Framework for *Healthcare4Life* - A Ubiquitous Patient-Centric Telehealth System

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ABSTRACT
Health care systems in many developed countries are rapidly approaching a crisis point. The reasons are an aging population, a shrinking number of workers, health care costs increasing faster than the economy, expensive new treatment options, poor public finances, and the reducing pool of health care professionals. The problem is compounded by the fact that elderly are more often affected by chronic diseases which require ongoing, often expensive, treatment. Telehealth and telecare applications are rapidly gaining in popularity because of their promise to use existing health care resources more effectively and hence to lower costs. However, usage is limited by a design often centered around the requirements of the clinical user, healthcare provider, and the equipment vendor. Many existing systems suffer from high initial costs, cannot be extended by third parties, require extra costs to add new functionalities, and are designed to create a continuing revenue source for the vendor. Furthermore the systems are usually designed to manage diseases rather than prevent them, and do not address the social and psychological needs of the patient. In this paper we critically analyse existing consumer health informatics systems and propose a framework for overcoming the identified shortcomings. The proposed system is ubiquitous, extendable by third parties, contains social aspects, and puts the user in control. Evidence from related research suggests that the design will increase motivation and participation, encourage family and social support, and improve the recording of health parameters by reducing user resistance.

Categories and Subject Descriptors
H.1.2 [**User/Machine Systems**]: Human factors;
H.5.2 [**User Interfaces**]: User-centered design;
J.3 [**Life and Medical Sciences**]: Health

Keywords
Telehealth, telecare, patient-centric design, ubiquitous system, human-computer interfaces

1. INTRODUCTION
The health care systems in many developed countries are rapidly approaching a crisis point due to an ever increasing demand for health care interventions and a serious demographic change. According to the World Health Organization, the proportion of people aged 60 and over worldwide is growing faster than any other age group, and there are more chronic diseases affecting them [74]. Health spending is rising rapidly [45] and the support ratio for people aged 65+ is predicted to fall from 9:1 in 2009 and to 4:1 in 2050 [70]. At the same time there is a world-wide shortage of health care professionals [75] and an increasing strain on public finances making the cutting of entitlement spending, such as health care, virtually unavoidable [30]. A recent five-country study revealed that the three emerging issues concerning public health are: providing access to affordable health care, solving chronic health problems and preventing disease [17].

One solution to address these challenges is to empower health consumers to better manage their health. Patients need to play an active role in preventing diseases instead of being passive recipients of treatments. Home-based health care applications can enable users to track their health status and to actively participate in treatment regimes and preventive strategies. In order to impact overall health care spending such systems must be widely available and affordable. Over recent years an increasing number of consumer health care applications have been developed [20]. Examples include Telehealth systems, health record management systems, health promotion websites, exertainment applications and serious games. While some of these tools have been clinically tested to confirm their efficacy, a common problem is that their design reflects market requirements as discussed below.

Professional telehealth and telecare systems are usually purchased by health care providers and hence their design reflects the needs of the clinical user and of the purchasing entity. Patients are mainly an information source of health parameters and the applications do little to motivate patients to change their lifestyles and proactively manage their health. Health information websites are usually created by commercial and charitable organisations and special interest groups. They often provide an excellent source of information, but are usually self-contained and provide little help with monitoring and improving the user's health. Health record management systems are usually provided by commercial organisations interested in selling the product or gathering user data for commercial purposes. The resulting applications have hence a limited availability and cannot be easily incorporated into other consumer health informatics applications. Finally exertainment applications and serious games are usually purchased by the health consumer and hence exhibit a very patient centric design. However, solutions are vendor specific and do not interface with other consumer health informatics applications.

In this paper we evaluate consumer health informatics applications from a patient perspective and discuss their strengths and weaknesses. Based on the results we propose a novel framework for a ubiquitous patient-centric telehealth system, which is designed to be as unobtrusive as possible and enables

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patients to be in control of and improve their own health. We believe that such a system will represent an important component of the solution for the approaching health care crisis.

Section 2 reviews and analyses consumer health informatics applications. Section 3 discusses the results and the identified shortcomings are used in Section 4 to develop our telehealth system framework. We conclude the paper in Section 5 with a summary of our contributions, lessons learned, and future work.

2. CONSUMER HEALTH INFORMATICS APPLICATIONS

2.1 Home Telehealth Systems

Telehealth technology can be defined as the devices and software that enable health care providers and educators to diagnose, consult with, monitor, treat, and educate health consumers remotely [65]. Home telehealth systems are an important subset, which enable health care providers to deliver remote care and monitoring services to patients in their home. The systems can employ real-time interactions between patients and health care professionals, e.g., using phone or videoconferencing, or use delayed analysis and feedback according to patient priorities [39].

Telehealth systems are most commonly employed for patients with chronic diseases where regular vital sign monitoring, such as heart rate, blood pressure, or weight, is necessary. The data can be input manually or recorded automatically using Bluetooth enabled monitoring devices. The patient's health parameters and answers to user specific monitoring questions are transmitted to the system's backend. The system's clinical interface allows the care providers to check individual patient data, e.g., using a graphical display of time series data, or to monitor an entire cohort by displaying patient alerts sorted by priority (e.g., monitoring data outside the permissible range). Not all clinical situations can be covered in such a way. For instance, in psychiatric assessments, observations of posture, speech and mental state are required [24].

The leading providers of telehealth system are incorporating a wide range of features to increase applicability of their systems: The American TeleCare Video Patient Station combines video telehealth and remote patient monitoring, which allows clinicians to monitor patients' health status, identify instabilities, and provide real time remote clinical intervention to re-stabilise patients [2]. Tunstall's telehealth monitors are very compact and contain just a few buttons similar to a simple game controller. The monitors support a wide range of languages, allow tailoring of questions to individual patient's health conditions, and have adjustable font sizes [69]. Docobo's HealthHub resembles a PDA and uses the principle of "store and forward". Vital signs measurements and changes in symptoms, side effects, life style and quality of life are securely recorded and transferred to the center of care. The patient can track their main health parameters (such as weight, blood pressure, medication compliance) via a four week trend display [16].

2.1.1 Benefits of Telehealth Systems

The Telehealth technology is able to reach underserved sections of the population, especially those in remote and rural areas [39]. The monitoring of vital signs via telehealth facilitates appropriate management of chronic conditions and enables tailored care, which improves patients' quality of life and reduces hospital admissions [13]. Telehealth enables patients to remain at their own homes while giving them and their family peace of mind knowing that monitoring and help is available. This is important since research suggests that patients prefer to self-manage their health and to "age in place" rather than in an institution [35].

Telehealth enables individuals to perform most of the measurements conducted at the primary healthcare provider and thereby reduces visits [32] and the resulting travel stress, waiting times and associated costs [39]. Home nursing conducted remotely via telehealth has been shown to be an efficient use of resources [39]. Patient monitoring data is sent electronically and the carer/doctor can check the data at the office thereby freeing time for conducting more detailed examinations or for seeing more patients [32].

2.1.2 Challenges of Telehealth Systems

Although there are many advantages of implementing telehealth solutions, there are limiting factors. The insurers' reluctance to pay for telehealth services is regarded as one of the main obstacles to total integration of telehealth into health care practice [21]. The reimbursement issues of telehealth remain unresolved and are complicated by conflicting evidence of its cost effectiveness [73]. Proper cost analysis is impeded by the rapid advancement of telehealth technology [39].

The second limiting factor is that telehealth systems are used as part of the formal health care system. The clinicians owe the same duty of care as with conventional forms of delivery and must be kept "in the loop" [15]. This necessitates commitment of practitioners to diagnose and suggest treatment to the patients, and hence limits involvement of the patient and third-party providers. It also requires substantial organisational change in order to be effective [39] and some clinicians are less receptive to the use of these new technologies [21].

Most telehealth systems available for consumers are expensive and difficult to operate [3]. Though they provide financial benefits with increasing duration of care [12], their set up cost is high. Since the systems require operation by patients or their family, usability and technical support are important concerns [6].

Home nursing reduces the close contact and resulting trust between recipient and care provider [9]. The clinician might not obtain the same information as in a face-to-face consultation [39]. The inability to touch the patient may hinder clinical decisions and some patients are concerned over the lack of physical presence of a medical professional [61]. Some patients, especially those living alone, value the social contact with their practitioners.

There is a concern over the liability and medical licensure for physicians providing telehealth services to patients residing in another state. Licensure is an ongoing issue and most existing telehealth services are not offered across state lines [21]. Different countries or states seem to have varying legislation [9].

2.2 Health Record Management Systems

A personal health record (PHR) is an electronic application through which individuals can access, manage and share their health information [47]. PHRs are not the same as electronic health records (EHRs), which are controlled by the health care provider [76]. PHRs provide patients with better access to their health care data and enable them to be stewards of this information [23, 42]. PHRs can be classified into three categories [18]:

- A provider-owned and maintained digital summary of relevant health information made available to patients.
- A patient-owned software program that lets individuals manage their health information.
- A portable, interoperable digital file storing the health data. Platforms for portable PHRs include smart cards, personal digital assistants, cellular phones and USB drives.

There has been increasing interest in the development and adoption of PHRs by employers, professional health groups, government agencies, and major software organisations. Google and Microsoft are creating their own free or subscription-based online health record applications. Both companies see the potential in attracting a large audience for health-related advertising and services [42].

Google Health allows users to store and manage all health information in one central place securely, privately, and for free. Users can create personal profiles and add medical info such as their conditions, medications, allergies, procedures, test results, and immunizations. Users can define access rights to their records and revoke them any time. Google assures that records are not shared unless asked by the user. Some of the main features of Google Health include building online health records, import medical records from hospitals and pharmacies, share health records and explore online health services offered by partners [22].

Like Google Health, Microsoft's HealthVault takes users' medical records and brings them online. This online platform provides a web based interface where consumers can upload or share health documents from their providers. The health data is stored in a secure and encrypted database. In addition, this platform allows anonymous Internet searches for health topics as well as interfaces to and from a number of health and communications devices and data sources, including fax, physiologic monitoring tools, and laboratory and encounter reports [50].

Both of these platforms are still in the development phase and available only at a limited number of jurisdictions. Several organizations such as the American Heart Association, Johnson & Johnson LifeScan, and the Mayo Clinic are partnering them to build applications and infrastructures that support and use PHR data [42].

2.2.1 Benefits of HRMSs

PHRs provide a number of potential benefits to patients, practitioners and health care providers. Some of the main drivers for development and adoption of PHRs include [18]:

- Empowerment of patients - enable patients to verify the information in their medical record and monitor health data.
- Improved patient-provider relationships - enable documentation of interactions between patients and clinicians and provide timely explanations of test results.
- Increased patient safety - provide drug alerts, help to identify missed procedures and services, and get important test results to patients quickly.
- Improved quality of care - improve the coordination between patients, physicians and other providers.
- Efficient delivery of care - avoid duplicative testing and unnecessary services.
- Better safeguards over health information - offer more selectivity in sharing of personal health information.
- Reduction of costs through information access - sharing of information reduces duplicate examinations and tests, and enables a faster more reliable diagnosis and treatment.
- Documentation - improved documentation of the decision making process decreases malpractice costs.

2.2.2 Challenges of HRMSs

Early experiences with three different PHR implementations indicated that they can be successfully deployed but require careful attention to policies regarding privacy, security, data stewardship, and personal control [23].

Interoperability is a major obstacle in the development and adoption of PHRs. A consumer controlled-record will be more useful if it includes complete health data including medical records from doctors, hospitals, insurers and laboratories. However, the process of gathering health data from different sources is often complicated since responses often come on paper, as photocopies, or faxes leading to inaccuracies and errors [71, 18]. Users are skeptical of their PHR's content and in a previous study expressed the desire to learn more about the information sources [59]. A common, preferably electronic, format is necessary, which requires partnerships and trust between health care providers, insurers and digital record keepers [42]. Privacy is a main challenge and users are generally very concerned about it [47]. Legal constraints and government policies further restrict usage and currently neither Google Health nor Microsoft HealthVault is available in New Zealand.

Usability issues are other concerns in the development and deployment of PHRs. A recent comparative study evaluated Google Health and Microsoft's HealthVault on five dimensions: overall usability, utility (usefulness of features), security, privacy and trust. Results suggested that both systems had flaws in the user experience. The survey participants stated that they only want to spend 10-30 minutes setting up a PHR, and after that at most monthly, and preferably yearly, updates [59]. It is hence important to make data entry of health information a simple, quick and enjoyable experience. Individual barriers that obstruct users from adapting PHRs are computer anxiety, lack of computer literacy, cognitive and physical impairments, and health literacy [40].

2.3 Health Promotion Websites

The arguably most common consumer health informatics application is health promotion websites. Available resources include general health care information [48], health care support tools [1], education resources [53], monitoring and self-diagnosis tools [44], health and fitness evaluation tools [55], online care providers [26], and patient discussion groups [8]. The Internet is allowing health care consumers to take a more active approach to health and users are increasingly turning to their computers and the web for health information and advice [25].

2.3.1 Benefits of Health Promotion Websites

Medical websites enable patients to be aware of symptoms, risk factors, treatments and prevention of diseases. This increased knowledge can help patients to take a more active role in their health care, help to diagnose problems earlier, and improve patient motivation and compliance. Furthermore health information websites and discussion boards enable patients to investigate alternative treatment options and learn from other patients' personal experiences. This can help patients to plan treatment more effectively with their doctors and to find solutions suiting their personal circumstances, which in turn increases compliance. A large survey revealed that 58% of people who looked online for health information discussed what they found with their doctors [25]. The improved communication between patients and physicians contributes to developing trust and patient motivation.

The number of health care services offering online doctor consultations is increasing [19]. The Hawaii Medical Service Association (HMSA) has launched an online program that offers online doctor visits free for consumers living in Hawaii [26]. MDLiveCare enables consumers to consult primary-care providers, specialists, and therapist in their network [49]. Kaiser Permanente allows members of their website to e-mail doctors, review lab test, make appointment, and refill prescriptions online [33]. Some of these websites provide 24/7 access to basic health care.

2.3.2 Challenges of Health Promotion Websites

The large volume of health information available on the Internet offers new opportunities to improve health care, but makes it increasingly difficult for users to discern which resources are accurate or appropriate. The lack of search precision can yield irrelevant or misleading results. For example, an elderly heart patient might read and follow advice only appropriate for younger patients, and a patient reading a warning about a medication on a discussion board might stop using it. Inappropriate actions of a patient can have severe medical consequences.

Medical websites might present extensive health information, but coverage can be inconsistent and require a high level of reading ability [56]. The problems are compounded by the large amount of advertisements disguised as independent medical advice.

The majority of health web sites are centred on the western society, with 80% of web sites in 2001 presented in English. Only about 8% could be classified as multilingual [36]. Although English is the universal language, there is a huge population of consumers that do not converse in or understand English.

Most health related websites merely provide information about a disease, but do not enable patients to actively improve their condition. A common problem is the lack of patient motivation, anxiety, low confidence, or ignorance when considering positive lifestyle changes. For example, many heart patients do not fully understand the relationship between their disease, symptoms, medication and lifestyle choices [37].

Some online health care services are excellent, but can be quite expensive. Lower income health consumers might not be able to afford these services.

2.4 Serious Games and Exertainment Applications

Research and development of digital games is putting an increasing emphasis on serious games and their benefits in therapy, interventions, health care programs and training [14]. Exergames or games that support physical and mental exercise are valuable tools for fostering patient participation in health-related activities by combining entertainment and therapeutic value. Recently, three trends have emerged in the use of games for health care: 1) the increased use of games for therapy and rehabilitation; 2) the use of games in gyms and other settings to promote physical activity; and 3) the greater role of gaming in corporations and health care providers [64].

An increasing number of games is developed targeting specific health problems and elderly users by promising mental simulation, social engagement and entertainment. Most of these games can be categorised as physical games or memory games.

2.4.1 Physical Games

Dancetown is a PC-based dance game specifically designed for older players and retirement homes, to give players regular exercise and reduce the risk of falling [10]. Research conducted by Humana's Health Services Research Center found that the game positively affected the participants' feelings about their general health and their perceptions and attitudes regarding their ability to perform certain activities. Research also reported a reduction in overall bodily pain, lower levels of depression, and significant improvements in the participants' ability to climb stairs and walk more than a mile [27].

Wii Fit is a home video game console by Nintendo which utilises the Wii Balance Board for measuring weight and weight distribution. The player interacts with a virtual world through the Balance Board and performs activities such as yoga, step aerobics, ski jumping and snowboarding. An enhanced version, Wii Fit Plus, contains more exercise activities and offers customized fitness routine [58].

Zyked is a new product that combines video games with online and mobile services to motivate people to do exercise activities such as running [77]. Actions are recorded using the GPS of iPhone devices. Users can compete against themselves, interact with teams, and compete against other teams. Repetitive game play is avoided by allowing users to create their own tracks and share them with friends.

2.4.2 Memory Games

MindHabits is a scientifically designed game with training challenges and measurement tools to help players gain and maintain a more positive frame of mind [51]. The game aims to reduce stress by repeating positive messages and words. In one challenge, for example, players are required to find the smiling faces in a crowd of frowns, which studies have shown can help train your mind to react to positive information [11].

MindFit is a computer program for training cognitive skills such as memory, planning, divided attention, and hand-eye coordination [52]. The effectiveness of this tool was tested in a trial with 121 healthy elderly people where half the participants used MindFit and the other half computer games. Results showed improvements for both groups on most outcome measures but users of MindFit improved significantly more [7].

Nintendo has conducted a successful campaign focusing on elderly as a consumer segment. The company's game “Dr Kawashima's Brain Training: How Old Is Your Brain” engages players on a daily regime of number games, word puzzles and reading exercises [57]. Players can test their “brain age” through quizzes that involve attention and memory processes.

Lumosity is an online program aimed at the older demographic. It targets mental processes that decline with age, including working memory, speed of processing and attention [43]. The program’s titles have attractive names, e.g., Bird Watching, Memory Match, and Monster Garden, and require players to recognize patterns and answer math questions as quickly as possible. Subscribers can track their improvement and advance to more challenging levels.

Brain Fitness, from Posit Science, is sold mainly to retirement communities. The program features listening exercises that attempt to help elderly users overcome developing difficulties in understanding words and phrases in conversation [60].

2.4.3 Health Monitoring Using Entertainment Devices

In recent years some innovative health care applications using entertainment devices have been suggested. Results have to be interpreted with caution since few independent, less alone clinical, studies have been conducted. Some of the more interesting applications include the iPhone and iPod Touch as heart rate monitor [4], pedometer (>15 iTunes applications), and to detect physical activity and falls using its accelerometers [34]. The iPhone's GPS capabilities can be used outdoors to measure walking distance.

Webcams have been used for monitoring patient location [41] and computer users' posture [31]. We currently develop webcam-based monitoring of hand exercises [38]. Recent work by large vendors such as Microsoft's “Project Natal” will drive the development of cheap consumer level devices and software for conducting 3D gesture recognition and tracking.

2.4.4 *Benefits of Serious Games*

Serious games and exertainment applications have become tools for improving fitness and changing behavior [14]. The game "Dance Dance revolution" has been reported to have a positive effect on the social life and physical health of players by improving endurance, muscle strength and sense of rhythm, and creating a setting where new friends can be found [28]. Positive health effects have been reported for the players' cognitive abilities (logic, memory, problem-solving, critical thinking), collaborative and pro-social behavior, general well-being, and therapies (phobia, hyperactivity) [62]. Digital games can play a positive role in Elderly care by providing fun and mental simulation [72]. The sense of accomplishment and perceived self-efficacy after mastering a game can provide a significant boost to one's self-esteem [29, 72].

2.4.5 *Challenges of Serious Games*

Despite the previous subsection listing a range of perceived benefits of serious games, there is some doubt about their usefulness for improving general fitness and social interactions. For example, while the Wii Fit has been endorsed by some healthcare providers such as UK's Department of Health, investigations into its effectiveness have been mixed and several researchers report no noticeable long-term increase in exercise activity and fitness [68]. One possible reason might be boredom developing from repetitive game play [63].

Exercises in memory games, which train tasks such as response speed, visual search and memorisation, are likely to improve the tasks that are being practiced. However, there is lack of evidence that this improves general cognitive abilities [7].

Game playing is a common activity at senior communities, e.g., in the USA bridge and bingo are popular. Most of the time game playing is viewed primarily as a means for social interaction. Elderly participants engage in conversations and "retell and reenact their life stories" [46]. Therefore, the game playing is more than a form of recreation, but an opportunity to teach positive self-concepts and coping with loss. So far little work has been done to incorporate these principles into computer-based games.

There is a significant need to explore and understand the needs and motivations of elderly and health conscious game users, e.g., by conducting focus group studies, interviews, surveys and general market segmentation research [29].

3. DISCUSSION

The previous section demonstrated that a wide variety of consumer health informatics applications are available, but that they are centred around different interest groups and follow different objectives.

Commercial telehealth applications and most health record management systems are centred around the clinical users, the health service provider and the vendor's interest of generating a reoccurring revenue stream. In general the applications provide a good job of collecting and managing monitoring and health data, but offer little support for users to commence positive lifestyle changes. In most cases the applications are obtrusive, i.e., they do not fit into the regular activities of the user, and hence can be perceived as disruptive. For example, in one study PHRs users expressed the wish to update data at most monthly or preferably yearly [59]. A few vendors offer kiosk-style applications which enable, for example, all family members participating in health monitoring and as such can increase patient motivation and compliance.

Health information websites offer an impressive range of information, but it can be difficult for the user to assess the reliability, meaning, and implications of the information. Web-based discussion and support groups can provide a more personal experience and add a social factor which can help patients with coping and commencing positive lifestyle changes.

Serious games and exertainment applications are arguably the most patient centered consumer health informatics applications. Since they are usually purchased by the patient, the vendor is motivated to make them as attractive as possible for the user. However, as discussed previously, research reports mixed results about their effectiveness. One hypothesis is that the content of such applications can become repetitive and boring and hence lifestyle changes are only temporary [63]. In most cases content is controlled by the vendor and in order to do a new type of exercises users would have to purchase a new game and possibly new equipment. An improvement is the iTunes concept which enables user to easily download new iPhone games. However, the costs can add up quickly and monitoring data is not shared between different games, i.e., a continuous recording of health parameters and activities is not possible.

In summary existing consumer health informatics applications are often obtrusive and require patients to do tasks which can be perceived as disruptive, repetitive and boring. Most applications are expensive and have limited content leading to user resistance after long term usage. Few applications address social and psychological aspects, and more support is needed for sharing monitoring and activity data.

There are also some more fundamental design issues. E.g., most telehealth applications are designed for monitoring and treating patients with chronic diseases, but do little to prevent them [15]. Furthermore, the high cost of these systems justifies their employment only for already seriously sick patients who otherwise would need expensive hospital or nursing care. In order to tackle the coming healthcare crisis telehealth systems must be developed which prevent diseases by encouraging positive lifestyle changes and recording fitness and vital signs. More emphasis must be put on rehabilitation and self-management in order to reduce healthcare costs.

Motivation and compliance must be increased by making the system easy to use, convenient, fun, and as unobtrusive as possible. Feedback from the research reviewed in the previous section suggests that this can be achieved by integrating health related tasks into everyday activities, by giving users a more active role, and by adding a social dimension. Note that nobody can force, say, an overweight person to diet or a smoker to quit smoking. Such decisions must be done by the user, but can be encouraged by education, a positive self-image, and social support.

4. FRAMEWORK FOR *Healthcare4Life*

The previous section discussed shortcomings of existing consumer health informatics applications and features necessary to improve their effectiveness. Based on these requirements we have developed a framework for a novel telehealth system, *Healthcare4Life*, which is illustrated in figure 1.

The framework has an open architecture which allows third-party providers to add new content and functionalities. This allows users to choose new monitoring and exercise tools if they get tired of existing ones. It also makes it possible to incorporate novel technologies such as new HCI devices. Functionalities include applications for monitoring, rehabilitation, education, and diagnosis in the form of, e.g., serious games, interactive web pages and expert systems. Good examples of a suitable architecture for our framework are middleware applications or social network applications such as Facebook, where new functionalities can be

added and shared with users. *Healthcare4Life* will need services supporting interoperability of different devices and applications. One problem of an open architecture is the difficulty of verifying and testing content. The problems exist already with existing online health care applications. We suggest employing a ranking system which displays user satisfaction and popularity of each service. The ranking system should contain separate scores from patients and registered clinical/academic users.

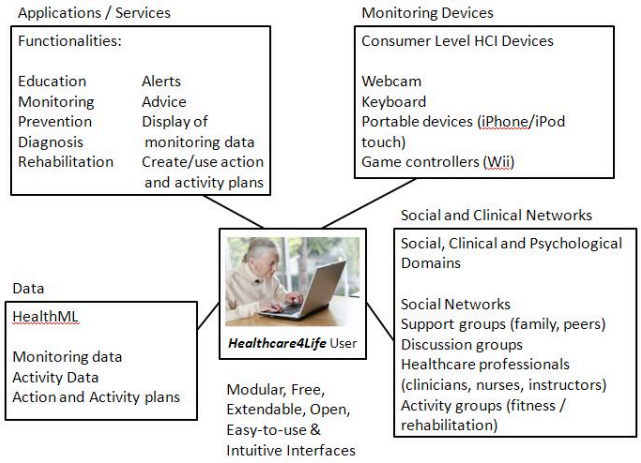

Figure 1. Framework for Healthcare4Life.

A major problem with existing health care applications is that monitoring and activity data is not shared. This is in particular the case for exertainment applications such as Wii Fit. Once the user gets tired of the application and uses another game the activity data is lost. We therefore suggest to store and manage patient data independent of the applications using it. This necessitates a common interface/structure, e.g., by using an XML-style language which we provisionally term "*HealthML"*. The language must be extendable and must contain unifying data elements in order to compare related types of data. For example, activities such as walking outdoors, Wii virtual tennis or iPhone bowling can be compared using a "Calories burned" and "perceived-level-of-exertion" [5] scale similar to those for gym equipment. An important component of the patient data are the activity and action plans, which allow users to set and monitor goals, and discuss progress with health professionals and social contacts. The plans should be stored in a way that different applications can recognise and access them, e.g., an exergame application would automatically add values to an activity plan in form of "Calories burned".

In order to obtain monitoring data the system must have a flexible architecture to interface with a wide variety of medical and HCI devices. Professional medical equipment, such as blood pressure cuffs and glucose meters, should be supported but not be required. Instead we propose to use as many consumer level devices as possible. Examples are using the iPhone as heart rate monitor, pedometer, walking distance recorder, and to detect falls (see subsection 2.4.3). With the advent of cheap 3D and high-resolution webcams we believe that in the next few years exercise monitoring and evaluation of skin parameters such as redness, swelling, and sweating will be possible. There is ongoing research on emotion recognition which would be an important factor for monitoring mental health, stress levels, happiness, and depression [54]. The system should still provide monitoring functionalities of traditional telehealth system and offer easy to understand graphical feedback. The system should alert the clinician, care provider or family member if the patient's clinical measures are found to be out of the acceptable range.

Prevention and rehabilitation can only be successful if users regularly use the system. Hence it must be made attractive, unobtrusive, easy-to-use and available to all users, young and old. This necessitates the use of "principles of universal design" [66]. Attractiveness is increased by making the system fun (games, social contacts) and useful (education, monitoring). Ease-of-use requires well designed interfaces and mental models enabling the user to understand the purpose and functioning of the system. Many important design concepts are already incorporated into commercial telehealth applications. Examples are multi-language support, audio instructions, useful reminders, iconic interfaces, scalable fonts etc. In order to keep overheads low the PC and portable devices represent the user's "patient station". Since these devices do not have large mechanical buttons we propose to use the Windows 7 touch screen capabilities in order to enable patients with, say, Parkinson disease or swollen fingers to interact with the system. In some cases even that will not be sufficient and control by voice recognition would be preferable.

The arguable most novel concept of the system is to make it ubiquitous. While traditional systems are designed as health informatics application, our goal is to hide the system's functionality where possible. The user can employ system components (computer, PDA, mobile phone) for everyday activities and monitoring will be performed in the background. Examples are the analysis of keyboard and mouse input (speed, reaction time, jitter in mouse movement, typing errors) and of webcam data (emotions, redness, excessive sweating). When using an iPhone the distance walked, number of steps, and falls can be determined. In addition unusual patterns in behaviour could be detected, e.g., a sudden change to a more sedentary lifestyle.

Finally we put a larger emphasis on social networks rather than and clinical networks. Clinical networks are a standard component of commercial telehealth systems. Health consumers can contact doctors via email, phone or video link and discuss medical complaints and treatment options, but services are usually expensive. The motivation for social networks is threefold: many patients and especially elderly suffer from loneliness. Social networks can help users to get in touch with their family, make new friends, and discuss medical complaints with peers and support groups. The aim is to improve emotional health, which is essential for overall well-being. Social networks can also help with motivating the patient, e.g., by achieving family support, or by doing monitoring task and exercises together via a video link or in a virtual environment.

Overall the design is patient-centric and involvement of health care professionals is encouraged, but depends on local health care policies. We believe that the proposed framework is empowering the user to take charge of their own health and makes this objective easier, cheaper, and more attractive than with traditional systems.

5. CONCLUSION AND FUTURE WORK

We have reviewed, evaluated and categorised a wide range of consumer health informatics applications. Benefits and shortcomings of each category of applications were identified and clinical and scientific evidence was given where available. Based on this research we identified principal barriers preventing a wider and more effective usage of these technologies in health care applications. In order to overcome these barriers we suggested a framework for a novel telehealth system, *Healthcare4Life*, which is ubiquitous, extendable by third parties, contains social aspects, encourages cognitive engagement, and puts the user in control. In contrast to previous work we propose an open structure with a

middleware-like functionality. The framework emphasises the need for social support and psychological factors influencing usage and compliance. In particular we argued that the system must be unobtrusive and ubiquitous. Monitoring data, if possible, should be a "side-effect" of everyday usage rather than requiring potentially disrupting and cumbersome actions by the users. Continued usage of the system is promoted and facilitated by using flexible interfaces and data structures so that monitoring and activity data can be provided and used by a wide range of applications. This avoids repetitive input and prevents boredom resulting from continuously using the same application. We are not aware of any other evaluation and framework providing such a holistic view of this domain.

We have developed a cardiac rehabilitation tool reflecting some of the aspects described in this research [37]. We are now commencing the design of the system described in this paper. Several service components are under development including a webcam-based tool for hand exercises [38] and iPhone tools for monitoring and exercising arm muscle strength and joint flexibility [67]. One of the main tasks for the immediate future is the development of the *HealthML* language in order to facilitate information exchange between system components from different developers.

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