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Design of Cognitive Rehabilitation Training System using Artificial Intelligence

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Abstract—This study is a study to design a cognitive(dementia) rehabilitation training system using the MMSE-DS protocol and the GDS protocol using artificial intelligence to analyze the user's cognitive ability and infer cognitive domain content correlation inference algorithms. For research on cognitive judgment technology using artificial intelligence, We provide an integrated cognitive rehabilitation service platform, provide customized training content by building a cognitive rehabilitation evaluation and training user data storage and analysis database, and design an algorithm to help improve users' learning ability by building an artificial intelligence system.

The user's cognitive ability analysis and cognitive domain content inference algorithm using artificial intelligence is the purpose is to design a cognitive judgment platform and implement a system to apply cognitive evaluation to people with mild cognitive impairment and utilize cognitive rehabilitation content based on cognitive judgment technology system design technology. Through this study, we aim to provide direction for the future field of cognitive rehabilitation combined with artificial intelligence

Keywords- cognitive rehabilitation; dementia; health care; recommender system; AI Recommendations AI;

I. INTRODUCTION

Artificial intelligence, a core technology in the era of the 4th Industrial Revolution, is a general-purpose technology that spreads across all industries and society, determining future competitiveness and developing as a key driving force for innovative growth. Artificial Intelligence (AI)[1], first used by John McCarthy in 1956, refers to a science and technology that implements human intellectual ability into machines. It learns deep learning technology to find the optimal answer, a conducts inference and prediction, and research in various fields is actively underway, ranging from the action stage of discovering and solving a given problem on its own[2][3][19].

In order to address the increase in chronic diseases due to the recent aging of the population and the shortage of professional manpower in the infrastructure and health and healthcare fields, We are researching augmented reality Augmented reality AR(: Augment Reality)[4], virtual reality VR(: Virtual Reality)[5] and mixed reality MR(: Mixed Reality) technologies in the form of convergence with artificial intelligence and realistic content technology through content that optimizes user experience. The aging of the population is emerging as a problem for developed countries due to a shortage of labor, expansion of welfare facilities for the elderly, and decline in cognitive function due to aging [6-8].

Cognitive function is closely related to daily living ability, and if cognitive function is improved and problems are minimized, daily living ability will increase [9][18]. Although various cognitive rehabilitation systems exist, both domestically and internationally, most of them mainly use 2D content in the form of embedded systems, and there is a lack of cognitive rehabilitation training systems that combine artificial intelligence technology and realistic content technology [10].

For cognitive rehabilitation training, cognitive evaluation of people with mild cognitive impairment was applied through the use of augmented reality technology, and based on data from research on cognitive judgment technology [11], the design and development of a cognitive judgment technology platform was presented as background research [12].

Accordingly, this paper is a study which is utilized artificial intelligence reinforcement learning technology and used the DKT(: Deep Knowledge Tracing) algorithm to build a user-customized cognitive (dementia) rehabilitation training content recommendation system, and analyzed the user's cognitive ability based on the MDP(: Markov Decision Process). and designing a customized cognitive training content recommendation algorithm, to implement a system that improves users' learning ability and induces interest.

II. RELATED RESEARCH

A. Cognitive rehabilitation and cognitive skills

The population is rapidly aging worldwide, and in Korea, the population in their 50s (baby boomers), who are entering old

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age, is rapidly increasing. The quality of life of people in their 50s or older is declining owing to anxiety about senile dementia due to impaired cognitive function. Therefore, continuous research and development of cognitive technology for cognitive rehabilitation programs and training equipment that can maintain and improve cognitive function for these elderly and elderly people is necessary. Cognitive rehabilitation programs and training equipment can be applied to a variety of disabilities and conditions, such as brain damage, aging, stroke, cognitive impairment, autism, and attention deficit hyperactivity disorder (ADHD), thereby improving an individual's cognitive abilities and improving their ability to improve their daily life. It must be possible to achieve a better quality of life.

Cognitive skills refer to various knowledge-based technologies that can acquire, grasp, remember, and utilize information from the human brain and mind using a computing system. In order to provide cognitive management services for the elderly and elderly through the use of cognitive technology in the medical healthcare field, a cognitive management platform necessary for integrated management must be established. The cognitive management platform includes cognitive data measurement, management, evaluation, service modules, and To support this, the convergence of biotechnology, databases, and representative technologies of the 4th Industrial Revolution era is absolutely necessary.

B. Cognitive judgment technology approach

Cognitive judgment technology used domestically provides cognitive rehabilitation training for the elderly and the disabled using computerized computer programs and keyboards. Commercialized equipment commonly used in Korea includes computerized cognitive rehabilitation programs such as RehaCom (Germany), Brain Dr (domestic), and CoCoTa (domestic). These systems provide a variety of contents as representative computerized cognitive rehabilitation programs, but have the disadvantage of reducing immersion in evaluation and training because they use 2D graphics and computers based on embedded systems [13].

In addition, the American 'IREX', the Dutch Silverfit', and the domestically produced 'VREAHT' are VR-based equipment for cognitive rehabilitation training for the elderly and the disabled.

C. Necessity of cognitive rehabilitation training

The 4th generation R&D trend in the era of the 4th Industrial Revolution is developing in the form of a convergence of ICT(: Information and Communication Technologies)-based technology and cognitive rehabilitation training technology in the health and healthcare fields [14].

Cognitive rehabilitation training techniques must include the MMSE (Mini-mental State Examination)-DS[15], which is a cognitive level for dementia, or the Geriatric Depression Scale (GDS) protocol, which is a geriatric depression scale. The evaluation items of MMSE-DS are six areas: Orientation, Memory, Attention, Visual Perception, Language, and Calculation.

The total score is out of 30, and the criteria for cognitive impairment are that 24 or more points are normal, 18 to 23 points are interpreted as mild cognitive impairment, and 17 points or less are interpreted as severe cognitive impairment [16]. In addition, in order to provide cognitive management services, cognitive abilities and cognitive training protocols must be designed in the form of an integrated platform to enable cognitive rehabilitation training.

III. ARTIFICIAL INTELLIGENCE RESEARCH NEEDED FOR COGNITIVE REHABILITATION

In order to design a cognitive rehabilitation training system, this study is designed to create user-customized content and design a recommendation platform according to content difficulty through a protocol that combines artificial intelligence reinforcement learning, DKT, and MDP.

A. Artificial Intelligence Reinforcement Learning

Reinforcement learning is a type of artificial intelligence machine learning method that learns by exploring appropriate behavior in a specific situation to maximize rewards that can be expressed numerically. The agent in reinforcement learning does not directly learn what action to take, like most machine learning methods, but instead discovers what action to take to obtain the best reward. Reinforcement learning provides the agent with a state that can be obtained in a given environment, an action acquired from the agent based on the state, and a reward that matches the given state and action pair.

Reinforcement learning sequence

- The agent measures the state (S_t) of the environment.
- Select the optimal action (A_t) according to the agent's rules (policy) in the current state.
- The state of the environment is converted to the next state (S_{t+1}) by the selected action.
- Based on the next state (S_{t+1}), the agent selects a new action (A_{t+1}).
- Calculate the agent's policy immediately or periodically by calculating long-term performance using the immediate reward (R_{t+1}) given from the environment.

In reinforcement learning, this process is repeated, and the agent measures the state of the environment at each time-step, switches to the next state when it takes appropriate action, and receives rewards immediately or periodically depending on the action.

Reinforcement learning can be divided into model-based reinforcement learning and model-free reinforcement learning. Model based reinforcement learning is reinforcement learning in

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which there is a model for the environment and the agent knows about the environment. On the other hand, model free reinforcement learning is where an agent without an accurate model of the environment explores based on state and reward without knowing the environment. It is being applied in various fields such as games, robot control, self-driving cars, natural language processing, stock trading, and medicine.

Model free reinforcement learning can be broadly divided into value-based reinforcement learning and policy-based reinforcement learning. Value-based reinforcement learning is reinforcement learning that directly learns a value function that predicts the reward that can be obtained from a specific state and a specific action, while policy-based reinforcement learning learns the agent's behavior patterns that determine which action to select in the characteristic state. It's reinforcement learning.

In the value-based reinforcement learning approach, if the value function is completely constant, the agent's behavior pattern simply selects the action that can obtain the highest reward in each state. In the policy-based reinforcement learning approach, if the agent's behavior pattern is perfect, the action can be decided based on the behavior pattern without the need for a value function to create the behavior pattern. Actor-critic reinforcement learning, which learns both the value function and the agent's behavior pattern, also exists.

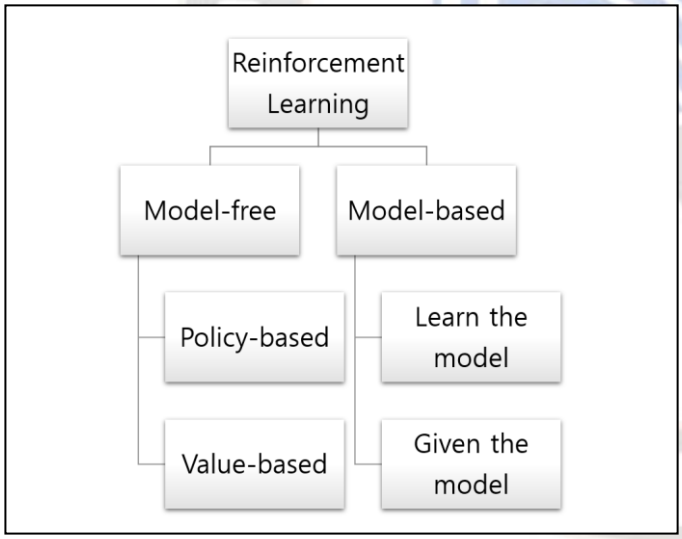

Figure 1. Reinforcement Learning Classification

B. DKT(Deep Knowledge Tracing) Algorithm

The DKT algorithm was jointly researched by Stanford, Google, and Khan Academy, and is a machine learning model designed for proven applications using Synthetic Data, Khan Academy, and Assistments, an open educational data source. DKT has the advantage of predicting two or more skills and understanding HIDDEN KNOWLEDGE, and is used to model and predict knowledge mastery in a specific area. Depending on the user learning system, DKT can provide customized content by activating various parameters to measure and predict the learner's accurate knowledge state. In the DKT algorithm, the spacing effect theory is treated as important.

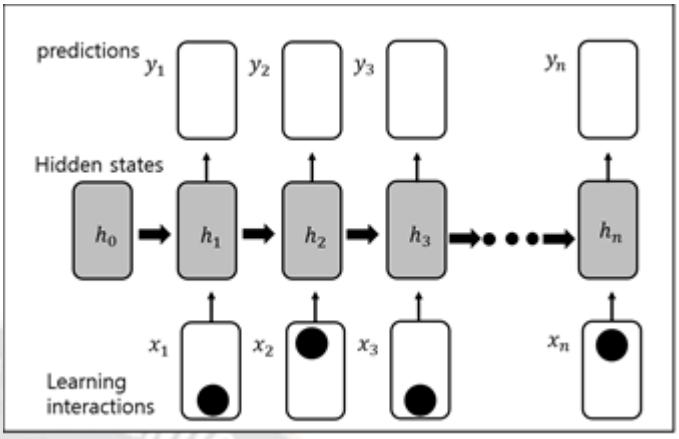

Figure 2. Deep Knowledge Tracing

The spacing effect refers to a method of learning effectively by providing space repetitions between repetitions. It is known that presenting gradually longer time intervals rather than the same time interval improves the learner's long-term memory and is more effective in learning.

DKT typically uses a recurrent neural network (RNN), such as a Long Short-Term Memory (LSTM) or Gated Recurrent Unit (GRU) network, to capture the temporal dependencies and sequences of user responses and to network the user's knowledge state over time. You can predict how it develops.

C. MDP(Markov Decision Process)

MDP is a model that adds Action elements to MRP (Markov Reward Process). It is a sequential decision-making problem in which an agent interacts with the environment to achieve a specific goal by utilizing probability and graphs for artificial intelligence reinforcement learning and decision-making processes. This is a method of modeling [17].

MDP is an optimization problem-utilizing algorithm that obtains the highest reward. The efficient action sequence is defined as “the state at time t is affected only by the state at t-1, and was designed based on the first-order Markov assumption.” First-order Markov assumption can be expressed as probability as equation (1).

$$p(s_t|s_0, s_1, s_2, \ldots\ldots, s_{t-1}) = p(s_t|s_{t-1}) \quad (1)$$

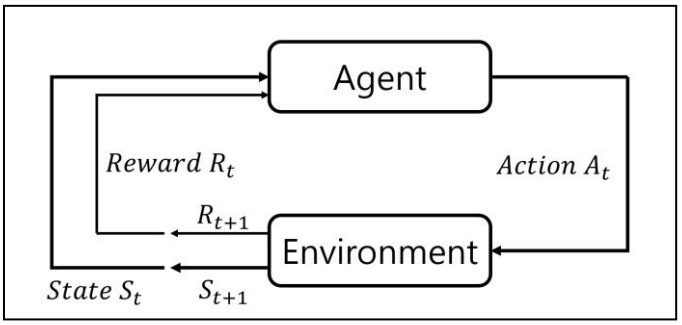

Figure 3. MDP Operaton

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The Agent performs the action corresponding to A_t in the state corresponding to S_t, and the Environment returns A_t corresponding to the next state and the corresponding reward R_{t+1} to the Agent.

The main components and concepts of MDP are as follows

- Status (S): Indicates the status of the environment.
- Action (A): Action represents a set of choices that the agent can perform in each state.
- Transition Probability (P): Transition probability refers to the likelihood of moving from one state to another when a certain action is taken. This probability is expressed by the transfer function $p(S_{t+1}|S_t,\ A_t)$.
- Reward (R): Reward is a numeric value associated with a state-action pair or state transition. It represents the immediate benefit or cost of taking a particular action in a particular state. The agent's goal is usually to maximize the cumulative reward over time.
- Policy (π): Policy is the policy that the agent follows to select actions that mapping from various states to actions.
- Value function (V): The value function represents the expected cumulative reward that an agent can achieve following a certain policy starting from a certain state.
- Q-function (Q): The Q-function represents the expected cumulative reward that an agent can achieve starting from a certain state, taking certain actions, and following a certain policy

The main goal of solving an MDP is to find an optimal policy that maximizes the expected cumulative reward over time. This is often done using various reinforcement learning algorithms such as Q-learning, SARSA or policy gradation methods. These algorithms aim to learn the optimal value function, or Q function, and derive an optimal policy from it.

IV. COGNITIVE REHABILITATION TRAINING SYSTEM DESIGN

In order to design a cognitive rehabilitation training system, reliable recent achievements and computerized data from cognitive science and measurement science must be compiled into a database. A module that analyzes and evaluates vulnerabilities in cognitive management based on reliable data is required, and a service module for maintaining and improving cognitive ability is absolutely necessary.

In the measurement module, building a big data database combined with content for evaluation and Intelligent Mining technology are essential. In addition, considering the cognitive characteristics of the elderly and elderly who require cognitive skills, modeling technology is needed that can create value by detecting and analyzing the structural relevance of various measurement data. and clear standards which are to distinguish risks and vulnerabilities are needed based on measurement data.

The cognitive rehabilitation training system is designed to deliver user information to a Django-based artificial intelligence API server and a cognitive rehabilitation system that communicates in a json structure, and the API is designed to analyze user data and deliver a cognitive rehabilitation recommended training list.

The designed interface visualizes data through React-based responsive UX/UI configuration and is designed to be mutually secure as an interface between users and systems that interact in real time by applying to devices of various sizes.

A. Cognitive Rehabilitation Training Content Production

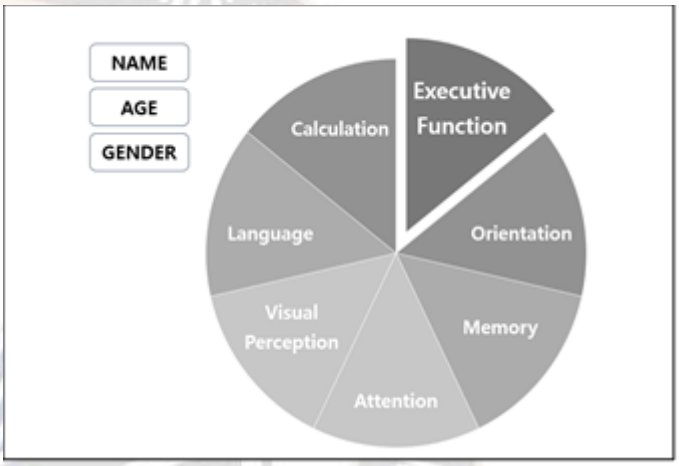

Figure 4. Cognitive Rehabilitation Protocol Components

Cognitive rehabilitation training content was designed as a cognitive rehabilitation evaluation and training protocol by adding the user's name, age, gender, and seven cognitive domains (perception, memory, attention, vision/perception, language ability, calculation ability, and executive function). In addition, 125 list-ups and content were planned and produced to evaluate multiple disorders through a cognitive rehabilitation evaluation algorithm reflecting cognitive evaluation.

Cognitive rehabilitation training content conduct an evaluation based on executive ability for brain-injured patients and dementia patients, and based on the results, it is compartmentalized into Level 1 (less than 50% of the evaluation score), Level 2 (50%-75% of the evaluation score), Level 3 (75-90% of the evaluation score) and it is recommended to personalized content.

The evaluation tool was developed by dividing it into cognitive functions and executive abilities related to executive ability, and rehabilitation training services are planned to be implemented according to the results of the evaluation of cognitive training content centered on executive ability.

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B. Reinforcement learning-based training content recommendation system

LOTCA (: Lowenstein Occupational Therapy Cognitive Assessment, SNSB-II (: Seoul Neuropsychological screening battery 2nd edition), LICA (: Literacy Independent Cognitive Assessment), which are used in actual clinical practice to evaluate executive ability and cognitive function in mild cognitive impairment and the elderly. , and MLAT (: Multi Level Action Test) to develop a reinforcement learning-based training content recommendation system.

As a first step in designing a reinforcement learning-based training content recommendation system, we design a database to build big data on user cognitive ability, analyze the correlation between cognitive domains of training content, and register it in the database.

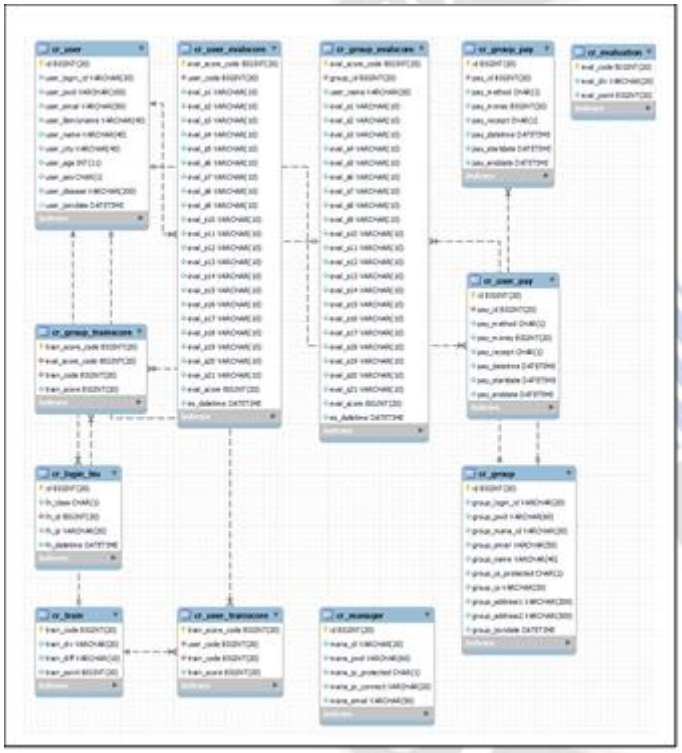


Figure 5. Database Design

C. User-customized training content recommendation system using MDP

In order to build a user-customized training content recommendation system, a large amount of user training data was secured and used to learn a DKT model. The MDP system was designed based on the training results of each user, reflecting the model's learning results. In order to maximize the efficiency of cognitive rehabilitation training content, reinforcement learning is introduced and consists of five elements: agent, environment, state, action, and reward. A learning method was used in which the agent measures the state of the environment (S), selects the optimal action (A), and maximizes the reward (R) when moving to the next state (S+1).

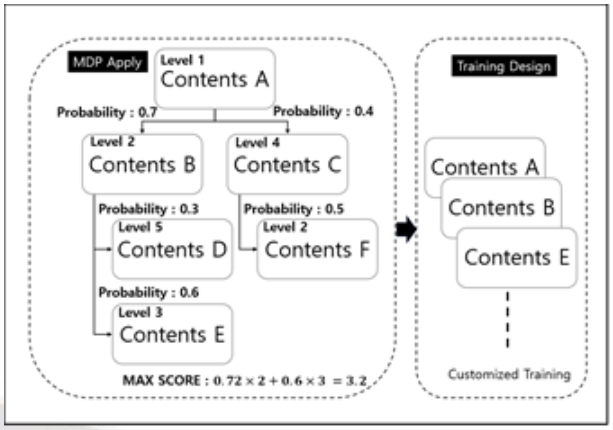
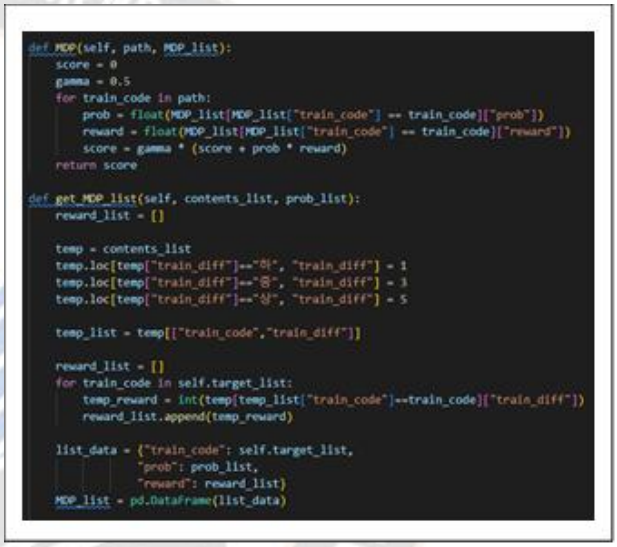


Figure 6. Apply MDP to Cognitive Rehabilitation



```
def MDP(self, path, MDP_list):
    score = 0
    gamma = 0.5
    for train_code in path:
        prob = float(MDP_list[MDP_list["train_code"] == train_code]["prob"])
        reward = float(MDP_list[MDP_list["train_code"] == train_code]["reward"])
        score = gamma * (score + prob * reward)
    return score

def get_MDP_list(self, contents_list, prob_list):
    reward_list = []

    temp = contents_list
    temp.loc[temp["train_diff"]=="하", "train_diff"] = 1
    temp.loc[temp["train_diff"]=="중", "train_diff"] = 3
    temp.loc[temp["train_diff"]=="상", "train_diff"] = 5

    temp_list = temp[["train_code","train_diff"]]

    reward_list = []
    for train_code in self.target_list:
        temp_reward = int(temp[temp_list["train_code"]==train_code]["train_diff"])
        reward_list.append(temp_reward)

    list_data = {"train_code": self.target_list,
                 "prob": prob_list,
                 "reward": reward_list}
    MDP_list = pd.DataFrame(list_data)
```

Figure 7. Cognitive Rehabilitation Training Content Recommendation AI System

Using the DKT-based RNN algorithm, the learning difficulty can be adjusted according to the user's individual cognitive level through the development of a pre-trained model, a recommendation AI system. Additionally, there are advantages in that negative problems can be resolved using immediate feedback and interaction between group members, and repetitive training is possible.

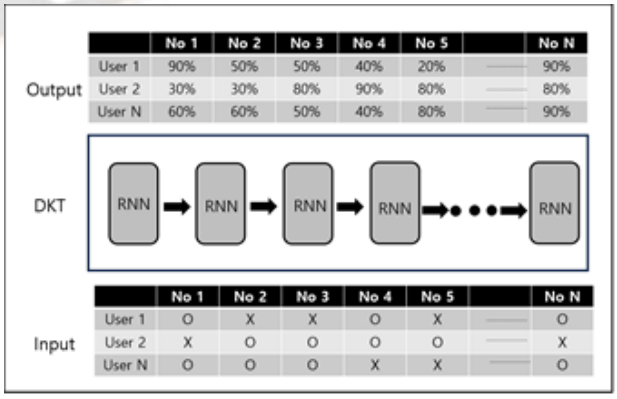


Figure 8. DKT-based training content recommendation AI system

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V. CONCLUSION

Artificial intelligence, a core technology in the era of the 4th Industrial Revolution, is a general-purpose technology that spreads across all industries and society, determining future competitiveness and developing as a key driving force for innovative growth. The expansion and application of artificial intelligence technology to health and healthcare convergence fields is steadily progressing. The aging phenomenon has emerged as a social problem in developed countries, and in particular, decline in cognitive function has become an issue in the health and healthcare fields.

Technologies such as artificial intelligence can replace professional manpower in the health and healthcare (cognitive technology, clinical medicine, psychology, ICT, and social welfare) fields. Through this, as research and interest in brain science increases, systems that recommend cognitive rehabilitation training content can be of great help to the health and healthcare fields.

The cognitive rehabilitation training system in this study provides automation, unlike existing embedded systems, through AI algorithms to provide customized content according to the user's cognitive ability, and is a cognitive evaluation tool system based on MMSE-DS. The system was implemented based on the hardware and software evaluation flow sequence algorithm of the cognitive evaluation tool system.

Through a cognitive rehabilitation training system, experiments are needed to increase reliability and efficiency by identifying test subjects who need cognitive rehabilitation in actual hospitals, securing a lot of data, and conducting evaluations. As a future research task, the general characteristics of the experiment participants should be analyzed frequently, the mean and standard deviation descriptive statistics should be confirmed, and data on a large number of subjects should be secured to secure the significance of the clinical effect. In addition, two-way communication must be possible rather than training that only relies on existing therapists, and the paradigm of immediate feedback and recommendation algorithm healthcare products using AI will be transformed.

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