Reference Model and Architecture of Interactive Cognitive Health Advisor based on Evolutional Cyber-physical Systems

KangYoon Lee[1]
[1] Department of Computer Engineering, Gachon University
SeongnamSi, South Korea
[e-mail: keylee@gachon.ac.kr]

Received March 7, 2019; revised May 16, 2019; accepted June 6, 2019; published August 31, 2019

Abstract

This study presents a reference model (RM) and the architecture of a cognitive health advisor (CHA) that integrates information with ambient intelligence. By controlling the information using the CHA platform, the reference model can provide various ambient intelligent solutions to a user. Herein, a novel approach to a CHA RM based on evolutional cyber-physical systems is proposed. The objective of the CHA RM is to improve personal health by managing data integration from many devices as well as conduct a new feedback cycle, which includes training and consulting to improve quality of life. The RM can provide an overview of the basis for implementing concrete software architectures. The proposed RM provides a standardized clarification for developers and service designers in the design and implementation process. The CHA RM provides a new approach to developing a digital healthcare model that includes integrated systems, subsystems, and components. New features for chatbots and feedback functions set the position of the conversational interface system to improve human health by integrating information, analytics, and decisions and feedback as an advisor on the CHA platform.

Keywords: Reference Model, Cognitive Health Advisor, Healthcare Cyber-physical Systems, Ambient Intelligence

A preliminary version of this paper was presented at ICONI 2018, and was selected as an outstanding paper. This version includes experimental implementation results of the Cognitive Health Advisor Platform.
This research was supported by the MSIT(Ministry of Science and ICT), Korea, under the ITRC(Information Technology Research Center) support program(IITP-2019-2017-0-01630) supervised by the IITP(Institute for Information & communications Technology Promotion).

1. Introduction

Cyber-physical systems (CPS) are a critical part of this changing age. CPSs emerged around 2006 and the term was coined by Helen Gill at the National Science Foundation in the United States. CPS is an orchestration of computers and physical systems [1]. CPS have substantially advanced in terms of design and operation because of the improvements in development techniques through the monitor-analyze-plan-execute loop operation on shared knowledge [MAPE-K] in computing systems [2]. The monitoring of humans in the loop has a challenging and promising class of applications with a considerable potential for influencing the daily lives of humans [3]. A CPS that uses MAPE requires more considerations of the human to provide feedback cycles for decision-making. When the system performs an analysis and identifies a problem or predicts the future, it can advise, consult, and train a user. The system suggests and recommends directions to improve the quality of life through a train-feedback MAPE cycle. CPSs are essential to the feedback loop systems; in addition a training system based on analytical results to improve the MAPE cycle is required.

According to the development of IoT technology in the health sector, there are several approaches to monitor and alleviate users' unhealthy behavior. Existing health monitoring and analytical approaches still face several challenges of limited intelligence due to insufficient healthcare data. In addition to comprehensive and intelligent health monitoring and guidance methods, analytics to improve personal health via a smart health advisor model are also required. [4]

A cognitive health advisor (CHA) aims at constructing a human health improvement system in the loop of CPS as a smart health advisor model; it is an integrated platform that has information on the lifelog, biometric data, medical check-up, EMR, training data, and conversational function. The conversational function, aka Chatbots, is crucial to check, obtain feedback and make recommendations for improvements. A conversational function represents an innovative approach to address challenges in telecare and prevention domains in healthcare [5].

Based on these requirements, a reference model and the architecture of CHA are used to explain a novel approach to the new CPS model. The e implementation of CHA is similar to that of as the CPS platform and it integrates a feedback based improvement system that is an interdependent and interactive advising system on top of the CPS. CHA employs an evolutionary type of CPS. Thus far, research in this area has focused on data collection, tracking, analysis and decision-making. The focus henceforth should be on supporting individual integrated decision-making in response to changes and improvements through health and biometric information, education, and testing. There is a strong demand for the following methods of collecting large scale information and improving the interactive training system.

1) Large scale information from device

The advances in information technology have resulted in the generation of a large amount of healthcare information that can help develop a healthcare industry model on the CPS which must be handled using Health-CPS assisted by cloud computing and big data [6]; this information also provides a method to integrate security and privacy issues into the CPS system [7].

2) Improvement using by interactive training system

By analyzing the collected biomedical information, expected diseases can be identified. Signs of these diseases can also be detected, and they can be prevented or improved through education or training [8, 9]. Furthermore, it needs to be communicated to humans using an interactive conversational technology [4]. The collaboration of service accelerates open API utilization with business partners, health institutions, and human users, which will be a new way of heath service platform revolution [10].

The remainder of this paper is organized as follows: First, the evolution model of the CPS in the health domain is described; next, the reference model of the CHA is defined; and finally, the implementation of an interactive CHA platform is discussed along with the explanation of the goals, scope, and development approach.

2. Evolutional Model of the CPS

2.1 Requirements of the CHA Platform

Assessment methods for the early detection of diseases such as dementia or depression, which often occur in the elderly,mainly depend on surveys, expert interviews or an examiner's neuropsychological tests. However, the methods to discover these diseases are becoming increasingly diverse. The ambient assisted living (AAL) system or a digital health platform can monitor an individual's facial expressions, gestures, walking steps, speech patterns, and so on using various sensor devices to recognize the signs of change and diagnose diseases using artificial intelligence algorithms [4].

The process of recording one's entire personal life has been simplified because of the miniaturization of smart devices and the development of wearable devices. Moreover, the technology of the utilization of lifelog information has increased because of the development of the big data technology. The human health status can be assessed using various artificial intelligence technologies that apply deep learning for biometric information analysis.

Education and training systems through virtual reality(VR) and augmented reality(AR) can reduce the likelihood of an ailment developing into a brain disease, improve their condition through training, monitor changes, and improve their personal health through feedback [11]. A solution to help an aging society is, therefore, very essential.

A messenger-based chatbot service can communicate with humans using information. The system monitors humans, analyzes human biometric data, suggests ways to fight diseases by anticipating changes in diseases, thereby protecting an individual against an expected disease, and providing the current health status to humans. Information regarding the improved state and the advisable function must be exchanged to recognize a problem and address it [12].

Chatbots can solve many issues of existing app users because they determine and organize user needs and provide necessary information to customized services.

Currently, chatbot services can identify and respond to the context of natural languages used by humans, and it can improve accuracy by self-training as conversations accumulate. The integration of artificial intelligence and chatbots, such as the cognitive computing technology, to medical services and health care is a natural trend in the development of technology.

A chatbot is expected to serve as a window of future growth for mobile messengers, as well as a solution to various medical needs such as conversations with artificial intelligence.
This platform technology is a convergence technology based on a deep understanding and integration of artificial intelligence, chatbot technology, mental health medicine, and gaming. It is also a technology to prevent diseases through the analysis of the lifestyle of modern people. This technology is a platform technology that can be given market value [5].

CHA is needed as an acceptable fused composite-integrated platform solution to these requirements..

2.2 CHA Platform Architecture

The architecture has the following design challenges: Combining and monitoring data and training algorithms is a crucial design issue, and the system must evolve from a monitor-analyze-plan-execute loop operation to train-feedback MAPE cycles (**Fig. 1**). The system requires training on improving health regarding brain diseases to predict and prevent a disease,

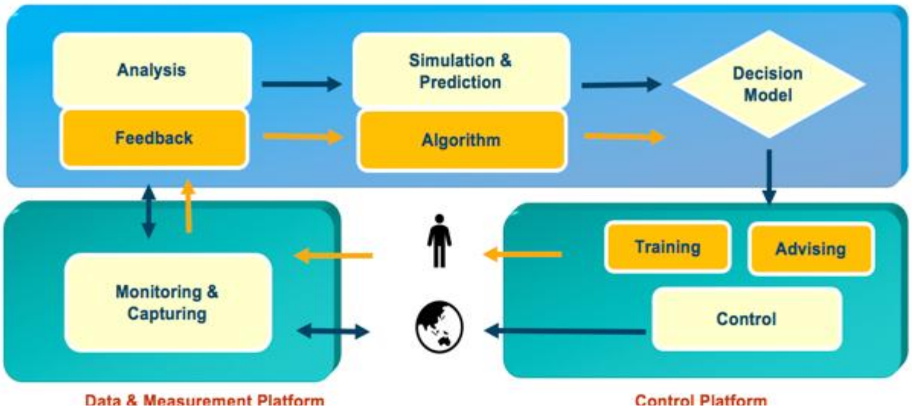

Fig. 1. Train-Feedback CPS model

A feedback cycle based on the results is necessary when the recommended training is decided and executed. The next step must then be decided.

Combining the chatbot and clinical decision support system is the second challenge in designing a CHA platform. A messenger based chatbot can drive a user conversational interface and provide personalization. It is linked with a knowledgebase, as shown in **Fig. 2**.

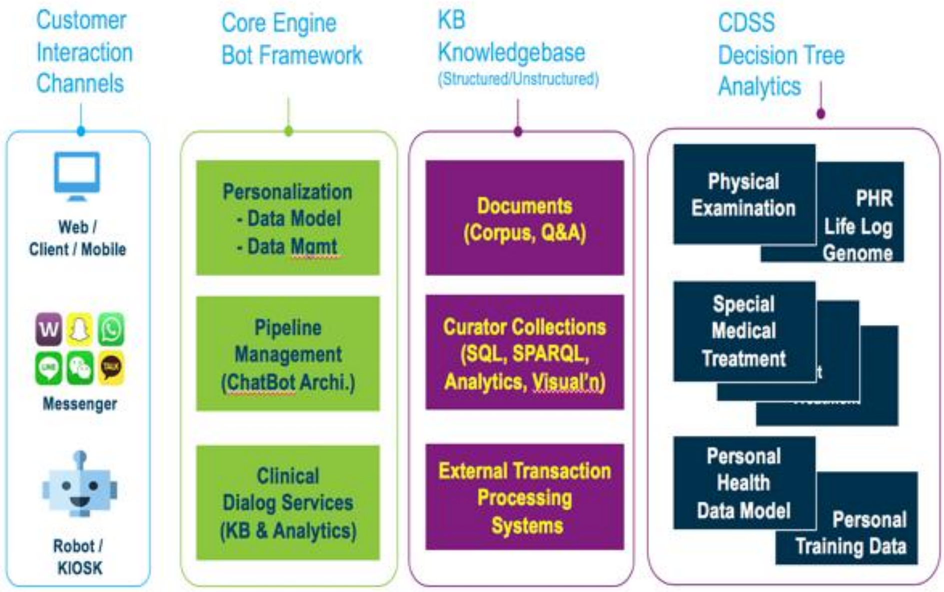

Fig. 2. Configuration diagram of CHA

Clinical decision support systems will be analyzed using various knowledgebases including internal structured and unstructured information and external knowledgebases. A chatbot must be able to handle multiple changes in the conversation using the memory of the previous conversation. Furthermore, it must be able to a build query sentence via branching for an internal Corpus, SQL DB, SPARQL DB, and an external Corpus, such that all the information may be integrated and all the ambient intelligence may be actively delivered.

3. Reference Model of the CHA Platform

CHA provides large block functions to advice human users regarding health.
First, an open conversational platform should be supported. Various functions are required for daily service for human users through the chatbot. In the basic implementation considerations of the platform, the development direction of the user interface is as follows:For a very short period, the app-based service will be implemented as a bot-based service and the chatbot service should be configured to be able to expand and combine services with multiple chatbots, namely universal-bot and sub-bots.

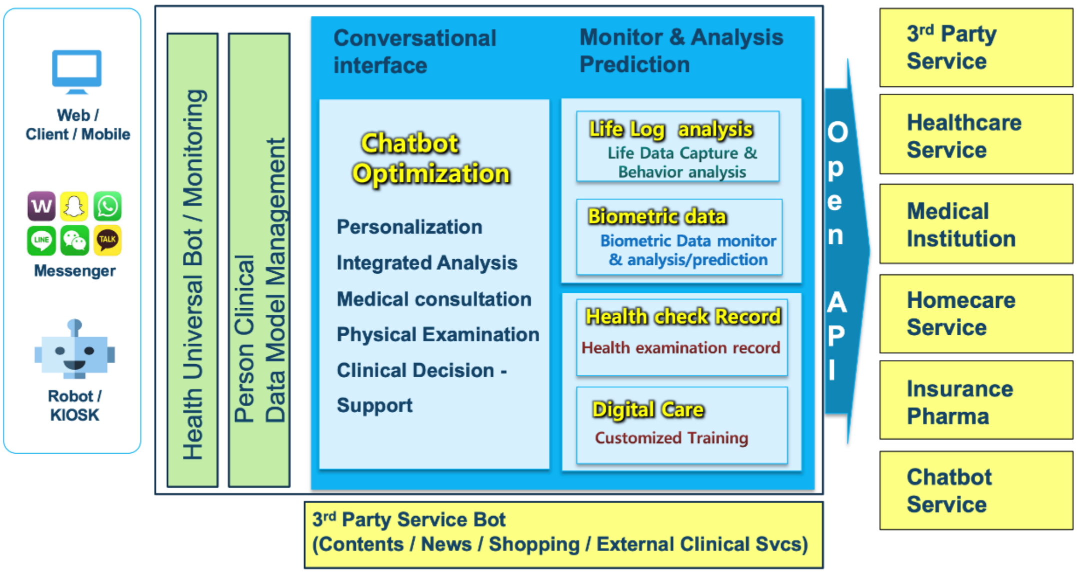

Fig. 3. Function block of the CHA reference platform

Second, the information collected and analyzed as the requirements of the open platform should be able to interface with other platform services through various interfaces. These two requirements should be made available as a channel to make new decisions in the CHA platform by integrating other services. They should also be supported in the form of open APIs to enable new services to be provided to users of other platforms of third parties.

The functional configuration is largely composed of a monitor and prediction systems and a conversational interface (**Fig. 3**).

The first sub-system is aimed at **monitoring and analysis** of the PHR data with a collection of life logs and biometric data along with the analysis based on the artificial intelligence technology with monitoring and prediction functions.

A) Lifelogging and behavioral analysis: Lifelogging is the collection of data from a camera audio and wearable devices based on the summary of major daily/weekly/monthly/yearly actions supported by ambient intelligence function. The image-based behavioral analysis comes with the development of the ambient intelligence data analysis technology and the human behavior pattern recognition technology. Information gathered, such as facial expression, life patterns, and actions, must be analyzed.

B) Biometric analysis and prediction: The prediction by biometric information comes from a physical-mental model, which combines an index to analyze physical conditions and emotional states, such as depression and fatigue of a human using a chatbot's voice conversation log, still image of the user’s expression, heartbeat signal, and so on.

The second sub-system is the **management of health records** related to the EMR data. A considerable amount of snapshot healthcare information is available, which also contains information regarding changes during a certain period. According to the health screen data and EMR data, clinical decision support functions as a guide, provides advice, and can be digitally delivered to a human.

The third sub-system is **education and training** for the treatment of the expected disease or an emerging disease. The following factors should be considered for the training.

A) Gamification: development of a game element to drive voluntary participation and motivation of senior

B) Decision model: courseware contents and decision models to provide health improvements and customized content based on a human's systematic state analysis model

C) User UX / UI: design and implementation of UX / UI according to psychological and physical characteristics of a human

D) Content development: development of customized healing contents (Smart TV, AR, and VR) to provide healthcare services to humans.

The fourth is a **conversational interface**, which functions as a service solution required by implementing a health screening scenario using customized functions for each human to provide ambient intelligence.

A) Medical knowledge DB and scenario: A limited medical knowledge database is required to express the value of chatbots because of a wide range of medical fields. Scenarios for users and active chatbot services in accordance with the health screening process are particularly necessary. Furthermore, testing whether the developed models can be used for actual services is necessary.

B) Extension of various external information: In healthcare, chatbots require a vast amount of knowledge and learning to naturally make responses. Access to the actual medical data is limited, and content to train must be acquired by building a corpus that can be implemented through open data, open service, or crawling technology.

C) Active chatbot technology: Active chatbot technology must be implemented to enable chatbots to engage users in a timely and conversational manner such they can recognize the user situation and support improved service accessibility. In particular, middle-aged people and the elderly have difficulties in using the latest technologies (e.g.,chatbots) ; therefore, chatbots can actively engage users and begin conversations. Active chatbots that specialize in smart healthcare must always monitor the health status of users and recognize certain situations based on collected information to induce conversation [12]. The answers from the user's query must be assembled and generated by natural language analysis and generate visualized responses in the same format as the chart, which is a form of visualization.

Many research topics exist in the healthcare domain(**Fig. 4**). CHA must integrate technologies and solutions together.

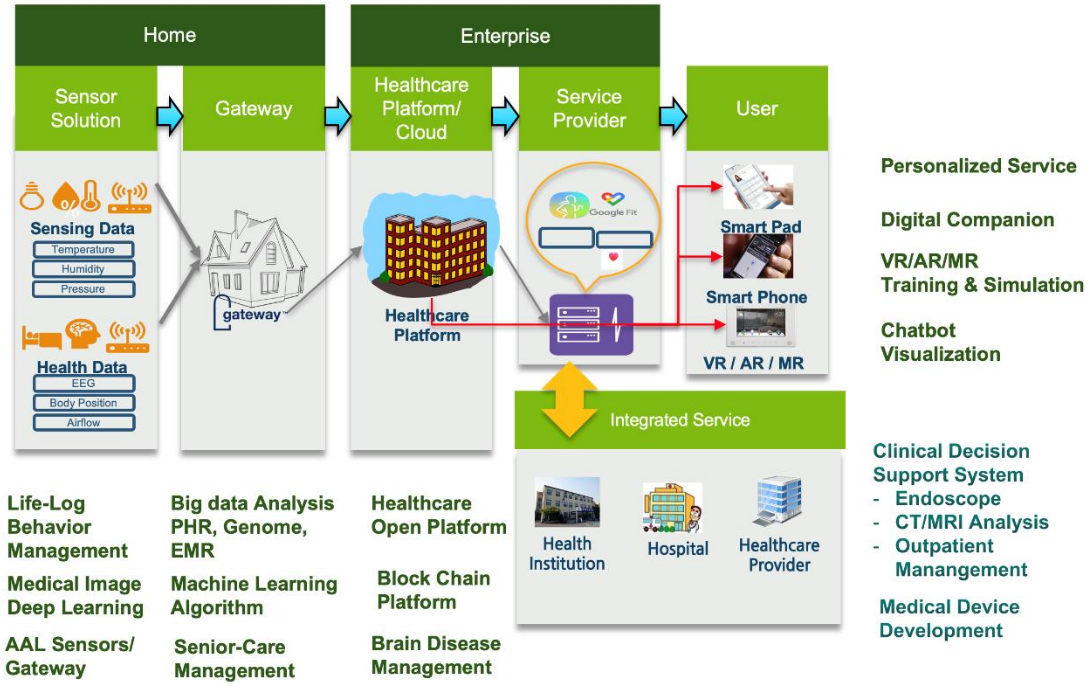

Fig. 4. Research topics in the healthcare domain

4. Experimental Implementation and Discussion

4.1 Goal of the Interactive CHA Platform

The goal of this implementation research is to develop a reference model for an interactive CHA platform. The function of the health status analysis, prediction and prevention of diseases, and promotion of health through training are achieved based on personal information (e.g., personal medical information,, life logs, biometric information, and training programs). A CHA platform supports optimal decision-making by exchanging information with individuals via a chatbot. We develop herein a platform to support integrated decision-making support services and analyze personal health information by connecting various external platform services. We support optimized decision-making through dialog by implementing a chatbot service based on the oneM2M-based ontology, which has IoT device information to support dynamic ontology based on a medical decision model. Dialog based chatbot services that support interoperability and interconnectivity among messenger platforms in a BotStore are built in an open chatbot marketplace.

The other goal of this study is to design and implement a reference model for CHA to support the function model combined with the standardized external bot service function through the connection between universal-bots and sub-bots. The following three target solutions should be realized to achieve this goal.

1) Ambient health solution platform

The PHR and lifelog, which are made by individuals and households, will be analyzed for health information, gene information and so on. The CHA model that can make an optimal decision on AAL must also be studied

2) Dynamic ontology-based decision model

The integrated development model of a chatbot and a health advisor supports the function of the advisor and the intermediator according to the change management; therefore, it must be prepared for the debate model of the decision process in the near future. The dialog model also supports the derivation of the result through the visualization technology. This will further evolve into a clinical decision support system (CDSS) in the field of healthcare information and decision support. This study implements a solution that dynamically creates a personalized dialog model and dynamically visualizes the contents of the common data model (CDM) as graphs, charts, and tables.

3) Design of an open chatbot marketplace

The app market has already become too difficult to manage because of the appearance of too many applications. The market is anticipated to be centered on bots within 5 years. The messenger platform evolves into an open bot marketplace, where the bot performs by calling a bot. This research studies and design the structure of an open solution market which combining the structure of universal-bots and sub-bots..

4.2 Scope of Interactive CHA Platform

The diversity of healthcare information and the complexity of medical technology are expanding into systems based on the cognitive technology and artificial intelligence, which require decision-making through the convergence of applications and bots created by various specialized domains.

A very limited amount of medical information is currently being provided to individuals and patients through health solutions.

The development of the ambient intelligence technology on individuals and the environment enables the integration of various personal medical information into the health platform and monitoring the health status of the current user through the integrated health advisor platform.Furthermore, it generates the treatment course to improve as suggestions and recommendations.

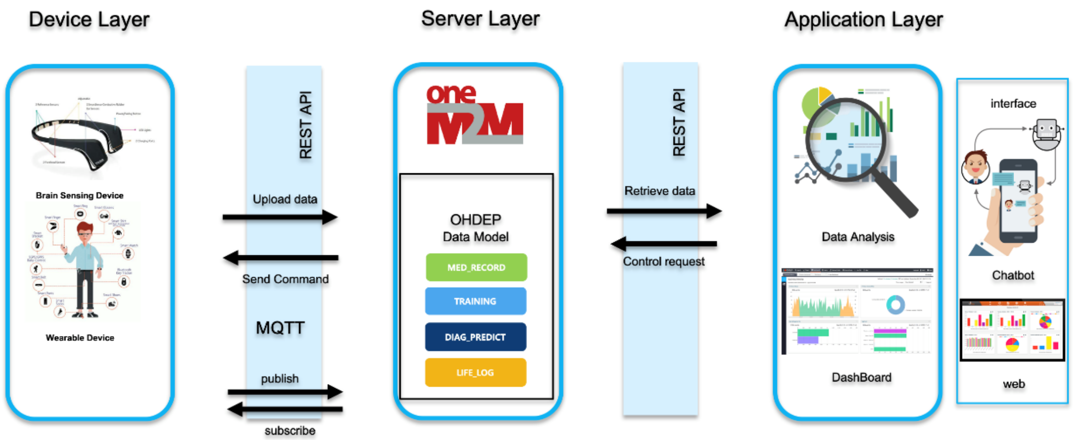

Fig. 5. Open oneM2M platform

Healthcare information is being integrated into healthcare applications based on the oneM2M platform to broaden the combination of data from various sensors. **Fig. 5** shows the standard oneM2M platform model as an open platform [13].

The design of the data model consists of the oneM2M-based ontology for each IoT device, integrating them into CDM, and configuring the functions and services of the chatbot to be mapped with the Entity and Intent of the chatbot function such that they can use the visualization technology to easily support personalized decision-making. A model that can determine the discovery result, reliability, and rankings based on the dynamic ontology, must be set up to support the interactive chatbot. Furthermore, the functions and decision process as cognitive intermediator and debater, respectively which will be future model of the cognitive advisor must be discussed. To support compatibility with different messaging platforms, the interactive interface requires an integration of bots to form an open architecture with universal-bots and sub-bots. Therefore, cognitive health and professional diagnostic solutions for healthcare platforms to create interactive healthcare decision-making solutions for the open chatbot marketplace will be integrated.

The PHR data collected from IoT devices, life logs, biometric data, and other types of data are implemented in the CDM model and combined with algorithms for analysis, prediction, and prevention based on the cognitive technology and artificial intelligence. Interactive CHA provides users with a personalized health status analyzed using the CDM model through an interactive interface and recommends education and training services for improvement and prevention according to the user circumstances.

The implementation of the API supports the link to external services (i.e., hospitals, insurance, and medical institutions) to provide information through the results of various data and analysis algorithms based on the CDM and make decisions for improvement. Interactive chatbots are designed and implemented to interoperate with external sub-bots as universal-bots.

Fig. 6 shows the implementation architecture of a CHA, in which functions and services are represented as blocks

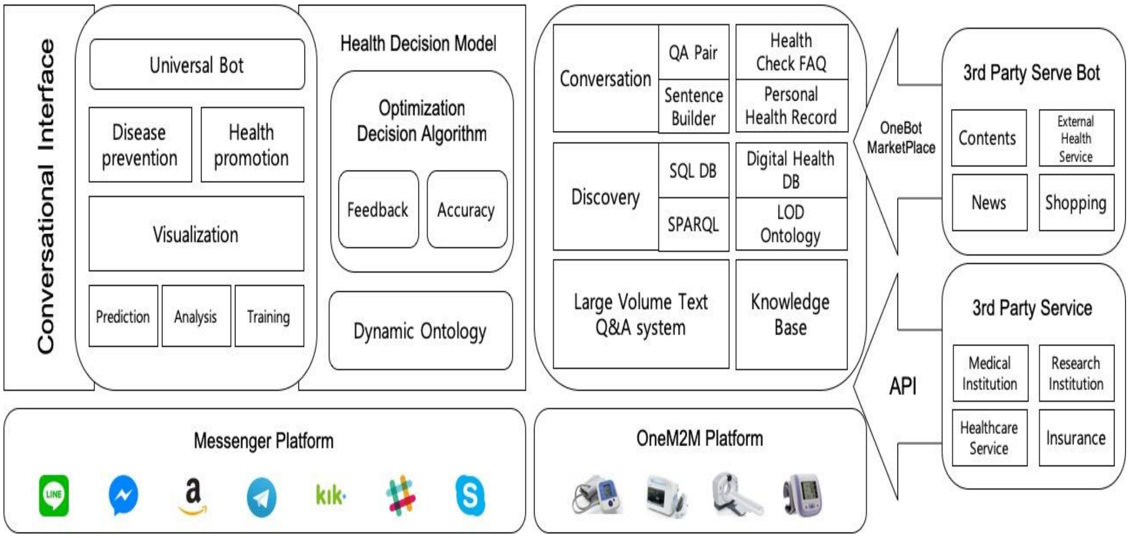

Fig. 6. Architecture of the CHA implementation

The CHA platform requests to define a new CDM focusing on personalization for patients and subjects. The data model consists of User META Data, Person META Data and Data Body. Hereinafter, "user" means the person who used the platform or the experimenter. Person means patient or subjects. The "User META data" were presented in **Fig. 7** to distinguish the user who puts data on this platform and who uses it. "User META Data" is consists of user identity(uid) and institute identity(did). "Person META data" was also presented in **Fig. 7** to provide personalized analysis services by subject and patient classification. "Person META Data" consist of person identity(pid), name, gender, birth, age, country, location, hospital and blood type. In this data model, type, date, tag and data categories that are non-metadata are defined to easily search for and sort data. Lastly "databody" is actual measurement data other than the User and Person META data. This "databody" can be accepted regardless of the type of existing data, and it can be freely formatted in json format.

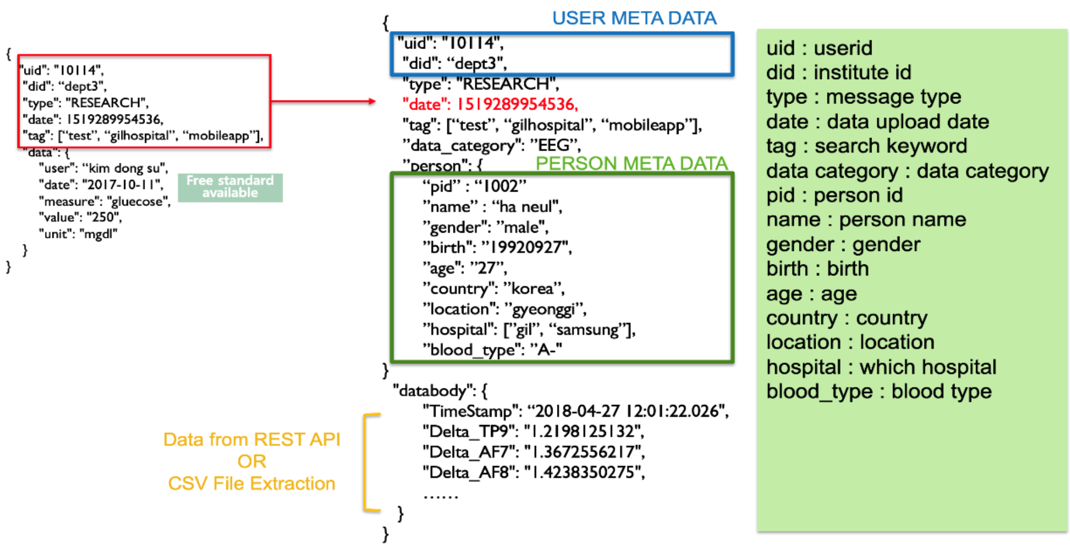

Fig. 7. Common data model of CHA

The data model of CHA has the health check data from the hospital at the part of CDM. Data such as the patient no., name, birth, age and gender are used as “Person META data”, while the others are utilized as the “databody” (**Fig. 8**). The health check data are compared with the IoT device to show the current status.

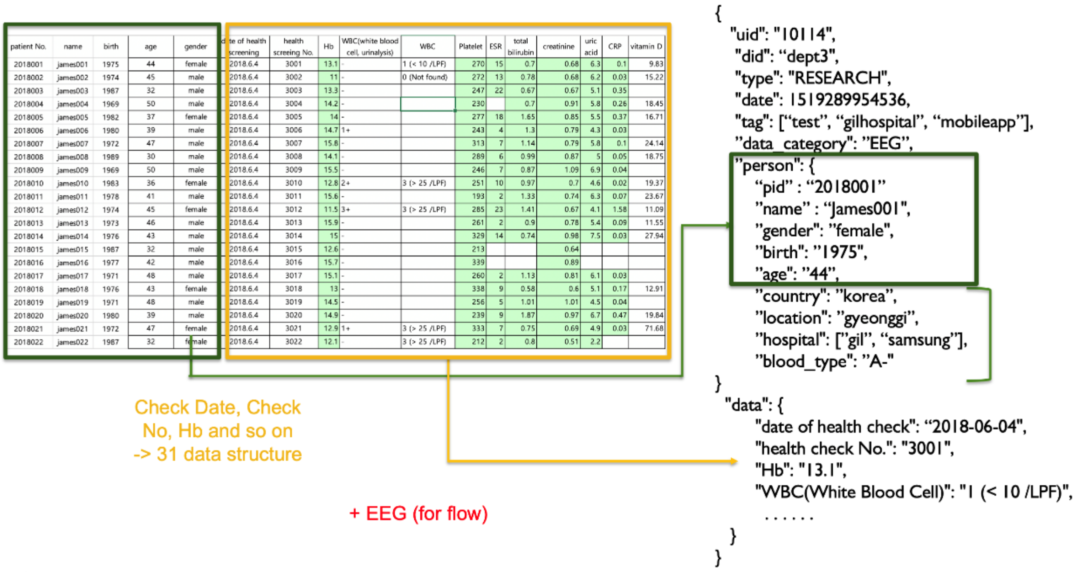

Fig. 8. Health check data in the CDM of CHA

In addition to the above, the EEG data were also experimentally implemented on the CDM of CHA. The EEG data are measured for 5 min in units of milliseconds by a MUSE device composed of three channels. The EEG data upload was, implemented with the existing measured CSV/Excel format data to the data model. After checking the data are then personalized, created in json format according to the data model, and saved in the databases. **Fig. 9** shows the method of adding data to the CHA platform implemented with Mobius.

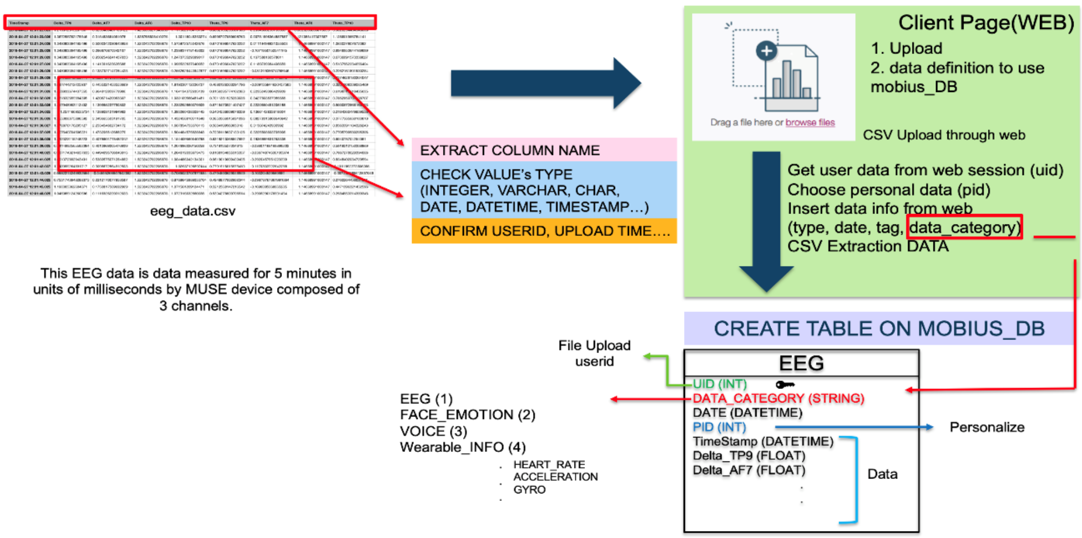

Fig. 9. The EEG data update on oneM2M Service(Mobius)

The chatbot in a CHA platform will build responses, use other bot functions, and use other bots in other platforms. When a bot calls another bot, the bot that can call other bots is called the universal-bot, while the bot that is called is a sub-bot. An architecture must be developed to accommodate this function. A new chatbot ecosystem will be built on messenger platform, and will be implemented to establish an open standard for universal-bot and sub-bot communication. Furthermore, the communication of bots will be supported between various messenger platforms. Fig. 10 describes the relation between a universal-bot and sub-bot on each messenger platform. A universal-bot can call three sub-bots on the same messenger platform, in addition to four sub-bots from other messenger platforms.

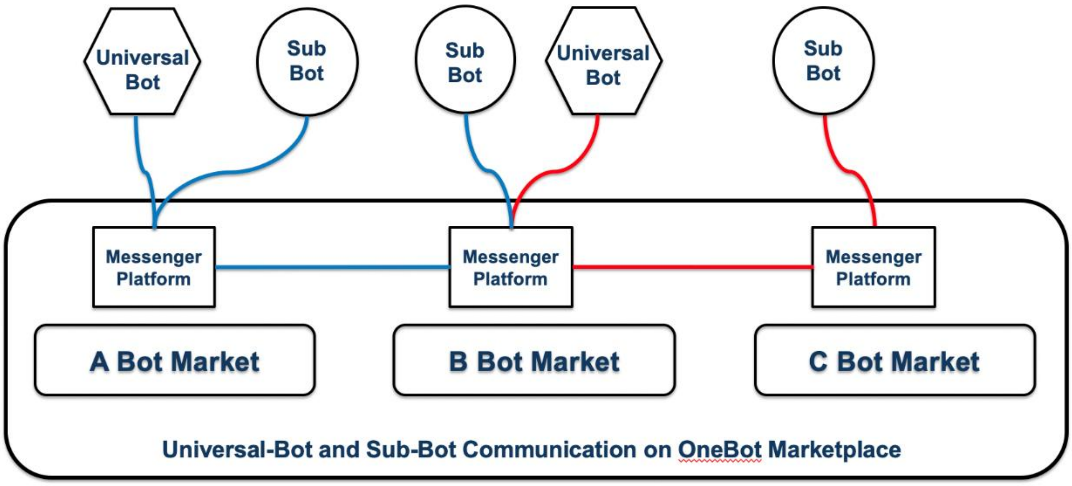

Fig. 10. Design of a universal-bot and a sub-bot

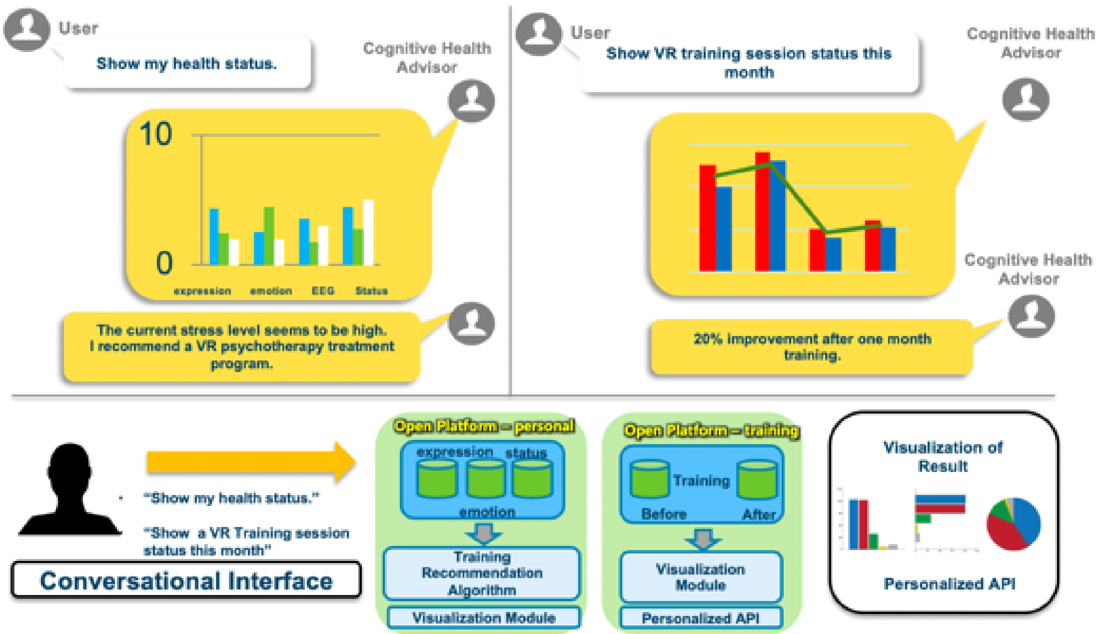

Fig. 11. CHA conversational service

The implementation for the RM of the interactive CHA supports the conversational services shown in Fig 11. The interactive CHA reports the current health status, and changes according to VR training, and provides recommendations to improve health.

5. Conclusion

This study described, an RM for a CHA with a conversational interface system, called a chatbot, The training, feedback system, and monitoring and prediction system for this CHA were also described.

Chatbots possess excellent growth potential because of their accessibility and mobility. With the development of artificial intelligence and natural language processing technologies, application services combined with chatbots are expected to appear not only in the CHA platform but also in more diverse fields.

Training and feedback systems must be focused upon, and new technologies that can prevent and improve diseases should be implemented through decision models of the delivery of courseware through a game.

In the age of aging, this research technology can be equally applied to healthcare, chronic diseases, and dementia management.

While this platform has provided such a foundation, multi-faceted research into the following issues is still required: How to extend multiple data models for behaviors, biometric and training types. how to obtain various clinical decision support bases. how to develop the best practices to train a learning management system to produce clinical results.

A basic model for the CHA platform was provided. This model will evolve into the next generation of CPS that enhances the quality of life for humans by creating improvements through training, education, and interactions with humans..

References

[1] Lee, E., "The past, present and future of cyber-physical systems: A focus on models," *Sensors*, 15(3), pp. 4837-4869, 2015. Article (CrossRef Link)

[2] Muller, H.A., "The Rise of Intelligent Cyber-Physical Systems," *Computer*, 50(12), pp. 7-9, 2017. Article (CrossRef Link)

[3] Schirner, G., et al., "The future of human-in-the-loop cyber-physical systems," *Computer*, 46(1), pp. 36-45, 2013. Article (CrossRef Link)

[4] Chen, M., et al., "SPHA: Smart personal health advisor based on deep analytics," *IEEE Communications Magazine*, 56(3), pp. 164-169, 2018. Article (CrossRef Link)

[5] Fadhil, A. and S. Gabrielli, "Addressing challenges in promoting healthy lifestyles: the al-chatbot approach," in *Proc. of the 11th EAI International Conference on Pervasive Computing Technologies for Healthcare. ACM*, pp. 261-265, 2017. Article (CrossRef Link)

[6] Zhang, Y., et al., "Health-CPS: Healthcare Cyber-Physical System Assisted by Cloud and Big Data," *IEEE Systems Journal*, 11(1), pp. 88-95, 2017. Article (CrossRef Link)

[7] Huang, C., et al., “FSSR: Fine-Grained EHRs Sharing via Similarity-Based Recommendation in Cloud-Assisted eHealthcare System,” in *Proc. of the 11th ACM on Asia Conference on Computer and Communications Security - ASIA CCS '16*, pp. 95-106, 2016. Article (CrossRef Link)

[8] Ahlskog, J.E., et al., “Physical exercise as a preventive or disease-modifying treatment of dementia and brain aging,” *Mayo Clinic Proceedings. Elsevier*, vol. 86, no. 9, pp. 876-884, 2011. Article (CrossRef Link)

[9] Bryck, R.L. and P.A. Fisher, “Training the brain: practical applications of neural plasticity from the intersection of cognitive neuroscience, developmental psychology, and prevention science,” *American Psychologist*, 67(2), pp. 87-100, 2012. Article (CrossRef Link)

[10] Lee, K. and N. Ha, “AI platform to accelerate API economy and ecosystem,” in *Proc. of Information Networking (ICOIN), 2018 International Conference on. IEEE*, 2018. Article (CrossRef Link)

[11] dos Santos Mendes, F.A., et al., “Motor learning, retention and transfer after virtual-reality-based training in Parkinson's disease-effect of motor and cognitive demands of games: a longitudinal, controlled clinical study,” *Physiotherapy*, 98(3), pp. 217-223, 2012. Article (CrossRef Link)

[12] Oh, K.-J., et al., “A chatbot for psychiatric counseling in mental healthcare service based on emotional dialogue analysis and sentence generation.,” in *Proc. of Mobile Data Management (MDM), 2017 18th IEEE International Conference on. IEEE*, 2017. Article (CrossRef Link)

[13] Ahn, I.Y., et al., “Development of an oneM2M-compliant IoT Platform for Wearable Data Collection,” *KSII Transactions on Internet & Information Systems*, 13(1), pp. 1-15, 2019. Article (CrossRef Link)

KangYoon Lee received the B.S. and M.S. degrees from Yonsei University, Seoul, Korea, in 1986 and 1996, respectively, and the Ph.D. degree from the department of IT Policy Management, Soongsil University, Seoul, Korea, in 2010. He is currently a Professor at the Department of Computer Engineering, Gachon University, Seongnam-Si, Korea. From 1991 to 2016, he was in IBM Korea, and he was a Lab director of Korea Lab to lead Ubiquitous, IoT and Watson Solution Research. His research interests include healthcare, IoT open platform, artificial intelligence and ambient intelligence.