MoSHCA – My Mobile and Smart Health Care Assistant

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***Abstract*—MoSHCA is a mHealth project designed to improve patient-doctor interaction and to promote the self-management of chronic diseases by the patients themselves. The number of people with a chronic disease is dramatically increasing worldwide. This is becoming a major obstacle for economic stability and growth and the sustainability of national health care systems. The introduction of self-management by patients with a chronic disease seems inevitable as a countermeasure against these developments. MoSHCA provides intelligent, user-friendly and secure, medical and well-being decision support through embedded software in mobile devices by utilizing specific sensors and data from customized information systems.**

I. Introduction

The World Health Organization (WHO) forecasts that the number of people aged over 60 will soon reach 2 billion. This ageing trend is fueling a dramatic increase in the prevalence of disability and chronic illnesses, with enormous impact not only on individuals but also on the countries' health care systems and economies [1], [2]. There is an urgent need for taking actions to reduce the increasing prevalence of chronic diseases and to introduce cost-effective prevention and treatment strategies to reverse this trend. Typical examples of such chronic diseases are chronic obstructive pulmonary disease (COPD) and diabetes mellitus type 2.

According to the European Lung White Book, COPD is one of the few leading causes of death that are increasing in prevalence worldwide [3]. The WHO Global Burden of Disease Study has projected COPD mortality rates from 1990–2020 and estimates that COPD will account for over 6 million deaths per year in 2020, which will move COPD from the sixth to the third leading cause of death worldwide over this period. Unlike many leading causes of death and disability, COPD is projected to increase all over the world as smoking habits rise in many countries and the population ages. In this paper, COPD is considered to illustrate one of the many envisaged use cases of the MoSHCA project.

Another chronic disease that is increasing in prevalence in many countries, in particular in the Western World, is diabetes mellitus type 2 - a metabolic disease that now affects hundreds of millions of people, often obese, around the world. It is closely associated with cardiovascular diseases, such as myocardial infarction and stroke, and it is the origin of reduced function and disability due to its impact on the neural, renal and visual systems, all of which are affected in the course of time.

An emerging solution to alleviate this burden is to empower patients with self-management technology; there is increasing consensus among health care professionals and patients alike that many chronic disorders can be better managed in the home environment than in an outpatient clinic or hospital. Self-management may involve taking self-measurements, behavior change encouragement, such as taking regular exercise, weight control and adopting a suitable diet. Adopting and maintaining such behavior is not easy, and strategies which assist the individual to change his behavior are welcome. Mobile technology and intelligent medical applications may play an important role in achieving this.

In this setting, MoSHCA's research focuses on the development of *smart health care assistance*, where smart refers to the ability of drawing clinical conclusions about the patient's health status without, or with limited, human intervention. Only by using intelligent self-management health care applications, it is possible to achieve sustainable, high-quality and cost-effective care of chronic diseases. The MoSHCA project will also create new business opportunities in mobile intelligent multimedia health care assistance systems.

In this paper we introduce the principles and ideas that will act as a foundation for the development of smart health care assistants within MoSHCA.

II. Motivation and Objectives

In the last few years a shift took place from the traditional computing and communication, using devices such as PCs and laptops, to mobile devices such as smartphones and tablets. Many medical mobile applications, also commonly called apps, have recently emerged on the market, although without an apparent strategy: often it is unclear in what way these apps will contribute, e.g., to tackle the major threats to the sustainability of the health care systems of the developed world, as mentioned above.

The MoSHCA project focuses on user-centered and inclusive design, ensuring that the technology developed is usable, accessible and ergonomic, and thereby it caters for the wide spectrum of design needs of patient populations in particular, and for the whole population in general. This is especially important in health applications where usability needs of people with chronic diseases and disabilities, namely the elderly, are paramount. MoSHCA's vision is that, as the current pressure on health care is mainly due to demographic changes in

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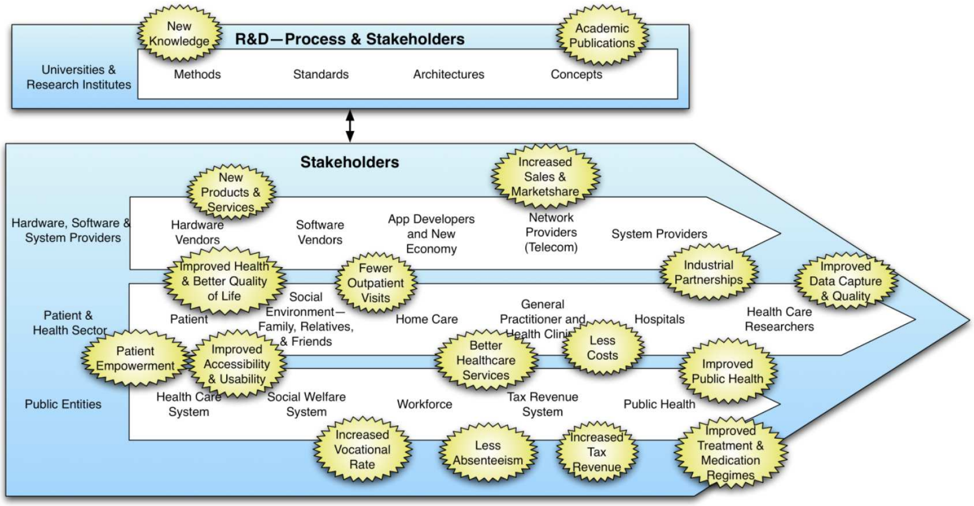

Fig. 1. MoSHCA value chain – stakeholders and expected benefits.

society, augmented by changes in the people's overall health, a patient oriented approach to health care innovation is essential. Building the system around its users will help bridging the gap between the health care system and the citizens. One of the main goals here is to provide a sustainable structure and simplicity to the end-users/patients.

The overall innovation of MoSHCA is to develop considerable and measurable advances in intelligent health care system solutions for patients with chronic diseases, and general health monitoring solutions, by offering:

- user-friendly medical applications embedded in smart computing and communication devices, such as smartphones and tablets, enhanced with sensor technologies;
- intelligent clinical decision support, taking into account the various parameters involved in the management of chronic diseases;
- a better understanding of the issues involved to maintain privacy and security, and available solutions;
- increased context awareness of health care applications;
- improvement of the reliability of medical sensors, and the reduction of its energy consumption;
- increased interoperability with information systems.

An overview of MoSHCA's value chain is presented in Fig. 1.

III. Related Work

From the mid-1990s onwards, when Internet access and usage became widespread and turned into the primary network for telecommunications, *eHealth* emerged as a promising field for better and more efficient health care delivery using web-enabled services. The subsequent eHealth revolution gave rise to a substantial growth in the number of available tools to monitor the patient's condition, usually in the home environment, and in facilitating earlier diagnosis and more effective treatment [4]. Examples of commercial systems employed in practice include Bosch Health Buddy [5], [6] and Intel Health Guide [7], which are devices that support the attachment of sensors and the transmission of data to a central server where they can be inspected by responsible caregivers.

Although existing eHealth systems support monitoring of the patient's condition, they provide very limited feedback to the user. Typically, a few, often just one, clinical parameters are measured, and stored within a database system to be interpreted by a health care professional. Thus, these systems just collect data and lack the clinical interpretation capabilities of a medical doctor, who takes the patient's history into account, including that of the underlying disease, and has the clinical expertise to interpret patient data.

The availability of modern mobile computing and communication technologies opens new avenues for computing, allowing a part of the medical decision-making tasks, such as diagnosis, selection of appropriate treatment, and prognosis, to be relocated from the doctor side to the patient, at any place and at any time [8]. This technology has given rise to the field of *mobile health* or *mHealth* [9]. Currently, the most commonly used mHealth technologies include smartphones, personal digital assistants (PDA), wireless tablet computers, wearable wireless bio-sensors and disease monitoring devices. The rapid penetration of this kind of devices into our daily lives is expected to provide greater access to health care, to larger segments of the population. Another great advantage of mHealth lies in its capability to support patient empowerment by helping improving the awareness on his/her own health condition and on the estimated outcomes, guided by the mentioned smart devices. Always with the explicit intention of the user/patient.

IV. MoSHCA Architecture

The MoSHCA general architecture is shown in Fig. 2. Basically, it consists of devices that collect information directly from the user or from databases that contain user data, typically in electronic health records. The essence of a mHealth architecture is that the user obtains appropriate feedback from the mobile device through the interpretation of available data. Such

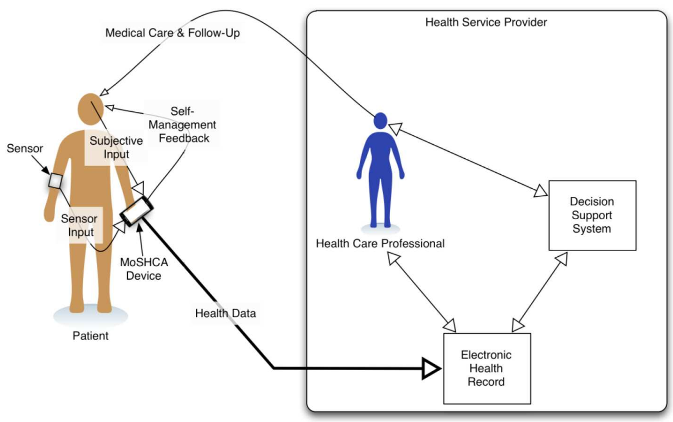

Fig. 2. MoSHCA general architecture.

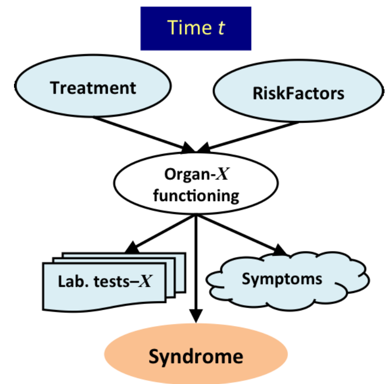

Fig. 3. State modeling the development of a syndrome.

feedback is provided by an embedded decision-support system. The most important components of the MoSHCA architecture are briefly described hereafter.

A. Mobile Computing Device and Sensors Interface

The MoSHCA user's device is a stand alone mobile computing and communication device, which supports collecting information about symptoms and further aspects directly from the patient, interpreting them and providing instant feedback about the patient's health status. In addition, the device communicates the patient's data to a web-center where a caregiver can further examine the patient condition. A common smartphone or tablet can act as the user device.

For COPD it is interesting to measure the lung function and blood-oxygen levels to complement the recorded clinical symptoms. Interfaces and devices relevant to the COPD use case include (i) external sensors, such as micro-spirometer and pulse-oximeter, and built-in sensors within the mobile device, allowing measurements of the lung function and (ii) a communication interface with external sensors based, for example, on Bluetooth or Wi-Fi.

B. Decision Support Systems

1) Basic Principles: Decision support systems act as a central component of the MoSHCA architecture, as they offer the required intelligent interpretation of data obtained from the user. How the knowledge is formally represented in a decision support system will depend on how and for what the knowledge is used. Knowledge representation principles range from simple rules defined for alerting the user, e.g. when a measurement exceeds the normal value of a parameter or when required clinical data is missing, to more advanced methods based on decision trees, flow charts, and Bayesian networks, used for example diagnosis or recommending appropriate treatment. The basic knowledge for the development of clinical decision support systems comes from evidence-based clinical guidelines, treatment protocols, research practices, and input from clinical experts. In a COPD use case, models need to interpret the information from sensors such as the micro-spirometer and pulse-oximeter, in the context of the patient's history and clinical aspects.

2) Probabilistic Methods: Given the cause-effect relationships and the uncertainty inherent to the medical domain, we use a special class of probabilistic graphical models – Bayesian networks – as a technique for building clinical decision models for smart health care assistants that need to be able to interpret clinical data in the context of chronic disease. A *Bayesian network* is an acyclic directed graph consisting of vertices, representing random variables of interest, and arcs, representing dependencies between variables [10]. Each random variable has a quantitative part, denoting *conditional probabilities* of the type $P(Y|pa(Y))$, that is the probability that Y takes on a specific value given the values of its parent variables $pa(Y)$ in the graph. Probabilities of interest can be computed from the joint probability of all variables. For example, in the case of COPD the probability of an exacerbation given the evidence obtained from monitoring is computed. An important observation is that although the model describes general relations between the variables of interest, all predictions are personalized by entering patient-specific data and the model can provide 'what-if'-predictions by entering virtual evidence. Bayesian network models can be built manually using domain knowledge, learned from data or constructed through a combination of both approaches.

An important advantage of Bayesian networks is that they allow modeling of temporal processes, which are typical for the medical domain. In a state model, the functioning of a particular organ X at a specific moment t determines the outcome of laboratory tests and the presence or absence of symptoms. The set of associated symptoms and signs are indicators for the dysfunction of one or more body organs and can be distinguished as major and minor in establishing the diagnosis of a disease, or *syndrome*, when there is no clear pathophysiological substrate. The association between the syndrome and the conditions may also be explained by risk factors such as existing diseases, age, gender, and genetics, which affect the functioning of the organs related to the syndrome. Apart from the risk factors, the intake of drugs also affects the organ functioning, e.g., by reducing the progression of the disease. The schematic representation of these relationships is depicted in Fig. 3, where the arrows exemplify the cause-effect direction.

3) Classifiers: Bayesian networks can be used as *classifiers*, i.e. as functions that map the state of the patient to exactly one of a fixed set of categories. In a health care context, the simplest possible classifier is one that would be able to establish whether a particular condition is present or absent.

Probabilistic methods are known to be very suitable as a foundation for building classifiers. Even the simple Bayesian network known as ‘naive Bayes’, a Bayesian network with a very restricted graph topology, is known to offer good, often acceptable, classification performance in many cases. In addition to probabilistic methods, further methods are explored to allow identifying particular patterns in data, such as in sound. In particular, neural networks and support-vector machines are state-of-the-art methods for building these classifiers.

4) Case-based Reasoning: While the above-mentioned methods interpret data from the user by means of models built from previously collected data or from expert knowledge, *case-based reasoning* takes a completely different approach: it interprets data by comparing a case to previous cases, selecting those that match the current case the best, as an explanation. Case-based reasoning is suitable when one has little or no interest in understanding a solution in terms of a model.

C. Electronic Health Records

Any form of clinical health assessment is based on knowledge about the history of the patient’s illness. Electronic health records, as available in hospitals and general practice, contain such information. Exploitation of such historic information would be very valuable for initializing a decision-support systems in such a way that it would be able to effectively manage the progression of a disease. However, access to electronic health records is hampered by technical issues – mostly the free text format of clinically relevant data – together with privacy and security issues.

V. COPD Use Case and MoSHCA’s Framework

The MoSHCA framework will be applied to various use cases, which include Rehabilitation Technology After Stroke, Treatment Advice for Diabetics, Dietary Advice for Prevention of Lifestyle-related Diseases, Early Detection of Epileptic Seizures, Monitoring of Premature Babies, and Monitoring of Hypertensive Patients. To illustrate MoSHCA’s architecture and technology, another considered use case – Disease Management of Patients with COPD – is described here in more detail.

Chronic obstructive pulmonary disease (COPD) is estimated to affect about 64 million people worldwide and is one of the major chronic diseases in terms of both morbidity and mortality. COPD is a lung disease affecting the respiratory system, decreasing lung capacity and obstructing airways, thus interfering with normal breathing. This results in reducing patient’s capability of performing day-to-day activities. The main cause of COPD is prolonged exposure to tobacco smoke, but other causes include severe air pollution as well. COPD is currently not curable, but treatment can reduce the effects considerably.

The pathophysiology of the patient’s respiratory system is assessed via symptoms such as dyspnea (shortness of breath), productive cough, wheezing breath and decreased activity due to dyspnea. Besides these symptoms a number of physiological signs are relevant, in particular the forced expiratory volume in 1 second (FEV1) and blood oxygen saturation. FEV1 measures airway obstruction by testing to what extend the patient can overcome obstructive and restrictive resistance during forced exhalation. A number of other indicators of deterioration exist, like blood oxygen pressure and white blood-cell counts, but measuring them requires hospital-grade equipment and incurs considerable inconvenience for the patient.

An important aspect of COPD which is particularly relevant in the present context is the progressive nature of the disease. Specifically *exacerbations* – acute events of worsening of the COPD-related health status – are important events in the progression of COPD and have a profound impact on the patient’s well-being and on health care costs. These exacerbations are mainly caused by airway infections, resulting in symptom worsening. Also important to note is that patients with frequent exacerbations usually have faster disease progression, which makes exacerbation prevention a particularly relevant goal. Additionally, a faster treatment response to exacerbations leads to better recovery. Due to the limited observability it is not yet possible to give a practical definition of exacerbations in terms of pathophysiology. Hence, exacerbations are usually defined as an increase in symptom appearance, use of medication, or unscheduled health care use.

Monitoring patients in a home setting, as supported by the MoSHCA framework and devices, can offer a cheaper, yet reliable solution to detecting and managing the occurrence of exacerbations of COPD at an early stage. We aim to decrease the impact of COPD on the patient’s quality of life, and avoid unscheduled doctor visits and hospitalization due to exacerbations.

VI. Evaluation

The usability and reliability of mobile health systems are key factors in their acceptance and adoption for long-term use, by the users, in disease self-management. To guarantee these properties, a thorough evaluation of each system’s components (hardware and software) is required, which involves multiple testing phases. This process usually starts by testing the individual components (for example, use of sensors, mobile device operation, manual data entry), then moves on to integrated testing to check whether or not the different components work together as intended (for example, data transmission, networking), and finally by performing field tests with the users in the environment for which the system was actually designed. During the first two phases, formal methods, such as model checking and program verification, may be applied, for example to prove the absence of deadlocks. During field testing, evaluation is done by a randomized clinical trial, where each patient is using the same system, but for half of the randomly selected patients the system will have no effect on the management of the disease, in such a way that the system does not provide any effective feedback to those patients, while for the other half of the patients the system will indeed give such appropriate feedback. As for many mobile health systems guarantees can be given that they will never be harmful to the patient, evaluation amounts to determine whether the originated intervention is effective, i.e. that it contributes to improve health care by comparing standard care results, such as the number of patients that are admitted to a hospital each year. If the number of admissions has dropped for patients who used the mobile health system, then there would be clear evidence that the system would have been effective.

Before an actual field test can be started, insights are needed regarding the usability, reliability, and user-friendliness of the system, because, if the system fails to meet reasonable requirements regarding these aspects, carrying out a proper field test will be a clear waste of time. Therefore, before any field testing is carried out, in the MoSHCA project, usability tests will be performed with future users, subsequently obtaining feedback through questionnaire. The feedback will not only report on issues with the technical operation of the system, but it will also relate to usefulness and added value in terms of self-management, confidence, and willingness for a continuous usage of the system. A usability test may also help pinpoint issues that need to be worked on to improve the system.

VII. Challenges

A. Hardware Limitations

Although current mobile devices such as smartphones have sufficient processing power for off-line data interpretation and signal processing, continuous and real-time interpretation of user data will inevitably put high demands on available battery power. There is a need for more insight in the trade-off between available battery power and apps algorithms execution, in association with energy consumption.

B. Communication

The concept of a smart health care assistant implies the need for deploying different sensors depending on the diseases which are dealt with. However, we are not yet in the position that one can easily integrate a new/unforeseen sensor in the smart health care assistant's architecture. Often, the data exchange protocol of a commercially available sensor is not publicly available and/or a generic interface device that allows integrating different sensors does not yet exist.

C. Model Building

Building disease models for the interpretation of user data from scratch is difficult and time consuming. However, after the introduction of a smart health care assistant it may become feasible to exploit machine-learning methods to learn and tune models from large sets of user data, giving rise to a gradual quality improvement of the device. However, until the widespread availability of these devices, manual building of models will be primarily practice.

D. Contextual Awareness

Patient characteristics, such as age, gender, personal and family history of diseases, lifestyle choices with respect to eating, alcohol consumption, smoking and sports, are often the factors that affect the risk of developing a disease. When a disease is already present, these factors and related options may, positively or negatively, affect the course of the disease. Such patient-specific information can be easily collected by answering questions or filling-out questionnaires on a mobile device. Part of this information is also available in health records. It will be a key challenge to integrate all this contextual information in order to provide robust and relevant feedback to the user.

E. Ethical Considerations and Safety

Current concerns for establishing the public's trust in mobile health systems relate to the security of collecting and transmitting patient data. However, these concerns are expected to be outweighed in the future by further developments in digital security using, for example, electronic signatures, authentication and multi-application smart-card solutions, and by proven health benefits to the individual by using *mHealth* systems. Furthermore, a mobile health system can in principle function without access to remote data, so future developments may allow the patient to control whether or not its sensitive data is transmitted, and when. Also, appropriate training programs can further enhance the willingness of health care professionals to adapt their clinical practices by using mobile decision-support technologies. Finally, *mHealth* systems are meant to stimulate sharing the responsibility between all stakeholders in the health care system, which in turn can stimulate further the development of the involved technologies.

VIII. Conclusion

The development of smart mobile health care assistants involves various research challenges, many of them technical, while others concentrate on the stakeholders, such as the end-user and society as a whole. In the MoSHCA project these challenges are addressed by well-chosen use cases that cover a wide range of current and future applications of smart mobile technology. This paper covers the main issues that must be tackled for the successful development and deployment of such systems.

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