A REVIEW OF HYBRID MODE OF INPATIENT CARE AND HOMECARE DESIGN BASED ON IoMT TECHNOLOGY

Abstract

IoMT has been developing fast since 2014 to support the healthcare industry around the world. This revolution will not only improve healthcare quality tremendously for both patients and givers but also advance the interrelationship between human behavior and the built environment. The United States owns the most advanced healthcare system worldwide; however, it has been facing many tough issues, such as facility limitation, healthcare insurance, and healthcare accessibility, etc. With the help of IoMT, the healthcare system is transferring from inpatient hospital-centered mode to hybrid mode (homecare and inpatient care). With this process, the healthcare system can be greatly improved, where healthcare givers and patients are supported by their health assistant devices to facilitate a healthier life, sustainable environment, and good behaviors.

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Internet of Medical Things (IoMT), inpatient care, homecare, built environment, augmented reality

Introduction

More than 150 years ago, Søren Kierkegaard stated, "Life can only be understood backwards; but it must be lived forwards." New technology will transform our current medical system, just as the Internet is trying to transform the way we work through connecting us smoothly with our team and tons of resources. A new technology named IoMT (Internet of Medical Things) was proposed to exploit the sensor technologies and wireless networks in monitoring medical conditions (Sallabi & Khaled, 2016). This internet-based technology can not only enhance the convenience of human life but also improve the sustainability of healthcare environment design tremendously.

Before IoMT was carried out, IoT (Internet of Things) has been developing for more than a decade; this term was coined by Kevin Ashton in 1999 during his work at Procter & Gamble. The popularity of the term IoT did not accelerate until 2010, then reached the mass market in early 2014 due to the fast development of Information Technology (Lueth, 2014). Unlike the traditional IoT, IoMT are extremely heterogeneous in terms of computing capability, communication protocols, and applications (Gatouillat et al., 2018). Today, various IoMT devices have been widely applied in the healthcare field.

It has been predicted that in the following decades, the way healthcare is currently provided will be transformed from hospital-centered to hospital-home-balanced in early 2030 and will be finalized as home-centered mode (Koop et al., 2008). Many types of research today are mainly focusing on how IoMT applies for remote homecare. However, other than homecare or remote healthcare facilities, IoMT also can be applied for inpatient hospital care widely.

Ever since COVID-19 started to spread out across the United States in April 2020, significant medical facility limitation has become the biggest problem facing the dramatically increasing demand in healthcare needs, especially in metropolitan areas. Tons of patients are unable to access proper healthcare in time, which has produced more than 200,000 deaths around the nation by October 2020 (Centers for Disease Control and Prevention, 2020). With the aid of the IoMT, more patients will be able to get medical attention, as they can be easily monitored and properly directed at home with mild symptoms and be more efficiently treated in hospitals under severe symptoms.

LITERATURE REVIEW

Koop et al. (2008) referred to future delivery of healthcare for the United States called Cybercare. In this research, Koop talked about the drawbacks of the U.S. medical care systems, including insurance policy, healthcare equality, and the healthcare environment. He mentioned that the healthcare system should be altered from a hospital-centered model to a home-centered model. He created a simple model for remote homecare monitoring based on IoMT, which shows how it will work in the future healthcare environment.

In the paper "From Smart Health to Smart Hospitals," Holzinger et al. (2015) involved their research in medical science with "big data" and how to keep pace with the growth of IT. Before this paper, Röcker et al. (2010) described the first steps in the design process of an open and integrated test for studying the acceptance of ambient intelligence assisted living environments in 2010. He also showed how IoMT applies to homecare by a simulation model.

In the book of Advanced Decision Making for HVAC Engineers: Creating Energy Efficient Smart Buildings, Khazaii (2016) wrote a chapter only for healthcare facilities. They stated various aspects about the intensity of energy-consuming in the healthcare industry. Moreover, the healthcare facility is one of the most complicated building types, as there are multiple regulations and standards that are different from other types of projects. At the end of the chapter, they also suggested how to improve sustainable design for healthcare buildings.

Lu and Zhao (2018) published a paper named "Augmented Reality: New Technologies for Building Visualized Hospital Knowledge Management Systems" at the 2018 International Conference for Smart Health in Wuhan, China. They stated the potential of Augmented Reality (AR) for inpatient care, especially in hospital management systems and technology architecture. They also addressed the potential of the recognition algorithm of AR. The application of AR could reduce energy consumption and build a comfortable environment for healthcare buildings.

CURRENT MEDICAL SYSTEM AND ISSUES

Ignoring the small but sensitive issues in human behavior is a common problem of built environment design. Pleasant interior temperature, suitable humidity, comfortable lighting, efficient architectural design, and accessibility can all be considered as the bridge between healthcare environments and human behavior.

There are now more than 47 million uninsured Americans, "those not old enough for Medicare or poor enough for Medicaid" (Koop et al., 2008). Most of them can hardly afford the high cost of insurance. The United States has been labeled as the nation with the most advanced healthcare service and technology. However, the fact is that many people who live in this country are not so lucky to access proper healthcare. The application of IoMT could alleviate the imbalanced medical resource distribution, through cutting the high medical cost and improving the efficiency of the medical system overall.

Increasing investment in hospitals is too high to afford by governments and private parties, partially because the building systems for healthcare facilities consume more energy than other types of buildings. They typically have intricate standards and design requirements. For example, ASHRAE standards specifically define the duty of the HVAC system, level of occupancy, specific function control, hazard control, life safety measures, and so on (Khazaii, 2016).

A U.S. Department of Energy report shows inpatient medical facilities (2.45 billion square feet) in 2015 using 0.51 quadrillion BTUs of energy with an intensity of 208.2 thousand BTUs per square foot (Khazaii, 2016). This report shows that the healthcare industry is one of the most energy-consuming applications in the building industry. Besides, most of the inpatient hospitals have additional laboratories which are also very energy consuming.

Therefore, transforming the traditional inpatient healthcare services encompassing almost all affiliation departments into the hybrid healthcare mode (homecare and inpatient care) is necessary. Inpatient healthcare services can be much simplified. To realize this, the key role is IoMT. This technology provides enormous possibilities for establishing smart health services (Holzinger et al., 2015). With the aid of IoMT, chronic patients, for example, can be transferred from inpatient hospital to homecare. This is going to improve the efficiency of healthcare service to a new level, and potentially makes healthcare more affordable in the long run. In a report called *The Smart Home: Can It Replace Traditional Healthcare?* by Michael Rucker, PhD, MBA (2020), it states that many health conditions could be monitored and treated in a home equipped with necessary smart home products. However, there will still be a need for hospitals and face-to-face health interventions.

HOMECARE BASED ON IOMT

Most of the IoMT technologies for homecare are for long-term illnesses, such as chronic illnesses, people with cardiac and circulatory heart diseases, etc. According to the statistics of the World Health Organization (WHO), 70% of the world's annual deaths are caused by chronic diseases (Chen et al., 2018). Thus, providing proper homecare has significant value in increasing life expectancy through properly treating chronic diseases.

It has been demonstrated that currently smart furniture to a limited extent can integrate sensory and intervention functionality (Hu et al., 2020). Regarding the interior of smart homecare, it can be both considered at the very initial phase of construction and post-occupied phase (operation phase). The smart homecare devices could also be fitted and installed into existing projects where smart homecare facilities were not considered during standard design and build phases. Homecare services may contain a diversity of fields, such as patient assessment, supervision, routine nursing care, health monitoring, medication administration, scheduled injections, management of dietary needs, and lifestyle advice, etc. (Demiris & Tan, 2005). Homecare delivery engines can communicate with patients online, reducing patients' medical costs and building better relationships between doctors and patients (Lu & Zhao, 2018).

Recently, various prototypes of IoMT-based homecare have been carried out by researchers and scientists. These prototypes are for different smart healthcare programs and multiple ages. A phase of Future Care Lab (Figure 1) which is an experimental space for studying users' "life" at home and examining how they interact and communicate with invisible technology has been introduced as the name of "RWTH Living Lab" in 2009 by Ziefle and Röcker (Ziefle et al., 2009). The lab explored how future homecare environments should

be designed to meet technical and medical requirements (Röcker et al., 2010). Meanwhile, it also satisfies fundamental user psychological needs regarding data protection, dignity, and intimacy.

Since the 1990s, IoMT-based smart homecare prototypes have been designed and published. This paper also structures a simple model related to remote homecare design (Figure 2). The core role in this model is patients with mobile devices, such as mobile phones, smart watches, and wristbands. With the apps available in mobile devices, doctors and medical givers are able to monitor patients remotely with the aid of mobile devices. The administrators play an important role to bridge medical professionals and patients. Besides, smart furniture, environmental design, and activity training are all integrated into this design model, which runs together with mobile devices. The smart facilities can be embedded into walls, floors, or other architectural components during the interior design and construction phase. Finally, the database server is responsible for integrating and processing all remote data from different ends.

Different groups of individuals have different types of special needs. For example, young populations' homecare design layout should not be the same as older generations, because they are more active in terms of movement. Thus, homecare design should always consider a variety of adaptation factors. Those dynamically changing factors could be reflected by integrating multiple interaction devices into the homecare systems (Röcker et al., 2010).

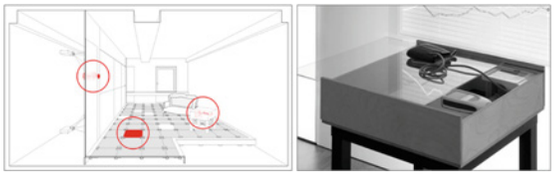

Figure 1: Medical sensors integrated in a smart home environment (left), blood pressure and coagulation-monitoring device embedded in a coffee table (right). (Source: The RWTH Living Lab by Ziefle et al., 2009.)

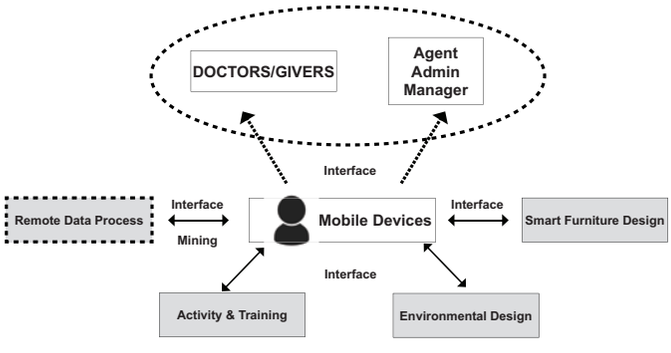

Figure 2: IoMT Based Interior Design Model Possibility Diagram. (Source: Authors.)

INPATIENT CARE BASED ON IOMT

Healthcare is undergoing a rapid transformation from traditional hospital and specialist focused approach to a distributed patient-centric approach (Ahad et al., 2019). The future hospital development trend will transform to more community-based healthcare facilities and remote homecare, which means less and smaller inpatient hospital centers. However, we would still need healthcare centers for specialized services, like trauma care, transplantation, surgery, oncology, and positron emission tomography scanning (Koop et al., 2008).

Type	Service	Description
Homecare	Doctor Consultant	A doctor may visit a patient at home to diagnose or virtual diagnose
	Health Monitoring	Smart monitoring by IoMT devices
	Nursing Care	Total patient care
		Functional nursing
		Team or modular nursing
		Primary nursing
		Case management
	Physical Therapy	Function, move, and live better
	Pharmaceutical Services	Medicine and medical equipment can be delivered at home
	Urgent Care	Schedule virtual urgent care
Inpatient Care	All Other Services	Surgery, certain examine, certain labs, ICU, emergency or other necessary in-person services

Table 1: Different Services Affiliation (Source: Authors.)

Other than the application for homecare, the IoMT technology can be also widely applied for inpatient healthcare facilities. For example, Augmented Reality (AR), an internet-based new visualization technology based on virtual reality technology, has been widely applied recently. AR is a bridge between the virtual world and the real world. It has three main characters: authenticity, interactivity, and practicality. (Lu & Zhao, 2018). With the aid of AR technology, hospital management systems, including human body structure, medical imaging, etc., can be better understood by physicians and patients (Lu & Zhao, 2018). Another trend is researchers and medical scientists are engaging to apply AR in surgery simulation, navigation and postoperative rehabilitation, medical teaching, and training, etc.

It is obvious that the design for the IoMT-based inpatient hospital is much more complicated than smart homecare. Possible development of inpatient healthcare design is to simplify the current inpatient hospital affiliations. As mentioned above, with the application of IoMT in the homecare environment, many affiliations in hospitals will be no longer needed, such as nursing, simple doctor consultation, health monitoring, physical therapy, urgent care, etc. Therefore, the future hospital complex will be simpler than it is today: only necessary programs, surgery department, ICU, emergency department, and specific examinations

that require expensive and specialized machines, etc., will be considered in the design layout (Table 1). A simplified inpatient healthcare model is beneficial to reduce hospital energy consumption, which alternatively can lead to more affordable healthcare both for the general public and for the owner of the healthcare entities.

CHALLENGES AND FUTURE RESEARCH

The positive outputs of IoMT technology application for homecare and inpatient care are obvious; however, there are also many challenges. One big challenge is the graphic data processing for homecare. When patients upload their symptom images or access virtual care, an accurate diagnosis requires high quality of graphic transmission; the resolution of symptom images is positively correlated to the resolution of the diagnosis result. As a result, it is important that homecare devices include a high-precision camera, environment lighting, pose instruction, etc. In order to increase diagnosis precision, homecare devices still have a long way to go.

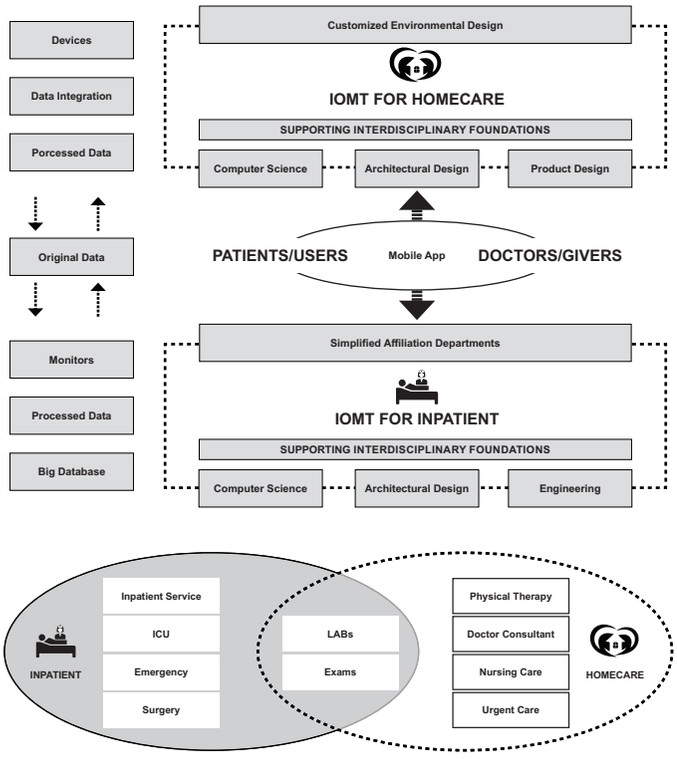

Figure 3: Hybrid Model Possibility Operation Diagram. (Source: Authors.)

Another challenge for IoMT inpatient care application is the limitation of the database. IoMT-based healthcare relies on dataset processing. However, during the early phase of the application, it takes time for the database to build up, so data sources can be uneven due to insufficient cases. The cases gathered should cover all regions, races, and sexuality to avoid a medical error. Also, the database should keep updating for both common cases and rare cases. As a result, for future research about IoMT for inpatient care, the database refinement is crucial.

Conclusion

Transferring the healthcare system from inpatient hospital-centered to homecare and inpatient care hybrid mode is a necessary trend. A ubiquitous and mobile integrated environment based on the IoMT offers support for large-scale connectivity within different users, which apply for both inpatient care and homecare (Figure 3). The maturity of IoMT technology will significantly benefit the environment and human life.

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