Abstract— Tele-home-care systems are becoming more important for patients and society at large. Despite some surveys focusing on medical devices interoperability used on home-care systems, electronic measurements in rehabilitation, configuration of body area networks, a survey and taxonomy of enabling technologies for tele-home-care systems does not exist. This paper presents a survey and taxonomy of the design approaches. The discussion of open issues and suggestions for further research are detailed in this paper.

I. INTRODUCTION

As the percentage of the aging population of industrialized countries increases, so does the cost to provide health care at the hospitals. As such, there is a trend to move from a primarily centralized Health Care system to one where much of the health care is distributed and at homes, hence decreasing both budget and the burden on health care professionals such as nurses, therapists, and doctors [1]. Tele-home-care, or telemedicine, services help physicians and medical professionals to provide clinical care services to patients remotely [1]. To this end, researchers and industry have proposed several multimedia technologies and solutions to realize such systems. There are many different uses that can be imagined from tele-home-care systems such as monitoring patients with chronic illness, tracking patients’ rehabilitation processes, elderly care etc. While such expected added values can lead to interesting technological advances, there are many challenges that may limit such systems and hinder their capabilities to meet real needs. These challenges are, but not limited to, complex home environments [2], adaptation to multimedia multimodal data about people as they do their activities [2], collecting and storing information, conflict detection of care devices [3] etc.

Currently, there is a large number of enabling technologies for remote measurement of a patient’s physiological signals and tele-home-care systems claiming to be efficient and beneficial to the patients at home or remote locations [1]. However, due to the different and somehow incomparable features of such technologies, understanding their true characteristics, their degree of realism with respect to the expected added values, and real capabilities is a hard task. Despite some surveys focusing on medical devices interoperability used on home-care systems [4], electronic measurements in rehabilitation [5], and configuration of body area networks [17], a survey and taxonomy of enabling technologies for tele-home-care systems does not exist. This paper presents such survey and taxonomy, and analyzes and discusses the challenges, contributions, and shortcomings of the existing literature. The intended contributions of this paper are: (i) providing survey and taxonomy of the existing technologies developed for tele-home-care systems and investigate their general trends; (ii) identification of system engineering challenges and provide suggestions for future research.

The rest of the paper is organized as follows: Section II presents the tele-home-care system value services. Section III discussed the enabling technology classification based on the design approach followed. Section IV presents the open issues and the suggestions for further research. Finally, in section IV we discuss our findings and provide a plan for future work.

II. TELE-HOME-CARE SERVICES FRAMEWORK

In this section, we provide an overview of tele-home-care systems services framework. As shown in figure 1, we have identified four core services of tele-home-care systems. The aim here is to map the technologies and the approaches followed by the research community to fulfill these services and later draw a taxonomy classification based on these approaches. Below are the details of such services.

A. Monitoring Services

Monitoring services are vital to the health and well being of home-based patients [6]. In tele-home-care systems, remote measurement and monitoring services communicate real-time physiological information of a patient’s condition over the internet or by phone (wire lines or wireless) that allow physicians to adjust and tailor therapy to meet the patient’s changing needs [7]. The effectiveness of monitoring services have been studied in several works, such as those in [6], [8] and [9] to name few, and have showed that tele-monitoring health parameters for home-based patients (e.g. blood pressure, heart rates, sleeping habits etc.) is crucial in predicting sudden emergencies. For this purpose several systems and technologies, as we will discuss later in this section, have been developed for home-based patients monitoring.

B. Activity Recognition

Activity recognition, in the context of tele-home-care, comprises the recognition of psychophysical performance of patients or elderly people for effective therapy intervention. For patients with chronic diseases such as congestion heart failure and parkinson illness, measuring and summarizing their physical activities and transmitting them to caregivers is important to better adapt and manage the therapy success [10]. Activity recognition is not limited to the repetitive motion of human body as in walking or exercising, but also for patterns such as patients moving things around (e.g. Cooking, socializing, etc) [11]. Such movement patterns may exhibit other psychophysical indications...
that are not possible to recognize when patients walk, run, scrub, or exercise.

C. Behaviour Detection

Behavior detection is mainly related to the measurement and detection of behavioral changes in patients’ normal profile [11]. As the number of elderly people who live alone grows, it is most likely that behavior downturns could happen due to aging or existing medical conditions. Also, patients who are suffering from psycho-behavioral disorders such as depression, agitation, apathy etc. need to be assessed on a continuous basis to detect any deviation from normal profiles. Tele-home-care systems provide physicians and psychologists with continuous data about patients’ normal activities (e.g. eating, cleaning, moving, bathing etc.) and help them measure the fragility level of such patients [11].

D. Data Collection

Tele-home-care systems collect data on a continuous basis, not only to monitor patients and provide remote help, but also to construct medical statistical analysis for the general population [12]. By so doing, physicians and health organization can understand the general trend of the society’s well being as a whole. It should be noted that data collection may take place from any location, not only from home, but also from any patient’s location to provide real time, around-the-clock evaluation. As we are going to see later in the next section, there are many systems and devices that have been designed to facilitate such process and provide automatic analysis on the collected data such as vital signs, electrocardiograms, and capillary blood glucose and then transmitted to a monitoring station for further analysis.

III. DESIGN APPROACHES AND ENABLING TECHNOLOGIES CLASSIFICATION

In this section, we present a taxonomy graph of our approach of classifying the enabling technologies based on the tele-home-care systems’ design. As shown in the figure 2, we identify four important aspects of a tele-home-care system design where we would like to focus: wearable systems, vision-based systems, Ambient-based systems, and others. Our objective is to provide readers with a guideline to easily understand and objectively compare the different models. Below we provide the details of each tele-home-care system design approach.

A. Wearable Systems

Wearable systems for tele-home-care consist of various miniature biosensors that are wearable or implanted. These biosensors are used to measure physiological parameters like heart rate, blood pressure, body and skin temperature, oxygen saturation, respiration rate, electrocardiogram, etc.

![Figure 3 An end-to-end wearable system design for tele-home-care](image)

In body area network (BAN) systems such as the work of [12], [13], [14] and [15] to name few, the patients are equipped with sensors attached to the body or actuators which may be implanted under the skin. In body area networks, the patient is continuously monitored thanks to the several sensors which provide physiological reading about the health of the patients. For example, in [12] the sensors of the body area network detects if the patients falls down at any moment. In [13], a BAN system is designed to collect the vital signs of the patient and transmit the information to the hospital. In [14] and [15], the BAN is used for activity recognition such as exercises and physiotherapy treatment.

It should be noted that the technology of BAN is still in its infancy stage. Besides the general challenges that are inherited from the characteristics of wireless sensor networks, BAN demand specific solutions for energy sources for data collection, processing, and transmission. One solution to this problem is

![Figure 4. Example of wearable systems BAN (a) [17], Textile (b) [16], wearable devices [24]](image)
energy harvesting based on the body temperature differences [18]. Another challenge is related to the user’s susceptibility of signal interference [19].

In textile-based systems such as those presented in [16], [20], [21] and [22], the sensors are integrated in the garment’s fabric of the Health Wear clothes [16] and the Smart Vest [20]. The parameters measured are heart rate, blood pressure, body temperature, and galvanic skin response (GSR). The Medical Remote Monitoring of clothes (MERMOTH) uses Interactive Textiles [21] which produce stretchable sensing for extra comfort and it is used to measure skin temperature and activity through accelerometers. In [22], the sensor elements are knitted in the fabric using conducting and piezoresistive materials. These sensors are able to monitor abdominal respiration rate, body position and movement, skin, and core temperature.

Wearable devices or microcontrollers, such as the work presented in [23], [24] and [25], are devices attached to the body. Such systems use belts to trap the device on the abdominal [23] to track physical activities or the chest [24] to measure the heart rate. Others use wrist straps like a watch to measure vital signals [25]. The main design criteria of these systems are small, light, and easy to use. The technical challenges of such systems are to make them practical and operating under different conditions [25].

B. Ambient Home Systems

Recently, ambient intelligence technologies have been rapidly developed to meet the requirements of the future smart homes and assisted living paradigms [33]. Tele-home-care has benefited from such advancements to a large extent. The industry and academia proposed several systems based on ambient homes for remote health care. This is especially so for monitoring and caring for senior citizens. Ambient sensors acquire context information about the environment, while body sensors collect data about the people. When both types of sensors are combined fine-grained activity profiles are produced. The general concept of ambient systems for tele-home-care is capture in figure 5.

Senior citizen’s mobility becomes limited as time goes by and hence their interaction with other people outside their home is difficult. Several ambient home care systems have been designed to overcome such challenge and to provide adequate care for elderly. The studies presented in [26], [27] [28], [29], [30], [31] and [32] are a few examples of ambient awareness systems for elderly care. In [26] and [27] ambient intelligent sensors and RFID technology is used to locate the elderly in side the house and provide assistance for mobility. In [28] the system uses an emotional type of communication to comfort the elderly. The systems combine artifacts such as ambient light and music to recognize the mood of the person being taken care. The systems in [29] and [30] are intelligent multi-device awareness systems to support intimate caring communication for elderly people using social radio and touch-bases devices.

C. Vision Systems

Computer vision technology, e.g. video, has greatly improved in the past few years and that is why it makes sense to take advantage of this technology in the tele-health research. A video can show entire views and give comprehensive overviews at a glance. Internet has tremendously increased the usability of vision systems. Vision Systems can be integrated with other systems to overcome the limitations of the system (e.g., body vital signs). Many studies have been conducted on the usage of video surveillance for tele-home nursing. The use of cameras inside people’s homes for care purposes has, by case study, proven to have the possibility to diminish caregivers’ burden and to postpone residential care with respect to the quality of life for both the person in care and his/her informal caregivers [36]. An example is the BIOTELEKINESY project [37], which uses video surveillance. It provides an innovative ICT based interface with a holistic approach to detect and prevent as early as possible in the daily environment of the elderly person. Figure 6 below shows the architecture of the BIOTELEKINESY interface. Video-based interaction in the Care context is only economically viable for clients with a high demand for services (i.e. several calls per week), or clients living in remote areas. However, if the costs of the equipment and connections become lower, the economies would allow more and more clients to be connected [35].

![Figure 6. Architecture of BIOTELEKINESY](image)

Parallel to the above studies, vision systems have been used to monitor the elderly falling problem such as the work of [39]. With video surveillance, it is possible to monitor risk and provide emergency care faster. Vision systems have also advanced from simple video surveillance to sophistication with technologies such as Omni-directional Vision Sensor (ODVS) (Figure 8) [40] and Video Capture Virtual Reality Technology (VCVRT) [41]. Furthermore, in vision systems, one aspect that requires attention is the mitigation of the risk of violation of the patient’s privacy. The use of video monitoring systems inside patient’s homes makes care on the other hand more privacy intrusive.

D. Other Systems

These are several other technologies in tele-home care systems that may not fall in the categories specified in this paper. For example, in [42] the system uses motion body sensors to monitor the progress of physiotherapy for patients. Another technology that is very promising is the use of RFID [43] in assisted living solutions, where it can be used for a surveillance mechanism. In another research, the use of a mobile phone [44] has been proposed to be used as a step counter in cardiovascular disease patients. Other work like [45] uses sensors to monitor body movement inside the house.

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IV. OPEN ISSUES AND SUGGESTIONS FOR RESEARCH

While tele-home-care systems will undoubtedly play an important role in providing quality health services for patients, some challenging issues remain to be addressed, as summarized below:

A. Architectural challenges

Tele-home-care systems are expected to deal with various amount of information coming from different sources. Such data differs in its semantic as well as structure. For example, sensors collect data about the state of the physical world and transform this information in raw format (e.g. camera stream) which needs to be processed before being usable by the application [47]. Information about patients in the environment requires to be updated continuously for health related interpretations. Typically, the data collected from the environment contains data at a medium level of semantics. When we describe architectures for tele-home-care environments, which may include multimedia and other pervasive computing technologies, we mean integration of several stand-alone health applications successfully together to help the patient [48]. For example, a vital sign monitoring system, a fall detection sensor and a hand held device for emergency contact which are added to an environment, but not integrated only produce output within their own perspective. In such case, the intended use of the applications is not fully utilized to better serve the patient. Furthermore, people who become elderly in the next decade may not have the necessary infrastructure to operate a “smart” tele-home-care system. Hence, new architectures have to be designed to allow efficient transformation of “traditional” homes into environments for patients’ assistance.

B. Collaborative behavior and reasoning

In tele-home-care systems many relationships exist among different entities. These relationships have to be collected to ensure correct behavior of the system to serve the patient [49]. Maintaining a synthesis graph of collaboration on relationship dependencies among entities in the environment increases the usefulness of the service. Multimedia context-aware applications for example, use context information to determine whether there is a sudden change to the patient’s health in the environment. In this case, taking an action whether medical attention is needed or adaptation to that change is necessary often requires strong collaboration among entities in the environment for effective reasoning. Therefore, it is important that tele-home-care designers and architects to consider collaborative behavior of the entities to be able to support both consistency verification, and reasoning about complex behavioral situations.

C. Communication services

Many tele-home-care systems rely on the merging wireless technologies which enable low power-based data communication as we have seen in the work of [13], [17], [24] and [33] to name few. Examples of such technologies are Bluetooth low energy, enhanced GPS, and other wireless solution for embedded applications. These technologies have less communication overhead compared to Zigbee technology and it is anticipated to achieve a dominating position in the ultra-low-power applications of tele-home-care systems [5]. However, since its performance is still in its infancy stage, proper quality of service handling for tele-medical applications needs further research and development. This is because the reliability of guaranteed delivery of data and in-order delivery affects the quality of patients’ health which could be fatal.

D. Synchronization and calibration

Synchronization and calibration of biomedical sensors is a critical problem. We have seen limited work addressing this issue. Calibration is obviously an untapped problem given that sensors may use different power sources and they require to be calibrated to communicate properly with the processing nodes.

E. Power supply

In wearable systems for example, battery technologies and energy scavenging are considered the biggest technical issue that may hinder the operation of the system for longer periods. Further development in sensor miniaturization needs also to be considered as the current systems still use some large and heavy biosensors. Research is being done to produce energy efficient devices. Power from human input could also be consumed [50]. In a tele-care health system, there is continuous interaction of the system with humans; the energy created by human movement could be utilized to power the devices. Self-powered devices can be created for the ambient systems, where the power consumption is minimal. For example, thermo-electric generators, which can provide power autonomy to devices that are operating at very low power [51]. We have studied the work of [52], [53] and [54] in this area.

F. Security, authentication and privacy

New technologies are being introduced to gain full ambient environment of health care systems. It is very important that along with the technology, the security aspect is not overlooked, as the systems are dealing with highly confidential information. There are many challenges due to wireless data transmission devices, which vary from data transmission, node mobility support, timely delivery of data, power management etc. [55]

In a tele-health care system data is transferred wirelessly. This increases the danger of compromising the security and privacy of individuals [56]. Due to the electronic storage of data, the data is exposed to hackers or other malicious attackers, who can access the data. Another aspect brought up by Meingst et al [56] is that who controls the data being collected by sensors installed in people’s homes. There is a requirement to chalk out certain guidelines and regulations for this.

There is a high possibility that patients will not be comfortable by being continuously monitored by a live human being 24/7. As mentioned in [57], the participant in the study completely rejected the idea of being monitored via a camera, claiming it to be too intrusive.

G. Usability

Simplification needs to be carefully analyzed as the level of interaction should be very basic since most of the populations the tele-health care systems are being designed for are not very technology oriented. If the sensors designed for the ambient system are embedded into items that the users are familiar with, it would lead to minimum resistance. For example the concept of a sensor watch was greatly appreciated in a study conducted by Steele et al in [57]. Emphasize is required on user friendly interfaces and proper training to use the systems. It has also been recommended that the users are introduced to the devices before they need them [58].

Validation of the current systems is yet to be comprehensive; this is particularly for clinical trials to evaluate the effectiveness of such systems, let alone the issue of security and privacy.

V. CONCLUSION AND FUTURE WORK

This paper provided a survey and taxonomy for tele-home-care systems. As it has shown, the current technology is
revolutionizing the concept of remote healthcare. But, there are several challenges and issues that need to be resolved for tele-home-care to be fully accepted by the patients. We have summarized these challenges and provided suggestions for further research. Our plan for the future is to extend this work to include aspects of new technological advances, discuss maturity level, evaluation, and the extent to which tele-home-care systems use intelligent features and decision support mechanisms.

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