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Developing a Puzzle using the Mixed Reality Technology for the Elderly with Mild Cognitive Impairment

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***Abstract*: Background/Objectives: As the number of elderly people around the world increases, urgent need to understand and find ways to cope with their problems arises. In particular, older people with mild cognitive impairment need a way to prevent or reduce it because of the high probability of dementia. Methods/Statistical analysis: The puzzle program is well-suited as a cognitive learning tool that is interesting and motivating to the user. Several studies have shown that puzzle activities have a positive effect on mental-health promotion and cognitive-function improvement in the elderly. There is growing empirical evidence that virtual reality (VR), augmented reality (AR) and mixed reality (MR) are valuable for education, training, entertainment and medical rehabilitation because of their capacity to represent real-life events and situations. In this study, an attempt was made to combine the puzzle program with the mixing technique to maximize brain activity in the elderly.**

Findings: Several studies have demonstrated the cognitive enhancement effect of the puzzle and the brain activation effect of the 3D image. Based on this, the responses of the elderly in terms of usability, ease of learning, and interest when using MR mixed puzzles were investigated. It received higher score than the conventional 2D puzzle in terms of ease of learning and interest, and it was rated higher than puzzles made only with VR technology in terms of ease of use. Overall, the combination of puzzles and the MR technology for use as a cognitive function improvement tool for the elderly seems to have a positive effect.

Improvements/Applications: If the puzzle varies in shape and difficulty, the boredom of running the same puzzle multiple times can be reduced for users. If this kind of puzzle is operated in the elderly welfare field, elderly-related institutions, hospitals or the family, the elderly can use it easily and voluntarily, thereby preventing mild cognitive impairment.

***Index Terms*: HoloLens, Puzzle game, Mixed reality, Augmented reality, Cognitive impairment.**

I. INTRODUCTION

It is predicted that the 21st century will be the era of population aging globally. Korea's pace of population aging is the highest in the world. In 2026, percentage of the population who are elderly is expected to reach 20.8% and then Korea is predicted to become the oldest society. There is, therefore, an urgent need to understand and find ways to cope with the problems that the elderly which depends highly on physical, mental and economic factors. A decline in cognitive ability causes difficulties in communication and social relationships formations, which adds to isolation or depression. Mild cognitive impairment is a transient state of cognitive change between normal aging and dementia, where a range of memory impairments or impairment of some cognitive functions are seen with age. It is reported that approximately 1% to 2% of normal elderly people contract dementia every year, whereas 10% to 15 % of elderly people who have mild cognitive impairment contract dementia every year. Therefore, it is important to prevent or reduce the progress of dementia through brain active management in the mild cognitive impairment phase. To date, cognitive therapy, recall therapy, music therapy, and art therapy have been performed for the normal elderly or elderly with dementia to reduce their cognitive decline, and the effects have been proven through systematic clinical trials. However, these treatments require the assistance of a person. They are difficult for the elderly to carry out by themselves without an assistant and there is the limit of continuous execution.

The puzzle program is highly suitable as a cognitive ability learning tool that can stimulate the user's physical manipulation activities and thinking activities simultaneously and that can make learners more interested and motivated. In addition, several studies have shown that puzzle activities not only contribute to the thinking and mental development of adolescents, but also positively affect mental health promotion and cognitive function improvement of the elderly. Puzzles have the advantage of being easy-to-use tools regardless of the physical changes caused by aging and the level of education, and puzzles can be continuously used in everyday life, making them highly applicable to elderly people.

Virtual reality (VR), augmented reality (AR), and mixed reality (MR) are implemented based on computer graphics (CG), and each technique can be distinguished according to the ratio of the CG image in the image spreading to the user's view [1]. Generally, if content is output such that the view of the user is wholly covered by only the CG, providing an immersive feeling and a sense of the field, the technique can be classified as VR. If the reality where the user is located and a part of the CG image are synthesized and output, the technique can be classified as AR or MR. Empirical evidence that VR/AR/MR is

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valuable for education, training, entertainment, and medical rehabilitation is increasing because of its ability to represent real events and situations. In recent years, these technologies have gradually been recognized as effective and valid support for therapy and educational treatment for people with cognitive disabilities. In one study [2], subject, with an electroencephalogram sensor attached, was shown 2D and 3D images sequentially and brain wave measurements were conducted. Measurements showed significant increases in brain activity when watching 3D videos compared to that when watching 2D videos.

This paper describes the development of a puzzle program for the prevention of dementia in elderly with mild cognitive impairment. This puzzle program was developed as MR game based on Microsoft's HoloLens to enhance the user's brain activity and add fun. The user can see the moving object in the 3D form through HoloLens while simultaneously adjusting the puzzle with the hand, and this puzzle program also has the function of hinting at the position of the piece when the puzzle piece cannot be aligned. This puzzle program is expected to be a good tool to prevent cognitive disorder in the elderly because it can improve cognitive abilities through puzzle and improve the brain activity through a 3D image.

II. RELATED WORKS

Many studies have demonstrated the usefulness of puzzles for educational purposes and cognitive ability improvement. While most studies show that puzzle activities have positive effects on thinking and mental development in children and adolescents, other research [3,4] explains the positive effects of puzzle diag-nostic activities on cognitive function and depression in the elderly. In these studies, the effects are verified by the pre-post-testing of experimental and comparative groups. Because the results were good, puzzle activities have been used as programs to improve cognitive and emotional functions of elderly with mild cognitive impairment in community dementia centers and long - term care institutions.

The development of mobile technology enabled the emergence of various smart devices and led to the popularization of VR, AR and MR services. With the announcement of HoloLens by Microsoft in 2016, hybrid-reality technology, which is a special form of augmented reality in which reality and virtual images interact, has attracted attention, and some of the technologies have been partly applied in automobile design, aerospace, and education areas. Gartner, in "Top 10 Strategic Technology Trends for 2018," predicts that MR technology will be integrated with multiple body sensory channels and surroundings environmental sensors, and it will evolve into future interfaces. HoloLens derives its own computing power by embedding holographic processor unit (HPU), which receives external information from one depth camera attached to the front and four environment recognition cameras, and can perform approximately one trillion operations per second. Many applications use the HoloLens, and research continues [5-8]. There are studies on the use of HoloLens in the medical field [9,10]. In particular, research [11] developed a program to practice everyday life patterns as MR technology for people with cognitive disabilities. For example, using such programs, one can practice separating trash and dumping it, and moving surrounding objects into place. There are also cases where the puzzle program is made using VR technology. However, VR technology may not be suitable for the elderly, because it operates completely separated from reality. Research [0] has reported the results of studies on the effects of 2D images and 3D images on brain activity. The results of the study showed that 3D images can further increase brain activity. Based on the above study's findings, in present study, an MR technology that uses HoloLens was developed so that 3D images can be added to a puzzle program that has cognitive enhancing effect.

III. MATERIALS AND METHODS

A. Materials of Puzzle Program

To develop an MR-based puzzle program, a holographic lens, and a real puzzle, a 3D asset model, Unity, Visual Studio 2017, and Vuforia API are used. HoloLens is an MR-based wearable device developed by Microsoft. Unlike VR technology that shows a full virtual space, or unlike AR technology that is overlaid on the real world, HoloLens complements the real world by providing an MR function that enables users to print 3D images in the real world and manipulate them. In addition, because it has a built-in processor, it does not need to be connected to a smartphone or a computer; therefore, it can be moved around freely and can recognize a user's voice commands and the gestures of a user's fingers, so it is easy to control. The structure of the HoloLens is shown in Fig. 1, and the specifications are shown in Table 1.

Fig. 1 HoloLens of Microsoft

Table 1: HoloLens specifications

Part	Specification
OS	Windows 10
CPU	Intel 32 bit architecture
Storage	64 GB
RAM	2 GB
Holographic Resolution	2.3M total light points

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Cameras	2-mega-pixel photo / HD video camera, depth camera, four gray-scale environment understanding cameras
Audio	Built-in speakers, audio 3.5mm jack
User Input	Gaze, voice, gesture
Weight	579g

Fig. 2 shows the overall scenario for the puzzle program using the HoloLens developed. The user wears the HoloLens and then executes the application. HoloLens tracks the eyes of users through the Gaze function. If users look at a puzzle piece for more than a certain amount of time, the application creates a 3D puzzle in the space and moves it to a position where it can fit the puzzle, providing hints for users to fit the puzzle. When the user looks at the completed puzzle after all the puzzles are aligned, the HoloLens recognizes it and provides moving 3D animation. The 3D asset model used in this puzzle program is shown in Fig 3. The dog, a 3D asset model, has various movements, such as walking, running, and wagging its tail [12]. The panda has such moves as walking, rolling, and eating bamboo [13].

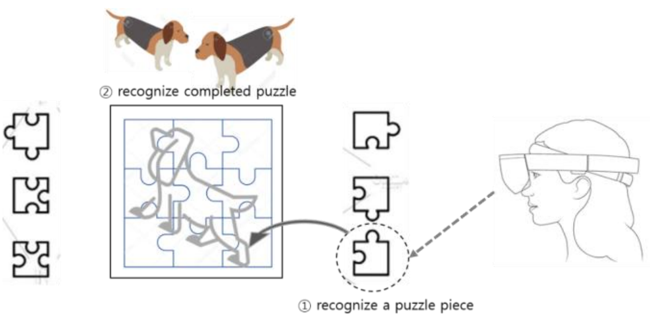

Fig. 2 Conceptual model for this puzzle program

Fig. 3 3D asset model (dog and panda) used in this puzzle program

The puzzle program consists of seven pieces of the dog puzzle and nine pieces of the panda puzzle. To differentiate the difficulty by puzzle, the dog puzzle pieces are made in different-shapes, and the panda puzzle pieces are made in the same-shape. Fig. 4 shows a real-world puzzle.

Fig. 4 Real-world puzzles with dog and panda images

B. Method of Puzzle Program

The interface of the HoloLens consists of Gaze, Gesture, and Voice. Gaze recognizes the user's gaze when the user gazes at an object in any direction and automatically switches the screen or selects an object. The HoloLens also provides RayCast, a kind of cursor that allows s user to conveniently recognize the point which they are staring. RayCast, intuitively recognizes the place (or place where the user should look) just as a mouse cursor on a computer screen does. In this puzzle program, when a user does not know the position of a puzzle piece and is gazing at it, it is recognized, and a hint event is called. To add the gaze input cursor from HoloToolkit, the gaze manager script calculates the RayCast hit position and the cursor in the scene is placed. The command input can be performed through voice by calling Cortona (say "Hey Cortona"); Cortona can be called the artificial intelligence lens of the HoloLens. Users can perform various operations through Cortona without entering the menu directly and changing the settings. If one wants to see the whole picture of the puzzle, one can say "show" and this event will be called.

This puzzle program uses the Vuforia engine. The Vuforia engine can be installed during the Unity installation phase, and the Vuforia functions can be available directly from Unity. Vuforia has the ability to recognize and track a variety of images and objects in real life for the development of AR and MR applications, and to create virtual images. With the Vuforia engine, flat image recognition, multiple image recognition, encrypted marker recognition, and character recognition are possible. This puzzle program uses the flat image recognition function. Image Targets (puzzle pieces) represent images that the Vuforia Engine can detect and track. Image Targets do not need special black and white regions or codes to be recognized.

The engine detects and tracks features that are naturally found in the image by comparing these natural features against a known target resource database. Once the Image Target is detected, the Vuforia Engine tracks the image as long as it is at least partially in the camera's field of view. Model Targets enable applications built using Vuforia Engine to recognize and track particular objects in the real world based on the shape of the object. To make a model target for a particular object,

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it is necessary to access the 3D model data of the object, such as a 3D computer-aided design (CAD) model or a 3D scan of an object obtained from a third party source or application. To create Model Targets in this puzzle program, the models for each puzzle piece and the model for the whole puzzle image are stored in the database.

Fig. 5 shows the C# source code written to use the display function for the MR when searching individual puzzle pieces through HoloLens.

```
protected virtual void OnTrackingFound()
{
   var rendererComponents =
GetComponentsInChildren<Renderer>(true);
   var colliderComponents =
GetComponentsInChildren<Collider>(true);
   var canvasComponents =
GetComponentsInChildren<Canvas>(true);
// Enable rendering:
   foreach (var component in
rendererComponents)component.enabled = true;
// Enable colliders:
   foreach (var component in
colliderComponents)component.enabled = true;
// Enable canvas':
   foreach (var component in
canvasComponents)component.enabled = true;
```

Fig. 1 C# source code for displaying the MR images

IV. RESULTS AND DISCUSSION

When the elderly wearing a HoloLens watch a puzzle piece that does not match, a hint is shown by converting the position of the puzzle piece into a 3D image (Fig. 6). After the elderly complete the puzzle, the HoloLens recognizes the completed puzzle and the image of the completed puzzle (puppy, panda) is displayed in 3D animation as shown in Fig. 7.

Fig. 6 Scene showing 3D animation when puzzle is completed

Fig. 2 Scene showing the location of the puzzle piece

This puzzle program was tested by 21 elderly people in an elderly welfare center. For the elderly to grow used to the HoloLens before the experiment, how to wear a device, the virtual-image description, the speech recognition method, and how to take a test were explained. The elderly subjects were able to adapt to VR/AR/MR by watching several sample images. For the two types of puzzle developed, the elderly solved only the puzzle for one kind without wearing the HoloLens and the puzzle for the other type wearing the HoloLens. In addition, the elderly solved one of the games that were open as VR puzzles.The elderly subjects' responses in terms of usability, ease of use, and satisfaction were collected. The results are shown in Table 2.

Table 2: Comparison of usability, ease of use, and satisfaction for each puzzle

	Questions	Puzzle	VR Puzzle	Puzzle + MR (this paper)
	Cognitive-function effect	●	●	●
	3D image effect	x	●	●
Usefulness	It helps me be more effective.	9 (13%)	2 (10%)	10 (48%)
	It is useful.	8 (38%)	2 (10%)	11 (52%)
Ease of use	It is easy to use.	14 (67%)	1 (5%)	6 (29%)
	It is user friendly	6 (29%)	3 (14%)	12 (57%)
	I can use it successfully every time	8 (38%)	3 (14%)	10 (48%)
	I learned to use it quickly.	15 (71%)	0 (0%)	6 (29%)
Satisfaction	It is fun to use.	2 (10%)	4 (19%)	15 (71%)
	I am satisfied with it.	5 (24%)	2 (10%)	14 (67%)

This puzzle program is slightly inconvenience in terms of ease of use because it requires the use the HoloLens unlike a regular puzzle; however, the satisfaction value is better than those for regular puzzles. Because the VR puzzle completely blocked out reality, using it was inconvenient for the elderly, and the satisfaction was somewhat reduced. The puzzles developed in this study were made meaningful for the elderly by using real-world puzzles that can be physically touched, while hints are provided or 3D images are displayed using MR technology. It is expected that the elderly will use it voluntarily so that, it can have a preventive effect on cognitive impairment.

V. CONCLUSION

The development of an MR puzzle program that includes 3D images to enhance brain activation while solving a puzzle that is effective in improving cognitive function was described. Among the various methods that can be used to improve the cognitive function of the elderly, puzzles have the advantage of enabling the elderly to do it themselves voluntarily. However, there are some inconveniences. Seniors can give up easily when making puzzles by themselves, because they cannot fit puzzle pieces or because they are not interested. This puzzle program has been improved using MR technology. When a puzzle game is played by the elderly using a HoloLens device, the entire completed picture can be easily seen. When the puzzle piece that is not aligned is stared, the place where the piece should be inserted is displayed in 3D. When the puzzle is completed, the image in the puzzle appears in 3D image and moves. This puzzle program was tested with the elderly, and the result was that most of them found it fun and easy to use; they also had a desire to use it again. In the future, the plan is to expand this puzzle program to include more interesting images, and make this program available in various places.

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