Home UbiHealth

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INTRODUCTION

At the third computing era, users interact with many computing devices surrounding or implanted in them, in a natural way. These anytime and anywhere interactions implement the concept of *ubiquitous computing*, which provides the framework for computational awareness and personalization. These properties are precious in healthcare applications since the operating computing devices in the patient's environment can be aware about the evolving situations and actively participate in the medical treatment. In addition, ubiquitously supported healthcare services can be provided anywhere and at any time, allowing specific cases of the hospitalization model to be transferred to the home healthcare model.

The adoption of the home healthcare model in a ubiquitous computing environment provides the prerequisites for the development of the presented *Home UbiHealth* model. Extending medical services at home provides the capability to cover the medical needs of all population categories. Specifically, the Home UbiHealth model refers to all major population groups, namely the healthy population supported with prolepsis policies that retain health status; individuals that suffer a health crisis that requires recovery; and chronic patients who must maintain their quality of life coping with known health problems. Within the above patient categories are included the special groups of infants, children, disabled, and pregnants, which have special healthcare needs.

Thus, the home environment is transformed to a reference starting point for the implementation of healthcare processes independently of location and time, thereby bringing together the various healthcare stakeholders and the market. In this framework, the Home UbiHealth model can change the perception about the structure of healthcare systems and the concerns about medically uncontrollable environments.

BACKGROUND

In recent years, medical research has offered tremendous developments. Within this framework, specialized personnel is required to carry out advanced processes within properly structured and controllable facilities, using state-of-the-art biomedical equipment. Unfortunately, the availability of medical resources hardly meets the current social demands for hospitalization in cities and rural areas. This is partially due to the long average hospitalization periods required to perform trivial medical and nursing procedures such as screenings, lab-tests, or follow-ups. The lack of adequate infrastructures leads to longer stay of the patient in hospital.

DOI: 10.4018/978-1-5225-2255-3.ch675

These deficiencies can be addressed through new healthcare models that are supported by modern computing technologies such as ubiquitous computing. Ubiquitous computing was introduced by Mark Weiser to describe the *third wave* or *calm computing* (Weiser, Gold & Brown, 1999), where computers are enweaved into every fabric supporting the end user. In this era, the users are supposed to subconsciously interact with many computers, concurrently, in such a natural way as one uses eye-glasses to restore vision problems.

The application of ubiquitous computing in healthcare systems introduced the term *ubiquitous health* (*UbiHealth*) to describe the use of inherited computing characteristics in healthcare models (Sarivougioukas & Vagelatos, 2015). UbiHealth refers to healthcare services that incorporate ubiquitous computing means. Such services can provide critical advantages to overcome limitations related to individualized care, medical personalized treatment, patient safety, economy of scale, as well as healthcare system efficiency, effectiveness, security, and scalability.

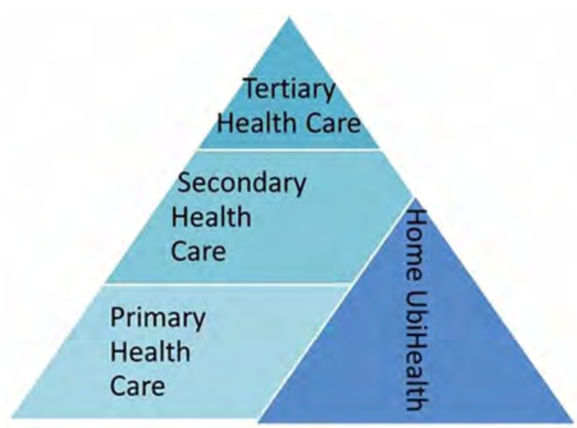
Controllable hospitalization is directly related to quality of treatment, continuity of care services, transparency of medical and nursing supportive activities, patient safety, and administration of the involved supply-chains and related costs. In principle, UbiHealth satisfies the requirements related to the quality of the provided medical and nursing services, the demands for continuity of the involved processes, the necessary conditions of transparency in the followed procedures, and the fundamental prerequisite of safety for medical professionals and patients. Hence, UbiHealth can highly contribute to overcome issues related to hospitalization by providing the ground for medical and nursing processes within ubiquitously performing environments, such as at home.

Treating and curing patients at home (see Figure 1) has been considered as beneficial for particular population groups and has been extensively tested (Madaris et al., 2016) to the point where the treatment is under complete control by the assigned medical personnel. Usually, this refers to post-acute care or chronic patient cases. A typical example is the *Medical Home* paradigm (American Academy of Pediatrics, 1992), which was introduced by pediatricians to control infant mortality and children vaccination.

The significance of home treatment has been verified with respect to prolepsis, prognosis, testing, cure, and treatment. However, the continuously increasing costs of advanced cures, which are habitually applied in highly specialized facilities by specialized medical personnel, has turned the interest of the scientific community to home-based alternatives in order to address the lack of adequate treatment resources. Moreover, the associated risks during hospitalization, such as nosocomial internal infections, accidents, medical mistakes, and human errors, motivate researchers to delve into solutions alternative to hospitalization.

In addition, the bureaucracy imposed by long hospitalization increases the complexity of the carried processes, resulting in significant time and cost growth. In turn, this imposes substantial overhead to social security services, insurance funds, and the related market. Furthermore, limited available hospital resources are incapable to offer individualization of the provided services due to the applying workload. This is in contrast to the endeavors of medical practitioners and healthcare systems, which aim at personalization in the of-

Figure 1. Home Care main components and their relationships



fered cures according to the patient needs and preferences (Snowdon, Scnarr & Alessi, 2014). Home UbiHealth offers a promising solution to this problem, given an adequate ubiquitous health ecosystem.

HOME UBIHEALTH ECOSYSTEM

Home UbiHealth systems operate in an environment where evolving compound processes follow complex workflows that involve stakeholders with diverging concerns and interests. The Home UbiHealth environment includes an underlying computing infrastructure that supports the patient's personal healthcare needs along with interaction with all participating stakeholders. Hence, Home UbiHealth can be considered as the common loci where computing and healthcare support personalized healthcare needs at home, eliminating time and space limitations.

The available technological developments provide the opportunity to resolve several issues in Home UbiHealth, which are related to three major problem areas. The first area is related to the lack of standardization in the home computing hardware infrastructure. This is tackled with the introduction of the *Internet of Things* (IoT), which allows overcoming problems such as the ones in local area networks applications (Riggins & Wamba, 2015). The second area is related to software infrastructures. This is addressed through *cloud computing*, which provides a variety of schemes such as software as a service (SaaS), platform as a service (PaaS), and infrastructure as a service (IaaS) (Ullrich, Vasileiadoy & Tamm, 2011). The third problem area is related to configurability that is necessary to address medical and social issues. This is handled by properties of ubiquitous computing such as the *computing awareness*. Thus, despite the raised problems, there is a variety of technological tools available to support the implementation of the Home UbiHealth paradigm.

The Home UbiHealth model aims at conditionally substituting parts of hospitalization (Leff, 2015), provided that prescribed prerequisites are fulfilled. Although the physical presence of medical professionals is irreplaceable, there are specific procedures that can be carried out in reformed fashion, assisted by computers and communication equipment. This can reduce dependability from specialized professionals. The Home UbiHealth model aims at sharing scarce medical resources by employing reliable and effective communication schemes. However, it may suffer from intolerable commuting overheads (Leff, 2009) since the supporting professionals are obliged to pay scheduled visits at patients' place.

The presence of medical professionals at home to consult family members and caregivers has a twofold purpose. First, the doctor at home audits and instructs about the appropriateness of treatment activities. Second, he coordinates all treatment activities regarding the in-house and out-of-house services. Therefore, the Home UbiHealth model relies on the cooperation and participation of the medical professionals, coordinated by an assigned medical doctor who determines the associated supporting services.

Medical treatment at home requires the availability of medical devices, consumables, and drugs. Also, the medical treatment involves approvals and reimbursements from social security organizations or insurance funds (see Figure 1). These procedures frequently produce delays, frustration, and significant overhead. However, the deficiencies can be eliminated through ubiquitous computing procedures. Additionally, by carrying ubiquitously performed processes, the necessary products, goods, drugs, and services can be organized on behalf of the patient, since all participating stakeholders are aware about the patient and the coverable treatment needs. Hence, multiple procedures can be concurrently activated involving all relevant stakeholders in order to meet the needs of the patient at home.

For instance, a doctor's prescription can receive the necessary approvals from the supporting insurance fund, be executed by the local pharmacy store, and delivered at the patient's home. Therefore, the Home UbiHealth model can become a reference point for ubiquitously performed healthcare processes on behalf of the patient with minimal bureaucratic overheads and complete approval control.

DESIGN PRINCIPAL PRIMITIVES

The implementation of the Home UbiHealth model requires adequate computing infrastructure, capability to achieve continuity of care, and ability to adjust the functional performance of the designed system in order to meet personal needs and preferences.

The context in the Home UbiHealth model is produced from signals of dispersed sensors and computer-controlled devices in the patient's environment. These signals form the holding *situational context*. The devices form ad-hoc cooperative communication networks that support the patient's activities. They fall into three main categories with respect to their location or mobility, namely they can be stationary, mobile or carrying, and implanted (Latre *et al.*, 2011). Major issues of the devices are related to their participation in cooperative networks and their power supply. The formed networks must follow protocols that guarantee patient's safety, security, and privacy, along with support of the patient's medical treatment and personal preferences.

Thus, the computing infrastructure is distinguished into *in-house* and *out-of-house infrastructures*. These are characterized by scalability, which is offered by the ubiquitous computing abstraction of services (Loeser *et al.*, 2003). Both infrastructures are supported by IoT and cloud reproductions, ensuring continuous and uninterrupted feeding of data over the internet. The infrastructure facilitates pre-processing, processing, cognitive, and controlling phases. The pre-processing phase involves the operations of data cleansing, normalization, fuzzification, fusion, and correlation, which exclude inaccuracies, ambiguities, and uncertainties from the obtained raw data. The processed raw data is adequate for the development of the situationally holding context, after the examination of existing relations among the obtained data through rule-based systems (Sarivougioukas & Vagelatos, 2014).

Then, the processing phase applies medical rules on the obtained context in order to produce useful information. The cognitive phase correlates information supported by medical knowledge representations, such as specialized medical taxonomies, in order to draw conclusions and develop a conceptual or knowledge model. Eventually, the controlling phase operates on networks of concepts, assisted by a decision-support system that makes decisions about the proper guidance of physical devices in the patient's environment. Therefore, the computing infrastructure analyzes and processes raw data from the surrounding sensors and returns particular data to each actuating device, thereby supporting the patient without requiring direct coupling between sensors and actuating devices.

Medical doctors can determine the objectives of the cure by prescribing, ordering, and instructing the individual patient's treatment activities through dedicated user interfaces. Thus, the treatment plan is scheduled along with the necessary procedures, within and outside of home. The involved nurses and caregivers receive specific instructions about the personalized treatment, allowing doctors to be regularly informed about the treatment progress, including alarms and warnings.

The model's software infrastructure is the reference or initiation point for all processes regarding the patient's support. Besides the direct support provided by the dispersed devices within the home environment, the patient's support requires the initiation of processes as instructed either by the doctor in charge or the patient's health conditions. For instance, the order of drugs for a chronic disease such as diabetes can be activated by one of the watching medical rules on behalf of the patient, requesting doctor's approval and placing the order to a predetermined pharmacy store according to a predetermined payment type. The performing processes are circular, starting from the UbiHealth software infrastructure and ending, upon completion, to the same system. Thus, the supporting software infrastructure can involve all necessary stakeholders for the patient's support, following workflows that bring together medical authorities, government agencies, as well as services and products from the market. The entire operation of the Home UbiHealth model depends on the availability of the internet and the capability of the software infrastructure to operate from the residing virtual cyberspace.

The autonomy of the Home UbiHealth model depends on instructions and orders provided by the medical doctor in charge. In other words, it depends on the availability of information upon which, decisions can be made. The model can be used equally well for all three distinct cases of individuals, namely the healthy ones, individuals undergoing a health crisis, and the ones with a chronic disease. The Home UbiHealth paradigm allows doctors to perform remote audits besides the necessary in-person clinical examinations. Thus, the entire health history (healthcare records) of the individual is available for consultation by the assigned medical doctor with updated, reliable, and accurate data. Also, the use of the internet as the underlying communication medium that connects the patient with the software infrastructure that resides at the cloud, provides a uniformly and continuously available reference to the personal health data. Hence, the continuity of care is achieved with respect to documentation, time, and space.

On the other hand, continuity of care in the Home UbiHealth model depends on the participation of the involved stakeholders during health-related events. The development of systems and adequate software applications motivates stakeholders to contribute to the patient's treatment. Also, hospitals can share data and continue providing support to the patient who is transferred for recovery at home. The involved social security organizations can support the home treatment of the patient by satisfying the financial issues on-time. Similarly, suppliers of medical products, consumables, and services can be proactively prepared, avoiding bureaucratic procedures regarding the administration, financing, and supply-chain support.

Therefore, the Home UbiHealth model possesses all the necessary properties that allow the patient's support at home in a holistic manner. It can be considered as the structural cell for building healthcare systems. Its parameters can be adjusted to match the desired conditions of an efficient healthcare system with respect to public health, social needs, environmental requirements, and financial constraints. The sustainable healthcare models meet operational requirements that satisfy individual medical needs at desirable level of quality. The operational requirements are satisfied by the prompt availability of data and information regarding the patient's personalized needs, while medical needs are satisfied through the provision of services of predefined quality. Given the desired policies, aimed purposes, operational objectives, and quality level of the offered products and services, the Home UbiHealth model can be optimized with respect to its parameters. This way, it promotes the development of optimal and sustainable designs.

CHALLENGING ISSUES

Contemporary research and development efforts on the extension of the Home UbiHealth model are focused on a number of challenging issues. First, the Home UbiHealth model relies on raw data that is transformed into medical knowledge to serve the medical needs of the supported patient. Second, the provision of services must be adjusted to support personalized medical needs of the patient. Third, the autonomy of the model is determined by the availability of information upon which, decisions are made. This underlines the need for adequately designed decision-making systems. Fourth, the Home UbiHealth model requires efficient methodologies for its formal description. Finally, the design of the model must properly address all security issues. Significant research efforts are paid on the foundations of the model's building blocks that will eventually lead to *in vivo* applications.

The medical support of patients at home requires the adoption of medical knowledge, which must be adequately represented in order to be processed and properly applied. Knowledge is obtained from the available information as a result of processing raw data provided by dispersed devices and smart objects in the ubiquitous computing home environment. The applied data transformations must be accompanied by well-structured and formally defined ontologies. These make available the current level of medical knowledge in various forms, such as rule-based systems, case-based systems, and adapted medical protocols.

The performed data transformations are affected by the patient's characteristics and personalized needs. The ontological support provides the ability to perform inferences and eventually extract the involved discrete medical concepts from the obtained information. Ongoing research efforts try to achieve such representations of the medical knowledge that can be composed from raw data in order to make decisions and, then, be decomposed into low-level data to control the dispersed actuating devices in the ubiquitous computing home environment (Sarivougioukas & Vagelatos, 2015).

Moreover, the Home UbiHealth model has additional inherent restrictions, presented below in decreasing order of significance (Teijeiro *et al.*, 2013). The first and most significant source of constraints refers to the applied medical rules that govern the decision-making components of the model. The second source of constraints refers to the introduced instructions and orders placed by the treating medical doctor, taking into consideration the particular physical and medical characteristics of the patient. The third source of restrictions is about the personal preferences declared by the patient. Current research efforts are focused on the accomplishment of formally defined uniform representations of constraints that nest the aforementioned sources of restrictions and eliminate conflicts and contradictions (Sarivougioukas, Vagelatos & Lagaris, 2015).

Another significant issue is the autonomy of the Home UbiHealth model, which depends on the availability of decision-making components (mechanisms). Decisions are the outcomes of processing operations that take into consideration the available options. The procedural processing in decision making proposed by Simon (Simon, 1979) approximates the practical limits. However, Simon's model requires restructuring since the identification of the problem upon which, a decision is pending, must be provided by the supporting ontology. Also, the process that provides the appropriate medical decision must be proactively available by the model, in order to minimize the necessary search time.

Thus, the model must be dedicated to synthesize actions and bridge the gap between the medically suggested solution and holding conditions. Also, it must be properly designed to provide either decision-making support to the medical professionals or decision making to follow the issued orders of the prescribing doctors. In other words, the decision-making component must follow and participate in the medically adapted workflow of operations carried by the patient and the assigned doctor. Therefore, the decision-making component must be designed to take advantage of the cognition effectiveness, efficiency of intelligence, and optimization.

The complexity of the presented Home UbiHealth model exceeds the efficiency of analytical mathematics to formally describe its components, their functionality, and their interactions. Set Theory and Algebra can hardly offer formal descriptions of the involved interactions and model's behavior. Thus, alternative mathematical methods must be employed to represent and manipulate all the involved quantities in order to allow the handling of the static and the dynamic properties of the model.

To this end, *Denotational Mathematics* (Wang, 2012) can provide the necessary efficiency and flexibility for the formal representation of the Home UbiHealth model. The formally presented mathematical premises must be capable of approaching self-referenced systems, such as the ones formed in the Home UbiHealth model. Also, they shall include the patient as part within (i.e., observed) and outside (i.e., observer) of the formed system. The model must provide the means to administer formal knowledge representations, manipulate algebraically controlled operations, formally describe behavioral abstractions, and handle dynamically changing content.

Finally, the Home UbiHealth model must tackle security issues at design-time, satisfying the technical and medical requirements. Thus, security is approached as a framework consisted of complete processes, participating and rectifying the system's behavior. The security framework is distinguished into infrastructural and application parts that correspond to the designer's and the user's degrees of freedom, respectively. Infrastructural security includes processes that ensure proper accommodation and facilitation of the carried processes of the Home UbiHealth model. The application security framework consists of the interrelated procedures that act as features to the carried end-user's processes and reflect to the medical constraints. Therefore, security must be considered during both the design and operation of the Home UbiHealth model, in order to ensure the proper management and administration of human lives.

FUTURE RESEARCH DIRECTIONS

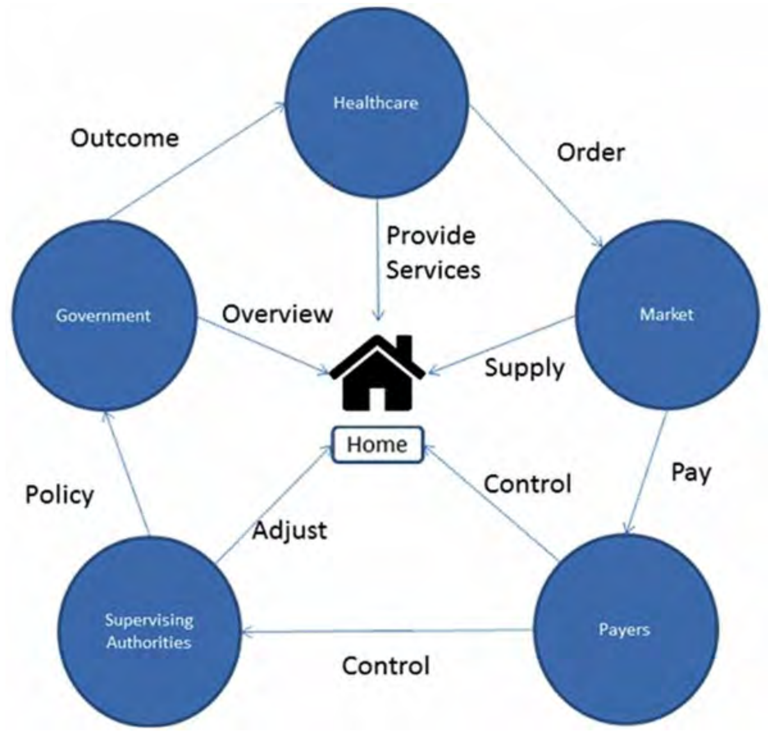
The ongoing technological progress offers the opportunity to include home healthcare services among the formal components of healthcare systems. In particular, Home UbiHealth can become an intermediate layer between primary and secondary healthcare systems (see Figure 2). As a consequence, novel medical professional specializations may appear in order to meet the emerging needs of healthcare services at home. For the realization of a formal home healthcare model, research efforts are required in medicine, nursing, computer science and engineering, oriented towards the Home UbiHealth paradigm. Nevertheless, computer simulation and optimization can accelerate scientific developments in home healthcare and bring it closer to real-world implementations. Thus, they appear to be fertile ground for future research.

Regarding technological aspects, the need for direct and indirect physiological signals, data, and information processing methods, reveals the necessity for efficient parallelization and data fusion applied upon configurable software applications capable of promoting personalization. Additionally, further research is needed on ad-hoc wireless networks, which suffer frequent interrupts due to the lack of continuous power supply, along with the unavailability of standardized communication protocols that meet the Home UbiHealth model requirements. Also, standardization of context-awareness is required in order to optimize the structure of future decision-support systems. Moreover, additional research is needed on the optimization of the underlying communication systems in order to be capable of supporting the increasing number of the dispersed sensors and actuators, as well as the carried mobile and implanted devices. This can reduce the time response of the entire system. Finally, cognitive research approaches must be considered to decrease the computational overheads aiming at the avoidance of analytical calculations to figure out the most adequate responses.

CONCLUSION

The Home UbiHealth model relies on the ubiquitous computing principles and characteristics

Figure 2. Home UbiHealth's place in the pyramid of healthcare



of context-awareness. The model processes contextual raw data that can be transformed into information which, in turn, produces knowledge supported by adequately designed medical ontologies. Knowledge representations and knowledge management provide the means to develop a formal model for treating patients of all categories at home. The model introduces the capability to control medical conditions at home, providing alternatives to the existing healthcare systems and hospitalization models. Thus, the Home UbiHealth model can have financial, social, and environmental impact through the personalization of the provided treatments and the transparent participation of healthcare stakeholders, including the related segments of the market.

The compound design of the Home UbiHealth model along with the complex workflows of its processes exceeds the capabilities of analytical mathematics. Alternative mathematical approaches are required to ensure the necessary formality in the involved descriptions of the model, providing efficient and effective expressiveness of the occurring healthcare situations. Recent research has offered evidence that Denotational Mathematics provide the capability to efficiently represent and describe the model's static and dynamic behavior. Moreover, Denotational Mathematics provide a conceptual system framework to administer the involved entities with algebraic tools. This increases the efficiency of the model and facilitates the use of established Systems Theory and Control Theory principles and methods. Thus, the Home UbiHealth model simultaneously considers the patient acting as observer of the system or independently performing as controller of its underlying control system.

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KEY TERMS AND DEFINITIONS

Calm Computing: Describes the calm (quiet) participation of computing in the interaction with the user without claiming exclusive attention.

Denotational Mathematics: Refers to advanced mathematical entities utilizing objects and conceptual abstractions, defining and manipulating complex relations, representing and administering knowledge, and expressing and handling formally behavioral aspects of executing processes without needing analytical mathematics. The involved mathematical processing is performed on algebraic abstractions denoting mathematical functionalities that obey axioms and laws in order to support the denotational and expressive needs in cognitive informatics, computational intelligence, software engineering, and knowledge engineering.

Internet of Things (IoT): Used to depict the connection of physical objects to the internet with the capability to introduce their identity and communicate with other devices exchanging data. Using the producer-consumer scheme over the internet, the IoT paradigm allows machine produced data to be exploited by other machines.

Knowledge Representation: Required for expressing intelligence and it concerns views of explicit instantiations of conceptual abstractions to facilitate knowledge sharing and exchange. The conceptual abstractions are formed by processed and interacting entities such as concepts, ideas, processes, and rules.

Pervasive Computing: Refers to the embodiment of computers into physical objects connected into networks, that are consistently available, exchanging information, existing everywhere and operating whenever and wherever needed. The term is used interchangeably with Ubiquitous Computing or UbiComp.

Personalized Healthcare Treatment: Refers to any biologic information that can assist in feasibly predicting on-time the occurrence of a disease or prognosticating a patient's response to a given treatment. It is used synonymously with Personalized Medicine which implies additional scientific aspects relying on the molecular basis of diseases with roots in genetics and genomics.

UbiHealth: Refers to the support of healthcare services taking place in a ubiquitous computing environment.

Ubiquitous Computing (UbiComp): The unobtrusively participation of computing at anytime and anywhere allowing users to interact naturally the way someone is using eyeglasses, without any additional effort.