Social Sensor Web: Towards a Conceptual Framework

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Abstract. Sensor technology has become increasingly pervasive, leading to its use in many areas, such as health care and wellness. Current technologies and services are based on one-way connectivity, such that sensors are primarily used to transmit information. Though data generation is essential to the pursuit of meaningful information, having the right information at the right time in the right context is what successfully integrates the social web into real-world situations. This paper extends the concept of the Internet of Things and develops a conceptual framework of the Social Sensor Web that employs sensors to elaborate context-aware information in order to determine an effective approach to social interaction. The paper also highlights the importance of dual connectivity of sensor devices through workshops based on the state of the art. We present five dimensions of the Social Sensor Web that can serve as a guide for designing future health and wellness technologies.

Keywords: Social web · Sensor · Monitoring · Context awareness · Dual connectivity · Health · Wellness

1 Introduction

The rapid development and increasing affordability of sensor technologies, together with the spread of Internet connectivity, have led to a massive number of connected sensors. In the health care context, connected sensors are used to transmit individuals' blood glucose levels and blood pressure information to health care professionals. Such functions can improve the quality and decrease the costs of health care [1].

Furthermore, in the domain of personal wellness, heart rate monitors and fitness tracking devices enable users to share information about their exercise routines and training progress with other people. Today, consumers who are interested in monitoring their health and wellbeing have access to several commercial applications, devices, and personal solutions for fitness, sports activities, and wellbeing [2].

Given this plethora of options, people utilize technological tools to monitor their health in various ways. For example, 'lifelogging' is an emerging concept referring to the continuous recording of physiological data and everyday life activities. Similarly, the 'quantified self' is a movement incorporating technology into the data acquisition

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of inputs (e.g. food consumed, quality of surrounding air), states (e.g. mood, arousal, blood oxygen levels), and performance (e.g. mental and physical) from users' daily lives. These trends of self-monitoring and self-sensing make use of wearable sensors (electrocardiogram, electroencephalogram, video, etc.) and wearable computing [3].

While the use of sensor technologies creates significant value for both individuals and society, this value could be increased through further advancements. For example, transmitting blood glucose levels or physiological data through sensors represents only one-way web connectivity. Sensor devices could play an expanded role if, first, their information they gather could be combined for realistic contextual perception and, second, if the sensor devices themselves could be empowered with basic interactive capabilities for consuming and producing meaningful information.

In this paper, we propose the concept of the Social Sensor Web. We define the Social Sensor Web as the interplay between sensors and the social web phenomenon, such that sensors elaborate on contextual space in order to determine an effective interaction approach. The essence of this concept sheds light on the dual connectivity between sensors and the web, such that sensors take on the form of social entities [4]. For example, information from the social web can be used to predict the spread of flu; this information could be refined and transmitted to users (e.g. to suggest changes in their workout programs). Thus, social sensor technologies could be used in the healthcare sector to design more efficient interventions or to persuade people to develop and sustain healthier lifestyles.

We present the results of two workshops, in which interdisciplinary groups of experts discussed and assessed the state of the art related to social sensor technologies and identified the most prospective applications of social sensors. Based on the findings of these workshops, we developed the conceptual framework of the social sensor web. Further, by setting a research agenda, the paper contributes to the research on social sensor technologies; its framework can serve as a guide for designing future applications based on the collaboration of sensors and the social web.

2 Context-Aware Sensors in the Social Web

Sensors that measure physical quantities, such as pressure or light, have grown increasingly pervasive. Smartphones and mobile devices typically feature sensor technologies (e.g. touch screens), which collect different types of data from changes to the environment or an object (e.g. temperature, vibrations, or movement) [5].

As sensor technologies have developed, people have changed their ways of using the Internet. Due to the large-scale adoption of social media and online social networking, the Internet has become a social space, to the extent that Oinas-Kukkonen and Oinas-Kukkonen [4] proposed the concept of the *social web*. This idea highlights the role of the web as a social space characterized by connectivity and interactions, both among people and between people and information [4]. Oinas-Kukkonen and Oinas-Kukkonen [4] describe the social web as follows:

> *The term* ***social web*** *refers to a pattern of thinking in which end-users jointly create or generate much of the content for the web, whereas companies try to harness the end-users with tools with which they can participate and engage themselves in content production and sharing. […] An essential feature of the social web phenomenon is that social web is not only a virtual world; what is remarkable about it is its interconnection with one's own life.*

Since the majority of people and an increasing share of physical objects have online digital presences, we propose the concept of a "Social Internet of Things" (SIoT). Whereas the Internet of Things focuses on devices that are connected to the Internet, SIoT shifts the emphasis to objects that interact on the web [6]. Sensors equipped with basic interactive capabilities (e.g. reception and processing capabilities) could interact with other sensors, people, and social web applications.

Aggarwal and Abdelzaher [7] discussed the drivers of integrating sensors with the social web, focusing primarily on social networks. One of the key incentives for users is real-time awareness of others' updates. Such integration could facilitate a better understanding of users' global behaviors. Sensors could also enable measurements of users' environments, thus facilitating context awareness.

Humans' role in this phenomenon is particularly important in terms of data generation and social relations. Although users who use contextual sensors might decrease their self-report data production, their activities will produce more data. Therefore, humans still play a critical role in terms of user-generated activities.

Recent sensor applications have sought to collect data that can be directly associated with individuals' real-time personal information. Some examples of such applications include GPS applications on mobile devices, accelerometers, and location sensors designed to track humans or vehicular traffic. These types of sensors can support a rich variety of applications in which sensor data can be used to model underlying relationships and interactions [1].

At an aggregate level, behavior measurements can be used to investigate and predict traffic conditions through collecting and processing massively distributed data (e.g. the collection of vehicular GPS trajectories to develop street maps) [8]. Currently, this use of sensor data involves very little, if any, social component. However, the same sensor-generated information can also be used on a real-time, daily basis to avoid traffic congestions. As an example of the viability of this vision, Google has acquired Waze, a company specializing in social mapping techniques. Google plans to use Waze's crowd-sourced data on users' locations to suggest alternate routes to outsmart traffic congestions [9].

Furthermore, an application called City Sense, a subscription that provides information on where the people in a city are through GPS-enabled phones, can be used to plan activities [10]. For instance, the service can inform a user walking in the city that his/her friends are sitting in a nearby cafeteria. Turning sensor devices into intelligent objects that communicate with users' social network sites can challenge the conventional information flow between a sensor object and the social web.

Networked sensor data have also been applied in social web applications to aid in the detection of earthquakes [11]. Integrating data from sensor networks into the web would further enhance the web integration of everyday devices and objects, resulting in a giant sensor network and wide-scale connection between the social web and the physical world [4]. In addition, the nomadic nature of the web, which can be accessed from anywhere through mobile devices, requires portable and environmental sensors.

According to O'Reilly and Battelle [12], the new direction of the web is on a real-time collision course with the physical world. Hence, using information generated by sensors requires real-time context awareness. This is where contextual information developed by sensors can complement information from other sensors by better utilizing their measurements. Schmidt [13] considers context awareness to be the key enabler for understanding situations in urban environments with ubiquitous devices. The goal of system context awareness is to arrive at a close representation of the user's perception of the surrounding world. Though the user's perceptions are multi-faceted and based on human senses, multiple sensors are required to develop contextual awareness close to human perception. This will help the system provide users feedback related to situation-based decision-making. Tamminen et al. [14] point out that the social acceptability of a context-aware system is dependent on how well the system fits into the routine processes of everyday life in a society. Therefore, the better a system is able to develop context awareness, the greater its chances succeeding in the race to technological adoption.

To address the issues discussed in this section, we now discuss the workshops held in this study and present the conceptual framework for the Social Sensor Web.

3 Towards the Social Sensor Web

3.1 Study Setting

We collected empirical data from two expert workshops on social sensor technologies, comprising a total of 14 experts from various fields, such as information systems, mobile technologies, and physical education. The participants had diverse cultural backgrounds in terms of gender and countries: Most were PhDs who are actively engaged in research, and half also had industry experience. The workshops were organized and facilitated by the first author. The objective of the workshops was

Fig. 1. State-of-the-art sensors and technologies.

to obtain participants' perceptions regarding social sensors and, ultimately, to develop a conceptual framework of the social sensor web.

The purpose of the first session was to familiarize the participants with one another, the research objectives, the focal concepts, and the state of the art of social sensor technologies. To this end, the participants were presented a number of different sensor devices (see Fig. 1), which they were then asked to scrutinize and discuss.

The first was *FitBit Surge* (device A), a fitness wrist device [15] with a built-in GPS; continuous heart rate monitoring capabilities; and tracking for daily activities, such as distance, steps taken, sleep pattern, and floors climbed. It synchronizes measurements wirelessly with a smartphone and presents the data in the FitBit app, as shown in the first two screenshots in Fig. 2. Additionally, the device displays calls and notifications from the smartphone, as shown in Fig. 3A later. The *FitBit One* (device B) is a limited version [15] of the Fitbit Surge; it lacks heart rate monitoring and is used with the FitBit Surge to provide measurement accuracy. The *FitBit Aria* (device C) is a non-wearable wireless device [15] that tracks weight and Body Mass Index (BMI) to determine body fat percentage. The device allows users to analyze weight data in relation to data on calories burned. Alternatively, the FitBit app can be used to manually log diet information, including food plans, water intake, etc., while also displaying all kind of measurements in graphical charts.

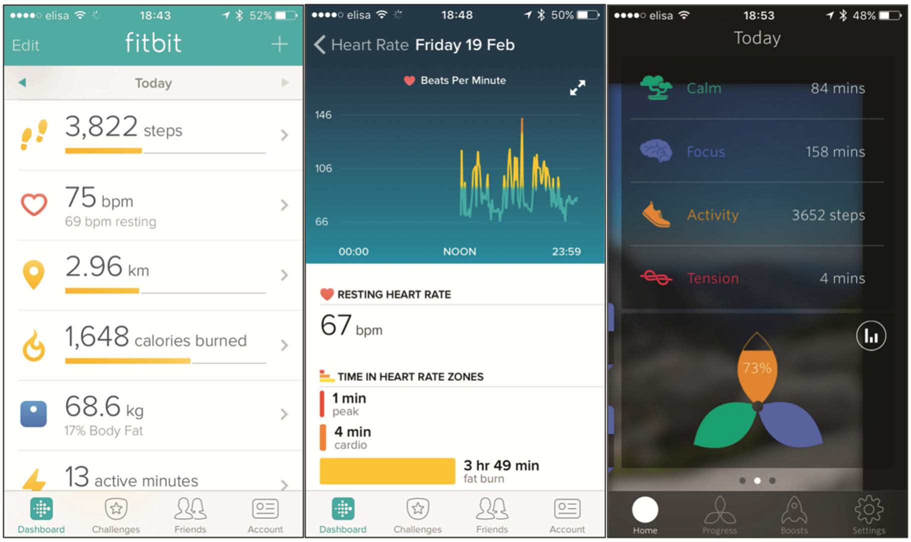

Fig. 2. Synchronization and presentation of physiological data.

Spire (device D) is waist-worn [16] device that monitors a user's breathing pattern in real time and assesses stress levels accordingly. It categorizes breathing patterns into three types: "low and uniform" corresponds to a user being calm, "high but uniform" corresponds to focus, and "high and erratic" corresponds to stress. Based on the collected data, the device sends notifications to the user's smartphone. For example, it may suggest

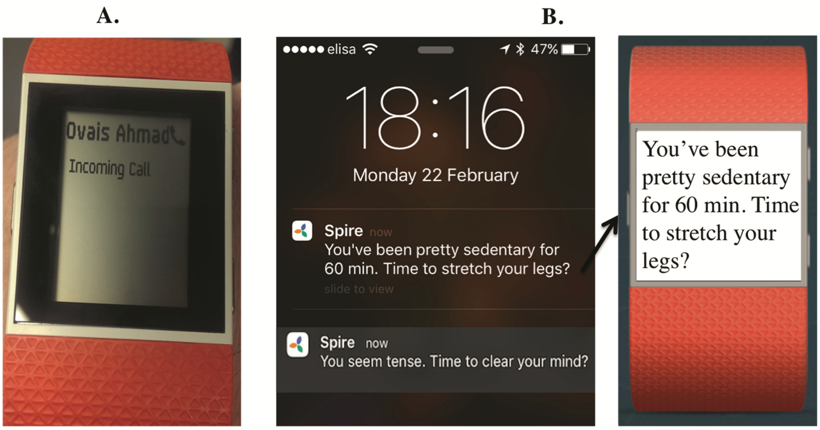

Fig. 3. *FitBit Surge* display and *Spire* notifications on the smartphone.

that a stressed user needs to relax or encourage a user who has been sitting idle to stretch his/her legs (see Fig. 3B). The device synchronizes with a smartphone app, which lets the user set goals and presents statistical analyses of their everyday breathing patterns, as shown in the last screenshot of Fig. 2.

Temperature (device E) is a non-wearable device that measures indoor and outdoor temperature using a small sensor probe that needs to be placed outside the window. *BiiSafe* (device F) is a smartphone accessory [17] that uses a smartphone's GPS via Bluetooth to enable users to share their locations to connect with or alert friends and family and help them find important lost items, such as keys, phones, wallets, etc. It is the only product on the market to combine location sharing, alert/distress functionalities and lost-item finding capabilities. A *smartphone* (device G), in addition to providing communication services and social web apps, has several sensors, including an accelerometer, a gyroscope, etc.

In addition to these items, the workshop participants were provided access to three weeks of data from the first author's Life Log. This Life Log included personal health measurements and assessments from the use of these state-of-the-art sensors; a calendar for the past three weeks of logged activities such as sport sessions, locations, work meetings and travel; and a mockup of social contacts.

The participants were asked to familiarize themselves with the sensor devices and their features and to consider their value and potential, as well as to provide suggestions for additional functionalities that could add value to users. For example, the participants suggested that *Spire* device notifications, which were currently displayed on the smartphone (Fig. 3B), could additionally be displayed on the device itself, as in the *Fitbit Surge* device (Fig. 3A).

In the second workshop, the same participants were divided into three groups. Whereas the purpose of the first workshop was to familiarize participants with state-of-the-art technologies, the second workshop encouraged participants to think "outside of the box" regarding sensor-based solutions not limited to the presented sensors. In consultation with the participants, the use scenarios were created to target three different domains: healthcare monitoring, fitness and wellness, and social interaction. The participants worked in teams for an hour, collaborating on how state-of-the-art sensors could provide effective solutions to the use scenarios. The scenarios ranged from monitoring the elderly at home, to child safety, to decreasing stress through personalized activities, to keeping in touch with family and friends.

The participants then presented their solutions and identified their core solution concepts. The teams' work was discussed, and remarks were noted, merged, and deliberated for the rest of the workshop. Ultimately, a consensus was reached; this consensus formed the dimensions of the framework.

3.2 The Framework

The following are quotes from the participants during their collaboration efforts in the second workshop:

> *One of the exciting aspects of sensors is their ability to work continuously and all the time, whether it's controlling traffic signals or monitoring my health.* - Participant 2

> *It is great that sensors can know more about me in order to help me, but it scares me to think that this information, unless controlled, might get out of the circle of people I trust.* - Participant 5

> *I think, no matter how much information sensors can generate, it still needs to be taken into account with artificial intelligence in parallel to precisely identify real-life context issues and provide solutions accordingly.* - Participant 11

Our conceptual framework of the Social Sensor Web is based on the participants' consensus and feedback, which can serve as guidance for designing future applications based on the combination of sensors and the social web. The framework contains four horizontal dimensions: keep alive monitoring, context awareness, interaction intelligence, and the personal social web (presented in Fig. 4).

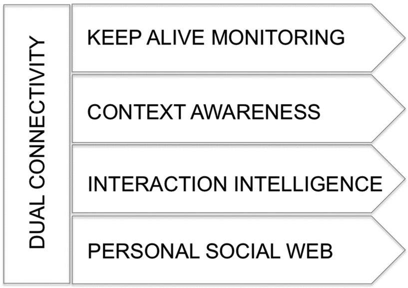

Fig. 4. The conceptual framework of social sensor web.

These four horizontal dimensions are connected via the fifth, vertical dimension: dual connectivity. The concept of monitoring serves as a basis for contextual awareness in systems, which is critical for determining suitable interaction approaches. Social interactions towards a target must take place within users' own social web. Within this exemplary system, dual connectivity allows the dimensions to coexist and work together in an effective way. Further sections elaborate on each dimension's importance and potential.

3.2.1 Dual Connectivity

The conventional information flow between a sensor and the social web has traditionally been one-way, meaning information extraction or placement: either sensor data are shared on the social web or a request is sent from the sensors and information is retrieved from the social web. Both cases require the user of the sensor device to initiate the information flow. Though this certainly serves a purpose, it involves minimal intelligence. A more sophisticated sensor could automatically invoke the social web to collect relevant information that could influence the user. Alternatively, the social web could serve as the initiator and provide useful information to the sensor [4].

The dual connection perspective presented in Fig. 5A can completely change the way we think about new solutions of information flow. For example, consider an individual's daily fitness workout, which is planned through a sensor that is a part of the social web. With one-way connectivity, workout data are shared on the social web. However, let us assume that a flu is spreading throughout the user's region and a local hospital shares information on the social web. If the social web were able to share this information with the sensor, this would allow the sensor to modify the user's workout to address the risk of flue. This is a clear case of a dual connection between sensors and the social web, in which each can invoke the other. For instance, in Fig. 5B, a notification is displayed to the user depicting information gathered from the social web by the sensor device, and the user can use the device's left button to let a nearby friend know of his/her proximity.

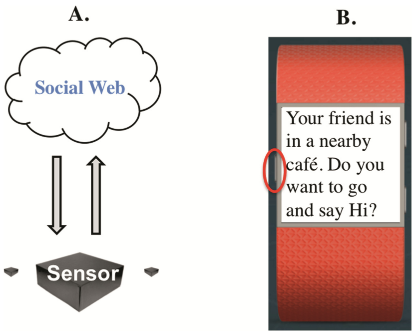

Fig. 5. Dual connectivity.

3.2.2 Keep Alive Monitoring

One of the key benefits of technology is its ability to keep working to serve its purpose 24/7. Increasing costs of healthcare are a major problem [18]. Remote health monitoring provides not only a way to address these rising costs but also opportunities to monitor petty health issues, which can turn into major health problems over time [19]. On a technical level, this has been possible due to the development of wireless devices and sensing equipment [20]. Many research groups are investigating novel and cheaper ways to support healthcare issues related to diverse groups, including the elderly and disabled, chronic disease patients, and sports enthusiasts [21].

To achieve continuous health and wellbeing management, monitoring and timely interventions are extremely important. For sensor-based systems to become instruments of continuity and control for end users, monitoring must remain alive for extended periods [22, 23]. This notion of *keep-alive monitoring*, which provides information on users' health and surrounding contexts at all times, can only fulfill its potential if the information can help in identifying threat-related information patterns. This is only possible if such information is reliable and continuously monitored.

Power consumption in these technologically advanced devices remains a concern. As a precaution, these boundary conditions should, by default, be considered within the overall monitoring scheme, where a sensor's power consumption is monitored. According to Satyanarayanan [24], the monitoring capabilities of futuristic sensing devices should make use of smart spaces and involve minimal user distraction; this will allow them to achieve both user satisfaction and their goals simultaneously. As Mark Weiser [25] stated: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."

3.2.3 Context Awareness

The value of "context" in the field of human–computer interaction has been widely acknowledged, particularly as the use of sensors to obtain context information has been widely practiced in the domains of robotics and machine vision [26]. Recently, the concept of context has received growing attention due to developments in mobile computing, which have led to the emergence of pervasive computing [13]. Context refers to a description of facts that add meaning. This is best described by Dey [27] as, "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves."

Knowledge of both the physical environment and the situational environment is important. Schmidt [13] presented a model for the concept of context, which is a context feature space that distinguishes context related to human factors from context related to the physical environment over time. The human factor categories rely on user information, biosensor readings, the user's social environment (e.g. social interaction), and the user's tasks (e.g. goals). The model's physical environment aspects also hold importance (e.g. tracking location and indoor/outdoor temperature).

One distinguishable feature of wearable computing is awareness of both a user and his/her environment. For instance, a heart rate measurement of 90 beats per minute (bpm) is considered to be average; however, for an individual whose average heart rate is 76 bpm, this is high and a possible cause for alarm. Here information revealing that the elevated heart rate is caused by jogging makes a difference.

Location is the most commonly used context information in present technology. However, detailed and reliable context awareness of various parameters would allow systems to make proper judgments concerning not only providing context-based services but also automatically executing these services for an enhanced user experience. Active context awareness, in which a service or application automatically adapts to discovered context through changes to its behavior, is required [28]. Santos et al. [29] summarized several system prototypes for context identification that support social networking services.

3.2.4 Interaction Intelligence

This dimension is the nucleus of the decision-making process based on contextual awareness. In its most simple form, interaction can comprise the act of notifying some social contact or user of the nature of a context. The type of interaction is dependent on the system domain and the type of contact.

In real-life scenarios, actions taken by a system can be proactive, preventive, or reactive, depending on the goals of the system or the problem domain. For example, in the case of healthcare, *proactive* measures or actions could include suggestions to eat healthy, while *preventive* actions could include specific suggestions such as to avoid obesity. Finally, *reactive* actions could correspond to emergency situations, such as a heart attack. For each of these actions, further decision-making on the part of the target recipient is needed. For instance, information related to personal fitness goals may be transmitted to the user or the trainer; the location of a kid in emergency care may be transmitted to parents or teachers; and, in the case of the elderly, information on heart issues may be transmitted to a caretaker or a hospital.

3.2.5 Personal Social Web

A user's personal social web comprises the user's network connections. The increased use of these connections through social web applications has increased people's comfort working with real-life social network connections at the technology level. Figure 6 presents a conceptual illustration of a personal social web as a network.

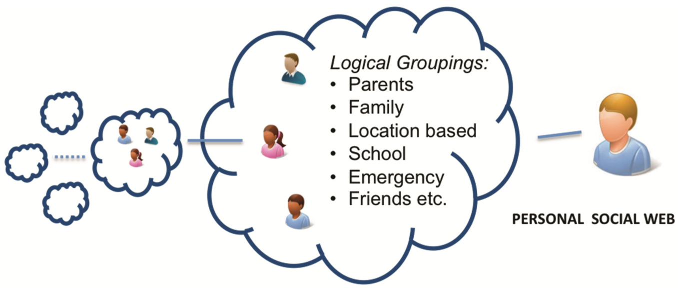

Fig. 6. Personal social web.

It is common for users to create logical groups of the connections in their own networks (e.g. family, friends, or work colleagues), typically based on static parameters. However, a personal network could also be divided into logical groups based on dynamic parameters, such as current location. Engagement with a dynamic social network based on, for example, location could benefit from the use of sensors that are part of the network in real time. In a dance group, meaningful information generated from sensors and the dynamic dance-group social web regarding the participants' wellness and the class environment can help teachers perform better. In school, a child's school sub-network has priority in case of an emergency. The logical groupings of an individual's personal social web can be utilized to achieve social interaction targets based on the contextual nature of the situation.

4 Discussion and Conclusion

The purpose of the study was to develop a conceptual framework for Social Sensor Web. Recent increases in lifestyle mobility increase the need for context-aware solutions based on sensor technologies. In practice, contextual awareness, when combined with the social web and sensor data, creates large volumes of data that need to be assessed. This information is collected through various sources; then, an accurate context is developed, and a meaningful result is given to the user in a presentable way. To achieve this, not only does the stream of information need to be intelligently processed, but, on a technological level, physical user interfaces (UIs) need to be dynamically advanced.

Figure 7 shows the inherent concept behind this part of discussion. The user is considered to be the center of the information hierarchy, and streams of information are expected from the user's Social Sensor Web. In the current state-of-the-art, as well as in the workshops, *sensors* (right in Fig. 7) are primarily connected to users' *smartphones* for wireless synchronization. However, for this user, the *FitBit Surge* is the main interaction device. The sensor's dynamic interface emphasizes the information that is most useful to the user based on a meaningful analysis of data from all streams. The streams of information from all channels are necessary to develop contextual awareness in the smartphone. This involves extensive real time data analysis on the smartphone, while simultaneously emphasizing the need for intelligent UIs in sensor devices like the *FitBit Surge*.

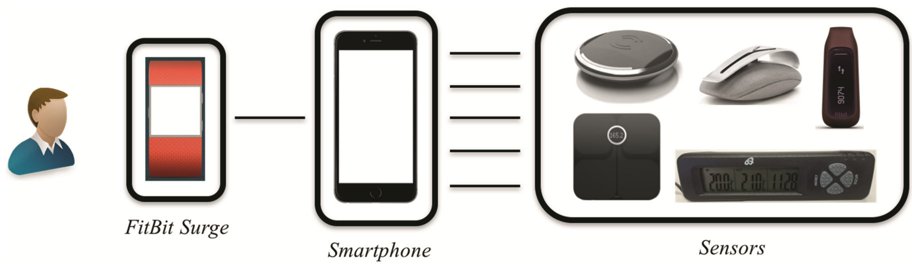

Fig. 7. Dynamic interface.

Insufficient protection of users' private information is a major security risk related to the extensive use of sensor-generated information. Mancini et al. [30] proposed that the investigation of mobile privacy requires a diversified approach, in which cross-interpretations of data from complementary studies should be mandatory.

Mobile privacy issues are difficult to study and poorly understood because direct observation methods are typically intrusive to study settings. On the other hand, exploiting user information is critical to success in proactivity, self-tuning, and behavioral change. Greater dependence on pervasive computing systems makes users aware of their own movements, behavior patterns, and habits [24]. However, Patil et al. [31] found that the motivations for using location sharing data were connecting and coordinating within own circles to project an image of 'checking in' and receiving rewards.

From a critical perspective, sensors can be noisy, and machine-learning algorithms are not always accurate. The concept is too technology-centric, and the expectation of exposing users to extensive physiological monitoring is an issue. Morozov [32] gives a detailed and interesting perspective of the nonsense raised by the advent of the Internet, the rise of the social web, and the smart gadgets that are making humans "dumb." Further, David Berry, a critical theorist [33] has pointed out that conceptualizing the world of digital media can have implications on society norms.

Accurate context detection is a challenging problem, as mentioned by Paul Dourish in his book, *Where the Action Is* [34]. Many assumptions might fail to hold true in challenging real-world situations. However, the pace at which the technology is progressing, the proposed framework presents an opportunity to be better prepared for future technology utilization. In this regard, it is essential for future research to focus on the robustness of the framework dimensions, and the links among these dimensions should be thoroughly studied.

The insights from our workshops suggest that the determination of context through sensors is emerging. The framework may have been limited by the participants' cultural backgrounds, professions, and the provided sensors, which may have introduced bias variables. The concept of a dynamic interface to give simple and reliable information is another issue in terms of user experience. In particular, content provided to a user needs to be credible and filtered in a such a way that objectivity and information value needs are maintained and the user's needs are addressed. This, in turn, calls for understanding the ethical implications related to social sensor technologies. Interestingly, however, ethical aspects have not been extensively discussed in relation to persuasive systems [35].

Finally, our findings are subject to limitations which offer avenues for future research. First, our research approach was highly exploratory. Hence, additional research in the area is needed to increase the trustworthiness of the results and their interpretations. Second, in order to keep the scope of the study manageable, several important issues, such as security, privacy, trust, and user experience were excluded from our investigation. We thus suggest future research covering these areas.

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