Digital Avatars for Older People's Care

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Abstract. The continuous increase in life expectancy poses a challenge for health systems in modern societies, especially with respect to older people living in rural low-populated areas, both in terms of isolation and difficulty to access and communicate with health services. In this paper, we address these issues by applying the Digital Avatars framework to Gerontechnology. Building on our previous work on mobile and social computing, in particular the People as a Service model, Digital Avatars make intensive use of the capabilities of current smartphones to collect information about their owners, and applies techniques of Complex Event Processing extended with uncertainty for inferring the habits and preferences of the user of the phone and building with them a virtual profile. These virtual profiles allow to monitor the well-being and quality of life of older adults, reminding pharmacological treatments and home health testings, and raising alerts when an anomalous situation is detected.

Keywords: Gerontechnology · Social Computing · People as a Service · Digital Avatar · Complex Event Processing

1 Introduction

The progressive growth in life expectancy comes together with increasing population aging, in particular in Western societies. Despite elder adults are nowadays more active and in better health and physical conditions than anytime in the past, their health requires assiduous supervision and care: regular medical revisions and tests, pharmacological treatments, and many other therapies. This poses a challenge for the health systems in those aging societies, especially with respect to older people living in rural and low population areas. Gerontechnology [1] is an interdisciplinary field that brings together gerontology and technology for creating technological environments for inclusive, innovative, and independent living and social participation of older adults. Its concerns deal with matching technological environments to health, housing, mobility, communication, leisure and work of elder people [2].

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Our approach to Gerontechnology advocates for making intensive use of the sensoring, computing and storing capabilities of smartphones for improving the well-being and quality of life of older adults. Indeed, current mobile phones have more capabilities than ever before [3]. We intend to use these capabilities for developing a framework in which to apply complex techniques of data processing and manipulation based on the *People as a Service* (PeaaS) model [4]. PeaaS provides a conceptual framework for application development focused on the smartphone as a representative and interface to its owner. By employing the capabilities of the phone' sensors, we are able to infer the routines and preferences of its owner a build with them her virtual profile. This information can then be offered to third parties to generate value-added services or to interact with the user's IoT environment in an automated way. All the information is stored locally in the smartphone, guaranteeing that its owner keeps full control over which data is being shared and whom.

At the same time, we apply Complex Event Processing (CEP) [5,6] to process the information obtained from the smartphone, in order to take complex decisions according to the data perceived. The processing of events will take place in the device of the user itself, avoiding the need of a server for data processing purposes and reducing the amount of online communication. This allows us to generate better and more appropriate responses to the situations encountered by users, increasing the interactivity and efficiency of their applications.

In the context of the research project *Digital Avatars: A Framework for Collaborative Social Computing Applications* (2019–2021) in which the authors of this paper are currently involved, we are extending virtual profiles with behavioral rules that govern their inference, evolution, and use. This combination of rules and data related to a particular user and her environment is what we call her Digital Avatar.

In this paper, we introduce our proposal for applying Digital Avatars to the Gerontechnology field. After this introduction, we present a motivating example for illustrating our proposal (Sect. 2), and we give an extensive description of the framework (Sect. 3), describing its architecture, how we obtain and treat the necessary data, and how uncertainty is addressed in the proposal. Some related works are presented in Sect. 4, while Sect. 5 discusses both the benefits and risk of the approach. Finally, Sect. 6 concludes the paper.

2 Older People in Rural Areas

In order to illustrate the application of Digital Avatars to Gerontechnology, in this section we present a motivating scenario of an older person living in a relatively isolated rural environment.

María is an older person living in a small village in a rural and almost deserted area. After her husband died, and with her children living away, María started feeling lonely and considered moving to a nursing home. However, she finally decided to stay in her lifelong house while she was able to help herself *properly. After all, she is fully autonomous, and only needs her sugar levels and blood pressure to be checked regularly, as she now suffers from diabetes.*

In order to avoid recurrent and cumbersome trips to the primary healthcare center, which is located in another town, the regional health services have provided María with some smart gadgets that can be connected to the smartphone she uses for talking with her children and for texting with her grandson. A glucose meter and a blood pressure monitor send their data by Bluetooth Low Energy (BLE) to her phone. These measurements are recorded there, together with relevant information about her daily activities, such as patterns of movements inside her house and within the village, and phone usage records (phone calls, app execution). Bluetooth is also used to detect proximity to other smartphones, particularly to those of her contacts, which enables detecting patterns of visits and social relations between María and her neighbors.

This way, both the healthcare center and María's children are aware of her health conditions, well-being, and even of her mood. For example, abnormal sugar levels in her blood, or the fact that she is not visiting her neighbor one afternoon, as she always does on Tuesdays, can be easily detected. In case that something seems to be wrong, the smartphone would request some interaction for checking with María whether everything is ok, or raise an alert to the appropriate contact person or to the emergency services.

In this scenario, the smartphone plays a central role in capturing, processing and storing information about its owner. With that purpose it monitors the sensors of the phone and also the devices in María's environment: movements detected by the phone accelerometer, GPS readings, usage of mobile apps, and BLE signals from IoT healthcare devices. The rules for processing all this information and detecting that any significant event has likely occurred are also stored in the phone, and managed by the Digital Avatar. Note the importance of dealing with confidence levels (i.e., aleatory uncertainty) when making decisions, given that all sensed data is subjected to deviations and potential measurement errors (e.g., a sensor may stop working properly for a short period of time), as well as María's variations in their regular habits due to uncertain environmental conditions (e.g., bad weather) or unexpected situations (e.g. a surprise visit from a relative) that may cause changes in her daily habits but do not represent any challenge to her health.

3 Framework Description

In this section we describe our proposal for applying Digital Avatars for older people's care. In particular, we discuss the requirements and expected functionality of the system, we describe the architecture of the framework, and we explain how a CEP engine will be used for generating, storing and processing in the smartphone the virtual profile of the user.

3.1 Functionality

The functionality of the system is primarily aimed at three types of active users: older adults living alone in small villages away from medical resources (older people), their social relationships and informal caregivers, usually close relatives or neighbours, and the staff (physicians, nurses) of the public health system.

The main goal of the system is to monitor the health and well-being of older people. The scenario presented in Sect. 2 represents independent older adults living alone. Thus, their smartphones are the main source of information about them, through their sensors (accelerometer, GPS, etc.), and also the health devices connected to them by Bluetooth, such as scales, blood pressure monitors or glucometers.

One of the functions of the system is to remind the older person to take the doses of their medications, which are fixed by the health professionals. At the time set, the smartphone alerts the elder to take the dose prescribed. If the user does not react to the alarm, the system may send a warning to the caregivers.

Another important function concerns the control of the elder's health parameters (e.g. weight, blood pressure, blood glucose level, etc.) Similarly, the system periodically reminds the user to measure them. The health device is connected via BLE and the measurement is transferred to the smartphone. If the values indicate an unhealthy condition, an alarm can be sent to health professionals, who can then consult the system for the latest measurements stored in the phone.

The mood and activity of older people are also monitored. Sudden changes in habits can be inferred from their use of telephones and how they interact with their neighbors. On the one hand, GPS readings are used to detect physical activities such as walking. On the other hand, Bluetooth detection of other smartphones indicates that users have made or received a visit, or have attended an event. One way to detect a change of mood is to check the use of the phone to call, and also social networks and text applications. Finally, the system may request the user to confirm whether it is fine when the phone has not been used or moved for a certain period of time. With all this information, the system infers patterns of behavior and health, which describe the regular development of user routines and the values of their health parameters. If an anomalous condition is detected, the Digital Avatar alerts neighbors, family or health system, depending on the severity of the situation.

3.2 Architecture

Present day smartphones have enough capabilities to run demanding applications, such as video games, manage all our social profiles, and work with office applications that required desktop computers not so long ago. This way, smartphones have become the most popular device for accessing computing resources and services. In this section, we present the architectural of our proposal, which builds on our previous work on the Internet of People [7] and PeaaS [4] models. The Digital Avatars architecture is deployed at the application level due to the restrictions of the operating system of the smartphone. Thus, all the modules of the architecture rely on OS calls to access any particular functionality or resource of the smartphone. The architecture is illustrated in Fig. 1. It represents the set of software elements required to build, populate, and share in a controlled way the user's information stored in the smartphone.

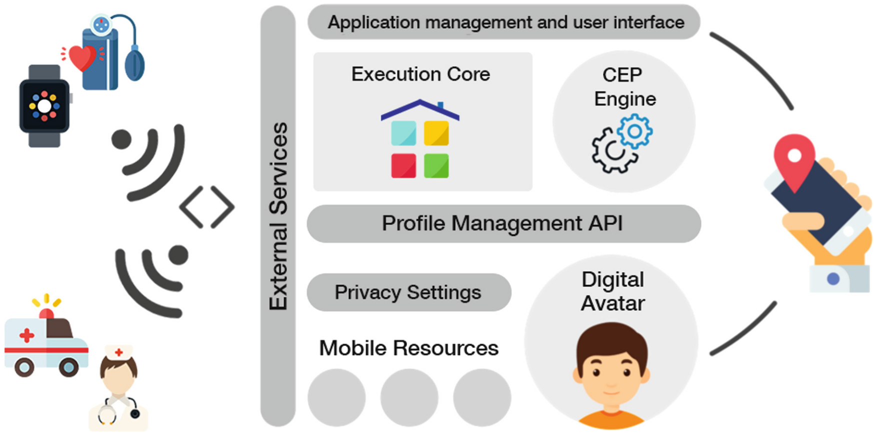

Fig. 1. Digital Avatars Architecture.

The digital avatar is the core element of the architecture. It consists in the user virtual profile and the privacy settings, which define the permissions to access that information. Virtual profiles are represented as JSON documents, and stored in the phone with Couchbase Lite, which offers NoSQL database storage for smartphones. The profile stores both the historic records of events of interest detected, chronologically ordered, and the higher-level virtual profile containing meaningful information about the user. In our case, this information will be mainly related with health: blood pressure and other health parameters, activity and rest time, and even the places the user has been to, or the people she has been with. The virtual profile can be offered as a service, allowing both other applications installed in the phone or external third parties to access it. Privacy concerns are addressed by the Privacy Settings, which define the access privileges to the user's information.

The digital avatar is built by an inference CEP engine capable of processing the raw data collected by the sensors in the smartphone and through other smart devices connected to it. The CEP engine extracts meaningful information from the raw data coming from different sources (built-in sensors, connected smart devices, etc.), by applying a set of rules and patterns. The engine performs two main tasks: detection of alarm conditions and inference of higher-level knowledge. From the first task, we are able to detect particular situations to derive some actions or changes in the system. For example, if the user suffers from an early stage of cognitive impairment and the smartphone detects that he has got lost, it will immediately alert a caregiver [8]. The inference task consists on the analysis of the information stored in the avatar for deriving added-value facts. For example, we can infer the regular activities of the user and the places she visits to predict where she will be at a certain moment [9]. This high level contextual information of the user is stored back in the profile. One of the main advantages of CEP is that it works in realtime, reducing latency in the decision-making process. Hence, it is very appropriate for asynchronous and realtime systems which must react quickly to changing or unusual situations.

The Profile Management API is the module that provides the operations to deal with the information in the profile and make some systems calls. It prevents unauthorized access to the virtual profile, and gives an unique and easy-to-use point of interaction with it. The API takes into account the Privacy Settings to allow or deny access to third party applications. For example, health professionals will have access only to the parts of the profile concerning health issues, not to other personal-related data.

The Mobile Device Resources layer is the element of the architecture that represents all the sensors available in the smartphone. Wearables and other devices connected to the smartphone are not represented here but they are accessed through the External Services module. This module gives support to the interactions of the smartphone with other external sources of information, like wearables, home assisting devices, or public web services offering contextual information like weather conditions, public transport, air quality, etc. Furthermore, this module manages the communications with third parties when a critical event is detected by the inference engine. For example, if a dangerous high blood pressure episode is detected, it will send an alarm to the emergency services.

Finally, the Execution Core module is where the front-end application is running. All the components of the architecture reside in the smartphone. Third parties will be able to access the digital avatar from the outside, provided they have the corresponding permissions. The traditional client/server approach breaks down into a decentralized architecture in which each smartphone node acts as server of its own produced data.

3.3 Data Collection

The raw data for feeding the digital avatar comes from several sources. The main source is the smartphone itself, which provides basic data on the use of the phone, such as the battery level or whether it is connected for charging. In addition, by means of the accelerometer it is possible to infer the activity of the user (if he carries it, obviously) and recognize different types of activities, such as typing, walking, driving, etc. We can also detect how much time has passed since the last time the user handled the device. The movements of the user can be monitored using the phone's GPS in conjunction with network detection via Wi-Fi, inferring if the user leaves home and the distance travelled during walks or visits to other places or people. In this sense, we can also detect if the user interacts with other people (who use Digital Avatars on their phones) since their phones will read BLE signals coming from other smartphones and detect the close presence their owners. In this way, it is possible to analyze if the user is accompanied or if she is related to other people in her everyday environment.

One step further is being able to detect the mood of the user. For that, we will observe the activity with the smartphone, analyzing the record of calls and their frequency, the use of various applications, programmed alarms etc. This data is available on most smartphones.

Finally, other sources of information are health devices that communicate with the smartphone to send their data. Today, most home medical devices communicate via BLE with their smartphone applications. Examples of such data can be provided by glucose meters or blood pressure monitors that are commonly and easily used in a domestic environment.

3.4 Extending CEP with Uncertainty

Complex Event Processing [5,6] is a form of information processing whose goal is the definition and detection of situations of interest from the analysis of low-level event notifications [10]. CEP allows the analysis of large amounts of data from different sources to detect significant information and react to a new situation in real time. CEP engines have typically been run on servers or desktop computers to detect domain-specific critical situations. However, our proposal integrates CEP in the Digital Avatars architecture, with the aim of building in the smartphone a complex virtual profile with high level information on health and habits of the user. This approach is known as mobile CEP [11] and has advantageous implicit characteristics, as there is no need to implement communication between the engine and the sensors. Everything relies on the smartphone, keeping the system information private and correlated.

When dealing with physical systems, sensors, and networks, as in our case, events received are not free from uncertainty. Uncertainty is the quality or state involving imperfect and/or unknown information and applies to predictions of future events, estimations, physical measurements, or unknown properties of a system. Measurement uncertainty is a kind of uncertainty that refers to the inability to know with complete precision the value of a quantity, an intrinsic aspect of any physical setting. Measurement uncertainty can be due to various causes, such as unreliable data sources and communication networks; tolerance in the measurement of the physical elements values; estimates due to the lack of accurate knowledge about certain parameters, or the inability to determine whether a particular event has actually happened or not.

The explicit representation and management of measurement uncertainty is a crucial issue in any faithful model of a given physical system. We have started working on the representation of measurement uncertainty in software models [12,13] and in CEP systems [14], using a probabilistic approach (instead of employing fuzzy logic or possibility theory). Our solution is presented in the form of a library that can be added to existing CEP engines. Note that the focus will be on measurement information (also known as epistemic uncertainty) and the confidence we have in the data we handle, and on the rules that determine the behavior of the digital avatars (aleatory uncertainty).

In particular, we plan to detect and incorporate measurement uncertainty in the events received by the different sensors, in the information stored in the digital avatars, as well as in the system of rules managing the generation of new complex events and alarms. In this way the models and applications will be more realistic by incorporating the uncertainty that exists in the real world.

As previously mentioned, we keep data and computations on the smartphone and avoid using a centralized server as much as possible. Hence, we need a fast, lightweight CEP engine that processes events directly on mobile devices. In this sense, Sebastian et al. [15] worked on a mobile CEP prototype of the Esper CEP engine for Android, named Esper-Android. At the present time, there is not an updated version of Esper-Android compatible with current smartphones, as its maintenance has been suspended due to dependence on third-party libraries not compatible with Android.

Instead, we plan to use Siddhi [16] which is a feature-rich stream processing platform from WSO2, successfully ported to Android devices and Raspberry Pi. The SiddhiQL query language is very similar to Esper's EPL (SQL-based) and includes the main types of operators needed to build the rules: select, filter, window, aggregations, group by, having, join and pattern. Combining these operators, we are able to build rules that implement the functional requirements described in Sect. 3: rules that infer a person's behavior and habits, rules that trigger alarms when a person's biometric values are outside the healthy range, etc.

4 Related Works

The amount of data available about users and their context is quite large, due to the number of integrated sensors available in smartphones, wearables and other devices found in our environment. In this regard, Ambient Intelligence has emerged as a discipline with the aim of making everyday environments sensitive and responsive to people's needs [17].

The main reason to gather information about the users of a system is to learn from them. With this knowledge we can proactively meet their needs to minimize their manual intervention. Contextual data is used to infer virtual profiles with more specific information about the users [18,19]. These profiles may be used to learn important aspects of the user's habits and health condition such as diets, movements, exercise habits and specific health information: heart rate, blood pressure or glucose levels among others. Currently, there are different approaches to create these virtual profiles [20–22].

Many existing solutions related to the monitoring of older people focus on geopositioning the user. Keruve and Neki[1] are two of the best-known enterprise solutions that allow the caregiver to locate the user in real time. However, the GPS devices that these and other companies sell are expensive, limiting their universal accessibility. In contrast, there are economic solutions based on mobile

[1] http://www.keruve.es/ *and* https://neki.es/.

applications like Cerqana and Tweri[2]. However, none of them offer any further information other than GPS positioning. We can provide a greater quantity and quality of knowledge by tapping into all the data the sensors in the smart devices have to offer, which allows us to infer the user's routines, movements and health, giving higher level appreciations. Several studies [23,24] relate the performance of outdoor activities, smartphone use and sleep routines with the probability of suffering depression. All of these indicators could be extracted from the data recollected by the sensors available in the smartphone. Moreover, there is also a good amount of studies about detecting the emotions of the users [25,26], where in many of them the smartphones have a great influence, since the users interact quite frequently with them, and the capabilities of phones such as being able to take pictures of the users facilitate this task.

The idea of transferring CEP processing from a centralized server to the smartphone is proposed in [15], using the sensors embedded in the device as a source of simple events. A similar idea is proposed in [27], where smartphone resources are used as part of the processing of the events generated by their sensors. However, none of the proposals analyzed incorporate the treatment of uncertainty in the data collected or processed.

5 Discussion

In this paper we have presented a research project that explores an alternative model for Social Computing, and applies it to the care of older adults. The benefits of this model are offered at three levels: for the the older persons, for their close caregivers, and for the public health system. The main benefits of the model are as follows:

- **Collaborative model**. We adopt a model based on a peer-to-peer architecture based on smartphones, as opposed to a more common client-server architecture. In this way, the Digital Avatars become a collaborative tool where the users may decide with which other avatars to share their data, and which external data they want to incorporate into their own avatar.
- **Control of the data**. The definition of an alternative paradigm in the area of Social Computing, where the exploitation of people's information can be owned and controlled by the people themselves, instead of being used or commercialized by third parties—without neither transparent control nor clear benefits to the data owners.
- **User safety**. The system is focused on monitoring the user's health: reminding them of their healthy guidelines by means of warnings, generating alarms for their caregivers or healthcare professionals, monitoring their habits and their state of mind.
- **Managing uncertainty**. The applications and models we propose manage the uncertainty that occurs in the real world, incorporating this uncertainty in the data obtained from sensors and devices, in the rules of the CEP engine and in the complex events that are generated.

[2] https://cerqana.com/ *and* http://www.tweri.com/.

- **Permanent contact with caregivers**. Digital avatars facilitate continuous contact and monitoring of older people's well-being by their caregivers. If authorized to do so, the caregiver can request health data for user monitoring and, in any case, receive warnings and alerts as soon as they occur.
- **Communication with health professionals**. Finally, for the Public Health System, our proposal allows health professionals to be informed of older people's health conditions in sparsely populated environments, avoiding complicated displacements that occur very spaced in time. Digital Avatar immediately communicates any health alarm and regularly transmits the biometric parameters that the family doctor deems necessary.

On the other hand, the project confronts some challenges and risks:

- **Smartphone storage capacity**. Data collected in real time from different sources can generate a very large volume of information and its storage can exceed the capacity of a smartphone. A solution is to store simple data for a limited time (e.g. one month) or to aggregate the information at various levels and to store only this aggregated information in the long term.
- **Smartphone processing performance**. If the number of CEP rules and patterns to be processed is high and the data collection is performed at a very high sampling rate, the smartphone may not be able to properly process all this information. There are several solutions to this problem: data can be collected at a certain frequency that is not constant, or a first level of data filtering can be carried out where events of little significance, erroneous, or disabled are discarded.
- **CEP engine for smartphones**. CEP engines require high processing power and are oriented to run on servers or in the cloud. There are few alternatives for direct execution on smartphones as indicated in Sect. 3.4.
- **Access to health devices**. Most of these devices communicate with their own smartphone applications via Bluetooth. However, these applications are usually closed and it is not common to be able to access the data they supply by means of a public API.
- **Evolution of Android versions**. The trend in the recent OS versions is to close access to their internal data, sensors and background applications. The applications we propose are based on these data sources that must be provided by the smartphone. Restricted access to them would greatly hinder their development and implementation.
- **The older does not use the smartphone**. Finally, a non-technological risk is that the user may not be using the smartphone. For a number of reasons, the user may not always carry the smartphone with them. Among them, forgetting, being uncomfortable with it, a certain reluctance to technology, or being out of battery, among many other possibilities.

6 Conclusions

This work is targeted to study the feasibility of using mobile smartphones to increase the quality of life and autonomy of elder people who live on their own in small villages. Specifically, we intend to empower these people by reducing their dependence, increasing the amount of personal data processing done on the smartphone itself.

In this way, the architecture of the system looks like to what is known as fog system. The smartphone acts as a fog device, processing primitive data obtained from sensors and connected health devices, and generating complex information with added value, which can be transmitted to remote nodes hosted on the network. This information is shared with remote nodes hosted in the cloud. In our case study, these remote nodes contain the elder person's monitoring applications and are managed by the healthcare professionals concerned.

Furthermore, this project will allow us to explore the limits of the use of CEP tools in current mobile devices, such as data storage capacity, processing performance, accuracy of the data collected by sensors and connected medical devices, and reliability of complex data generated by CEP tools. For addressing the two last issues, we integrate in the project the concept of uncertainty in the data collected and in the CEP patterns and rules.

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