Healthy Aging through Pervasive Predictive Analytics for Prevention and Rehabilitation of Chronic Conditions

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ABSTRACT

The current aging of the population is linked to many societal challenges, especially in healthcare. Co-morbid chronic conditions are prevalent in older age and drastically affect people's wellbeing, but they are difficult to study due to the many health determinants involved. For this reason, we propose a multidisciplinary ICT-based approach for the prevention and rehabilitation of chronic conditions using unobtrusive and pervasive sensors, interactive activities, and predictive analytics. This framework allows fine monitoring of older people's health and improved personalized care for healthy aging. To illustrate the advantages of this pervasive and data-driven approach we set forth a conceptual model, in which we use cardiovascular disease, Alzheimer's disease, depression and falls as examples of common co-morbid conditions in older people.

CSS Concepts

• Applied computing ~ Health informatics • *Human-centered computing ~ Ubiquitous and mobile devices*

1. INTRODUCTION

The world's population is aging rapidly, mainly due to increased lifespan and lower birth rates. An aging population is at higher risk of cognitive and physical impairment, frailty, and social exclusion, with noteworthy negative consequences for the quality of life (QoL) of individuals and relatives (or caregivers), as well as for the sustainability of healthcare systems. In particular, QoL may be significantly reduced by the onset of several comorbid chronic conditions in older age, especially around the age of 65 years. Given this demographic change and the increasing role of ICT in our everyday life, considerable research has focused on the health-related uses of ICT for and by older people, particularly regarding innovative sensor technologies [7]. Many of these research projects have demonstrated the benefits of ICT solutions at home for the prevention and intervention of chronic conditions in older adults. These solutions empower patients and allow a greater degree of health self-management. Nevertheless, despite the high interdependence of many of these chronic conditions in older age [6], most of this research only focuses on one or two conditions at the same time. This is partly due to the difficulties of analyzing the myriad of health determinants related to chronic conditions, even in a controlled environment. These determinants are vast in number and of varying complexity, as they include the individuals' characteristics and behaviors, as well as their socio-economic and physical environments.

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Recording and analyzing even just a few of the most important health indicators generates enormous quantities of data, too large or complex for traditional data processing methods, an instance of *Big Data*. Furthermore, thanks to the interconnection of everyday objects and applications of the so-called Internet of Things (IoT), it is now possible to collect more and better patients' daily life health data. In addition, the use of virtual and augmented reality techniques allows innovative and immersive interventions that can be thoroughly monitored. These large quantities of data, generated by these connected health devices, techniques, and services offer the possibility of better analyses and studies to increase our understanding of health. Moreover, predictive analytics, the use of innovative statistical models and techniques to make predictions, would allow better decision-making regarding the future of the health of individuals, groups and populations.

Based on these ideas, we believe that a more holistic approach is necessary, in both technology and multidisciplinary terms, to promote healthy aging in terms of prevention, minimization of negative effects, and rehabilitation of chronic conditions associated with aging. Thus, we propose a conceptual model focused on the use of data-driven technologies and methods, and based on established and internationally validated concepts of human functioning and disability.

2. HEALTH DETERMINANTS

Health determinants are decisive contextual factors that affect people's health status. These factors can be classified into characteristics inherent in an individual (personal factors), and factors related to their socio-economical and physical environments (environmental factors). We could further classify health factors into modifiable and non-modifiable, based on the possibility of change by the individual. For instance, diet is a modifiable behavioral set forth factor that can be changed; age is a non-modifiable biological factor. However, some factors are difficult to classify based on this criterion (e.g., healthcare access, largely considered non-modifiable), or their classification may raise sensitive ethical issues (e.g., transsexual people).

Positive health determinants for successful aging are associated with the maintenance of physical and cognitive function, as well as with sustained engagement in social and productive activities [13]. In addition, different studies have demonstrated that these kinds of activities reduce the risk of chronic conditions in older age and can be used together with other rehabilitation therapies [11]. Besides individual socioeconomic differences, people's health also determines and is determined by the structure of societies, norms, institutions, and the state's strategy, governance, tools, and capacity building for the population's wellbeing.

3. COMORBIDITY OF CHRONIC CONDITIONS IN OLDER AGE

Comorbid conditions, individual disorders or diseases that occur at the same time, increase significantly in older age [12]. Among the most prevalent of older age chronic conditions, we have cardiovascular disease (CVD), Alzheimer's disease (AD), and depression, which are closely related conditions that can lead to or be aggravated by accidental falls. In older age, these four conditions are frequently co-occurring. For instance, research indicates that CVD predicts AD, vascular dementia and depressive symptoms, and that cognitive impairment predicts mortality in CVD patients [15]. In addition, in older age physical and cognitive activities are hampered by falls with injury, which are caused by physical, sensory, and cognitive decline, and they are the largest single cause of restricted activity days among older adults [14]. Therefore, analyzing this group of four conditions at the same time is important because they disrupt both physical and mental wellbeing, and because of their high prevalence and significant interrelation. Lastly, this analysis should be made with an established and validated description and classification of disability and health.

4. CLASSIFICATION OF FUNCTIONING, DISABILITY AND HEALTH

The International Classification of Functioning, Disability and Health (IFC), approved by the World Health Organization (WHO) in 2001, provides a framework for the description of health and health-related states. It is a health domain classification for changes in people's body function and structure, what individuals with a health condition can do in a standard environment (level of ability), and what they actually do in their usual environment (level of performance). This approach stresses health and functioning rather than disability, recognizing that every person can experience a decrement in health and therefore experience some form of disability. ICF makes it possible to collect data on levels of functioning and disability in a consistent and comparable manner in prevention and rehabilitation medicine [17]. This allows determining overall healthcare needs and performance based on reliable and comparable health data of individuals and populations. The main concepts of the IFC framework are:

- *Body Functions*: physiological function of body systems, including psychological function
- *Body Structures*: anatomical parts of the body such as organs, limbs and their components
- *Activity*: the execution of a task or action by an individual.
- *Participation*: involvement in a life situation
- *Environmental factors:* make up the physical, social and attitudinal environment in which people live
- *Personal Factors:* individuals' inherent characteristics.

In ICF disability and functioning are viewed as outcomes of interactions between health conditions (diseases, disorders and injuries) and contextual factors (personal and environmental). The framework has three main levels of human functioning: at the level of the body or body part (body functions and structures), the whole person (activities), and the whole person in a social context (participation). The relationship between health condition, functioning levels, and contextual factors is illustrated in Fig. 1. Thereby, disability involves dysfunctions at one or more of these functioning levels: impairments, activity limitations and participation restrictions. For the classification of body function and structure, the primary qualifier indicates the presence of impairments and the degree of the impairment of function or

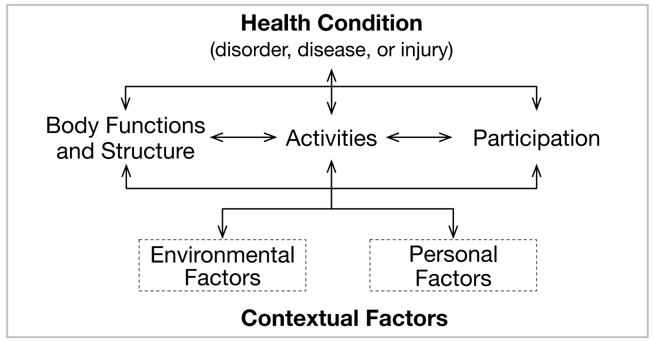

Fig. 1. Representation of the IFC conceptual framework

structure. In the case of the Activity and Participation functioning levels both the level of capacity and the level of performance are used. Because ICF offers the basis for the standardization of human functioning and disability, people with disabilities and professionals can use it to evaluate different healthcare settings. A setting example could be ICT-based solutions that deal with chronic conditions and disability in older age, for example in independent living, rehabilitation centers and nursing homes.

5. CONNECTED DATA AND DEVICES FOR PERSONALIZED HEALTHCARE

ICT can empower older people to better manage their health, stay connected to their communities, and get access to the services they need to remain independent in their homes via eHealth. For example, Remote Patient Monitoring (RPM) is a type of domestic ICT-based health system, used in disease management to remotely monitor and transfer patient health data to a healthcare provider [4]. Its process consists of five main tasks; the first three are to collect, transmit, and evaluate the patient's health data; the last two are to notify stakeholders when a problem based on the evaluation is detected, and then to intervene with an appropriate treatment if necessary. If RPM is done through wireless technology it overlaps with the realm of Mobile Health (mHealth), which covers medical and public health practice supported by mobile devices. It also includes applications, such as lifestyle and wellbeing apps, which may connect to medical sensors or devices (e.g., bracelets) or personal guidance systems, health information and medication reminders provided by SMS and wireless telemedicine.

The spread of mHealth has enabled the growth of Personal Health Record (PHR) systems, data repositories maintained by the patient that combine data, knowledge, and software tools, which help patients to become active participants in their own care. Moreover, in recent years the massive adoption of smartphones has accelerated the convergence to ubiquitous services envisioned by the IoT, a paradigm that considers the pervasiveness of a variety of connected things/objects that interact with each other to offer new services in a smart environment. This new approach can play a central role in personalized health services in ways that go beyond the current concept of mHealth. Another technology that facilitates the IoT is Cloud computing, which allows the transfer of computer services (i.e., software, platform, and infrastructure) to offsite locations available through the Internet. The goal is to maximize the use and scalability of organizations' computing resources by sharing them through specialized Cloud infrastructures. Thus, IoT Technology based on Cloud computing is attractive to the health community given the potential savings and computer power gains, and the easy data collection.

IoT is particularly apt for ICT-based prevention and rehabilitation solutions focused on behavior interventions [2]. In addition, by creating empirical predictions and methods for assessing their predictive power via predictive analytics, we could go beyond causal-explanatory statistical modeling of traditional health data analytics [16]. For instance, predictive modeling can used to create controls for disease management evaluation using readily available administrative data. Such evaluation aims to assess whether or not the intervention under study did indeed have an effect on the intervention group that would not have occurred otherwise [8]. The use of predictive analytics also allows offering personalized care recommendations based on comprehensive datasets. For this process, the datasets must first be cleaned and structured for training. Then relationships among the data are analyzed to develop algorithm sets by identifying indicators that act as predictors. Next, predictive indicators are collected on a case-by-case basis for individual analysis that results in an algorithm-based recommendation for intervention. Finally, a performance evaluation is carried out to record outcomes and improve the adopted algorithms. Nowadays, many connected devices and Cloud ecosystems to monitor personal health and behavior with basic data analytics are already available on the market (e.g., Android Wear and Google Fit; Apple Watch and the Health app). However, although there are specialized solutions, most of these services are designed for the general public, and are not specifically adapted to the needs of older people. In addition, the use of personalized activities and care recommendations in these solutions is almost non-existent or very limited.

6. INTERACTIVITY, SERIOUS GAMES AND GAMIFICATION

Activities could be classified in interactive and non-interactive, based on the presence of reciprocal action or influence. Interactivity can be between humans and other humans, animals, or artifacts (e.g., computers or devices). We use the term interactivity in the context of Human-Computer Interaction (HCI), in which the main interface is between a person and a computer, even if the final action receiver is a person, animal or artifact. Some examples of interactive activities are online chatting, web browsing and videogames. The latter is frequently related to virtual reality (VR), an immersive computer multimedia environment. There are different degrees of use of VR, ranging from none (real environment) to fully immersive (virtual environment), with anything in-between considered Mixed Reality (MR). This scale is called the Reality-Virtuality continuum [10], illustrated in Fig. 2. VR is an interesting case of interaction that has many applications in healthcare, from medical visualization to rehabilitation therapy and serious games.

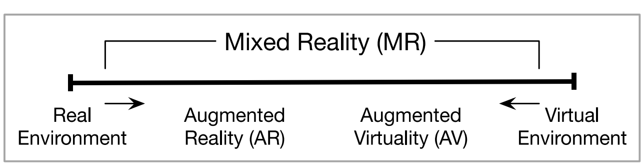

Fig. 2. Reality-Virtuality continuum

Serious games are interactive games that are specifically designed to elicit a change in the player, be it knowledge, attitude, physical ability, cognitive ability, health, or mental wellbeing [9]. For example, *exer-gaming*, entertaining videogames that combine play with significant physical exercise, can help older people with depression, balance, dementia, heart failure, and loneliness. Moreover, adapted games for older people can enhance cognitive control as well, especially for multitasking [1]. In addition, games can be played alone (single-player) or with others (multi-player), either cooperatively, competitively, or both. Gamification, on the other hand, is the use of game design elements in a non-game context [3]. Its use in healthcare has been proved to be beneficial, although much research is still underway on the subject. The main goal of this approach is to engage people in certain activities by making them entertaining and rewarding, based on peoples' intrinsic and extrinsic motivators. Therefore, gamification goes beyond the use of scoreboards or achievement badges (e.g., for walking distances). For instance, the activities' gameplay could use narrative elements to entertain, and the game mechanics could be based on any combination of skill, luck, and strategy.

7. PERVASIVE PREDICTIVE ANALYTICS HEALTHY AGING FRAMEWORK

Based on the aforementioned ideas, we propose the use of the ICF framework, together with a pervasive ICT framework to monitor, analyze and improve older people's functioning levels and health determinants for the prevention and rehabilitation of chronic conditions. The ICT framework would provide personalized activities and recommendations that are accessible and adaptive based on the collected data and analysis. Regarding older people's social setting, the objectives of this framework are: 1) to promote self-management of prevention and rehabilitation; 2) to provide tools and mechanisms that aid in care provided by close relationships (e.g., family); 3) to enable a better understanding of older people's health by the community (e.g., medical personnel, researchers, policy makers); 4) and to ease the older individual's participation in society.

The ICT framework is comprised of four main parts: Remote Monitoring (RM), Predictive Analytics (PA), a User Online Platform (UOP), and a set of Interactive Activities (IA). Key health determinant indicators would be selected according to the appropriate predictive models for the target conditions. These key indicators could refer to measures of risk factors for prevention, the performance of a rehabilitation technique, or a combination of both. The data for some of these indicators would be collected unobtrusively via RM, using sensors for domestic and personal use, such as biosensors, fixed motion sensors, wearable sensors (e.g., smart bracelets) and other discreet sensors. The UOP would allow collecting other indicators, such as individual profiles and periodic self-assessment questionnaires, and it would allow end users (older people) or authorized third parties (e.g., close relationships) to monitor the current health state and receive risk alerts. The UOP should be user-friendly, and available from both desktop and mobile devices, and most likely based on open web technologies. It would also function as a gateway for the set of IA and related indicators. Initially, the end users would have access to a common set of activities designed to maintain the overall levels of physical and mental wellbeing related to the users' age. To engage and entertain end users, many of these tasks would consist on activities such as MR videogames and gamified activities, as well as non-game activities. In this manner, we intend to stimulate social participation and increase the interest of the users in intellectual and physical activities, reducing the risk of chronic conditions such as CVD, AD, depression and falls. All of the end users' data from the RM, IA, and UOP would be harmonized for PA, which is also behind the most significant characteristic of the system: personalization.

In the beginning, the IA and UOP would be customized to the specific end user, based on their characteristics and preferences and on an initial monitoring period. As time passes, starting from a baseline relative to the individual end user him/herself, the IA and

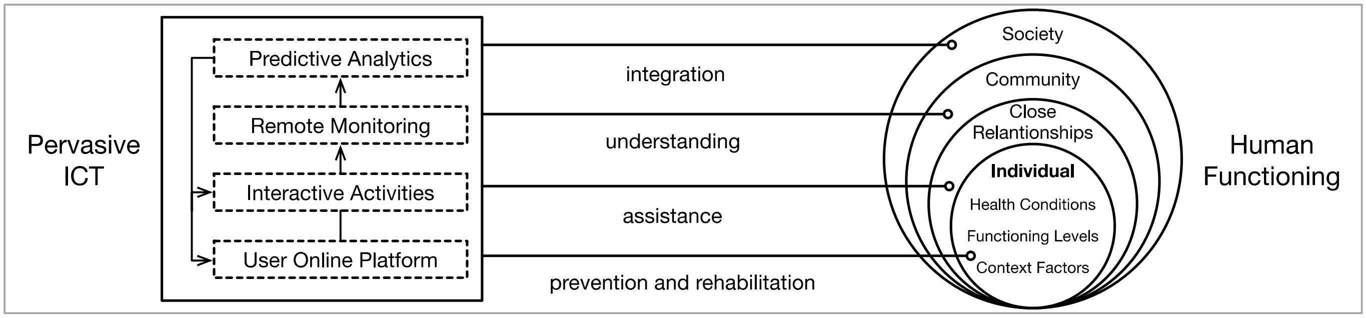

Fig. 1. Conceptual model of the proposed approach for healthy aging through pervasive ICT

UOP would automatically adapt to the end user also based on the functional levels needs and changes detected by the selected statistical models. PA would be used to analyze data and detect changes in physical state or behavior based on predictive models that can be related to one – or more – of the target conditions. In this way, specific risks might be promptly minimized when detected by the system, or progress or regress of specific rehabilitation therapies could be evaluated. In both cases, an alert could be emitted in case of significant risks or functioning levels decrease. Although the ICT framework would perform these monitoring and personalization tasks, the involvement of care people and other key figures is crucial for this approach. The UOP would provide access to authorized professional care providers (physicians, nurses, etc.) to follow the health evolution of their patients, as well as authorized caregivers, in order to ease their daily tasks or to be updated on the state of the end user. Data could also be made available to other authorized figures for research, statistics and management purposes through the PA. For instance, researchers from different disciplines could analyze anonymized data of end users to study patterns, causes and effects of health conditions across different categories, or discover possible socio-behavioral patterns, etc. Of course, to respect the privacy of the patients and other sensitive information, a strict access control policy for each role would be established.

8. DISCUSSION AND CONCLUSION

We have proposed an approach that combines state-of-the-art and established practices and technologies into a pervasive and data-driven framework for healthy aging. However, many issues need to be resolved in order to start implementing successful solutions based on this approach. For instance, there are no universally accepted open standards for comprehensive health data and IoT technology, although much work is being carried out on these topics by academia, industry, and standardization bodies. The current and future legal framework of data protection and privacy is another critical issue, as our approach implies collecting sensitive data and profiling of older people that could be misused (e.g., mass surveillance). Nonetheless, we believe that our framework can be a solid conceptual basis for future research on pervasive and personalized health prevention and rehabilitation of chronic conditions in older age.

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