ISSN 1330-3651 (Print), ISSN 1848-6339 (Online) https://doi.org/10.17559/TV-20221102120953
Original scientific paper

A Design and Development Approach for Mild Cognitive Impairment Screening

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Abstract: Mild cognitive impairment (MCI) is a precursor to dementia and its early diagnosis in patients is important for appropriate intervention. In this study, an IoT (Internet of Things) device is developed that easily and conveniently screens for MCI, provides emotional comfort for elderly patients, and has a friendly design. It enables us to screen MCI by efficiently identifying the user's condition in non-face-to-face manner. The experimental result and survey of this study show that this device will establish itself as a distinguished companion doll that can be widely shared with the elderly.

Keywords: companion doll; dementia; internet of things device; mild cognitive impairment; senior behaviour; virtual mild cognitive impairment screening

1 INTRODUCTION

Modern innovations are extending the average human life expectancy through a highly developed medical and pharmaceutical industry. Data reveals that this phenomenon is, predictably, more pronounced in developed countries than in developing countries. Additionally, an aging population has a large and widespread effect on economic growth, productivity, intergenerational inequality, and the sustainability of public finances [1].

As the average age of the population increases, the number of patients diagnosed with dementia also increases. As of 2019 in Korea, it is estimated that 864,805 people aged 65 and over suffer from dementia, representing 11.2% of that demographic. The number of patients diagnosed with dementia continues to increase and is expected to exceed 1 million by 2024, 2 million by 2039, and 3 million by 2050. Dementia is estimated to have an economic impact of approximately 16.7 thousand USD per person, where the cost to managing the health and well-being for patients in Korea over 65 who are diagnosed with dementia is estimated at 12.5 million USD [2].

Despite concerted efforts by the government, awareness of dementia among the elderly in Korea is still at a remarkably low level; a survey of 8000 people over 65 years of age showed that the awareness of dementia is as low as 60%. In particular, five questions are asked on information pertaining to dementia considered to be common sense (1% of elderly people can get dementia; all dementia patients can be registered as disabled in Korea), where the correct answer rate is less than 50% [3]. This indicates that there are numerous widespread misconceptions about dementia among Koreans, meaning that early detection and treatment are significantly less likely.

However, in approximately 10% to 15% of cases, dementia is fully reversible, and in the remaining cases, its progress can be delayed or symptoms can be significantly improved if detected early and treated appropriately. Therefore, it is important to detect mild cognitive impairment (MCI), a precursor to dementia, in the early stages. Therefore, the primary objective of this study is to development of an internet of things (IoT) device that is able to effectively screen for MCI and aid in preventing or mitigating the effects of severe dementia at an early stage. Various services and products for the prevention and management of dementia have been introduced [4-9]; however, there still remain numerous limitations in the screening for MCI, preventing dementia, and delivering the emotional care and comfort the elderly deserve. Therefore, the proposed device adopts friendly designs such as that of dogs and chicks, which are common animals in the countryside, and enables efficient interaction through the use of positive phrases that cultivate an emotional bond. The proposed device has the potential to replace time consuming and logistically complicated in-person visits with more convenient and comfortable in-home MCI screening, helps to effectively and efficiently detect the early symptoms of dementia with simple interactions, and automatically transmits precise diagnosis to medical institutions such as hospitals and public health centers.

2 RELATED STUDIES

2.1 Mild Cognitive Impairment

2.1.1 Definition

MCI is a precursor to dementia, and is defined as "a state in which cognitive decline is more severe than expected, but not enough to be called dementia" [10]. From previous studies, we know that 5% to 10% of the people age 65 and above with MCI progress to dementia, so MCI can be classified as a risk factor for dementia. We also know that 25% to 30% of patients diagnosed with MCI recover to normal. Therefore, it is important to receive regular checkups and to receive early treatment when indicated [11].

2.1.2 MCI Screening Methods

The currently available screening tools for MCI include the Mini-Mental Status Examination (MMSE), Hasegawa Dementia Scale (HDS), 7-Minute Screening (7MS), and Korean Cognition, which include the K-Cognitive Impairment Screening (K-CIST) and the Korean Version of the Hasegawa Dementia Scale Revised (K-HDS). Various types of dementia screening tools have been developed through numerous studies prior to now and have each been modified and supplemented; however, each has definite limitations and heavily depends on the expert's skills and efforts [12].

2.2 IoT Technology

The Internet of Things (IoT), one of the core concepts of the 4th Industrial Revolution, refers to an information technology that enables real-world objects and virtual worlds to constantly and reliably communicate with each other through a network. The "things" in the IoT, includes not only end-devices within the wired and wireless networks, but also possibly includes humans, vehicles, infrastructure, various other electronic equipment, and the natural environment. In this study, in the spirit of IoT, the development of machine-to-machine technology (M2M) has been extended, which enables intelligent people-to-object and object-to-object communication using a mobile communication network, to interact with all the information in the real and virtual world [13-17].

2.3 Existing Technologies and Product Groups Related to Dementia

The interest in and development of preventive medicine is rapidly progressing in countries with high income levels and large elderly populations, with in vitro diagnostic technologies being developing for numerous fields [18].

Besides, the need for and marketability of service robots is expected to expand owing to the increase in demand, changes in lifestyle, and the increasing aging population. The demand for robots for the elderly is growing rapidly in Europe, and robots for life and mobility assistance and dementia are currently in trial operation. In particular, it is estimated that a total of 32500 units of these robots has been sold between 2015 and 2018, as the elderly will become a major market [19]. The elderly care robot market is growing rapidly, particularly in Europe and Japan, where the elderly population is rapidly increasing, and the robot industry is estimated to be worth $4 billion by 2035 [20]. Additionally, as the market for psychotherapeutic pet robots grows, the price of robots will decrease, enabling them to become ubiquitous appliances used at home as well as in nursing homes [21].

With the recent advancements in technology, various services and products are being introduced, which are specialized in the prevention and management of dementia for the elderly [4-9]; however, there remain a number of aspects to be improved, such as high prices, complicated usage methods, services limited to medical or technological development, and limited functions akin to toys (see Fig. 1).

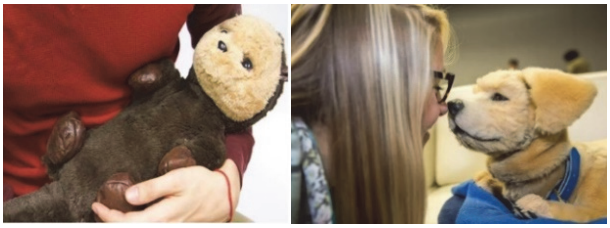

Figure 1 Pet robots for psychotherapy [11, 13]

3 DESIGN DETAILS OF THE PROPOSED DEVICE

3.1 Requirements for Screening for MCI

A noble set of requirements is proposed for screening for MCI to improve the simplicity, reliability, and user comfort. The details are defined in Tab. 1.

Table 1 Constraints and requirements for screening for MCI

Definition	Description
Improvement or maintenance of performance	Equal or better MCI screening performance
Quick and easy functionalities	Screening for MCI should be easier and more convenient than with the conventional methods
Friendly appearance	Users should be able to interact with the system in a positive manner.

3.2 System Overview

The overview of the proposed system, which meets the requirements in Table 1, is presented in Fig. 2. The proposed device is installed in the home, and is located next to the user, like a pet or companion animal. It is designed so that experts can regularly manage MCI and dementia through virtual examinations via the user's recorded responses and through daily conversations.

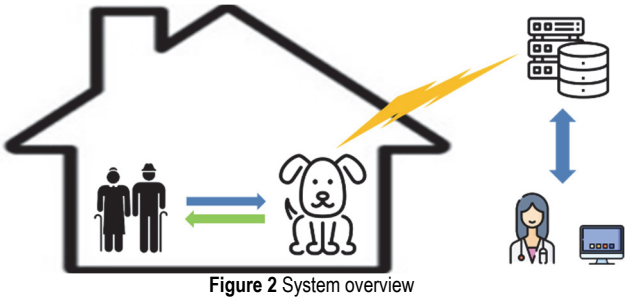

Figure 2 System overview

3.3 Appearance

The proposed device is intended to take the form of animals, such as dogs and cats (see Fig. 3), which are common animals in the community and countryside, providing a positive image rather than those of the formal and unfamiliar dementia test devices [22]. As a result, users are provided with psychological and emotional comfort and stability, and it is predicted that it will be possible to screen for MCI in the comfort of the home in a comfortable and effective manner.

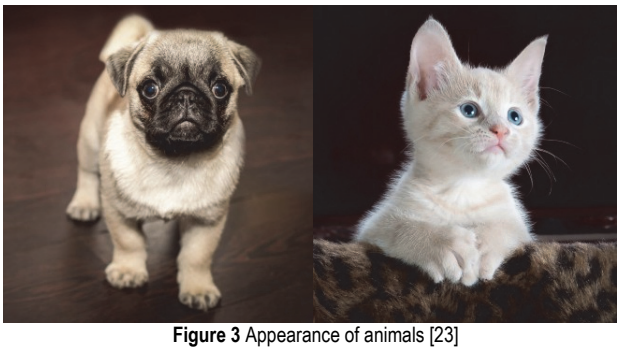

Figure 3 Appearance of animals [23]

3.4 Hardware Design and Implementation

The proposed system consists of four main parts: the main processing unit, power and audio amplifier board, audio input-output board, and peripheral devices such as a microphone, a button, a volume controller, and an LED screen.

The prototype device is designed utilizing commercial IoT board, a Raspberry Pi 3 B+, as the main processing

units. A separate power board is designed to provide stable power for the rechargeable lithium-ion battery pack. Additionally, by utilizing I^2C communication, the power boost and gauge circuits are added to determine the battery status. The USB hub and USB audio circuits are designed to expand the USB port and to add audio input/output devices. Circuits for the microphone (with a preamplifier for the recorded signal), 4 buttons, power operation, volume control, and LED screen are also added. The overall circuit assembly is shown in Fig. 4.

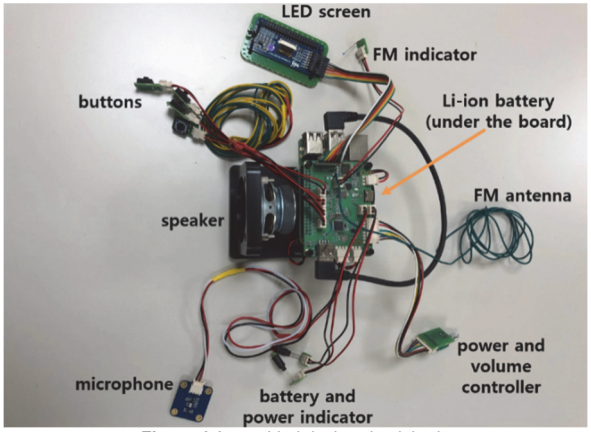

Figure 4 Assembled device circuit body

3.5 Software Implementation

Python 3.8.5 is utilized to implement the system. Each user is given a unique ID and the unique number of responses to the MCI questions. As shown in Fig. 5, the system checks events in real-time, calls the designated module for the event, and executes it autonomously. A detailed description of events is provided in Tab. 2.

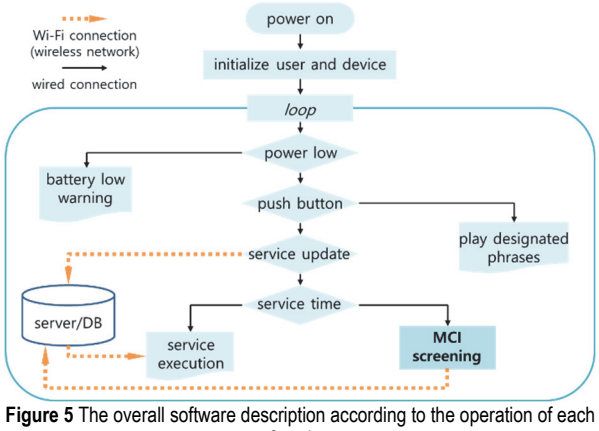

Figure 5 The overall software description according to the operation of each function

Table 2 Detailed software events

1) Power Low - When the battery is below a specified level, a battery-low warning is issued, such as playing an audio notification. 2) Push Button - When the user presses the button, various phrases such as greetings and stretching guidance are played according to the user's settings. 3) Service Update - The device accesses the server and downloads the user's request 4) Service Time - At a designated time, the device performs the MCI screening (playing the MCI question and recording the user's responses). In addition, the device performs user-defined services, such as wake-up calls, meditation alarms, body stretching and relaxing music, according to preset settings for each user

3.6 Server, Database and Webpage

The server, database, and webpage necessary for the expert to examine the user's voice responses in a virtual manner are also developed in this study; Where Apache 2.4.46, MySQL 15.1, and PHP 8.0.0 are used, respectively.

Figure 6 Non-face-to-face MCI screening webpage

The user's voice recordings are stored in the database through the Internet. When experts log in to the webpage, they are able to listen to the recordings and screen for MCI, similar to a conventional face-to-face MCI screening interview, as described in Fig. 6.

On the website, by clicking the voice icon (a), experts can listen to the user's voice recordings, and are then able to check the score for each MCI question (b). A final determination is then made in (c), such as "no abnormality", "continuous observation required", 'notify the guardian', 'link to a medical staff, or "call emergency service". Additional opinions or comments can be found below (d). The results can be reported to all stakeholders, including the user (the testee), family and community members, medical/emergency staff, or to a group specializing in dementia and MCI, with separated permission.

3.7 Application of MCI Screening Methods

After analyzing the various screening tools in Section 2, it is determined that the available MMSE-oriented methods include necessary face-to-face questions, where some are impossible for virtual environments. Additionally, these questions are not suitable for those who are disabled or illiterate.

Table 3 Comparison with original and modified K-HDS

Original K-HDS	Modified K-HDS
What is this place? Is it a hospital or office?	What is this place for?
Say these numbers backward. 1) 6, 8, 2; 2) 3, 5, 2, 9.	Say these numbers backward: 6, 8, 2.

Therefore, the K-HDS, which has relatively few restrictions compared to other tests, is adopted in this study as the main methodology for screening for MCI. Some questions are modified according to the characteristics of the device without any performance degradation, where Tab. 3 shows the differences compared to the original K-HDS.

4 IMPLEMENTATION OF THE PROPOSED DEVICE

The completed appearance of the device is shown in Fig. 7. The nest-shaped base supports wireless charging. The service and operation workflow of the device are presented in Fig. 8, followed by a detailed description in Tab. 4.

Figure 7 Appearance of the complete device

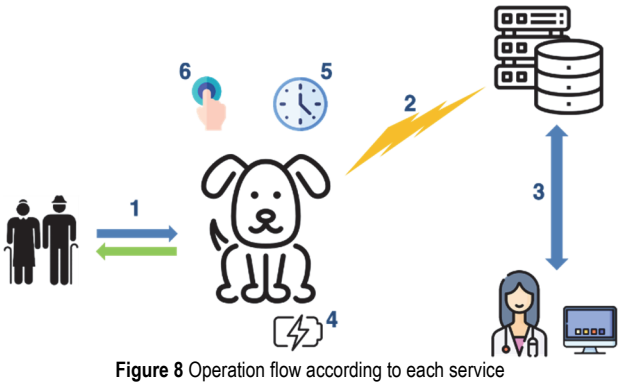

Figure 8 Operation flow according to each service

Table 4 Detailed service

1) Activities in screening for MCI - Using the modified K-HDS, where the questions for screening for MCI are asked and the user's response is recorded in the device through the microphone. 2) Delivery via network - The user responses are transmitted to the pre-defined server with the database through a wireless network 3) Expert analysis - The user's responses are analyzed by the expert in a virtual manner 4) Notification of power shortage - When the battery drops below a specified level, an audio notification is played. 5) Customized alarm and playback function - Various customized voice alarm functions (wake up, bedtime, medication, etc.) are performed according to the pre-defined user information 6) Push Button Service - Interaction between the user and the device using friendly and comfortable phrases such as greetings

5 EXPERIMENTAL RESULTS WITH SURVEY

A survey consisting of 34 questions is conducted on 441 respondents in Korea, who are evenly distributed in age, gender, residential area, occupation, and educational background. The survey is conducted as a blind trial in which the respondents' personal information is unknown. The responses are received online using a mobile or networked device over 4 months, from February 1 to May 31, 2021.

The results of the survey show that 80.0% of the respondents are aware of dementia (64.4% knew, 15.6% knew well), but 51.1% do not know about MCI (26.7% did not know, 24.4% do not know at all). The severity and fear of dementia have been highlighted through various media, but interest and awareness of MCI has proved to be lacking.

57.8% of the respondents believe that dementia is difficult to cure, but not impossible. Additionally, responses for the most effective preventative measures for dementia, such as active brain use (31.1%), early care and treatment (26.7%), maintaining appropriate interpersonal and social activities (24.4%), and regular health checkups (17.8%) are relatively evenly distributed.

75.0% of the respondents are not aware that there is an IoT companion doll for the elderly, but 90.9% believe that an IoT companion doll for the elderly is necessary in an aging society, and their stated intention to purchase one is very high at 80.0%.

With regard to the respondents' preferences for the appearance of the device, dogs account for 73.3%, and cats account for 8.9%. Interestingly, all of the respondents prefer the appearance of animals with an endearing and warm image that can be easily found around them. 57.8% of respondents prefer fur and 28.9% prefer cloth, materials that are comfortable and huggable.

The preferred services include a customized medical questions (35.6%), medication notification function (20.0%), and music playback function (15.6%). Considering the survey results, it is implied that respondents expect the companion doll to be a close and comfortable friend.

Each of the questions and designated answers are presented in Fig. 9.

Figure 9 Questions and answers of the survey

The prototype device is tested by experts who have experience working in facilities related to elderly care to check if the device meets the requirements from Tab. 1. First, the device is able to record and transmit users' response accurately, which results in precise and reliable MCI screening results. Second, the proposed device do not require a scheduled time and place for the experts to visit in person, and enabled patients to answer questions comfortably and quickly. Third, by adopting the most preferred appearance according to the survey, users are able to interact with the device in a friendly and comfortable manner.

6 CONCLUSION

Numerous IoT devices related to the care for the elderly are currently being developed. However, these devices offer overly complicated technologies with excessive costs, making them difficult for the elderly to use. Therefore, in this study, an IoT device that can be more easily used by the elderly has been developed. A short and simple question-and-answer test capable of effectively screening for MCI is added. Additionally, by implementing two-way communication with the users and the device, efficient emotional management and comfort are achieved.

As a result, symptoms of MCI or early dementia can be quickly and easily detected for each individual. Easy usage, user-friendly design, and press-and-smile (push button) services relieve the difficulties of using IoT devices and provide emotional pleasure and comfort. The proposed device has the potential to establish itself as a distinguished companion doll that can be widely shared with the elderly in the local community.

In the future, it will be necessary to add advanced speech recognition technology that automatically analyzes the user's response and screens for MCI. Moreover, by adding additional sensors such as motion, temperature, gas, humidity, and dust sensors, the information about the user's environment can be gathered and analyzed, which enables a rapid response to various emergency situations leading to a more comfortable environment for the user.

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