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Innovative Integration of Brain-Computer Interface and Virtual Reality Technologies for Cognitive Rehabilitation

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Abstract

In this paper, the training contents for cognitive rehabilitation as part of the healthcare service model were designed and examined with 20 elderly users on to improve their concentration level and assess their satisfaction with the proposed game contents compared to existing ones. In order to increase the motivation of training contents as a gamification model, the Brain-Computer Interface (BCI) component and virtual reality (VR) training contents were proposed that induce the users' movements. Through the developed training contents, the possibility of the cognitive rehabilitation was examined in order to expand the variety of contents for the elderly users and their healthcare. The promising evaluation results demonstrate that incorporating BCI technology enhances user concentration levels during training sessions. Future research will further verify BCI information to improve signal and image processing techniques for managing specific diseases.

Keyword : Cognitive rehabilitation, Training contents, Gamification model, BCI, VR

1. Introduction

In recent years, the integration of advanced technologies into healthcare has grown exponentially [1]. In particualr, the application of Brain-Computer Interface (BCI) and Virtual Reality (VR) technologies has emerged as an efficient approach to enhance the effectiveness of cognitive rehabilitation [2][3]. However, the practical implementation of such technologies remains a challenge primarily due to the lack of understanding of their potential and the scarcity of efficient frameworks for deploying them in real-world settings. In response to this gap, this paper focuses on the development of training content for cognitive rehabilitation that is implemented within a healthcare service model. The proposed model emphasizes the need for a system that demands user concentration and utilizes gamification elements to enhance users' motivation. Through the integration of BCI and VR technologies, the paper aims to provide an engaging and efficient rehabilitation training experience for the elderly users.

The BCI component uses improved beta signal contrast to evaluate user concentration levels whereas the VR component provides an immersive and interactive platform for the delivery of the training

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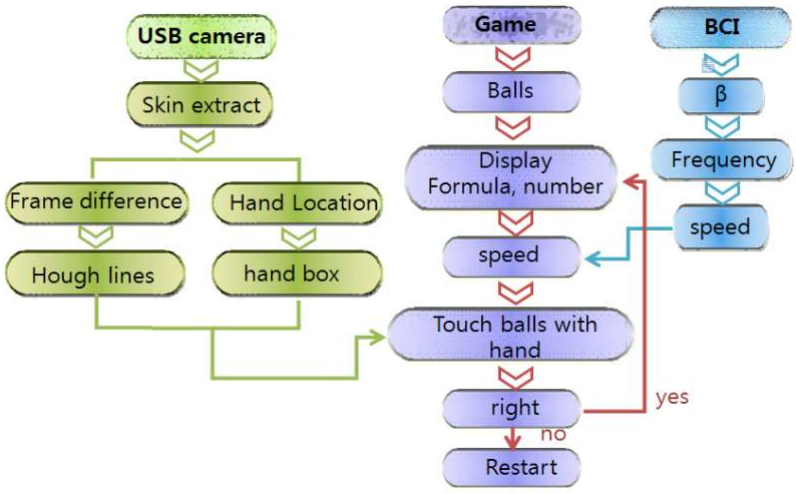
content [4]. Along with these technology, the designed system further utilizes Fuzzy C-Means (FCM) clustering to categorize user concentration levels which are then used to determine the difficulty level of the training content. In addition, the training contents were developed for cognitive rehabilitation as part of the healthcare service model in this paper. The BCI and VR was added based on training contents component in a gamification model in order to increase the users' motivation.

2. Methods

This study advances into two steps. The first step is a calculation of the training contents level by improved contrast of measured beta signals. The second step is the development of the training contents interface through real-time VR training processing technique as shown in [Fig. 1].

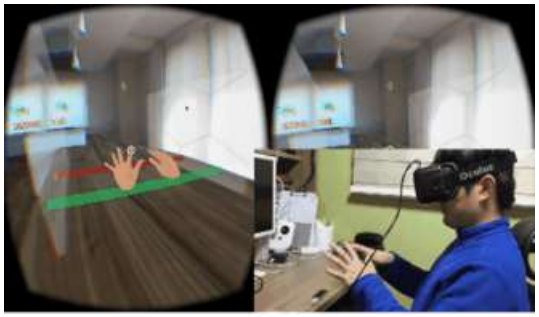


[Fig. 1] Flow chart of the entire development

In BCI part, the shock filter was employed to improve beta wave detected through BCI equipment [5]. The detected BCI wave has a beta waveform that informs the concentration level of users. The characteristic of this functional training contents is that shock filters are used eventually for training contents play through meaningful beta waveform information. When a result value of three classes is specified in the processed beta waveform and is belonged to the final group using FCM clustering [6], it is regarded as a high concentration level. The reasons of using FCM clustering are unlike the K-mean clustering method. The result value does not change each time and the number of variable-setting factors is limited. Thus, the border line of the greatest variation value between the classes can be found [7].

Improved beta waveform is used as the necessary information to determine the training contents difficulty level. The beta waveform reflects the user's concentration level by analyzing its characteristics such as amplitude and frequency. BCI information is moved at random in the video object specified prototype so it is used to randomly move to adjust the speed factor as well. It allows for a personalized and adaptive training experience where the difficulty can be adjusted based on the user's concentration abilities. This approach has the potential to provide an engaging and challenging training program tailored to the individual's cognitive abilities.

[Fig. 2] BCI devices and beta improvement



[Fig. 3] Training contents based on VR

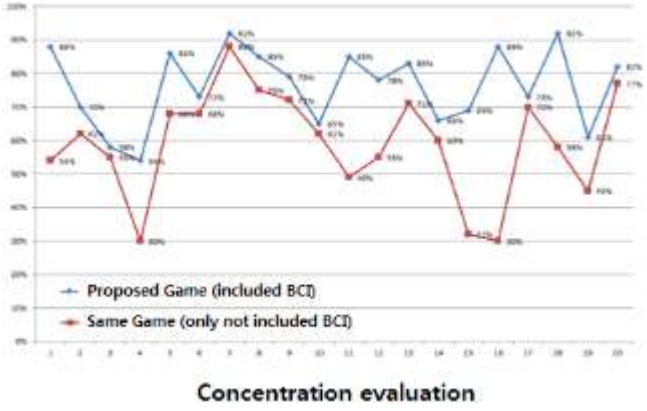
As shown in [Fig. 2]. BCI devices consist of electrodes or sensors that are placed on or near the scalp to detect brain signals. These signals are then processed and analyzed to extract meaningful information such as cognitive states, motor commands or emotional responses. The processed signals are

subsequently used to control external devices, provide feedback or facilitate communication. In addition, VR training contents were developed to play it as an input as shown in [Fig. 3]. In order to detect the hand region, an leap motion device was used to interact with training contents. The training contents was for cognitive rehabilitation.

3. Results

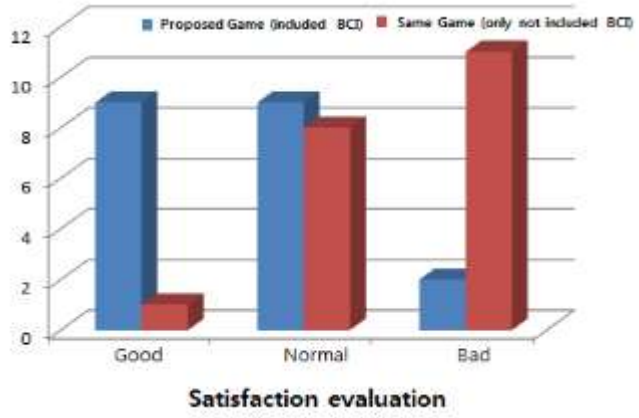
In order to evaluate the performance of proposed training contents, 20 elderly were collected and surveyed. The experiment was evaluated for comparison with the same contents included BCI component and not included. Also, the gamification model was added based on BCI processing. Concentration was calculated in proportion to the training contents play time and satisfaction was conducted through an offline-survey.

As illustrated in [Fig. 4], when BCI was included in the game content, the level of concentration was significantly higher than when it was not. Without BCI, the average was 75 percent while the average was 83 percent with BCI as of 8 percent higher.



[Fig. 4] Concentration results

As shown in [Fig. 5], the satisfaction survey at the end of the VR game showed that the elderly participants were much more satisfied with the game that were designed in this paper than with the conventional serious games. It also illustrates that majority of the elderly users were less satisfied with the conventional games overall, which means most game were not produced tailored to the elderly users in terms of their commercial power and their cognitive abilities.



[Fig. 5] Satisfaction results

4. Discussion

The BCI component of the proposed model in this paper utilized improved beta signal contrast to evaluate user concentration levels. By employing shock filters, the beta wave detected through the BCI equipment was enhanced and provided meaningful information about the users' concentration level. The results of the evaluation demonstrated the effectiveness of the proposed model. The inclusion of the BCI component in the game content significantly increased user concentration levels compared to when it was not included. Moreover, the satisfaction survey revealed that the elderly participants were much more satisfied with the game designed as opposed to conventional serious games. This highlights the importance of tailoring games to the specific needs and cognitive abilities of the elderly population.

The successful integration of BCI and VR technologies within the healthcare service model for cognitive rehabilitation training holds significant implications. It provides a promising approach to enhance user concentration and motivation levels, ultimately improving the effectiveness of cognitive rehabilitation programs. The utilization of FCM clustering for determining high concentration levels and adjusting the difficulty of training content further contributes to the model's effectiveness. These findings underscore the potential for these technologies to be deployed in real-world healthcare settings and their ability to address the existing challenges in cognitive rehabilitation.

Although this study focused more on the impact of BCI information on the training content, it also illustrates the potential of integrating these advanced technologies into functional training content development environments. The promising evaluation results endorse the model's future applicability and

paves the way for further advancements.

5. Conclusion

In conclusion, the integration of BCI and VR technologies in cognitive rehabilitation training shows significant promise. The evaluation results demonstrate that incorporating BCI technology enhances user concentration levels during training sessions. Also, the use of VR provides an immersive and enjoyable experience for users and it leads to higher satisfaction levels. These findings highlight the potential of BCI and VR technologies to improve cognitive rehabilitation outcomes and suggest the need for further research and development in this area.

In future research, the BCI information will be further validated and improvements in signal and image processing techniques will be implemented. First of all, larger and more diverse populations are needed to validate the effectiveness of the proposed model. In addition, long-term follow-up studies are necessary to assess the sustained impact of the training content on cognitive rehabilitation outcomes. Moreover, the potential of the latest AR and VR devices will be explored to extend the application scope of the developed model. The aim is to develop content that can be effectively used in the management of specific diseases, thereby contributing to the overall advancement of healthcare services.

The paper expects to make a crucial stride in understanding the potential of BCI and VR technologies in healthcare and setting the foundation for future research. It extends the current state of knowledge in cognitive rehabilitation and contributes to the development of more effective and engaging training programs. Furthermore, it explores potential future applications of these technologies including their integration with newer augmented reality (AR) devices and their use in managing specific diseases.

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