Journal of Digital Art Engineering & Multimedia
ISSN 2508-9099(p) 2672-1198(e)
Vol.8, No.4, December (2021), pp.429-439
http://dx.doi.org/10.29056/jdaem.2021.12.07

A Study of Mobility Management Support for AR/VR-based Cognition Recovery and Rehabilitation

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Abstract

Cognition recovery and rehabilitation programs are essential to improve the well-being of the elderly and person's suffering from cognitive impairments and chronic diseases. Most of this programs have utilized augmented reality/virtual reality (AR/VR) technologies to enable an immersive cognitive training through virtual environments capable of providing a realistic cognitive task simulations. This paper deals with leveraging the features of AR/VR technologies to improve the performance of cognition recovery and rehabilitation programs specifically on the seamless transmission of physiological information over open network systems. It aims to include mobility management as an integral factor in measuring the quality of service (QoS) for such feature of the healthcare system. In this regard, it is proposed to utilize the network-based Proxy Mobile Internet Protocol version 6 (PMIPv6) mobility management protocol to fully implement a seamless mobility support for the system, thus, making the elderly and those with cognitive impairments become more productive and active members of the society.

Keyword : Healthcare systems, AR/VR, Cognition recovery and rehabilitation, PMIPv6, Mobility management

1. Introduction

Modern healthcare systems include features of cognition recovery and rehabilitation programs to improve the well-being of the elderly and persons suffering from cognitive impairments and chronic diseases. This is essentially necessary as most countries continues to reach the aging society in a faster pace that will greatly affect on almost all aspects of the society [1][2]. At the end of 2020, there are already more than 1 billion people who are aged 60 and above and most of them are living in low- and middle-income countries. Most of them may not have or with limited access to the basic resources of life necessities (e.g., healthcare benefits) that prevents them to become fully active members of the society [2].

For example, in Japan, almost one-third (1/3) of its population are already over the age of 65 [1]. In

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* This Paper was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. NRF-2019R1G1A1100341)

Received(October 8, 2021), Review Result(1st: October 24, 2021, November 18, 2021), Accepted(December 10, 2021), Published(December 31, 2021)

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South Korea, the elderly population (i.e., persons aged 65 and older) made up 16.5% of its population, in which, according to Statistics Korea, this population will be up to 8.53 million in 2021. It is also expected that in 2030, the elderly population reach 12.98 million and 17.22 million in 2040. In addition, this number could account for 43.9% of the entire Country's population [3]. Managing of the aging population poses significant pressure for most countries in order for the elderly to live longer and in prosperity as they get involved in the society. Recent studies also shows that most elderly (i.e., accounted for 70% of their number) were not participating in leisurely activities and most of them were anxious, bored, and not too healthy. Some of them are also with cognitive impairments and chronic diseases such as cancer, diabetes, asthma, arthritis, osteoporosis, Alzheimer's disease (AD), and dementia [4].

Cognitive recovery and rehabilitation programs have been implemented aiming to improve the cognition skills and functions of the elderly and persons with cognitive impairments and chronic diseases. Cognition training programs has been significant in enhancing the individual's cognition process in order to naturally interact with its environment [5]. The incorporation of Augmented Reality (AR) and Virtual Reality (VR) technologies into healthcare services and systems have enabled an efficient utilization of immersive virtual environments providing a realistic simulation on the tasks within the cognitiion recovery and rehabilitation training and programs [6][7]. AR and VR technologies have allowed an immersive program to enhance an individual's sensory perceptions such as hearing, touch, smell, vision, taste, and kinematics [8]. The adaptation of AR and VR based technologies in cognitive training and programs increasingly becomes popular and widely accepted [9-11].

In order to improve the quality of service (QoS) for such programs, mobility management needs to be integrated as movements of patients, doctors, and other healthcare personnel are inevitable and some programs are even administered remotely. Seamless, real-time, and continuous transmission of bodily or physiological information for processing in healthcare systems is a major requirement in ensuring accurate, timely, and proper diagnosis and administrations of healthcare medications and treatment. Thus, this paper suggests the utilization of the network-based Proxy Mobile Internet Protocol version 6 (PMIPv6) [12] mobility management to support the seamless transmission of such essential healthcare information across wireless networks to guarantee the full functionality of the program and user satisfaction.

The rest of this paper is organized as follows: Section 2 discuss the related literature and technologies involved in implementing the AR/VR-based cognition recovery and rehabilitation program; the methodology for utilizing the PMIPv6 mobility management support is outlined in Section 3; the

discussion on the significance is outlined in Section 4; and the concluding remarks and future research directions were presented in Section 5.

2. Related Literature

This section provides an overview of the existing and proposed programs related to cognition recovery and rehabilitation services which includes the utilization of ubiquitous sensor networks in implementing remote healthcare diagnosis, monitoring, medication, and treatment of patients; the incorporation of AR/VR technologies in healthcare programs; and mobility management support implementations.

The ubiquitous sensor networks (USNs) have evolved from wireless sensor networks where it became pervasive or intelligent and be able to connect objects with another capable of detecting, storing, processing and integrating information gathered from geographically distributed sensors [13]. USN is comprised of a network of devices that is “aware” of its context. It can tell, for example, whether an object is moving or stationary and whether it is hot or cold, thus, making it a perfect technology for health monitoring, such as of a patient's blood pressure, and other physiological or environmental conditions.

The implementation of Ubiquitous Sensor Network (USN) middleware for applying data obtained from heterogeneous sensor nodes to u-Healthcare system maximizes its extensibility and usability [14]. The USN middleware allows abstraction of various healthcare sensor node, data filtering, event processing and Context-Awareness. The implementation is summarized as follows: (1) obtaining health and environmental conditions through the deployment of bio-sensors; (2) transmission of healthcare data to the middleware through a gateway; (3) data transformation into the standard format through abstraction; and (4) data storage in healthcare database server. Stored information in healthcare servers can be monitored in real time by the users [14].

USN provides continuous patient monitoring and enables significant improvement in medical services. An evaluation has been provided by Said and Ibrahim [b] for the e-Health signaling model in the USN that is based on using the IP Multimedia Subsystem (IMS) as a service controller sub-layer for the USN platform. They have provided a USN-based IMS detailed network design for e-Health implementation with emphasizes on Session Initiation Protocol (SIP) modification and middleware entities functions and proved its applicability and reliability [15].

Augmented Reality (AR) technology allows the augmenting of additional information, videos, and graphics on smart devices over reality while Virtual Reality (VR) technology refers to a simulated

reality which were created through computer technology [16]. In VR, the user can be completely immersed with the simulated digital environment. AR and VR technologies are both beneficial to healthcare services for enhanced data analysis and healthcare practices. Healthcare systems and services will be able to establish working connections with their patients to provide remote and personal care.

Another challenge in implementing AR and VR based healthcare services is that these technologies require unlimited access to high-speed networks (e.g., 5G networks). Currently, The open network consists of various heterogeneous wireless radio access networks that must coexist and cooperate with each other.

According to Atto and Guy [17], a WSN for healthcare applications need an efficient Medium Access Control (MAC) and routing protocols in order to guarantee the reliability of the data delivered from the patients (i.e., collected through bio-sensors) to healthcare centers. They have proposed the implementation of GinMAC with a mobility management module that includes energy saving, delay and reliability for end-to-end data delivery over multihop WSNs.

Mobility has been required for the network nodes of healthcare services and systems and must maintain their network connectivity as they move across the different radio access networks. The standard Mobile Internet Protocol version 6 (MIPv6) [18] by the Internet Engineering Task Force (IETF) has also been proposed to manage the handovers of mobile devices in the healthcare domain. However, MIPv6 typically suffers from various drawbacks specifically on having high signaling overhead caused by tunneling and binding messages exchange operations [19]. Such huge signaling overhead can result in excessive power consumption during handovers and movements of power-constrained bio-sensors nodes. In addition, MIPv6 is also limited by large packet sizes caused by encapsulations and decapsulations during tunneling operations, high packet loss ratio, and the sleep mode operations. This limitations will not be acceptable in healthcare applications as transmission of healthcare information is critical to the safety and well-being of its patients.

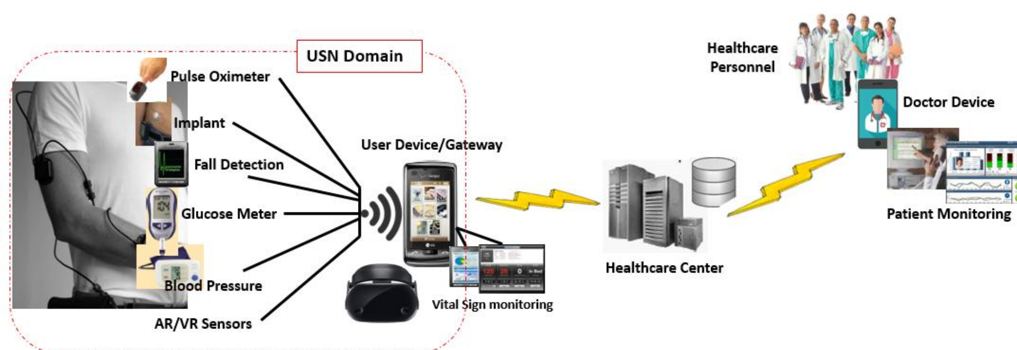
A resource mobility scheme for service continuity in an Internet of Things (IoT) environment has been proposed by Ganz et al. [20] that utilizes two operating modes of caching and tunneling in order to enable healthcare applications to access the sensory data when a resource becomes temporarily unavailable. That is, instead of the sensor transmitting all the collected physiological and environmental information, the sensor gateway caches the measured data and transmits them in response to a service provider's request. In addition, the tunneling mode reduces the packet loss rate during the bio-sensor's handover through creating a tunnel between the sensor gateways. However, the data transmission can be interrupted as both the bio-sensors and the gateways are capable of moving across different radio access

networks.

3. Mobility Management Methodology

Mobility management has become an essential requirement implementing healthcare services specifically on cognition recovery and rehabilitation programs that employs AR and VR technologies. Patient and Healthcare provider movements are inevitable in administering AR/VR-based cognition treatment programs such as:

- Physical therapy. AR/VR technologies helps the elderly or patients to overcome high pain levels easily and ensure faster recovery when performing physical therapy.
- Post-traumatic stress treatment. Whenever a patient is placed into the simulated virtual environment with a traumatic situation and he/she tries to find the solution and overcome the unpleasant situation.
- Anxiety, phobia, and depression treatment. AR and VR technologies can be used by patients for meditations or relaxation in safe simulated virtual environments.
- Emergency treatment. AR maps overlaid on reality can help people find medical centers, pharmacies, and other healthcare facilities easily and quickly.
- Personalized approach to patients. AR and VR technologies can help doctors better explain to their patients how their programs can be performed or which steps a patient should take for more effective recovery.

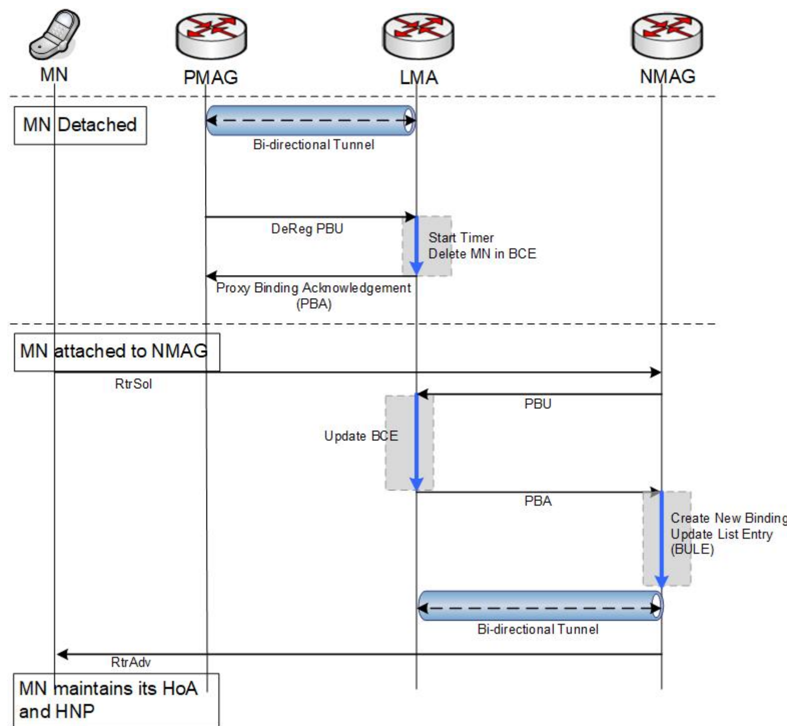


[Fig. 1] Architecture for AR/VR-based Healthcare System

The physiological and environmental information (i.e., including AR and VR collected data) gathered by the bio-sensor nodes are required to be transmitted in real-time and continuous manner, thus, a

seamless transmission mechanism must be implemented through mobility management support. The architecture of the AR/VR-based healthcare system that features to cognition recovery and rehabilitation programs is depicted in [Fig. 1]. The mobility management must support the seamless handovers of user devices, doctor devices, and some bio-sensors capable of dynamic movements.

In the implementation of the standard MIPv6 [18], mobile nodes are allowed to move across different access networks without losing its connectivity, however, some limitations are incurred as to high signaling overhead, high packet loss rate, large packet sizes, high latency, triangular routing, etc. High signaling overhead resulted from tunneling operations and exchanging of binding messages between the mobile devices and the network entities.



[Fig. 2] PMIPv6 Handover Operations

In this regard, a network-based mobility management support in PMIPv6 [12] has been suggested to address the signaling overhead problems of the standard MIPv6. The mobile devices or nodes in PMIPv6 are freed of participating in mobility related signaling operations whenever it roams across the localized mobility domain (LMD) of PMIPv6. The mobility related operations to perform the handover were relegated to the network entities, thus, there will be no need for the mobile node to update its

home agent (HA) everytime it moves into a different network. [Fig. 2] depicts the handover operations for PMIPv6 that employs two functional entities to handle the mobility management of mobile nodes. The mobility anchor gateway (MAG) is responsible in detecting the mobile node's attachment and providing IP connectivity, while the local mobility anchor (LMA) is responsible in assigning home network prefixes (HNPs) (i.e., address allocations) to mobile nodes and it also acts as the overall network anchor. In addtion, the LMA acts as the intermediary for all the IP packets (e.g., healthcare information) that belongs to the mobile node. It is responsible in distributing the IP packets across the different interfaces that a mobile node attaches to within the LMD.

When the mobile node enters the LMD, it receives router advertisements from available MAGs with the HNP to configure a Care-of address (CoA) through stateless autoconfiguration. Mobile nodes can also alternately use stateful address autoconfiguration mechanisms. A bidirectional tunnel is established between the LMA and MAG only, thus, allowing the mobile node to maintain its originally assigned home address (HoA) within the LMD. The LMA then intercepts all IP packets intended to the mobile node, encapsulate, and forwards them through the tunnel to the MAG where the mobile node is currently attached to. The MAG in turn, decapsulates the received packets and transmits them directly to the current CoA that the mobile node allocates.

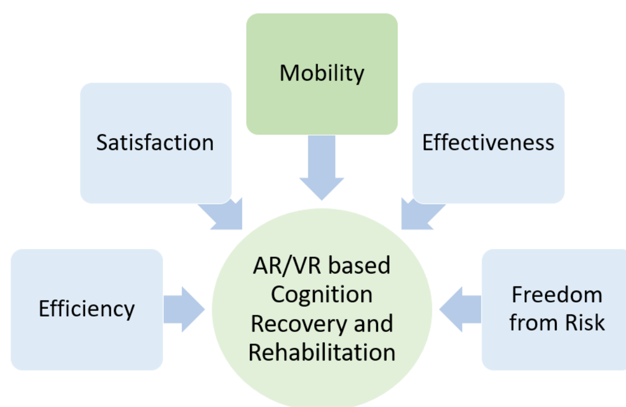
Whenever a mobile node moves to attach into a different MAG, it is no longer required to send any mobility related signaling to the network entities (LMA or MAG), only that it detects for available MAGs through Router Solicitation (RtrSol) message. When the new MAG (NMAG) detects the presence of a mobile node, it sends a proxy binding update (PBU) message to the LMA indicating that a mobile node has attached to its domain. The LMA then updates its binding cache entry with this movement and sends back a proxy binding acknowledgement (PBA) message to the NMAG to create a new binding update list entry (BULE). A bidirectional tunnel is then established between the LMA and NMAG. On the other hand, as the PMAG detects the movement of the mobile node away from its range, it send a Deregistration PBU message to the LMA indicating that the mobile node is no longer within its range.

The PMIPv6 handover indicates a shorter latency as compared with the standard MIPv6 as the exchange of mobility related messages has been reduced and the mobile node is freed of such responsibilities. Reduced signaling overhead can also result to shorter latency, reduced packet losses, minimal delays, and thus, ensures the seamless transmission of real-time healthcare information which are critical to the patient's well-being.

4. Discussions

AR and VR technologies greatly impact the healthcare services as it enables cognition recovery and rehabilitation programs to be effectively and efficiently implemented. Some of the specific uses of such feature includes the following:

- In ophthalmology, AR and VR technologies can help specialists in providing an app that stimulates the vision of a patient with specific conditions such as Cataract or Age-related macular degeneration (AMD).
- VR and AR technologies can be used to enhance self-diagnostics. Check-ups and treatments can be done remotely.
- VR and AR-based apps can be designed for use in self-guided treatments such as addressing chronic pains, having meditation sessions to overcome anxiety, or planning recovering joint dysfunctions exercises.
- Through AR and VR technologies provides an enjoyable and better engaging rehabilitation in gamified approach for survivors of brain injuries and strokes.
- Through AR maps, information on healthcare facilities location can be easily tracked. Emergency needs can be easily assisted with AR information on available life-saving facilities and amenities in certain locations.



[Fig. 3] Properties Measuring the Quality of the AR/VR based Cognition Recovery and Rehabilitation

Quality of service (QoS) for healthcare systems is necessarily important as human life and the well-being of every member of the society is always at stake with its services. Five major properties

depicted in [Fig. 3] have been identified in measuring the quality of AR/VR-based cognition recovery and rehabilitation program for healthcare systems which are specifically intended for the elderly and patients with cognitive impairments and chronic diseases. The five properties are summarized as follows:

- Mobility is defined as the capability of the system to deliver real-time, continuous, and seamless services to the users of healthcare system while allowing them to freely move or to go on with their treatments and diagnosis remotely. It allows self-monitoring, self-guided treatments, and self-diagnostics which are brought by AR and VR technologies and mobility management support of PMIPv6.
- Effectiveness is defined as the measure in relation to the accuracy and completeness with which patients and healthcare personnel have achieved their goals.
- Efficiency is defined as a set of attributes indicating the level of the performance of AR/VR based cognition recovery and rehabilitation in healthcare systems. It also include the delivery of timely healthcare information by the bio-sensors for analysis and diagnosis.
- Satisfaction is defined as the measure to which user needs are satisfied with the services specified and delivered by the AR/VR based cognition recovery and rehabilitation in healthcare systems. It is the user's response to interaction with the healthcare service, and includes attitudes towards the use of the features of the system.
- Freedom from risk is defined as the degree to which the AR/VR based cognition recovery and rehabilitation mitigates the potential risk to human life, health, or well-being of the elderly or patients with cognitive impairments and chronic diseases.

The evolution of healthcare systems to incorporate AR and VR technologies have enhanced the implementation of cognition recovery and rehabilitation programs. In addition, the provision of mobility management support has guaranteed the best results in terms of training effectiveness, user satisfaction, comfortability, suitability, and allowing for system users to freely move while undergoing the cognition recovery and rehabilitation program.

5. Conclusion

Mobility management has become a challenge in implementing cognition recovery and rehabilitation programs for healthcare systems moreso that AR and VR technologies have been incorporated. The integration of AR and VR technologies in healthcare systems has enabled the efficient implementation of

the cognition recovery and rehabilitation programs allowing patients to get immersed in better engaging simulated environments. In addition, the utilization of PMIPv6 mobility management to support the handovers of mobile devices and bio-sensors in healthcare systems has allowed for the real-time, continuous, and seamless transmission of healthcare information among the network entities of the healthcare system. Thus, the integration AR and VR technologies and the provision of network-based mobility management support can provide a mobile, effective, efficient, satisfactory, and risk free cognition recovery and rehabilitation programs for the elderly and patients with cognition impairments and chronic diseases.

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