Key Factors for Innovative Developments on Health Sensor-Based System

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Abstract. In the current technological revolution, the proliferation of sensors in smart devices and environments convert users into a real-life data source that ranges from the monitoring of vital signs to the recognition of their lifestyle, behavior and health. In this work, we describe current trends and issues on innovative healthcare systems, which are integrating wearable devices and smart environments into numerous health applications. The report includes a revision of the literature with academic, technical and legal concerns on the development of health solutions.

Keywords: Health technology · Sensor-based systems · Disruptive innovation

1 Introduction

In this work, we present new trends and entrepreneurship opportunities for innovative developments [1] on Health Systems based on the disruptive changes [2] in health systems [3], which is being developed by the deployment of sensor and devices whose accessibility spreads to much of the population of the developed world. The disruptive innovation is key for the next generation of Health System because of being *needed for organizations to survive dynamic and complex markets and uncertain economic situations* [4] and contributing to higher organizational sustainability [5]. Disruptive innovations are usually driven by entrepreneurs and innovative developments due to the initial risk profits and their scarce-resource development [6]. However, when the innovation successes, it achieves a much deeper penetration and impact on individual, functional, company and market levels [7].

The aim of the paper is describing the key factors where the academic world and the entrepreneurship can merge in order to develop the future generation of Health Services. Specifically, we analyze the sensor-based systems for mobile and wearable devices, as well as, within smart environments, emphasizing the challenges and opportunities in these sectors.

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The remainder of the paper is structured as follows: in Sect. 2 we describe the issues for innovative developments of health applications for mobile and wearable devices; in Sect. 3, we analyze more complex scenarios of smart environment where the innovation in health services require handling with modelling, storing, privacy an legal issues; finally, in Sect. 4, we present the conclusions of the report.

2 Health Sensors and Devices for Describing the Life of the People

The penetration of mobile devices has enable capabilities of the Ubiquitous Computing [8] in our daily activities. Additionally, sensors embedded at mobile devices and their pervasive communication *enable new applications across a number of sectors but particularly in personal healthcare* [9]. In this way, mobile technologies [10] has been demonstrated to be effective for changing health behaviors [11], for example, increasing exercise time, knowledge of health or weight loss in patients [12].

On a recent stage, wearable devices [13] have emerged as smart portable sensors analyzing user activity by means of reliable measures, such as movement, steps or vital signs, such as hearth rate. In health context, they have provided a new perspective of real-time monitoring for decision support systems and prognosis [14] becoming facilitators of health behavior [15]. We highlight real case studies, which have been carried out by means of remote monitoring on treatments of patients with cardiovascular diseases [16,17].

Moreover, the irruption of these health devices and systems have break down traditional business model translating to an innovative perspective which handle this disruptive process. For that, the report of the European Medical Technology industry [18] has taken a snapshot of development of health devices noting that:

- Prices for implantable medical devices have been reduced between 17% to 34%.
- 25,000 companies are focused on medical technology, where 95% are small and medium-sized enterprises.
- Patents in medical technology represent the largests of all sector (more than 11,000)
- 7.5% of total health expenditure corresponds to medical technologies.
- The Medical Devices Expenditures are centered in USA (40%) and Europe (30%).
- The development life cycle is from 18 to 24 months.

2.1 Ubiquitous and Fog Computing in Mobile Health

Based on the computing capacity of the wearable sensors and health devices, recent paradigms, such as Edge Computing [19] or Fog Computing have translated the computing of data and services within the devices where data are collected [19]. This new perspective displaces the focus from Cloud Computing, with a centralized processing [20], to Internet of Things (IoT) [21,22] with

a collaborative network where the Smart objects *interact with each other and cooperate with their neighbors to reach common goals* [23,24].

In these last years, Ubiquitous Computing (UC) [8] has provided a stable development frameworks, to which the capabilities of wearable devices [25] have been integrated into the health applications [15]. These trends have enabled driving remote rehabilitation [26], ubiquitous mobile telemedicine [27,28] or health-monitoring systems [29].

These mobile applications are needing a new perspective to integrate intelligent processes by means of Ubiquitous and Fog Computing. The challenge of mobile health requires locating the information processing of sensors to generate richer and higher-level information [30] in the devices where data are collected in real time. This key issue needs for analysis of raw data, which are summarized and merged with other sensor information by means of context-aware computing [31–33].

On market perspective and enterprise innovation, mobile health applications is currently handling relevant issues, such as: (i) needing for regulatory and funding issues [34], (ii) solving data privacy and security as a major issue on deployments for public health [35], (iii) demonstrating to be cost-effective for handling chronic disease in developing countries [36], (iv) focusing on assistive and monitoring applications, the most frequently used applications [37], (v) integrating collaborative high-quality professional practice protocols [38].

3 Moving Health Care Services to Smart Environments

Smart Environments [39] are interactive spaces where technological devices are adapted to solve daily activities of people. They are developed under networks of physical objects, so Internet of Things (IoT) [22] has recently arisen as a new paradigm where Ambient Intelligence [40] and Ubiquitous Computing [8] converge [41] to provide connected smart things within the Smart Environments.

Among other applications, Smart Environments can provide a successful solution to the ageing population, which is going to raise the percentage of population over 65 up to 15% [42]. In this scenario, the current system, where the health personnel care and supervise patients in an individual way, is untenable. So, smart environments are proposed to help elderly people to stay with the best quality of life as long as possible in their sustainable, healthy and manufacturing homes [43].

The main difference regarding mobile health, is that smart environments analyze a more complete vision of daily-life from users in order to provide an ambient assisted living [44–46]. It is due to the *integration of data from heterogeneous sources* [47], where a wide range of sensors are deployed to collect multiple data from mobile, wearables devices of different users together with ambient devices [48].

Due to this diversity, a key aspect for smart environments is *designing models and structures of knowledge representation*. On semantic health modeling,

the development of ontologies have been successfully adapted to human behavior identification [49]. In parallel, other general models have been focused on providing scientist interoperability [50] or the enterprise interoperability [51].

Furthermore, it is necessary to *distribute the information processing of sensors*. The adequate distribution of services in ambient environments is key to provide sensitivity to real time [52] when distributing the information processing in several central processing units [53,54]. In this area, the concept of *middleware* highlight as an infrastructure in which are distributed the sensor streams from ambient and user devices by remote services.

For developing enterprise solutions of smart environments handling this topics, the open source model have resulted as an important initiative making that the disruptive innovation based on open business models [55] had provided high quality tools. We highlight some open tools such as: (i) ZeroC Ice [56], which is an object-oriented distributed computing tool with support for several languages and platforms, (ii) Global Sensor Network (GSN) that applies sliding window management [57] in changing data stream [58], or (iii) W3C Semantic Sensor Networks (SSN) [59,60], an open semantic annotating for sensors.

On the market opportunities, on the first hand, they are focused on translating health care services to smart environments. This ambitious goal aims to solve issues related to dependency and ageing, where we highlight:

- Monitoring chronic diseases, which are suffered by a half of the inhabitants of developed countries [61,62].
- Reducing medication administration errors due to non-compliance with medication instructions, because of (i) arising as cause of approximately 10% of hospitalizations and (ii) producing 23% of hospitalizations of elderly people incomes [63–65].
- Identifying mental disorders by analyzing user activities, such as dementia [66].
- Promoting telenursing, which is demonstrated to *decrease the number of outpatient and emergency room visits, shortening hospital stays, improving health-related quality of life, and decreasing the cost of health care* [67].

On the second hand, these market opportunities can be faced by enterprise innovations for developing *smart health environments*, but in literature several challenges have been noted to be crucial in real deployments:

- Detecting when and where telemedicine is most effective for avoiding ineffective programs [68].
- Training of healthcare professionals in new technology [28].
- Keeping alive the communication between patient and healthcare professionals [69], for example by integrating video conference systems.
- Creating the legal and regulatory infrastructure for telemedicine [68].
- Integrating contact-less technology because of: (i) being now mature to be part of smart environments by means of low-cost and energy-autonomous sensors [70], and (ii) increasing security and minimizing accidents and mistakes [71].

3.1 Big Data, Cloud Services and Security for Health Environments

A special mention is necessary for the services and persistence in smart health environments due to they require handling a vast amount of sensitive data from sensors, which are the key to generate knowledge about patients and illnesses [72]. These huge amount of data is described as Big Data [73], which is on the point of emerging thanks to the proliferation of health sensors and environments [74]. The analysis of these data will be able to provide new researches and to evaluate health care programs using Machine Learning [75]. However it is necessary to solve the key problem of the exponential growth: in 2020, it will only take 73 days for doubling the volume of medical data [76].

For that important reason, the enterprise and innovative solutions, which aim to service a relevant number of environments and patients for health services, needs for handling critical points on health data:

- Including long-term recording of biosignal and sensor streams, by means of recent tools which solve the large-scale of data analysis. For entrepreneurial solutions based on open source, we highlight the great potential of source non-relational, distributed databases, such as Hadoop [77,78] and Spark [79].
- Including international healthcare informatics interoperability standards, where the most important is Health Level Seven *HL7* [80].
- Integrating the monitoring application in cloud services, making them easily accessible [81].
- Including business intelligence processes. It is a recent and demanding need for *embed analytics into decision-makers across the business gain insight into financial and medical data and become more proactive* [82].
- Adopting the prevention protocols at home by means of the uninterrupted communication with the patients, which allows us to anticipate or predict possible problems, making appropriate decisions at any time. In addition, they optimize the service model itself and reduce the expense of the necessary resources [83].

On the security, privacy an legal issues in electronic health records, the visibility of health data have to be encrypted and restricted to the own users, and in the same way, to be shared with health care personnel from the prior authorization of the owner [84]. These issues are involving relevant works on legal aspects from the real deployments of the innovative health-care systems:

- In [85], the *lack high-quality evidence that supports the adoption of many new technologies and have financial, regulatory, and security hurdles to overcome* is highlighted.
- Base on experiences from England and Australia, the rights and responsibilities of electronic health records need for *moral re-ordering required to transform health care through such means* [86]. In concrete, in data protection of Electronic Health Record (EHR), where *EU and other countries are determined to find solutions, impose policies and standards as to implement EHR at national level and international levels* [87].

Table 1. Technologies, paradigms, applications and issues, which are evolved in sensor-based systems for Health

Technology	Paradigms	Applications	Issues
– Mobile devices	– Ubiquitous Computing	– Access to remote health services and protocols – Hand recording of activity or health status – Knowledge of health process	– Stable mobile application development – Contact-less technology – Low training of health personnel
– Wearable devices – Mobile devices	– Ubiquitous Computing – Fog Computing	– Real time recording of physical activity or health status – Monitoring and physical activity	– Recent development and permanent change – Low familiarity with wearable of health personnel
– Ambient devices – Wearable devices – Mobile devices	– Ubiquitous Computing – Fog Computing – Ambient Intelligence	– Real time recording of daily activity – Telenursering and monitoring rehabilitation at home – Identifying mental disorders at home	– Middleware & Modeling Open tools – Training of healthcare professional
– Big data – Business Intelligence – Ambient devices – Wearable devices – Mobile devices	– Ubiquitous Computing – Fog Computing – Ambient Intelligence	– Evaluation of health care programs – Financial analytics by business intelligence – Identifying mental disorders at home	– Cloud Services – Including interoperability standards – Machine Learning – Permanent changes and uncertain in legal regulation

– In order to provide secure cloud services for health data, it would be necessary to advance in service level agreements for security [88]. These services must include restricted-role access, which permits health personnel to have various view based on the profiles [89].

Once the governments, health institutions and companies agree on a common standardization, the Health Big Data will be a benchmark in health sciences to study and to improve the life of society [90].

4 Conclusions

In this work, we have presented opportunities and key factors on the development of health technology based on mobile, wearable and ambient devices. The most important paradigms, issues and applications have been summarized in Table 1.

In summary, the efforts are focused on two main areas: (i) integrating wearable sensors and mobile applications in daily health activities and (ii) processing huge volumes of data for discovering knowledge and identifying patterns of health problems. Both aim finding answers to current problems of healthcare systems, but to find new questions which improve health of people in the future.

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