. Its focus is on users with motor impairments; however, the application design takes into account also some characteristics of other kinds of disabilities. In this chapter, we describe the MEP project in general and present our mobile applications and their design to meet the requirements of usability, accessibility, and usefulness. In particular, we report our usability–accessibility evaluation done both with automatic tools and with manual/visual analysis and describe the experience in using it in different cities and in campaigns with middle and high school students, to understand the perceived usefulness and its ease of use.

6.1 Introduction

Mobile technology has enabled a wide range of applications that improve the quality of everyday life, possibly targeting people with specific needs and characteristics. The usefulness of mobile applications, i.e., the quality of being helpful and serving some purpose, has increased greatly in recent years allowing users to perform several tasks in a mobile context.

Maps for Easy Paths (MEP) [13] is an ongoing project for the enrichment of geographic maps with information about the accessibility of urban pedestrian pathways, targeted at people with mobility problems. The main goal of the project is twofold: to provide to target users with motor disabilities, blind people, etc. information about accessible routes (and possibly guiding them through the city to easily reach the desired destinations), and supporting the surveying task through the collection of motion data from sensors commonly available in mobile devices [5].

S. Comai (✉) · E. De Bernardi · F. Salice · A. Vali
Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Milano, Italy
e-mail: sara.comai@polimi.it

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MEP offers two mobile applications: *MEP Traces* and *MEP APP*. The former allows to automatically trace a path traveled by a user by exploiting GPS positions and motion sensors (like accelerometer and magnetometer measurements): the user simply activates the application at the beginning of the path, leaves it running in background until the end of the path, and, when a Wi-Fi connection is available, with a simple click, she/he sends the data to the MEP server for path computation. Innovative algorithms based on sensor fusion reconstruct the path [2]. *MEP Traces* has been designed to be used by people with motor disabilities, with the idea that if the person is able to do a path, that path may be considered accessible and be shared with other people having the same type of disability.

The second application, *MEP APP*, is instead thought for any user who wants to display on a map the accessible routes collected through *MEP Traces*. Anyone can also denounce impediments (e.g., architectural barriers) and/or malfunctions through messages or pictures; it is also possible to enrich other accessibility information like, for example, availability of parking lots for disabled people, accessible transport, accessible entrances, etc. The MEP application can also guide the user from his/her current GPS position to a preferred destination, avoiding the signaled architectural barriers.

Visualization and interaction of the information over the map, path visualization, and navigation tasks are crucial activities; accessibility and usability must consider different types of disability impairments, such as visual, physical, hearing, and cognitive impairments. Some important parameters such as connectivity, small screen size, limited processing capability, and power identified in [9, 23] have been considered in the design of the application. Such parameters address some of the shortcomings of existing usability models when applied to mobile applications.

In the chapter, we describe the MEP project in general, illustrate the usage of *MEP Traces* and *MEP APP*, and discuss their design to meet the requirements of usability, accessibility, and usefulness. We report our usability–accessibility evaluation done both with automatic tools and with manual/visual analysis and describe the experience in using it in different cities and in campaigns with middle and high school students, to understand the perceived usefulness and ease of use.

The chapter is organized as follows: Sect. 6.2 reports related work. Sect. 6.3 explains how the two-mobile applications work and Sects. 6.4 and 6.5 describe in detail all the issues regarding their usability and their evaluation for the two applications. Sect. 6.6 analyzes the user experience of different kinds of users and reports the results of the cities mapped by such users. Finally, Sect. 6.7 draws the conclusions and reports future plans.

6.2 Related Work

Several collaborative projects aim to improve city accessibility, through the Web, or, more recently, through smartphone/tablet applications, as surveyed in [7]. The main contributions available in the scientific literature consist in surveys and studies mainly targeted at wheelchair users: requirements were usually collected for the identification of barrier types in order to identify areas where planning activities could improve city accessibility [3] or to measure the experience of reaching (or failing to reach) a destination [17].

The most cumbersome activity in providing an enriched map with accessibility information is gathering such information through field surveys; this has been faced with Web/Mobile applications, available to the public and, typically, by involving target users in surveying. However, Points of Interests (POIs) like restaurants, museums, etc. are the main focus of most of the available applications, whereas sidewalks are considered only by few applications like, e.g., ComuniPerTutti [8] and Mapability [14]. In these applications, typical elements that are evaluated include conditions of sidewalks, presence of cobblestones, conditions of pedestrian crosswalks, curb ramps, street lighting, pedestrian semaphores, tactile paving, visual signaling, reserved parking, sidewalk congestion, etc.; typical barriers are related to holes, depressions, poles, trees, narrow sidewalks, etc. In all these applications, data about city accessibility are collected manually by users through volunteer's surveys. Some approaches exploit crowdsourcing and collaborative techniques [4, 20] through web or mobile applications to facilitate the data collection process. Only a few contributions proposed a solution for the identification of accessible paths, typically exploiting GPS data [3, 16, 17]. Compared to such proposals, we try to extract as much as information as possible from the available sensors fusing the GPS with the inertial data to reconstruct the exact path of the user.

Considering mobile applications, the majority of available accessible map apps targeting physically impaired users focus on the accessible spots and places within the cities, regardless of the travel experience through the city paths. With active contribution of the users through reviewing, ranking, and adding pictures of the places, these applications (services) provide a set of information that helps the user choose an accessible place to eat, to shop, to hangout, and to find the accessible public transport stations. Wheely NYC [21], Wheelmap [22], and AXSmap [1] are among the most recognized applications in this category. In fact, the use of mobile devices in such applications is limited to having access to the maps on move and the possibility to take and upload single pictures and to add reviews.

On the other hand, all the common navigator applications use GPS/Magnetometer, Proximity, Gyroscope, and Accelerometer sensors in smartphones to calculate speed, direction, and position of the device. However, they lack the information that may help those users for whom the accessibility condition of the path may extensively affect their experience. With the focus on a POI (accessible point of interest) within the outdoor environment, mPASS [18] aims to equip users with the path choices within which the disliked elements are avoided to provide a personalize navigation based on the accessibility preferences of the user. This system uses the data collected by the smartphone sensors, the user reviews, and the authorities' database to rank the POIs within the city; considering the profile of the user, the system is able to provide him with the potential preferred accessible path to his destination. However, the system does not extract the continuous user experience to calculate the preferred accessible path, it only considers the POI rakings and the total length of the paths.

Extending the use of mobile devices and their embedded sensors, authors of [12] introduced a system to measure street-level accessibility in Tokyo. Within this system, a combination of sensory data and the videos taken by smartphones from the route surfaces are processed to extract the human action sensing. Then, using machine learning techniques, the system is able to navigate users based on previous experiences. The proposed application is basically relying on the data taken from the human action sensing in addition to the surface condition detection. The use of videos taken in this application is limited to the assessment of ground condition, while much more benefits could be derived from a continuous video recording system that could be added to the current capabilities of the current version of the application.

With the aim of enhancing the ground-level perspective, Mapillary [15] application is designed to collect pictures and sensory data taken simultaneously by the users' smartphone to create a free, huge, street-view picture dataset. Analyzing the raw data to derive a 3D model of the scene, this application is an example of how to extract more information about the surrounding environment. However, the collected raw and analyzed data are only available for further use, and the application itself does not provide anything more than the possibility of uploading images and exploring other's pictures.

6.3 Data Collection and Processing Overview

Figure 6.1 describes the general architecture of the two MEP applications: *MEP Traces* is highlighted in the top part and *MEP APP* in the bottom part. The former is thought for target users, who can trace an accessible path for their disability; the latter can be used by any active citizen, willing to contribute with reports about accessibility problems, and by all the target users interested in information about accessibility.

When a user starts a route, she/he can activate the *MEP Traces* mobile app to collect along the whole path data needed to reconstruct it in an accurate way; such data include GPS position estimates and motion sensor data (e.g., accelerometer, gyroscope, etc.); all the data are first stored on the device SD card and, when a Wi-Fi connection is available, they can be uploaded on the server in a PostGIS spatial database [1] for further processing.

On the server, since the accuracy in the positioning of GPS data is quite low for mobile device GPS receivers, we fuse GPS positions with motion data to provide a better estimate of the path, especially in those parts of the route where GPS satellites are not visible like, e.g., urban canyons. The adopted sensor fusion algorithm is based on the adaptation of a framework for robots tracking, to be suitable also for users on wheelchairs, for which step detection-based approaches cannot be used; details about the algorithm can be found in [2]. The output is a path, which is further corrected exploiting the cartography so that paths do not pass over buildings and is

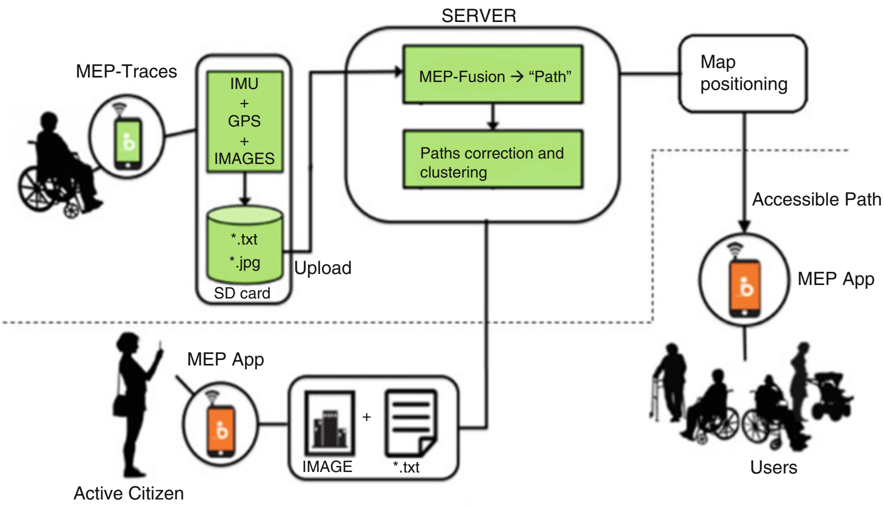


Fig. 6.1 Overview of the process for data collection and processing

positioned in a geographical map [6]. All the collected data are displayed in the *MEP APP* application.

Both *MEP Traces* and *MEP APP* allow also the notification of (geo-localized) obstacles met along the path: users can take pictures and describe their characteristics. It is possible to enrich maps also with accessible elements like, e.g., parking lots for disabled people, accessible transport, accessible entrances, and presence of elevators, etc.

In the next subsections, the final design of *MEP Traces* and *MEP APP* obtained after usability tests is illustrated in more detail.

6.3.1 MEP Traces Application

MEP Traces is the application for the collection of data from common hardware sensors like GPS, accelerometer, magnetometer, gyroscope, etc., embedded in the current generation of smartphones and tablets. Sensor data are collected simultaneously, at the highest possible frequency, and locally stored in the mobile device.

Figure 6.2 shows some snapshots of our Android prototype: after registration, the user visualizes a simple menu (Fig. 6.2a) to start the recording of the route, manage his/her profile, send collected data, and exit the application. The main task of *MEP Traces* is the tracking of the route while the user is travelling, with the idea of mapping only accessible paths. Tracking works in background can always be paused/resumed/stopped with a single click (see Fig. 6.2b); obstacles or accessible elements can be reported along the path, and information, like available memory,

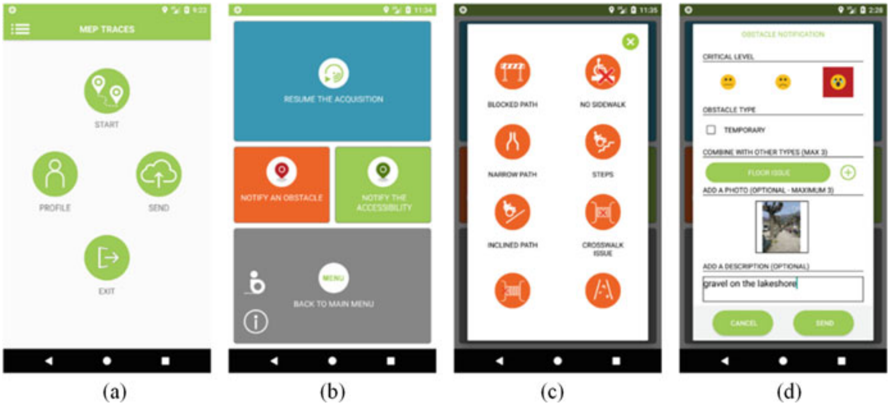
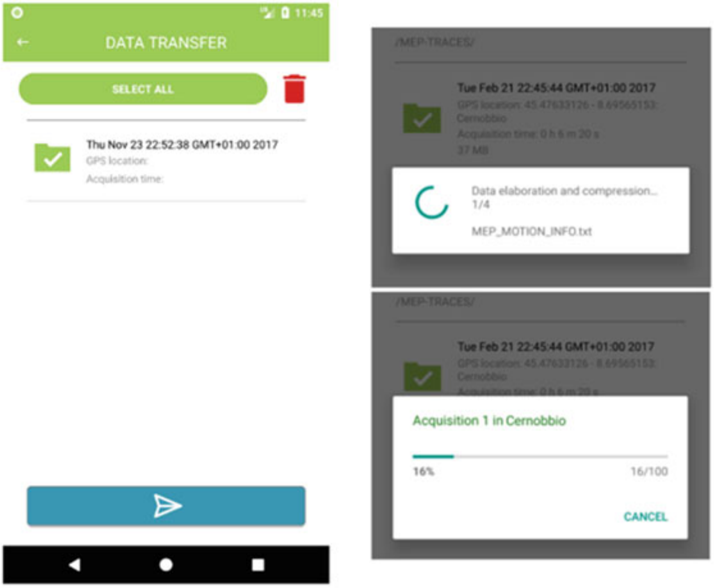


Fig. 6.2 Some snapshots of the *MEP Traces* app: (**a**) main menu; (**b**) sensor recording; (**c**) obstacle type selection; and (**d**) obstacle description and notification

and battery level can always be checked. This information is used to warn the user when critical levels are reached and promptly save the acquisitions not to miss important data for processing. The interface has been designed with large buttons, to be usable also on small screens. Also, accessibility has been considered: to improve text visibility, bold format has been used; to better focus the attention of the user, icons dimension has been increased using different background colors; some attributes used by the operative system to read images for blind target people have also been implemented. Cognitive Load has been considered as well: the acquisition phase allows the user to take the smartphone in standby and put it, e.g., in the pant pocket while tracing routes, to maintain this task as transparent as possible. User attention is required only when he/she wants to report a problem along the way.

During the acquisition phase, the application performs many tasks in background, so its execution is only possible on devices that are at least dual core. The issues of limited processing capability and power have been tested in [5]: despite many computations in parallel, *MEP Traces* does not exhibit high battery consumption, which is on average around 5–6% per hour.

Obstacles can be notified with a simple click among predefined obstacle types (Fig. 6.2c), including a blocked path, absence of sidewalk, narrow path, presence of steps, inclined path, issues at the crosswalks, or pavement problems. Once the barrier type has been selected, the user specifies some characteristics of the obstacle like the fact that it is temporary (e.g., in case of works in progress) and the criticality level of the barrier that can range from low, i.e., accessible with some help, to high, i.e., not accessible at all (Fig. 6.2d). If the same barrier is characterized by different obstacle types (e.g., there is a pavement issue and the path is also inclined), the same notification can be associated with more types. Optionally, some pictures of the obstacle and a description can be included. In a similar way, also accessible elements like accessible entrances/toilets/transport, parking lots for disabled persons, etc. can be notified.



(a) (b)

Fig. 6.3 *MEP Traces* upload interface example: (**a**) manual selection of all the acquisitions; (**b**) data compression and connection/uploading task

All the collected data (sensor data and obstacles reports) are sent to the server for further processing and sharing. Before sending them, the upload effort is minimized thanks to data compression, to overcome the issue of connectivity described by [14]. The upload is forced to happen with a connection between the device and our server over Wi-Fi using the SSH File Transfer Protocol (SFTP). Fig. 6.3 shows the activities to manage the local folders on the mobile device containing the sensor data (e.g., folders may be deleted in case of mistakes) and the compression/upload tasks. During this task, the acquisitions uploaded correctly to the server, after a client/server check, are automatically deleted from the mobile device.

6.3.2 *MEP APP*

MEP APP is the application displaying on a map all the data collected with *MEP Traces*, i.e., traveled paths, obstacles, and accessible elements. Currently, the visualized map is based on OpenStreetMap [19]. The final goal is to drive the final user to his/her preferred destination, avoiding obstacles along the path, and considering his/her specific disability.

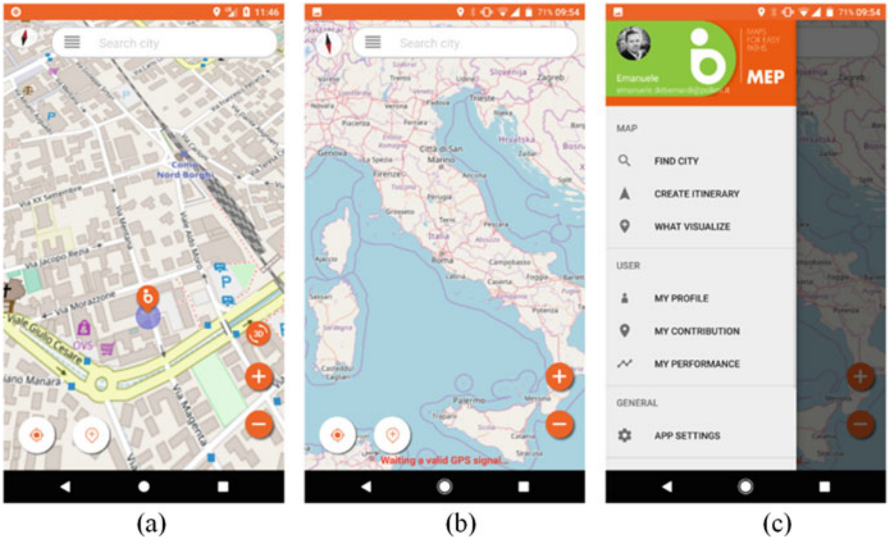


Fig. 6.4 Some snapshots of *MEP APP* application: (**a**) map visualization; (**b**) main menu; (**c**) localization message; and (**d**) current GNSS position map rendering

Fig. 6.4 shows some snapshots of *MEP APP* Android prototype. Users can access most of the collected information without authentication: they can visualize the city accessibility, obstacles with comments, and photos geolocalized over the map and use the navigation tools. User authentication is required only when the user wants to notify obstacles, insert comments, and visualize the path computed avoiding obstacles considering his/her specific type of disability, i.e., when the user actively contributes by providing data or needs a personalization of the results according to a predefined profile.

When the user accesses the application, it asks the user the permission to enable the GPS sensor (if not already enabled) and loads all the elements close to the current position, highlighted in Fig. 6.4a. The user may also explicitly specify the city to visualize, by using a simple searching toolbox in the interface (Fig. 6.4b). The main menu of the application (Fig. 6.4c) allows to compute the path to a given destination, to specify which kind of information to visualize on the map (e.g., only paths, only obstacles of a given type, etc.), to manage his/her own profile and contributions (e.g., to update or modify previous contributions), and to see the user performances in terms of recorded distances.

Figure 6.5 shows some results applied to Como city. Figure 6.5a depicts all the paths that have been collected using *MEP Traces* (details about the field surveys will be described in the User experience session).

To improve the organization of all the map information, very close obstacle elements are clustered together (Fig. 6.5b). By zooming-in the map, clusters are disjoint into subclusters, until the final element visualization is reached. By clicking

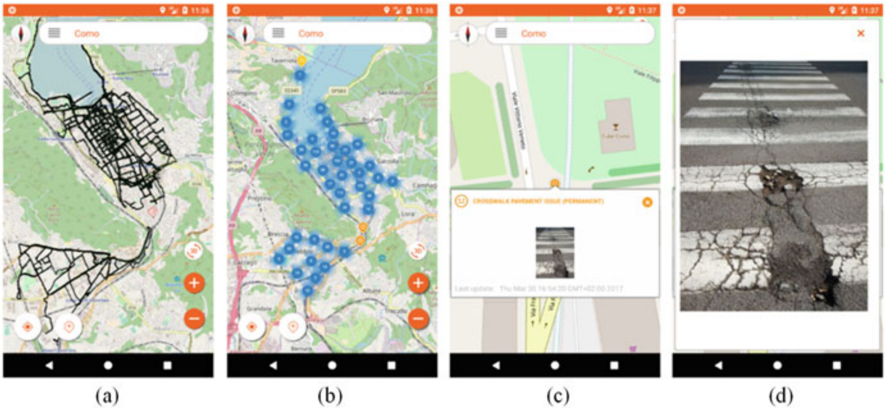


Fig. 6.5 Some snapshots of *MEP APP* visualization in Como: (**a**) accessible paths visualization; (**b**) elements clustered; (**c**) obstacle detail visualization; and (**d**) image of the obstacle

on an obstacle or accessible element, details are provided (e.g., the type, description, and photo of the obstacle) as shown in Fig. 6.5c and Fig. 6.5d.

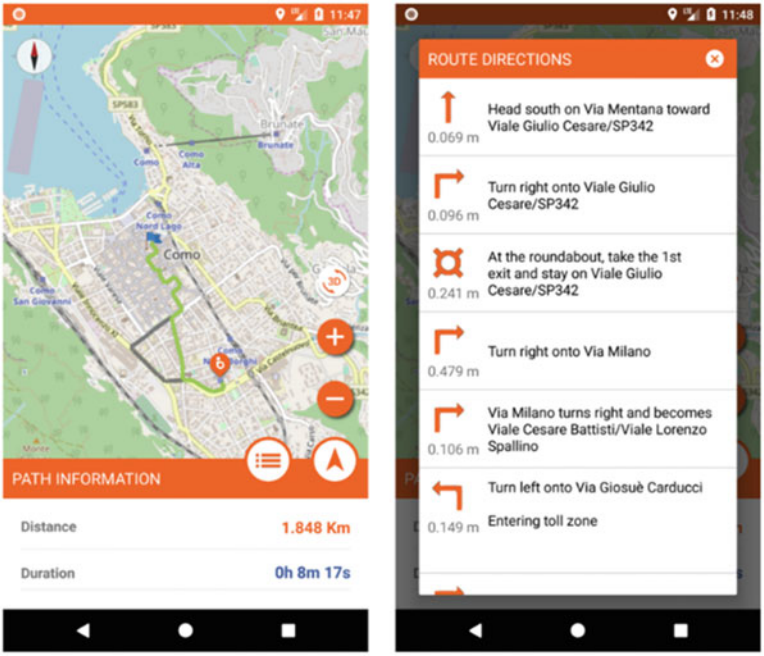
The application has been developed to provide to the user the path to navigate from its current GPS position (or any other initial destination) to a destination point, avoiding obstacles along the path according to his/her disability. Figure 6.6a shows an example of a path with some associated information (i.e., distance expressed in meters and the walk duration estimate). Figure 6.6b renders the route directions.

6.4 Usability and Accessibility Issues

A good application, in a general sense, is an application that is Accessible, Usable, and inclusively designed. All these factors are closely related, and depending on the target audience and the functionalities that the application is designed for, the focus on each aspect may vary.

According to the definitions offered by ISO standard:

- "**Accessible design** focuses on principles of extending standard design to people with some type of performance limitation to maximize the number of potential customers who can readily use a product, building or service" [11].
- "**Usability** extends to how a product can be used by specified users to achieve specified goals effectively, efficiently and with satisfaction in a specified context of use" [10].
- "**Inclusive design**, or **Universal design**, is the design of products, environments, programmes and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design" [11].



(a) (b)

Fig. 6.6 Some snapshots of *MEP APP* navigation: (**a**) path visualized on map; (**b**) route directions

However, since the focus of MEP applications is on people with mobility impairments, the inclusive design is not considered a priority. However, in our use case scenario, the accessibility requirements would improve also the usability of the application and would cover most of its aspects in terms of efficacy, efficiency, and user satisfaction. Therefore, having people with mobile impairment as target users, accessibility standards and usability requirements can be simultaneously considered as usability–accessibility measures.

6.4.1 Mobile Usability–Accessibility

Mobile devices, as the name implies, refer to handheld computers used on move. Therefore, to fit the context, they come up with some hardware, and consequently software, limitations that the normal computers do not deal with. Lower display resolution, smaller screen sizes, limited input methods, limited process capability and power, and the mobile context itself are of those issues that have been introduced by the advent of mobile devices.

As discussed by [9], the commonly used usability models are not applicable on mobile devices since they do not consider the mobility factor. Instead, PACMAD (People At the Centre of Mobile Application Development) Usability model considering the user and his special needs to access and use the application, context of use (i.e., the environment in which the user will use the application), and the task (i.e., the goal the user is trying to accomplish with the mobile application) extends the former definition of usability mobile devices.

Ensuring that in a given situation, the final user with his limitations is able to use the application and perform the tasks efficiently and effectively with satisfaction without any health threads, PACMAD provides an inclusive model including both usability and accessibility matters. In our work, we were inspired by the PACMAD model as a comprehensive mobile usability–accessibility framework. This includes

- *Effectiveness*: the ability of the user to complete a task in a specified context;
- *Efficiency*: the ability of the user to complete his/her task with speed and accuracy;
- *Satisfaction*: the perceived level of comfort and pleasantness while using the software;
- *Learnability*: the ease with which a user can gain proficiency with the application;
- *Memorability*: the ability to retain how to use an application effectively;
- *Errors*: the possibility to recover from them in case of a mistake;
- *Cognitive Load*: the impact that using the mobile device while performing additional tasks, like walking.

6.5 MEP Usability–Accessibility Evaluation

To ensure the usability–accessibility of MEP applications, we have considered both technical (using standards checklist and guidelines) and user interface (real user experience) components. Therefore, we accomplished the tests in the following steps:

- In-lab tests with target users, starting already in the earliest phases of the design. It helped us to avoid design and development mistakes and to ensure that the application works well and is usable for the end user.
- We asked a group of “Accessibility: Models and Applications” course students in the Como Campus of Politecnico di Milano University to do an Accessibility test on both MEP applications as their final course project.
- A group of volunteer users with/without mobility impairment have tested the *MEP APP* and *MEP Traces* to map the accessibility of Como and other cities.

6.5.1 In-Lab Tests

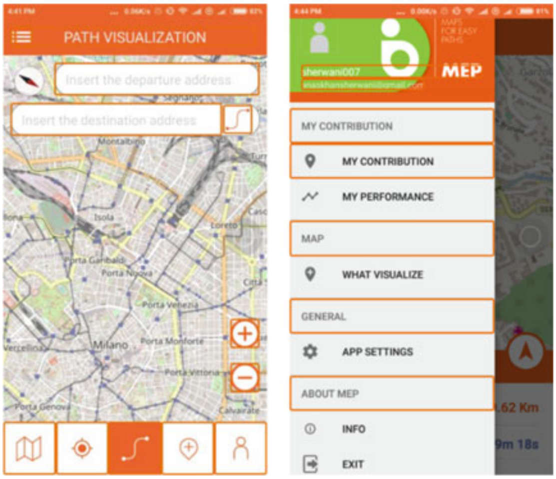
In-lab tests with target users were done before the development, on an interactive mock-up simulating the apps. The following tasks were considered: (1) registration as a new user, (2) visualization of the map and selection of an obstacle, (3) search for an accessible path from point A to B, (4) insertion of a new obstacle to contribute to the map, and (5) set up of the user profile. After task completion, they were asked some qualitative and quantitative questions to evaluate their experience with the interface. General results were positive: users found the interface comprehensible and could easily understand the icons and their meanings; participants with the electric wheelchair did not have any particular problems with interaction with the app through their joysticks. However, also some issues were highlighted and improved in the current version: in some tasks, they found the interaction sequences too long to follow (the navigation has been redesigned with shortest sequences and activities were simplified); tests done indoor and outside provided different results, since the designed icons couldn't be easily seen in an outdoor setting due to reflections on the screen (larger buttons, possibly with different colors, have been introduced with this aim in both applications); they required a simple menu always available on the screen to understand which is the current activity (the current activity remains on the screen).

6.5.2 Accessibility Tests

To evaluate accessibility of the applications, the Accessibility Scanner (a Google app) was run on all the activities of both applications (an example of use is in Fig. 6.7).

Then, other critical aspects were inspected "manually" by the students of the accessibility course. All the possible impairments were considered by different groups of students (visual, hearing, physical, and cognitive) to provide an inclusive interface. However, collecting the reports, we prioritized the reported issues by putting the users with physical impairment on top. Doing a trade-off, we omitted those issues that by considering them we could worsen the user experience in physically impaired context. For example, considerations related to replacing buttons with touch gestures have been excluded to reduce the complexity and difficulty of use for people with advanced physical impairments: some participants in our tests could only move one or two fingers, could use a mini-joystick to control their smartphone or had a special button located under their head on their wheelchair or could use their smartphones but with some restrictions. In general, buttons with single clicks could be used by all the participants.

With the accessibility scanner, it was possible to check if all the elements have an associated label that can be read from the screen reader and all their descriptions are different to avoid confusion; if the contrast between images or text and the



(A) (B)

Item label // activity A
com.polimi.mep:id/zoomInButton
This item may not have a label readable by screen readers.
com.polimi.mep:id/zoomOutButton
This item may not have a label readable by screen readers.
…
Touch target // activity A
com.polimi.mep:id/settingButton
This item's size is 30dp x 30dp. Consider making this touch target 48dp wide and 48dp high or larger.
com.polimi.mep:id/id_menu_title_text
This item's height is 27dp. Consider making the height of this touch target 48dp or larger.
…
Text contrast // activity B
com.polimi.mep:id/id_user_name The item's text contrast ratio is 2.05. This ratio is based on an estimated foreground color of #FFFFFF and an estimated background color of #8CC63F. Consider increasing this item's text contrast ratio to 3.00 or greater.
…
Item descriptions // activity B
[0,570][840,714] This clickable item's speakable text: "MY CONTRIBUTION" is identical to that of 1 other item(s).

Fig. 6.7 Example of accessibility scanner results background is sufficient; if the touch target is large enough (e.g., also in case of fat fingers or to allow both left- and right-handed persons). Tests for visual impairments were simulated also using the Talkback application and checking that all the elements of the activities were properly considered.

Issues with no conflict have been already implemented or planned for the next release. The proper resizable text, audio alternatives for static texts, color contrast, and many other matters to ensure the application is perceivable, operable, and understandable for the final user have been applied. In *MEP Traces,* several issues related to the contrast between the green icons and the white text/background were highlighted by the scanner: texts were made bold and their sizes maximized. Dialogs and messages of completed operations have all been checked.

6.6 User Experience and Results: Test and Evaluation

MEP Traces has been largely tested and evaluated in two different ways: through its use by individual users (autonomously and without time and path constraints) and in organized groups.

As far as organized groups are concerned, awareness-raising campaigns on the issue of motor disability have been organized. The MEP application was used for 1 day by four middle school classes (ages between 10 and 13 years – a group of 35 students in the city of Como and a group of 40 students in the city of Brugherio (Milan)); eight high school students (all males, aged 16–18 years) used it for 4 weeks.

The students of the middle school were organized in groups, equipped with Android devices, and had to map an area of their city. They were accompanied by a person with motor disability (on electric or manual wheelchair), whose role was to help the working groups to better understand his/her difficulties in traveling through a city.

The usage of the application was briefly explained before starting the mapping task. After the mapping was concluded, a questionnaire was provided, including some questions about the age and the usage of smartphones in daily activities and about the following indicators: simplicity in using the application, clarity of the user interface, usefulness of the application, ease of learning, intention to recommend the application to other users, satisfaction in using the application, and future use of the application. Each indicator was associated with a score from 1 to 5 (1 = strongly negative, 5 = highly positive).

The responses returned by the working groups of the campaigns were very similar both for the group of students aged between 10 and 13 years (Group 1 in the following) and the group of students aged 16–18 years (Group 2 in the following). Results are reported in Table 6.1.

It is important to point out that the questionnaire for Group 2 was distributed in two different moments: at the end of the first day and at the end of the whole

Table 6.1 Questionnaire results about MEP usability by groups of users

	Group 1			Group 2 (first day)			Group 2 (last day)		
	Min	Max	Min	Min	Max	Median	Min	Max	Median
Simplicity	4	5	4	4	5	4	4	5	4
Clarity	3	5	4	3	4	3.5	4	5	4
Utility	3	5	5	4	5	5	4	5	5
Learning	1	5	4	3	5	4.5	–	–	–
Recommended	1	5	4.5	3	4	3.5	4	5	4
Satisfaction	2	5	5	3	4	4	4	5	4
Future use	1	4	3	–	–	–	1	5	3.5

period. This double analysis was carried out to intercept the existence of a difference between the perception of first use and that of prolonged use.

Most of the results are comparable. All the participants found the application easy to use and its interface clear. Group 2, after using the application for a longer period, still reported some difficulties during the signaling of the obstacles, especially in its correct classification.

Ease of learning for Group 2 was evaluated only on the first day. Learning was a little bit more difficult for middle school students; they had some difficulties in the registration phase and in the final upload of the data.

It is interesting to note that “simplicity” is in contradiction with the “ease of learning”: if the application is simple, it should also be easy to learn. Scores with values 1 and 2 under “ease of learning” represent only 5.5% of the total; they were interpreted (it was not possible to find out who responded) as outliers and are perhaps due to the young age of the respondents. By excluding these outliers, the answers to the questionnaires of the two groups are aligned.

The clarity of the application and the “recommendation to others” has similar results, emphasizing that the perceived difficulty in using it at the beginning is a deterrent to the disclosure of the application.

The satisfaction variable is particularly high for the middle school students: indeed, it includes also the “satisfaction” for the whole experience both in using a new application and in having the possibility of doing a new experience.

The usage of the application in the future for Group 2 has been evaluated only in the second questionnaire. In Group 1, some students added a comment at the end of the questionnaire and remarked that they assigned a low score, because at home they have only non-Android devices, and therefore, it will be impossible to use it.

The total satisfaction level assessed on both groups is between 2 and 5, with 5 as median; it is represented in the histogram in Fig. 6.8.

Overall, the strengths highlighted by the analysis concern the ease of use, the utility, and satisfaction. A point of weakness remains the “future use.” The absence of a real need for participants reduces the perception of utility for the future, as the potential contribution does not fall directly on themselves, even if during the campaign their role in contributing to a meaningful and useful goal was appreciated and made them proud of the experience.

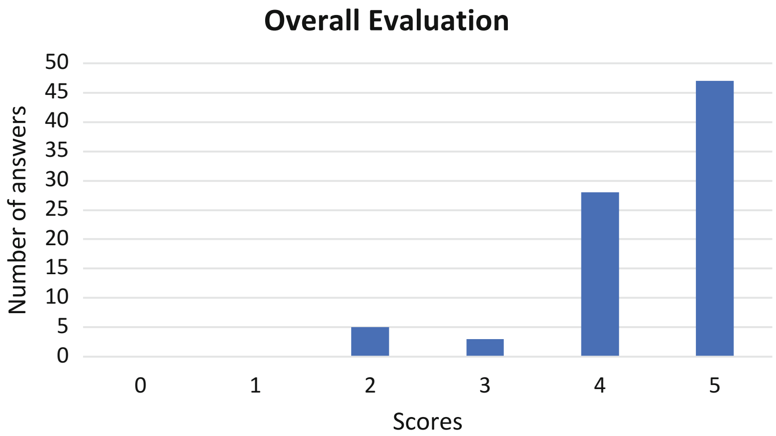


Fig. 6.8 Overall evaluation of the user experience with *MEP Traces*: number of answers (on the y axis) for each score between 1 and 5 (on the x axis)

Table 6.2 Data about Italian cities traced by individual users

City	Area	Inhabitants	Characteristics	Traveled distance
Cantù	Como	39.917	Hills – business activities	81.53 km
Como	City center	83.713	Almost flat – touristic – historical heritage	25.36 km
Cernobbio	Como	6.748	Flat on the lake – touristic	24.1 km
Anacapri	Naples	6.986	Island with hills – touristic	19.94 km
Tavernerio	Como	5.790	Hills – small village	16.79 km
Rome	City center	2.876.051	Almost flat, some hills – historical heritage	10.63 km
Capri	Naples	7.151	Island with hills – touristic	6.64 km
Ravenna	City center	171.057	Flat land – historical heritage	5.51 km
Loano	Savona	23.899	Almost flat – touristic	4.6 km
Magreglio	Como	662	Mountains – small village	3.72 km
Ferrara	City center	132.497	Flat land – historical heritage	2.96 km
Corsico	Milan	34.869	Flat land – Hinterland city	2.69 km
Giulianova	Teramo	23.899	Flat on the sea – touristic	846 m
L'Aquila	City center	69.399	Basin in the mountains – historical heritage	800 m

The application has been used independently but for longer time also by some individual users (without disabilities) who have tested its functionalities in different contexts: a 55-year-old male, a 47-year-old female, and a 52-year-old female. In Italy, in total, they traced the municipalities listed in Table 6.2, sorted by traveled distances.

The mapped areas are all urban but positioned in different geographic contexts and with a different historical and economic characterization, briefly reported, to better understand the kinds of detected obstacles.

Cantù is in the Italian Alpine foothills and is characterized by an economy based on handicraft and small enterprises; its urban development is mainly linked to support business activities and paid little attention to pedestrians. Often you can find roads without sidewalks and streets with a cobblestone pavement.

Como, with a center situated on the lake – and therefore mainly flat – is characterized by an important historical nucleus (mainly pedestrian) with medieval walls and with a history dating from the Roman period; being very attractive for tourists, it is sensitive to pedestrians. However, to retain some of the medieval characteristics, there are often cobbled or granite floors that make mobility for wheelchairs and walkers more difficult. Cernobbio, very close to Como on the same lake, shares similar characteristics. In a similar way, L'Aquila, located on the slope of a hill, in a basin at 721 m above sea level, has often cobbled pavements and granite slabs. Rome, traced only for a small part of the city center, features urbanization, population density, and historical features that make urban changes for accessibility extremely hard; except for large squares and pedestrian areas (which, however, have some pavement problems linked to its history), it is frequent to find narrow sidewalks, problematic crosswalks, and unpaved pavement. Ravenna and Ferrara, although quite flat cities, due to their cultural heritage (Ferrara was a Renaissance city and Ravenna a Byzantine city), have accessibility problems similar to Como and L'Aquila.

Tavenerio and Magreglio are two small villages in the Italian Prealps. They developed from small nuclei and have characteristics that make mobility for people with wheelchairs particularly difficult: pavement, sloping paths, pathways, and sidewalk absence are the most significant obstacles.

Capri and Anacapri, two cities of the island of Capri, though characterized by strong slopes, narrow streets, and paths, thanks to the tourist attraction, have evolved in the direction of accessibility.

Giulianova is a city divided between hinterland and sea. The part along the sea (the part that has been mapped) that is strongly linked to tourism is very accessible. Likewise, Loano, a tourist town on the Ligurian Riviera, is very attentive to accessibility issues.

Corsico is a small town in the Milanese hinterland, based on agriculture in the nineteenth century; in recent decades, it is among the most urbanized areas of Milan; it has some pedestrian areas but has accessibility deficits mainly due to carelessness.

Considering the characteristics of the cities (historical, industrial, and size), soil morphology (mountain, hill, plain), and their geographic location, it can be noticed that the most common problems are caused by carelessness, especially for the sidewalk pavement and the crosswalks (representing 57.1% of all reports). Less frequently, nonaccessibility is due to steps (9.1%) and narrow paths (8.1%). The slope problem is profoundly different: although it represents 8.8% of the reports, this type of obstacle is typical of the hinterland and mountain regions; although not solvable (at least not in a simple and inexpensive way), this type of alert is important,

Table 6.3 Data about non-Italian cities where the applications were experimented

City	Inhabitants	Travelled distance
Helsinki, Finland	621.863	33.83 km
Brussels, Belgium	178.552	12.72 km
Sheffield, UK	551.800	6.69 km

Table 6.4 Usability results of individual users

Individual users	Median
Simplicity	3
Clarity	3
Utility	5
Learning	4
Recommended	5
Satisfaction	5
Future use	4

because it gives users a conscious choice of a place (e.g., for holidays) and/or help identify the less demanding path for them. An example of excellence is represented by the municipalities of Capri and Anacapri that offers transport buses suitable for the transport of disabled persons that can be booked by the users themselves. However, both municipalities have a hilly geo-morphology and many routes are accessible only with some help (electric wheelchairs or an accompanying person).

Abroad, the cities listed in Table 6.3 were traced. These cities have the same level of accessibility of Italian cities. Helsinki is a city overlooking the Baltic Sea, mostly flat; the main detected problems concern the pavement. Sheffield is a morphologically different city with hills; excluding the problems related to the inclination (natural in its context), the city presents problems of pavement and narrow paths. Brussels (traced only in the central part) is a city with some slight slope characteristics. As an historic city, it presents some paving problems and narrow paths. These European cities (mapped for a total of 53.28 km) have the same characteristics as the corresponding Italian cities drawn for the same population and historical importance.

Individual users evaluated simplicity, clarity, and the other usability dimensions. The results are reported in Table 6.4.

The result of interviews on individual users has highlighted the need to deepen the “simplicity” and “clarity” aspects. A first analysis has shown that these two items are closely related to each other. The application is considered very clear and very simple in terms of pure tracking because no specific knowledge, skills, or user intervention is required; the interface is considered simple and intuitive.

The complicated and unclear identified point concerns the alerts that the user posts in case an obstacle is found and must be signaled. The user’s opinion is that it is simple, intuitive, and very quick to report situations involving small areas or specific points of the path (e.g., rough pavement, a bottleneck point, steps, etc.), while it is unclear how you can report situations related to long and continuous paths (e.g., a climb, a route with several problems). In fact, the application allows you to report an obstacle at the exact point where the user is and not the continuity of the obstacle. Users agree on the fact that an improvement in this direction would require an increased user involvement by producing the side effect of making the application costlier and with the added risk of introducing errors or inaccuracies. For example, reporting a climbing path should prompt the user to trigger the alert at the start of the path and deactivate it at the end, making the user more responsible during the acquisition; forgetting to "close" the signaling would make the whole traveled route an uphill road. The current version of the application allows the user to simply trace an accessible path and to focus only on specific points, with a limited cognitive load during the mapping task.

Overall, the application is considered simple. User profiling, track activation, and data delivery are easy and intuitive. Reporting obstacles (excluding the problem highlighted above) is simple and intuitive: signaling them through icons, taking pictures, and having the possibility of specifying different types of obstacles for the same problem is considered a significant advantage over adding descriptive texts (long and challenging). In general, the application is considered very good.

6.7 Conclusions and Future Work

In this chapter, we have presented the two applications developed within the MEP project, *MEP Traces* and *MEP APP*: the former is used to trace an accessible path, the latter to show the collected data on a map to the final users and to allow them reporting barriers or accessible elements.

They have been carefully designed to consider the usability and accessibility issues of the target users, including mainly people with motor impairments; tests considering all the kinds of disabilities have been conducted, and many changes have been implemented to meet most of the accessibility requirements.

Usability and user experience tests have been carried out with different kinds of users: middle school students organized in groups and accompanied by people on wheelchairs, high school students, who used the applications for 4 weeks, and individual users, who used them in different contexts and for quite long distances. *MEP Traces* and the functionalities to signal barriers/accessible elements have been largely tested. Evaluation of the applications was in general positive.

In addition to the tangible results of experimentation in the different cities, campaign with students had also a social impact in

- raising the awareness of the mobility problem, to make students (and, more in general, citizens) more aware and sensitive to people with disabilities;
- sustainability: the user involvement is minimized, and data can be easily kept updated; indeed, paths can be automatically detected with *MEP Traces* and system data are dynamically updated;
- participation: the proposed method allows anyone to become an active user by participating directly in creating content.

It is interesting to notice that the municipality of Cernobbio (in the province of Como) has participated in the experimentation of the project and has shown the intention to improve the accessibility of the city over the next few years by considerably reducing pavement problems (excluding certain sections of gardens), some narrow-path problems.

Plans for the development include, at one side, enhancements of some functionalities: for example, for *MEP Traces* it will be possible to send collected data automatically as soon as a Wi-Fi connection exists; for *MEP APP* advanced interactions with voice synthesis, usage of vibration during navigation or acoustic alerts when the person approaches obstacles. On the other side, further usability tests to better evaluate routing and navigation will be performed.

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Part III
Health

Chapter 7
A PHR-Based System for Monitoring Diabetes in Mobile Environment

Yugal Kumar, Geeta Yadav, Pradeep Kumar Singh, and Punkhari Arora

Abstract Currently, people are more concerned about their health and diseases. Therefore, their interests in health and diseases have increased tremendously in the last decade. Till date, medical industries developed several programs and services to promote the health-related issues such as awareness programs regarding HIV, diabetes, dengue, overweight, etc. Due to increased concern for ubiquitous health services, it incorporates the advantage of information technology which can lead to design a preventive management system for various types of disease and health conditions. Further, the technological advancement is also favorable to the management of chronic diseases. In this work, a personal health record (PHR)-based decision support model is proposed for monitoring diabetes using mobile environment. In order to facilitate the people, a graphical user interface is incorporated into the PHR-based model for analyzing their lifestyles.

7.1 Introduction

In the world, more than 40 million people die of various noncommunicable diseases like cancer, cardiovascular diseases, diabetes, heart failure, chronic obstructive diseases, etc. [1]. The majority of people belong to low- and middle-income countries. But, these diseases are also responsible for mortality in high-income countries. This can be prevented by adopting healthy behaviors and also decrease the mortality rate worldwide. A study on smoking habits presents that the risk oflung

Y. Kumar (✉) · P. K. Singh · P. Arora
Department of Computer Science and Engineering, Jaypee University of Information Technology, Waknaghat, Solan, Himachal Pradesh, India

G. Yadav
Department of Pharmaceutical Science, Manav Bharti University, Soaln, Himachal Pradesh, India

S. Paiva (ed.), *Mobile Solutions and Their Usefulness in Everyday Life*,
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cancer is reduced up to half for a person who has stopped smoking since the last 10 years in comparison to those who continued smoking [2]. From this study, it is observed that the risk of cardiovascular disease is similar to the risks of a person who has stopped smoking since the last 15 years and a person who never smoked. The risk of HIV can be reduced by adopting safe sexual practices and awareness about this disease [3]. In high- and middle-income countries, most people suffer with overweight problem due to unhealthy eating habits and lack of exercise and it can lead to the risk of diabetes. Further, it is reported that the risk of onset of retinopathy and nephropathy can increase due to diabetes, and these risks can be reduced up to half and two-third levels, respectively, by controlling diabetes [4, 5]. The main function of healthcare services is to inspire and support the people to adopt healthy behaviors and self-manage the chronic diseases [6]. But, the main obstacle regarding this is the way through which information can be propagated. The main sources to propagate the information are consultations, existing service infrastructure, and through traditional media, but these sources can be used in a limited way. Due to advancement in mobile telephone technology, the numbers of mobile users are increasing day by day. A variety of mobile phones and mobile service providers are available in the market. The invention and advancement in mobile phones changes the traditional communication system and entertainment industry and also affects the life of people [7]. The dependency of human beings on the mobile phone is increasing day by day, especially of the youth. The mobile technology includes a variety of mobile phones such as personal digital assistants (PDAs) and PDA phones (BlackBerry and Palm Pilot), smartphones (iPhone), enterprise digital assistants (EDAs), etc. These devices have a variety of services and functions such as SMS, MMS, WWW, multimedia access, and application software. These features and functions of mobile technologies also encourage the scientists and researchers to explore the capability of mobile phones for providing individual-level support to patients in the healthcare domain [8]. Few examples are to send a text message to avoid smoking habits, awareness message regarding HIV, weight loss programs' message, diabetic disease-related message, asthma patients access information regarding exacerbation of asthma, etc. Due to incremental growth and deployment of mobile devices into private devices such as smartphones, tablets, pads, etc., large numbers of applications regarding medical treatment are available on mobile application stores and half of applications are related to daily health tips and disease information [9–13]. The trend of self-healthcare can increase exponentially to meet the demand of patients.

7.1.1 Objective of the Chapter

This chapter proposes a personal health record (PHR)-based health index mobile service using a decision support model. This PHR can enable medical staff to inquire and manage health- and medical-related information of patients. Further, this information can analyze information in different situations and extracts pattern of behaviors of patients which are not explored. The aim of the PHR-based decision support system is to improve the lifestyle of patients and also to overcome the risk of chronic diseases. In addition to it, a user interface is developed for the users such that it can communicate in the optimized mobile environment. This decision support system is available for users at all times and provides the status of their health. The objectives of the proposed chapter are as follows:

- To design a PHR-based diabetes monitoring system to monitor the health of users
- To develop the user interface for the proposed monitoring system
- To incorporate the proposed model into mobile environment
- To analyze the information of the patients and give suggestions

7.2 Related Works

This section describes the related work in the direction of e-health monitoring system and usability of mobile phones to monitor the health of mobile users.

7.2.1 E-Health Model

Recently, the applicability of mobile devices has increased rapidly in health services. In the present era, the growth of mobile users is exponential, and it can act as an important tool regarding health communication. It is also a good medium for the low literacy and low-income populations to get information regarding health issues. The aim of the e-health is to monitor the health of the individual person. It includes a variety of fields such as monitoring individual bio-signals, area of telemedicine, analyzing signals, and customized health and medical services [9, 10]. In bio-signal monitoring, several sensors are combined together to obtain the sample output using some predefined procedure [12]. It also provides a graphical user interface to enter the information through patients. These types of monitoring systems are available in the market, which transmit the information regarding heart rate, blood pressure (BP), and body temperature of patients. Some of applications that can be used in this process are wireless communication terminals, Bluetooth, near-field communication (NFC), wireless local area networks (WLANs), and service providers are delivering processed healthcare information to users. On the other side, telemedicine is a remote treatment process carried through video conferencing and analyzes the collected PHRs for rehabilitation training. The aim of the e-health model is to mine the gathered information and predict the occurrence of disease. Due to the increase in interest of mobile phones in healthcare, several applications have been developed to monitor the health of mobile users.

7.2.2 PHR-Based Health Management

The personal health record can be defined as to store and manage the health record of a person throughout their life [13, 14]. Due to technological revolution, it is possible to measure the activity related to PHR data, such as amount of exercise, blood pressure, diabetes index, and so on. Hence, the demand of customized health management services is increased in present scenario due to the availability of health-related data. Further, it is also conceivable to cure the chronic diseases via PHR. The PHR of individuals can be used for continuous health management and health promotion activities. The other reason is that such type of health management can improve the health of persons [13, 15, 16]. For, continuous individual health management, it is necessary that personal health record of a person can be collected continually and, in this direction, mobile phones are the appropriate medium to collect that health data. Further, the more the PHR data are collected, the greater the usefulness and utilization, and patient-oriented environment is developed rather than hospital-oriented environment. In addition, patients can obtain accurate health information due to the various types of information integrated with PHR. This can lead to the prevention of disease and controlling the health of an individual. In literature, it is noticed that large numbers of health-based monitoring and management systems are reported. Some of these are listed as. Zhu et al. [17] have proposed a cardiac monitoring system to label the electrocardiogram (ECG) data. The proposed system integrates the mobile end of the system with a back-end annotation system for reviewing and scoring the quality of an ECG signal. In the proposed system, crowdsourcing methodology has been used to determine the ECG annotations from a set of experts including doctors, trainees, and automated algorithms. It is observed that the proposed system gives diagnosis accuracy equivalent to experts with reduced cost. Benharref and Serhani have proposed Service Oriented Architecture (SOA) and cloud-based framework for e-health monitoring [18]. The aim of the proposed framework is to collect real-time data from patients, provide nonintrusive monitoring, and provide medical and lifestyle management activities. In this framework, the mobile technologies are incorporated to collect and communicate data from a patient. The effectiveness and usability of the proposed framework are investigated using a case study, and it is observed that the proposed framework provides promising results. Xu et al. have developed an m-Health monitoring system based on cloud computing platform (Cloud-MHMS) and mobile network for implementing pervasive health monitoring [19]. In the proposed system, data storage, data processing, and data analysis processes are carried out using cloud storage and multiple tenants' access control layer, healthcare data annotation layer, and healthcare data analysis layer. Further, it is observed that the usability of the proposed monitoring system is tested on antimicrobial drug usage. It is reported that the proposed system provides better results for personal health care analysis. To determine the impact of the lifestyle and environmental parameters on the seminal quality and fertility rate, especially in man, a seminal quality prediction model is presented in [20]. To determine symptom trajectories of depression, a mobile-based monitoring system is presented in [21]. The proposed mobile-based system is used to classify the depression severity. The performance of the proposed system is evaluated on 344 primary care patients with depression. The depression symptoms are measured weekly through interactive voice response (IVR) calls using the patient health questionnaire. Further, it is noticed that multivariate linear regression is applied to predict the trajectories. To efficiently and accurately determine the light exposure, mood, and activity levels of individual people, McNamara and Ngai have designed a personal mobile sensing system [22]. The proposed system explores the technologies embedded into smartphones. The functionality and performance of the proposed system is evaluated through various users up to a time period of 2 years. The authors claimed that the proposed system can estimate accurate light exposure and also predicted well both personal light exposure and general seasonal trends. A rule-based classification system has been designed for the diagnosis of different types of liver disease [23]. In this work, a rule base is constructed for effective diagnosis and prediction of liver diseases. The rule base consists of 20 rules to classify the liver disease. It is noticed that the proposed rule-based system provides better results in terms of classification of liver diseases. Hossain has developed an elderly monitoring system to continuously monitor the health of older adults and support them with various services like emergency detection and alarm, information and media service access, and interaction and communication [24]. The performance of the proposed system is evaluated using ten elder adults of the age group of 60–70 years. It is reported that the proposed system gives better results in terms of efficiency, effectiveness, and user satisfaction. Santos et al. [25] have proposed IoT-based mobile gateway for mobile health (m-Health) scenarios. The proposed gateway is applied to collect the information of patient-like location, heart rate, and possible fall detection. The objective of the proposed system is to forward the collected information to a caretaker, and it will manage a set of actions and alarms appropriately. It is observed that the proposed mobile gateway act as an effective communication channel. The usability and applicability of the different predictions and monitoring systems have been presented in [26]. For earlier prediction and diagnosis of dengue disease, a PSO-ANN-based diagnostic model is reported in [27]. In the proposed model, PSO is applied to optimize the parameters of the ANN. The results report that the proposed model effectively predicts the occurrence of the dengue disease. A systematic review on the diabetic personal health record is reported in [28]. A diabetes electronic health record for effective diabetes management is presented in [29]. Some diagnostic systems for predicting diseases using machine learning approaches are described in [20, 23, 30].

7.3 PHR-Based Diabetic Monitoring System

This section describes the proposed PHR-based diabetes monitoring system. A PHR can be described as a software tool which permits the patient to enter the desired information regarding the disease and provides the possible solution for the disease. Further, patients can manage their health information using the PHR system and can access the medical information anytime round the clock. This system also associates the patient's information with the medical institutes, hospitals, consultation, doctor's appointments, etc. and can be accessed easily whatever is needed. As the medical awareness among people is increasing day by day, such types of systems are in demand and can also improve the lifestyle of people. But, the effectiveness and utilization of these systems are highly dependent on the medical data; as more and more medical data are gathered, these systems can be utilized effectively. Further, the aim of the PHR system is to covert the hospital-centered medical environment into the patient-centered one. Hence, in this work, a PHR-based diabetes monitoring system is developed for effective management and diagnosis of the diabetes disease. Diabetes is one of the metabolic diseases that can occur due to nonconversion of glucose into energy by body cells. It can be classified into two types such as type-1 diabetes and type-2 diabetes. It is reported that only 10% patients of the total diabetes population suffer from type-1 diabetes and rest of them suffer from type-2 diabetes. In type-1 diabetes, insulin is not produced by the human body, and for the treatment of this type of diabetes, insulin can be given to the patients. Type-2 diabetes can occur due to genetic factors, stress, obesity, and lack of exercise. The effects of type-1 diabetes are quite complicated, such as they are responsible for heart disease, limb disease, blindness, kidney failure, etc. while lifestyle factors are more responsible for type-2 diabetes. Highly obese and overweight people have more chances for type-2 diabetes. It is observed that type-2 diabetes can be controlled by changing lifestyle, weight loss, diet control, and exercise. In this work, a Personal Health Record (PHR)-based model is proposed for accurate diagnosis and effective management of diabetes. Further, this model will help and make the people aware regarding diabetes. Figure 7.1 illustrates the proposed PHR-based diabetes monitoring system. The proposed system is divided into three phases, such as, user information, PHR-based diabetic monitoring system, and clinical information. To identify the people with diabetes, some diagnosis standard is considered for the prescreening of diabetes. The descriptions of these standards are mentioned in Table 7.1. The diagnosis standards considered for the prescreening of diabetes are body mass index (BMI), blood pressure (BP), cholesterol levels, history of heart disease, sedentary lifestyle, prenatal history, and age. Further, blood pressure is divided into three categories, such as, healthy BP, early high BP, and high BP. Similarly, cholesterol level is also categorized into three classes, such as, low-density lipoproteins (LDL), high-density lipoproteins (HDL), and triglycerides. Tables 7.2 and 7.3 give information regarding the categories of blood pressure and cholesterol-level diagnosis standards. The above-mentioned diagnosis standards are applied to diagnose whether a person has diabetes or not. Further, diabetes is classified into two types, such as, Type-1 and Type-2. Tables 7.4 and 7.5 present the diagnosis standard to identify the patients affected with either Type-1 diabetes or Type-2 diabetes. In case of Type-1 diabetes, it is recommended that some insulin dose will be considered for the patients. But for Type-2 diabetes, it is suggested that patients can take a healthy diet as well as go for daily workouts.

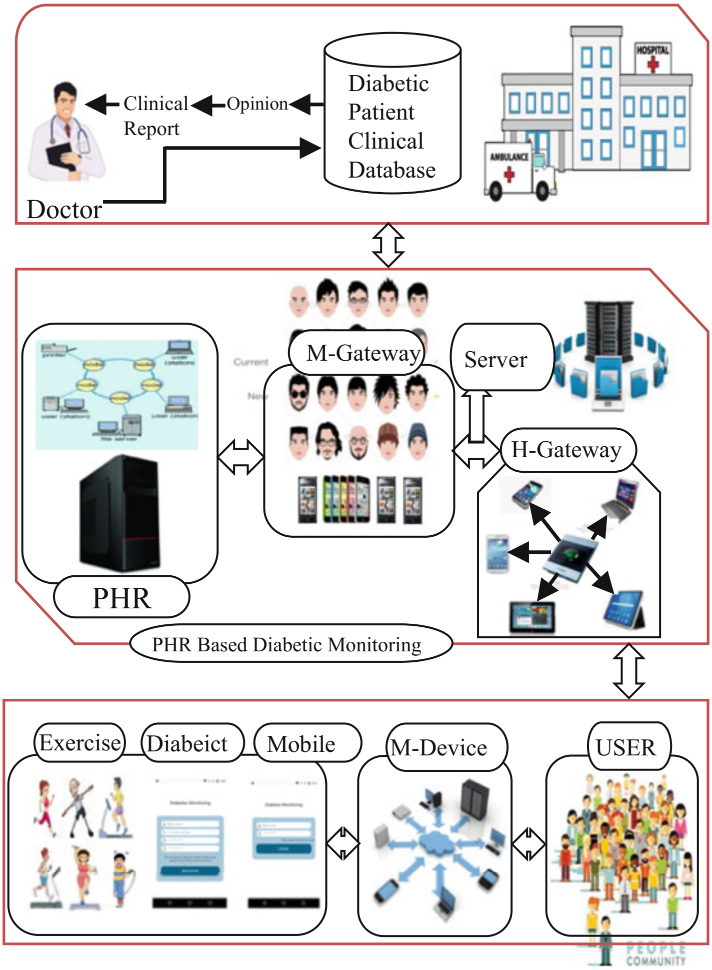

Fig. 7.1 Proposed PHR-based diabetes monitoring system

Table 7.1 Diagnostic standard for classification of prediabetic screening

Sr. no.	Diagnosis standard	Range
1	Body Mass Index (BMI)	Higher than 25 kg/m^2
2	Blood pressure	Higher than 120/80 mmHg
3	Cholesterol level	Higher/Lower
4	History of heart disease	Yes/No
5	Sedentary lifestyle	Yes/No
6	Prenatal history	Yes/No
7	Age	More than 40 years

Table 7.2 Classification of the cholesterol diagnostic standard

Standard	Classification	Range
Cholesterol	LDL	Higher than 100 mg/dl
	HDL	Less than 40 mg/dl
	Triglycerides	Higher than 150 mg.dl

Table 7.3 Classification of the blood pressure diagnostic standard

Standard	Classification	Range
Blood pressure	Healthy BP	120/80 mmHg
	Early high BP	In between 120/80–140/90 mmHg
	High BP	Higher than 140/90 mmHg

Table 7.4 Classification of type-1 diabetes

Diabetes classification	Standard diagnosis	Range
Type-1	Random blood sugar test	Higher than 6.4 mg/dl
	Fasting blood sugar test	Higher than 126 mg/dl
	Glycated hemoglobin	Higher than 6.4

Table 7.5 Classification of type-2 diabetes

Diabetes classification	Standard diagnosis	Range
Type-2	Two-hour postprandial test	Higher than 7.0 mmol/L
	Oral glucose tolerance test	More than 200 mg/dL

7.4 Implementation Details, Results, and Discussion

In this work, a mobile-based application is developed to monitor the diabetes. In the proposed system, a user can enter the medical details regarding diabetes through a mobile application; then, this information is analyzed using the PHR-based system. This analyzed information is used for monitoring the diabetes-affected person through a mobile app. The main task of the proposed app is to classify the person as normal, prediabetic, having type-1 diabetes, and type-2 diabetes. Further, this app also provides some suggestions to overcome the diabetes like life health index, exercise therapy, health information, and dietary nutrient information. The proposed system considers the body mass index (BMI), blood pressure (BP), cholesterol levels, history of heart disease, sedentary lifestyle, prenatal history, age, and some clinical features for effective diagnosis of the diabetes. The proposed PHR-based diabetes monitoring system is developed using Android Studio 1.1.0in environment on window-based operation system having Intel(R) Xeon(R) processor, CPU E5–1620 v2, 3.7 GHz, and 8 GB RAM. The process of identification of diabetes is mentioned in Fig. 7.2. Figure 7.3 illustrates the login screen of the proposed

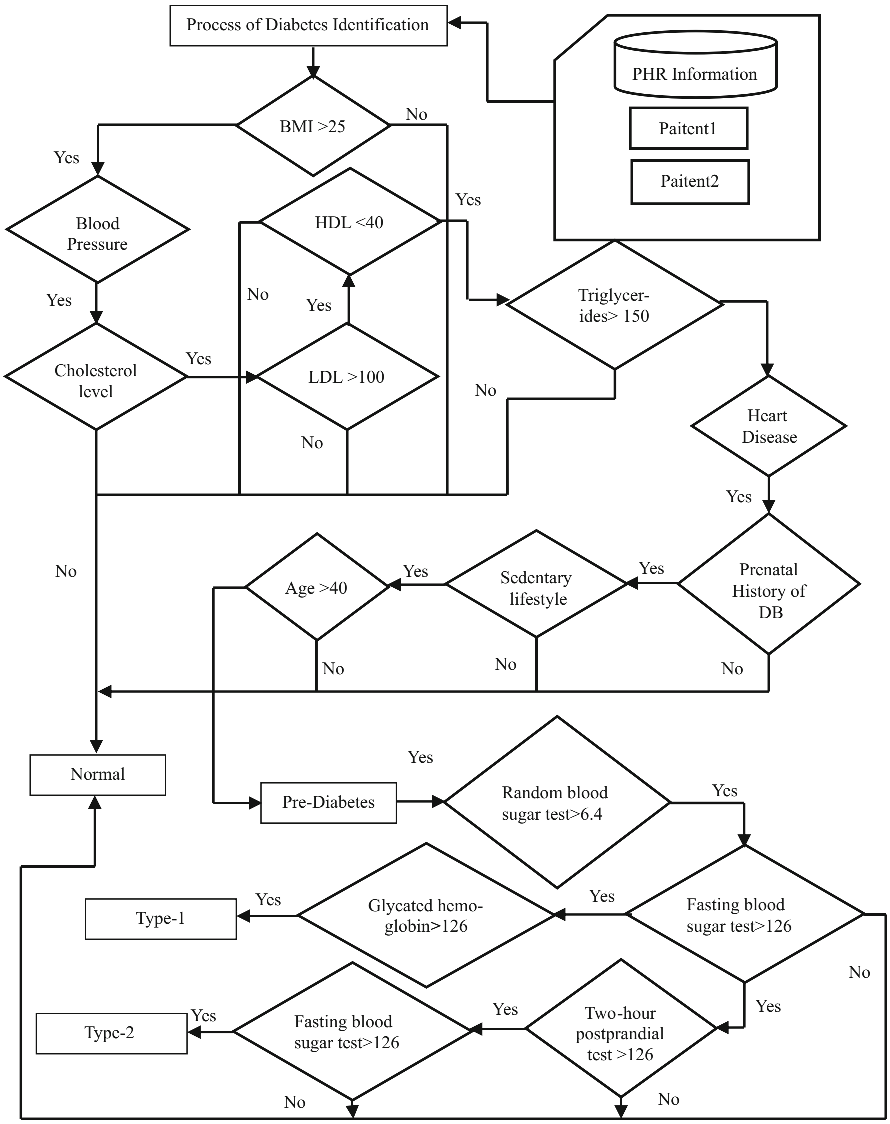

Fig. 7.2 Diabetes identification rule base process

diabetes monitoring app. If the user is already registered with the app, then it will login into the system using the user name (refer Figs. 7.4 and 7.5). Otherwise, users can initially register with the app using create account option. Figure 7.4 shows the user registration process interface of the proposed app. After registration process, an account of user is created and unique user name and password is given to every user for further processing. Figure 7.5 shows the interface of the pre

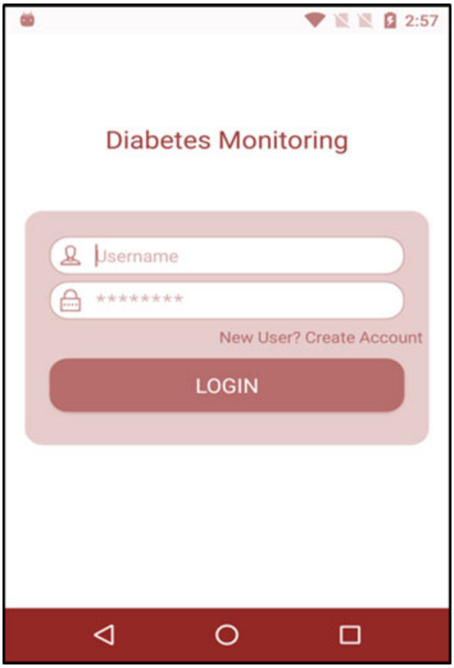

Fig. 7.3 LOGIN screen

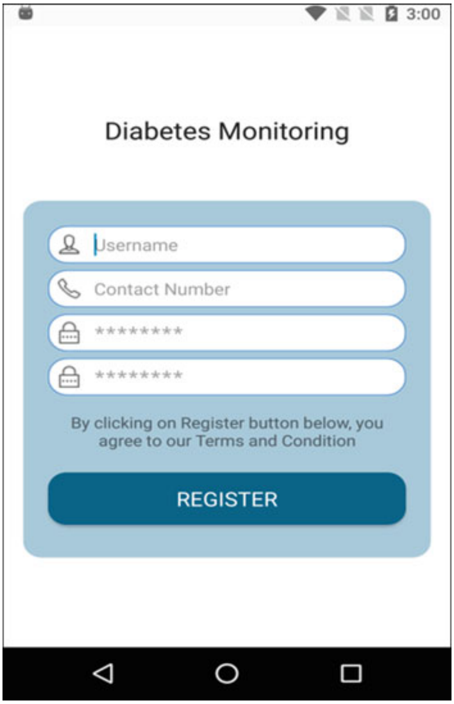

Fig. 7.4 Registration interface

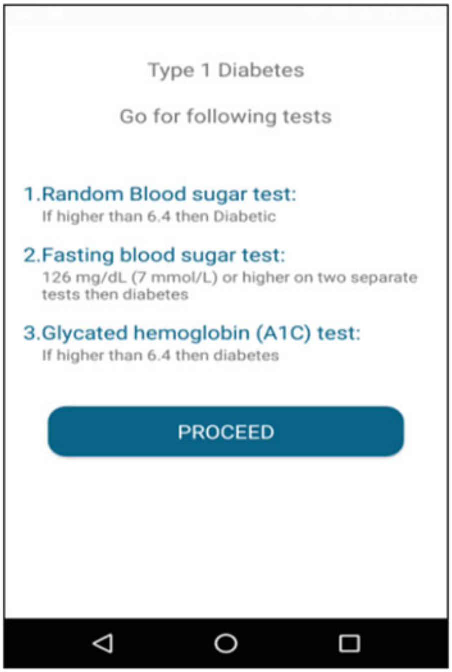

Fig. 7.5 Prediabetic screening interface

diabetes screening. This interface requires information like BMI, BP, cholesterol level, heart disease history, life style information, and parental history of diabetes for successful diagnosis of a person either pre-diabetic or normal. If a person has high BP, high BMI score and also having parental history of diabetes, then the person has maximum chance of pre-diabetes and further, it is suggested that to control the BP and BMI to reduce the chance of pre-diabetes.

Figure 7.6 describes the nonclinical parameters for diagnosing and monitoring type-1 diabetes. These parameters include excessive thirst, high level of urination, weight loss, tiredness, and blurring of vision. If such symptoms occur, then definitely the possibility of diabetes exists, and it is recommended that the person undergoes some clinical tests. Figure 7.7 illustrates the diagnostic tests which are used for the confirmation of diabetes.

These tests include random blood sugar test, fasting blood sugar test, and glycated hemoglobin test. These tests clearly notify the presence of type-1 diabetes. Figure 7.8 shows the list of suggestions that can be taken after diagnosis of the diabetes. It is suggested that in case of type-1 diabetes, the patient should take the insulin dose as per recommendation. Further, it is advisable that the patient should go for regular monitoring of the diabetes and also improve eating habits. The nonclinical parameters for diagnosing and monitoring type-2 diabetes are reported in Fig. 7.9. These parameters include being unwell, eating too much, and ineffective diabetes medication. Further, it is suggested that if these symptoms occur, then some clinical tests are recommended for identifying the presence of diabetes. These

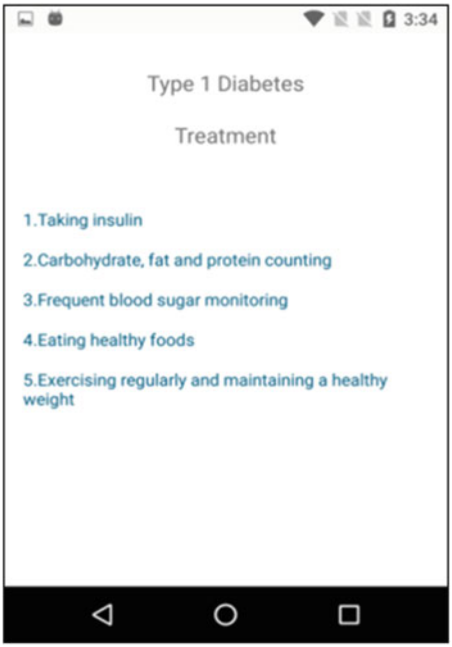

Fig. 7.6 Nonclinical symptoms of type-1 diabetes

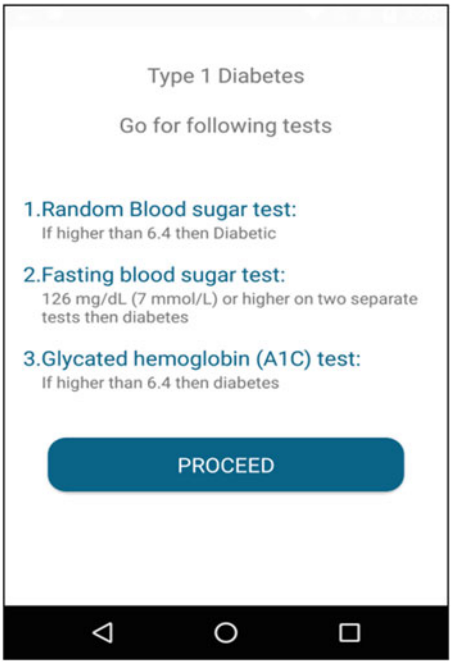

Fig. 7.7 Clinical symptoms of type-1 diabetes

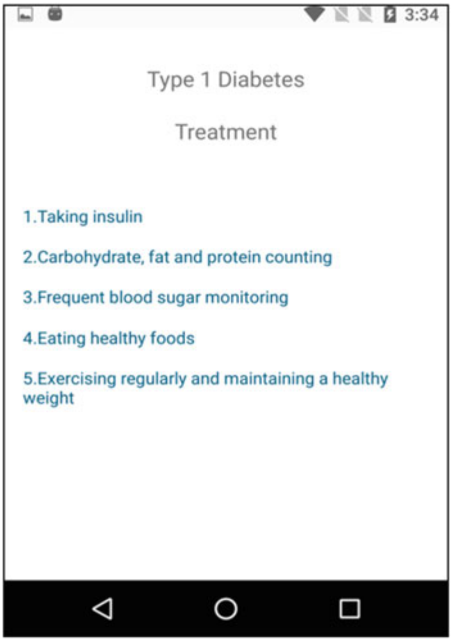

Fig. 7.8 Lifestyle improvements to reduce type-1 diabetes

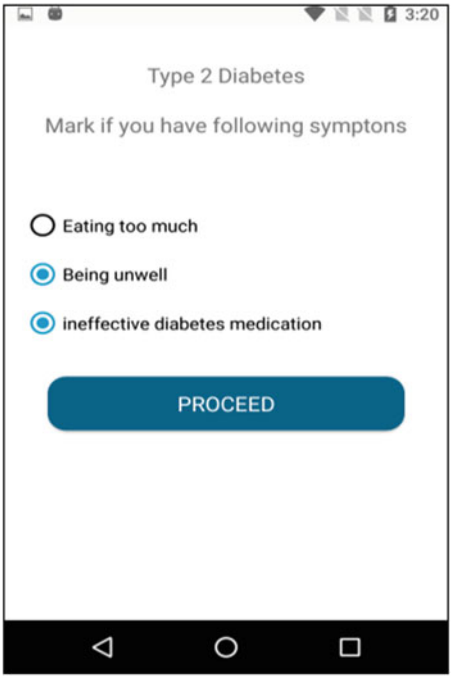

Fig. 7.9 Non-clinical symptoms of type-2 diabetes

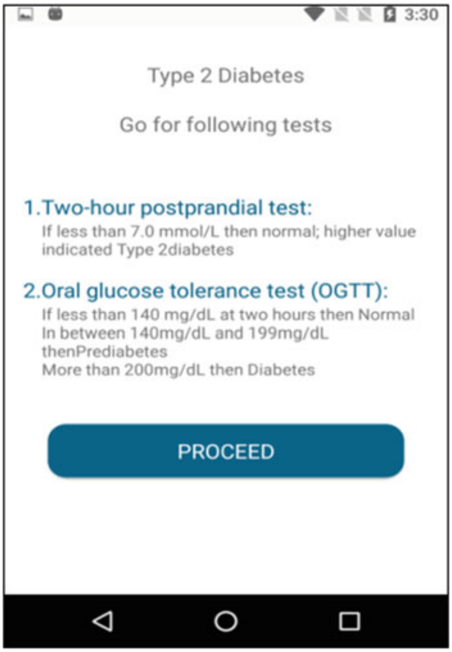

Fig. 7.10 Clinical symptoms of type-2 diabetes

Fig. 7.11 Lifestyle improvements

tests are 2 h postpyramidal tests and oral glucose tolerance test (OGTT) which are described in Fig. 7.10. If the results of these tests are positive, then the patient is affected with type-2 diabetes. Figure 7.11 illustrates the precaution taken in case of type-2 diabetes. In most cases, type-2 diabetes is reduced by adopting habits such as healthy eating, daily exercise, reducing the intake of Bailey fat, and so on. In some cases, the insulin dose is also given to maintain the sugar level in the body. Further, it is advised that the patient should go for the regular monitoring of diabetes and control the sugar level by adopting healthy habits.

7.5 Conclusions

Currently, people are more concerned and conscious regarding their health. Moreover, large numbers of medical services and devices have been developed to automate the medical facilities. The concept of M@M, IoT, and smart health has become widely popular among human beings, and people want to collect more and more information on health issues. Further, it is noticed that chronic diseases increase due to eating habits, obesity, lack of exercise, late-night sleep, excessive smoking and drinking, unmanaged lifestyle, etc. Hence, due to advancement in medical technology and increased convergence, it is possible that the patient can control himself to avoid some chronic diseases like diabetes and obesity by using the PHR platform. In this paper, the PHR-based diabetes monitoring system is proposed that performs the real-time monitoring of the diabetes user. In this system, the real-time data are collected through mobile phones, and these mobile phones are connected with the PHR server for monitoring and diagnosis of diabetes of the individual user. Further, the PHR server is connected with the hospitals in case of emergency service and also for consultation with doctors.

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Chapter 8
Automated Cardiac Health Screening Using Smartphone and Wearable Sensors Through Anomaly Analytics

Arijit Ukil and Soma Bandyopadhyay

Abstract With the advent and rapid deployment of Internet of Things (IoT), artificial intelligence (AI), powerful smartphones, and wearable sensor devices (e.g., smartwatch), we are entering into the era of automated, remote, on-demand mobile healthcare services. According to the WHO, cardiovascular disease is the modern-day disease. However, prognosis rate of cardiac disease patients can be potentially made high with early detection and diagnosis. In this book chapter, we describe automated cardiac health monitoring system using smartphone and wearable sensors. The main contribution of such mobile applications and systems is to form a connected universe with biomedical sensors, patients, physicians, clinics, hospitals, and other medical service providers and to exploit robust analytics to infer and actuate the appropriate information and formative actions. The powerful anomaly analytics exploit AI, signal processing, and deep learning mechanisms that enable predictive decision-making and facilitate preventive cardiac health screening. The main emphasis is to develop and deploy smart, computationally efficient, rather than human-in-loop, user-friendly, data-driven cardiac healthcare solutions, where patients and healthcare service providers are seamlessly connected. In this book chapter, we discuss about important cardiovascular signals, namely, electrocardiogram (ECG), photoplethysmogram (PPG), and heart sound or phonocardiogram (PCG), and describe their role in the process of developing a mobile-based cardiac care solution. These cardiac marker signals constitute an intelligent and robust feature space for detection of different cardiac abnormalities and diseases like coronary artery disease, cardiac arrhythmia, and others. These sensor signals can be captured by affordable wearable sensors. In order to develop such mobile applications and systems, we need to address different challenges like noisy signal removal and data privacy protection along with providing robust analytics engine.

A. Ukil (✉) · S. Bandyopadhyay
TCS Research and Innovation, Embedded systems and Robotics, Kolkata, India
e-mail: arijit.ukil@tcs.com; soma.bandyopadhyay@tcs.com

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8.1 Introduction

The ubiquity of smartphones and emergence of advanced sensor technologies along with the development of powerful artificial intelligence (AI), natural language processing (NLP), machine learning, and other robust computational techniques are capable of radical transformation of healthcare services. In order to provide impactful healthcare analytics, robust machine learning algorithms are to be developed. Many of the deadly diseases are preventable if timely action is taken and continuous monitoring is ensured. We mention few of the preventive health screening possibilities:

1. Smart contact lenses that predict glaucoma outcome
2. Smart pills that monitor the efficacy of medication
3. Intelligent detection of daily activities to detect neurological disorders
4. Smart band for sleep pattern analysis, calorie burn measurement, blood pressure and heart rate (HR) monitoring
5. Smart brain chips for neurological health monitoring
6. Inbuilt smartphone sensor-captured physiological signals like PPG
7. Low-cost smartphone attachments that capture photoplethysmogram (PPG), electrocardiogram (ECG), phonocardiogram (PCG), and electroencephalogram (EEG) signals to assess cardiac health

Such smart sensors along with powerful AI, signal processing, and deep learning algorithms can enable predictive analytics to facilitate preventive health screening, whereas personal genomics analysis can pave ways for prescriptive analytics to ensure improved recovery and also impact assisted living for the elderly, monitoring of newborn, and quality of life for chronic disease patients. The main emphasis is to develop precise computational, rather than human-in-loop (or minimum human intervention), expert-based data-driven healthcare solutions.

In this chapter, we focus on automated screening of cardiac health using smartphone and wearable sensors, particularly for the reason that statistics shows that cardiac health problem is the highest worldwide. According to the American Heart Association, it is found that the cardiovascular diseases are the biggest killers of human life and one adult American dies every 40 seconds due to cardiovascular disease [1]. In fact, more than two-thirds of the deaths reported due to cardiovascular diseases are out of the hospital. So, a mobile, easy-to-use, affordable cardiac risk determination platform can potentially provide highly preventive actions for the early treatment that results in a higher probability of improved prognosis and consequently lesser mortality rate.

It is to be noted that most of the cardiovascular diseases are preventable when early detection of the prevailing disease is made, and we can successfully avoid loss of human life. It is to be further emphasized that external manifestation of failing cardiac condition would be felt after severe damage of the cardiovascular system. Subsequently, the detection of deteriorating cardiac condition through echocardiogram, treadmill test (TMT), or angiogram would be costly to treat and sometimes, prognosis becomes difficult. Cardiac health condition deterioration is mostly a slow process, and early detection with a continuous screening mechanism and consequent medical supervision would result in higher prognosis, inexpensive treatment, and better quality of life. In fact, early cardiac disease detection is a prime need in today's world. Internet of Things (IoT) adds a new dimension toward providing healthcare support by early detection of diseases. Smart monitoring devices like different wearables constituting different sensors, smartphones, as well as remote health monitoring systems have been the main ingredients to set up an automation framework for healthcare analytics. In this chapter, we mainly focus on the detection of anomalous conditions of cardiac systems as well as the early detection of different cardiovascular diseases by exploiting sensor signal analytics with minimal human intervention for the execution of early cardiac health screening setup. Smartphones, smartwatches, or wearable sensors constitute a significant role that facilitates a proactive cardiac management system [2].

The fundamental physiological signals used as cardiac health markers are ECG, PPG, and PCG. Analysis of such physiological signals requires extensive processing and learning mechanism. Starting from capturing the raw signals from the wearable sensors to disease prediction at the edge (smartphone) or cloud, every signal is passed through a Learning Life Cycle (LLC) with four important stages, namely, preprocessing, removal of noise, important features' detection, and disease prediction through robust signal processing and machine learning models. In Fig. 8.1, we depict a typical LLC for analyzing physiological signals like PPG, PCG, and ECG. LLC engine is responsible for end-to-end management of cardiac health analysis, starting from physiological signal capturing to inferencing on the condition (say, whether the subject suffers from cardiac diseases).

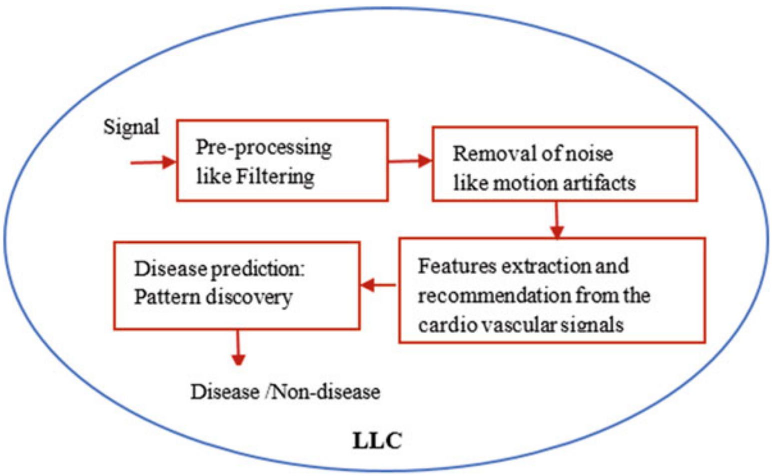


Fig. 8.1 LLC: Learning Life Cycle

In this chapter, we initiate our discussion first by describing a representative system architecture of the IoT-based cardiac health screening system. Next, we introduce different cardiovascular signals responsible for early cardiac disease detection. One of the major aspects of disease prediction is to learn from the morphology of the signal. Morphology enables the recognition of diverse patterns inside the signals as well as the state of different physiological parameters. We have elaborated on morphology in the signal morphology section. Next we have described the analytics applying machine learning as well as signal processing with exemplary analysis. We have described further different use cases and the risk involved. We also have touched upon the future aspects and finally drawn a conclusion.

8.2 Architecture

The major hardware components of the mobile cardiac screening system are wearable sensors, computational platform, and Internet Gateway. Many off-the-shelf wearable sensors are available that capture ECG, PPG, and PCG signals. For example, AliveCor [3, 4] is used for capturing single-lead ECG signals as an attachment to smartphones. PPG signal can be conveniently captured by using the inbuilt camera of the smartphone. This is extracted from the video sequence of a user's index fingertip that records the change of blood flow as a function of heart cycle [5]. PCG signal can be extracted using a simple chest piece and the smartphone microphone or using a digital stethoscope. The computational complexity of the analytics algorithms would determine whether computation would be performed at the edge (smartphone) or at the cloud. However, with the emergence of highly powerful smartphones with octa-core processors, 4GB RAM, and 64 GB ROM, moderate to high load analytics task can be performed by the smartphone. In such a scenario, Internet connection and communication latency would not be required, and we would be able to set up a completely stand-alone mobile cardiac care solution. The overall ecosystem would generate alarm in the extreme cases to the concerned caregiver as well as periodically alert the patient about the cardiac health condition. When alarm is generated, caregivers would rush for medical assistance, and when alert is generated, the patient may proactively schedule consultation with the medical practitioner for human-assisted cardiac health checkup and subsequent diagnosis. Alarm is meant for emergency services, a reactive procedure, whereas alert is for a proactive procedure. Alarm ensures quick delivery of emergency medical services to the cardiac patient, whereas alert enables the patient for early diagnosis of cardiac health much before the physical (external) manifestation. We depict the two architectures: (1) edge analytics, where analytics is performed with the smartphone and Internet is used for alert message sending to the concerned stakeholders, and (2) cloud analytics, where cloud is used for providing the computation required for analytics operation. A smartphone is used to capture the physiological signals from wearable sensors and acts as an Internet Gateway for

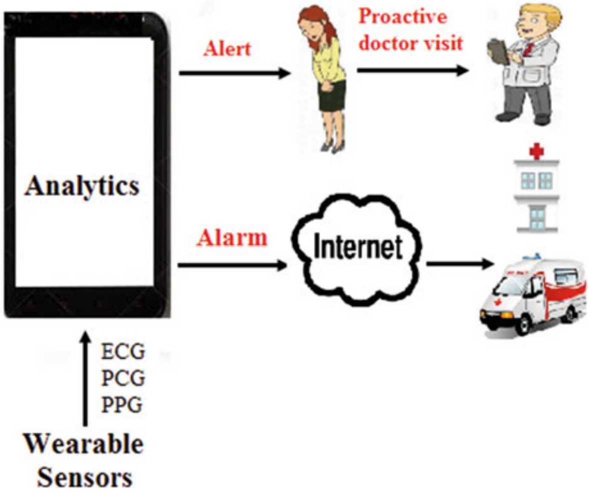


Fig. 8.2 Edge analytics architecture for smartphone-based mobile cardiac screening

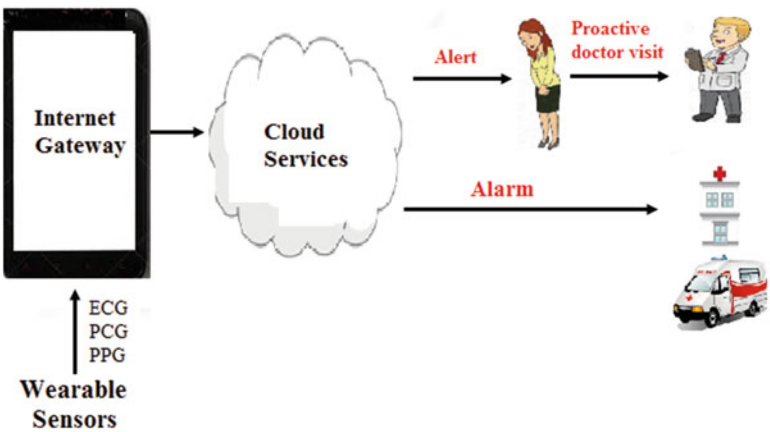


Fig. 8.3 Cloud service-based analytics architecture for smartphone-based mobile cardiac screening

accessing cloud services. When the smartphone is less powerful or the analytics operation requires complex computation, cloud analytics is used.

We show the broad-level architecture of edge analytics-based cardiac health management system in Fig. 8.2 and cloud service-based anomaly analytics for remote cardiac health management system in Fig. 8.3.

Further, we illustrate the layered architecture for the deployment of the cardiac care mobile application in Fig. 8.4. There are three distinct layers: (1) physical world or sensor layer, (2) edge or data capture or local analytics layer, and (3) cloud platform or integrated analysis or service layer as depicted in the next section.

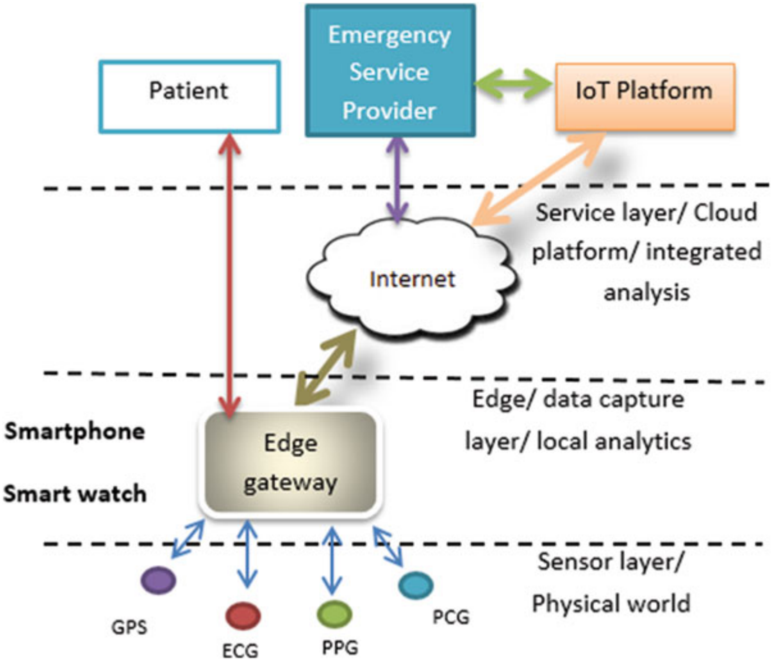


Fig. 8.4 Layered architecture of the mobile cardiac care system

Layer 1 is responsible for capturing sensor data from different sensing devices or the smartphone, and a smartwatch can itself capture the signal on its own. When a signal is captured from external sources, for example, proper establishment of a communication channel (e.g., Bluetooth) is to be ensured as well as the data format is to be agreed upon. Next is the local analytics layer. We conceptualize that most of the processing and first-level inference would be determined in this layer. A smartphone or other high-performance mobile devices including a personal laptop would be responsible for performing the local analytics services. In a scenario of highly complex computational requirements, analytics work would be offloaded to cloud services. When cloud services provide the analytics job, a smartphone or a laptop would act as the Internet Gateway between the sensors and cloud platform. The third layer is the cloud platform that provides the analytics work in addition to the edge analytics. The main responsibility of this third layer is to integrate an IoT platform to assimilate other secondary information or metadata. For example, the IoT platform would fetch a patient's historical medical records from the Electronic Health Record (EHR) database to consolidate the inference drawn at the edge analytics. The alert message sent by the edge or cloud platform is in the form of $\text{Alert} = \{\text{Cardiac parameters}, \text{ inference}, \text{ GPS of the patient}\}$. The alert message to the emergency service providers contains the inference drawn by the analytics service, GPS location of the patient, and the important cardiac parameters.

The inference message provides information about the criticality of the cardiac condition. For instance, when a patient is diagnosed with cardiac arrest or coronary block, the amount of estimated blockage is also shared with the energy caregivers.

8.3 Physiological Signals in Cardiac Health Screening

In order to enable round-the-clock cardiac health monitoring, a noninvasive, affordable solution is required. A smart wristwatch or a smart bracelet can be dedicatedly used to capture different cardiac markers [6, 7]. The main emphasis is to capture the cardiac marker signals in a noninvasive way through affordable, easy-to-use procedures. Moreover, the cardiac healthcare ecosystem would be sustainable when the signals are captured without the need for a large number of additional sensing devices such that the pervasiveness and ubiquity of automated cardiac care would smoothly pave ways to empower a remote, in-house, easy-to-use cardiac wellness management solution. Smartphones typically provide a number of sensors like accelerometer, camera, and microphone along with significant processing power. There are a number of heart-related physiological signals that can be directly extracted from smartphone sensors. With the facility of continuous monitoring of the heart sound or PCG signal and PPG signal directly from the smartphone, it is possible to accurately estimate the cardiac health of a human being as well as to trigger an alert when anomalous events or interesting cardiac markers can be detected through robust signal analysis and statistical learning of different parameters and important features. ECG signal can be conveniently captured using AliveCor [3] attachment at the smartphone. A 30-sec, single-lead ECG signal can be captured using AliveCor, which is available as an attachment to IPhones and a number of Android phones. In a nutshell, we can directly extract important cardiac marker signals like PPG, PCG, and ECG and digitally record at the smartphones. Smartphones equipped with robust analytics would be able to realize affordable, easy-to-use, remote preventive cardiac health monitoring and management particularly as an early warning system. In the next section we describe the important cardiac marker signals: PPG, ECG, and PCG.

8.3.1 Photoplethysmogram (PPG)

A photoplethysmogram (PPG) is an optically obtained plethysmogram, a volumetric measurement of an organ [52]. With each cardiac cycle, the heart pumps blood to the periphery. The light-emitting diode (LED) from a smartphone camera flash or pulse oximeter illuminates the skin (preferably fingertip) and detects the change in volume caused by the pressure pulse. The signal is periodic, and it beats according to the pulse rate as shown in Fig. 8.5. A PPG is usually obtained by using a pulse oximeter which illuminates the skin and measures changes in light absorption [8].

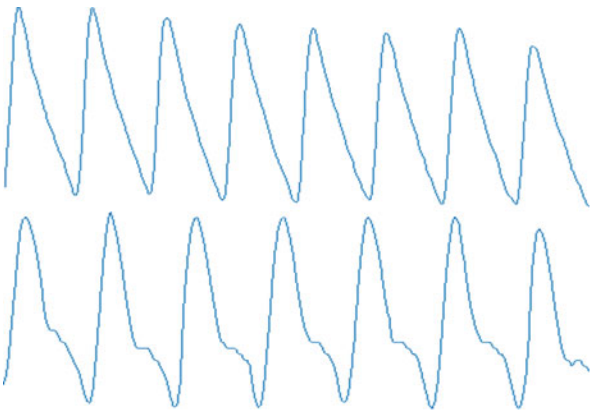


Fig. 8.5 Typical PPG signals

A conventional pulse oximeter monitors the perfusion of blood to the dermis and subcutaneous tissue of the skin. PPG signals can also be extracted from video sequences of blood flow at the fingertip [5], when illuminated by the LED flashlight of the smartphone inbuilt flashlight. A typical PPG signal beats at the heartbeat frequency. We depict typical PPG signals in the next section.

8.3.2 Electrocardiogram

Electrocardiography (ECG or EKG) records the electrical activity of the heart. It is a periodic signal and beats with a pulse rate. Our cardiac activities produce a number of tiny electrical impulses. These electrical signals are spread throughout the different heart muscles that enable the heart to contract. An ECG contains a signature of these cardiac electrical impulses. For extracting ECG signals, the procedure requires trained or skilled persons along with additional hardware (mostly expensive instruments) [9–11]. However, AliveCor hardware attachment of a smartphone reliably captures single-lead ECG signals that contain a significant amount of the electrical activities of the heart. A typical ECG signal is shown in Fig. 8.6.

8.3.3 Phonocardiogram or Heart Sound

A phonocardiogram (PCG) or a heart sound contains the description of the vulvar activities of the heart. The plot is generated by recording the sounds and murmurs made by the heart. In fact, PCG captures large spectra of sound signals emitted by the heart at each of the cardiac cycles, and the sounds are produced by the vibrations

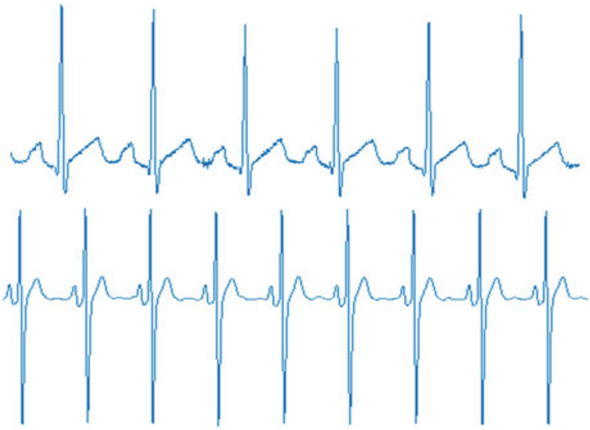


Fig. 8.6 Typical ECG signals

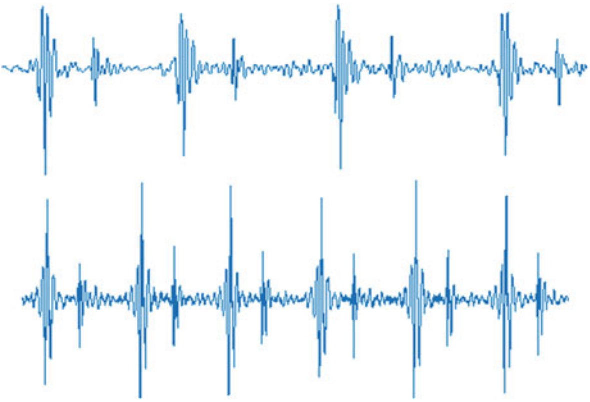


Fig. 8.7 Typical PCG signals

created during the closure of the heart valves [12, 13]. A typical PCG signal is shown in Fig. 8.7.

Each of these signals has certain characteristics that describe the underlying activity of the heart. In case of cardiac problems, at least few of the activities would become abnormal and that abnormality is captured by these signals. In the next section, we describe the important morphological features of these signals.

8.4 Signal Morphology: With Maxima and Minima

Signal morphology plays an important role in portraying different cardiac disease markers. Information carried by the PCG signal contains considerable details of cardiac activities. In fact, the complete morphology of the PCG signal is directly related to the contractile activity of the cardio hemic system. When a person suffers from cardiovascular diseases, the state of the heart changes in terms of contractility and rhythm is reflected. Additionally, audio characteristics of PCG changes and murmur sounds are associated with cardiovascular diseases. The PCG signal is nonstationary in nature but has predefined segments. A normal PCG signal consists of S1, systole, and S2, diastole, parts. When the subject is cardiac abnormal, additional sounds like S3, S4, and different murmurs (M) are present. Let Υ_k, $k = 1, 2, \ldots, K$ be the PCG signal with total K number of intervals, $\Upsilon_k^{\text{Normal}} = \{S1, \text{ Systole}, \ S2, \text{ Diastole}\}_k, \ k \in K$ and Υ repeats with $\{S1, \text{ Systole}, \ S2, \text{ Diastole}\}$. Sub-segments, whereas, $\Upsilon_k^{\text{Abnormal}} = \{S1, \text{Systole}, S2, \text{Diastole}, S3, S4, \text{Murmur}\}_k, \ \ k \in K$.

ECG signal is one of the fundamental cardiac health markers. ECG represents cardiac electrical activities and captures different electric potentials during cardiac cycles. There are five distinct waves called P, Q, R, S, and T. ECG beats in rhythm with the heartbeat and the R-R interval determines instantaneous heart rate. Let Ω_k, $k = 1, 2, \ldots, K$ be the ECG signal with total K number of intervals, $\Omega_k = \{P, Q, R, S, T\}_k, \ \ k \in K$, and Ω repeats with $\{P, Q, R, S, T\}$ sub-waves. When a subject is cardiac abnormal, different features of $\{P, Q, R, S, T\}$ would deviate from the regular patterns. Heart rate, heart rate variability (HRV), and inter-beat separation are the fundamental features derived from ECG.

PPG signal is also a vital cardiac marker. It is mainly used to measure pulse rate and blood oxygen saturation (SpO2). However, PPG is rich in information. PPG is periodic with the heartbeat rate. Spectral analysis of PPG shows a strong presence of the heart rate spectral component. If ρ is the heart rate of the subject in beats per minute, then spectral analysis of PPG would show a strong component of $60/\rho$ Hz. When a person is cardiac abnormal, heart rate may fluctuate at each cycle. For example, when a patient suffers from atrial fibrillation, heart rate fluctuates rapidly. In such a scenario, we find blunt spectral presence of the heart rate.

In Fig. 8.8, we show different features that are extracted from the PPG signal. In Table 8.1, we describe important physiological parameter measures correlating with the morphology of PPG. We observe that there are a number of important cardiac markers present at the PPG signal.

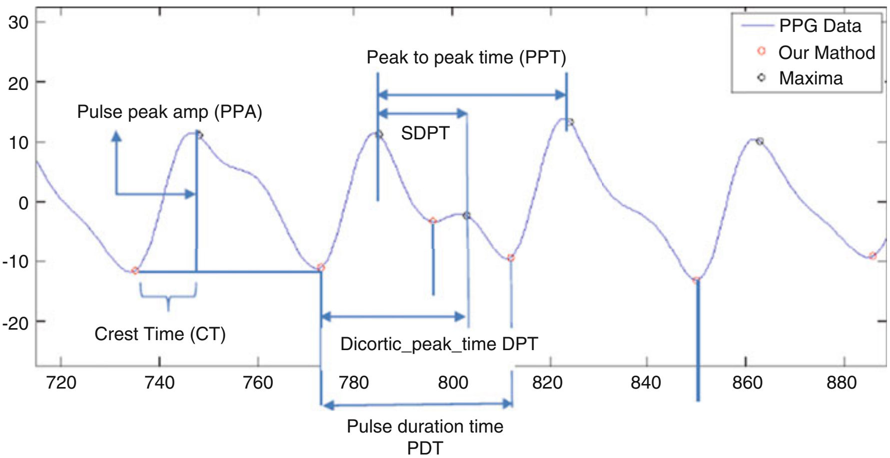


Fig. 8.8 PPG signal showing important features related to different maxima and minima points

Table 8.1 Pulsating signal features with physiological parameters—PPG exemplary case

Features	Physiological parameter	Notes	Main reference
Pulse peak amp (PPA) (systolic amplitude)	PVC (premature ventricular contraction), continuous blood pressure	The height of the Alternating Current component of a PPG signal is proportional to the pulse pressure, the difference between the systolic and diastolic pressure in the arteries	https://en.wikipedia.org/wiki/Photoplethysmogram
		Morphology of PPG pulse along with low-amplitude blood pressure together indicates presence of PVC. We can further identify ventricular tachycardia and ventricular fibrillation It is observed that systolic amplitude is a suitable indicator to estimate blood pressure than pulse arrival time	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3394104/
Pulse duration time (PDT)	HRV (heart rate variability)	It is known that ratio of *pulse interval* to its systolic amplitude could provide an understanding of the properties of a person's cardiovascular system. In [14], the authors made a comparative study of heart rate variability (HRV) from the PPG signal along with the R-R interval of simultaneously captured ECG signals. They have concluded high correlation between the HRV derived from PPG pulse and R-R interval from ECG, which further confirms that HRV estimation can be accurately computed from the PPG signal	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3394104/
Pulse transit time (PTT)	Vascular wall	Pulse transit time (PTT) provides a critical indication of blood pressure and is strongly related to cardiac health [15]	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3394104/
Systolic to diastolic peak difference (SDPT)	Large artery stiffness index	It is demonstrated that transit time of pressure waves from the root of the subclavian artery to the apparent site of reflection and back to the subclavian artery is related to the time delay between the systolic and diastolic peaks. Further, it is assumed that the reflection path length is proportional to subject height	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3394104/
Pulse wave velocity (PWV)	Arterial stiffness	We classify subjects into high and low pulse wave velocity (equivalent to high and low cardiovascular disease risk)	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3394104/

8.5 Clinical Analytics Techniques

We present the analysis performed on various sensor signals by applying methods that exploits different learning approaches encompassing signal processing, statistical and machine learning mechanisms, as well as information theoretical analysis.

1. *Preprocessing:* Signal preprocessing is performed to filter out-of-band spectral components. For instance, the PCG signal carries spectral information from 0.2 to 500 Hz. So, we can safely put a band-pass filter with a cutoff at 0.2 and 500 Hz. Further, the extracted physiological signals are corrupted with various forms of noise like motion artifacts and ambient noise. Noise removal is an important step in the preprocessing stage. It is often argued that computational methods of physiological signal analysis fail in practical scenarios because of their inability to intelligently remove noisy components [2, 16].
2. *Feature engineering:* Features play an important role in determining the ability of the classifier to learn on the training datasets [17]. The optimized, parsimonious feature set that represents the properties of the underlying phenomena would enable the classifier to build a robust and accurate learning model [53]. We need to find a relevant, yet nonredundant, feature set that extracts distinct features to maximize the classifier performance [18, 19]. We have described feature selection in a PPG signal in [20].
3. *Macro-decision*: The prerogative of clinical analytics is to identify the fundamental inference from physiological signals, which is termed as a macro-decision process. In the macro-decision process, the subject is identified as cardiac abnormal or normal. Further, disease specific detection would require more parameters and possibly, invasive tests. However, it is to be perceived that macro-decision is sufficient to understand the cardiac health, and subsequent investigation would warrant early disease identification and consequent medical intervention.
4. *Anomaly detection:* It is a learner model, either supervised, unsupervised, or semi-supervised, that uses the feature set and builds a learning model for detecting anomaly in the ECG, PCG, and PPG signals. Here, we emphasize that anomaly detection is an imperative need to perform clinical analysis. The inference outcome is to declare normal or abnormal cardiac subjects. In low Signal to Noise Ratio (SNR) conditions, where noise floor is high, anomaly detection is to be more robust with low false-negative alarms [21]. We observe that noise removal plays an important role in analyzing clinical inferencing from physiological signals.

The main focus of cardiac health analysis is to detect anomalous phenomena. We first discuss anomaly analytics on the physiological signals. The basic steps of anomaly detection are shown in Fig. 8.9.

The main focus of clinical analytics is to provide macro-decisions on cardiac health. By macro-decision, we mean that whether the subject is clinically abnormal with respect to cardiac health. When clinical abnormality is detected, patients would

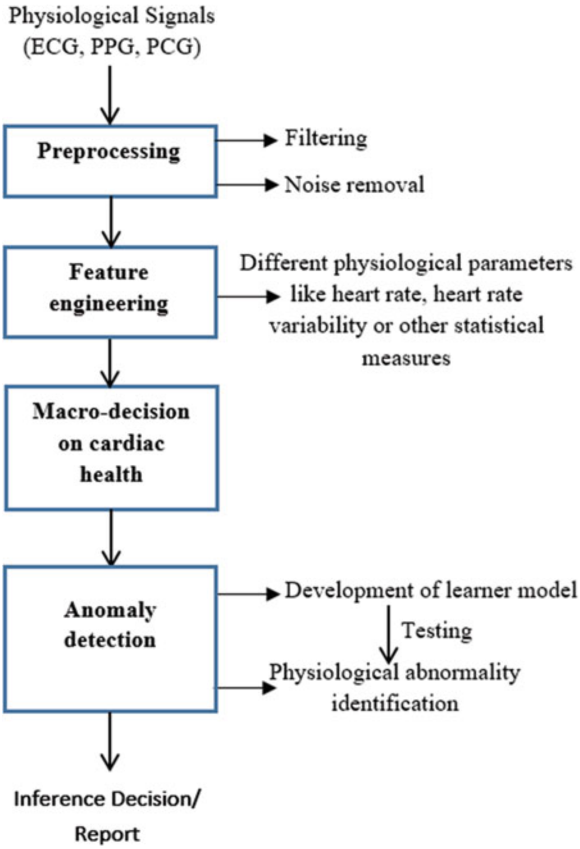


Fig. 8.9 Basic steps in anomaly analytics

visit medical practitioners to find out the specific disease condition, where she would be subjected to a gamut of screenings and tests.

In order to ensure accurate macro-decision from a mobile-based analytics system, robust anomaly detection from the physiological signals has to be developed such that the underlying cardiac abnormality can be discovered. One of the critical requirements is to address practical issues. Practical anomaly detection methodology has to address a number of constraints. For example:

1. Class imbalance problem: E.g., training data may contain a minor number of examples from the negative class.
2. Constraint cost function: E.g., to achieve performance with highly accurate (low false alarms) or balanced specificity and sensitivity or high sensitivity with bounded specificity (or vice versa).
3. Trade-off is maintained with computational complexity and accuracy.

In Fig. 8.10, we illustrate the complete scenario of anomaly detection constraints.

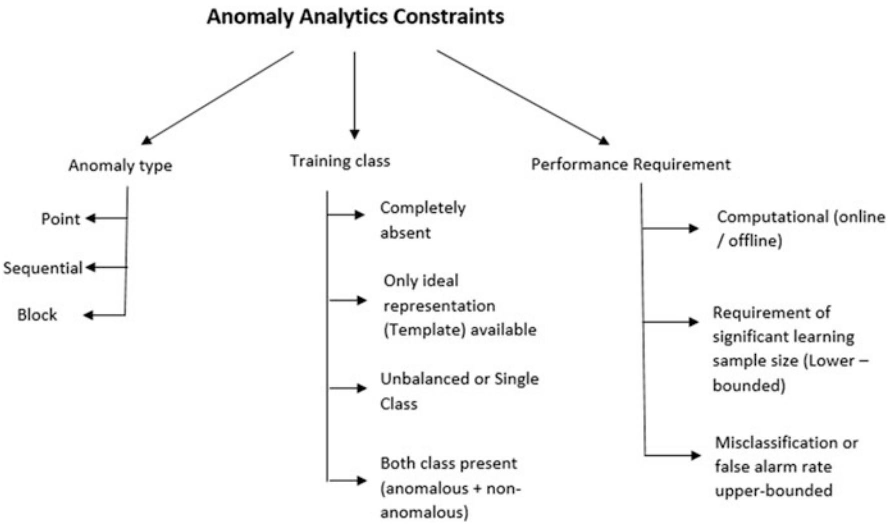


Fig. 8.10 Constraints in anomaly detection model

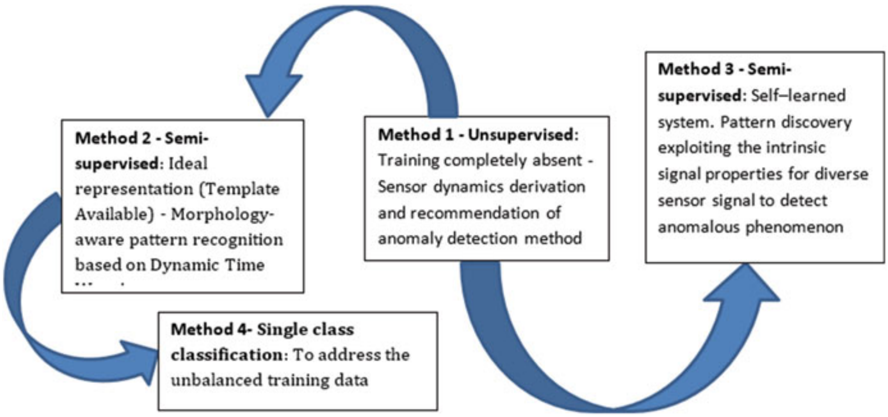


Fig. 8.11 Evolution stages of anomaly analytics

8.5.1 Evolution Stages

Our proposed models have been evolved following different learning approaches like pattern discovering by exploiting the intrinsic morphological characteristics [22]. Figure 8.11 shows the evolution stages of the anomaly analytics model generation process.

- *Method 1: Unsupervised* (training completely absent)—It addresses the salient features of sensor dynamics discovery. Sensor dynamics derivation (like quasi-periodic, aperiodic, cyclo-stationary, etc.) along with density analysis is the recommended anomaly detection method. One of the typical methods of determining the presence of anomalies in unsupervised learning is through applying Hampel filter, which is a median absolute deviation (MAD) scale-based statistical estimator. The method is as follows:

$\mathcal{L} = \{\mathbb{I}_n\}^N$ be the instance space, which is either of the datasets (PPG, PCG, or ECG signal) under investigation.

$$\text{median}\left(\{\mathcal{L}\}\right) = \frac{\mathcal{L}\left(n+1\right)/2 : n + \mathcal{L}n/2 : n}{2}$$

$$\text{MAD}\left(\{\mathbb{I}_n\}\right) = \text{median}\left(\left|\mathbb{I}_1 - \text{median}\left(\{\mathcal{L}\}\right)\right|, \ldots, \ \left|\mathbb{I}_n - \text{median}\left(\{\mathcal{L}\}\right)\right|\right)$$

An observation ϕ_α in $\mathcal{L}$ is declared as anomaly when

$|\phi_\alpha - \text{median}\ (\{\mathcal{L}\ \})| > \Omega(K, \Lambda)\text{MAD}(\{\phi_\alpha\}),\ \phi_\alpha \in \mathcal{L}$ where Ω is defined in [23].

Rosner filter-based statistical investigation is also a suitable point-based unsupervised learning method that uses the underlying distribution of the dataset. Rosner filter performs $\mathcal{Q}$separate tests in a sequential order for the calculation of the deviation parameter $\Delta_n = \frac{\max_n(\mathbb{I}_n - \text{median}\ (\{\mathcal{L}\}))}{\sigma}$, $n = 1, 2, .., \mathcal{Q}$, and σ is the standard deviation of $\{\mathcal{L}\}$. We first find $\phi_\alpha \in \mathscr{L}$ that maximize(In – median ({L})). Those ϕ_α are declared as anomalous observations and subsequently removed from further investigations while the test is repeated. The final declared anomaly points in $\mathcal{L}$ for which $\Delta_n > \eta_n$, where $\eta_n = \frac{(N-n)t_{p,N-n-1}}{\left(\left(N-n-1+t^2_{p,N-n-1}\right)(N-n+1)\right)^{1/2}}$, where $p = 1 - \frac{\theta}{2(N-i+1)}t_{p,\nu}$ is computed as the $100p$ percentage point derived from ν degrees of freedom in the student's t distribution.

Another technique is to explore the morphological pattern of the signals that finds out block or segment-wise anomalous portions. For example, in case of quasi-periodic signals (PPG and ECG), collaborative outlier class and adaptive window-based discord discovery (AWDD) are recommended [24]. One of the major drawbacks of the AWDD method is the high computation cost. It is difficult to process sensor data having large sizes with AWDD. However, the quasi-periodicity of ECG and PPG signals (it beats with heart rate frequency) would ensure highly effective anomaly detection in the absence of (reliable) training datasets. Another interesting approach is spectral analysis, particularly for the PCG signal. It is to be noted that the PCG signal is an audio domain signal and usually sampled at high frequencies, more than 2000 Hz, whereas ECG is usually sampled at 300 Hz and PPG is sampled at 200 Hz. Thus, PCG has rich spectral components. Spectral component study through window-by-window analysis of the PCG signal is done in [25] to find the spectral-level anomalous events.

- *Method 2: Semi-supervised*—In this case, an ideal representation or template of the signal segment is available. It addresses the salient features of morphology-aware pattern recognition. Here, a fixed standard template with minimal domain knowledge is provided to detect the anomaly. The method attempts to adapt to the template to find out the anomalous morphological pattern [26]. In [26], morphological trend determination of the PPG signal is performed for detecting cardiac condition, where arrhythmia (which is an irregular heartbeat phenomenon) is detected, particularly a joint learning with k-mean clustering with K-Nearest Neighbor (KNN) learning is applied to find out whether the PPG signal is captured from a person with arrhythmia conditions like tachycardia and bradycardia. Another technique in the semi-supervised method is self-learning, where the pattern is discovered through a self-learning process [22].

- *Method 3: Supervised*—When a sufficient number of balanced training examples are available, traditionally supervised learning methods are employed. In [18], we have shown that robust analysis of cardiac abnormality detection can be performed from the PCG signal by optimal feature selection and a nonlinear support vector machine (SVM) classifier is chosen. Here, minimum Redundancy Maximum Relevance (*mRMR*), a filter feature selection method in *mRMR*, satisfies relevancy property $\mathbb{A}$ and redundancy property $\mathbb{B}$ from the set of features $\Theta = \{\theta_1, \theta_2, \ldots, \theta_z\}$ to the target class $\mathbb{C}$ based on mutual information, where $\mathbb{A} = \frac{1}{|F|} \sum_{F_i \subseteq F} \mathbb{I}\left(F_i, C_T\right)$, $\mathbb{B} = \frac{1}{|F|^2} \sum_{F_i,\ F_j \subseteq F} \mathbb{I}\left(F_i, F_j\right)$, $F_{mRMR}|_{\text{rank}} = \arg \max_F (|\ \mathbb{A} - \mathbb{B}|)$. $F_{mRMR}|_{\text{rank}}$ is the ranking of Θ in terms of capability of properly determining target class $\mathbb{C}$ from the training set. Cardinality of Θ and F_{mRMR}, $|\Theta| = |F_{mRMR}|$, i.e., there exists bijection from Θ and F_{mRMR} [19]. We have to select a top-ranked feature set from $F_{mRMR}|_{\text{rank}}$.

  Researchers have approached anomaly detection problems in different supervised learning methods. The authors in [27] have proposed an ensemble empirical mode decomposition (EEMD) for S1 and S2 segmentation in PCG signals. In [28], the authors used the EEMD approach to identify the abnormality in S1 and S2 segments.
- *Method 4: Single-class classification*—When the number of training examples of one of the classes is much less, we face a class imbalance problem. Formally, we state the problem as follows:

  Let $\mathcal{L} = (\mathbb{L}_+, \mathbb{L}_-)$, where $\mathbb{L}_+$ be the available known-labeled positive training set and $\mathbb{L}_-$ be the unknown-labeled negative training set, $\mathbb{L}_+ = \left\{\mathbb{I}_i^+\right\}_{i=1}^{\Omega}$, $\mathbb{L}_- = \left\{\mathbb{I}_i^-\right\}_{i=1}^{\omega}$, where $\Omega \gg \omega$; $\mathbb{I}_i^+, \mathbb{I}_i^- \in \mathbb{R}^d$.

  In practice, normal class training examples are easily available than abnormal or anomalous class examples, which leads to a class imbalance problem. In such a scenario, the learner model is to be carefully constructed to avoid biased model generation or over-fitting with respect to the abundance class. In order to address the class imbalance problem, a number of approaches are presented. Researchers have mainly followed two distinct ways: (1) resampling of the training dataset and boosting over it, Random Under Sampling Boosting (RUSBoost) [29] and Synthetic Minority Oversampling Technique Boosting (SMOTEBoost) [30], and

(2) improving the hyper-parameters of support vector machines to construct smooth decision boundary between the normal and abnormal classes [31, 32].

8.5.2 Exemplary Analysis

In order to develop a mobile-based clinical analytics application, we need to consider the above-mentioned anomaly analytics constraints, namely, (1) anomaly type, (2) nature of balance in training class examples, and (3) performance requirement, particularly in terms of computational complexity and detection capability in terms of minimizing false alarms. It is to be kept in mind that all the constraints cannot be satisfied simultaneously. For instance, when we need to build a powerful learner model, computational complexity often goes up. So, we find an obvious trade-off between learner model complexities with computational affectivity. In the context of smartphone-based development, we recommend:

1. Efficient computational load while optimizing on the anomaly analytics learner model when the complete analytics is performed locally at the edge or the smartphone
2. A powerful learner model maximizes the detection capability by minimizing the false alarm rate or maximizing accuracy, F1-score and offloads the complete or part of the analytics algorithm.

   We depict the primary model of our analysis as follows: Let $\mathcal{L} = (\mathbb{L}_{+}, \mathbb{L}_{-})$ be the instance space; $\mathcal{D}$ be the decision space (decision space corresponds to anomaly type); $\mathcal{K}$ be the knowledge base that consists of recommendation engine, which is either a rule-based or semi-supervised domain-adapted inductive transfer learning mechanism, or unsupervised model, or a supervised learner model, or a one-class classification model; $\mathcal{P}$ be the considered model; $\mathcal{P} \subset \mathcal{K}$ and $\mathcal{T}$ be the available training sets; $\mathcal{S}$ be the testing datasets; and δ be the performance requirements like bounded computational time (say, the detection declaration to be made within a latency of 10 sec) and detection capability (say, the accuracy score is to be more than 80% or the F1-score is to be $\geq$0.85). Formally:

$$\mathcal{L} \xrightarrow{\mathcal{K},\, \mathcal{T},\, \delta} \mathcal{P} \xrightarrow{\mathcal{S}} \mathcal{D}$$

- Scenario 1: Local or edge analytics

  In case of a local analytics-based application, strict computational time ($\mathbb{c}$)bound-based constraint is to be maintained while trading off with the detection performance ($\mathbb{d}$).

$$\mathcal{L}|_{\text{local analytics}} \xrightarrow{\mathcal{K},\ \mathcal{T}} \mathcal{P} \xrightarrow{\mathcal{S}} \mathcal{D}$$

Such that:

$$\text{maximize } (\delta_{\mathbb{d}}), \delta_{\mathbb{c}} \le \mathbb{c}$$

- Scenario 2: Cloud-based analytics

  In case of a cloud-based analytics application, we can safely assume that the cloud platform has a significantly high computational power, and consequently, we ignore the computational time requirement. The aim is to maximize the detection performance $\mathbb{d}$ by constructing a powerful learning model.

$$\mathcal{L}|_{\text{local analytics}} \xrightarrow{\mathcal{K},\ \mathcal{T},} \mathcal{P} \xrightarrow{\mathcal{S}} \mathcal{D}$$

Such that:

$$\text{maximize } (\delta_{\mathbb{d}}),$$

We depict a simple pseudo-code form of performing the clinical analytics task:

Anomaly analytics (test data = $\mathcal{S}$, training set = $\mathcal{L}$, computational latency requirement $=\mathbb{c}$, performance requirement $=\mathbb{d}$)

If $\mathcal{L} = Null$

Choose Method 1 or a suitable unsupervised method.

Else if

$\mathcal{L} \neq Null$ and only template available of the data type

Choose Method 2

Else if

$\mathcal{L} \neq Null$

Choose Method 3

Else if

$\mathcal{L} \neq Null$: Unbalanced training

Choose Method 4

End

If ($\mathbb{c}$ = Low, $\mathcal{L} \neq Null$)

Choose trade-off ($\mathbb{c}$ is upper bounded while maximizing $\mathbb{d}$) learner model

If (δ = High, $\mathcal{L} \neq Null$)

Choose the most powerful learner model irrespective of computational latency that maximizes $\mathbb{d}$

End

For example, we perform template-based multistage anomaly detection for photoplethysmogram (PPG) signals, where an ideal PPG signal template is available [33]. In the next section, we show one example considering the PPG signal. We have proposed Cardiofit scheme, which is a PPG-based cardiac condition analytics tool. There are five functional blocks: (1) raw PPG signal extraction: First, the raw PPG signal is extracted from wearable sensors or a smartphone; (2) multistage corruption

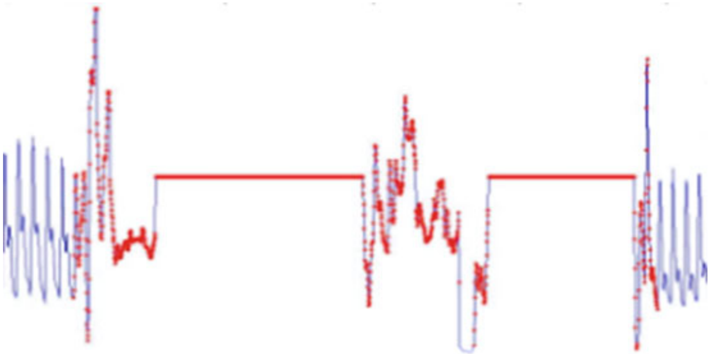


Fig. 8.12 Anomaly analytics on the PPG signal

removal: In this block, corruption from PPG signals is identified and discarded so that a clean PPG signal is fed to the subsequent analytics blocks, (3) estimation of cardiac parameters: In this block, important cardiac parameters like heart rate (HR) is estimated from the clean PPG signal, (4) statistical analysis: In this block, the statistical trend of estimated cardiac parameters is evaluated, (5) decision: Here, decision is generated and the PPG signal is classified as cardiac normal or abnormal. The proposed method provides recall >80% and sensitivity 96%.

In Fig. 8.12, we depict a PPG anomalous segment detection.

In [18], we have demonstrated a PCG-based cardiac condition detection method. It is a supervised learning-based approach. First, a universal set of 54 features is selected. There are two types of features:

1. Application-independent features: These features consist of statistical-, spectral-, and wavelet-based features, like kurtosis and wavelet packet (WP) energy coefficients.
2. Application-dependent features: These features exploit physiological characteristics of the PCG signal. A typical PCG signal consists of Ψ_i, $i = 1, 2, \ldots . N$ time-series segments and each of the Ψ_i segments consists of S1, systole, S2, diastole, and murmur events, i.e., $\Psi_i := [S1, \text{Systole}, S2, \text{Diastole}, \text{murmur}]_i$. We follow the method mentioned in [34] to segment the PCG signals into blocks of Ψ_i. We consider application-dependent features like mean and standard deviation of the duration between the S1 intervals, S2 intervals, RR beats, systole intervals, and diastole intervals.

Next, feature optimization using the mRMR method [19] is applied, and the top five features are selected. Radial basis function (RBF) kernelized support vector machine (SVM) is used to construct the classifier model. A further enhancement of ensemble learning is done over a number of supervised learning methods like SVM, RUSBoost, and bagging. The ensemble-based supervised learning technique is used to train multiple learners and combine through the criterion function to construct a strong classification model. The ensemble learning method with a majority voting-based criterion function improves over RBF-SVM, and a sensitivity of 0.77 and a specificity of 0.79 are reported for more than 3500 expert-labeled PCG signals in publicly available Physionet Challenge 2016 dataset [16].

8.6 Risks

Healthcare data and consequent actions are private in nature. Healthcare data are vulnerable to privacy attacks [35]. Electronics Health Records (EHR), physiological signals, and parameters are very sensitive, and the highest security and privacy safeguards are to be deployed to prevent any data leak or theft [36, 37, 55]. The first priority is providing secure infrastructure, particularly when the analytics part is serviced from the cloud platform incorporating trust management [38]. Strict security policy provisioning and ensuring secure transaction and computation over the cloud platform is to be enabled when such a mobile healthcare system is publicly deployed [39, 40]. The overall ecosystem is a wireless sensor network, where sensors, smartphone, and gateway cloud form the network. We need to secure the routing of sensitive data from source to destination [41]. Data privacy is another important aspect that needs prior attention. Patient's data like diagnosis and medication reports as well as the consequences of data analytics are to be privacy preserved against privacy breaching attacks and intrusive interpretation. Health data sharing and content management policy have to follow certain regulations like HIPAA (Health Insurance Portability and Accountability Act of 1996) [42].

Physiological signals and data are noisy in nature. It is emphatically stated that the presence of corruption in physiological signals like ECG, PCG, and PPG is one of the main reasons for lower accuracy and unacceptability of automated disease identification systems [16]. Sophisticated denoising is of utmost importance for bringing out the best of the outcomes in terms of accuracy (or specificity and sensitivity) from the elegant AI and deep learning algorithms.

The other prime challenge is to obtain sufficient data for learning, as in the case of physiological signals, morphology may vary with respect to different individuals even for the normal scenario. Availability of proper annotation or label certified by the experts is another important bottleneck for evaluating event detection performance from physiological signals.

8.7 Use Cases

In this section, we illustrate two use cases. First, we describe a holistic view of patient care in IoT setup, where we integrate different cardiac-specific physiological signals integrated with EHR and radiology reports. Second, we discuss unobtrusive continuous monitoring of cardiac health through continuous monitoring in daily activities.

8.7.1 Case Study 1

We illustrate the complete IoT-healthcare ecosystem in Fig. 8.13, where a holistic view of a patient's treatment plan can be drawn as well as healthcare emergency can be quickly identified and taken care of.

1. A patient's clinical parameters are remotely collected (on-demand or event triggered), most of them through low-cost sensors to capture PCG, blood pressure, EEG, PPG, and ECG signals. MRI-on chip is also on its way to becoming a reality.
2. These signals and parameters are sent to concerned physicians, hospitals, and analytics engine through Internet gateways like smartphones along with the patient's precise location through GPS information.
3. Analytics engine can be in-house/local (smartphone) or remote, where cloud computing is used to infer clinical significance.
4. In case of remote analytics, the patient's historical EHR is fetched; summary and clinical insight are presented to the concerned physician.
5. Local analytics quickly raises an alert to caregivers like the nearest hospital or ambulance services when an unusual physical condition is detected.

With the vast availability of body sensors, the unobtrusive sensing would assist patients to check their cardiac health condition on demand. Instead of typical reactive diagnosis, such active participation of patients mostly from a remote setting would usher preventive health maintenance. For example, an active healthy person aged 55 years periodically checks his cardiac health parameters by body sensors like ECG and PPG leisurely at his residence. The inference is normal, and the person tends to move to passive lifestyle with less amount of physical exercises and after a year, his ECG reading shows abnormality, and the App advices him for medical expert intervention. He immediately rushes for expert opinion, and the doctor prescribed invasive procedure angiography, which reveals a small blockage at the artery (30%). The doctor advises him to have few lifestyle changes; certain medications; and regular checkup of blood pressure, blood sugar, and lipid profile along with noninvasive screening. In fact, he was saved for an expensive treatment and tougher diagnosis regimen if artery blockage was detected later, when chest pain surfaces. Thus, the man is saved from major cardiac illness, and early screening helped him to lead a healthy life. In another case, an elderly patient is being constantly monitored by healthcare providers through IoT-connected ecosystem and it alerts them for medication, health checkup, and an emergency health condition through a higher form of transparency.

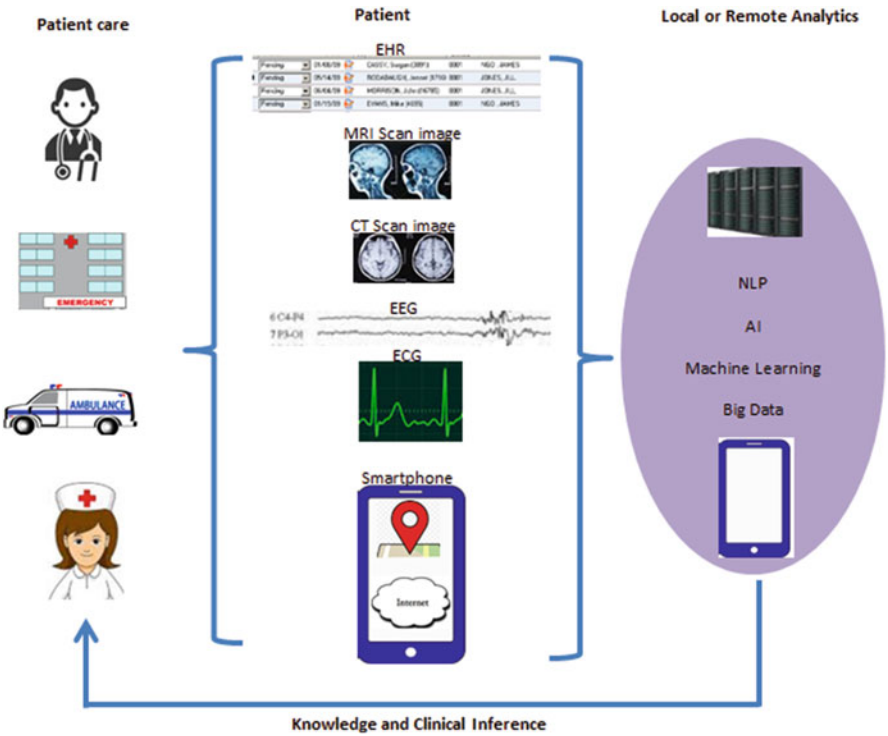
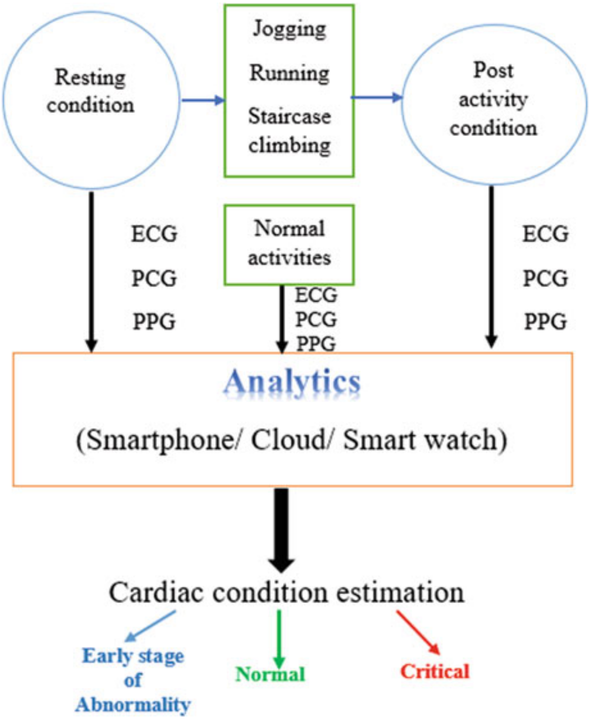


Fig. 8.13 Integrated architecture of a remote, personalized cardiac care system leveraging the IoT infrastructure

8.7.2 Case Study 2

Another interesting cardiac health screening problem is the estimation of a person's cardiac condition before and after strenuous activities like jogging, running, staircase climbing, etc. It is an established fact that people suffering from cardiac diseases would react to physical stress conditions differently than a normal person, and cardiac parameters like heart rate (HR) and heart rate variability (HRV) would change differently before and after such activities. Traditionally, the cardiac condition is determined from stress tests like treadmill test (TMT) to evaluate the health of the cardiovascular system. Even the fatigue generated from day-to-day normal activities would be different in cardiac patients. When a person feels like (external physical manifestation) suffering from excessive fatigue, she reports to the doctor, which may be too late, and the heart is already damaged. However, continuous monitoring of cardiac parameters throughout normal activities and physical stressful activities would potentially reveal an early sign of cardiac health deterioration. We show a sketch in Fig. 8.14.

Fig. 8.14 Cardiac condition estimation through daily activities: unobtrusive continuous monitoring



8.8 Current Scenario

Researchers and developers have put immense effort to build mobile-based cardiac health management applications. For instance, Cardiio Rhythm app developed by MIT - Massachusetts Institute of Technology uses facial signs for recognition to estimate heartbeat and other cardiovascular states [43]. The unique feature of this app is that it does not require physiological signals, but instead, facial images are analyzed for estimating the state of cardiac health. We have already observed that heart rate measurement provides a strong marker for the cardiovascular system. Azumio Inc. developed Instant Heart Rate: HR Monitor that provides instant measurement of heart rate [44]. Different health conditions, specifically cardiac health condition, would be determined by continuous heart rate monitoring throughout daily activities as well as at the time of physical exercises or cardio training. QardioCore, developed by Qardio, is a wearable ECG band that extracts ECG signal, heart rate, respiratory rate, and other vital parameters and shares them to a paired smartphone [54]. Kardia-band and Kardia-mobile, developed by AliveCor, directly capture the ECG signal and analyze cardiac health; particularly, it detects atrial fibrillation condition [4]. Other meaningful developments are implanted sensors and textile electrodes [45]. In [45], the authors have presented an integrated wearable sensor system that connects garment-embedded sensing for the diagnosis of various cardiovascular diseases. In

[46], the authors have demonstrated a real-time heart monitoring system, where cost, usability, prediction accuracy, and data privacy are considered. They have used the off-the-shelf sensor, Zephyr BT, that monitors heart rate and developed Android-based applications to analyze the cardiac health condition. The authors in [47] have presented an overview of smart sensor analytics that drives healthcare systems. However, the basic assumption is that most of the technological advancements are IoT-enabled, requiring an active Internet connection. In the absence of such connectivity, edge analytics need to be powerful and analytics inference would be sent as a short message service (SMS) to the respective stakeholders like doctors, emergency service providers, hospitals, and nurses. Yet another interesting challenge is to provide a friendly user interface for the use by elderly people. In fact, such proactive, remote-screening solutions would impact the lives of elderly people more. The realistic solution is to provide a training video for the elderly and ensure highly simplified, user-friendly development of human interface.

Currently, ballistocardiograph (BCG) that measures the ballistic forces on the heart has shown immense potential for noninvasive identification of cardiac health abnormality [48, 49]. Ballistocardiography is a graphical representation of the periodic motions in the human body due to the incidence of blood ejection at every heartbeat. While ECG provides us information on heart muscle activity, BCG represents the blood circulation and acceleration activity. Both of them are important for enabling the investigation of cardiovascular health. The development of unobtrusive BCG measurement and related analytics would reinforce our understanding of the cardiac health and cardiovascular disease detection.

We observe that existing applications for clinical inference of the cardiac condition in a smartphone or other mobile platforms are yet to deliver a practical solution. Currently available applications mostly derive basic cardiac health parameters like heart rate and respiratory rate, which would enable the analytics engine to report the cardiac health condition. The utopian thought of the holistic solution of disease detection may not be a near-future realization. However, macro-decision-centric analysis, where anomaly detection would be the analytics engine, will be the stepping-stone for realizing the automated mobile cardiac diagnosis platform.

8.9 Future Perspectives

The first major breakthrough for smartphone-based mobile cardiac screening is to develop stable, accurate wearable sensing along with robust analytics engine. The IoT-based setup with edge analytics or cloud-based analytics would ensure the early detection of cardiac parameters and basic cardiac health assessment. Nonetheless, the mobile applications of such cardiac health analytics contain high potential for enabling a paradigm shift in cardiac health diagnosis and treatment plans. The maturity of the present-day mobile cardiac screening system would pave ways to futuristic applications. In the next section, we illustrate our own envision on its future perspectives.

8.9.1 *Personalized Treatment Along with Augmentation of Physician's Decision-Making*

Current evidence-based treatment is an "average" case scenario, where the line of treatment is guided through some randomized controlled trials. Such treatment does not consider the vast heterogeneity of patient features and minute disease symptoms. Therefore, conservative diagnosis is usually followed. With the widespread availability of EHR, medical research literature, physiological signals captured by IoT devices along with immense development of natural language processing (NLP), and deep learning algorithms, inference of a suitable line of treatment could be drawn with high reliability through "information cascade," "wisdom of the crowds," and high-dimensional information assimilation. This will augment the knowledge of the physicians and, in turn, virtually augment physician's experience and quality of decision-making. By using sophisticated multidimensional clustering with given features of the patient, disease symptoms, and historical records, we can discover a subgroup of a similar kind of patients and an appropriate treatment plan. Such targeted intervention would reduce over-treatment and speed up the recovery process. Through mining and aggregation of social data and health records collected from various IoT feeds, personal socio-health conditions can be predicted and holistic personalized treatment, medication, and therapeutic approach are planned. Such an AI-based expert inference support system would definitely increase the quality of decision-making, hence preventing loss of life and improving quality of life. It is argued [50] that today's static patient-reported outcomes will transform to completely patient-driven outcomes to enable a dynamic-care environment. However, privacy protection of such an aggregation framework is to be designed for the prevention of data privacy breach [38, 51].

8.10 Conclusion

In this chapter, our main focus is to demonstrate that biomedical signal processing and computational model for disease prediction from physiological signals would ensure impactful IoT-enabled healthcare applications. We have looked at noninvasive solutions for cardiovascular diseases. We have elaborated major physiological signals like ECG, PPG, PCG, and Learning Life Cycle (LLC) with four important stages, namely, preprocessing, removal of noise, important features detection, and disease prediction, as the core of analytics for inferring the important markers. We have briefly described the architecture of cardiac health screening using mobile/wearable sensors specifically for generating an automated alert and proactive doctor's visit.

The major component of the analytics engine is to learn the morphology and pattern discovery. Here, we have described two basic features, maxima and minima, which indicate the nature of rise and fall of the signal and the role of morphology.

Impacts of maxima and minima points related to different physiological features have been described with reference to the PPG signal. We have presented different signal analytics aspects emphasizing the anomaly detection, like unsupervised, semi-supervised, and supervised machine learning techniques along with practical constraints on developing an anomaly analytics solution. Our endeavor is to describe how to obtain the macro-decision, which is the basic need of cardiac analytics, through anomaly detection. Multiple stages and model of detecting the anomalous phenomena in the physiological signals are elaborated. We have illustrated two important use cases to demonstrate the practical utilities of the proposed models, which would bring a significant leap toward an affordable, remote cardiac health management system.

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Chapter 9
Mobile Social Media for Preventing the Ebola Virus Disease Spread in Liberia and Nigeria: A Comparative Analysis

Emmanuel Eilu and John Sören Pettersson

Abstract The aftermath of the Ebola Virus Disease (EVD) crisis in West Africa in 2014 was horrific. The EVD epidemic claimed 11,315 lives and had almost a 40 per cent killing rate. The EVD had huge negative effects on social, economic and political fronts of the four most affected countries Guinea, Liberia, Sierra Leone and Nigeria. Liberia was the country worst hit and Nigeria was the least affected among them. In both countries, social media was widely used to provide public health messaging and behavioural change guidance to the population on how to avoid getting infected with the deadly EVD. However, while the use of social media significantly reduced the spread of Ebola in Nigeria by 75 per cent, it was not effective in reducing the spread of the EVD in Liberia. In this paper, we reflect factors responsible for the ineffective use of mobile social media in aiding social behavioural change guidance towards the prevention of EVD spread in Liberia and the successful use of mobile social media in doing the same in Nigeria. We further reflect on the definition of 'mobile social media'.

9.1 Introduction

Wisner and colleagues [1] make the interesting observation that disasters are not naturally catastrophic. Disasters basically '*occur at the intersection between earthquakes, typhoons or disease outbreaks and the particular social, economic and political environment in which these events occur'* [2]. Sub-Saharan Africa (SSA) is the most vulnerable region in the world in that when a disaster occurs, it turns out to be catastrophic in many cases. For instance, reports released on the state of food insecurity and malnutrition in SSA note that more than one-quarter of the region's

E. Eilu (✉)
Uganda Christian University, Mbale University College, Mbale, Uganda

J. S. Pettersson
Karlstad University, Karlstad, Sweden
e-mail: john_soren.pettersson@kau.se

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population is suffering from hunger, either as a result of the prolonged drought or as a result of rampant pests and diseases that affect crop yield [3]. This would not have been a catastrophe if governments in SSA countries encouraged and facilitated the use of irrigation and effective pest and disease management approaches. One of the greatest disasters that turned catastrophic in SSA was the outbreak of the Ebola Virus Disease (EVD) in West Africa in 2014 and 2015. There is no other natural disaster that has claimed lives of so many people in SSA in such a short time as the Ebola Epidemic. The UNDG [4] states that '*the EVD epidemic in the three West African countries of Guinea, Liberia and Sierra Leone is the longest, largest, deadliest, and the most complex and challenging Ebola outbreak in history*'.

9.1.1 The 2014 Ebola Crisis in West Africa

The Ebola Virus Disease (EVD) started as a simple public health issue in Guinea in December 2013. It then quickly degenerated into a development crisis (economic, social, humanitarian and security threats) in the three epicentre countries Guinea, Liberia and Sierra Leone in less than 6 months [2, 4, 5]. The EVD epidemic in Guinea, Sierra Leone and Liberia had enormous effects such as loss of thousands of lives, stifled growth rates, reversed recent socio-economic gains, aggravated poverty and severe food insecurity [4, 6]. The EVD epidemic was so vicious that it claimed 11,315 lives from among the 28,601suspected cases, meaning that the virus had a 39.5 per cent killing rate [7]. The EVD epidemic in Guinea, Liberia and Sierra Leone developed its enormous destructive wings from the glaring unpreparedness prior to the outbreak. The three countries had extremely weak health systems which were inadequately equipped. These health facilities were not able to handle such a massive and largely unexpected epidemic. Furthermore, lack of experience in dealing with EVD, coupled with insufficient financial resources and a highly mobile population, led to the rampant spread of EVD in Guinea, Sierra Leone and Liberia [2, 6, 8].

Besides the weak health systems, inadequate financial resources and a highly mobile population, it is reported that a combination of two major factors exacerbated the massive spread of the EVD, that is, misinformation and lack of information about critical aspects of the response, including EVD transmission, case notification, infection control options and geographic spread [8–10]. Since the EVD was not yet a well-known disease in these three countries, there was very limited information about how it spreads and how it can be prevented and treated. Even the little information that was available was not always reliable. Therefore, lack of information and false information aggravated the Ebola scourge.

As a result of its destructive and spread effect, the EVD epidemic was declared 'a public health emergency of international concern' by the World Health Organization [4]. In September 2014, the United Nations Security Council (UNSC) declared the crisis a 'threat to international peace and security'. The UNSC unanimously called for a coordinated approach in dealing with the outbreak [4]. The epidemic challenged governments in both developing and developed countries to come up with strategies on how future occurrences of such an epidemic can quickly be combated [2]. The EVD crisis demonstrated the critical need for communication efficiency to reach populations in educating them about health and disease prevention methods [11]. This is normally referred to as 'social and behavioural change guidance/communication'. According to the USAID's Health Communication Capacity Collaborative project, HC3 [12], social and behavioural change guidance aims at providing knowledge or information which positively influences attitudes and social norms towards a particular phenomenon. Several studies show that social behavioural change communication is very effective when used in a variety of health areas, such as HIV and Ebola. In the case of Ebola, it plays a critical role in curtailing the spread of EVD by calming fears, dispelling false news or rumours, providing answers and pulling together a coordinated response [12].

9.1.2 Social Media in Behavioural Change

Therefore, timely and accurate health-related information is fundamentally critical for improving public health outcomes, whether to help people take action during an outbreak or to prevent them from being infected [13, 14]. Nigeria, for instance, was one of the SSA countries hit by the Ebola Virus in 2015. However, the country with the support from international agencies effectively handled the spread of the virus through a massive social behavioural change communication program for both health workers and the public [10]. Eventually, only eight people died compared to 11,315 deaths in Guinea, Sierra Leone and Liberia [10]. Many commentators have attributed the success of the social behavioural change communication initiative towards EVD prevention in Nigeria to the impact of social media [10]. Several studies have shown that mobile communication technologies, Internet access and, more particularly, social media have demonstrated fundamental shifts in filling in the social behavioural change communication gaps [11, 15–17]. The increased access to the Internet and mobile communication technologies like smartphones and laptops combined with strategic uses of social media like Facebook, WhatsApp, Instagram and many others can bring public health information to many more people than at any time before in history [18].

The term 'social media' is very diverse. Scott and Jacka [19] observe that there is no single recognised definition of social media. In their attempt to define social media, they associate social media with '*a set of Web-based broadcast technologies that enable the democratization of content, giving people the ability to emerge from consumers of content to publishers'* [20]. The American Academy of Pediatrics, on the other hand, defines social media as '*any website that allows social interaction'* [21]. The English Oxford Living Dictionary [22] defines social media as '*Websites and applications that enable users to create and share content or to participate in social networking'*. While there are many descriptions of social media, Schein et al. [23] observe that social media is fundamentally defined by its ability to provide an interactive environment for users, where there is a two-way communication and discussion, and users are encouraged to contribute content. The restriction to the web in the definitions by Scott and Jacka [20] and by O'Keeffe and Clarke-Person [21] does not seem appropriate. Based on the definition from English Oxford Living Dictionary, this paper considers the following websites and applications as social media tools, namely, Facebook, Twitter, WhatsApp, Messenger, WeChat, PalmChat, SMS (short-message service), MMS (multimedia messaging service), YouTube, Instagram and Google, to mention but a few.

Social media platforms such as Facebook have grown from extremely few users in Sub-Saharan Africa to become the most widely used social media platform [24]. According to Facebook's 2015 statistics, the average South African subscriber spends 3 h on Facebook every day, while in Nigeria, there are over 7 million active daily users of Facebook, 97 per cent of whom access the service on mobile devices [25]. By 2012, 50 per cent of the 1 million Internet subscribers in Angola were using Facebook [24]. The most commonly used technology for accessing social media is the mobile phone. Access to social media through mobile phones has been majorly boosted by the relative availability of telecommunication infrastructure in many Sub-Saharan countries. Therefore, using such popular social media platforms on mobile phones to convey health-related messages can have a wide reach to millions of people. As McNab [18] puts it, '*one fact sheet or an emergency message about an outbreak of an infectious disease can be spread through Twitter faster than any influenza virus*'. In this paper, we refer to the use of social media via mobile phones as 'mobile social media'.

Kamara [11] observes that during 2014–2015, when the EVD scourge was at its peak, there was an increased use of mobile social media in Sierra Leone and Liberia, from villages to cities and to the broader world. Kamara further notes that people utilised mobile social media to convey news and to educate the masses on preventative measures. However, besides the huge potential that social media offered in curbing the spread of the EVD, there is very little evidence-based knowledge on the effectiveness of social media in curbing the scourge, and particularly providing social behavioural change guidance towards EVD prevention in Liberia. Yet in neighbouring Nigeria, mobile social media campaigns helped to reduce reporting times of EVD infections by 75 per cent [26]. By 2014, Nigeria's population was about 174 million people, with 114 million mobile phone subscriptions, that is, 65.5 subscriptions per 100 citizens (sometimes called 'mobile penetration'); 56 million Nigerians used the Internet regularly, mostly through mobile devices, with a rapidly growing interest in social media [27]. GSMA gives a mobile subscriber penetration (unique users by population) of 31 per cent in 2015 [28]. Likewise, for Liberia, by 2014 during the height of Ebola epidemic, mobile penetration in Liberia was at 69 per cent—thus higher than in Nigeria—and Internet penetration was at 7.4 per cent. It should be noted that about 87 per cent of Nigerian [29] and 65 per cent of Liberian [30] households owned mobile phones (mobile ownership). However, this difference does not seem big enough to explain the huge difference between death tolls in the two countries (8 compared to over 5,000 people) as there is sufficient evidence that mobile social media was widely used in Liberia to stem the EVD spread.

9.2 Aim and Scope of This Paper

In this paper, we present a comparative analysis between Liberia and Nigeria. We investigate factors responsible for the unsuccessful use of social media in Liberia and the successful use of mobile social media in Nigeria in aiding social behavioural change guidance towards the prevention of EVD spread. In order to guide our discussion, three questions were derived:

1. What social media platforms were used for aiding social behavioural change guidance towards the prevention of EVD spread in Liberia and Nigeria?
2. How effective were these social media platforms in aiding social behavioural change guidance towards the prevention of EVD spread in Liberia and Nigeria?
3. What factors were responsible for the unsuccessful usage of social media in Liberia and the successful use of mobile social media in Nigeria?

The discussion relies mainly on a few sources, especially [2, 9, 26, 31, 32, 33]. However, during the review process, an extensive literature search was conducted based on the research questions of the study. A review was conducted on Government and United Nations Organizations' reports, such as UNICEF, USAID, WHO and others. Different journals, conference proceedings, books and websites were also reviewed. Google Scholar and the (American) National Center for Biotechnology Information (NCBI) journal site was of much help for this review. Finally, we bring in discussions from the M4D 2016 conference in Maputo (Mobile communication technology for Development) to put the discussed factors for mobile social media usage in a larger media context.

9.3 Social Media Applications Used in Liberia and Nigeria

Before assessing the effectiveness of mobile social media, there is a need to identify and understand the major social media applications or tools that were deployed by government and other international agencies to provide behavioural change guidance and prevent the EVD spread in Liberia and Nigeria. Discussed below are some of the most famous social media tools that were deployed in both Liberia and Nigeria though there were many other social media applications deployed.

UNICEF and Internews developed two SMS services that enabled any cell phone user to submit information to a central database nicknamed the 'Rumour Bank' [31]. The first one, launched in November 2014, was called *U-Report*. The Federation of Liberian Youth helped UNICEF to recruit U-reporters from the 15 counties of Liberia. The *U-Report* is said by one UNICEF officer to have been critical for reaching the younger population, which often served as a vocal agent of change [31]. In March 2015, the *Dey Say* SMS service was opened; 'dey say' is a phrase that connotes rumours. Both systems used the same cell phone USSD code 8737. With *Dey Say*, one had to text the word 'rumour' to 8737 to access the USSD prompts.

One then received an automatic reply saying '*Thanks for contacting the Dey Say system. What rumour would you like to report?*' whereupon one could send text. Users received a thank you message to confirm that their texts would be forwarded to a higher authority. The two systems did not require users to have smartphones [31]. When the two systems were launched, more than a thousand rumour reports came in weekly. Every week, the database was analysed, including geographic distribution of messages. The reports were compiled along with facts and aggregated based on counties in a newsletter sent to the Ministry of Health, media houses, the humanitarian community and the Internews network of journalists. By June 2015, the *U-Report* had 51,000 users. UNICEF also developed and deployed a *U-report* SMS platform in Nigeria in April 2014 as part of the social mobilisation strategy against Ebola. One month after the start of the EVD outbreak, the number of *U-Report* subscribers in Nigeria had risen to 63,000 [34]: '*Many people were asking for and contributing information on Ebola – causes, symptoms, treatment, and how to prevent it – as well as sharing with non-U-reporters*', USAID reports in one of their Technical Brief, referring to the Nigerian part of the web site ureport.in.

The BBC launched an Ebola public health information service on WhatsApp, with the intention of servicing in West Africa. The service provided audio, text message alerts and images to help people get the latest public health information to combat the spread of Ebola in the region. WhatsApp is the biggest 'chat app' in use in Africa. The content was limited to three items a day with service in both English and French. Getting involved was as easy as texting '**JOIN'** via WhatsApp to +**44 7702 348,651**, after saving the number in the contact register of the phone. To unsubscribe, one would send '**STOP'** to the same number. The service delivered safety information on Ebola's warning signs and distributed multimedia image and audio campaigns [35]. Over 19,000 subscribers mostly from West Africa joined, including in Nigeria and Liberia [36].

UNICEF launched an @EbolaAlert Twitter account and the #StopEbola campaign to dispel myths about the disease; this Twitter account has gained 76,000 followers in Liberia [37]. In Nigeria, Dr. Lawal Bakare, a Nigerian dentist, created an Ebola Alert on twitter with the hashtag #StopEbola and hosted #Ebolachat online discussions. The aim was to halt the spread of Ebola. The account got about 72,000 followers from all over the world already in 2014 [38]. Table 9.1 summarises the social media platforms used to provide behavioural change guidance and prevent the EVD spread in Liberia and Nigeria.

Table 9.1 Summary of social media platforms mentioned in the text

Country	Project	Social media tools	Number of users [source]
Liberia	U-report and Dey say	SMS	51,000 [9]
Nigeria	U-report	SMS	63,000 [31]
Liberia/Nigeria	BCC WhatsApp	WhatsApp	19,000 [36]
Liberia	UNICEF twitter @EbolaAlert	Twitter	76,000 [37]
Nigeria	Bakare twitter @StopEbola	Twitter	72,000 [38]

9.4 The Effectiveness of the Social Media Campaign in Liberia and Nigeria

This section presents results on the effectiveness of the social media tools towards providing behavioural change guidance and preventing the EVD spread in Liberia and Nigeria. The Liberian case reported in this paper is based on the March 2015 UNICEF-sponsored, comprehensive national study conducted by the Liberian Ministry of Health [32], on the Knowledge, Attitudes and Practices (KAP) on Ebola in Liberia. By the time of the study, EVD epidemic had been contained to minimum levels, though Liberia was not yet declared Ebola-free. Whereas the aims of the study were many, two major aims of the study are of significant interest to this paper, namely, determine the knowledge and awareness levels on EVD specifically on transmission, signs and symptoms, prevention and care. The second one was to determine sources of messages and information on EVD.

The Nigerian case is based on the November 2015 report of the Bureau of Public Service Reforms. The report uses both primary and secondary sources of data. It also draws on documentary sources to support and validate key evidence from primary sources. The report focuses on the lessons learned from Nigeria's strategy of EVD containment. It presents how Nigeria was able to rise to the critical challenge of containing the EVD spread regardless of ethnic, religious and political differences. The major question that the report addressed was 'How was Nigeria able to record a far lower fatality rate (36.8% with only 8 deaths in 20 confirmed cases) than the global average of 70% recorded by the WHO?' [26].

It should be noted that the two reports from Liberia and Nigeria are also supplemented with other literature for the present discussion.

The Ebola outbreak in West Africa and particularly in the three epicentres of Guinea, Sierra Leone and Liberia turned out to be a global health crisis, with the most affected, Liberia, succumbing to close to 5000 deaths from the epidemic. Many of the countries affected had and still have weak health systems, which were stretched to the breaking point. The health authorities had limited capacity to respond to the epidemic. There was also a widespread fear and misunderstanding about the nature of the disease and how to prevent it [33]. In fact, USAID [9] observes that the EVD epidemic widespread was greatly boosted by either misinformation or lack of information about critical aspects of the response, including Ebola transmission and prevention. Communication is a significant factor to public health delivery. The advances in digital media and communication technology hold important prospects for addressing major public health and development issues in Africa [9, 10]. Social media platforms such as Twitter, WhatsApp, Facebook, SMS, MMS, Instagram and YouTube accessed through mobile phones have now become indispensable for health literacy and overall improvement of health outcomes [10]. The findings (as presented in Sect. 9.3) indicate that a number of social media tools were deployed to fill the communication gap in Liberia. The *U-Report* and *Dey-*

Say Project, WhatsApp Ebola, Twitter initiatives and many others were deployed to provide behavioural change guidance and prevent the EVD spread Liberia. However, given the results of the survey carried out by the Ministry of Health in Liberia in 2015, there is no indication that social media was significantly responsible for closing the communication gap. The survey shows that only 7.9 per cent of the respondents attributed their behavioural change guidance to Social Media. Only 0.4 per cent received information from mobile phone/text messages. Yet, 93 per cent of respondents reported they first learned about Ebola through the radio, and about 80 per cent of the respondents listened to the radio almost every day. Radio, therefore, was the most common source of information on Ebola in spite of the fact that close to 65 per cent of Liberian households owned mobile phones and a slightly lower percentage (59 per cent) owned radios [30].

Whereas there is no indication in Liberia that social media influenced behavioural change guidance and prevented the EVD spread, in Nigeria, the tangible influence of the use of mobile social media in curbing the Ebola virus spread was felt. The November 2015 report of the Bureau of Public Service Reforms [26] to the Presidency in Nigeria indicated that the combined use of Facebook and Twitter and an Android app were instrumental in Nigeria's fight to contain Ebola. The report further reveals that social media campaign was very instrumental in reducing reporting times of Ebola infections by 75 per cent. Mobile phone technology accelerated access to health information as millions of Nigerians besieged social media sites such as Facebook, Twitter, WhatsApp, Messenger, WeChat, PalmChat, Bulk SMS, YouTube and Google+ via their mobile phones not only to learn more about the deadly disease but also to spread information about how to avoid infection [26].

Newbold and Campos [39] observe that a significant number of studies indicate that the dominance of one type of media is based on that outlet's ability to better reach consumers. For example, one intervention promoting glaucoma awareness among patients named radio as the most effective source of information that most people claimed to have gained glaucoma information from. In another study, different types of media were evaluated in the context of improved recall by consumers: it was found that TV and Internet sources are more likely to reach youth, while TV and radio messages can be more easily recalled by them later [40]. Newbold and Campos [39] observe that the low adoption rates of social media as a health communication tool in some cases (we note the one in Liberia, occurring after Newbold and Campos's literature survey) may partly be due to the lack of evidence about how effective communication based on social media is for public health purposes. There are a number of reasons that may have rendered social media insignificant in providing behavioural change guidance and preventing the EVD spread in Liberia. Some of those reasons are discussed below.

9.5 Why the Use of Mobile Social Media Failed in Liberia and Succeeded in Nigeria

9.5.1 Limited Information and Misinformation

At the beginning of the Ebola scourge, both accurate and inaccurate information was disseminated through public media and social media campaigns. The dissemination of incorrect and misleading healthcare messages complicated social learning by inculcating anxiety [33]. There was a huge qualitative shift in local populations' perceptions of the truthfulness of public health messages disseminated by the media and social media [41]. These inaccurate messages created inaccurate perceptions. A good example of such a misleading message was that taking bath with salty water would prevent Ebola infection. This message was proposed by a Nigerian traditional king of Igala Kingdom. He said that saltwater baths are the '*magical prescription*' for Ebola. Twitter was flooded with posts about how people should both bathe and gargle with the solution [2]. The claims became so lush that the World Health Organization (WHO) pinned a tweet on its official page debunking the rumour [2]. The other false message was that properly cooked bush meat is not a threat. This led some communities to believe that avoiding bush meat, or properly cooking it, was more important than not touching victim dead bodies [2, 41].

To make matters worse, there was poor coordination among the various groups struggling to contain Ebola spread in Liberia. NGOs, government offices, traditional leaders and religious figures sometimes disseminated conflicting and divergent advice and recommendations [31]. This made the population believe in all sorts of rumours. This conflicting information could have led to many people in Liberia to believe, for example, that taking saltwater bath could prevent Ebola spread. According to the study carried out by the Ministry of Health in Liberia [32], 33 per cent of Liberians still believed that EVD could be spread by mosquito bites, and 26 per cent still believed that the EVD could be prevented by bathing in salt and hot water. These kinds of responses were received from the population one and a half year after the EVD had been contained. In Nigeria, the Ministry of Health, together with WHO, developed and disseminated scientifically proven information, education and communication (IEC) materials that built awareness and knowledge around Ebola. The team further developed official social media platforms, e.g., on Facebook, Twitter and Ebola Alert websites that were an integral part of the outbreak response. These official social media sites disseminated scientifically proven information and dispelled all sorts of wrong information that circulated in the public [26]. The question that we pose in this section is that why did the Nigerian public listened to official information while the Liberian public did not? The following section will point to one additional answer besides the already mentioned poor coordination in Liberia.

9.5.2 Lack of Government Trust

The misinformation or lack of information on Ebola prevention discussed above was further escalated by the mistrust of government. The Liberian government, which was relatively transparent in acknowledging the disaster scale, was heavily accused by its citizens for exaggerating the situation to get more aid [8]. Despite pledges by political parties to depoliticise the issue, deep political divisions and distrust between communities and between citizens and government were strong in Liberia. This hampered faster response towards EVD, particularly in opposition areas. These areas had very high distrust towards the central authorities and did not trust any government messages received through SMS and other platforms [4, 33]. A survey conducted by researchers affiliated with International Growth Centre, a United Kingdom-based research agency, in late 2014 interviewed about 1500 residents living in the capital city, Monrovia. The study ultimately confirmed that a universal distrust of the Liberian government was '*associated with lower uptake of EVD preventative measures and lower support for control policies'* [19]. Perceptions of corruption within the government contributed to credence to conspiracy theories. Some Liberians concluded that Ebola was a government scheme to attract funds from international donors; such people were citing the country's heavy reliance on foreign aid, which accounts for 73 per cent of Liberia's gross national income in 2011 [42, 43]. In contrast, in Nigeria where the fight against Ebola was highly successful, the readiness by top-level government leadership to demonstrate strong, effective and decisive leadership at the crisis moment was vital. Top government leaders built public trust and upheld it throughout the Ebola epidemic period. The leadership coordinated a joint response at the national and sub-national levels and ensured that all relevant stakeholders supported the strategic containment plan [26]. A Strategic Command Centre (SCC) was set up to serve as an engine room for the Ebola national response. The SCC not only was responsible for providing coordinating mechanism for prevention, surveillance, patient care, tracking, data analysis and containment of the spread of the virus but also facilitated the coordination of partners, serving as a platform to connect the medical community, both across the country and internationally [26].

9.5.3 Technology Penetration

In the last decade, there is no doubt that both public and private sectors in Liberia have made great strides to improve the telecommunication sector. For example, by 2014 mobile penetration in Liberia was at 69 per cent, 65 per cent of Liberian households owned mobile phones and 59 per cent of Liberian households owned radios. Despite the advances made, communication abilities in Liberia remained limited in both capacity and reach. For instance, there is only 25 km of fibre optical cable enabling high-speed Internet. Internet was extremely slow in the capital Monrovia, and it was virtually unavailable in all areas outside the capital. Sometimes, phone calls could not get through for hours. Text messages sometimes were delivered days later. Mobile money transfers took almost 1 week to process [30]. So, even when 65 per cent of Liberian households owned mobile phones, only 7.9 per cent learnt of Ebola from messages sent on their mobile phones. Reports of degrading telecom infrastructure, including long latency between short message system (SMS) texts and poor voice quality greatly lead to the low contribution of mobile technology towards curbing the spread of Ebola virus. As stated earlier, many scholars do concur with the assertion that the digital media and majorly social media were primarily responsible for significantly curbing the Ebola virus spread in Nigeria. At the time, Nigeria had over 114 million mobile phone subscriptions and 56 million regular, but mostly mobile, Internet users and active social networks, which played a significant role [27]. While the percentage of mobile users in Nigeria is slightly lower than that in Liberia, the latter country's problem with the telecommunication indicates that the Nigerian Internet spread is not necessarily a sine qua non for emergency health information via social media. Indeed, in a USAID 2016 report, Fast and Waugaman [9] recommend governments, mobile network operators (MNOs) and regulatory bodies to increase reliable telecommunications network access in emergency situations. This will facilitate rapid collaboration with key actors and support the deployment of ICTs during an emergency response.

However, as the dissemination of correct information and correction of false information definitively plays a decisive role in changing people's mindset and behaviours, it is important to consider alternative ways of communication, both for broadcasting and for 'social' communication, i.e., within social groups. As the Liberian case shows, a telephone network may be overloaded in times of crisis. Typically, this occurs in regions with weak Internet infrastructure.

9.5.4 Re-thinking Mobile Social Media

In contrast to the mobile networks and Internet network discussed so far, it is interesting to consider also ordinary radio from the 'mobile' perspective. HC3 reports about its activities in Liberia that '*Radio was a critical channel for SBCC [Social and Behaviour Change Communication] messages during the Ebola outbreak. HC3 produced six radio spots about Ebola in partnership with the Ministry of Health that aired in 18 local languages on 32 radio stations throughout the country'*. [12] Similar statements are made in [9]. This information can be used to illuminate a debate within the M4D community (Mobile for Development) whether or not there is a need for a particular focus on mobile devices among the ICTs in poor countries [44]. In his 2015 book *After Access. Inclusion, Development, and a More Mobile Internet*, Jonathan Donner [45] argues that 'M4D' be treated as just one aspect of 'ICT4D'. However, it should be noted that the whole book has a bias towards Internet as the obvious 'next step'. To better see the multitude of opportunities for developing mobile social media in resource-constrained regions of the world, one should contrast such Internet fatalism with the RootIO project reported by Mukundane and Csikzentmihályi [46], where low-power FM stations had been installed at four locations in Uganda, providing for dissemination of very local contents in local languages. For instance, local advertisements were made possible by the existence of local FM stations. What is more, this micro-local approach to FM radio even provided for discussion, not only dissemination, of local contents because listeners could call in to comment or ask for help. Many listeners in fact use their mobile phones for listening to radio. Thereby it is natural for them also to participate in radio programs.

This combination of low-power FM and GSM telephones provides for a social media of relevance for the discussion earlier in this chapter. Observing that the mobile phone as an object possesses other features than mere 'digital connectivity' (SMS and the 'ultimate' Internet access), will make it possible to observe and invent uses of the trivial features afforded by loudspeaker and microphone. At the same time, it should be noted that Mukundane and Csikzentmihályi identify several weaknesses of their system: '*However, FM radio and GSM networks in rural settings are exposed to relatively weak revenue basis, unreliable power supply and shortage of skilled labor*' (p. 167). They discuss solar power, voluntary worker, centralised technology platforms and also the problem that regulatory frameworks are not geared towards community-based FM stations. To this can be added in the present discussion, that misinformation, as the one exemplified by a Nigerian traditional king on the protection provided by saltwater baths, is not silenced by an FM + GSM media mixture. Re-actions will still be needed. Listeners have to report rumours, and local stations will have to be willing to give airtime to claims countering local potentates. Early engagement of local leaders is also a must [31]. The data from Liberia indicate it would be feasible in emergency cases to use ordinary (national and regional) FM to comment on local misinformation, or even to temporarily broadcast on future local stations' frequencies in order to quickly reach communities with relevant information. (One caveat though, Schriber notes '*Citizens spoke 30 languages, whereas public officials spoke mainly in English, and radio broadcasts did not mirror the country's full linguistic spectrum*' [31] (compare the quotation from HC3 [12] above).

Whatever the exact mixture of actions to be taken in a certain situation, the above discussion clearly indicates one thing: one must try to expand the connotations of the term 'social media' in order to reach people in less digitally connected areas of the world.

9.6 Conclusion

Sub-Saharan Africa is the most vulnerable region in the world. When a disaster occurs in this region, it turns out to be catastrophic in many cases. The 2014–2015 EVD epidemic in West Africa is already a classic case. The epidemic, within 6 months of its breakout, had quickly degenerated into a development crisis. The EVD epidemic was so spiteful that it claimed 11,315 lives and had an almost 40 per cent killing rate.

Four major factors exacerbated the EVD epidemic in West Africa.

- First, there was very little information about critical aspects of the response, like EVD transmission, case notification, infection control options, geographic spread and health service availability.
- Second, even the little information available about EVD spread and prevention was inaccurate. Inaccurate information such as 'taking bath with salty water would prevent Ebola infection' created inaccurate perceptions.
- Mistrust of government messages. The high fatality of the EVD in Liberia was associated with lower uptake of EVD preventative measures and lower support for control policies.
- The telecom infrastructure in Liberia remained limited both in capacity and reach to the extent that an SMS message could take hours to reach the recipient.

Therefore, this information gap created a conducive environment for the highly contagious epidemic. This communication gap presented a huge challenge to Liberian government and the international community. In an attempt to close the communication gap, millions of dollars were invested in social media technologies to provide behavioural change guidance and prevent the EVD spread Liberia.

While numerous studies have shown that social media technologies have demonstrated fundamental shifts in filling in this communication gap, there has been very little evidence on the effectiveness of social media technologies in providing behavioural change guidance and preventing the EVD spread in Liberia. The available literature demonstrates that the role of social media in providing behavioural change guidance and preventing the EVD spread in Liberia was insignificant. Even when 65 per cent of the Liberians owned mobile phones, only 7.9 per cent learnt of Ebola from messages sent on their mobile phones. In contrast, radio played a key role played as the first and most widespread source of information on Ebola. We connected this observation with the non-Internet social media attempted by the RootIO project in Uganda. The *omnipresent* mobile phone makes it an excellent receiver for radio programmes in local languages. Moreover, the possibility of listeners to call into the station makes this a kind of social media, a real community media if the stations are equipped with cheap low-power FM transmitters that only serve a rather limited area. On the other hand, this does not in itself solve the problem with inaccurate advice in early stages of a disaster. But it would provide a means to quickly reach people, catch misconceptions and develop local discussions around urgent topics.

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Chapter 10
Prevention, Early Detection, and Treatment of Cervical Cancer in Sub-Saharan Africa (SSA): A Mobile Social Media Approach

Emmanuel Eilu and Rehema Baguma

Abstract The cancer epidemic causes more deaths in developing countries than the more hyped HIV, malaria, and TB combined. Sub-Saharan Africa has the highest prevalence of cancer in developing countries, and the most prevalent type of cancer is the cancer of the cervix, with 57,381 deaths yearly. Many medical scholars agree that the high death rate from the cervical cancer scourge is preventable with effective cervical cancer control strategies such as appropriate prevention strategies in the form of awareness campaigns, effective screening for early diagnosis, and treatment programs. There have been numerous calls for measures that can improve prevention, early detection, and treatment of cervical cancer among women in Sub-Saharan Africa, and numerous approaches have so far been piloted. This paper presents an analysis of the potential of social media technologies to effectively support prevention, early detection, and treatment of cervical cancer in Sub-Saharan Africa.

10.1 Introduction

For the last 10 years, communicable diseases such as Ebola Virus Disease (EVD), malaria, and HIV/AIDS have been the major challenge to the health sector in many Sub-Saharan African countries [1]. Over 70 percent (about 24.7 million) of people living with HIV in the world are from Sub-Saharan Africa (SSA), with about 1.5 million new HIV infections, and 1.1 million AIDS-related deaths every year [2]. Furthermore, close to 90 percent of the yearly Malaria cases in the world are from Sub-Saharan Africa [3]. The outbreaks of deadly virus causing epidemics are

E. Eilu (✉)
Uganda Christian University, Mbale University College, Mbale, Uganda

R. Baguma
Makerere University, Kampala, Uganda

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a common phenomenon in Sub-Saharan Africa. For example, the 2014 outbreak of the EVD epidemic in the three West African countries, Guinea, Liberia, and Sierra Leone, was the deadliest and the most complex and challenging Ebola outbreak in recent history, which claimed 11,315 lives from about 27,000 infected and suspected cases [3–5]. Yet again, Sub-Saharan Africa continues to battle with frequent occurrences of other viral hemorrhagic fevers (VHF), such as Yellow Fever, Marburg Virus, Rift Valley Fever, or Congo-Crimean Hemorrhagic Fever Virus, and others [6].

The high prevalence of communicable diseases in Sub-Saharan Africa often highlights popular and repeated narratives in global health summits and conferences. However, whereas common knowledge within the global health fraternity constantly places communicable diseases such as Ebola, malaria, and HIV/AIDS at the forefront of raising money and supports efforts in both national and international settings, a disease that is yet to gain considerable attention for global health funding and advocacy is the cancer epidemic in Sub-Saharan Africa [1]. The cancer epidemic is not yet considered by many as a significant challenge in low-resource settings like Sub-Saharan Africa and needs urgent attention [1]. However, recent statistics have shown that this disease is swiftly becoming the next overwhelming hurdle, particularly for the under-resourced regions in the world. The cancer epidemic causes more mortalities and morbidities in developing countries than the more hyped HIV, malaria, and TB combined [1, 7]. Over 50 percent of all the new cancer cases worldwide are from developing countries [7]. Estimates from the International Agency for Research on Cancer (IARC) show that about 14.1 million new cancer cases were registered worldwide in 2012, and developing countries, inhabited by about 82 percent of global population, accounted for close to 60 percent (8 million) of these new diagnoses [8, 9]. Furthermore, out of the 236,000 women, who died from cervical cancer worldwide in 2013, about 90 percent of these women were in developing countries [10]. This shows that cancer is an emerging pandemic in developing countries and needs urgent attention. The next section discusses the state of cancer in the Sub-Saharan region.

10.2 Cancer in Sub-Saharan Africa (SSA)

Sub-Saharan Africa is the most hit region with the cancer epidemic in the developing world [11]. Studies have established that breast and cervical cancer in women and prostate cancer in men are the main causes of cancer deaths in Sub-Saharan Africa [9]. However, the most prevalent cancer in Sub-Saharan Africa is cancer of the cervix, or neck of the uterus, with 57,381 deaths, followed by breast cancer with 47,583 deaths, and then prostate cancer with 47,583 deaths as shown in Table 10.1.

Cervical cancer affects approximately 12 percent of the women population in the region. In 2013, 39 out of 48 countries, classified as part of the Sub-Saharan African region, identified cervical cancer as the most common cause of cancer-related death in women [9, 10]. Within the Sub-Saharan region, the Eastern Africa region, in

Table 10.1 Leading cause of cancer death in Sub-Saharan Africa and associated risk factors

Rank	Cancer	Mortality	Common risk factors
1	Cervical	57,381	HPV infection
2	Breast	47,583	Genetic predisposition, reproductive, patterns, alcohol and tobacco use, obesity, environmental contaminants
3	Prostate	37,802	Genetic predisposition, dietary patterns
4	Liver	37,353	Hepatitis B and C, alcohol use, schistosomiasis, aflatoxin contamination
5	Kaposi sarcoma	25,352	HIV infection

Source: IARC [12], American Cancer Society [9]; adapted from Olsen [1]

Table 10.2 Age standardized cervical cancer incidence and mortality rates by World area

Rank in the world	World area	Incidence per 100,000	Mortality per 100,000
1	Eastern Africa	34.5	25.3
2	Western Africa	33.7	24.0
3	Southern Africa	26.8	14.8
7	Middle Africa	23.0	17.0

Sources: Adapted from [8]

particular, has the world's highest occurrence and death rates for cervical cancer [11, 13]. The Eastern African countries, Zambia, Malawi, Mozambique, and Tanzania, have among the highest cervical cancer rates (50 cases per 100,000) worldwide [9]. Table 10.2 summarizes the incidence and mortality rate per 100,000 in Africa.

As seen in Table 10.2, the incidence and mortality rates are the highest in Eastern Africa compared to West, South, and Central Africa. Many scientists have associated the high prevalence of cervical cancer in the Eastern Africa region to a matching high prevalence of HIV/AIDS rates. HIV rates among women in Eastern Africa accounts for more than 50 percent of the total HIV infections in the region, and this has been reported to exacerbate the high prevalence of cervical cancer [2, 14]. There have been several other studies that have linked HIV infection and cervical cancer among women in Sub-Saharan Africa such as Bateman et al. [15] and Parham et al. [16]. As a result, cancer of the cervix is turning out to be an emerging major challenge for the health sector in Sub-Saharan Africa. Besides linking HIV to the high prevalence of cervical cancer in the region, the increased prevalence of cervical cancer has also been associated with the following factors: the ever-growing and aging population, increased prevalence of human papilloma virus and hepatitis B virus, as well as increased prevalence of key risk factors—including those associated with social and economic transition [9]. Despite the high prevalence of cervical cancer in Sub-Saharan Africa, the region seems to have inadequate capacity to curb the cervical cancer scourge as discussed in the next section.

10.3 The Challenges of Controlling Cervical Cancer in Sub-Saharan Africa

The huge cancer burden coupled with the weak health systems incapable of handling the disease burden has greatly aggravated the cervical cancer pandemic in Sub-Saharan Africa. Many women diagnosed with cervical cancer are incapable of accessing comprehensive cancer care simply because of poor cervical cancer control strategies [11]. Poor cervical cancer control strategies have led to very high incidence rates per 100,000. For example, the age-specific incidence rate per 100,000 in Malawi-75.9, Mozambique-65.0, Comoros-61.3, Zambia-58.0, Zimbabwe-56.4, Tanzania-54.0, Swaziland-53.1, and Burundi-49.3 [17]. This, therefore, represents a massive failure in Sub-Saharan African countries to implement a functional cervical cancer control strategy [1, 10]. Data from global cancer incidence, mortality, and prevalence (GLOBOCAN portal) warn that if preventive actions are not taken, the problem of cervical cancer in Eastern and Southern Africa regions will only get worse in the years ahead [15]. Many medical scholars agree that the high death rate from the cervical cancer scourge is preventable with effective cervical cancer control strategies, which include prevention in the form of appropriate awareness campaigns, effective screening for early diagnosis, and treatment programs [18, 19]. However, these three major cervical cancer control strategies are extremely inadequate in Sub-Saharan Africa as discussed in the next section.

10.3.1 Prevention (Awareness Campaign)

Whereas 90 percent of the world's cervical cancer deaths occur in Sub-Saharan African, cervical cancer is the most preventable of all the three most common types of cancers in the region [15]. As discussed earlier, a lot of urgency is usually given to communicable diseases such as Ebola, HIV, malaria, and tuberculosis. This has created a lot of awareness about these communicable diseases. However, a number of scholars agree that there is very limited knowledge about the existence and prevalence of cervical cancer in Sub-Saharan Africa, and this is happening across different literacy levels [20–23]. A study carried out in Nigeria in 2000 revealed that out of the 500 attendees of a maternal and child health clinic in Lagos-Nigeria, only 4.3 percent were found to have some knowledge on the existence of cervical cancer [24]. Another study carried out in Lagos-Nigeria in 2004 revealed that out of the 139 patients with advanced cervical cancer, over 80 percent had never heard of cervical cancer [24]. The same trend is seen in Eastern Africa as reported by [11, 25, 26]. Recent studies carried out in Zambia, for example, showed that one of the biggest challenges in curbing the cancer scourge was lack of awareness and the motivation to access cancer services. Many of the participants in the survey wondered how the proposed project (a mass country wide screening initiative by the Zambian government in 2016) would create awareness among women to come forward for screening [11]. Limited knowledge about the existence of cervical cancer among the female population in Sub-Saharan Africa demonstrates the critical need for communication efficiency about the disease. There is a need for a better communication strategy to reach out to the population and educate them about the cervical cancer disease, the need for vaccination, and the significance of early diagnosis and treatment.

10.3.2 Screening for Early Detection

Sub-Saharan Africa has the world's lowest screening rates despite the availability of proven simple screening and treatment approaches to cervical cancer, and a majority of the few people who come for screening come in late when the cancer is in its advanced stages [11, 27]. In 2008, only about 1 percent of women in four West African countries had ever screened for cervical cancer, while in Nigeria, only 9 percent of healthcare professionals in two sampled healthcare institutions had ever administered a Pap smear [24]. It is further alarming that many of the women who turn up for screening came in late. For example, at the Ocean Road Cancer Institute in Tanzania, 91 percent of breast cancer patients were diagnosed with stage III or IV cancer [28], while in major cancer screening hospitals in Harare (Zimbabwe), 80 percent of cervical cancer cases are in advanced stages of the disease [11]. Yet, in regions, such as Europe and the United States, where cervical cancer screening is a routine care, research has shown that early screening prevents about 80 percent of potential cervical cancer mortalities [29]. The low screening rates in Sub-Saharan Africa are further aggravated by the limited availability of screening services especially in rural areas. The few that are available are only in urban centers. In 2006, there was only one pathologist, one colposcope, no cyto-technicians, and no facilities for cervical cancer screening or treatment in Malawi, a country which had 47 per 100,000 cervical cancer incidence rates of women by then [30]. Cervical cancer screening facilities in Sub-Saharan Africa are significantly inadequate, yet early screening is still the most viable way the high prevalence of cervical cancer in Sub-Saharan Africa can be curtailed. There are urgent calls for cost-effective cervical cancer screening methods [31].

10.3.3 Treatment (Adherence)

The cervical cancer advocacy efforts in low- and middle-income countries to date have arguably been heavily skewed toward prevention rather than treatment [1]. The management of invasive cervical cancer continues to be a major challenge in many Sub-Saharan African countries due to, among others, poor follow-up, as many of the women who get the disease are poor, live in distant villages, and find it difficult to travel to the urban center hospitals for follow-up after initial treatment [24]. Yet, WHO standards on cervical cancer recommend successful screening programs of above 80 percent coverage, appropriate follow-up, and management of patients with positive tests [19].

However, there have been numerous calls for measures that can improve prevention, early detection, and treatment of cervical cancer among women in Sub-Saharan Africa [11, 15, 26]. Numerous approaches have so far been piloted, and one of the approaches that have registered some success is the use of Social Media Technologies (SMTs) to provide the much-needed awareness and knowledge for the prevention, early detection, and treatment of cervical cancer among women in Sub-Saharan Africa. However, the scale of usage is still very low yet with the considerable ownership and growing use of smartphones in Sub Saharan Africa; this technology has a great potential to provide the much-needed knowledge and awareness about prevention, early detection, and treatment of the disease. The next section discusses social media technologies and their potential toward the prevention, early detection, and treatment of cervical cancer in Sub-Saharan Africa.

10.4 The Potential of Social Media Technologies in Prevention, Early Detection, and Treatment of Cervical Cancer

Although Scott and Jacka [32] recognized that there is no single definition of social media, they attempted to define social media as *a set of Web-based broadcast technologies that enable the democratization of content, giving people the ability to emerge from consumers of content to publishers*. The American Academy of Pediatrics on the other hand defines social media as *any website that allows social interaction* [33]. The English Oxford Living Dictionary [34] defines social media as “*Websites and applications that enable users to create and share content or to participate in social networking*.” While there are many loose descriptions of social media, Schein et al. [35] observe that social media is fundamentally defined by its ability to provide an interactive environment for users, where there is a two-way communication and discussion, and users are encouraged to contribute content. The restriction to the Web in the definitions by Scott and Jacka [32] and by O’Keeffe and Clarke-Person [33] does not seem appropriate. Based on the definition from English Oxford Living Dictionary, this paper considers the following websites and applications as social media tools or technologies: Facebook, Twitter, WhatsApp, BlackBerry Messenger, WeChat, PalmChat, SMS (Short Message Service), MMS (Multimedia Message Service), YouTube, and Instagram to mention but a few. With over 1.7 billion Facebook users, 900 million WhatsApp users, 1.12 billion WeChat users, and 320 million Twitter users, using such popular platforms to foster prevention, early detection, and treatment of cervical cancer would have a wide reach to millions of people [36]. As McNab [37] noted that one fact sheet or an emergency message about an outbreak of an infectious disease can be spread through Twitter faster than any influenza virus.

Rapid advances in social media technologies are currently supporting a burgeoning number of novel clinical and public health initiatives in Sub-Saharan Africa. Several studies have shown that mobile communication technologies, Internet access, and more particularly social media have demonstrated fundamental shifts in filling the communication gap in the health sector [38–40]. The increased access to the Internet and mobile communication technologies like smartphones, laptops, and digital personal assistants combined with strategic uses of social media like SMS, Facebook, WhatsApp, Instagram, and many others can bring public health information to many more people, more quickly and directly than at any time in history [37]. There is evidence throughout Sub-Saharan Africa, and beyond that, the exciting innovations in social media applications are occurring across the cancer spectrum, from primary prevention and early screening to treatment, survivorship, and end-of-life care in a number of Sub-Saharan African countries [11, 41–43]. For example, in regard to prevention by creating awareness about a particular disease, studies outside Sub-Saharan Africa also show promising results in using social media technologies in improving awareness and fostering early screening. A study carried out in the United States to test the feasibility and efficacy of a culturally tailored mobile health intervention designed to increase knowledge about, intent to obtain, and receipt of the HPV vaccine. In a quasi-experimental research design, a 7-day text message on HPV intervention was sent to 30 Korean-American women. The results of the study demonstrated substantial increases in knowledge of HPV with an intent to get vaccinated, and 30 percent of participants received the first dose of the HPV vaccine within 1 year [44]. Another survey conducted among an African diaspora in a high-income country revealed that there was a substantial readiness from users to receive information on cancer prevention and awareness delivered via SMS, WhatsApp, or Twitter on their mobile phones [45]. Social media technologies could also be used to create awareness about the different primary preventions measures such as healthy lifestyles, abstinence and safe sex, cessation of smoking, and HPV vaccination [19]. In 2014, 28 articles on the use of mobile applications in educating people on cancer prevention and management were identified and reviewed. The findings showed that cancer patients who engaged with health professionals using their mobile applications demonstrated increased understanding of both the importance of self-monitoring and knew how and where to seek medical assistance if needed [46]. In regard to early disease diagnosis, a feasibility study in Uganda demonstrated that it was possible for a trained pathologist to make an accurate diagnosis from images sent via MMS [47]. Images taken from a mobile phone have been proven to be very useful for dermatological diagnosis. Preliminary studies in Uganda and Egypt have shown the possibility of using mobile phones to take skin infection images and then send them via MMS to an expert for analysis. This has improved diagnostic rates of dermatological conditions [48, 49]. However, although MMS have significantly aideddiagnosis of cervical cancer (with an average specificity of 82 percent), larger scale studies are still needed. In regard to treatment adherence, successes of using social media technologies to foster adherence have also been reported. For example, appointment and adherence SMS messages saw a significant adherence improvement mostly among TB patients in Malawi [31], and text messaging for treatment adherence with or without the use of smart pillboxes has been reported in Mozambique [50]. Generally, SMS-based reminders have been proven to reduce patient appointment nonadherence by 40 percent [51]. Reviews of clinical trials of SMS appointment reminders carried out in 2012 and 2013 concluded that the intervention is moderately effective in improving attendance [52]. From the findings, this paper would be right to state that the use of social media technologies such as SMS text messages can potentially increase the adherence rate to an average of 82 percent.

However, throughout the literature, there is very little empirical evidence on the extent to which social media technologies have leveraged prevention, early detection, and treatment of cervical cancer among women particularly in Sub-Saharan Africa. Yet, social media technologies have a great potential in raising awareness of cancer risks and symptoms, preliminary diagnosis by health workers, clinical appointment management, and diagnostic follow-up [53]. Although there are a few individual case studies done, they are isolated and do not provide a good overall picture on how social media have leveraged prevention, early diagnosis, and treatment of cervical cancer in Sub-Saharan Africa. There was a need to provide an overall assessment on the extent to which social media has leveraged prevention, early diagnosis, and treatment of cervical cancer in Sub-Saharan Africa.

Therefore, this paper presents the extent to which social media technologies can leverage the prevention, early detection, and treatment of cervical cancer among women in Sub-Saharan Africa.

10.5 Methodology

This paper used a systematic review of literature on the use of social media in prevention, early detection, and treatment of diseases in general and cervical cancer in particular to establish the potential social media can offer to prevention, early detection, and treatment of cervical cancer in Sub-Saharan Africa. A systematic review was the main method used in this paper. In 1984, Cooper [54] proposed a five-stage systematic review process that was followed in this chapter’

- Problem formulation—Statement of objective
- Data collection—An unbiased literature search
- Data evaluation—Assessing the studies for inclusion in the review
- Public presentation—Discussion and context of findings

The strength of systematic review method lies in using empirical evidence to establish what works and how it worked [55, 56]. The systematic review method has been extensively used in medical research and the natural sciences. It is commonly used by international agencies such as the Australian Agency for International Development (AusAID), the UK's Department for International Development (DFID), and many others directly or indirectly by individuals or organizations contracted to do research on their behalf with the sole aim of finding what works and how it worked in generating development outcomes [55]. The purpose of the systematic review carried out in this paper was to establish the extent to which use of social media technologies can support the prevention, early detection, and treatment of cervical cancer among women in Sub-Saharan Africa.

Data collection: An extensive and unbiased literature search was conducted on the extent to which social media technologies can leverage the much-needed services in the areas of cervical cancer prevention, early diagnosis, and treatment in Sub-Saharan Africa, and the likely challenges of deploying social media technologies in fighting cervical cancer in the region. The review covered reports, journals, conference proceedings, books, and Web sites. Google Scholar and PubMed journal sites were of much help for this review.

About 52 journal/conference/book chapters/articles on topics related to the use of social media in the prevention, early detection, and treatment of diseases in general and cervical cancer in particular were selected for the review. The review included two papers on the use of social media technologies to support the prevention (creating awareness) of cervical cancer in Sub-Saharan Africa, with five supporting papers (on the use of social media technologies to support awareness in other diseases); three papers on the use of social media technologies to support early diagnosis of cervical cancer in Sub-Saharan Africa, with five supporting papers (on the use of social media technologies to support early detection in other diseases); and one paper on the use of social media technologies to support treatment (adherence) of cervical cancer in Sub-Saharan Africa, with four supporting papers (on the use of social media technologies to support treatment in other diseases) (see the Appendix for details). About 33 research articles were removed because they were found to be irrelevant. The remaining 20 (six papers on the use of social media technologies to support the prevention, early detection, and treatment of cervical cancer in Sub-Saharan Africa and 14 supporting papers) were reviewed.

Data evaluation: Khan et al. (2010) observe that selected papers for a systematic review must be subjected to a more refined quality assessment procedure. This can be done through general critical appraisal guides and design-based quality checklists. In this paper, we used a simple data extraction table to organize the information extracted from each review (e.g., authors, country, publication year, study design/number of participants, the technology used, and the outcomes of these study). The findings of the review are presented in the next section.

10.6 Finding from the Systematic Review

10.6.1 Prevention (Awareness Campaign)

Throughout the search for scientific literature, very few published papers were found on the use of social media technologies in creating awareness about cervical cancer in Sub-Saharan Africa. However, this paper managed to identify two published papers as presented below.

In an attempt to raise awareness of cervical cancer and dispel myths, misconceptions and advocate for early screening, the Tanzania Youth Alliance (TAYOA) in partnership with the Ministry of Health and Social Welfare (MoHSW) deployed a free SMS and toll-free helpline service to raise awareness about cervical cancer and the importance of early screening nationwide. About 41,751 SMS subscribers were registered, and a total of 843,496 text messages were sent out. In addition, 22,172 calls were made during the pilot scheme. Each subscriber received 20 text messages for a period of 20 days (at least one text message a day). As a result, the total number of women who had a screening visit as a result of receiving a text message was 9,247, representing about 22 percent of SMS subscribers [57].

Another study was conducted in Kenya, in 2012, to establish the extent of mobile phone and Internet used by cervical cancer patients would increase access to information related to cancer treatment and management. The study recruited 205 participants, and about 96.5 percent ($n = 192$) of the participants owned mobile phones. The participants were asked to give their opinion on how mobile phones could be used in cancer management. About 31.7 percent ($n = 63$) of the participants recommended that educational messages via SMS text should be sent through their mobile phones [58]. Table 10.3 summarizes the cases studies from Tanzania and Kenya.

10.6.2 Screening for Early Detection

The scarcity of literature suggests that the application of social media technologies in cervical cancer screening is still in its infancy [59]. A few Sub-Saharan African countries are currently piloting the use of social media-based technologies to foster early screening as presented below.

Table 10.3 Social media technologies used in creating awareness for cervical cancer

Author	Country	Year of publication	Social media technology used	No of participants	Outcome/Response to screening (%)
Ndakidemi [57]	Tanzania	2014	SMS	843,496	22
Kivuti et al. [58]	Kenya	2012	SMS	205	31.7

In Botswana, a pilot study was conducted with about 95 HIV-positive women in Gaborone. Visual inspection of the cervix with the application of 4 percent acetic acid (VIA) was performed among 95 participants, and the images of the cervix were then taken using a mobile phone camera and sent via MMS to an expert gynecologist. The expert received the pictures and made definitive positive or negative reading based on the PIA results. The average specificity of all the 95 readings was 82 percent. Hence, social media technologies may be useful in improving access to cervical cancer screening for women in remote areas utilizing the VIA 'see-and-treat' method [43].

The Zambian program called electronic cervical cancer control (eC3) uses a digital camera to capture images of the cervix (Cervigrams). The images are then shared via MMS with remote experts based in tertiary hospitals in Lusaka for consultation and further diagnosis. One of the goals of eC3 is to bridge the gap between screening and diagnosis in order to facilitate screen and treat model thereby minimizing the loss of patients to follow-up [16]. The program was found to be successful with an average specificity of 83 percent and was rolled out to the other parts of Zambia. An evaluation of the initiative was carried out in 2013 which found out that a total of 102,942 women had been screened for cervical cancer in Lusaka alone through the initiative. This represented a 95 percent screening uptake by the women who were offered the chance to screen [11].

A similar successful approach (using eC3 and digital cameras) to the Zambian model was also piloted in Madagascar. The study in Madagascar recruited 332 women for the exercise. To improve VIA screening performance, digital images of the cervix were taken after acid acetic application (D-VIA). The aim of this study was to evaluate the use of a smartphone for on- and off-site D-VIA diagnosis. The study found out that the on-site physician had a sensitivity of 66.7 percent (95 percent CI: 30.0–90.3) and a specificity of 85.7 percent (95 percent CI: 76.7–91.6). The off-site physician on the other hand who received images on MMS had consensus sensitivity of 66.7 percent (95 percent CI: 30.0–90.3) with a specificity of 82.3 percent (95 percent CI: 72.4–89.1) [42]. Table 10.4 summarizes the cases studies from Botswana, Zambia, and Madagascar.

Table 10.4 Social media technologies used in cervical cancer screening

Author	Country	Year of publication	Social media technology used	No of participants	Outcome/ Specificity rate (%)
Quinley et al. [18]	Botswana	2013	MMS	95	82
Owuor et al. [29]	Zambia	2016	MMS	102,942	83
Catarino et al. [42]	Madagascar	2015	MMS	332	82.3

Table 10.5 Social media technologies used in adherence for cervical cancer

Author	Country	Year of publication	Social media technology used	No of participants	Adherence rate (%)
Karanja	Kenya	2015	SMS	286	67.1

10.6.3 Treatment (Adherence)

There is very little evidence on the use of social media technology for cervical cancer patient follow-up and adherence [11, 60]. However, a study conducted by Karanja [60] gives, to some extent, clear results on the effectiveness of social media technologies in fostering cervical cancer patient follow-up and adherence. Karanja [60] accessed the use of mobile phone short text message service in enhancing cervical cancer screening in the Thika Level 5 Hospital; four SMS reminders were sent to women on the next cervical cancer screening dates. The study revealed that, out of the 286 recruited participants, 67.1 percent of the participants in the intervention group re-attended to schedule repeat cervical cancer screening compared to only 20.3 percent in the control group. The study concluded that the re-attendance for cervical cancer screening as scheduled was found to be eight times more likely when SMS reminders were sent [60]. Table 10.5 summarizes the study conducted in Kenya.

10.7 Discussion

Whereas there is scientific literature on the use of social media technologies to leverage disease prevention, diagnosis, and treatment in Sub-Saharan African, much of the literature focuses on Ebola, HIV, malaria, and TB. The literature on the use of social media to combat cervical cancer in Sub-Saharan Africa is still limited in many respects. More so, many of these initiatives are still being piloted. Therefore, there is a need for full scales, enabling more rigorous experimental and quasi-experimental studies to be undertaken in order to strengthen the evidence base [61]. Furthermore, the variety of social media technology that has been so far used in the prevention, early detection, and treatment of cervical cancer has so far been limited to SMS and MMS, yet there are more social media technologies with more useful functionalities like interaction one on one or as a group; easier sharing with other individuals or groups; safe storage of messages; and better multimedia capabilities like sharing video, audios, and pictures. Hence, there is need to explore the potential of these too.

However, the reviewed studies present a promising role of the use of text SMS and MMS in cervical cancer prevention, diagnosis, and adherence in Sub-Saharan Africa as exemplified by the two successful cases under prevention, three successful cases under early detection, and one successful case under treatment.

10.7.1 Prevention (Awareness Campaign)

It is unfortunate that 90 percent of cervical cancer infections and deaths are found in Sub-Saharan Africa cervical cancer, yet, cervical cancer is the most preventable of all the three most common types of cancers. However, social media technologies can be leveraged as prevention tools. From the studies, there is evidence that the appropriate use social media technologies can help prevent cervical cancer by creating awareness about the existence of cervical cancer, the importance of routine screening and change of behavioral life styles. From the findings, an initiative by TAYOA in Tanzania on the use of SMS messages to encourage women to screen for cervical cancer saw over 9000 women (22 percent) who had registered for the initiative participate in the cervical cancer screening exercise. Likewise, in Kenya, 31.7 percent of the participants in the study recommended receiving educational SMS messages on their mobile phones. From the findings, the use of social media technologies to promote awareness has been found to encourage routine cervical cancer screening by an average of 28 percent. Generally, successful trials on the use of social media technologies to create awareness about cancer in developed country setting have been done, and this kind of initiative has seen information delivered by SMS increase in female screening rates by 23 percent [62]. When using social media technologies to create awareness among the population, it is important to note that, it is not the social media channel which will be successful but the effect the message it contains has on the recipient. It is therefore important that message content itself be tailored appropriately—if the health awareness initiative using social media technologies is to be successful in promoting awareness cancer prevention and self-management.

10.7.2 Early Detection/Screening/Diagnosis

Social media technologies have also been deployed to aid early screening of cervical cancer. Promising levels of accuracy have been reported. From the findings, an initiative in Botswana, Zambia, and Madagascar was taken where the images of the cervix are taken using a mobile phone camera during the screening process and then sent via MMS to an expert gynecologist who makes diagnosis with a specificity of 82 percent in Botswana, 83 percent in Zambia, and 82.3 percent in Madagascar. Using social media technologies to transmit images for remote expert analysis and interpretation could be a perfect solution to shortages of specialist physicians in developing countries [61]. Studies have established that smartphone cameras have adequately high resolutions that make it possible for an expert to see key infectious agents and hematological signs [61].

10.7.3 Treatment (Adherence)

In cervical cancer treatment, social media technologies are majorly deployed in follow-ups and adherence. From the findings, SMS text messages sent to cervical cancer patients to remind them of scheduled appointments have been piloted in Nigeria and Kenya. SMS message reminders enabled 67.1 percent of cervical cancer patients to honor their appointments in Kenya.

This paper, therefore, concludes this discussion with the following observations. First, there is a significant contribution of social media technologies toward leveraging the prevention, early diagnosis, and treatment of cervical cancer in Sub-Saharan Africa and is substantial as seen in Kenya and Tanzania (prevention/awareness), Botswana, Zambia, and Madagascar (diagnosis) and Kenya (treatment). Second, it should be noted that the most widely used form of social media technology for prevention, early diagnosis, and treatment of cervical cancer in Sub-Saharan Africa is SMS text messaging and MMS. Finally, as future research, there is a need to conduct a systematic review of the challenges of using social media technologies in the prevention, diagnosis, and treatment of cervical cancer in Sub-Saharan Africa.

10.8 Conclusion

There is evidence that social media technologies have been useful in improving prevention (encouraging routine screening by 28 percent), early detection/diagnosis (specificity of 82 percent), and treatment of cervical cancer in Sub-Saharan Africa (improving adherence rate by 67.1 percent). From the findings, the most commonly used social media technologies for preventing, diagnosing, and treating cervical cancer are SMS text messaging for prevention and treatment and MMS for diagnosis. Other forms of social media are rarely used despite their potential. Whereas there are very limited scientific studies on the use of social media technologies to prevent, diagnose, and treat cervical cancer in Sub-Saharan Africa, substantial studies have been conducted on their use in the prevention, diagnosis, and treatment of other communicable diseases like HIV, malaria, and TB [63]. Therefore, cervical cancer researchers and practitioners have an opportunity to leverage the potential of social media technology in its application to prevention (health awareness campaigns), diagnosis (interpretation), and treatment (appointment tracking and follow-up, patient reminders) in other diseases. The current initiative on the use of social media technologies to prevent, diagnose, and treat communicable diseases like HIV, malaria, and TB in Sub-Saharan Africa allows replicability and avoids the need to reinvent the wheel.

A.1 Appendix

Strategies	Papers (use of SMT in cervical cancer)	Supporting papers (use of SMT in other diseases)	Other literature
Prevention (creating awareness)	Ndakidemi (2014) [57] Kivuti et al. (2012) [58]	Lee et al. (2014) [62] Lee et al. (2016) [58] Schoenberger et al. (2014) [45] Jordaan et al. (2016) [19] Davis and Girvan (2014) [46]	Buga (1998) [21]; Ajayi and Adewole (1998) [20]; Walker et al. (2002) [22]; Wellensiek (2002) [23]; Anorlu et al. (2003) [24]; Anorlu (2008) [64]; Gichangi et al. (2003) [25]; Kidanto et al. (2002) [26]; Owuor et al. (2016) [11]; Kamara (2015) [38]; Neuhauser and Kreeps (2010) [39]; Waters (2011) [40]; McNab (2009) [37]; Olsen (2016) [1]; Karanja (2015) [60]
Early screening/diagnosis	Owuor et al. (2016) [11] Catarino et al. (2015) [42]	Charles et al. (2014) [61] Tuijn et al. (2011) [47] Tran et al. (2011) [48] Fruhauf et al. (2013) [49] Misrahi (2017) [65]	Mwanahamuntu et al. (2011) [27]; Owour et al. (2016) [1]; Anorlu (2008) [64]; Finocchario-Kessler et al. (2016) [29]; Denny et al. (2006) [30]; Louie (2009) [66]; Owuor et al. (2016) [59]
Treatment (adherence)	Karanja (2015) [60]	Ndakidemi et al. (2014) [57] Davey et al. (2012) [50] Downer et al. (2005) [51] Dey (2014) [52]	Olsen (2016) [1]; Anorlu (2008) [64]; Owuor et al. (2016) [11]; Karanja (2015) [60]

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Chapter 11
Assistive Mobile Technologies for Health Monitoring and Brain–Computer Interface for Patients with Motor Impairments

Raluca Maria Aileni, George Suciu, Victor Suciu, Jean Ciurea, and Pasca Sever

Abstract This book chapter presents the importance of mobile solutions based on body sensor network (BSN) architecture for health monitoring in case of motor-impaired people. In this work, we present a noninvasive system based on mobile technology that allows biomedical signal monitoring by wearable electrodes. The concept of brain–computer interfaces (BCIs) is the ultimate trend for the entertainment industry (gaming), but this technology has potential by providing signal alerts to motor-impaired people (epilepsy or to enable communication). The mobile technologies allow developing the private cloud for tracking data from biomedical sensors and temporary data storage. Motor impairment is total or partial loss of function of a body part that can be translated to muscle weakness, lack of muscle control, or total paralysis. In case of people with motor impairments, monitoring at home involves a monitoring system based on body sensor network (BSN), Internet of Things (IoT), and feedback from doctors. Such a system may lead to reduced costs of hospitalization.

11.1 Introduction

Motor impairments are generated in several neurological disorders, such as cerebral palsy, Parkinson's disease, spinal cord injury, muscular dystrophy, cerebrovascular accident (CVA), sclerosis, and dystonia that affect body movement, muscle control,

R. M. Aileni (✉) · G. Suciu · V. Suciu · P. Sever
Politehnica University of Bucharest, Faculty of Electronics, Telecommunication and Information Technology, Bucharest, Romania

J. Ciurea
Neurosurgery Department, Bagdasar-Arseni Hospital, Bucharest, Romania

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muscle coordination, muscle tone, reflex, posture, and balance. Motor-impaired people have walking, running, grasping, and handwriting disabilities.

In such cases, hospitalization is very expensive and must be adopted as alternative self-monitoring systems based on BSN and IoT in order to reduce the hospitalization costs, to prevent the negative events (e.g., to avoid falling of the patient), and to alert the doctor in emergency situations. In our case, *things* are interconnected sensors integrated in wearable devices. These wearable devices are useful for people with disabilities and motor or visual impairments, and they allow interaction with the environment using specialized assistive technologies (ATs) to interface information and communication technology (ICT) by standardized human–computer interface (HCI).

For understanding the role of the human brain in motor impairments, it is important to know that the nervous system acts in the same way as a kernel for an operating system, taking the control of metabolic processes and the body by maintaining homeostasis. In human body, the nervous system has the major roles in:

- Monitoring internal/external environment
- Processing sensory information
- Directing and coordinating the responses of the organ to the sensory input [1]

Moreover, the nervous system is similar to a decision support or an expert system by coordinating and establishing the conditions and events. According to PubMed Health, the nervous system is composed of many billions of neurons, and it has two parts, the central nervous system (CNS) and peripheral nervous system (PNS). The nervous system is voluntary and involuntary. The somatic nervous system controls the processes that we can consciously influence, such as the movement of the arms, legs, and body parts. The autonomic nervous system (vegetative nervous system) controls the processes in the body that we cannot consciously influence (breathing, heartbeat, blood circulation, metabolic processes). The autonomic nervous system is composed of the sympathetic nervous system and parasympathetic nervous system (Fig. 11.1).

Many scientific researchers [2, 3] have explored the brain neural interfaces in order to restore the functionality for motor-impaired people. By using invasive techniques, through a neurosurgical procedure that implants electrodes on the surface of the brain involved in motor function (primary motor cortex involved in generating neural impulses that control voluntary movement execution), brainwaves can be captured. The raw data from the brain must be amplified and filtered by signal preprocessing, in order to reduce the noise and be sent to a mobile device. In such a way, motor-impaired people can command objects in the environment (moving a wheelchair, writing something in the computer). This invasive system can provide an appropriate view of the brain activity, which can allow prosthetic limb applications that can restore control for many motor-impaired people. In addition, robotic devices such as exoskeletons can be used in rehabilitation exercises.

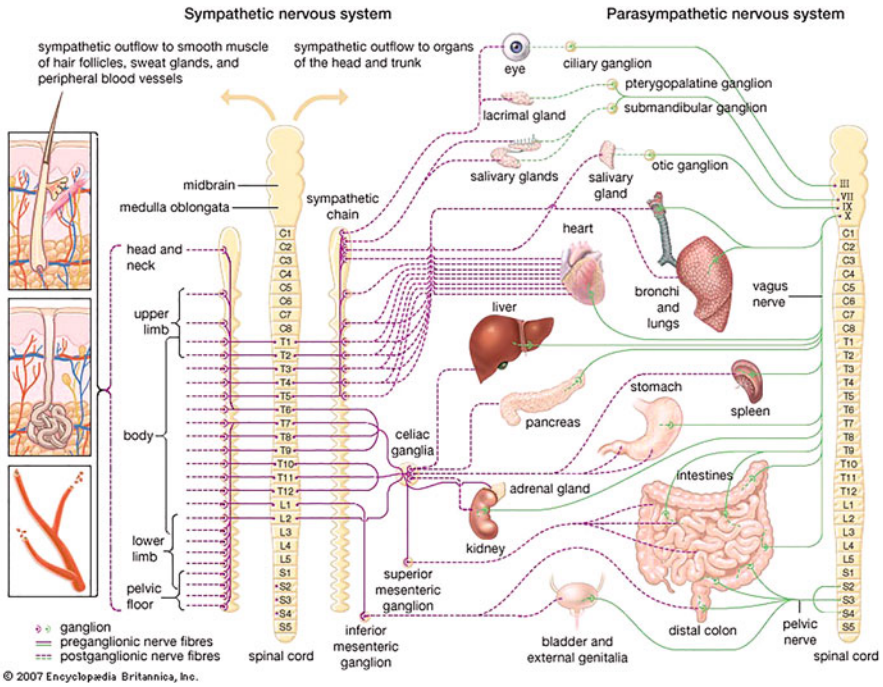

Fig. 11.1 Schematic representation of the autonomic nervous system, showing distribution of sympathetic and parasympathetic nerves to the head, trunk, and limbs. (Encyclopaedia Britannica, Inc. 2017©)

11.2 Physical Disabilities

Physical disability represents a limitation of the physical activity for a person due to the disorders or accidents. According to the World Health Organization [4], disability means impairments, activity limitations, or participation restriction and is a problem in body function and structure. In addition, disability includes the inability to communicate or to perform mobility, activities of daily living, or necessary vocational or vocational activities. According to the Williams College [5], a physical impairment means any physiological disorder or condition, cosmetic disfigurement, or anatomical loss affecting one or more of the following body systems: neurological, musculoskeletal, special sense organs, respiratory (including speech organs), cardiovascular, reproductive, digestive, genitourinary, hemic and lymphatic, skin, and endocrine. The condition for disability is to limit a major life activity. According to the National Institute of Neurological Disorders and Stroke [6], these effects can consist of the loss or the impairment of one's body part or function, such as experiencing difficulties in walking, standing, use of your hands or arms, sight, hearing, speech, breathing, bladder control, muscle control, sleeping, fits, and seizures or chronic tiredness. A physical disability could be genetic or developed before or during birth through an illness. According to the M&N Healthcare [7], a physical disability may be visible, such as the loss of a limb, or not visible (epilepsy). People with physical disabilities may have a physical weakening, which has a long-term effect on their ability to carry out daily activities, while other limitations may include respiratory disorders, blindness, or epilepsy. The physical disabilities can have a temporary or permanent character. The causes of the physical disabilities are brain or spinal cord injury, spina bifida, cerebral palsy, cystic fibrosis, epilepsy, multiple sclerosis, muscular dystrophy, Tourette syndrome, and dwarfism. In function of the systems (neuronal, muscular, or skeletal) involved in development of the physical disability, there are musculoskeletal and neuromuscular disabilities [8]. According to the Handicaps Welfare Association [9], musculoskeletal disability is the impossibility to have distinctive activities associated with movements of the body parts due to muscular or bony deformities, diseases, or degeneration. The musculoskeletal disabilities are loss or deformity of limbs, osteogenesis imperfecta [10], and muscular dystrophy. In the case of neuromuscular disability, the patient cannot perform controlled movements of affected body parts due to the diseases, degeneration, or disorder of the nervous system. Neuromuscular disorders are cerebral palsy, spina bifida, poliomyelitis, stroke, head injury, and spinal cord injury. According to the National Institute of Neurological Disorders and Stroke [6], physical disabilities may cause difficulties with walking and mobility, sitting and standing, use of hands, arms, legs, sight, hearing, speech, breathing, bladder control, muscle control, sleeping, fits, and seizures or chronic tiredness.

Traumatic brain injuries are physical disabilities that occur through accidents, strokes, cancer, infections, degenerative neurological diseases, or lack of oxygen [10]. Brain damage could affect the cognitive, physical, emotional, and sensory functions of the brain, resulting in minor or physical disabilities that can be temporary or permanent [11].

Epilepsy represents the disruption of the activity of the brain, causing recurrent unprovoked seizures. The causes of epilepsy are not always known, but brain trauma, strokes, brain cancer, and drugs are thought to be important factors. Some people can control their convulsions with medication and live relatively healthy lives, while others may develop secondary physical disabilities due to brain damage caused by the seizures. However, the condition is not permanent for every person [12].

11.3 Motor Impairments Types

Motor impairment is defined as the impossibility to process movement, coordination, or sensation [13]. According to the Center for Persons with Disabilities, motor impairment can be generated by:

- Traumatic injuries (e.g., spinal cord injury, loss or damage of limb(s))
- Congenital conditions (e.g., cerebral palsy, muscular dystrophy, spina bifida)

- Diseases associated with the aging process (e.g., arthritis, Parkinson's disease, geriatric triad, multiple sclerosis, essential tremor)
- Other diseases (ALS (Lou Gehrig's disease))

Motor impairment is evident in neurological conditions such as Parkinson's disease, cerebral palsy, multiple sclerosis, and stroke [14]. According to the International Neuromodulation Society (USA) [15], an extreme form of motor impairment is represented by the locked-in syndrome, in which voluntary movement of the eyes or muscle control is lost, in the case of a person who keeps cerebral function. The syndrome is caused by damage to a part of the lower brain and brainstem, from a stroke or other insult. To restore functionality for severely motor-impaired individuals, scientists have explored neural interfaces. Implanted devices in the area of the brain's motor cortex sense brain states and the interpreted signals are transmitted to a computer. With training, users develop commands over objects in the environment, which could be applied to such essential efforts as communicating or moving a motorized wheelchair.

Spinal cord injury can generate paraplegia (paralysis of legs) or quadriplegia (paralysis of all four limbs). Hemiplegia is the loss of the use of the arms, torso, and legs, usually caused by spinal cord injury, especially in the fifth to the seventh vertebrae (Fig. 11.2). This level of paralysis is associated with the loss of sensation from the neck down. The spinal cord can become injured by road accidents, falls, or disease. About 51% of spinal cord injury cases are the results of accidents, while

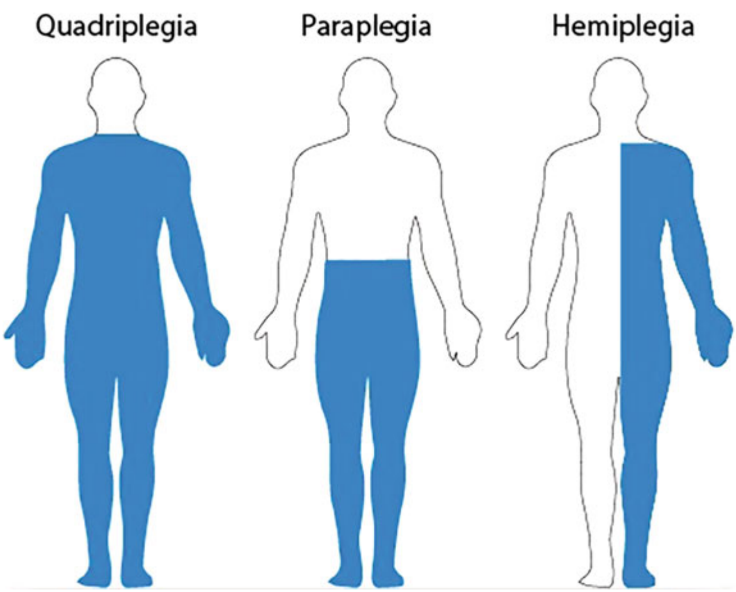

Fig. 11.2 Paralysis types in case of patients with spinal cord injury (WebMD) [19]

the remaining 49% being results of diseases. They affect the use of limbs, as well as cardiovascular and respiratory systems, bladder and bowel function, temperature, and sensory abilities [16, 17].

The *loss or damage of limb(s)* means loss of one or both arms/legs.

Cerebral palsy describes a loss of motor function that interferes with the way the brain controls the body's muscles resulting in speech, movement, and posture difficulties. It is caused by the abnormal development of the brain occurring while the child's brain is still developing before birth, during birth, or immediately after birth. However, this is considered a non-life-threatening condition, and children are expected to live well up to adulthood. According to WebMD [19], brain lesion is the effect of a one-time brain injury and will not produce any further degeneration of the brain.

Muscular dystrophy is a genetic disorder and consists in a progressive degeneration of the muscles due to the genes for muscle that are damaged. Muscular dystrophy is most common in children.

Spina bifida describes many different congenital disabilities that contribute to problems with the development of the nervous system and the spinal column. Spina bifida results from problems in the first month of pregnancy when the neural tube is developing. The severity of this disease often develops learning difficulties, mobility symptoms, paralysis, muscle wastage, scoliosis, and bowel and bladder symptoms.

Arthritis occurs in the elderly.

Parkinson's disease is a disorder of the central nervous system that generates uncontrollable tremors and/or rigidity in the muscles.

Multiple sclerosis is a disease caused by the eroded myelin and nerve fibers incapable of sending signals from the central nervous system to the muscles of the body. The symptoms are unpredictable and can vary in intensity. According to WebMD [19], multiple sclerosis is a progressive autoimmune disorder where protective coverings of nerve cells are damaged, causing diminished functions of the brain and spinal column. While some people only suffer from fatigue and numbness, severe cases can also cause paralysis, vision loss, and reduced brain function. It affects women twice as often as men, and symptoms are not necessarily common.

Essential tremor is a disorder that can generate uncontrollable tremors. Essential tremor most frequently affects the upper body, such as the hands, arms, head, and larynx (which makes the voice more difficult to understand).

Amyotrophic lateral sclerosis (ALS) is a neurological disease that attacks the motor neurons responsible for controlling voluntary muscles. Motor neurons serve as controlling units and vital communication links between the nervous system and the voluntary muscles of the body. In individuals with ALS, the motor neurons degenerate or die and do not send messages to muscles. If all muscles are affected, the patients lose the ability to move their arms, legs, and other body functions.

11.4 Technologies Used for Motor Impairments

Motor impairments come in many forms and can be classified as a loss or limitation of functions in muscle control or a restriction in mobility. This may include hands that are too large or too small for a keyboard, shakiness, arthritis, paralysis, and limb loss, among other difficulties.

According to the General Medical Council, UK [20], there is a wide range of assistive technologies available that should help with all these impairments:

- *Mouth stick* enables users to control input through a stick that they manipulate with their mouth.
- *Head wand* has a function very similar to that of mouth sticks, except that, in this case, the rod is strapped to the head.
- *Single-switch access* is for people with slow mobility. For example, if a person can move his head, a switch would be placed on the head allowing the click with head movements. This clicking would then be interpreted using different programs.
- *Trackball mouse* has the rollerball on top instead of beneath the device. Rather than moving the mouse to control movement, the rollerball is rolled. Some users find this easier to manage, and it works well when joined with other devices, such as head wands or mouth sticks.
- *Adaptive keyboard:* There is a wide range of alternative keyboards to help motor-impaired users, including compact, expanded, ergonomic, on-screen, concept, and rubber and ABC keyboards.

According to the WebAIM [21], a patient who has lost a limb will use the Internet without too much difficulty by a one-handed keyboard (Fig. 11.3). A patient who has lost both limbs should use other technologies (head wands, mouth sticks, voice recognition software, etc.).

Fig. 11.3 One-handed keyboard for people with limb loss [22]

- *Eye tracking:* Eye-tracking devices can be a compelling alternative for individuals with no control, or limited control, over their hand movements. The plot follows the movement of the eyes and allows the person to navigate through the web with only eye movements.
- *Voice recognition software:* This enables the user to enter text and carry out everyday computer tasks just by speaking into a microphone, without having to use a keyboard or a mouse. In case of text entry, the computer analyzes the user's voice, tries to recognize the words, and types them as he or she speaks.
- *Sticky Keys:* This enables to press a modifier key (SHIFT, CTRL, or ALT) that will remain active until another key is selected. This method is very useful for people who have motor impairments that make it difficult to press combinations of keys.
- *Slow Keys:* This is a keyboard feature that prevents keystrokes from registering until a key has been held down for a specified period. It is extremely useful for people with motor impairments that make it challenging to target keys accurately or that cause a random motion.
- *Wheelchairs* are devices that can be manually or electrically propelled; they include a system for seating, are designed to be a substitute for regular mobility, and are used by most people. This method allows people to perform movement which provides for feeding, toileting, dressing, grooming, and bathing. For this device, the human uses electrical controls to manage motors through a joystick or other devices. Sometimes, there are handles behind the seat for someone else to do the pushing or input devices for caregivers. People with both sitting and walking disability usually need to use a wheelchair or walker.
- *A walker* is a tool for disabled people who need additional support in order to maintain stability while walking. This consists of a frame which is approximately 12 inches deep and slightly fuller than the user. Walkers are also available for children or heavy people. Modern walkers are height-adjustable [23]. The front two legs of the walker could have wheels attached depending on the abilities of the person. It is common to see caster wheels or glides on the back legs of a walker with wheels on the front.
- *Prosthesis* represents a device that replaces a missing body part and can be developed by biomechatronics technologies. Biomechatronics uses mechanical and electronic devices for human muscle and nervous systems, in order to assist or enhance motor control lost by trauma or disease.

People with arthritis are able to use a keyboard and mouse, but they do not have a good hand control to click on small links, by using mouse or touch screens. According to the Center for Persons with Disabilities, people with arthritis do not use assistive technologies, but in advanced arthritis, people should use a trackball mouse, voice recognition software, or foot pedals [24]. According to WebAIM [25], assistive technologies, such as head wands, mouth sticks, adaptive keyboard, and voice recognition software, can help people with muscular dystrophy [26]. Patients with Parkinson's disease may not be able to use a mouse or keyboard. Assistive software based on voice control interface and video can be used for surveillance and user interaction with the environment or for multimodal transport.

11.5 System Structure Based on Sensors Networks and IoT for Disabilities

The Internet of Things (IoT) applications are challenged to be incorporated into assistive technology (AT) services. The utilization of sensors can be divided into two noteworthy classes: medical applications and nonmedical applications. Wearable devices are those that can be used on the body surface of a human or just at a close proximity of the user to measure temperature and monitor blood pressure, heart rate, respiration, etc. The implantable medical devices are those that are inserted inside the human body to monitor cardiac arrhythmia, brain liquid pressure, etc. So, population health improvements can be facilitated by embracing wearable medical devices. A sensor network connects sensors with one another and transmits signals [27]. Wireless sensor networks are ideal for remote monitoring and event detection in geographically large regions or inhospitable areas [28]. IoT applications perform specific functions, such as medical apparatus monitoring, informing a caregiver of the real-time medical condition of a person with disability, and analyzing environmental data collected from sensors [29]. An independent cloud-based platform environment for ATs is presented in Fig. 11.4.

The proposed IoT architecture from a technical perspective is shown in Fig. 11.4. It is divided into three layers.

- The basic layer and their functionalities are summarized as follows:
- Perception layer: Its main function is to identify objects and gather information. It is formed mainly by sensors and actuators and monitoring stations (such as cell phone, tablet PC, smartphone, PDA (personal digital assistant), etc.).
- The network layer transmits information obtained from the perception layer. The application layer sets off intelligent solutions that apply the IoT technology to satisfy the needs of the users.
- The perception layer provides to disabled people information concerning the environment. The components of this layer according to the disability of the person (visually impaired or hearing impaired) are described in the next section.

The invasive system visually impaired patients is based on components such as body nanoelectrodes and microelectrodes (sensors) and radio frequency infrared (RFID)-based assistive devices. These components are implanted to the brain. The implants of nano-sized components are powered by a special pair of activation eyeglasses. An essential RFID-based application is the navigation system. It helps blind people find their way in an unfamiliar area. RFID tags are distributed through the area. The RFID cane (see Fig. 5.1) has a tag reader with an antenna that emits radio waves; the tags respond by sending back their stored data, hence identifying

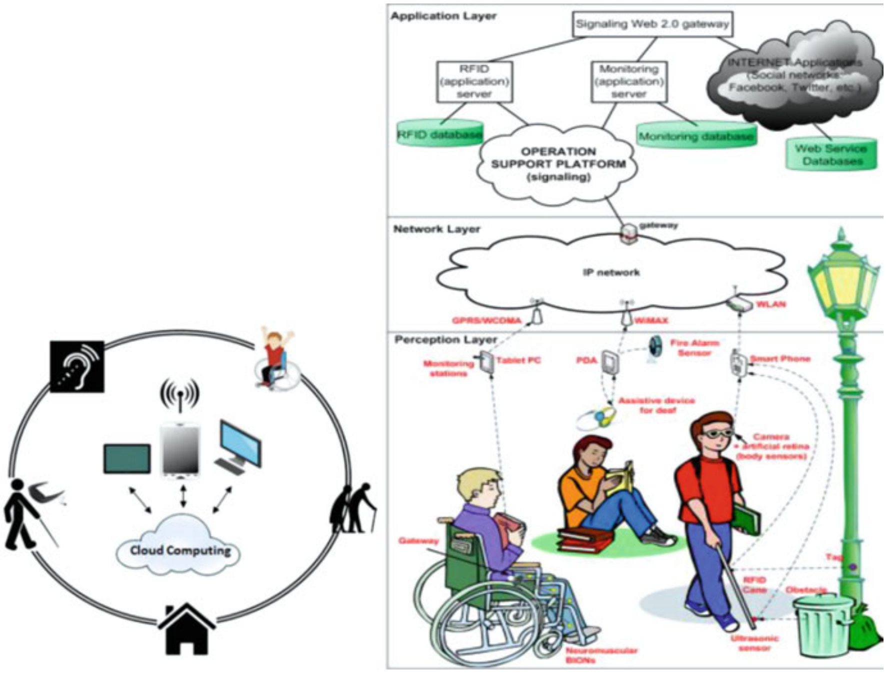

Fig. 11.4 Cloud-based platform architecture

the location of the blind person. The components designed for the hearing impaired are (1) assistive devices and sensors and (2) RFID-based devices. People who are hearing impaired can benefit from external or internal (implanted in the ear) assistive devices that improve hearing. Different types of sensors (such as doorbell or smoke detectors (Fig. 5.1)) detect events or malfunctions that give rise to alarm conditions. Consequently, an alarm signal is sent from the sensors to the monitoring station, which forwards it to the assistive device as an amplified alarm signal [30].

11.6 Brain–Computer Interface for Motor Impairments

As it was mentioned in the third chapter, motor impairments come in many forms. Patients with motor impairment can use event-related desynchronization (ERD)-based brain–computer interfaces (BCIs) as assistive technology [31]. One of those motor impairment forms refers to the persons with no control or with limited control over their hand movements. By using gaze, eye trackers enable users to communicate or control devices. A study [32] aimed at comparing an eye-tracking device with a switch scanning system; people diagnosed with amyotrophic lateral sclerosis (ALS) reported that the use of the eye-tracking device is easier to access. However, reaching Midas is a problem in using eye-tracking devices. Some researchers [32] conducted a study, which showed that the life of ALS patients improved significantly after using the eye-tracking device. They could communicate independently and easily. The system was not only used for face-to-face communication but also for emails or phone calls. A brain–computer interface (BCI) provides a direct connection between the brain and any device capable of receiving its signals. The P300 speller has been used by people with motor impairment [33]. This is an event-related potential (ERP) designed to reflect processes that are involved in the evaluation or classification of incentives and has a latency between 200 and 700 ms. P300 users are placed in front of a 6 x 6 alphanumeric array. Each row and every column flashes randomly, but at fixed intervals, and the user chooses the desired character by focusing on the corresponding cell. Focusing attention and random intermittent make the matrix cell a challenge stimulus that causes a response. The P300 speller also has applications in wheelchair control [34], real and virtual environments [35], browsing the Internet [36], and painting [37]. A comparison study [32] was conducted between the users who controlled a BCI and an eye tracker. Twelve people of German origin, including four women and eight men, participated in this study. Of these, 11 people were affected by ALS and 1 was affected by Duchenne muscular dystrophy. There were four sessions, two for BCI and two for eye tracker, where the participants performed the task of selecting a character three times in a row. In all four sessions, users used one of access technology and completed two questionnaires. On average, BCI sessions had a duration of 4 hours, and eye tracker sessions lasted for 2 hours. This difference was motivated by the need to prepare and calibrate electroencephalogram (EEG) and BCI. The duration of the session was also influenced by the time Speller asked to run one or more full cycles and matrix rows, unlike the eye tracker where users can select characters at their own pace. The equipment used for BCI was made up of an IBM Thinkpad laptop, used to collect data using BCI2000 software [38], an electrode head, more precisely Easycap GmbH, with 16 electrodes, and an impedance below 5 kΩ. The electrodes were connected to a 256 Hz amplifier. Calibration consisted of writing the same two words (Apfelkuchen and Goldfisch in German, which in English means apple pie and goldfish) by all 12 participants. The smallest number of sequences reached was five and the highest was eight. As far as the eye tracker is concerned, a SeeTech Pro with a 7×7 network was used, which is a binocular infrared system with a 32-sample camera. The grid has the role of capturing the look in a cell for better precision. A matrix like the Speller P300 was used to select the characters. The participants were able to select the desired character by fixing the target and closing their eyes for 1.5 s. The acquisition system of the eye tracker is different by BCI, even if for both cases (BCI and eye tracker), the screen was located at a distance of about 50 cm by the participant. For browsing the Internet, a newer version of the P300 Speller browser was used [36]. While loading a page, the browser automatically assigns an alphabetical code to represent the hyperlinks. Using the Speller, the user can select the codes for a particular hyperlink and thus explore the web pages. Verifying weather forecasts using an Internet browser was the first task assigned to the participants. They searched for the name of a German magazine and then asked them to select the section related to weather forecasts. They were then asked to read the legend at the bottom of the page, available down the page. To accomplish this task, a selection of at least 15 character selections was required. The second task was to look for an online encyclopedia starting from its home page. The participants searched for the brain term, checked the resulting page, and were asked to select the section about the human brain and scroll the page down. This task required a minimum of 11 selections. The third task was to play two songs on a music site starting from its main page. The participants searched for the Jazz term and produced a list of songs that can be played in 30 s. After selecting and listening to the sixth song on the list, they were asked to select the "Country" section and listen to the first track. This task required at least 14 selections. Bits per minute were used to compare the performance of BCI and eye tracker. Bitrate is a standard measure used in communications systems and represents the amount of information transmitted per unit time [39]. The SUS (*System Usability Scale*) scale was used for assessing the use of systems. This range of measurement varies between 0 and 100 units, where 70 units represent an acceptable minimum of utility [40]. NASA-TLX is a tool for assessing cognitive workload. NASA-TLX consists of several scales, namely, mental demands, physical demands, time requirements, performance, effort, and frustration, evaluated in two stages [41]. In the first step, the user has to assign a value to each scale, and in the second step, the user receives the results obtained by combining the six scales. The final score varies between 0 and 100, where 100 represents the highest workload experienced by the user. The relationship between functional status and performance was assessed using the ALSFRS (Amyotrophic Lateral Sclerosis Functional Rating Scale). This evaluation involves the appreciation of several functions such as speech, swallowing, writing, and walking. The final result varies between 0 and 48 points, where 0 represents major depreciation and 48 depreciations. All participants in the study used both BCI and eye tracker. The data transfer rate with BCI was 8.67 bits/min and the eye tracker was 12.87 bits/min. The result of the suspension test for BCI was 71.15 and the eye tracker was 78.54, the BCI score being superior to the other. But the results of the NASA-TLX show that it is a favorable eye tracker that has achieved a score of 49.75 units, compared to BCI by 49.75 units [32]. Age was not relevant in the study. It has been concluded that the longer the duration of the disease, the lower the BCI utilization and the higher the cognitive load of BCI. Finally, it has been shown that people with severe physical disabilities prefer eye trackers to visual BCIs, for their performance, usability, and required cognitive effort [32].

11.7 Future Challenges for Assistive Technologies

For a better integration of people with such disabilities, technology can be used in various ways. As mentioned before, wearable devices represent an intensely used and noninvasive solution. It can be implemented in order to guide users, to retrieve relevant data, and send it to a cloud. Thus, wearable sensors can be successfully used in Internet of Things (IoT) applications. Below are presented several possible concepts and future applications in order to help impaired people. According to the Center on Technology and Disability, USA, the solution for people with epilepsy [42] is that seizure activity could be monitored or even anticipated and the report could be sent to doctors and families, and the device could also call the ambulance. Also, the EEG PatchTM [43] concept represents a waterproof patch with two electrodes used for monitoring the patients and easily recording an electroencephalogram (EEG). It is a discrete and waterproof scalp-mounted device and only needs to be removed once a week, in order to recharge its batteries. Also, IoT can be used to make houses more comfortable for impaired people, by allowing them to turn on the lights or home appliances, such as the dishwasher or the washing machine, through Smart Home [44]. It makes possible turning off the lights using a virtual switch, monitoring power consumption, and switching off the ironing machine. Another smart solution is represented by the assistive robotics limbs [45] which are to be developed for situations in which a person cannot move because of damages of the nervous or muscular system, and neural communication cannot be established. It has adjustable elements and a detachable controller and is designed to be considered an operational medical device. Also, a person who uses a wheelchair is not always able to open doors and cannot open the wheelchair ramp when using a bus. People with reduced mobility often cope with transportation problems, as they need permanent assistance. A concept [46] which has been presented by a group of students seems to have a positive impact among researchers. The test pilot communication is based on Bluetooth: the device would be attached to a door's motor, in order to detect the user's smartphone and to be able to open the door automatically.

Talkitt [47] is a concept designed for speech-impaired people, while taking into consideration their need of being listened to and of being able to communicate with the loved ones. Talkitt is introduced as a mobile application which is able to give speech-impaired people their own voice. It features multiple languages and is compatible with devices such as smartphones or tablets.

Be My Eyes [48] is a mobile application through which blind people can ask for help. The application will connect them to volunteers from around the world, who can answer questions or can help the blind people explore the surroundings. For example, if a visually impaired person doesn't know how to get to a certain place, a volunteer can help them online. In addition to this, in order to help people with eyesight problems, researchers have launched *Dot Watch* [49], which is the world's first tactile smartwatch. It is a different way of receiving digital information, as users can learn how to read, check time, listen to music, or receive notifications.

The battery lasts for a week, and the smartwatch offers a variety of benefits, such as discretely reading messages. It has recently been launched, and it already has improvement points. Also, its developers plan to launch the Dot Mini, a tactile e-book reader for patients with visual impairments.

11.8 Conclusion

The sensor technology generates the Internet upgrade to the Internet of Things. These things (interconnected sensors integrated into wearable devices) are useful for people with disabilities such as motor or visual impairments. Moreover, these things allow the interaction with the environment using specialized assistive technologies to interface information and communication technology by standardized human–computer interface (HCI). The brain–computer interfaces (BCIs) are a challenge for the future solutions in restoring the functionality for motor-impaired people. The primary motor cortex is involved in motor function and has the role to generate neural impulses that control the voluntary movement execution. By using invasive techniques such as a neurosurgical procedure that implants electrodes on the surface of the brain involved in motor function, brainwaves can be captured. These invasive techniques can provide an appropriate view of brain activity, which can allow prosthetic limb applications that can restore control for many motor-impaired people. Also, robotic devices such as exoskeletons can be used in rehabilitation exercises. In conclusion, the assistive technologies such as BCI or HCI are based on multidisciplinary concepts from information technology (IoT), electronics and microelectronics, mechatronics, and bionics.

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Chapter 12
Mobile Solutions to Air Quality Monitoring

You-Chiun Wang

Abstract Air pollution is one of the most compelling global problems since it poses a serious threat on everyone's health. Governments and people thus put a premium on the reduction of air pollution in the living environment. Consequently, it draws considerable attention on how to efficiently collect air quality data, especially in cities. In the past, the job of air quality monitoring was usually conducted by installing a few monitoring stations on fixed locations. However, this scheme provides just coarse-grained monitoring, where the resolution of air-quality samplings may be poor. Even worse, it is difficult to move monitoring stations after installation, but the monitoring mission could be often changed. To deal with the problems, many studies propose various mobile solutions to air quality monitoring by equipping gas sensors on mobile devices or vehicles, which allow people to actively and cooperatively detect air pollution in their surroundings. In the chapter, we provide a comprehensive survey of these mobile solutions, and our discussion has four parts. First, we introduce the techniques to evaluate air quality, including an index to report the quality of air and models to predict the dispersion of air pollution. Then, we present the mobile solutions to collect air quality, which can be realized by pedestrians, cyclists, and drivers. Afterward, we discuss how to analyze raw data collected by smartphones, followed by the issue of reporting sensing data collected by cars. Some research directions and challenges for future mobile solutions to air quality monitoring will be also addressed in the chapter.

12.1 Introduction

Since the industrial revolution, numerous factories and vehicles have been discharging a large amount of exhaust gases and airborne contaminants to the atmosphere.

Y.-C. Wang (✉)
Department of Computer Science and Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan
e-mail: ycwang@cse.nsysu.edu.tw

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These air pollutants are harmful to humans, animals, and the ecosystem. The World Health Organization also warns that air pollution has become one of the most serious environmental health risks in the world [1]. Nowadays, people pay more and more attention to environmental protection and health, which prompts the governments and scientists to keep monitoring air quality in our living environment and strive to reduce air pollution.

A traditional solution to air quality monitoring is to install some large, expensive monitoring stations on the dedicated locations in a city [2]. These stations provide large-scale monitoring of air quality around their locations. However, the samples of air-quality data are pretty few, causing the resolution to be poor. Besides, it lacks flexibility to use static monitoring stations, since some sites chosen to install stations such as displaced plants or new parks may become redundant due to the development of a city. Unfortunately, these stations are not easy to move to support dynamic monitoring missions (e.g., to detect air pollution in a new industry district).

In recent decades, the rapid advances of microelectromechanical systems and wireless communication technologies have made *wireless sensor networks (WSNs)* become popularized [3]. A WSN is composed of many tiny sensor nodes deployed in a region of interest, where each node contains sensing modules to detect events and a wireless transceiver to send its sensing data to a remote sink [4]. Therefore, WSNs provide a cheap and convenient manner to monitor the physical environment. Many WSN applications have been also developed to enrich our life, from health care [5, 6] to intelligent buildings [7, 8], light control [9, 10], security surveillance [11, 12], and smart shopping [13, 14].

Thanks to their context-aware sensing capabilities, many studies adopt WSNs in the applications of air quality monitoring. For example, Tsujitaa et al. [15] use a WSN along with monitoring stations to increase samplings of air quality. Each sensor compares its sensing data with the data collected by neighbors and nearby monitoring stations, so as to calibrate its sensing module. Wang et al. [16] deploy a WSN to monitor the concentration of CO (carbon monoxide) and PM (particulate matter) pollutants. Sensors are powered by solar batteries for energy harvesting. Besides, they can turn off transceivers during a suspended period to extend lifetime. Penza et al. [17] install gas sensors on some positions in a city to measure the variation of CO, PM, H_2S (hydrogen sulfide), NO_2 (nitrogen dioxide), and SO_2 (sulfur dioxide) gases. The collected data are transferred to the format of *data quality objective* defined by European Directive [18]. Brienza et al. [19] develop a sensor suite for people to easily install gas sensors on their houses to monitor air quality in the community and share their monitoring data through social networking.

Introducing mobility to a WSN further improves its flexibility and allows it to conduct different missions such as moving sensors to replace broken nodes or dispatching sensors to analyze events [20]. *Mobile sensors* can be implemented by putting sensing devices on mobile platforms like smartphones, robots, or vehicles [21]. With the concept of mobile sensors, a number of researchers develop their mobile solutions to air quality monitoring, which allows pedestrians, cyclists, or drivers to carry sensors to measure air quality when they move in a city. Two interesting issues are also arisen from these mobile solutions. In particular, people may prefer using simple (and cheap) gas sensors or even inbuilt (non-gas) sensors on their smartphones to collect air quality. In this case, how can we estimate the concentration of monitoring pollutants by analyzing the raw data collected by these sensors? In addition, some mobile solutions are implemented by equipping gas sensors on cars to collect air quality in a city. Because the mobility of cars is usually uncontrollable [22], how can we make cars collect air quality on desired positions and report their sensing data accordingly?

This chapter gives a comprehensive survey of existing mobile solutions to the problem of monitoring air quality. It is organized as follows. In the next section, we give background knowledge of some techniques to evaluate air quality. Section 12.3 presents the mobile solutions to collecting air quality in cities. We discuss how to analyze raw data collected by smartphones in Sect. 12.4 and also how to report sensing data collected from cars in Sect. 12.5. Then, Sect. 12.6 addresses research directions and challenges. Finally, Sect. 12.7 concludes this chapter.

12.2 Techniques to Evaluate Air Quality

There are a number of common techniques to evaluate air quality and model air pollution. In this section, we first introduce the technique of *air quality index (AQI)* to measure the degree of air pollution. Afterward, we present the mathematical models used to simulate the dispersion of air pollutants. Among these models, we detail one popular dispersion model, called *industrial source complex (ISC3)*, to evaluate the effect of air pollution.

12.2.1 The AQI Technique

AQI provides an intelligible index to measure and report to the public how clean or polluted the air is during one day. We take AQI defined by the US Environmental Protection Agency (EPA) [23] as an example, whose range is within [0, 500]. It is divided into six classes, where each class is assigned with one color for ease of understanding, as presented in Table 12.1.

Table 12.1 Six AQI classes defined by US EPA

Class	AQI range	Dedicated color
Good	0–50	Green
Moderate	51–100	Yellow
Unhealthy for sensitive groups	101–150	Orange
Unhealthy	151–200	Red
Very unhealthy	201–300	Purple
Hazardous	301–500	Maroon

In addition, each AQI class is also associated with some health effects that people may experience when they are doing outdoor activities.

- **Good:** The air pollution poses little or no risk on health, so the outdoor air is basically safe to breathe.
- **Moderate:** Although the quality of air is acceptable, unusually sensitive people, for example, patients who have lung diseases, are suggested to reduce prolonged or heavy outdoor exertion.
- **Unhealthy for sensitive groups:** Most people are not likely to be affected by the air pollution, but members of *sensitive groups*, such as the elderly, children, outdoor workers, and patients with asthma, need to reduce prolonged or heavy outdoor exertion.
- **Unhealthy:** Members of sensitive groups should avoid prolonged or heavy outdoor exertion. Everyone else has to reduce prolonged or heavy outdoor exertion for health concern.
- **Very Unhealthy:** Members of sensitive groups have to avoid all outdoor exertion. Everyone else should reduce outdoor exertion.
- **Hazardous:** The government will announce health warning of emergency conditions. Everybody should avoid possible outdoor activities.

To compute the value of AQI, EPA suggests sampling five common kinds of air pollutants, including ground-level O_3 (ozone, measured in parts per million, which is abbreviated to "ppm"), CO (measured in ppm), SO_2 (measured in parts per billion, which is abbreviated to "ppb"), NO_2 (measured in ppb), and PM (measured in microgram per cubic meter, which is denoted by $\mu g/m^3$). In particular, for each air pollutant k, its AQI value A_k is calculated by

$$A_k = \frac{A_{\text{high}} - A_{\text{low}}}{B_{\text{high}} - B_{\text{low}}} \times (C_k - B_{\text{low}}) + A_{\text{low}}, \tag{12.1}$$

where C_k is the rounded concentration of pollutant k, B_{high} is a concentration breakpoint no smaller than C_k, B_{low} is a concentration breakpoint no larger than C_k, A_{high} is an AQI value corresponding to B_{high}, and A_{low} is an AQI value corresponding to B_{low}. The suggested values for breakpoints can refer to EPA's technical assistance document in [24]. To estimate the value of C_k, EPA suggests taking the average concentration of different pollutants as follows:

- O_3 (short term), SO_2, and NO_2: 1 h.
- O_3 (long term) and CO: 8 h.
- PM: 24 h.

The overall AQI value is the maximum value of A_k from all observing pollutants.

12.2.2 Air Pollution Dispersion Models

Air pollution is caused by the emission of pollutants such as particulates or harmful gases to the atmosphere from some sources. According to their dimensions, these emission sources can be divided into four categories. In particular, a *point source* has zero dimension (0D), where there is only one identifiable source which diffuses air pollutants. Examples of point sources include a single smokestack, a flue, or a furnace. On the other hand, a sequence of point sources together will form a 1D *line source*. One can image traffic congestion in a road, where each car is viewed as a point source, but they together form a line source. Then, an *area source* is a 2D plane on which air pollutants are emitted, for instance, methane gases diffused from a landfill. Finally, a *volume source* can be treated as an area source, but it has a third dimension (i.e., the height). One representative is the smoke emission caused by the forest fire in a mountain.

Given the emission sources in a monitoring region, there are five common mathematical models used to imitate the dispersion of air pollution in that region:

- **Box model:** This model considers a simplified environment, where the given volume of atmospheric air in the monitoring region is constrained to a box-shaped space. Based on the assumption that air pollutants are homogeneously distributed, the box model calculates the average concentration of pollutants in the space. Consequently, the box model cannot provide accurate estimation of air pollution dispersion due to its impractical assumptions.
- **Lagrangian model:** In the Lagrangian model, we assume that an observer follows along with the *emission plume* of air pollution, which is a flow of pollutants in the form of smoke or vapor discharged into the air. Suppose that the motion of each pollution plume parcel (i.e., a particle) complies with the random walk mobility model [25]. The Lagrangian model associates with a mobile reference system for particles to predict their trajectories when they move in the air. Then, the dispersion of air pollution can be estimated according to the statistics of moving trajectories caused by a great deal of particles.
- **Eulerian model:** The Eulerian model can be viewed as one variation of the Lagrangian model, where it also computes the moving paths of particles inside the emission plume of air pollution. However, this model considers that an observer is watching the emission plume of air pollution as plume goes by. Besides, instead of using a mobile reference system, the Eulerian model adopts a fixed 3D Cartesian coordinate system to track the trajectories of particles when they leave from their initial positions.
- **Dense-gas model:** As its name would suggest, the dense-gas model aims at simulating the diffusion of gas pollution plumes which are heavier than the general air (usually toxic gases such as the leakage of chlorine from a trunk). When a stream of dense gas is injected into the flowing air, it may produce a wide and flat plume at the ground level. There are many variations of this model, including ALOHA, HGSYSTEM, SLAB, SCIPUFF, PHAST, and TRACE. The work of [26] gives a comparison of these six variations in actual railcar accidents.

- **Gaussian model:** This model adopts a Gaussian distribution to evaluate the dispersion of air pollutants. In other words, the dissemination of pollutants has a normal probability distribution. The major application of the Gaussian model is to estimate the diffusion of continuous, floating air pollution plumes from ground-level or elevated emission sources. However, the Gaussian model can be also used to estimate the dispersion of noncontinuous air pollution plumes, which is usually called the *puff model*.

These dispersion models are useful for scientists to evaluate the effect of industrial districts on air quality or forecast AQI after some disasters, for example, haze and smog caused by a large-scale wildfire. Among these models, the Gaussian model is the most popular one to evaluate the diffusion of air pollution due to its flexibility.

12.2.3 The ISC3 Model

ISC3 ("3" indicates the version) is developed from the Gaussian model to evaluate both diffusion and sedimentation of pollutants in the air, which is able to estimate different types of emission sources including point, line, area, and volume sources discussed in Sect. 12.2.2. It can also deal with the separation of point sources. In addition, ISC3 is usually adopted to analyze some characteristics of air pollutants, such as settling and dry deposition of particles, effect of downwash, and limited terrain adjustment.

In ISC3, the concentration of air pollutants on a position (x, y, z) in the 3D space is calculated as follows:

$$\hat{C}(x, y, z) = \frac{\varphi \xi R V}{2\pi \mu_s \delta_y \delta_z} \times \exp\left[-0.5 \times (y/\delta_y)^2\right], \tag{12.2}$$

where φ is a coefficient used to convert the output into concentration, ξ is a coefficient of disintegration, which is used for certain pollutants with a half-life period (e.g., SO_2), R is the discharge rate of the pollutant (measured in grams per second), V denotes the reflection in the vertical direction, μ_s is the wind's speed (measured in meters per second), δ_y is the diffusion factor in the horizontal direction, δ_z is the diffusion factor in the vertical direction, and $\exp[\cdot]$ denotes the exponential function. In Eq. (12.2), we use parameter V to measure the pollutant concentration in the earth surface or the inversion layer of the atmosphere. Given the height H of an emission source, it can be derived by

$$V = \exp\left[-0.5 \times \left(\frac{z - H}{\delta_z}\right)^2\right] + \exp\left[-0.5 \times \left(\frac{z + H}{\delta_z}\right)^2\right]. \tag{12.3}$$

Figure 12.1 illustrates an example of ISC3, where the smokestack has a height of H and the wind blows along the x axis. In this case, the air pollutant spreads in

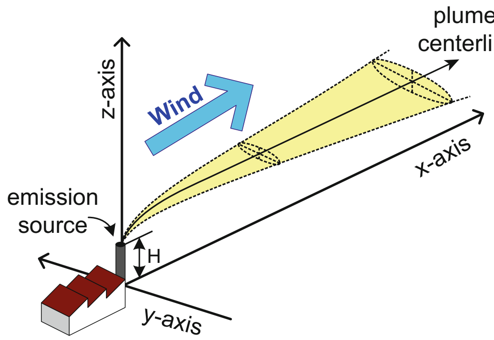

Fig. 12.1 An example of the ISC3 model

both horizontal and vertical directions, which depends on the parameters of δ_y and δ_z, respectively. The colored area points out the range of the emission plume of air pollution. It is worth of noting that the coefficients in Eqs. (12.2) and (12.3) will be determined by the weather and temperature. In addition, EPA suggests the minimum observing period of ISC3 to be 1 h.

12.3 Mobile Solutions to Collecting Air Quality

In this section, we discuss the mobile solutions to collecting air quality. Based on their collecting methods, we classify these solutions into three categories: *pedestrian-based*, *bike-based*, and *car-based* solutions. The pedestrian-based solutions ask pedestrians to carry smartphones along with gas sensors and walk in the monitoring region to collect air-quality data. On the other hand, bike-based and car-based solutions equip gas sensors and communication devices on bikes and cars, respectively, which support the collection of air quality in a much larger region. These solutions also have different mobility models [25]. Generally speaking, pedestrians may follow either random waypoint or reference-point group mobility models. On the other hand, the Manhattan grid model is suitable to depict the moving behavior of bikes and cars, as they usually move along roads and streets.

12.3.1 Pedestrian-Based Solutions

Many people choose smartphones as their major computing and communication devices. Smartphones are programmable, so most phone vendors provide their APP stores to allow developers delivering new applications to the public. Moreover, each smartphone can be viewed as a sensor suite, as it usually has accelerometer, camera, digital compass, GPS (global positioning system) receiver, and microphone. Therefore, a new sensing paradigm called *participatory sensing* [27] is proposed to allow people using smartphones to collect environmental information on their own. Based on the motivation, a number of studies develop their mobile solutions for pedestrians to collect air quality by their smartphones and exterior sensors.

Nikzad et al. [28] propose a participatory sensing system called *CitiSense*, which allows pedestrians to carry smartphones and wearable sensor boards to monitor air quality throughout one day, especially during times when exposure to air pollutants will be the highest, for instance, during a rush-hour commute. A lightweight sensor board that contains CO, NO_2, and O_3 detectors is developed for pedestrians to easily carry. It also includes weather-related sensing devices to monitor temperature, humidity, and barometric pressure. The sensor board can communicate with the user's smartphone wirelessly through Bluetooth, whose communication range is below 60 m (in Bluetooth version 4.0). Besides, an Android-based APP is developed to display the current air quality on the smartphone and also help the user post the collected data to social networks such as Facebook and Twitter. The APP reports the last estimated AQI along with the health-effect class presented in Table 12.1. Each sensor reading collected by the sensor board is tagged with the user's position gotten from GPS. However, since the GPS receiver is an energy-consuming module, it is used only when the user is moving. Moreover, CitiSense has a web interface to let users browse through the readings of air quality that they collected on any given day, which is displayed on the Google Maps. Each sensor reading is placed on the map as a color-coded and numbered marker, which are ordered by its monitoring time. Therefore, users can identify the hotspots of air pollution in locations where they passed through during the commute. A prototype of CitiSense was deployed in San Diego, California, USA, where 16 participators each had a commute journey for at least 20 min, and they were regular users of the same social network.

Yang and Li [29] develop a smart sensor system for air quality monitoring, where each pedestrian can carry a smartphone and a box of embedded sensors (called a *sensor unit*) to detect various air pollutants in the surroundings. The smartphone serves as the middleware between the sensor unit and the server. When a user wants to measure air quality, he/she can execute a specific APP installed on the smartphone, which triggers the sensor unit to detect air pollutants and report sensing data. The data of air quality will be immediately displayed on the smartphone, and the user can also feed back these data to the server. Afterward, the server manages the collected data and present the monitoring result of air quality through a map-based interface. In [29], the following sensors are included in the sensor unit to monitor different types of air pollutants:

- *PM sensor*, which detects particles in the size of around 1 micrometer (i.e., 10^{-6} m) in diameter, with the detection range from 0 to 1.4 mg/m^3;
- *CO sensor*, which can estimate the CO concentration from 20 to 2,000 ppm;
- *CO_2 sensor*, which measures the concentration of CO_2 (carbon dioxide) gas to at most 2,000 ppm, with the maximum inaccuracy of $\pm$50 ppm;

- *temperature and humidity sensor*, where the humidity measurement range is between 0% and 100% with at most ±2% error, and the temperature measurement range is between −40 and 80 °C with no more than ±0.5 °C inaccuracy;
- *hazard gas sensor*, which is used to detect noxious gases such as ammonia, benzene, nitrogen oxide, and smoke;
- *volatile organic compound (VOC) gas sensor*, which can detect acetone, alcohol, formaldehyde, methanol, nitrogen, styrene, sulfur, and toluene in the air.

With the hazard and VOC gas sensors, users can be warned in real time once they enter a region with high concentration of harmful gases. These sensors are coordinated by an ARM-based microcontroller, and their readings are transmitted to the nearby smartphone through a Bluetooth chip. Since all modules in the sensor unit are powered by small batteries, they usually stay in the sleeping state to save energy unless the smartphone sends a command to wake them up. A prototype of the proposed system was demonstrated in Prairie View, Texas, USA.

Dutta et al. [30] propose an *AirSense* system to let people participate in monitoring air quality in their neighborhood, which is composed of four tiers:

- **Crowd sensing tier:** Participators can carry both sensor suites and smartphones to collect air quality indoor and outdoor, which offers raw data to AirSense. They can also consume the service provided by AirSense (i.e., the analyzed result of air quality monitoring) through their smartphones.
- **Air quality sensing tier:** Each sensor suite sends the collected data to a nearby smartphone through Bluetooth. Instead of sending data periodically, the sensor suite reports its data only when there is a significant change in the measurement of sensor readings. Thus, the Bluetooth bandwidth can be saved accordingly.
- **Data forwarding tier:** Sensing data collected by smartphones will be transmitted to a cloud server via 4G or Wi-Fi connections. Since GPS receivers are the basic modules in most smartphones, these sensing data can be associated with the positions where they are monitored.
- **Data analysis tier:** The cloud server finally calculates the AQI value according to the collected data. It can also construct a pollution footprint for each participator, which is shown on the smartphone in the form of a mobile APP.

To implement the sensor suite, [30] adopts an Arduino board to integrate with multiple gas sensors to monitor PM, O_3, NO_2, and SO_2 pollutants and also a Bluetooth device for data transmissions. Arduino is an open-source, single-board microcontroller kits for developers to easily build digital devices and embed sensing modules [31]. On the other hand, a free cloud service provider, called OPENSHIFT [32], is used to manage and analyze the collected data. OPENSHIFT adopts MySQL as its database to store sensing data, where the identification of each sensor suite is selected as a primary key to query data. A prototype of the AirSense system was deployed in Kolkata, India, for demonstration.

12.3.2 Bike-Based Solutions

Since bikes provide better mobility than human walking and it is easy to ask cyclists to ride along the pre-scheduled routes, some researchers suggest putting multiple sensors and communication devices on bikes to collect environmental information.

Eisenman et al. [33] propose a *BikeNet* framework, whose objective is to use multiple sensors installed on each bike to gather quantitative data related to the ride of a cyclist. In particular, BikeNet provides two types of information collected from these sensors. One is the context in terms of the cyclist's performance, for instance, the riding speed, distance traveled, and calories burned by the cyclist. The other is about the environmental conditions for the ride, for example, the degree of air pollution, allergen, noise, and terrain roughness of the given route. To do so, each bike carries the following sensors and devices to conduct the monitoring job:

- *microphone*, which detects the surrounding noise;
- *magnetometer*, which detects the moving direction;
- *pedal speed monitor*, which is used to estimate the amount of calories burned by the cyclist;
- *inclinometer*, which measures the angle of slope;
- *lateral tilt*, which has the similar purpose of inclinometer;
- *stress monitor*, which detects the galvanic skin response;
- *speedometer*, which measures the moving speed;
- *GPS receiver*, which acquires the cyclist's position;
- CO_2 *meter*, which detects the potential air pollution.

These sensors and devices are wirelessly connected via ZigBee, whose physical communication range is around 10–20 m. In addition, cyclists carry smartphones with cameras to take snapshots from the surroundings and collect the readings from the sensors. There are multiple Wi-Fi and GSM (global system for mobile communications) base stations deployed along some pre-planned paths where cyclists will follow to ride. When a cyclist rides close to a base station, the smartphone transmits sensor readings and snapshots to the back-end servers for analysis. The analyzed data will be visually displayed on web portal. BikeNet aims at improving cyclist experience, but it also provides air quality monitoring. In particular, a CO_2 map of streets where a cyclist ever rode through is also shown on the web portal. The CO_2 map identifies the regions with high CO_2 concentration, which can be used to warn cyclists not to ride in these regions for health concern. A prototype of BikeNet was deployed in Handover, New Hampshire, USA, for demonstration.

Vagnoli et al. [34] also use bikes to develop a *SensorWebBike* framework for air quality monitoring, which is composed of three major components:

- *Arduino-based sensor platforms*, which are installed on bikes to monitor urban air quality and weather parameters;
- *GeoDatabase*, which is a database to store and manage the collected data;

- *web application*, which helps users view, query, and analyze the information of air quality.

In particular, SensorWebBike adopts an Arduino board to integrate multiple gas sensors to monitor different types of air pollutants, including CO, CO_2, O_3, NO_2, and CH_4 (methane). In addition, the Arduino board also contains noise, humidity, and temperature sensors used to collect the weather information. Participators can ride bikes equipped with the Arduino-based sensor platforms to collect the data of air quality and weather condition in a city and report their monitoring data through GPRS (general packet radio service) communications. The collected data are maintained by GeoDatabase, which follows the data format defined by the open geospatial consortium (OGC) for interoperability, where OGC is an international organization committed to making quality open standards for the global geospatial community [36]. Besides, the web application is developed by using Java2EE to provide the visualization of sensing data in GeoDatabase with multiple formats such as tabular, chart, and geographic map. SensorWebBike was adopted to monitor air quality in the city of Siracusa, Italy, as a case study.

12.3.3 Car-Based Solutions

In general, cars move much faster and in longer distances than pedestrians and bikes, and they can move in some regions where pedestrians or cyclists are prohibited to enter, for example, highways and freeways. So, it attracts attention to use cars as mobile platforms to carry sensors to conduct monitor jobs in urban areas [21]. Therefore, a number of studies also use cars for the application of air quality monitoring.

Hu et al. [35] develop a mobile solution by cars to monitor the concentration of CO_2 gas in urban areas, as shown in Fig. 12.2. Specifically, each car is equipped with four components: *CO_2 sensor*, *GPS receiver*, *GSM module*, and *Jennic board*.

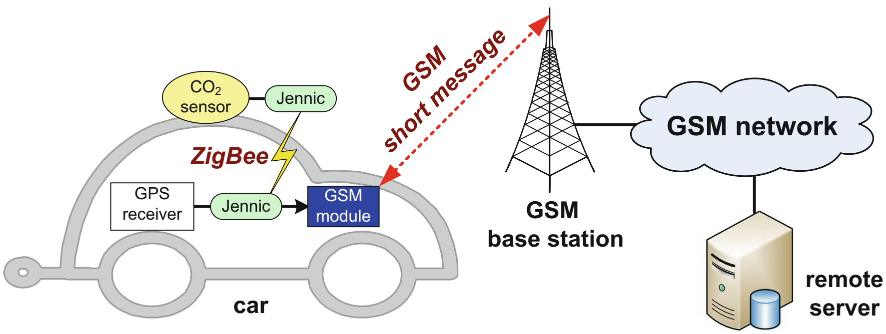

Fig. 12.2 The car-based mobile solution proposed in [35] for CO_2 monitoring

The CO_2 sensor is installed outside the car (e.g., the windscreen) to collect the surrounding CO_2 concentration. Both the GPS receiver and the GSM module are placed inside the car. The CO_2 sensor and the GPS receiver each connect with a Jennic board [37], which supports ZigBee communications. On the other hand, the GPS receiver adopts an RS232 interface to communicate with the GSM module. By combining the positioning information from the GPS receiver and the sensing data from the CO_2 sensor, the GSM module then periodically transmits the monitoring data to a nearby GSM base station through GSM short messages, which have the following data format [38]:

$$(6 - \text{bytetime}, 6 - \text{byteCO}_2\text{reading}, 11 - \text{bytelatitude}, 11 - \text{bytelongitude}).$$

For example, when the base station acquires a GSM short message of "(151055, 000405, 2447.3630N, 12060.8732E)," it points out that a car detects the CO_2 concentration of 405 ppm on the geographic location of 2447.3630 degrees north latitude and 12060.8732 degrees east longitude at time 15:10:55 (in the format of hour:minute:second). A 16-node prototype was implemented to monitor CO_2 concentration in Hsinchu City, Taiwan. The monitoring result was presented on the Google Maps, on which each dot indicated the location where a car collected sensing data and its color showed the range of detected CO_2 concentration.

Sivaraman et al. [39] propose a HazeWatch project that targets at fine-grained spatial measurement of air pollution by cars in Sydney, Australia. In HazeWatch, a driver can choose to mount either a cheap but simple metal oxide sensor or an expensive but sophisticated electrochemical sensor on the car to collect the concentration of CO, NO_2, and O_3 pollutants. Moreover, some commercial monitors which provide more accurate detection of the pollutants are installed on the roadside to calibrate the readings of sensors on cars. On the other hand, HazeWatch relies on the GPS and 3G capability of smartphones to report positions and sensing data to the server, where the collected data from sensors are transmitted to the smartphone via Bluetooth communications. The server software is composed of three layers:

- **Database layer:** It stores sensing data and provides a simple interface to extract and filter these data. The database layer is implemented by MySQL.
- **Model layer:** This layer gives an abstraction of the collected data, which can return the data of air quality from any location in the monitoring region.
- **Web-server layer:** The layer presents the data (from the model layer) to users, which is displayed in the form of web pages and maps.

However, it is infeasible to collect air quality on every point in the monitoring region, so two interpolation methods are used by the model layer to estimate the value of air quality on those points without actual sensing data. The *inverse-distance weighting method* estimates the pollutant's concentration on a point by assigning weights to all neighboring points, where a point farther away from the interpolation point has a smaller weight. On the other hand, the *kriging method* is based on the calculation of the empirical semi-variogram over the data, where variogram is usually used to describe the degree of spatial dependence of a spatial random field or stochastic process. This method can be implemented by clustering pairs of data points into bins that have similar distances and plotting the semi-variance of each bin as a function of distance which corresponds to that bin. Then, the interpolation weights are estimated by solving a system of linear equations derived from these bins. The kriging method is more complicated, but it provides more accurate data estimation than the inverse-distance weighting method, especially when the points with actual sensing data are sparsely distributed in the monitoring region.

Devarakonda et al. [40] propose two mobile sensing models to use cars for air quality monitoring in a city:

- **Public transportation infrastructure:** In this model, buses are used as a mobile platform to collect air quality, where they will periodically move along the fixed routes (usually along high-volume roads). To do so, each bus is installed with a mobile sensing box, which contains an Arduino board to integrate with multiple devices including a 3G communication module, a GPS receiver, a CO sensor, and a dust sensor (to monitor the PM pollutant).
- **Social community-based sensing:** Drivers can install a personal sensing device on their cars and register to participate in collecting air quality. The personal sensing device has a CO sensor, and it can communicate with the driver's smartphone through a Bluetooth link.

All collected data are geo-tagged (by the GPS receiver in a mobile sensing box or a smartphone) and sent to a central server through the cellular network. Afterward, the server translates these sensing data to AQI values and adopts two user interfaces, *maker map* and *heat map*, to display the degree of air pollution on a web page. The maker map is composed of data makers, each corresponding to a location where the sensing data are collected. When the user clicks on a data maker, it will show the related information such as the monitoring time, GPS coordinates, and pollutant concentration. On the other hand, the heat map illustrates all available measurements with gradient color display, where higher pollutant concentration is represented by higher-ranked color in the color spectrum. The proposed system was demonstrated in two US cities to monitor the CO pollutant, including Turnpike, New Jersey, and Staten Island, New York.

12.3.4 Discussion

Table 12.2 compares the mobile solutions discussed in Sect. 12.3. Because most smartphones have Bluetooth modules, many solutions choose to use the Bluetooth protocol for sensors to transmit their sensing data to nearby smartphones. However, both [33, 35] adopt the ZigBee protocol for sensors and devices to communicate with each other, while [34] integrates all sensors into one single board. Unlike the bike-based or car-based solutions, pedestrians usually carry small batteries as the power supply for sensors and smartphones. Therefore, energy is a critical concern in the pedestrian-based solutions. To save energy of devices, [28] turns on the GPS

Table 12.2 Comparison on the mobile solutions to air quality monitoring

Mobile solution	Collecting method	Device link	City for demo	Energy saving	APP	Map	AQI	Air pollutants				
								CO	CO_2	NO_2	O_3	PM
[28]	Pedestrians	Bluetooth	San Diego	✓	✓	Google	✓	✓		✓	✓	
[29]	Pedestrians	Bluetooth	Prairie View	✓	✓	Google		✓	✓			✓
[30]	Pedestrians	Bluetooth	Kolkata	✓	✓	Google	✓			✓	✓	✓
[33]	Bikes	ZigBee	Handover			Other			✓			
[34]	Bikes	Wired	Siracusa			Other		✓	✓	✓	✓	
[35]	Cars	ZigBee	Hsinchu			Google			✓			
[39]	Cars	Bluetooth	Sydney		✓	Google		✓		✓	✓	
[40]	Cars	Bluetooth	Turnpike			Google	✓	✓				✓

receiver only when necessary. The solution in [29] makes sensors sleep until the smartphone wake them up. Besides, [30] allows sensors to report data only when there are significant changes in sensor readings.

For user interface, the solutions in [28–30, 39] develop APPs for users to submit their collected air-quality data and obtain the analyzed result through their smartphones. Most solutions adopt the Google Maps to display the monitoring result of air quality. However, [33] and [34] choose to use their own maps to demonstrate the result. In addition, the solutions in [28, 30, 40] adopt AQI discussed in Sect. 12.2.1 to display their measurement of air quality. Finally, both [33, 35] aim at collecting CO_2 concentration in a city. Other solutions allow users to monitor two or more types of air pollutants in their surroundings.

12.4 Analyzing Raw Data Collected by Smartphones

Due to the budget consideration, some people may use simple gas sensors linked to their smartphones to measure air quality. Moreover, they may prefer directly using inbuilt sensors of smartphones (e.g., cameras) to monitor certain air pollutants. Therefore, a few research efforts propose different approaches to analyze raw data collected by smartphones to provide more accurate monitoring result of air quality.

Hasenfratz et al. [41] connect a smartphone with an O_3 sensor through its USB (universal serial bus) interface to support participatory air quality monitoring. To detect the ground-level O_3 concentration, they measure the resistance of the sensor's SnO_2 (tin dioxide) layer. In particular, the smartphone polls the O_3 sensor to acquire its raw sensor readings every 100 ms, which contain the SnO_2 layer's resistance R and the onboard temperature T. Since the value of resistance highly depends on the temperature, we can estimate the value of temperature-compensated resistance by

$$R_t = R \times \exp[K(T - T_0)], \tag{12.4}$$

where T_0 is the reference temperature and K is a coefficient used to adjust the difference of temperature. In general, T_0 is set to 25 °C and K is set to 0.025. Because the response curve of the O_3 sensor is quasi-linear with respect to the concentration of O_3 pollutant, the concentration can be approximated by a first-order polynomial as follows:

$$f(R_t, \alpha, \beta) = \alpha + \beta R_t, \tag{12.5}$$

where α and β are two parameters used to calibrate the sensor readings. According to the observation from [42], the spatial dispersion of O_3 pollutant in a street canyon is usually kept constant, and its concentration would slowly change over time (specifically, in the order of minutes). Based on this observation, the smartphone can stream data sets of sensor readings through a data filter to construct tuples for data calibration. Specifically, given a data set S with calibration tuples (R_t, M), where M is the reference measurement, for example, the sensing data acquired from the nearby monitoring station, we can adopt the least-squares method to determine both parameters α and β in Eq. (12.5) such that the sum of squared differences between $f(R_t, \alpha, \beta)$ and M is minimized:

$$\arg \min_{\alpha,\beta} \sum_{\forall(R_t,M)\in S} [f(R_t, \alpha, \beta) - M]^2. \tag{12.6}$$

Through the above scheme, we can calibrate the sensor's readings to improve the accuracy of monitoring result. However, Eq. (12.6) is specific to O_3 pollutant. It may not be directly applied to other air pollutants.

Liu et al. [43] use inbuilt cameras on smartphones to estimate the concentration of PM 2.5 pollutant. Their proposed method works based on the relationship between the haze model and the photographic images [44]. Specifically, haze is one atmospheric phenomenon caused by dust, smoke, and PM 2.5 to obscure the clarification of sky, which makes the image look brownish and blurry. In the haze model, given a pixel x on the image, we can estimate its observed image irradiance by

$$O(x) = I(x) \times t(x) + L(1 - t(x)), \tag{12.7}$$

where $I(x)$ denotes the scene irradiance and L is the global atmospheric light. In Eq. (12.7), $t(x)$ is a meteorological parameter called *transmission*, which reveals the amount of light that can pass through the atmosphere. Its value is calculated by

$$t(x) = \exp[-\varepsilon d(x)], \tag{12.8}$$

where ε denotes the light extinction and $d(x)$ is the scene depth that displays the distance between the object in the image and the participator who takes the photograph. It has been shown in [45] that PM 2.5 particulates have significant effect on the light extinction, so the value of ε can be approximate to pM_f, where p is a constant (usually set to 3.75 in the urban area) and M_f is the concentration of PM 2.5 pollutant. Therefore, we can use Eq. (12.7) to measure PM 2.5 concentration from the image. In addition, three image features are considered to improve the accuracy of concentration estimation:

- **Spatial contrast:** We can use the decrease of spatial contrast to observe the degradation of image caused by haze, where distant objects in an image with haze will lose its acuity.
- **Dark channel:** The value of dark channel of a given pixel x is the minimum intensity of the three color channels (i.e., red, green, and blue) of the image block around x. The dark channel of an image without haze should be zero in theory.
- **HSI color difference:** HSI is the acronym of three terms used in chromatology: hue, saturation, and intensity. The HSI color difference of the sky taken under different weather conditions will change with the visibility and hazy situation.

To construct the prediction model, we should not only take a sequence of photographs $P_{ts} = \{P_{ts}^1, P_{ts}^2, \cdots, P_{ts}^m\}$ at a location L for m days but also acquire the data of PM 2.5 concentration $C_{ts} = \{C_{ts}^1, C_{ts}^2, \cdots, C_{ts}^m\}$ from PM 2.5 monitoring stations. Then, given a new photograph P also taken at location L, we can use Eq. (12.7) and the above three image features to compare it with the photographs in P_{ts} and estimate the concentration of PM 2.5 pollutant by consulting the data in C_{ts} accordingly. The scheme in [43] provides a cheap way for people to monitor PM 2.5. However, it incurs a high cost to build the prediction model, as a user needs to take many photographs from the same locations in the monitoring region.

12.5 Reporting Sensing Data Collected by Cars

The mobile solutions discussed in Sect. 12.3.3 provide large-scale monitoring of air quality in a metropolitan area, since cars can move very long distances. However, since drivers have their own destinations, we may not control the moving directions and paths of cars. Besides, it is not a good idea to ask drivers to move to certain locations to collect air quality, as cars also discharge exhaust fume. Otherwise, the distortion of collected data and traffic jam will occur on these locations. Therefore, the mobility of cars is not intentional [46] but could follow some mobility models in VANET (vehicular ad hoc network) [22]. To provide better monitoring of air quality by cars under the above consideration of mobility, several studies propose adaptive algorithms to control the data reporting procedure of cars.

Mitra et al. [47] adopt *mobile agents* installed on some cars to conduct the mission of air quality monitoring. In particular, mobile agents are migratory programs capable of moving from one node to a neighboring node in the network and being executed at the destination node. Each mobile agent is composed of three components: (1) the program which implements the mobile agent, (2) the current status of the program, and (3) user data. Mobile agents can decide when and where to move on their own, so they are useful to collect sensing data in a mobile WSN. In

[47], the remote server creates a few mobile agents in the beginning, each with the configuration information including the target monitoring region, the time period to collect sensing data, and the type of sensing data to be collected. These mobile agents are arbitrarily launched in some cars. During the movement of cars, mobile agents can migrate from one car to another to reach the monitoring region in time. Once the time period expires, mobile agents then transmit their collected sensing data to the remote server (e.g., through a cellular network). The advantage of using mobile agents is that they can move between different cars to collect only the relevant data. In this way, we can reduce network load because each car will discard unnecessary data after its mobile agent leaves [48]. However, since the movement of cars is uncontrollable, the route of a car that the mobile agent currently lodges may not be desirable. For example, the car may be driven away from the monitoring region, or it could be stuck in a traffic jam. In this case, it would be better for the mobile agent to immediately migrate to a neighboring car, or the number of air-quality samplings collected by the mobile agent may not be sufficient. To do so, each mobile agent periodically checks whether its lodging car is still moving toward the target region or whether the car is stuck in the traffic jam by the following two strategies:

- **Distance strategy:** The mobile agent calculates the Euclidean distance between the lodging car and its destination. If the distance does not decrease as time goes by, there is a high possibility that the lodging car is stuck in a traffic jam. Therefore, the mobile agent will jump to another car within the communication range.
- **Angle strategy:** The mobile agent measures the angle between the moving vector of the lodging car and the straight line to the destination. When the angle increases as time goes by, it means that the lodging car may move away from the destination. Thus, the mobile agent should conduct the operation of migration.

The above two strategies are easy to implement, because the moving direction and geographic position of each car can be acquired by its GPS receiver. Therefore, mobile agents can determine whether to migrate to another car in a short time and collect as many air-quality samplings as possible. However, when a mobile agent is lodged in a car that currently moves toward the destination but will become isolated soon (i.e., there are no neighboring cars), the mobile agent will have no chance to migrate to other cars.

Hu et al. [49] divide the monitoring region into a 2D array of homogeneous grids, as shown in Fig. 12.3, and then dynamically adjust the data reporting rates of cars in each grid based on its car density and the variation of pollutant concentration. Consider that it incurs a cost for car drivers to transmit sensing data to a remote server (e.g., via GSM short messages). The objective is to reduce the overall cost while ensuring the accuracy of monitoring result (in particular, obtaining sufficient air-quality samplings to calculate the distribution of pollutant in the monitoring region). Generally speaking, a higher reporting rate should be assigned to a grid where the variation of pollutant concentration increases, and vice versa. Figure 12.3 presents some examples. Grids (4, 2), (5, 2), (4, 3), and (5, 3) have high variations

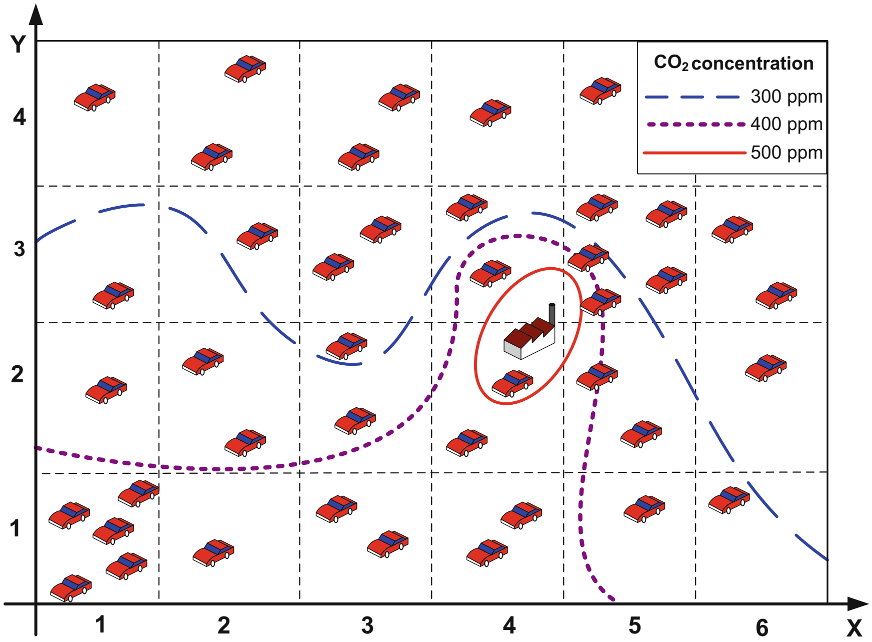

Fig. 12.3 Homogeneous grid partition by [49] for air quality monitoring

of pollutant concentration, so higher data reporting rates should be imposed on these four grids to improve the monitoring accuracy. On the other hand, the pollutant concentration is almost flat in grid (1, 1), but there are many cars in that grid. Thus, a lower reporting rate can be assigned to grid (1, 1) to reduce the amount of data transmissions without significantly reducing the monitoring accuracy. With these observations, two schemes are proposed to dynamically adjust the reporting rate of cars in each grid.

- **Variation-based scheme:** Let us denote by σ_i the standard deviation of pollutant-concentration values collected from grid G_i in the previous time frame. Then, we can estimate the number of air-quality samplings that should be received from grid G_i in the next time frame to keep its monitoring accuracy by

$$S_i^{\text{var}} = \alpha_i^{\text{var}} \times \sigma_i + \beta_i^{\text{var}}, \tag{12.9}$$

where α_i^{var} and β_i^{var} are two constants based on the past experience and larger values imply higher monitoring quality but larger message overhead. In Eq. (12.9), β_i^{var} is the minimum number of air-quality samplings that we expect to receive from grid G_i. Then, the new reporting rate for grid G_i will be set to S_i^{var}/n_i, where n_i is the number of cars in grid G_i which submitted their reports to the server in the previous time frame.

- **Gradient-based scheme:** Let $V_i^{\max}$ and $V_i^{\min}$ be the sets of the highest γ ratio and the lowest γ ratio of pollutant-concentration values collected from grid G_i in the previous time frame, respectively. The gradient of two air-quality samplings $x \in V_i^{\max}$ and $y \in V_i^{\min}$ is defined by

$$\xi(x, y) = \frac{x - y}{D(x, y)}, \tag{12.10}$$

where $D(x, y)$ is the Euclidean distance between the two positions where x and y are sampled. We can also measure the average gradient in grid G_i as follows:

$$\xi_i^{\text{avg}} = \frac{\sum_{x \in V_i^{\max},\ y \in V_i^{\min}} \xi(x, y)}{|V_i^{\max}| \times |V_i^{\min}|}, \tag{12.11}$$

where $|\cdot|$ denotes the number of elements in a set. Then, the necessary number of air-quality samplings expected to be collected from grid G_i in the next time frame is estimated by

$$S_i^{\text{gra}} = \alpha_i^{\text{gra}} \times \xi_i^{\text{avg}} + \beta_i^{\text{gra}}, \tag{12.12}$$

where both α_i^{gra} and β_i^{gra} are constants based on the past experience, just like the variation-based scheme. Also, the new reporting rate for grid G_i is set to S_i^{gra}/n_i.

We remark that the gradient-based scheme can provide higher monitoring accuracy than the variation-based scheme, since it takes the positions of air-quality samplings into consideration. In particular, consider two samplings with a fixed amount of pollutant-concentration difference. When these samplings are acquired from two very close positions, the drop of concentration is regarded as more significant than the fluctuation of concentration acquired from two farther away positions. Consequently, the gradient-based scheme collects high-value and low-value air-quality samplings and then measures the gradients of all pairs of samplings between the two sets $V_i^{\max}$ and $V_i^{\min}$, as given in Eq. (12.11), to increase the monitoring accuracy.

Nevertheless, the performance of variation-based and gradient-based schemes highly depend on the size of grids. In particular, the monitoring accuracy may decrease when the grid size increases, since a large grid results in lower resolution of air-quality samplings. On the other hand, reducing the grid size would increase the overall message overhead, because the cars in each small grid will report more data to the server. To conquer this problem, Wang and Chen [50] propose a heterogeneous grid partition, as illustrated in Fig. 12.4. Specifically, the monitoring region is recursively quartered and indexed by a *region quadtree*. It is a data structure popularly used to describe a partition of 2D space by iteratively decomposing the space into four equal quadrants. Each tree node in the region quadtree has either four children (i.e., an internal node) or zero child (i.e., a leaf node). To maintain the heterogenous grid partition, four operations are developed, where we call the set of

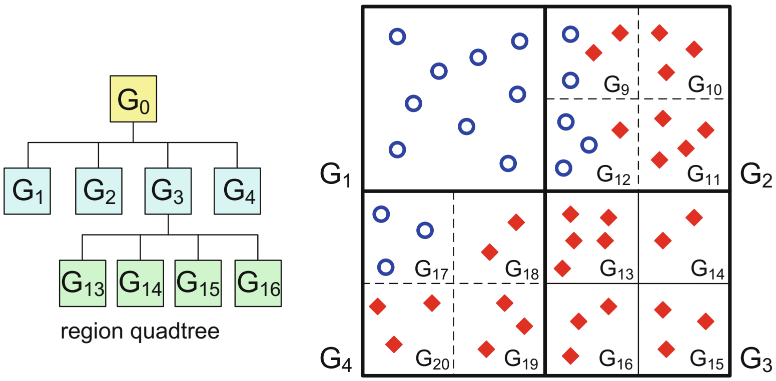

Fig. 12.4 Heterogeneous grid partition by [50] for air quality monitoring, where dotted-line grids do not appear in the current region quadtree

air-quality samplings collected in a grid G_i λ-*similar* if these samplings belong to the same AQI class discussed in Sect. 12.2.1 and the difference between the largest and the smallest samplings does not exceed λ.

- **No-change operation:** When all air-quality samplings in grid G_i are λ-similar, it implies that the pollutant concentration keeps steady in grid G_i. Therefore, there is no need to change the grid. Grid G_1 in Fig. 12.4 gives an example.
- **Dividing operation:** If some child grids of grid G_i have air-quality samplings that are not λ-similar, it means that the pollutant concentration may significantly change in grid G_i. Consequently, it is better to divide grid G_i to acquire a more fine-grained observation. Grid G_2 in Fig. 12.4 shows this case. Because its child grids G_9 and G_{12} have non-λ-similar air-quality samplings, grid G_2 should be further divided into four small grids.
- **Merging operation:** It is a special case of the no-change operation. When grid G_i and its three sibling grids possess only λ-similar air-quality samplings, we can merge these four grids into the same one, as the current grid partition is too narrow. An example is given in Fig. 12.4, where grids G_{13}, G_{14}, G_{15}, and G_{16} can be merged into a large grid G_3 on account of their similar air-quality samplings.
- **Marking operation:** The operation is a special case of the dividing operation. It is invoked when a grid has non-λ-similar air-quality samplings, but each of its child grids possesses only λ-similar air-quality samplings. Grid G_4 in Fig. 12.4 presents an example, where it has two types of λ-similar air-quality samplings, but its child grids G_{17}, G_{18}, G_{19}, and G_{20} each have only one type of air-quality samplings. For this situation, we prefer not to divide the grid, because each child grid of grid G_i in fact can share the same data reporting rate.

Once deciding the grid partition by the above four operations, we can calculate the data reporting rate of each grid by

$$R_i = \mu \times \frac{\omega(G_i)}{\phi(G_i) \times t_{\text{avg}}(G_i)}, \tag{12.13}$$

where μ controls the speed to sample air quality, $\omega(G_i)$ is a baseline for the number of air-quality samplings expected to be collected from grid G_i, $\phi(g_i)$ is the traffic density in grid G_i, and $t_{\text{avg}}(G_i)$ is the average time that cars stay in grid G_i. In Eq. (12.13), $\omega(G_i)$ is a constant which depends on the application requirement, and the coefficient μ can be set as follows:

$$\mu = \begin{cases} 0.5 & \text{ifallair} - \text{qualitysamplingsingrid} G_i \text{are} \lambda - \text{similar} \\ 2 & \text{otherwise.} \end{cases} \tag{12.14}$$

Specifically, when the pollutant concentration keeps steady, it is unnecessary to collect a large number of similar air-quality samplings in that grid. Therefore, we halve the data reporting rate by taking $\mu = 0.5$. On the contrary, when there is significant variation in the pollutant concentration, we should double the data reporting rate by taking $\mu = 2$ to capture such high variation. Figure 12.4 illustrates an example. We slow down the data reporting rates of grids G_1, G_3, G_{10}, and G_{11}, since they cover the subareas where the pollutant concentration remains stable. On the other hand, the data reporting rates of grids G_4, G_9, and G_{12} should be speeded up to react to the significant change in the pollutant concentration. To verify the performance of this heterogenous grid partition, [50] uses the *simulation of urban mobility (SUMO)* [51] to imitate practical car traffic in a city and the ISC3 model discussed in Sect. 12.2.3 to simulate the dispersion of air pollution. Experimental results demonstrate that the proposed scheme significantly reduces message overhead while keeps the monitoring accuracy as compared with the variation-based and gradient-based schemes, which shows the superiority of heterogeneous grid partition.

12.6 Research Directions and Challenges

In this section, we discuss some research directions and challenges for the mobile solutions to air quality monitoring:

- The mobile solutions can combine with incentive mechanisms [52] to encourage more people to voluntarily participate in the monitoring missions. In this way, we can significantly increase sampling data of air quality and thus improve the accuracy of monitoring result. Moreover, it is useful to dynamically adjust the frequency to sample air-quality data in various situations, for example, increasing the sampling frequency when detecting abnormal air pollution, based on the designs of these incentive mechanisms [50].
- Collecting air quality on every position in the monitoring region is evidently infeasible. Therefore, it is a challenge to provide accurate estimation of air

pollutant concentration for the positions with just little information or even without any sensing data. Some techniques like the dispersion models of air pollutants discussed in Sects. 12.2.2 and 12.2.3 and the data mining approaches popularly used in big data analysis [53] would be helpful in the estimation of air quality.

- In practical applications, people may use various types of devices for communications (e.g., smartphones, laptops, or tablet computers). Moreover, they could carry different kinds of gas sensors to measure the concentration of different air pollutants. Consequently, it deserves further investigation on how to efficiently collect sensing data from heterogeneous devices and combine their data with different attributes. Interestingly, this issue has some similarities with the problem of dispatching multi-attribute mobile sensors discussed in [54].
- Since the technology of *unmanned aerial vehicles (UAVs)* [21] and autonomous cars [55] is evolving and getting mature, it is attractive to use these mobile platforms to carry gas sensors and communication devices to collect air quality. In particular, UAVs are able to provide 3D monitoring of air quality, while autonomous cars can move to certain places where people are difficult to enter, for example, the location of toxic gas leakage. In this way, more comprehensive measurement of air quality and detection of air pollution can be achieved.

12.7 Conclusion

Air pollution is a global problem, and it is beneficial for the residents living in cities to keep monitoring air quality and provide the detailed monitoring result to the public in real time. However, the traditional approach of using static monitoring stations to collect air quality may not meet the requirement. Thanks to the development of WSN technology, many researchers propose different mobile solutions to air quality monitoring by allowing people to carry gas sensors to detect air pollution on their own. This chapter discusses existing mobile solutions to collect air quality by pedestrians, cyclists, and drivers, which have different mobility models. Two issues arisen from these mobile solutions are also addressed, including how to analyze raw data collected by smartphones to estimate the concentration of the monitoring pollutants and how to make cars efficiently collect air quality on desired locations and report their sensing data accordingly. We also point out some research directions and challenges for future mobile solutions to air quality monitoring in the chapter.

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Chapter 13
Smartphone Sensing Technologies for Tailored Parkinson's Disease Diagnosis and Monitoring

Gabriela Postolache and Octavian Postolache

Abstract Parkinsonian syndromes are a heterogeneous entity of movement disorders, with various described subtypes. This systematic review aimed to examine the available literature on smartphone applications for assessment of Parkinson's disease motor and nonmotor symptoms and signs. Papers published from 2013 to 2017, listed in two electronic databases—IEEE Xplore and PubMed—were searched, to identify the works related with smartphone use for PD patients' diagnosis and monitoring. Full-text articles were analyzed to evaluate the quality of the reported methods and results, considering the validity, reliability, and sensitivity of the techniques used in the measurements as well as the Grading of Recommendations Assessment, Development and Evaluation guideline. The data from 26 full-text articles suggest that many and relevant data can be collected automatically and accurately via mobile phone. Inertial measurement units as well as capacitive, force/pressure, acoustic sensors were used for the development of smartphone-based tools to improve assessment and monitor symptoms and signs of Parkinson's disease. Smartphone-based information on upper limbs tremor, gait, posture, balance, activities, and speech may improve quality of healthcare services for Parkinson's disease patients and their quality of life.

13.1 Introduction

> I am going to take a nap now. It was more one night of struggle to continue to stay alive, when physical infirmities and torment of soul are worsening. I remember the panic of awakening without capacity to breathe and the effort to breathe again, the sleeplessness produced by fear of dipping in agony of having to traipse while the body functions failures take me through a distant place . . . where my deep love that I keep in my soul might be lost forever. I got up with the joy of sun rays that wash my sorrow face. I must get up from bed but fear of falling, stop me to think on other things, and to move. Sadness and frustration,

G. Postolache (✉) · O. Postolache
Instituto de Telecomunicações, Lisbon, Portugal
e-mail: opostolache@lx.it.pt

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> I feel when I see my hands tremor . . . Who, why is producing these movements . . . It is not me . . . are not mine . . . .
>
> I am going to spend my day in front of television. Sad, in powerlessness . . . From time to time I wish a lot to speak with someone . . . I want to talk about . . . but now they not understand me, or they haven't patience to listen what I said. Oh, so many neighbours that so many time when I was healthy came to me to talk on . . . so many things . . . So many time have passed without any visit of my neighbours or friends.
>
> I should stand up from my chair . . . My heart began to beat strongly . . . .if I fall . . . how many time I would wait in agony of minutes that seams hours or days until someone would help me . . . The shame, the infirmity, the pain in my soul . . . The dead is better than life . . . I stand up after a while and with small and rapid steps I go to kitchen . . . I need more space . . . The dead is better than life . . . I feel the fear . . . I hope not falling . . . The dead is better than life . . . More one day . . . .
>
> What I am going to do today . . . as yesterday, and the day before yesterday I will spend my time in front of television . . . sometime falling asleep, sometime bored . . . More one day will pass. Perhaps, the dead is better than life . . . So deeply I wish to live for my dears . . . . More one day . . . one day . . . day . . .

Although it is not a fragment from a written or spoken diary of a person with Parkinson's disease (PD), as the used words suggest a high degree of PD severity that is characterized by the low ability to write or speak, it can describe the quality of life of a person having this long-term illness. Based on observations and report from a caregiver, the story suggests a health state with a negative score of health-related quality of life (HRQL) measured by Health Utilities Index (HUI) instrument. HUI is a standardized system to measure health status. The two HUI systems HUI2 and HUI3 can describe almost 1,000,000 unique health states [1]. The HUI2 classification system includes seven attributes—Sensation, Mobility, Emotion, Cognition, Self-Care, Pain, and Fertility—each from three to five levels. The HUI3 classification system comprises eight attributes—Vision, Hearing, Speech, Ambulation, Dexterity, Emotion, Cognition, and Pain—each with five or six levels of ability/disability. Negative scores of HRQL represent health state considered by a person as worse than dead.

The first scientific document on Parkinson's disease—*An Essay on the Shaking Palsy* [2], reprinted in [3], with more details on the history in [4]—was published by Dr. James Parkinson 200 years ago. Well-known individuals having the disease, such as Pope John Paul II, actor Michael J. Fox, and boxer Muhammad Ali, contributed to wider public awareness and scientific research on PD. Knowledge on Parkinson's disease seems to be present in India since ancient times. *Ayurveda,* an ancient system of medicine dating around 5000–3000 B.C., characterized the *kampavata* disease by symptoms that currently are considered as the main symptoms of Parkinson's disease as tremors, stiffness, depression, and a depletion of movement [5]. For this disease with strong clinical resemblance with PD, the ancient Indians prescribed diverse therapeutic plants. Moreover, a lower prevalence of PD was registered in India, mainly in some population (i.e., Bangalore district in South Karnataka) [6]. In our knowledge, no data on the factors that produced or are associated with this lower prevalence were published.

Heterogeneity of Parkinsonian syndrome and similarity of various clinical signs and symptoms with those from other diseases increase the error in PD diagnosis.

Parkinsonian syndrome is a heterogeneous entity of movement disorders, which can be subdivided into idiopathic Parkinson's disease, rare genetic forms of Parkinson's disease, as well as symptomatic and atypical Parkinsonian syndromes (APS) [7]. Multiple system atrophy (MSA), progressive supranuclear palsy (PSP), corticobasal degeneration (CBD), and dementia with Lewy bodies are included into APS. Furthermore, many other disorders (i.e., essential tremor, drug-induced Parkinsonism) may show clinical signs of Parkinsonism.

Many PD patients, both from developed or undeveloped countries, mainly those with low accessibility to healthcare services (i.e., those who live in remote rural areas or in countries with unaffordable healthcare services), perceive their quality of life much lower than the age-matched control group (see [8]). A decline in physical function measured with Short-Form Health Status Survey (SF36) in PD patients relative to a cohort of 51,530 male health professionals and 121,701 female registered nurses from the USA began approximately 7.5 years prior to diagnosis in women and 3 years prior to diagnosis in men and continued to decline thereafter with a rate of 2.35 and 1.43 points per year in women and men, respectively ($p < 0.001$ for both) [9]. The decline in individuals without PD was on average 0.42 and 0.23 points per year in women and men, respectively [9]. All the eight dimensions scored measured with the 39-item Parkinson's Disease Questionnaire (PDQ-39) were shown to be significantly lower in PD participants; the highest score was found in "bodily discomfort" and the lowest in "social support" [10]. Moreover, many people diagnosed with PD do not see a neurologist [11]. Even in most developed countries, the doctor appointments are once or twice per year (e.g., in Sweden 1.7 times/year with regional variation between 1.1 and 2.1) [12] and accessibility to healthcare services is the worst in rural regions [11].

The advances in hardware miniaturization combined with increased capacity for large data processing and storing, and in implementation of algorithm for higher measurements accuracy and signal pattern recognition, have made the wearable devices important tools for disease diagnosis and long-term health monitoring. Different benefits are envisioned or are already proven: portability of medical devices; customizability and deployment scalability; healthcare cost saving; better communication between patients and healthcare professionals; objective measurements of subjects functioning, disability, and health; increased patient access to health information; medication reminders; to help track progress in physical exercise regime; patient assessment and monitoring for an extended duration in clinic or remotely; opportunities for patients in chronic condition to engage in their healthcare; and capacity to improve the quality of healthcare services and to reduce medical errors while reducing clinician workloads.

Modern smartphones integrate a growing number of sensors, powerful portable media tools, connectivity to the Internet, and cloud computing resources. Major mobile operating systems, such as Android, iOS, and Windows support customizable interfaces and signal processing. In the past years, various smartphone or tablet applications for diagnosis and monitoring of PD signs and symptoms were developed. In this chapter, we present our analysis on smartphone applications for Parkinson's disease symptoms and signs assessment and monitoring. These sensing technologies may have great potential to improve accessibility to healthcare services, quality of diagnosis, and treatment of patients with Parkinson's disease as well as to increase their everyday quality of life.

In the Sect. 13.2 of the chapter, a brief literature review on non-electronic methods used for the assessment of Parkinson's disease motor and nonmotor symptoms and signs and their precision is presented, followed by the Sect. 13.3 by presentation of the methods and results on analysis of literature related to smartphone applications for PD diagnosis and monitoring.

13.2 Non-electronic Instruments Used for PD Diagnosis

The gold standard diagnosis of PD is based on histopathological analysis, after patient death, and requires cell loss in substantia nigra and the presence of Lewy bodies, which stain for alpha-synuclein and ubiquitin [7]. While these criteria are useful only post mortem, several attempts have been made for real-time effective diagnosis and monitoring. Several biomarkers (i.e., genetic markers, biochemical markers, neuroimaging markers, and clinical biomarkers) were described in the last decades for diagnosis, tracking disease progression, identification of specific therapeutic targets, or determination of the efficacy of agents designed to influence disease progression [13–15]. However, the initial diagnosis varies greatly in PD. Clinical diagnosis performed mainly by nonexperts might have an accuracy of 73.8% (95% CI 67.8–79.6%) [16]. The accuracy of PD diagnosis made by a general neurologist was found to be 76% [17], and clinical diagnosis performed by movement disorders experts rose from 79.6% (95% CI 46–95.1%) of initial assessment to 83.9% (95% CI 69.7–92.6%) and up to 90% [18] of refined diagnosis after follow-up [16]. When patients present atypical Parkinsonism, the accuracy of diagnosis is low (41–88% in progressive supranuclear palsy; 50–66% in multiple system atrophy) [19, 20]. Furthermore, in a recent prospective study with 110 subjects [21], in which the accuracy of various technologies for differentiating diagnosis of PD and APS was tested, the clinimetrics of Unified Parkinson's Disease Rating Scale (UPDRS) have showed more benefits and efficacy for PD diagnosis. In the study, the accuracy of magnetic resonance imaging (MRI), 123I-iodobenzamide single photon-emission computed tomography (IBZM-SPECT) analysis of the cerebrospinal fluid (CSF), and electromyography (EMG) of the anal sphincter to diagnose PD were investigated. This study also analyzed data from: a structured interview, including information on medical history; used medication; presenting complaints and progression of the disease; most affected body site; balance and fear of falling as well as from UPDRS III and IV; Hoehn and Yahr (H&Y) score; International Cooperative Ataxia Rating Scale (ICARS) for cerebellar symptoms; and Mini Mental State Examination (MMSE). Participants underwent a structured interview; detailed and standardized neurological examination; and within 6 weeks after the initial visit brain MRI, IBZM-SPECT, lumbar puncture, and anal sphincter EMG. After 3 years, the examination was made again following the same procedures, for all patients. In 92 out of the 110 patients who completed the 3-year follow-up, the initial diagnosis at baseline was correct. APS diagnosis at baseline was incorrect in 33% of patients. Clinimetric procedures yielded 138 clinical parameters that were potentially able to differentiate between PD and APS. Higher age, rapid disease progression, autonomic dysfunction, impaired tandem gait, abnormal fluency, higher ICARS total score, higher UPDRS axial score, and higher disease stage were the parameters that have shown fair to good accuracy to differentiate between PD and APS. The study has shown that none of the ancillary investigations contribute for better accuracy to differentiate PD and APS but tandem gait and axial UPDRS score yielded a very good accuracy (AUC = 0.92), a sensitivity of 73% and specificity of 92% [21].

The UPDRS scale, published in 1987 [22], and U.K. Parkinson's Disease Society Brain Bank Clinical Diagnostic Criteria (UKPSBB) [17] are nowadays the most used clinical criteria for PD diagnosis. The diagnosis of PD based on the UKPSBB criteria demands the presence of bradykinesia (slowness of initiation of voluntary movement with progressive reduction in speed and amplitude of repetitive actions) and at least one of the following: muscle rigidity, rest tremor, or postural instability not caused by primary visual, vestibular, cerebellar, or proprioceptive dysfunction. UPDRS have six parts: part I. mentation, behavior, and mood (four items); part II. activities of daily living (13 items); part III. motor examination (13 items); part IV. complication of therapy in which dyskinesia, clinical fluctuation, and other fluctuation are studied; part V. modified Hoehn and Yahr staging; and part VI. Schwab and England activities of daily living scale. A shorter version of UPDRS for the assessment of motor impairment and disabilities in PD—the Short Parkinson's Evaluation Scale (SPES) [23]—was created. Later, the Scale for Outcomes in Parkinson's disease (SCOPA) study brought some modification to SPES, improving clinimetric aspect of the SPES scale, which resulted in a new scale—SPES/SCOPA [24, 25]. However, the UPDRS scale has some weaknesses: (i) it is time consuming—mean completion time is 30 min; (ii) the evaluation using this scale is prone to clinicians' subjectivism; (iii) several ambiguities in the written text are present in UPDRS scale, inadequate instructions for raters, some metric flaws, and the absence of screening questions on several important nonmotor aspects of PD [26]. Founded on the critique that was formulated by the Task Force for Rating Scales in Parkinson's disease, a new scale was published in 2008 powered by the Movement Disorder Society (MDS) [27, 28]. The MDS–UPDRS has four parts: part I. nonmotor aspects of experiences of daily living (13 items); part II. motor aspects of experiences of daily living (13 items); part III. motor examination (21 items); and part IV. motor complication. In comparison with UPDRS, the new scale includes more nonmotor aspects of PD, and patients reported symptoms and signals.

Despite PD nonmotor symptoms being described for long time ago (e.g., sleep disturbances, gastrointestinal dysfunction, bladder dysfunction, and even fatigue were described by Dr. Parkinson) and extensive demonstration of the importance of nonmotor aspects of experience of daily living, the PD continues to be viewed by most clinicians as a motor disorder, and for simplicity, the UKPSBB criteria are the most used. The nonmotor symptoms received in the last decades an increasing interest by their importance recognition for diagnosis purposes but also because they are the major source of deterioration in quality of life [29]. Various nonmotor aspects were associated with Parkinson's disease: (i) sensory dysfunction—hyposmia, decreased visual contrast and color discrimination, and decreased visual motion perception, abnormal sensations, such as paresthesias; (ii) dysautonomia—orthostatic hypotension (OH), constipation, urinary dysfunction, sexual dysfunction, excessive sweating, seborrhea, and sialorrhea; (iii) sleep disorders—insomnia, rapid eye movements (REM) behavior disorder (RBD), restless legs syndrome, periodic limbs movements in sleep, and excessive daytime sleepiness; (iv) pain; (v) fatigue; and (vi) neuropsychiatric features—apathy, anxiety, panic attacks, mood disorders, hallucinations, illusions, delusions, cognitive deterioration, and ranging from mild impairment to dementia [29]. Aging may be associated with all PD nonmotor symptoms. However, the nonmotor symptoms are more frequent, more severe, and in a larger number of different aspects, in PD individuals [30, 31]. Some of these nonmotor features may be present before any motor signs are noticeable. In a study with 115 PD patients, it was shown that most frequently self-perceived symptoms in the early and very early prediagnosis phase (>2 years) were hyposmia (23.1%), musculoskeletal pain (21.9%), and depression/anxiety (14.1%). In the late prediagnosis phase (<2 years), mild motor signs, especially asymmetric bradykinesia and rest tremor, increasingly dominated the self-perception [32]. By measurement of the slope of a marker in patients who have already been diagnosed with PD, then back-extrapolating to estimate the time at which the measure crosses normal control values was estimated as a duration of premotor (prodromal) stage, averaging 3–15 years [33]. Prodromal disease refers to the stage wherein early symptoms or signs of PD neurodegeneration are present, but classic clinical diagnosis based on fully evolved motor Parkinsonism is not yet possible [34]. Extrapolation based upon progression of the UPDRS in the early stage of PD suggests an interval of 5 years before diagnosis [35]. Recently, MDS proposed criteria and probability methodology for the diagnosis of prodromal PD [34]. Nonmotor as well as motor clinical symptoms, clinical signs, and ancillary diagnostic tests were included. Assessment of nonmotor signs as orthostatic hypotension and respiratory dysfunction (not recommended in MDS-UPDRS) were included in recently published MDS clinical diagnostic criteria for PD [36]. However, the nonmotor aspects of PD continue to be more a research issue and less the support for better management of PD patients' treatment. Therefore, a simple objective and quantitative measure of motor and nonmotor symptoms and signs that may be used for the diagnosis of PD in the early stage may improve the quality of healthcare services and PD treatment outcomes. Moreover, subjectivity impact on the measurements with instruments that mainly use structured observation carried out by clinicians may be related to lower effectiveness of PD diagnosis, monitoring, and treatment. Patient tracking now available via mobile devices that align to the measurements that have shown the greatest ability to predict and diagnose PD and that allow assessment and monitoring of PD symptoms and signs may contribute for better therapeutic approach and increased number of years with better quality of life for the PD patients.

13.3 Smartphone Use for PD Diagnosis and Monitoring

13.3.1 Methods

A systematic review on papers related to smartphone applications for Parkinson's disease symptoms and signs assessment and monitoring was carried out. According to Zenith's *Mobile Advertising Forecasts 2017*, in 2018, 66% of individuals in 52 countries will own a smartphone, up from 63% in 2017 and 58% in 2016. Development of many software and hardware technologies for using with smartphone applications turns the smartphone as an affordable, user-friendly tool that may be used in healthcare services.

Papers published from 2013 to 2018 listed in two electronic databases—Medline via PubMed and IEEE/IET Electronic Library, IEEE Xplore—were searched by title and abstract to identify the works related to smartphone use for diagnosis and monitoring patients with Parkinson's disease. Search was made using the following terms: "smartphone AND Parkinson's disease," considering 5 years (2013–2017). To be eligible for inclusion, papers were required to be available in English; include patient(s) with Parkinson's disease; include assessment of Parkinson's disease symptoms, signs, and treatment outcomes by using a smartphone. Articles were excluded if they were a systematic review or meta-analysis; described smartphone-based technology for treatment purposes; the articles were published in languages other than English; and were not available in full text. Each record identified through database searching was screened based on their title and abstract and a decision was made based on the criteria above on the suitability of inclusion of the papers in our analysis. The analyzed papers were categorized by technology and the symptoms or treatment outcome that was evaluated. The analysis of full-text articles has taken into account the validity, reliability, and sensitivity to change the technique used in the measurements as well as the GRADE—Grading of Recommendations Assessment, Development and Evaluation guideline (www.gradeworkinggroup.org). The GRADE working group presented its initial proposal for patient management in 2004 [37]. GRADE's four categories of quality of evidence on diagnostic test and methods of monitoring—very low level of evidence (VLE), low level of evidence (LLE), moderate level of evidence (MLE), and high level of evidence (HLE)—represent a gradient of confidence in estimates of the effect of an assessment method on patient-important outcomes. The quality of reported methods and results was assessed by taking into account: (i) the spectrum of patients representative of who will receive the test in clinical practice; (ii) description of the selection criteria; (iii) what method and how it is used as a reference standard to assess the diagnostic accuracy of the new test; (iv) independence of a new test in relation to reference standard; (v) execution of the new test and reference standard in sufficient detail to permit its replication; (vi) influence of knowledge of reference standard results on the results of the new test; (vii) interpretation of test results based on the same clinical data available as would be available when the test is used in practice; (viii) uninterpretable/intermediate test result; (ix) withdrawals from the study [38, 39].

NVivo10 software was used to manage the data. Decision on the quality of evidence was based on: (i) number of subjects included in study and description of control condition; (ii) clinimetric properties including validity, reliability, responsiveness, and performance; (iii) influence of confounding variables and risk of bias/study limitations; (iv) consistency of results, precision of measurements, and data reporting. For reliability, we required statistically significant correlations of measurements realized using wearable technology, with those instruments considered as reference standard or commonly accepted in clinical studies. Data on Intraclass Correlation Coefficient (ICC) were considered for reliability analysis. For validity, statistically significant correlations with clinical ratings (convergent validity) were required. For responsiveness (sensitivity to change) and performance measurements, the data on overall accuracy, sensitivity, and specificity were considered. Area under the receiver operating characteristic (ROC) curve (AUC) < 0.70 was considered as showing poor accuracy, 0.71–0.80 as fair accuracy, 0.81–0.90 as good accuracy, and > 0.91 as very good accuracy. To evaluate the overall quality of each paper, using above described criteria, a Likert scale of five points was used. A score of four points was assigned for the best quality, zero if the criteria were not met, and one and two if the criteria were unclear. Using these methods, we aimed to summarize the findings related to smartphone-based tools for assessment and monitoring of Parkinson's diseases symptoms and signs.

13.3.2 Results

The literature search yielded 68 records, of which 60.3% were obtained from PubMed database. More studies related to smartphone use in Parkinson's disease context were later identified by "snowballing" method in PubMed and ScienceDirect databases. However, we present in this chapter only data identified directly through searching IEEE Xplore and PubMed by the "smartphone AND Parkinson's disease" query. A total of 26 articles (38.2%) were included in the full-text format for further evaluation (Fig. 13.1, Table 13.1). Only four papers (15.3%) were categorized by using criteria of our analysis as having moderate level of evidence (see Table 13.1) related to the use of smartphone-based tools for assessment or monitoring PD symptoms and signs. The classification of the data in the papers taking into account GRADE guideline is not intended to recommend any specific commercial product or technology. These categories only stress what technologies need more research to test their effectiveness.

Many clinicians and researchers have used smartphone technology for monitoring various aspects of PD (i.e., bradykinesia, tremor, posture, balance, and speech). Nowadays, many sensors are included in smartphones, and many applications were implemented based on the progress in sensor development, communication features, and data storing capacity of smartphone. Motor system functionalities as gait, posture, tremor, activities, speech, as well as nonmotor functions as sleep, light

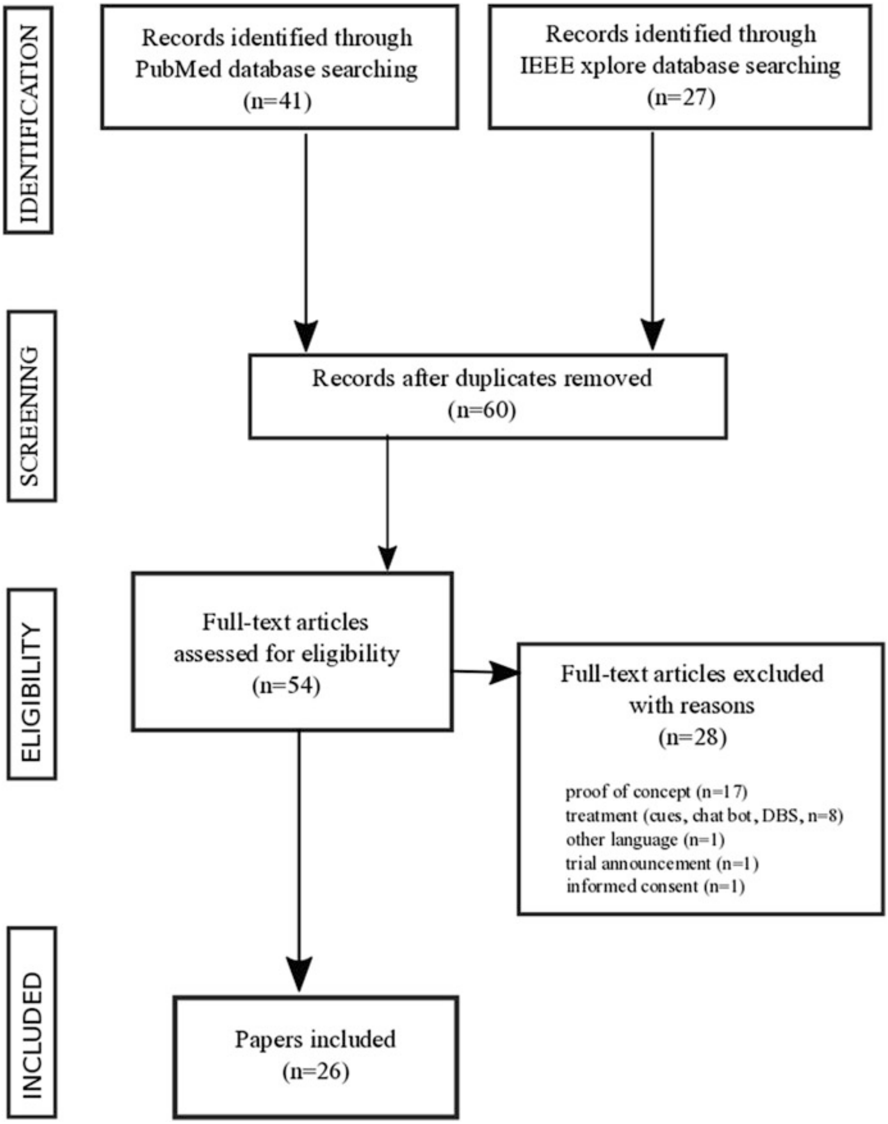

Fig. 13.1 Flow diagram for data extraction

Table 13.1 Overview of classification in papers

Ref	First author and publication year	Database	Measurements	Operating system	Sensors	Nr. PD pat	Overall quality
[40]	Milosevic et al. 2013	IEEE Xplore	Balance, gait	Android	IMU	3	1 / LLE
[41]	Graça et al. 2014	IEEE Xplore	Hands coordination and bradykinesia (spiral drawing, tapping), gait	Android	Accelerometer, capacitive touch screen	17	2 / LLE
[42]	Kostikis et al. 2014	IEEE Xplore	Tremor	iOS	IMU	23	2 / LLE
[43]	Pepa et al. 2014	IEEE Xplore	Freezing of gait	Not indicated	Accelerometer	18	1 / LLE
[44]	Printy et al. 2014	IEEE Xplore	Hand coordination and bradykinesia	iOS	IMU, capacitive touch screen, microphone, camera	26	2 / LLE
[45]	Arora et al. 2015	PubMed	Hands coordination and bradykinesia, gait, posture, voice	Android	IMU, capacitive touch screen, microphone	10	2 / LLE
[46]	Ayena et al. 2015	IEEE Xplore	Risk of fall, balance	Android	Force sensitive resistors in insole	4	1 / LLE
[47]	Bazgir et al. 2015	IEEE Xplore	Tremor	Android	IMU	52	2 / LLE
[48]	Ferreira et al. 2015	PubMed	Usability, activities, balance	Not indicated	Wii balance board, 3 IMU	22	2 / LLE

Ref	First author and publication year	Database	Measurements	Operating system	Sensors	Nr. PD pat	Overall quality
[49]	Ellis et al. 2015	PubMed	Gait	iOS	IMU, foot-switch sensor	12	3 / MLE
[50]	Kim et al. 2015	IEEE Xplore	Freezing of gait	Android	IMU	15	1 / LLE
[51]	Kostikis et al. 2015	IEEE Xplore	Tremor	iOS	IMU	25	2 / LLE
[52]	Lan et al. 2015	IEEE Xplore	Gait	Not indicated	Accelerometer	1	2 / LLE
[53]	Pepa et al. 2015a	IEEE Xplore	Freezing of gait	Not indicated	Accelerometer	6	2 / LLE
[54]	Pepa et al. 2015b	IEEE Xplore	Freezing of gait	iOS and android	Accelerometer	18	2 / LLE
[55]	Assis et al. 2016	PubMed	Hand rigidity	Android	Gyroscope	19	2 / LLE
[56]	Cancela et al. 2016	PubMed	Gait, balance, hand coordination and bradykinesia (tapping), heart rate, temperature, activities, cognitive function	Android	Insole sensors, wristband	20	1 / LLE
[57]	Contreras et al. 2016	IEEE Xplore	Tremor	Android	IMU smartwatch	12	1 / LLE
[58]	Lee C et al. 2016	PubMed	Hand coordination and bradykinesia (tapping)	Android		57	3 / MLE

(continued)

Table 13.1 (continued)

[59]	Arroyo-Gallego et al. 2017	IEEE Xplore	Hand coordination and bradykinesia (tapping)	Android	IMU	21	3 / MLE
[60]	Barrantes et al. 2017	PubMed	Tremor	iOS	IMU	17	3 / MLE
[61]	Cheng et al. 2017	IEEE Xplore	Activities, gait, balance	Not indicated	Accelerometer	44	2 / LLE
[62]	Lee et al. 2017	PubMed	Sleep movements	Not indicated	Accelerometer	92	2 / LLE
[63]	Stamate et al. 2017	IEEE Xplore	Hands Bradykinesia, gait, tremor	Android	IMU, capacitive touch screen	12	2 / LLE
[64]	Tsiouris et al. 2017	IEEE Xplore	Hand coordination and bradykinesia, tremor, gait, freezing of gait, posture, balance, cognitive functions, speech, medication intake, nutrition	Not indicated	IMU, insole sensors, heart rate, temperature, microphone	20	1 / LLE
[65]	Zhang, 2017	PubMed	Speech	Android	Microphone	23	2 / LLE

Ref References; *pat* Patients; *LLE* low level of evidence; *MLE* moderate level of evidence according GRADE guideline headedness on standing, fatigue, anxious mood, and depression can be analyzed by using smartphone applications or different wearable devices linked to smartphone.

The larger data from PD patients, using a smartphone, were acquired with the *mPower* applications for iPhone. Within weeks after its release, over 15,000 participants enrolled in *mPower* [66]. The participants were asked to respond to a subset of questions from the MDS-UPDRS and to perform short activities such as speeded tapping for 20 s on the screen of the phone or phonating a vowel for 10 s into the microphone, multiple times a day. For those participants with PD and taking medication, the timing of each recording with relation to their last dose of medication was also evaluated. A quantitative measure of movements was obtained by using algorithm that extracts different information from a signal. For example, in addition to reporting bradykinesia by measuring the total number of taps on the screen performed in 20 s, the accuracy of each tap related to targets on the screen was also analyzed to obtain information on tremor. Majority of respondents to survey on *mPower* app have said that their data can be used for future research, and these data were made available for other research (https://www.synapse.org/mPower). The prototype of *mPower* was developed, for the Android platform, at Johns Hopkins University in Baltimore, Maryland, by Andong Zhan. Hopkins-PD app is also being assessed in several trials, including one called *SmartphonePD*, which has been running since 2014 [67]. The app includes also contribution of John Hopkins team in speech processing. A wealth of information related to characteristics of speech in PD patients was published in the last years. The research groups with members from Czech Technical University, Brno University of Technology, and Masaryk University, Czech Republic, stand out by the comprehensive and high-quality methods used for speech research in PD patients [68–74]. *Neurological Disorder Analysis Tool (NDAT)* was developed at the Brno University of Technology, Czech Republic.

The position of microphone for speech recording varied in the range of 5–20 cm in different studies with a median at 15 cm. The calibration of the microphone recording is established using a sound-level meter placed at 15 cm from the participant's mouth while the participant produced for 1–2 s a prolonged "ah" at 70 dBA SPL as indicated on the sound-level meter [75]. In PD speech analysis, the records include vowel phonation (i.e., short vowels pronounced with normal intensity, sustained vowels pronounced with normal intensity, sustained vowels pronounced with maximum intensity, sustained vowels pronounced with minimum intensity but not whispered); counting number from one to 20; word pronunciation; phrase sentence pronunciation; reading a text; reading a text with neutral emotion; stress-modified reading task (interrogative, imperative, and indicative sentence); diadokinetic evaluation through the rapid repetition of the syllables /pa/−/ta/−/ka/; affirmative, interrogative and exclamatory phrases; and conversation.

Many works published in the past years have presented algorithms for automatic identification and classification of speech impairments in PD patients (e.g., [68, 71, 72, 76]). The mean habitual conversational speech intensity level was found being reduced by 5 dB SPL in PD group confirming hypophonia observed in PD patients [75]. The intensity level of conversational speech was 66.86 ± 3.48

db SPL in PD patients versus 71.8 ± 2.5 db SPL in the control group [75]. Speech intensity increases as PD patients increased their walking speed [77]. Using sustained and silent vowel classification within each vowel set allowed classification of PD patients with AUC = 84.2%, sensitivity 85.7%, and specificity 81.6% [69]. By using all vowel realization, and extracting 12 features (where seven of them were obtained by empirical mode decomposition of the signals), the accuracy increased to 94.0%, the sensitivity to 96.4%, and the specificity to 89.8% [43]. Good accuracy (AUC = 88.7%), sensitivity (91.7%), and specificity (83.7%) were observed in the case of classification based on parametrization of sustained vowel [e], although many works have shown good accuracy of differentiation of PD patients by sustained vowel [a] [68]. The highest pith level was significantly lower in the PD group than in the control group, both in males (258.1 Hz vs. 353.0 Hz) and female (361.7 Hz vs. 473.9 Hz), whereas the lowest pitch level was significantly higher in the PD group (126.4 Hz) than that in the control group (110.4 Hz), only in males. Voice pith range was significantly narrower in the PD group. The lowest pitch level in the PD group was as low as that in the female control group, probably because of the tendency of mucosal edema generally found in elderly female subjects [78]. An automatic speech recognition system that assesses the intelligibility deficits of the patients by automatic classification of utterances of patients in comparison with healthy controls was implemented by [79]. The proposed system had an accuracy of up to 92% to detect Parkinson's disease from speech.

The architecture and tests of a complex smartphone app for PD monitoring were also recently published [56, 64]. The so-called *mHealth* platform integrates motor and nonmotor assessment including cognitive, speech, sleep monitoring, and treatment adherence monitoring. The clinicians' platform allows personalized prescription for medication based on periodic reports with major events. The recommendations for modification in medication, diet, physiotherapy, and activity are sent to the patient through the *mHealth* platform. The platform also has an app for caregivers where they receive information on PD patient symptoms as well as on patient's adherence to the management plan. Monitoring in these studies was realized with four devices—two insoles (Moticon, Germany), a smartphone (BQ Aquaris E4.5) in the pocket, and one wristband (Microsoft Band, the USA). Based on insole sensors, information on center of foot pressure trajectory (COP), staggering, balance impairments, gait variance, foot loading, freezing of gait, and fall may be obtained. Continuous heart rate patterns (i.e., heart beat signals were acquired with optical blood flow sensor), motion (acquired by three-axes accelerometer and gyroscope), skin temperature, activity (i.e., gait and calories burned), and periods of restful and light sleep were captured with Microsoft wristband. The smartphone captures motion data (finger tapping and alternate finger tapping) and temporarily stores the raw data in the smartphone memory and sends them to the cloud for prolonged storage. This app was developed in the framework of a European Union project (https://ec.europa.eu/programmes/horizon2020/en/news/pdmanager-mhealth-platform-parkinsons-disease). Another project—PD_manager project—aimed to develop a platform that integrates motor and nonmotor assessment including cognitive, speech, sleep monitoring, and treatment adherence monitoring.

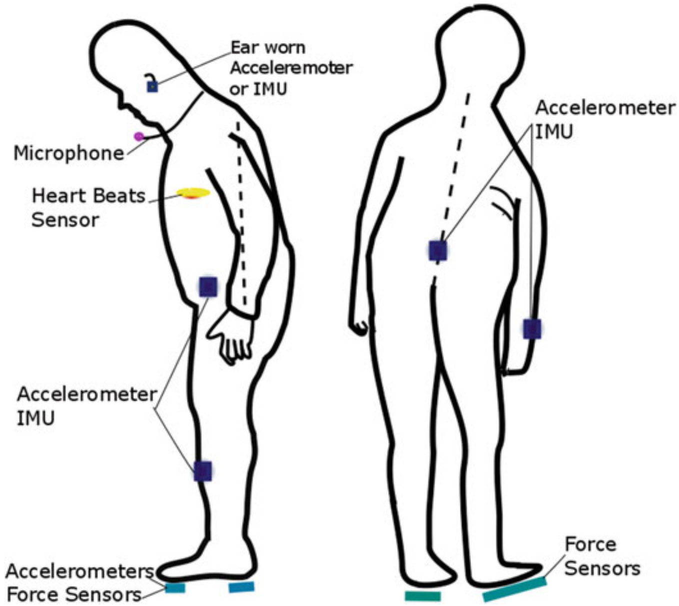

Fig. 13.2 Sensing technologies for posture, gait, tremor, speech, and heart beat assessment and their position representation

It is also aimed at delivering different services for the patients, caregivers, and professionals based on this holistic approach. Once the data are processed and symptoms are assessed, a knowledge management platform will be developed to provide a Decision Support System (DSS) that suggests modifications in the medication plan [64]. The research team communicates their plan on testing PD_manager during 2017, involving 200 PD patients, from clinical centers in Ioannina, Surrey, Venice, and Rome. Patients with motor fluctuations and significant disability (Hoehn and Yahr stage 3 or greater) and with at least 3 h OFF time during the day (based on MDS-UPDRS) are considered eligible for this study. All patients will be daily evaluated according to UPDRS and will keep their 3-day diaries [64].

Many wearable technologies for vital signs and activities that are nowadays commercially available (e.g., Withings, France; Polar Electro Oy, Finland; XSens Technologies, Netherland; and FitBit, the USA) and a lot of technical and technological solutions that were presented in the last decade for wearable body sensor network can be combined within a smartphone app. Moreover, design, implementation, and adoption of smart clothes for health monitoring and healthcare are gaining weight in research, healthcare systems, and businesses. A comprehensive review of smart clothes with capability of body vital functions and activity monitoring, with potential use in neuro-motor rehabilitation, might be found in [80]. Figure 13.2 represents various sensing technologies that can be combined in a smartphone platform and their potential position on the body.

Smartphone applications can monitor PD patients' (i) gait (i.e., by using accelerometer and/or force sensors embedded in insole or shoes and also inertial measurement unit from inside smartphone or attached to legs or waist); (ii) posture (i.e., by using inertial measurement unit or accelerometer attached to ear or lumbar region, and force sensors in shoes); (iii) vital signs (i.e., heart beat and respiration by using smartphone embedded sensors or by using wearable devices attached to the chest or arms); (iv) speech (i.e., by using a microphone from smartphone or attached microphone); (v) daily activities (i.e., by using inertial measurement unit from smartphone or wearable devices that include accelerometer and/or gyroscope, linked to smartphone). Also, smartphone apps (i) may improve communication between patients and health professionals and also between different health professionals and informal caregivers for better PD patient healthcare; (ii) may empower and engage patients in their treatment; (iii) may improve medication and therapy adherence; (iv) may provide access to educational resources related to PD and healthy life style; and (v) may contribute for reduction on PD patients' social isolation (i.e., facilitating access to online social networks and information on nongovernmental actions related to PD patients or elderly people). These technologies may contribute to increase diagnosis accuracy and to assess fluctuating events (e.g., ON and OFF state of PD), to capture and send alerts on some events (e.g., falls, freezing of gate) and to better define therapeutic strategies. Simple examination using a smartphone-based tool, during tandem walking [21] or hand grip [81] can serve as an effective clinical assessment tool to determine changes in posture, gait, and muscle activity. Moreover, much information on different aspects of the disease can be obtained using smartphone apps. This information may contribute to differentiate PD subtypes. Nowadays, different PD subtypes were described, all having weaknesses highlighted by different clinicians. Recently, analysis of 769 PD patients with mean disease duration of 1.3 years had identified three subtypes that were characterized by (i) psychological well-being features; (ii) nontremor motor features, such as posture and rigidity; and (iii) cognitive features [82]. Their subsequent five-cluster model identified groups characterized by (i) mild motor and nonmotor disease (25.4%); (ii) poor posture and cognition (23.3%); (iii) severe tremor (20.8%); (iv) poor psychological well-being, RBD, and sleep (18.9%); and (v) severe motor and nonmotor disease with poor psychological well-being (11.7%). These subtypes are clearly more adequate than those described in the previous study based on systematic review of the 242 case files of PD patients registered at Queen Square Brain Bank for Neurological Disorders, in which also three subtypes of PD were identified: (i) earlier disease onset (25%), (ii) tremor dominant (31%), and (iii) nontremor dominant (36%) and rapid disease progression without dementia (8%) subgroups [83]. Other classification of PD patients was proposed based on the largest retrospective review of the DATATOP trial [84] considering empiric investigator-determined UPDRS characteristics. The 800 subjects with early PD were classified as exhibiting (i) postural instability and gait difficulty-predominant disease (PIGD; 55.1%); (ii) tremor-predominant disease (29.1%), or an (iii) indeterminate subtype (15.8%). This classification system has now been updated for the MDS-UPDRS motor scale [85]. The formula used to categorize PD patients as having the PIGD subtype involves calculating the ratio of tremor-related items on the MDS-UPDRS to PIGD-related items [85]. Vikas Kotagal [86] questioned these classifications, considering that few patients fit well within these discrete categories, and many patients can exhibit elements that may be characterized as transitory from one subtype to another. He suggests a classification of PD subtype taking into account a model of postural instability and gait difficulty—predominant features that emphasize the overlooked pathological influence of aging and medical comorbidities on the development of axial motor burden and postural instability and gait difficulty predominant features. Also, he proposes thinking the PD postural instability and gait difficulties not as a discrete subtype but rather as multidimensional continuum influenced by several overlapping age-related pathologies. We add to this view the suggestion for a model that takes into consideration the influence of aging and medical comorbidities not as a linear progression from early to severe stage of the disease but as a nonlinear model in which the improvements produced by medication, cues exposure therapy, and environmental factors are represented. These data will better draw upon the new source of data from digital mobile sensors.

The large inter- and intra-subject clinical variability in clinical symptoms of PD patients require development of methods for tailored technology considering PD subtype and patient current and anticipated needs. Affordability of the wearable technology, the increase in data availability related to PD patients (i.e., inclusion and analysis of many data in open databases with acquired signals from patients as Physionet database—www.physionet.org; REMPARK—www.rempark.eu; UC Irvine Machine Learning Repository—Voice Recordings and Daphnet Freezing of Gait Data Set; mPower—www.synapse.org) may contribute for better PD diagnosis and monitoring.

13.4 Conclusions

There are important advances on smartphone-based tools for objective, relevant, accurate information on motor and nonmotor aspects of PD. Research is still needed to overcome various limitations of nonelectronic and smartphone-based tools for assessments and monitoring of PD symptoms and signs and to build smartphone applications that may improve the quality of life of PD patients. As no high-level evidence was identified related to the use of smartphone-based applications for PD diagnosis or monitoring, more research is needed for the validation of the new technologies, methods, and their performances across various PD subtypes and degrees of disease severity, in clinical laboratory settings, in home, or community settings.

Moreover, in the near future, the development of the valid algorithms and techniques that may allow accurate detection and differentiation of PD symptoms against a background of various activities in home or community settings is required. Building high level of evidence on the effectiveness of these smartphone applications will be essential for adoption in large scale of these technologies. The information from this chapter is therefore important for developers and researchers interested in new technologies for PD assessment. It is also important for clinicians who may define new strategies for improving PD diagnosis accuracy and diagnosis of PD in the early stage, for improving the clinical care reasoning and therapeutic decisions, and for more personalized therapeutic approaches. But for all—the developers, researchers, and clinicians alike—it is essential that a pool of high-level evidence is built up through many studies that people obviously are willing to conduct.

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Chapter 14
A Mobile Solution Based on Soft Computing for Fall Detection

Serkan Ballı, Ensar Arif Sağbaş, and Musa Peker

Abstract Falling is an important health risk, especially for the elderly people. This situation prevents individuals from living independently. Automatic and high-accuracy detection of the falls will contribute in preventing the negative situations that may occur. In this study, a mobile solution with a new architecture for the detection of falls is presented. For this purpose, motion sensor data have been collected simultaneously from smartwatch and smartphone with Android operating system. Data sets for both smartwatch and smartphone have been created by labeling the falls and actions which are not falling in the data. The performances of Decision Tree, Naive Bayes, and k-Nearest Neighbor (kNN) methods have been tested on these data sets, and the kNN method has given the best result on two data sets. Accordingly, the kNN method is used for classification in the developed Android-based mobile solution. In addition, it is aimed to detect and prevent actions that could lead to bad results by monitoring the heart rate of the user with the built-in heart rate monitor on the smartwatch.

14.1 Introduction

Falling is the cause of hospitalization in elders, which can result in injury [1]. A low-cost, high-efficiency mechanism for detecting falls is also important for many health and safety applications, including elderly care [2]. There are numerous deadly injuries due to falls. It is important to establish an automatic fall detection system, including the home environment, as reduction of the rescue period after the fall

S. Ballı · M. Peker
Faculty of Technology, Information Systems Engineering, Muğla Sıtkı Koçman University, Muğla, Turkey
e-mail: serkan@mu.edu.tr; musa@mu.edu.tr

E. A. Sağbaş (✉)
Faculty of Engineering, Department of Computer Engineering, Ege University,İzmir, Turkey
e-mail: ensar.arif.sagbas@ege.edu.tr

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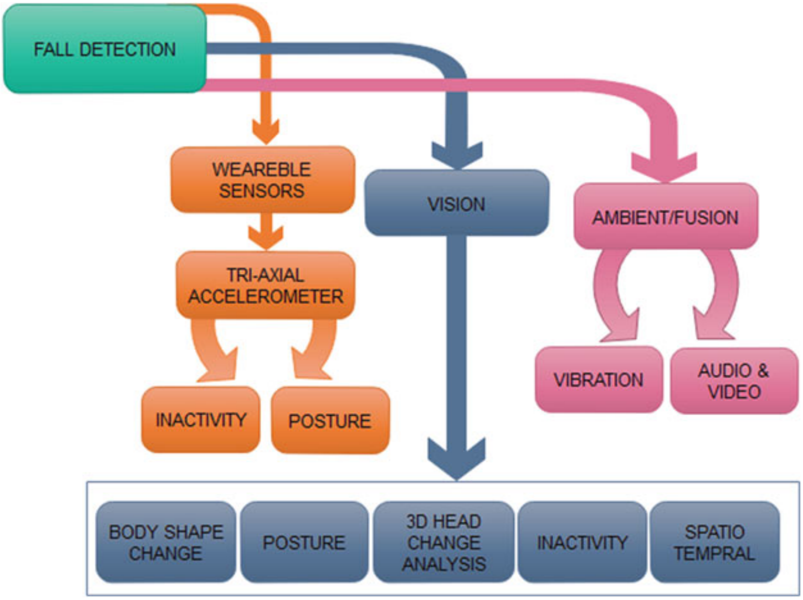

Fig. 14.1 Classification of fall detection methods [5]

detection may increase the overall survival rate of the aged person to an extreme extent [3]. Automatic fall detection helps people stay at home safely by reducing the negative consequences of falls in elders by encouraging independent living [4]. The methods used for automatic fall detection are classified in Fig. 14.1.

Thanks to wearable technology, many products such as watches, shoes, glasses, and clothes we use in everyday life have more features than normal [6]. With these devices, various information about the user can be obtained and evaluated. When falling detection is considered, most systems that have been described till today include threshold-based algorithms; machine learning-based fall detections carried out in recent years provide increased accuracy [1]. There are studies in the literature that provide mobile solutions for falling by using machine learning methods and wearable detectors.

Gibson et al. [7] have presented and evaluated an accelerometer-based multiclassifier fall detection and diagnostic system for remote health control. Kwolek and Kepski [8] have presented a new approach for reliable fall detection. In their study, the moment of the collision has been determined using the acceleration data; thus, it has been possible to calculate the time exposure transitions. Srinivasan et al. [9] have developed a wireless sensor network system for automatic fall detection. To detect falls, they used a combination of motion detectors placed in the field of view and a three-axis accelerometer attached to the body. Amin and Zhang [10] have described the signal processing algorithms and techniques involved in detecting the fall of the elders with radar signals. Radar signals have a nonstationary structure and play a fundamental role in defining the motion, including determining and classifying falling features. Wang et al. [3] have investigated correlations between different types of radio signals and their activities by analyzing the radio propagation model. In this context, they have proposed a fall detection system that is named WiFall. Skubic et al. [11] have described two studies in which fall detection sensor technology has been tested. Bourke et al. [4] have extracted 12 different features from the data set which includes 89 fallings and 368 days of action. Machine learning method has been applied to the extracted features, and a number of algorithms based on different feature combinations have been created. Chen et al. [2] have proposed an accurate, over-sourced, adaptive fall detection approach by using smart devices with integrated wireless connectivity and sensors. Hsieh et al. [12] have proposed a machine learning-based fall detection algorithm using multiple Support Vector Machine (SVM) and k-Nearest Neighbor (kNN) classifiers with linear, quadratic, or polynomial kernel functions. Aziz et al. [1] have compared the accuracy of machine learning-based and threshold-based fall detection approaches in the fall data set obtained from ten young participants. Cola et al. [13] have investigated the use of a barometer (e.g., embedded in a pair of eyewear) placed in the wearer's head as a means to develop existing wearable sensor-based fall detection methods.

In this study, an Android-based mobile solution has been developed in order to minimize the injuries via notifying related persons or organizations by detecting falls for elderly people. For this purpose, motion sensor data have been obtained from smartwatches and smartphones with Android operating system, and these data have been evaluated by machine learning method. With this mobile solution that has a new architecture of using smartwatch and smartphone together, it is aimed to minimize the problems that may arise as a result of falls. After the detection of the fall, information about the patient or elderly (position, position changes, and actions) is transferred to the necessary units (caregiver, hospital, etc.) in mobile environment.

Smart device sensors will be explained later in Sect 14.2. The method used in experimental study and the findings will be discussed in Sect 14.3. After that, the architecture of the developed Android-based mobile solution will be elaborated in Sect 14.3.1. Finally, the study will end with the obtained results.

14.2 Sensors

In the scope of the study, gyroscope and accelerometer sensors have been used to detect the fall. When fall detection is performed, the global positioning system (GPS) sensor is used to determine the location of the fall. In addition, thanks to the heart rate monitor, it is aimed to prevent the occurrence of a negative situation for the person by detecting and monitoring the heart rate of the person during the day.

14.2.1 Accelerometer

The built-in accelerometer sensor of smartphones and smartwatches measures the acceleration affecting the smartphone and smartwatch in the direction of the axes shown in Fig. 14.2. The raw sensor information is obtained from the accelerometer in three axes in m/s^2. The content of the raw accelerometer sensor data is given in Eq. 14.1:

$$\mathrm{Acc}_i = < x_i, y_i, z_i >, \; i = (1, 2, 3, \ldots) \tag{14.1}$$

Time information is also obtained in addition to the acceleration values. Most existing accelerometers allow you to set (on the user interface) how many sample data will be collected in seconds. Thanks to this, users can select the most appropriate sample rate for his/her study [14].

Accelerometer is often used in smart device-based action recognition applications. This sensor's popularity comes from the fact that the sensor can directly calculate the physical movement of the device or user. For example, if the user moves from walking to jumping state, accelerometer signals will change on the vertical axis [14, 15]. According to Fig. 14.2, the *X*-axis gives information for the side face of the device, the *Y*-axis for a vertical position, and the *Z*-axis for the flat (supine) position [16]. For example, if the *Z* value is 0 or very close, it means that the device is standing on one of its edges. When operating with an accelerometer, it should be kept in mind that, the accelerometer calculates the linear acceleration of the device, the numerical value obtained is the gravitational force affecting the device, and if the device is in motion, it is the acceleration of the device and gravitational force [17].

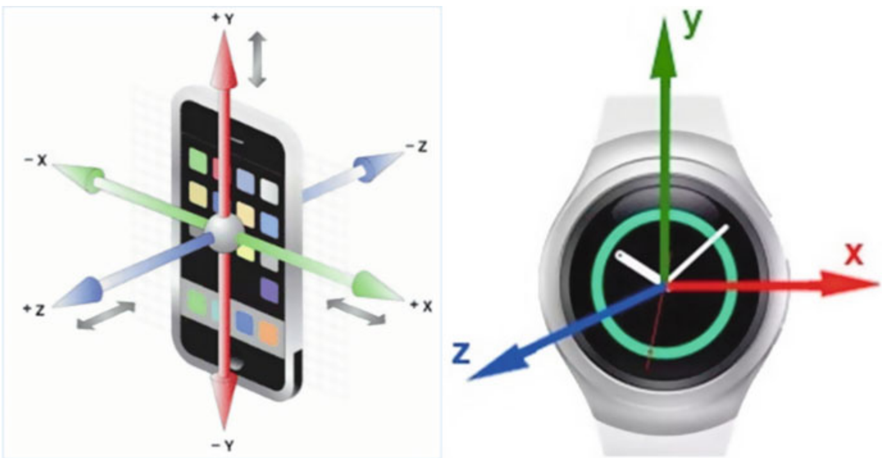

Fig. 14.2 Accelerometer sensor axes of smartphone and smartwatch

14.2.2 Gyroscope

A gyroscope is a tool which is used to detect or measure direction. It is used to find direction in aircrafts and ships in everyday life [17, 18].

The rotation of the Earth, shown in Fig. 14.3, also carries the characteristic feature of a gyroscope. The Earth's rotation on its axis creates a balancing effect and allows it to rotate while showing the pole star. Rapidly rotating propeller, sphere, ball, etc. are basically a gyroscope. As shown in Fig. 14.4, the gyroscope consists of a rotor (disk) with free rotation and interconnected joints (gimbal joints) [19].

The gyroscope sensor on the smart devices gives the angular velocity that the smart device has made on the x, y, and z axes. The gyroscope axis trajectories for smartphones are shown in Fig. 14.5. The raw data obtained from the gyroscope sensor report the rotation of the smart device around the three physical axes in rad/s. The contents of raw gyroscope sensor data are given in Eq. 14.2:

$$\text{Rotation}_i =< x_i, y_i, z_i >, \ i = (1, 2, 3, \ldots) \tag{14.2}$$

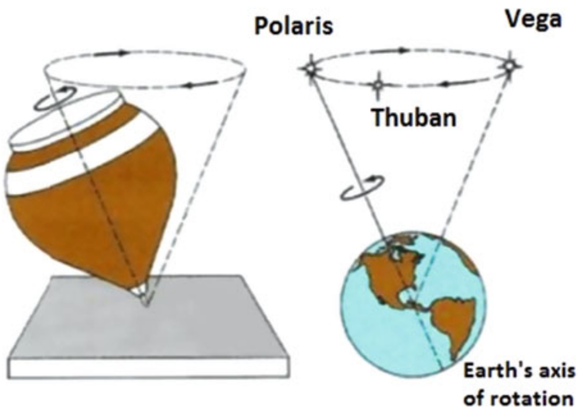

Fig. 14.3 The world's rotation movement [19]

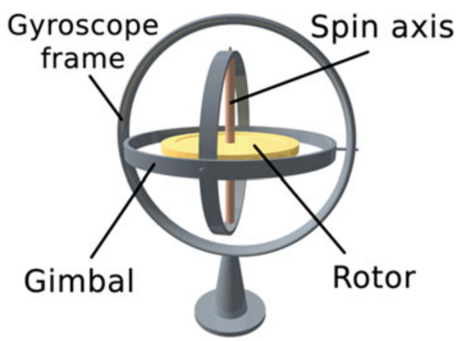

Fig. 14.4 Structure of gyroscope [20]

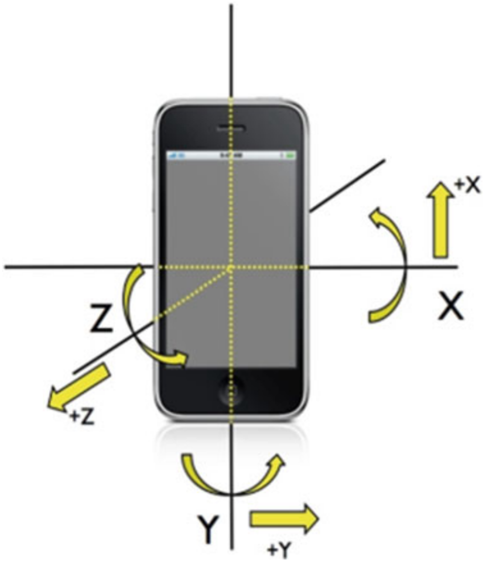

Fig. 14.5 Sensor axes of smartphone gyroscope

The gyroscope sensor is used in smartphone games with character orientation. This sensor is used to perform direction determination in action recognition studies [14, 15].

14.2.3 Global Positioning System (GPS)

GPS, which is shown in Fig. 14.6, is a satellite-based guidance system developed by the US Department of Defense in the beginning of the 1970s. This system has been developed primarily for military purposes, but personal usage has become possible with time. GPS is a passive system that can provide location and time information to unlimited persons anywhere in the world under any weather conditions. In other words, users have position information by processing the signals coming from the satellite [15, 21].

In smart devices, location can also be determined with the help of wireless networks and associated base stations. However, if the device does not have a GPS sensor, position detection can be performed with limited accuracy. The GPS signal contains the following parameters [17, 22]:

- *Latitude:* Obtained in degree unit. Latitude positive values denote the north of the equator, and negative values denote the south of the equator.
- *Longitude:* Measurements are according to zero meridian. It is obtained in degree units. Positive values indicate eastern meridians, and negative values indicate western meridians.

Fig. 14.6 GPS satellites in orbit around the world

- *Velocity:* The device's instantaneous velocity is calculated in meters/second. It cannot be calculated if it does not receive a GPS signal. The velocities with a negative value are invalid.
- *Altitude:* Altitude is calculated in meters. Positive values indicate the altitude of the device from the sea level.

In addition, other features of GPS are as follows [17, 23, 24]:

- GPS devices are passive receivers. They do not give feedback to satellites.
- GPS satellites are synchronized using atomic clocks.
- Satellites periodically transmit signals containing current location and time information. The distance between the receiver and the satellite can be calculated according to the time of arrival of these signals to the receiver. Figure 14.7 shows an example of positioning in two dimensions. If the satellite positions (S_1, S_2, S_3) and distances (ρ_1, ρ_2, ρ_3) between the user and the satellites are known, the user position indicated by U can be found. If two distance information is used, there will be two candidates for the user's position because the circles will have two intersection points. With the third distance information, the user position can be determined precisely [25].
- GPS does not work in an indoor environment.

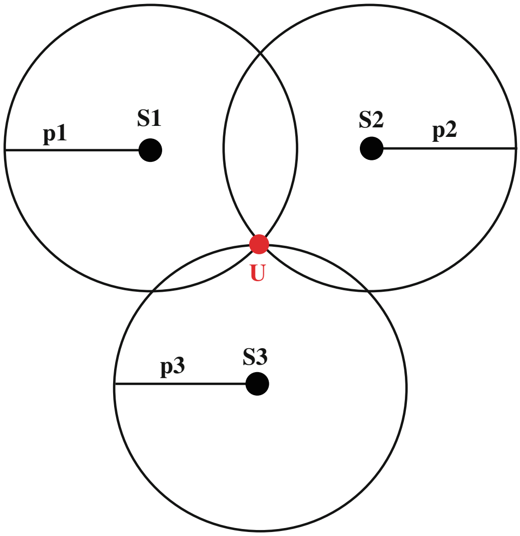

Fig. 14.7 Positioning in two dimensions [25]

- GPS quickly consumes the battery life of the device.
- A position fix takes a very long time (30 s–12 min).
- The buildings reflect or block GPS signals. Due to this reason, the accuracy rate decreases in settlements.

14.2.4 Heart Rate Monitor

The heart rate sensor transmits the information of how many times the user's heart beats in a minute. The accuracy rate reported by the sensor provides information about the situation in which the pulse has been read [26]. Many wearable devices with a heart rate sensor use a method called Photoplethysmography (PPG) to calculate heart rate. PPG is a technical term that calculates the amount of light scattered by blood flow by illuminating the skin. Thus, the change in heart rate can be calculated. The structure of the heart rate sensor is shown in Fig. 14.8 [27]. PPG uses four technical components to calculate heart rate.

- *Optical transmitter:* Generally, it consists of at least two LED light sources for transmitting light waves into the skin. This is because of differences in skin tones.
- *Digital signal processor:* The digital signal processor captures the light waves broken from the user's skin and calculates significant heart rate data between 1 and 0.
- *Accelerometer:* An accelerometer measures the motion, and it is used with digital signal processor's signals as input to motion-tolerant PPG algorithms.

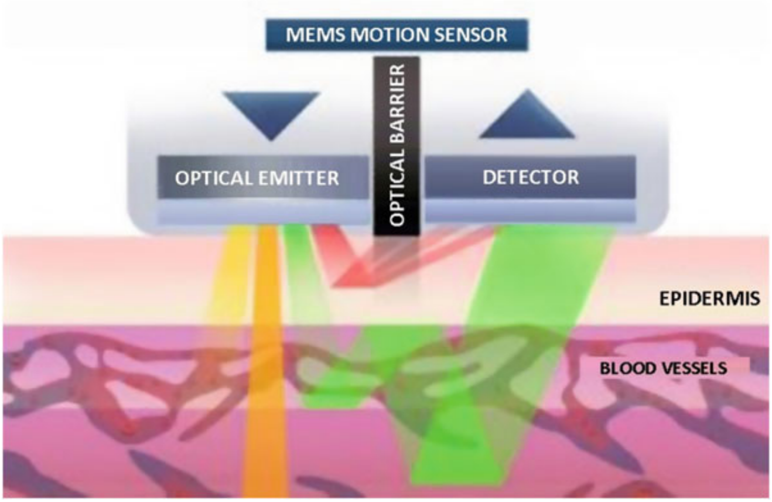

Fig. 14.8 Optical heart rate sensor structure [27]

- *Algorithms:* Information such as calories burned, heart rate variability, and heart oxygen level can be calculated by the data from the digital signal processor and accelerometer.

14.3 Methods

14.3.1 k-Nearest Neighbor (kNN)

The k-nearest neighbor method, which is a classification method, is an algorithm that classifies based on distance. This method, which does not have a connection between its features, is one of the controlled machine learning algorithms that is simple to interpret and implement and easy to have results. kNN uses the nearest neighbor samples to classify or estimate patterns in n-dimensional feature space. In order to be able to classify in the kNN algorithm, the number of nearest neighbors to be considered is expressed with a positive integer k. If k is 1, the pattern to be classified will be included in the class where the nearest neighbor is located. This method is also used for estimation.

In the determination of the nearest neighbors, the distance between the selected sample and the samples in the training set is measured. The distances between the samples are sorted from least to the maximum; this sequence also shows the order that is from the closest neighbor (from the selected sample) to the farthest neighbor [28]. For distance calculation, Manhattan, Euclid, and Minkowski distance measures are used. The formulas for these criteria are presented in Eqs. 14.3, 14.4, and 14.5, respectively:

$$d\,(i, j) = \left|X_{i1} - X_{j1}\right| + \left|X_{i2} - X_{j2}\right| + \cdots + \left|X_{ip} - X_{jp}\right| \tag{14.3}$$

$$d\,(i, j) = \sqrt{\left|X_{i1} - X_{j1}\right|^2 + \left|X_{i2} - X_{j2}\right|^2 + \cdots + \left|X_{ip} - X_{jp}\right|^2} \tag{14.4}$$

$$d\,(i, j) = \sqrt[p]{\left|X_{i1} - X_{j1}\right|^p + \left|X_{i2} - X_{j2}\right|^p + \cdots + \left|X_{ip} - X_{jp}\right|^p} \tag{14.5}$$

14.3.2 Decision Tree (C4.5)

The C4.5 algorithm provides obtaining the classification trees of features with categorical and numerical values. During the creation of the classification trees, starting (from which feature) of branching is important. Uncovering all possible tree structures by taking advantage of a training data set and selecting the most suitable ones among these tree structures causes the repetition of many operations. For this reason, the classification tree algorithms calculate the various values at the beginning of the process and proceed to create the tree according to these values. Entropy can be used for this purpose. Branching of the tree will take place according to the entropy value.

Assume that the class attribute is divided to k class as $\{C_1, C_2, \ldots, C_k\}$ according to the values class attribute will take. Class attribute is the probability distribution of P_T classes for (T) and calculated as shown in Eq. 14.6:

$$P_T = \left(\frac{|C_1|}{|T|}, \frac{|C_2|}{|T|}, \ldots, \frac{|C_k|}{|T|}\right) \tag{14.6}$$

$|C_i|$ gives the number of elements in the C_i set. For example, $p_1 = |C_1|/|T|$ probability. Thus, $P_T = (p_1, p_2, \ldots, p_k)$. The average amount of information for T is expressed in entropy using Eq. 14.7 [29]:

$$H(T) = H\,(P_T) = -\sum_{i=1}^{k} p_i \log_2\,(p_i) \tag{14.7}$$

14.3.3 Naïve Bayes

Naive Bayesian Classifier is a simple algorithm based on probability, with strong attribute independence assumption. The Naive Bayesian Classifier performs learning through the test data and includes the highest sample into the class. Assume that C denotes a class. $x\langle x_1, x_2, x_3, \ldots, x_m\rangle$ values are the values of the observed features. c denotes a known class label, and $x\langle x_1, x_2, x_3, \ldots, x_m\rangle$ denotes the values of known and observed features. The Bayes Theorem calculates the probability to estimate the class according to x test data:

$$p\left(C = c_j \middle| X = x\right) = \frac{p\left(C = c_j\right) p\left(X = x | C = c_j\right)}{p\left(X = x\right)} \tag{14.8}$$

After that, it estimates the class with the highest probability. In this example, $X = x\ X_1 = x_1 \ \hat{}\ X_2 = x_2 \ \hat{}\ X_3 = x_3 \ \hat{}\ \ldots \ \hat{}\ X_m = x_m$. $p(X = x)$ is ignored in cases where it does not show any change between classes, and Eq. 14.8 is as follows:

$$p\left(C = c_j \middle| X = x\right) = p\left(C = c_j\right) p\left(X = x \mid C = c_j\right) \tag{14.9}$$

where $(C = c_j)$ and $p(X = x|\ C = c_j)$ are predicted from learning data. X_1, X_2, X_3, $\ldots$, X_m features are conditionally independent from each other. In this case, Eq. 14.9 is as follows:

$$p\left(C = c_j \middle| X = x\right) = p\left(C = c_j\right) \prod_{i=1}^{m} p\left(X_i = x_i \middle| C = c_j\right) \tag{14.10}$$

Using the Naive Bayes equation given in Eq. 14.10, it is much easier to calculate test samples and estimate from the learning data. The Naive Bayes Classifier can handle both categorical and numeric features. For each discrete feature, $p(C = c_j \mid X = x)$, which in Eq. 14.10 is modeled with real numbers between 0 and 1. Estimation probabilities are obtained by the frequency of samples in the training data. In this approach, if x_i is not among the training data then zero will be obtained as a result of $p(X_i = x_i \mid C = c_j)$ [30–32].

14.4 Experimental Results and Applications

14.4.1 Data Set and Feature Extraction

The data set has been created with motion sensor (accelerometer and gyroscope) data simultaneously collected from smartwatch and smartphone. To this end, Android and Android Wear-based mobile applications that work in sync with each other have been developed. Among the obtained motion sensor data, the parts of the fall action have been separated manually and the patterns of the FALL class have obtained. As a result of examining the data, it has been deemed appropriate to use a window interval of 0.7 s for FALL patterns. As in the previous studies [6, 15] carried out with smartwatches and smartphones, smart devices were set up to collect 50 sensor data in a second and patterns were generated with $0.7 \times 50 = 35$ sample data. Data samples of falls for smartwatches and smartphones are shown in Fig. 14.9 (accelerometer) and Fig. 14.10 (gyroscope).

104 FALL patterns have been obtained for smartwatch, and 115 FALL patterns have been obtained for smartphone. Classes other than the fall class are completed with the data (walking, descending a ladder, ascending a ladder, using stationary, and using an elevator) used in the study [15] for smartphone, and data (brushing teeth, writing, writing board, using keyboard, stationary, vacuuming, and walking activities) used in the study [6] for smartwatch. However, these classes have been evaluated as NOT_FALL. In other words, incorrect classifications between NOT_FALL classes have not affected FALL classification. Features of the patterns have been created by calculating the max, min, standard deviation, and mean values of the data obtained from the triaxial accelerometer and gyroscope at 0.7 s. The extracted features are presented in Table 14.1.

14.4.2 Classification

Classification of data sets created for smartwatch and smartphone has been carried out with machine learning methods. At this stage, the kNN, Naive Bayes, and C4.5 algorithms have been used and their performances have been compared. In the developed fall detection mobile application, the most successful method has been

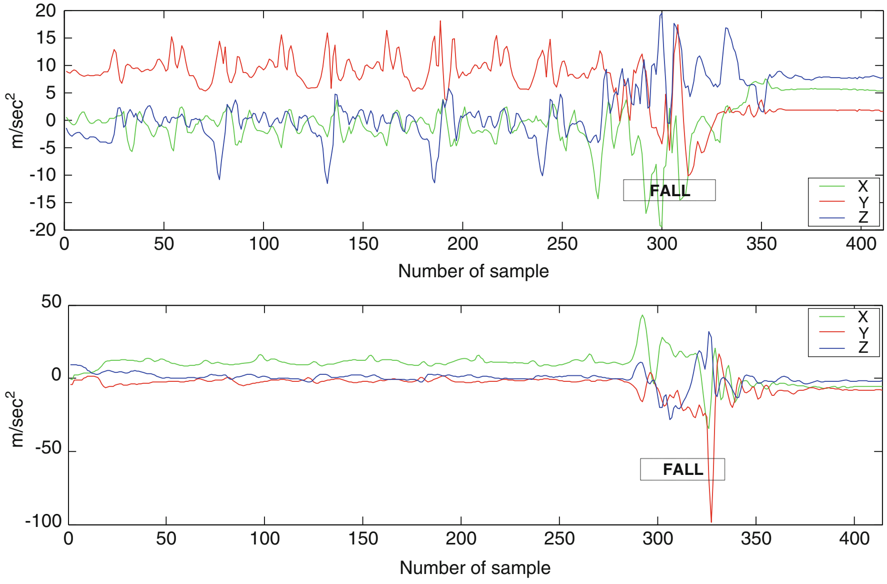

Fig. 14.9 The fall data obtained from accelerometer sensor

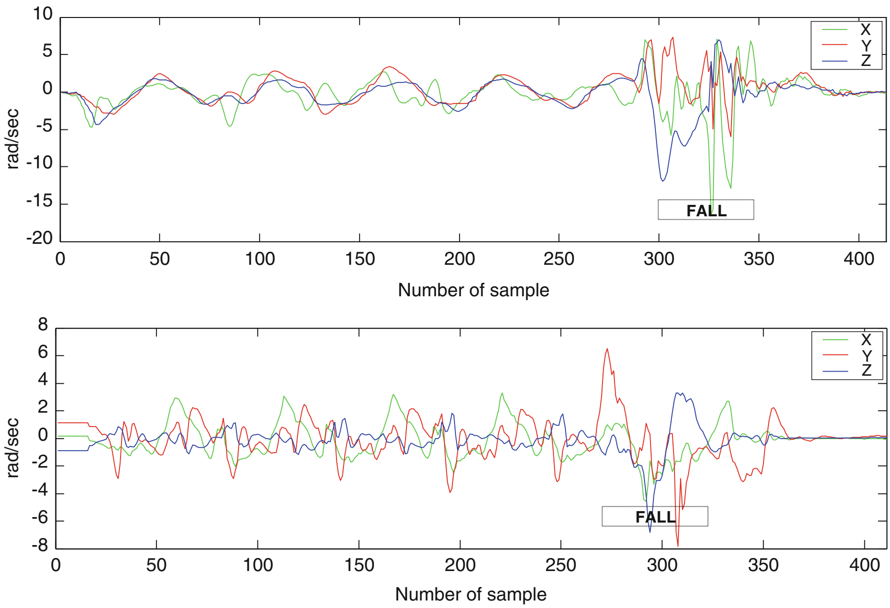

Fig. 14.10 The fall data obtained from the gyroscope sensor

Table 14.1 Feature list

Feature number	Sensor	Description of features
1, 2, 3	Accelerometer	Standard deviation of accelerometer (*x*, *y*, and *z* axes) sensor data
4, 5, 6	Accelerometer	Mean of accelerometer (*x*, *y*, and *z* axes) sensor data
7, 8, 9, 10, 11, 12	Accelerometer	Maximum and minimum values of accelerometer (*x*, *y*, and *z* axes) sensor data
13, 14, 15	Gyroscope	Standard deviation of gyroscope (*x*, *y*, and *z* axes) sensor data
16, 17, 18	Gyroscope	Mean of gyroscope (*x*, *y*, and *z* axes) sensor data
19, 20, 21, 22, 23, 24	Gyroscope	Maximum and minimum values of gyroscope (*x*, *y*, and *z* axes) sensor data

chosen. Numerical results of the experiments (classification accuracy, Root Mean Square Error (RMSE), area under Curve (AUC), and F-measure) are given in Table 14.2. Tests have been conducted using the ten-fold cross validation method which is a reliable and frequently preferred data selection method.

When Table 14.2 is examined, it is seen that classification has been carried out with an accuracy of over 97% in all of the tests performed with the smartwatch. In accordance with the accuracy rates, the lowest quadratic error is 0.0523, AUC 0.997, and 0.986 is the highest F-measure obtained with the kNN method. In the tests performed with the smartwatch, the most successful result has been obtained from the kNN method as in the smartphone. With this method, 0.1172 RMSE, 0.989

Table 14.2 The result obtained with smartwatch and smartphone

Method	CA	RMSE	AUC	F-Measure
Smartwatch				
Naive Bayes	97.6	0.0752	0.997	0.976
kNN ($k = 5$)	98.55	0.0523	0.997	0.986
C4.5	98.44	0.0594	0.996	0.984
Smartphone				
Naive Bayes	91.74	0.164	0.982	0.915
kNN ($k = 5$)	94.78	0.1172	0.989	0.948
C4.5	91.3	0.1628	0.951	0.913

Table 14.3 Confusion matrices obtained from the kNN method

Smartphone		
Classified as	**FALL (%)**	**NOT_FALL (%)**
FALL	93.9	6.1
NOT_FALL	0	100
Smartwatch		
Classified as	**FALL**	**NOT_FALL**
FALL	97.1	2.9
NOT_FALL	0	100

AUC, and 0.948 F-Measure values have been obtained. In the developed mobile applications, the kNN method has been used in the direction of the experiments performed. The confusion matrix obtained with the kNN method is presented in Table 14.3.

When the confusion matrices are examined, it is seen that NOT_FALL actions are classified with 100% accuracy in both devices. FALL action is classified with approximately 94% by smartphone and approximately 97% with smartwatch.

14.4.3 Mobile Solution for Fall Detection

Within the scope of the study, falls have been determined by using the data together obtained from smartwatch and smartphone. The data obtained from both devices are classified within itself, and if both devices decide FALL, then the system decides that the person falls. ListenerService, whose codes have been shared in Fig. 14.11, has been used in the communication between the smartphone and smartwatch. The fall detection algorithm is shown in Fig. 14.13.

In the developed mobile solution, the smartwatch only gathers the motion sensor data and transmits to the smartphone. In the same time frame, the smartphone also acquires sensor data. The extraction of the features from the raw data and the classification of them by the kNN method are performed by smartphone. In order for the system to operate at the same time, the user sends a “BEGIN” signal to the phone by pressing the “BEGIN” button (Fig. 14.14a) in the smartwatch interface and this button becomes “END” button (Fig. 14.14b). The smartphone receiving the

```
public class ListenerService extends WearableListenerService{
    @Override
    public void onMessageReceived(MessageEvent messageEvent) {
        if (messageEvent.getPath().equals("/message_path")) {
            String message = new String(messageEvent.getData());
            Intent messageIntent = new Intent();
            messageIntent.setAction(Intent.ACTION_SEND);
            messageIntent.putExtra("message", message);
            LocalBroadcastManager.getInstance(this).sendBroadcast(messageIntent);
            Log.v("myTag", "Message path received on watch is: " + messageEvent.getPath());
            Log.v("myTag", "Message received on watch is: " + message);
        }else {
            super.onMessageReceived(messageEvent);
        }//else
    }//onMessageReceived
}//WearableListenerService
```

Fig. 14.11 ListenerService codes

```
SensorManager sensorManager;
sensorManager = (SensorManager) getSystemService(Context.SENSOR_SERVICE);
sensorManager.registerListener((SensorEventListener) MainActivity.this,
sensorManager.getDefaultSensor(Sensor.TYPE_GYROSCOPE), 20000);
sensorManager.registerListener((SensorEventListener) MainActivity.this,
sensorManager.getDefaultSensor(Sensor.TYPE_ACCELEROMETER), 20000);
```

Fig. 14.12 Codes for activating sensors

“BEGIN” signal changes its state from “WAITING” (Fig. 14.20a) to “ACTIVE” (Fig. 14.20b) and starts collecting the sensor data. The sample code block needed to collect the sensor data is as shown in Fig. 14.12.

With this process, the watch and the phone start collecting sensor data at the same time, and patterns are generated every 0.7 sec. These patterns are classified by the kNN method and are added to circular queue structures separately for the smartphone and smartwatch (Fig. 14.15). These queue structures are set to consist of three elements. This method has been applied with the purpose of preventing the possible error caused by the time elapsed between the communication of smartwatch and smartphone.

If FALL action is found in both of the queues when both of the circular queues reach at three elements, the system decides that the FALL action is performed and the smartphone sends a “FALL” signal to the smartwatch. The system that decides the FALL action gives the user 3 s to cancel this decision. The “END” button on the smartwatch turns into the “CANCEL” button (Fig. 14.14c), and the screen background turns into red as an alert and the smartwatch vibrates. After 3 s, if the user does not cancel this decision, the final fall decision is made and the “CANCEL” button turns into the “FALL” button (Fig. 14.14d). Then, the “FALL” signal is sent to the smartphone. A 3-sec waiting period for canceling the detected fall is provided by the codes presented in Fig. 14.16.

After the smartphone receives the “FALL” signal, the system stops (Fig. 14.20c) and the location of the fall is sent to the predefined phone number via SMS (Fig. 14.20d). The use of the SMS library is as shown in Fig. 14.17:

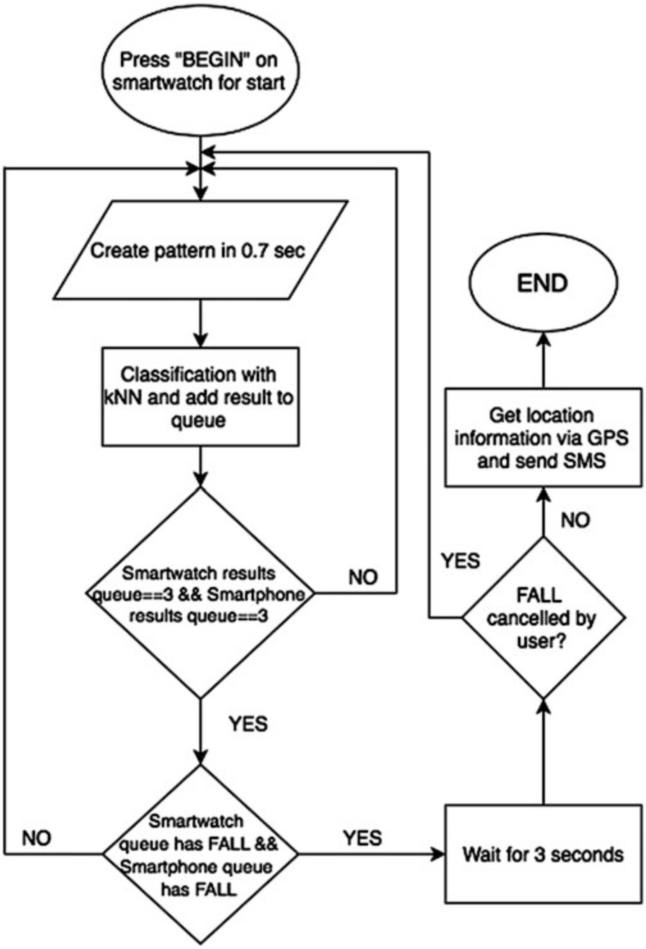

Fig. 14.13 Fall detection algorithm

Fig. 14.14 Smartwatch mobile application screenshots

For location detection, sending SMS, and using the heart rate sensor on devices with Android operating system, the lines in Fig. 14.18 should be added to the AndroidManifest.xml file.

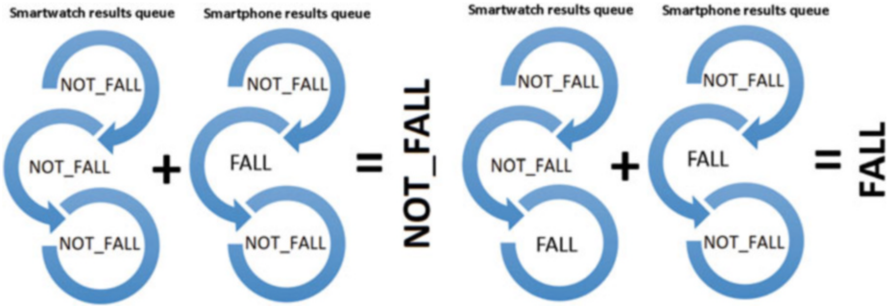

Fig. 14.15 Circular queue structure

```
handler.postDelayed(new Runnable() {
    @Override
    public void run() {
        if (status == 2) { //status=2 FALL
            new SendToDataLayerThread("/message_path", "FALL").start();
            button.setText("FALL");
        }
    }
},3000);
```

Fig. 14.16 Codes for cancellable waiting process

```
String phoneNo = "123456789";
SmsManager sms = SmsManager.getDefault();
String messageText = "Message text here!";
sms.sendTextMessage(phoneNo, null, messageText, null, null);
```

Fig. 14.17 Use of SMS library

```
<uses-permission android:name="android.permission.ACCESS_FINE_LOCATION"/>
<uses-permission android:name="android.permission.SEND_SMS"/>
<uses-permission android:name="android.permission.BODY_SENSORS"/>
```

Fig. 14.18 Permission list for using sending SMS, accessing GPS, and heart rate sensor

```
LocationListener locationListener;
LocationManager locationManager;
locationListener = new myLocationListener();
locationManager = (LocationManager) getSystemService(Context.LOCATION_SERVICE);
locationManager.requestLocationUpdates(LocationManager.GPS_PROVIDER, 0, 0, locationListener);
```

Fig. 14.19 Codes for location detection with GPS

The code lines required for location detection with GPS are shown in Fig. 14.19.

At the time when the falls are detected, the smartwatch can also check the user's pulse. With a specified threshold point, it is possible to detect situations that may be dangerous. Thus, if an individual is an elderly one, it is possible for the

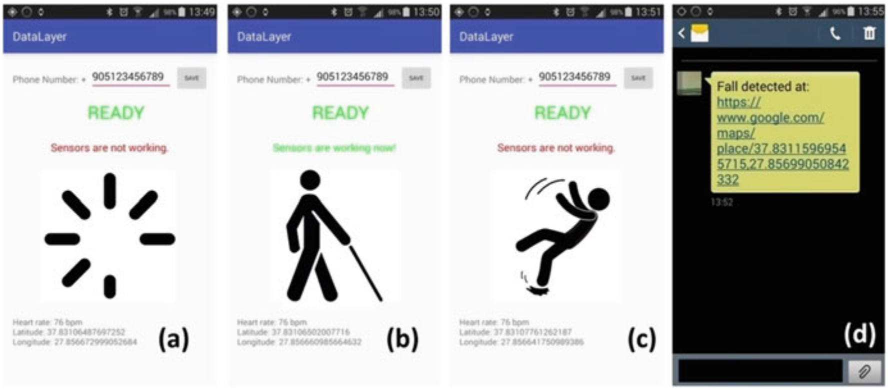

Fig. 14.20 Smartphone mobile application screenshots

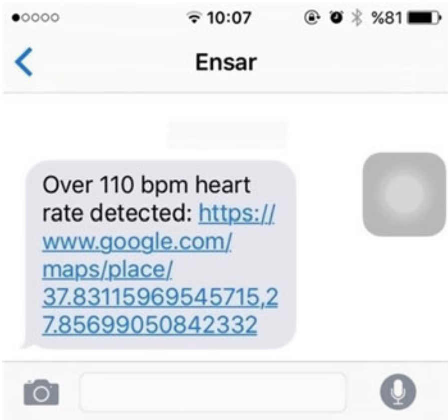

Fig. 14.21 Warning SMS at high heart rate

elderly person's relative to take precaution by being informed (Fig. 14.21) when the followed heart rate signals show an active movement in a harmful level (for instance, running).

In the study, heart rate is determined by the smartwatch, and when the upper limit is exceeded, information is sent by SMS.

14.5 Conclusion

In this study, a new architecture that uses smartwatch and smartphone together has been developed to perform the fall detection more accurately. The features have been extracted from the data obtained from both the smartwatch and smartphone motion sensors. It has been observed that very sharp transitions have occurred in the motion sensor when the falls are occurred. But these transitions can also occur when the user shakes his/her hand hardly or when he/she hits an object on the ground with his/her foot. Thanks to the developed system, it is required to detect the fall for two devices at the same time, so that false fall detections are avoided. Classifications have been carried out by machine learning methods, and over 90% accuracy rate has been obtained. In addition to this, it is aimed to prevent the unwanted situations by following the heart rate information of the user.

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Part IV
Usability

Chapter 15
Improving Trend Analysis Utilizing Misra-Gries Algorithm of User Responses acquired from an Audience Response System

Sarah Y. Doniza

Abstract Innovation in response systems has evolved over time, moving away from hardware that requires extensive wiring to achieve network connectivity. There has been an increasing demand for clickers, a handheld remote control device, used to convey responses to questions. However, clicker-based audience response systems have been difficult to use and deploy. In today's mobile-centric world, an individual with a mobile device has access to infinite opportunities. This study aims to utilize mobile technology to enable members of the audience to respond to questions through their mobile devices instead of additional hardware, which is inconvenient and expensive. This mobile application provides presenters with an important analytics tool that would help process identified aspects, based on participants' responses, with illustrated graphs and identify the most frequent items with minimal user time and effort using Misra-Gries algorithm.

15.1 Introduction

Innovation in response systems has addressed the problems regarding the effectiveness and efficiency of conveying responses [1, 2]. As a result, response systems have evolved over time, moving away from hardware that required extensive wiring toward web-enabled devices [3, 4]. The usage of clicker-based systems has increased. However, problems regarding deployment and accessibility have also been exposed.

S. Y. Doniza (✉)
Malayan Colleges Laguna, Cabuyao, Philippines
e-mail: sarahdoniza@yahoo.com

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EAI/Springer Innovations in Communication and Computing,
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After comprehensive interviews, observations, and surveys, the proponent concluded that because of some practical issues, some institutions have resorted to utilize paper and pen to collect opinions and other information from an audience that have led to some consequences.

With a large number of participants, a presenter or facilitator does not have enough time to obtain every participant's responses. There is also not enough time to provide feedback for every participant's response. Current methods utilizing paper and pen or verbal communication do not allow presenters to assess participants' responses at the time of the session. This leaves the portion of the activity inconclusive, which may lead to misunderstandings and misconceptions. Certain aspects of the session need to be analyzed by the event organizers, for reasons pertaining to future improvements, determined by data gathered from each session. The audience size of each session demands time and manpower to produce necessary reports based on gathered data.

In today's mobile-centric world, an individual with a mobile device has access to infinite opportunities. Over the past few years, the increased penetration rate of smartphones utilizing the Internet has made it feasible to develop a response system that may leverage a new potential [5]. Thus, this study aims to take advantage of mobile technology to enable an audience to respond to questions using mobile phones, instead of additional and unnecessary hardware, for gathering feedback. The proposed mobile application will provide presenters with a tool to accommodate each participant's concerns or questions regarding topics of interest, and give feedback to address these concerns or questions, in a timely manner. The Engage-Monitor-Show mobile app, also known as EMS, allows presenters to collect activity responses from an audience, reduce the paperwork, export and save the response data for either automated or personal assessment. Because data are captured electronically, it eliminates the need to transfer data from paper forms, thus reducing errors, increasing data accuracy and completeness, and the amount of time required for data management. This mobile app delivers efficient collection of data while maintaining participant confidentiality, even in large-group settings. Lastly, EMS provides the presenters important analysis regarding identified aspects, based on the responses of participants, to improve subsequent sessions, eliminating unnecessary manpower and time. This mobile app allows data to be collected and entered simultaneously in real time. It identifies the frequent item using Misra-Gries algorithm. Furthermore, it graphs the results automatically with minimal user time and effort.

15.2 Methodology

15.2.1 Project Design

The EMS mobile-based response system development used the Agile Methodology principles, since it is one of the most preferred methodology adapted for mobile application development [6]. Agile development is defined as the ability to move quickly and easily, relating to a method of project management that is divided into short phases of work and frequent reassessment and adaptation of plans. It allows periodic product delivery to the customer and further development after each release.

Agile development methodology provides opportunities to assess the direction of a project throughout the development lifecycle.

- *Planning Stage:* During this phase, the proponent defined requirements and gathered data through surveys given to students and professors and interviews given to some political leaders. One of the interviews conducted was with the Honorable Municipal Mayor, Walter Echevarria Jr., of General Mariano Alvarez, Cavite. The purpose of the interview is to get information about how the city officials gather information from their constituents for the purpose of census data, opinion survey, satisfaction survey, and public participation regarding municipal issues. The proponent also interviewed Barangay Captain Benjamin C. Detic of Francisco Reyes in the same municipal town and one of the barangay councilors, Beth Biojon. For the business institution sector, the proponent interviewed the Human Resource Manager of Malayan Colleges Laguna, Ms. Mariecel Salivio, since this department organizes events, trainings, and seminars for MCL employees. The proponent also conducted some unobtrusive methods in data gathering such as investigation and observation.
- *Development*: In this phase, the proponent drew the logical workflow model, created new user stories based on the workflow, designed the user interface, and implemented the identified functionalities, which led to an anticipated prototype which passed all required unit and integration tests. Changes can be accommodated even at the later stage of the application development process. During this phase, initial reviews and feedback have been acquired and fed back to the process to incorporate crucial fixes, before launching the mobile app to Google's distribution platform Google Play Store.
- *Deployment:* In this phase, EMS was getting ready for market release. It has been tested against functional requirements to ensure that objectives are met. The build was thoroughly tested against specific test cases. Any bugs or issues were resolved prior to release. When the app was ready for deployment or release, it was put up for approval at Google Play Store.
- *Feedback*: Since mobile app development, like the EMS development, needs rapid change and constant updates, in this phase, the proponent continuously recorded and incorporated changes, adjusted, and tracked priorities for the next iteration of the agile methodology process. This led to a more stable version of the mobile app that is easy to use, adaptable, and anticipatory of changing user demands.

As agile works in highly planned stages, it helped build the EMS mobile application to perfectly suit the customer requirements. As a result, the EMS mobile app was completed effectively and efficiently.

15.2.2 Population and Locale of the Study

The sample population for this study was selected from different institutions such as educational, political, economic, and religious organizations, since these institutions are made up of individuals or organizations with similar purposes, having a face-to-face setting.

This study used statistical sampling, accomplished by using the stratified random sampling. This technique is a probability sampling wherein the proponent divided the target population into different subsets or strata and then randomly selected the final subjects proportionally from the different strata. These subgroups are identified as educational institution, political institution, economic institution, and religious institution.

The proponent used stratified random sampling because of its practicality. After identifying the specific subgroup within the population, According to Research Methods in human–computer interaction [7], 30 responses should be considered as the baseline minimum number of responses for any type of research.

Consequently, the proponent gathered feedback from 30 respondents of each stratum was limited by the deployment architecture.

For the educational institution, the study was conducted against some of the classes in Malayan Colleges Laguna, located at Barangay Pulo, Cabuyao Laguna. Quizzes are brief tests of knowledge. As part of the learning tasks, students take their quizzes on a piece of paper and have them checked individually in a traditional way, which consumes time. Thus, members of these classes are potential users of the EMS as an alternative tool for taking quizzes that will give them immediate results and feedback.

When it comes to political institutions that deal with the authoritative allocation of public social goals and values, the proposed system was tested in Barangay Francisco Reyes in General Mariano Alvarez, Cavite as a tool that would aid activities such as community surveys.

The EMS provides economic institutions a tool that may support corporate trainings, market research, stockholders voting, management decision making, product launches, trade show exhibits, awards events, franchise meetings, corporate officer elections, employee perception surveys, conferences, and events, allowing people to give their true opinions anonymously. For the business Institution, the EMS conducted the study for Malayan Colleges Laguna employees.

For the Religious Institution, the EMS was tested at the Grace Baptist Church, San Jose Inc., in some of their gatherings and activities. Members were able to use the EMS for seminars, youth congress, training summits as well as leadership, staff and team meetings and activities.

15.2.3 Data Instrumentation

- *Interview:* The interview is the primary technique for information gathering. Interviews are instrumental sources of data. The proponent was able to generate ideas in a discourse way and was able to identify sources of information from respondents.

  As part of the methodology, the proponent gave a nondirective interview because it is the most appropriate type of interview to use when investigating issues where the respondent is allowed to talk without being interrupted regarding a very broad topic. To get information based on the opinion of some of the community leaders, the proponent interviewed the Honorable Municipal Mayor Walter Echevarria Jr. of General Mariano Alvarez, Cavite, Barangay Captain Benjamin C. Detic of Francisco Reyes in the same municipal town, Barangay Councilor, Beth Biojon and Ms. Mariecel Salivio—Human Resource Manager of Malayan Colleges Laguna.
- *Questionnaire:* A questionnaire is a tool for collecting and detailing information about a particular subject. The proponent used an electronic questionnaire or the self-completion questionnaires through google forms and disseminated them to some people involved in the study to elicit responses for the purpose of collecting data.
- *Observation:* As part of this methodology, the proponent became an observer. The proponent existed as a member of the subject of the study while observing and keeping notes about the attributes of the subject that is being researched. Since the proponent is a teacher, student, employee, church member, and is part of the barangay community, the proponent got firsthand exposure with informants. The election process was managed at Grace Baptist Church, San Jose, by which church members casted their votes to fill their next set of officers, and accordingly, the election process normally takes one to one and half hours to complete.

15.2.4 Data Analysis

The proponent had gone through several processes to determine how the proposed system should operate. The proponent determined possible system functionalities, identified data that should be collected and analyzed, and identified possible problems and solutions. The process started with data gathering, facilitated through data gathering measures discussed in the data instrumentation section.

The gathered information served as the basis in the development of an Audience Response System using the android mobile platform. To take full advantage of the current mobile technology, this wireless response system technology is designed to provide interactive communications between the audience and the presenter. This will function as an additional tool which can be used in different types

Fig. 15.1 EMS mobile-based response system screenshots (Presenter). (**a**) Login, (**b**) Sessions List – Presenter, (**c**) Reports – Presenter, and (**d**) Histogram – Presenter

of institutions. The following are the sample screenshots of EMS mobile-based response system. See Figs. 15.1 and 15.2.

15.3 Results and Discussion

With the use of agile development methodologies, the proponent was able to develop some prototypes that continuously integrate and test until the proponent reaches substantial milestones on the EMS mobile app.

The proponent designed test cases for particular scenarios that may occur to each functionality, pertaining to each requirement. A test case is a set of conditions under which a tester determines whether particular application functionality behaves as projected as a result of expected and unexpected circumstances. Functional testing was conducted to respondents whose characteristics parallel those of the main respondents.

During this testing, all comments and suggestions of the respondents were documented. The tests helped find problems in the design of the application.

The proponent performed compatibility testing of the application in different mobiles devices, screen sizes, and Operating System (OS) versions according to the following minimum android device requirements.

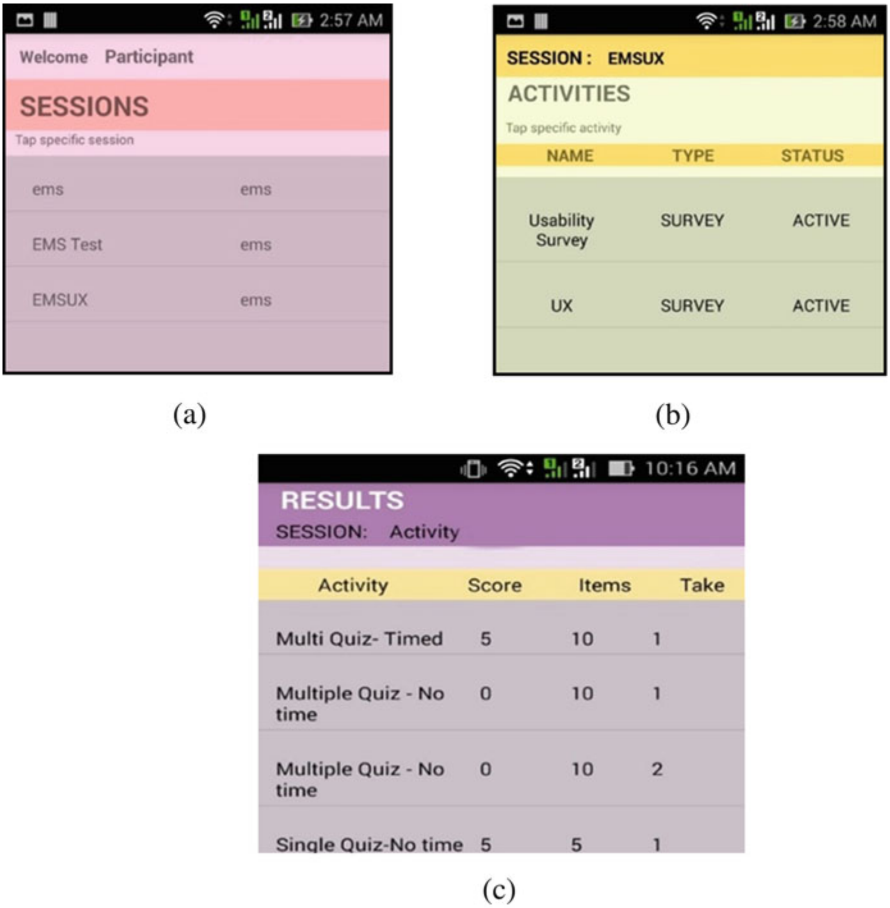

Fig. 15.2 EMS mobile-based response system screenshots (Audience). (**a**) Joined Session – Audience, (**b**) Activities List – Audience, and (**c**) Result – Audience

OS Version: API Level Android 3.0 – "Honeycomb"
Processor: Dual-core 1.2 GHz Cortex-A9
Size: 4.0 inches IPS LCD capacitive touchscreen

The proponent conducted usability testing to a specific population of users. Usability testing ensures that the mobile app is efficient, effective, and easy to use and provides a satisfactory experience to the users.

Usability testing requires heavy involvement of users, and the output might affect the application design; thus, it is very important to get usability testing in place from the early stage of the application, so it would be difficult for the proponent to have some change in the later stages of the project.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
RESPONSE	A	C	C	C	B	D	B	A	A	A	B	D

Problem: IS THERE ANY NO. THAT OCCURS > N ?

N= Stream Size/2

=12/2

N =6

Fig. 15.3 Sample given stream of items

Since EMS mobile-based audience response system is a tool in gathering feedback and responses from people, the proponent decided to accomplish the usability testing through the EMS itself using the sets of questions mentioned in usability questionnaire and given rating scale. The proponent was able to convey 120 feedback as the total number of respondents from different institutions.

EMS will exploit this analysis in identifying the frequency of some item in a long stream or the most frequent items. EMS analytics is the discovery of meaningful pattern in a data streams from group of people with distinct variables such as socio-demographic characteristics including age, gender, and occupation and other variables such as score.

Aside from histogram as synopsis data structure methods that used in EMS trend analysis. The proponent used one of the approximate algorithm which the Misra-Gries algorithm [8].

Given the stream of items of responses, see Fig. 15.3, the proponent used Misra-Gries algorithm to find to most frequent items. Misra-Gries identified half of the items. Item stores k-1 (item, counter) pairs. The algorithm responded quickly to the new information with less amounts of resources as compared to the total quantity of data. The following figures illustrate how the Misra-Gries algorithm identifies the frequent item and stores k-1 (item, counter) pairs.

Based on the Fig. 15.4, if the updated count is 0, "kick out" the stored element and store the current element of the file; increase the count to 1 and then proceed to the next element of the file. If the counter >0, then its item is the only candidate for majority. The id will only change if the previous item's counter is 0 and if the stream is different it will be −1.

With histogram, data seen on stream can be summarized. According to Misra-Gries algorithm, it keeps fixed number of item buckets. See Fig. 15.5.

The Misra-Gries algorithm was fed into the application engine and was consumed and implemented by the prototype as seen in the Fig. 15.6.

The next tables show the summary and the equivalent interpretation of the results of the usability testing with some of Malayan Colleges Students, Teaching and Non-Teaching employees, Barangay, and to some members of Grace Baptist Church San Jose members. The range and interpretation of the five-point scale are shown in Table 15.1.

Fig. 15.4 Computation result

	R1	R2	R3
RESPONSE	A	C	C
ID	A	A	B
COUNT	1	0	1

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
RESPONSE	A	C	C	C	B	D	B	A	A	A	B	D
ID	A	A	B	B	B	B	C	C	D	D	D	D
COUNT	1	0	1	2	1	0	1	0	1	2	1	0

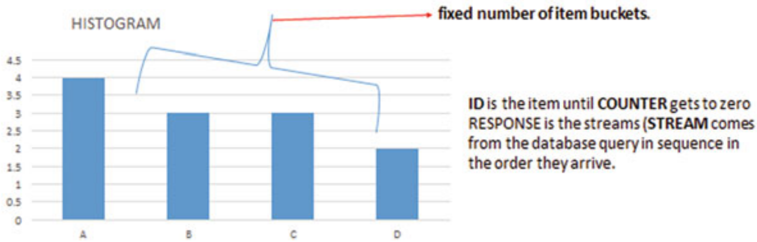

Fig. 15.5 Misra-Gries algorithm results and histogram

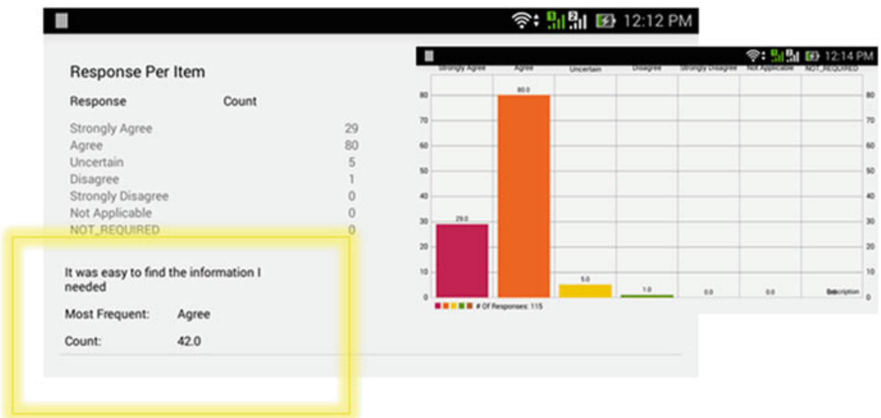

Fig. 15.6 EMS prototype result

Table 15.1 Likert scale

Scale	Range	Verbal interpretation
1	1.0–1.8	Strongly disagree
2	1.9–2.7	Disagree
3	2.8–3.6	Uncertain
4	3.7–4.5	Agree
5	4.6–5.0	Strongly agree

Table 15.2 Usability testing results

	Question No.	1	2	3	4	5	Weighted mean	Verbal interpretation of the weighted mean
System quality	Q1	0	1	3	95	19	4.12	Agree
	Q2	0	0	3	77	36	4.28	Agree
	Q3	0	1	2	35	79	4.64	Strongly agree
	Q4	0	1	4	87	25	4.16	Agree
	Q5	0	0	5	78	34	4.25	Agree
	Q6	0	0	8	84	25	4.15	Agree
		0	**3**	**25**	**456**	**218**	**4.27**	**Agree**
Information quality	Q7	0	1	5	80	29	4.19	Agree
	Q8	0	1	12	76	28	4.12	Agree
	Q9	0	1	11	77	28	4.13	Agree
	Q10	0	0	3	44	70	4.57	Strongly agree
	Q11	0	0	1	79	36	4.3	Agree
	Q12	0	1	5	74	37	4.26	Agree
		0	**4**	**37**	**430**	**228**	**4.26**	**Agree**
Interface quality	Q13	0	0	6	78	32	4.22	Agree
	Q14	0	0	4	76	37	4.28	Agree
	Q15	0	1	3	84	27	4.19	Agree
	Q16	0	0	3	76	37	4.29	Agree
		0	**1**	**16**	**314**	**133**	**4.25**	**Agree**

Weighted mean was used to measure the general response of the survey samples, whether they agree to a given statement or not (Table 15.2).

The poststudy usability Questionnaire was based on UX Research Standardizes Usability Questionnaires [9]. This test has a 16-item survey that measures users' perceived satisfaction with the system. Obtaining an overall satisfaction score is done by averaging the four subscales of System Quality (the average of items 1–6), Information Quality (the average of items 7–12), and Interface Quality (the average of items 13–16).

The tables above show the summary and the equivalent interpretation of the results of the usability testing for some of MCL's students, teaching and nonteaching employees, barangay, and some members of the Grace Baptist Church San Jose members. The range and interpretation of the five-point scale are shown in the table.

The results previously presented represent the evaluation for the developed system. The proponent used Likert scale to find the final evaluation for the developed system.

The following are the summary of the evaluation from the responses:

- For the system quality of the EMS Mobile App, the verbal interpretation of the weighted mean is Agree.
- For the information quality of the EMS Mobile App, the verbal interpretation of the weighted mean is Agree.
- For the interface quality of the EMS Mobile App, the verbal interpretation of the weighted mean is Agree.

15.4 Conclusion and Recommendation

After conducting several testing and revisions on the developed mobile app and based on the results of the respondents of the usability testing, the proponent was able to meet the objectives of this study including the following.

In Question 3, users were able to complete the tasks and were able to gather data immediately. The tasks included the creation of a quiz, a poll, and a survey as a presenter and answering each as a participant.

In Question 10, The EMS mobile-based audience response system was able to allow anonymous results and further graph the result.

Therefore, this study demonstrates that the EMS app is able to provide presenters with a tool, through their android smartphones, that accommodates individual participant responses and give result in a timely manner. The EMS mobile-based response system proves that it can reduce paperwork and eliminate unnecessary manpower and time in collecting and tabulating responses. Moreover, the proposed system provided presenters with an important analytics tool regarding identified aspects, based on participants' responses and illustrated graphs with minimal user time and effort.

As technology continues to improve, an electronic audience response system such as this will continue to impact an audience–presenter environment with more interactivity during lectures and presentations.

Hence, this study has established indispensable features in gathering responses from people. For continuous improvement of this research, in the future, it is important that the statistical analysis of qualitative information and inferential analysis that draw conclusions and interpretation about the results is covered.

Based on these possible implications, the proponent believes that this study offers valuable insights into the future development of mobile technology or tools that can make good use of those features as introduced in this study.

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Most importantly, none of this would have been possible without the unconditional love of our Almighty God, Jesus Christ, my source of all, strength, provisions, wisdom, and knowledge. Without Him, I am nothing. To God be the glory!

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Chapter 16
Usability of Foot-Based Interaction Techniques for Mobile Solutions

Taeyong Kim, Jeffrey R. Blum, Parisa Alirezaee, Andre G. Arnold, Pascal E. Fortin, and Jeremy R. Cooperstock

Abstract Although hand-based interaction dominates mobile applications, this can be unsuitable for use by motor-impaired individuals or in situations such as musical performance or surgery, where the hands are otherwise occupied. The alternative of foot-based interaction, the subject of this chapter, has been shown to offer reasonable performance in such conditions and offers benefits in terms of diversity of input techniques, wide applicability, and social acceptability. This chapter also describes potential applications of foot-based interfaces, with an emphasis on factors related to usability. We aim to inspire designers and developers to consider the potential for leveraging interaction through the feet as a replacement for, or complement to, more traditional application designs.

16.1 Introduction

Hand-based input is a dominant interaction method of interacting with mobile devices. However, the hands are often occupied with various activities such as operating a tool or playing a musical instrument, and manual input interfaces are often unsuitable for use by populations with hand-motor impairments [47]. We regularly and comfortably use our feet in daily life, whether for walking, playing sports, or control of machinery, e.g., driving a car. These factors motivate the development of foot-based interfaces, whether for scenarios in which the hands are fully occupied, or for supporting, extending, or replacing hand-based interfaces.

Usability of foot-based interfaces has been a major topic of exploration, related both to the use of the foot as a means of providing input to a computer, and of the approaches for providing feedback to the user via the foot. With regard to the former, input gestures must be designed or selected in such a manner as to minimize fatigue, which depends on an awareness of physiological constraints and the achievable

T. Kim (✉) · J. R. Blum · P. Alirezaee · A. G. Arnold · P. E. Fortin · J. R. Cooperstock
Shared Reality Lab, McGill University, Montreal, QC, Canada
e-mail: taeyong@cim.mcgill.ca

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accuracy of foot motor control. Effective performance limits may be determined with measurement tools such as Fitts' Law [14] and used in the design of appropriate interfaces for parameter control. When used for conveying information to the user, foot-based interfaces can be compared on the basis of quantitative measurements of signal values and on the qualitative effects of their perception by the user. A significant body of work has considered the design of haptic icons [11], or "tactons" [9, 10], for which unique challenges arise when delivered to the feet as discussed further in Sect. 16.3.

In this chapter, we discuss the main foot interaction approaches, including foot-controlled input and sensing through the feet. Our aim is to convince the reader of the usability, usefulness, and effectiveness of foot-based interaction.

16.2 Foot-controlled Input

Significant research efforts have been invested toward supporting and replacing hand-based interfaces with foot-controlled systems. The feet have been shown to have great potential as an interaction tool to handle secondary tasks [21, 28] or as the main source of information [15, 33] in situations where the user's hands are occupied or unavailable. These interfaces usually take advantage of one or more of the many gestures and actions available via the feet, e.g., distributed pressure, 3D motion and positioning, pointing, flexion, etc.

Here, one of the first key issues that need to be addressed with foot-based interfaces is how to capture input from the feet. For detecting position and motion, some of the most common approaches rely on shoe platforms equipped with a battery of sensors (e.g., inertial measurement units, pressure sensors, proximity sensors, etc.) [13, 15]. Video-based tracking that relies on traditional camera technologies [33] as well as highly accurate motion capture systems [21] are also used for capturing position. Position and motion data are most often used in spatial tasks since they are better than more constrained approaches (e.g., using force sensors) at capturing the full degrees of freedom of the foot and leg. As a result, systems can be trained to recognize precise gestures and associate them to software-specific functionality. Due to the relative strength of the lower body limbs and the frequently limited extent to which they are occupied with other tasks (e.g., while sitting or standing in place), the addition of instrumentation in custom or conventional shoes is often less cumbersome and more comfortable than equivalent systems installed on the users' hands.

Foot gestures that are based on foot-pressure or foot-force data are called foot rocking gestures. To detect rocking gestures, sensors are typically embedded in a shoe's insole [15] or into the floor itself [29] and detect the foot pressure distributions at strategic anatomical positions. An obvious advantage of rocking gestures in comparison to their motion-based relatives is that they offer a discrete and natural interaction [15]. They lend themselves particularly well to selection and scrolling tasks. In the following subsections, we summarize a variety of foot gesture studies and applications.

16.2.1 Foot Gesture Research

While each application has its own set of constraints, fundamental studies exploring the general properties of foot movements have been and are still being reported. For example, Velloso et al. recently reported a performance comparison between (1) the dominant and nondominant foot, (2) preferred foot movements, and (3) interaction techniques and visualization [40]. First, employing the ISO 9241–9, one- and two-dimensional tasks based on Fitts' law (Fig. 16.1), they compared the performance of the dominant foot versus nondominant foot. In their experiment, each participant performed a total of 468 Fitts' law trials with both feet under nine difficulty levels that varied the width (W) of the targets and the distance between them (which the authors refer to as "amplitude" so is marked "A" in Fig. 16.1). They concluded that there is no statistically significant difference between the dominant and nondominant foot, with regard to the throughput in one- and two-dimensional Fitts' law tasks. In addition, after the second round of trials, the average throughput of horizontal foot movements (2.11 bit/s) was found to be significantly superior to that of the vertical movements (1.94 bits/s) in two-dimensional space.

Second, they compared five different foot gestures: dragging in horizontal/vertical directions, lifting, and heel/toe rotation, to find which input modality was preferred by participants in a targeting task. Their findings determined that the heel rotation movement was the most comfortable and preferred by the users. Participants reportedly experienced significant fatigue while performing the dragging and lifting

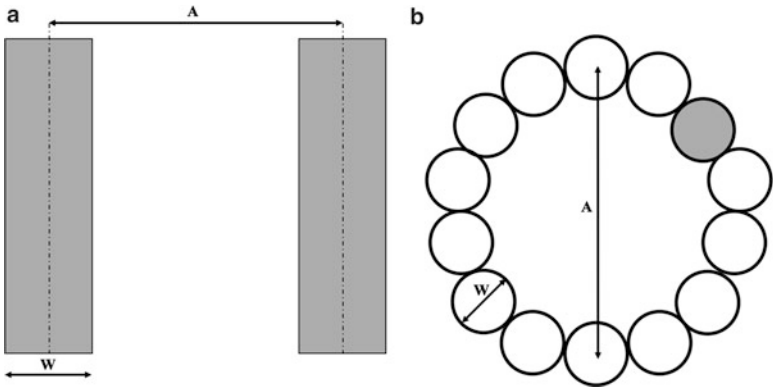

Fig. 16.1 Fitts' Law task (ISO 9241-9). (**a**) One-dimensional Fitts' law task. (**b**) Two-dimensional Fitts' law task

gestures because of the friction observed between the shoe and the floor and of the constant need to work against gravity.

Lastly, they studied how interaction and visualization techniques can influence performance in tasks involving the control of two parameters. Three interaction methods were designed, with a range of options involving one or both feet, and using horizontal and/or vertical foot motion to control multiple parameters in a software simulation. After participants performed tasks that involved different visualizations of the data, they determined that visualization has a significant impact on the performance of multiple variable entries in foot-based interfaces. For example, they observed the worst performance when participants controlled two vertical sliders by using the horizontal and vertical axes with a single foot. However, the same mapping allowed an effective and efficient method for resizing virtual rectangles. This highlights the importance of consistency between users' actions and the effect in the interface. These performance comparisons of different gestures and techniques by Velloso et al. would help to design improved foot-based mobile solutions by considering performance of each gesture and the effect of visualization.

Scott et al. explored the performance of foot lifting and rotation gestures with regard to their axis of rotation [35]. Participants performed a target selection task using gestures informed by anatomical characteristics of the human foot (e.g., dorsiflexion from 10° to 40°; Plantar flexion from 10° to 60°; and heel and toe rotation from −90° to 120°). Their findings showed that plantar flexion exhibited the lowest average selection error at 6.31°, followed by the heel rotation (8.52°), toe rotation (8.55°), and dorsiflexion (11.77°). Unlike the other gestures whose error rates varied as a function of the target angle, plantar flexion had relatively consistent error across the input space. Based on their findings, they proposed to discretize the angle range into three sections to account for the limited accuracy of the gestures. They proposed that the toe/heel zones span from 0° to 25°, 25° to 60°, and more than 60°. For plantar flexion, ranges from 0° to 20°, 20° to 50°, and more than 50° were chosen as optimal. Therefore, the range of each foot gesture and its properties should be considered according to targeted foot-based interactions for mobile solutions.

Finally, Han et al. explored the feasibility of kicking gestures for mobile use cases [16]. In this study, participants used a kicking gesture to specify either direction or velocity. The gesture was detected by a depth camera (Xbox Kinect) using the Open Natural Interaction (OpenNI) library, and all experiments were performed with participants viewing the scene on a 7inch display. To investigate the human ability to control the direction of a kick, they first designed a football game where participants had to kick a virtual ball into a target area. The target area was ranged according to the number of angular divisions where a provided area (from −60° to 60°) was divided into 3–10 divisions. In their result, three divisions showed the highest performance as 96% whereas 10 divisions achieved only 46% accuracy. They determined that five-division condition is the best division since it has reasonable performance a 88% and a suitable number of segments for selection applications. As a second step, they measured the users' ability to control the velocity of the kicking gesture by placing the ball in a fixed location in front of the player and asking them to adapt their motion to match the visually displayed velocity range.

Their results showed that the two-division condition achieved around 87% overall velocity accuracy. However, the three- and four-division conditions did not exhibit significant differences with observed accuracies of 60% and 50%, respectively. Overall, undershooting was observed and participants had difficulty controlling their velocity to match the target ranges when more than two divisions were provided. Thus, the kick gesture for mobile solutions can controll up to five directions, and two kicking velocities. Therefore, to design improved mobile solutions with foot-based interactions, the characteristics, performance, and constraints of each gesture should be considered.

16.2.2 Mapping Foot Gestures to Functions

In the previous section, we discussed several examples of how gestures are constrained by the limits of the human body but covered only limited examples of how those gestures were mapped to specific functionality in the application itself. This section discusses this mapping in greater detail.

Because of our experience with using our feet in the real world, foot gestures are often interpreted in specific ways, which can be used to design more intuitive mappings. For this reason, assigning a suitable foot gesture to a specific function is as important as accurately capturing the foot gesture in the first place. Recent research has pursued finding an optimal gesture set suited to functional aims. For example, Alexander et al. conducted an elicitation study to generate a set of foot movement-based gestures for mobile applications [1]. They observed 537 commands by 19 participants and then extracted 30 commands and mapped each gesture to a specific function by evaluating participant agreement and gesture generalization. After these processes, they selected 13 commands for a follow-up experiment, such as media control and map navigation, and measured the recognition accuracy using a pseudo-wizard-of-oz method. Similarly, Fukahori et al. collated a set of foot pressure-based gestures appropriate for diverse functions [15]. First, they collected 563 gesture concepts in 29 operations from 20 participants and after observation of the gestures performed by participants proposed 29 gestures. The suggested foot gestures aimed at functions, and also the experimental designs in these works would be helpful to design a gesture for a specific function for further mobile solutions.

Whereas most studies limit themselves to mapping a foot gesture to a single function, Saunders et al. [33] explored how a single set of gestures could be mapped onto functions across multiple applications. Although this approach reduces the number of gestures to be memorized, it was confusing to users when they switched between applications, even with access to an integrated help function. For a diverse set of applications, a one-to-many mapping of gestures to functions across different applications may be criticized as risking inconsistency. So, considering both how many gestures and how to map them to functions is required when designing specific solutions.

Although the inconsistency inherent in mapping gestures to diverse applications is difficult to entirely avoid, an approach, based on observations of ordinary foot movements and social acceptability can help to design gestures that have common meanings across applications. The tapping gesture is one example that has a high level of social acceptability and is considered a subtle and everyday gesture [31]. Using tapping gestures effectively has been investigated by many previous works. Crossan et al. compared single tapping with double tapping and observed that single foot tapping was preferable to, and more robust than, both feet tapping, where the user tapped both feet at the same time [13]. Tapping could be accomplished either by toe tapping or heel tapping. Toe tapping is generally preferred to heel tapping due to its relatively low effort and historical operation of pedals [41].

16.2.3 Foot Pointing: Spatial Data

Significant literature exists on the topic of foot-controlled interfaces applied to spatial manipulation tasks. The vast majority explored the performance of foot-based interfaces in comparison with hand-based interfaces and their ability to transfer spatial information. Pakkanen et al. investigated the usability of foot interaction for non-accurate spatial tasks [28]. In their study, participants were given four tasks with different complexity levels, controlled via a trackball operated by either the dominant hand or foot. In each task, participants were required to move toward a target point where the range of movement was set as under 300 pixels. Overall, the hands outperformed the feet for average completion times, accuracy, and user satisfaction. Furthermore, the foot showed limitations for fine manipulations that needed less than ten pixels.

However, recent literature has shown us that while hand-based interfaces using mice and track pads remain dominant, foot-based devices are becoming increasingly accurate. Indeed, Horodniczy and Cooperstock have recently shown that the foot can compete with traditional hand-based interfaces in a pointing task based on a Fitts' law task (ISO 9241–9), by using variable friction to assist users in reducing pointing overshoot and increasing selection accuracy [21]. In their recent experiment, users wore custom shoes (Fig. 16.2) that allow the system to increase the friction between the user's foot and the sliding surface as they approached the targets. Variable friction was achieved by controlling the vertical position of a high-friction material located under the sole, leading to an increase or decrease of the normal force at the point of contact (Fig. 16.3).

They found that the variable friction interface showed significant performance effects on the throughput. In the one/two-dimensional foot interaction, the throughput was increased from 3.04 (bits/s) to 3.22 (bits/s) and from 2.09 (bits/s) to 2.21 (bits/s), respectively, when the friction was added. Additionally, significant differences were shown between the performance of one-dimensional and two-dimensional tasks, with two-dimensional tasks requiring around double the time for pointing tasks at the same index of difficulty. Although this foot-based variable

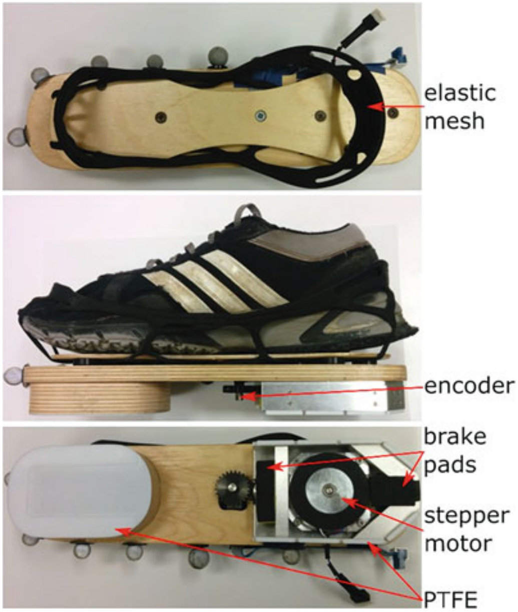

Fig. 16.2 Top, side, and bottom pictures of the prototype. The prototype fastens to participant's shoe using an elastic mesh [21]

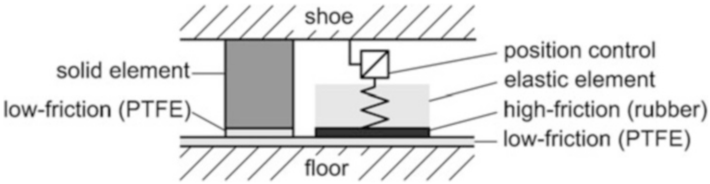

Fig. 16.3 The variable friction mechanism employed by the prototype [21]

friction interface did not achieve performance competitive with the best hand-based interfaces, it demonstrated comparable error rates to traditional pointing devices as well as relatively strong performance (Table.16.1). For example, they observed that on a low-friction surface, participants can perform foot-pointing tasks comfortably and with low fatigue.

Although exploring direct comparisons of hand versus foot interfaces is valuable and illustrates the strengths and weaknesses of each, they need not be exclusive. Foot-based interfaces can be combined with hand-based interfaces. Schoning et al. combined hand and foot control to effectively perform spatial data tasks [34]. The hand gesture showed benefits for precise input, whereas the foot gesture was adequately suited for continuous data collection within comfortable movement ranges and could control a specific function with simple movement, such as zoom/panning. For these reasons, the combined hand and foot outperformed on both throughput and comfort, reducing fatigue and effort.

Table 16.1 Reported throughputs and error rates of hand- and foot-operated pointing devices evaluated using ISO 9241–9 on 2D tasks [21]

Hand-controlled device	**Throughput (bits/s)**	**Error (%)**
Mouse	3.7–4.9	11.0
Trackball	3.0	8.6
Touchpad	0.99–2.9	7.0
Wiimote	2.59	10.2
Joystick	1.6–2.55	9.6
Wii classic controller	1.48	6.58
Foot-controlled device	**Throughput (bits/s)**	**Error (%)**
2D variable friction shoes	2.21	8.19
Depth camera	1.16	7.64

Further, hand and foot interfaces can be augmented with additional control mechanisms. For example, researchers have investigated how to incorporate additional mechanisms, such as eye gaze, to form a more complete solution. Klamka et al. compared performance of hand-based interfaces with performance of foot-based interfaces combined with eye gaze [24]. In this research, participants navigated the spatial data using gaze input in coordination with pedal-based interfaces. Compared to the hand-based interface (mouse) condition, the performance of the gesture combination (foot and gaze) condition did not outperform. However, the gaze-supported gesture was a promising with respect to comfort and ease of control. So, using foot-based interactions to manipulate spatial data, such as controlling a cursor in mobile solutions, could not outperform hand-based interactions, but still they can developed to achieve the better performance by changing frictions by incorporating additional mechanisms.

16.2.4 Menu Interactions

A specific application for foot-based interfaces that has been heavily explored is navigating menu structures. A menu can have different styles in terms of direction of motion, such as linear or radial, and foot gestures can be can be designed to work well in either case. For example, Zhong et al. explored foot-based ergonomics for radial pie menus [47]. Radial movement, as explained in Sect. 16.2.1, is a more comfortable and preferred foot movement, in comparison with horizontal and vertical movements. However, when radial movements are used to navigate menus, they have significant limitations with respect to the ergonomic and comfortable range of motion. From this research, they found the heel rotation movement of the right foot has a usable range from $-20°$ to $40°$. As the number of menu items increases, the angular span of each item is reduced. For this reason, although rotational motion showed advantages in terms of comfortable movement, the radial menu style cannot incorporate sufficient menu items.

Another method for controlling a menu is position tracking, where the menu layout is represented on a 2D display, and the cursor is controlled with the foot. Saunders et al. [33] have explored foot tracking-based interaction techniques to control diverse applications. In their system, users can see the position of their foot as a dot on a display and select an application by foot tapping the area of the virtual target layout, which was represented on the display.

An additional menu design by Crossan et al. implemented hierarchical style menus [13]. They focused on hands-free and eyes-free situations where mobile devices remain pocketed. The primary situation they considered is when the user wants to respond to an event and would typically need to take their mobile device out of their pocket or bag to do so. To mitigate these inconveniences, a foot-tapping technique with audio feedback was used to navigate menu items. They compared user performance while interacting with a two-level hierarchical menu system using either a foot-based or hand-based method. One of the findings was that if the target could be reached with few operations (e.g., less than five taps), the tapping technique was faster than hand-based operation when the phone was in the user's pocket. Thus, they confirmed the advantages of foot interfaces as an alternative method when the device is not held in the hand. These menu interactions based on foot gestures could be developed easily to control diverse parameters in mobile solutions, such as media manipulation, but due to ergonomics and properties of foot gestures, interaction designers need to spend some time on finding and researching suitable gestures for their targeted solutions.

16.3 Sensing Through the Feet

Although the feet can be used for input and manipulation, as described earlier, feet also offer several advantages for the reception of haptic information. They are well separated from other areas of the body, such that it can be easier to localize vibration or other haptic information being delivered to the foot area versus more traditional areas such as the wrist (e.g., smartwatch) or pant pocket (e.g., smartphone). Generally, such haptic information can be similar to that on other portions of the body, used for perceiving simple notifications or more complex haptic patterns (tactons [8]). The feet directly perceive the ground surface while walking and are thus the primary area to use for modifying or simulating the perception of different ground surfaces. This stimulation can come from portions of the foot coming into contact with a stationary or mobile surface with vibration actuators [42] or stimulation may be rendered through actuators coupled via a wearable interface to the foot itself. The latter can be used for mobile systems, by placing actuators in the shoes [3], or else attached to the top of the foot or ankle with straps.

The feet also bring their own set of unique challenges. First, haptic sensitivity is somewhat lower on the feet than on the most perceptive areas of the body such as the fingers and face, but still better than other parts of the body such as the legs and belly [45]. The feet are also a mechanically difficult area to situate haptic actuators, especially on the foot soles, since a high proportion of the user's entire weight presses on the sole of the foot with every step, causing significant repetitive mechanical strain that requires robust electronics and mechanical design to overcome. For example, with health organizations calling for 10,000 steps each day [38], this would result in over million stress cycles each year and potentially more for devices used in athletic training or rehabilitation. On the other hand, the shoes also provide a robust area to attach or embed the actuators, e.g., in the sole of the shoe itself. However, the changes in haptic coupling as the user's foot moves through the gait cycle mean that predicting what the user actually perceives in terms of intensity and duration, or even if they perceive a given stimulus at all (masking), can be more difficult than on other areas of the body. Sensors can be used to partially address these general haptic issues [7], but the ergonomics of haptic coupling for the foot nonetheless represent a significant challenge to be addressed versus haptic coupling on other areas on the body. Specific sensors such as accelerometers and proximity sensors that detect the gait cycle and trigger haptic feedback at appropriate times is a promising approach to overcoming foot-specific perception and masking issues [3]. To produce haptic stimuli, various actuators can be used, including the following types most often found in commercial devices:

- Eccentric Rotating Mass (ERM): An unbalanced weight on a motor, causing it to shake when spinning. Force is along two axes. The ERMs' stimulation amplitude and frequency are strongly correlated and dependent on the voltage being applied to the motor.
- Linear Resonant Actuator (LRA): A mass and spring system that resonates best at a particular frequency. Force is along a single axis. Although its frequency and amplitude can be controlled independently, an LRA's effectiveness will drop significantly when deviating from its recommended operation peak frequency.
- Voice Coil: Shares the mechanical structure of a speaker, with the exception that it does not have a membrane to produce air pressure differentials. It instead moves a mass that produces a rich haptic signal. Force is along a single axis. Since it can be controlled with arbitrary waveforms, frequency and amplitude can be modulated independently.

Hijmans et al. [20] investigated diverse types of actuators and compared their properties, such as dimensions, available frequency, and portability. They compared six different actuators, including the C2 Tactor, C1026B200F Vibration motor, B5A11W vibration motor, P-289 Piezo actuator, APA400M Actuator, and VBW32 Skin Transducer. They pointed out that the input source is also an important consideration when choosing an actuator for a specific application. For example, to activate Piezo actuators, a high voltage and low amperage is required, but conversely for C2 tactor and the VBW 32 skin transducers, a lower voltage and higher current is necessary.

Vibrotactile feedback using ERM, LRA, or voice coil actuators is not the only way of providing haptic information to the foot. Because the foot is in motion and applies pressure while stepping down, passive elements can be incorporated into haptic systems, such as giving the feeling of stepping into snow using potato starch that compresses and cleaves inside a boot as the wearer takes steps [46]. Many of these applications, however, move away from information delivery to instead unconsciously modifying the user's gait or foot position, and are therefore discussed in greater detail in the following sections.

16.3.1 Information Delivery with Vibrations

In comparison to hand-delivered vibrotactile feedback, foot-based studies have received significantly less attention. Early perception studies of the foot measured its tactile sensory characteristics. Kennedy et al. explored glabrous cutaneous receptors in the human foot sole and mapped out the distribution and behavior of each type of haptic receptor [22]. Their study is premised on a model of the foot having four different mechanoreceptor types: slow-adapting (SA) types I and II and fast-adapting (FA) types I and II [22]. For a fuller description of the mechanoreceptors in the skin, see Choi and Kuchenbecker [12]. Given that sections of the foot present different tactile properties depending on mechanoreceptor distribution and type, Hijmans et al. [20] developed a vibrating insole by placing vibration actuators at four locations where the most crucial mechanoreceptors are located (Fig. 16.4b).

Based on these prior works, Anlauff et al. [3] investigated rendering vibration patterns through haptic shoes (Fig. 16.4) for mobile applications. Participants were exposed to six different vibration patterns (Fig. 16.5) during either standing or walking situations, with each tacton composed of three buzzes, each of 250 ms duration, which were generated by pancake-shaped linear resonant actuators (LRA). In their work, the walking condition had significantly lower performance than the standing condition, with a recognition rate of 92% while standing and 62% while walking. They pointed out that when haptic pattern signals were delivered to the user while walking, the haptic artifacts were distorted by gait because the contact points between the actuators and foot sole kept changing. Overall, among the six patterns,

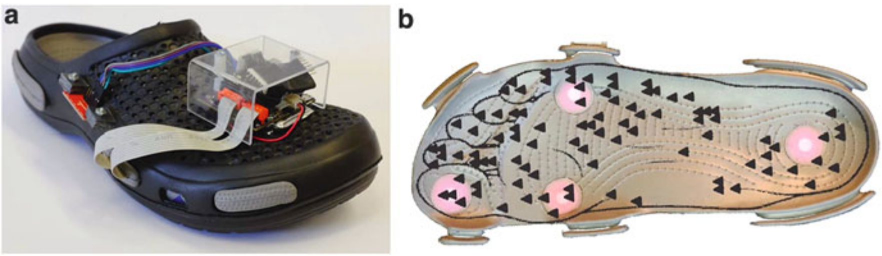

Fig. 16.4 Portable haptic shoes [3]. Left: Shoe, Right: Insole. (**a**) Haptic Shoe Platform. (**b**) Insole with actuator inserts and mechanoreceptor afferent units. (Adapted from Hijmans et al. [20])

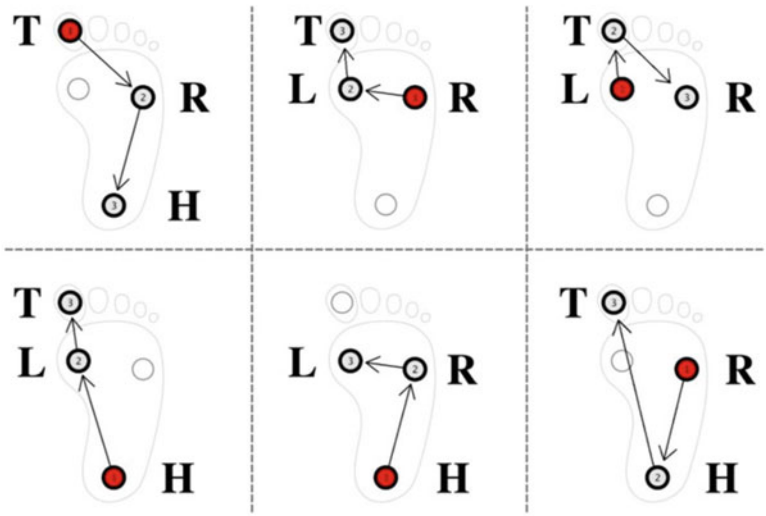

Fig. 16.5 Foot tacton study. Red circle indicates starting actuator position [3]

patterns that spanned the entire foot, such as Toe-Right-Heel or Heel-Left-Toe, had the highest overall accuracy.

Although recognition performance is higher while standing, the perception of vibration feedback while walking has been explored in both general [44] and navigation-specific contexts [25]. Watanabe et al. adjusted cyclic vibration feedback to guide walking-pace [44]. In their experiment, participants were trained to walk according to various vibration intervals, provided through the shoes. A small disk-shaped vibrating motor (FM23A, Tokyo Parts Industrial Co., Ltd) generated vibration at a frequency of 160 Hz. In their work, they found that participants could easily change their walking pace to match that of the vibrotactile cueing. Promisingly, modifications were made unconsciously by the users in response to gradual modification of the feedback pattern's pulsing frequency, which would be adjusted for mobile solutions, such as rehabilitation.

Although we commonly navigate while looking at our phone screen, this can be dangerous. Applications have therefore been developed to send vibrotactile patterns to the feet, freeing the user's vision so that they can remain better aware of their surroundings. Meier et al. [25] evaluated vibrotactile feedback for navigation tasks by attaching actuators to different parts of body. First, they compared the navigation performance with actuators on the foot, wrist, or waist, measuring both accuracy and level of concentration. Each participant was given 104 vibration signals, which were generated by four actuators in four different directions. Among the parts of body, the foot outperformed the other locations. The foot showed 100% accuracy, followed by waist (94.24%) and wrist (86.54%). For the required level of concentration, the foot (−3.63) needed half the concentration of wrist (−1.88) and waist (−1.38). Based on these results, they implemented four different patterns (forward, right, backward, and left), using eight actuators positioned around the foot evenly, and examined the navigation performance across three speed levels: standing, walking (∼3 km/h), and jogging (∼5 km/h). In their work, as speed increased, participants achieved lower pattern recognition accuracy, reported the vibration strength as lower, and required greater concentration to feel the stimuli.

To summarize, in this subsection we described various means of delivering information, including from tactile sensory characteristics to vibration feedback perception studies. Those who want to design mobile solutions based on foot-based information delivery need to carefully consider their experimental designs, vibration patterns, and recognition accuracy in order to implement better solutions.

16.3.2 Foot Interfaces for Medical Settings

Critical care units in hospitals are filled with an overwhelming number of loud and obnoxious alarms originating from patient-monitoring devices, mobile medical equipment, background music in the operating room, and verbal conversation between the staff. The high sound levels in these environments result in disrupted sleep for patients [4] as well as increased ambient stress levels for clinicians [37]. In addition, the composition of the existing auditory alarms is not generally informative of, or associated with, the urgency of the situation. Mondor et al. showed alarms associated with a patient condition to be perceived as less urgent than alarms associated with an equipment technical failure [27].

This makes a hospital setting an excellent case study for illustrating some of the advantages of foot-based interfaces as an interaction method for surgeons and nurses whose hands are occupied during a medical procedure. For example, in order to reduce the auditory burden and improve the information delivery of the alarms, several studies investigated the possibility of including privately delivered vibration as part of the alerts. Complementary tactile displays offer the possibility to reduce the noise level, decrease reliance on visual displays, and deliver information selectively to those who are responsible for responding to a particular alarm [5, 32]. In order to compare information delivery via different modalities, Sanderson et al. reported a comprehensive comparison between characteristics of visual, auditory, and haptic modalities of information presentation [32].

Since haptic stimuli can be rendered simultaneously with that of other modalities, some studies have investigated how simultaneous haptic signals can be used to augment the perception of other modalities. This is an instance of the Principle of Inverse Effectiveness (PoIE), which occurs when stimuli from two modalities are simultaneously presented, causing the overall neural response to be enhanced [26].

To choose a location for delivering the simultaneous vibration, the environmental factor of hospitals should be considered. In order to maintain sterile conditions and reduce the spread of infection, clinicians' hands are typically kept free of external devices. Therefore, positioning actuators on the feet is advantageous in comparison to the arms or wrists because of handwashing and cross-contamination concerns.

Fig. 16.6 Position of the vibration motor on the ankle for exploring the differences between unisensory and multisensory perception of medical alarms [2]

Fig. 16.6 shows the positioning of the vibration motor in the study comparing the perception of auditory alarms with and without vibration [2]. Alirezaee et al. studied the perception rates of participants, responding to high priority alarms when receiving either audio-only or multisensory audio-haptic high-priority alarms. The findings did not support the additive effects of sub-threshold vibration on the threshold of perception of alarm sound, yet introduced an experimental setup to explore the employment of haptic foot-interfaces for patient monitoring purposes by investigating ecologically valid parameters such as clinical performance and preference [2].

Although notifications alone would be an excellent use of the foot region, the user interface input and manipulation techniques discussed in earlier sections also have obvious applications in the medical environment. For example, a closed loop interaction between the clinician and the patient monitoring system could be implemented by using a haptic shoe. Such a system could, for example, render vibrotactile effects to communicate information about patients' vital signs, which the clinician could navigate using gestures as introduced in Sect. 16.2.4. For example, Hatscher et al. implemented foot-based interfaces for successfully reducing the workload of the hands, which are commonly occupied, particularly in an operating room environment [19]. In their experiments, three interaction techniques were designed to select target images from a series of medical images displayed on a monitor. They compared all three options in terms of task completion time and responses to the NASA-Task Load Index questionnaire [18]. The three tested designs were:

1. Discrete button: The angle ranging from −40°to 60° in front of the foot was segmented into five sections (called buttons) where each button occupied 20°. Rotating the foot changed the rate at which the medical images changed to move forward or backward in a list. When the foot was located in the leftmost/rightmost buttons, the image was changed every 0.2 s, while in next inner buttons (from

−20° to 0°or from 20° to 40°), the image was changed at a slower rate of every 0.8 s. The button in 0°–20° left the current image displayed.
2. Foot scrolling: In this interaction, every 10° of foot movement triggered an image change to the previous/next image, depending on direction. The user could raise their foot from the floor to reposition it and scroll further, since images were only changed when the foot was in contact with the floor.
3. Step and scroll: This concept combined foot scrolling with discrete button interactions. In the middle range of −20°–40°, the foot scrolling concept was implemented and the discrete button concept was applied in the outermost areas, covering from −40° to −20° and from 40° to 60°ranges.

They found that the foot scrolling method (#2) outperformed the others, with the shortest completion time and lowest overall workload, followed by discrete button (#1), and with step and scroll (#3) having the poorest results. The authors conclude that even though the scrolling method required repeated operations, the gesture's similarity with sliding hand gestures on touch screens offered performance benefits.

Aside from medical personnel receiving and manipulating information with their feet, it is important to note that patients themselves can also benefit from foot-based interfaces. For example, although seemingly counterintuitive, introducing noise to improve detection and transmission of weak signals was shown to be effective [17]. Accordingly, several studies demonstrate that administering appropriate haptic noise to the foot during rehabilitation results in systems that enhance balance control. For example, Priplata et al. studied the effects of rendering vibrations using instrumented insoles. Their results showed improved balance control for patients suffering from diabetic neuropathy or stroke, and more generally in geriatric populations [30]. In their study, participants were required to close their eyes in order to remove visual cuing. A white noise signal, low-pass filtered to 100 Hz, was delivered by three C-2 actuators on the bottom of each foot. The degree of sway was measured by a motion analysis system (VICON) for 30 s while standing. Five trials were performed with the haptic noise, and five without. They found the noise condition significantly reduced postural sway with respect to a range of sway parameters, such as the anteroposterior and mediolateral axes. They attributed these findings to the noise promoting the detection of bodily pressure changes, as indicated in previous literature [30].

16.3.3 Virtual Feedback Through the Feet

Beyond conveying information or interacting with applications through the feet, much prior work focuses on how to provide virtual immersive experiences. Although the foot has been less explored compared to the hands, tactile stimulation of the foot presents considerable potential for improving the fidelity of virtual reality (VR) experiences. In current VR systems, despite the dominance of audio and visual stimuli, additional modalities are used to convey compelling immersive sensations, including via haptic feedback. VR applications that rely on the feet include feeling diverse surfaces [39, 43], walking simulations [36], and collision detection [6]. To examine the importance of haptic stimuli through the feet in virtual environments, Visell et al. simulated virtual surfaces, such as soil or ice, through an augmented floor [43]. In their work, participants walked on a 6×6 array of 30.5×30.5 cm rigid tiles, each with four force sensors and a vibrotactile actuator embedded. By estimating the foot pressure distribution applied to the tiles, different audio and tactile feedback was rendered (Fig. 16.7). For providing immersive visual feedback, the floor was surrounded by overhead projectors (Fig. 16.8).

Use cases for virtual reality applications, including immersive walking experiences, have also been extensively investigated. People can be provided diverse sensations while walking. For example, when they step on the ground, many variables determine the varied tactile and sound feedback from the ground, such as their weight, pressure, and foot speed. Terziman et al. simulated each virtual step by rendering tactile vibration through the feet [36]. They conveyed the vibration using low-frequency loud speakers on tiles and designed different vibrations according to the contact position, physical model, and force of the feet on the tiles. In

Fig. 16.7 Still images from the frozen pond scenario [43]

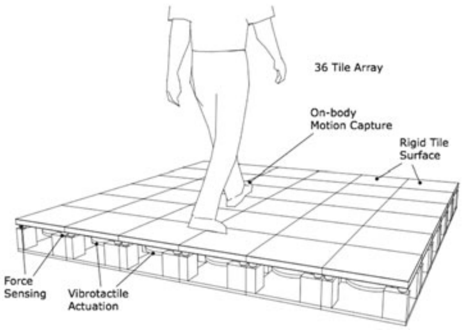

Fig. 16.8 Left: Distributed floor interface situated within an immersive, rear projected VE simulator. Right: illustration showing sensing and actuating components [43]

Fig. 16.9 Haptic shoes and positions of foot pressure sensors [23]

their experiments, to generate immersive stepping effects, they examined diverse factors, such as vertical versus lateral oscillations, physical versus metaphorical patterns, and heel strike versus heel and toe strike. Vertical vibration outperformed horizontal vibration when generating effects, based on the results of performance questionnaires. For the study of vibration type, the physics-based vibration (Rigid Contact Model), where the user's feet were considered as rigid objects, showed similar effects with those of the metaphorical-based model (Ground Reaction Force Model), which simulated the force generated by footsteps. In addition, they determined that only heel contact was suitable to be stimulated for conveying walking effects in virtual environments.

However, these tile-based architectures exhibit difficulties in scalability and mobility due to their significant hardware requirements and space limitations [23]. Thus, shoe-based architectures are beginning to emerge to overcome these limitations. Turchet et al. implemented interactive feedback experiments [39] where the participants were provided audio and visual stimuli with and without haptic feedback through the shoes. Vibrotactile actuators were embedded in the shoes and used to render virtual surfaces, such as snow and sand. Overall, participants preferred the added haptic effects with respect to enhancing the realism of the experience. To improve immersion, Kim and Cooperstock integrated foot-pressure sensing and vibration actuation into shoes [23]. Foot pressure was measured by four force-sensitive resistors (FSR), and the centroid pressure value of the foot was calculated by normalizing the locations of the four FSRs, such as Left (−0.5,0), Right (0.5,0), Toe (0,1), and Heel (0,−1) (See Fig. 16.9). Delivering haptic feedback based on pressure distribution of the feet could play an important role in designing mobile VR/AR solutions, including immersive VR/AR experiences, gaming, balance control, or rehabilitation applications.

In addition, as another foot based experience, as opposed to walking on different virtual surfaces, a foot-based virtual collision study has been developed to render immersive experience to the user. Blom et al. explored collision notification methods based on haptic feedback for virtual reality environments [6]. In their experiments, the participants were tracked by an optical tracking system (ART AR-Track2) and received vibration feedback through the floor or through a wand, where nine different collision effects (only visual: 1, only sound: 3, only vibration: 1, sound and vibration: 2, and other: 2) were rendered to the participants. The vibration feedback generally outperformed other feedback with respect to user preferences. Among vibration feedback modalities, the floor-based vibration outperformed the wand-based vibration. They also indicate collision recognition performance could be enhanced via multi-modal feedback.

Due to the advantages of the foot-based interactions, such as usable space for actuators in the shoes, and sensitivity to stimuli as described in Sect. 16.3, diverse experiences and techniques to render virtual feedback through the feet have been studied in many fields. We expect that foot-based mobile solutions will expand more broadly to improve virtual experiences, such as mobile gaming experiences or immersive virtual/augmented environment for rehabilitation.

16.4 Conclusions

Even though most interaction design is focused on the forearms and hands, in this chapter, we discussed various scenarios where using the feet can be an effective alternative or improvement. We explored multiple studies focused on foot interfaces and their promising future directions, both as foot-gesture-based interaction methods by detecting foot movement or toe/heel pressure as well as sensing-based techniques through delivering information to the foot. We provide and discuss examples that demonstrate scenarios where the hands are frequently occupied or body limitations were considered, and thus where foot interaction is promising for use cases such as doctors performing a medical procedure or a machinist operating a tool. These foot-based interactions and solutions for augmenting the communication of information are a cutting edge human–computer interaction method and offer potential benefits to mobile applications. Based on the literature and examples we have discussed, we hope that future researchers and developers are inspired to consider the feet as a viable alternative to mobile interaction techniques that occupy the hands.

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Correction to: Human-Centered Design Components in Spiral Model to Improve Mobility of Older Adults

Jayden Khakurel, Jari Porras, Helinä Melkas, and Ainara Garzo

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