VR based Collaborative Errorless Learning System using Humanoid Avatar for People with Alzheimer's Disease

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Abstract: Everyday action impairment is one of the diagnostic criteria of Alzheimer's disease and is associated with many serious consequences, including loss of functional autonomy and independence. It has been shown that the (re)learning of everyday activities is possible in Alzheimer's disease by using errorless learning approaches. The purpose of this study is to propose a newly revised Virtual Kitchen system that allows training of everyday activities to integrate a new approach of errorless learning (EL) framework using collaborative learning with a virtual agent. In this paper, we describe a concept of the proposed framework, as well as explore user's attention change to analyse eye tracking data during a training task in order to review the effectiveness of the proposed EL framework.

1 INTRODUCTION

1.1 Everyday Activities Intervention

Everyday activities are familiar tasks that require multiple cognitive processes such as serial ordering of task steps and object selection, in order to achieve practical goals such as preparing a cup of coffee, making a sandwich, and so on. Usually these familiar tasks are routinely performed with subjective ease in real life. However, in people with brain damage, errors are frequent and sometimes may preclude the achievement of the task goal (Chevignard et al., 2008; Fortin et al., 2003). In fact, everyday action impairment is one of the diagnostic criteria of Alzheimer's disease as well as is associated with many serious consequences such as institutionalization, depression, and death (Adam et al., 2000; Hargrave et al., 2000; Noale et al., 2003).

In a common approach to prevent these dire consequences, neuropsychologists suggest that patients with dementia learn or relearn instrumental activities of daily living to increase the patients' functional autonomy (Giovannetti et al., 2007; Dechamps et al., 2011). To date, research on everyday action interventions for people with dementia has shown that repetition of everyday activities improves performance on trained tasks (Avila et al., 2004; Farina et al., 2002).

1.2 VR based Intervention

Today, there are no doubts that (re)learning methods have beneficial effects for patients with Alzheimer's disease especially when they have explicit memory deficits. However, conventional methods are not always feasible in typical clinical settings.

Virtual reality (VR) based technology is one of the emerging tools that has great potential for use in rehabilitation (Le Gall et al., 2008). VR is a technology that allows people to view, touch, navigate, as well as interact with a computer-generated three-dimensional world in real time. In addition, Virtual environments allow people to be engaged in activities as in the real world (Broeren et al., 2008). In the domain of everyday activities, several virtual environments have been developed to

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simulate daily tasks, namely cooking (Allain et al., 2011; Richard et al., 2010; Zhang et al., 2002) as well as shopping (Klinger et al, 2006). In fact, VR allows intensive repetition of meaningful tasks with augmented feedback for rehabilitation (Crosbie et al., 2012).

Since no study so far has captured the scope to create a virtual environment specifically designed for the (re)learning of everyday activities in patients with Alzheimer's disease, we have designed a dual modal VR application which allows patients with Alzheimer's disease to practice everyday activities: Virtual Kitchen (VK) system (Yamaguchi et al., 2012). In the previous study, we have developed the VK for use as an intervention tool to treat everyday cooking deficits in patients with Alzheimer's disease, as well as examined the effectiveness and usability.

1.3 Virtual Kitchen System

Previous VK system was designed as a dual modal VR platform. The system was composed of one notebook PC, a mouse, a headset, and the VK application, which runs on the PC. The system was designed to be as simple as possible in order to make it portable and to facilitate setup. The application was visually implemented in a 3D environment in order to make it immersive as well as improve the reality of the system. As for the interaction technique with the system, 2D mouse interaction was supported for patients since it was the most common and usual interaction model for them and since the system focuses on cognitive performance but not on motor abilities, we decided to control the vertical and horizontal position of objects in the 3D environment.

The VK application consisted of (re)learning everyday tasks, especially cooking tasks such as preparing two pieces of toast for breakfast using an electric toaster (breakfast task); and preparing a cup of coffee with a coffee machine (coffee task). The breakfast task trains subjects how to prepare two pieces of toast in everyday life. It contains seven manipulable visual objects: a toaster, two pieces of bread, two spoons of jam, and two pats of butter. As for the coffee task, it trains subjects how to prepare a cup of coffee with a coffee machine in everyday life. The coffee task also contains seven manipulable visual objects: a coffeemaker, a coffee filter, ground coffee, a coffeepot, a water pot, sugar cubes, and a milk carton. In both tasks, these seven objects can be manipulated with the mouse. To finish both tasks, a total of 10 manipulations were severally required.

1.4 (Re)Learning Methods

In the previous VK system, we focused on developing two cooking tasks as descried above on a dual modal VR platform with integration of two (Re)learning methods: Written Instruction Learning Method (Written ILM), and Self-Recorded Instruction Learning Method (Self-Recorded ILM). Both methods provide step-by-step written instructions to achieve the applied task. These instructions were proposed to reduce errors during (re)learning. Written ILM was based only on written instructions, while the Self-Recorded ILM combined written ILM with verbal repetition of instructions.

In fact, written and/or verbal instructions approaches have proven to be successful in patients with action disorganization problems (Bickerton et al., 2006). Such approaches could be very helpful to guide their actions. However, this approach could only provide errorful learning which is not associated with an avoidance of errors during leaning.

1.5 Errorless Learning

Errorless learning (EL) is one of the effective learning methods for everyday activities intervention. The EL allows teaching techniques that prevent people from making mistakes during learning process (Dechamps et al., 2011).

Some recent studies suggest that errorless learning principles may be beneficial in memory rehabilitation for people with dementia (Dunn & Clare, 2007). In addition, EL has been applied in developing practical interventions for people with a range of disabilities so that recently EL has been an important focus of interest for researchers interested in memory processes (Clare & Jones, 2008).

1.6 VR based Errorless Learning

Although there are many evidences based studies and successful cases that support the use of the EL, usually EL approaches are conducted by therapists, but not by system operation. On reviewing the literature, we found a few studies on the EL approach implemented in VR environments. For instance, Connor et al tested the effectiveness of their errorless learning system using haptic guidance with patients with post-stroke visuo-perceptual deficits. In their errorless learning condition unproductive or incorrect approaches to objects within a virtual environment are prevented by applying a 'force field valley' when the patient take a wrong direction (Connor et al., 2002). Kober et al. developed VR based neurologic rehabilitation system for patient with spatial disorientation. Their EL system was designed by means of verbal feedback from the experimenter when patients took a wrong route during navigating in virtual scenarios (Kober et al., 2013). At least according to the related studies, researchers focus on how well instruction provide from the system helps a patient better understand his or her performance, as well as how patient's error behaviour can be prevented by using multimodal VR interaction when they make an error during rehabilitation task.

In fact, typical algorithm of the EL usually consists of a couple of processes: "(a) breaking down the target task into small to discrete steps or units; (b) providing sufficient models or instruction before a patient is asked to perform the target task; (c) encouraging the patient to avoid guessing; (d) immediately correcting errors, and (e) carefully fading prompts" (Sohlberg et al., 2005). As the point of view of the system requirement when designing an EL framework, it should be considered that not only the typical process of the EL, but also (1) how well patient's attention can be induced to the instruction and the target task, (2) how naturally patient's motivation can be created for them to conduct the target task, (3) how naturally patient's error behaviour can be predicted, as well as (4) how effectively prompts can be reduced.

In this paper, we propose a newly revised VK system to integrate an EL framework for (re)learning of everyday activities in patients with Alzheimer's disease. The proposed EL framework was designed to achieve these requirements as described above. We present an implemented prototype system as well as the effectiveness of the system's capability.

2 PROPOSED SYSTEM

2.1 Requirements Analysis

The purpose of the requirements analysis process is to define the functionalities needed in the proposed EL framework. Four main requirements of the proposed framework were actually extracted based on the discussion in the previous section: (1) control a visual attention of a patient, (2) create a natural situation in which a patient can be motivated into an applied task, (3) predict a patient's error behaviour, as well as (4) adaptively provide a level of prompt based on patient's progress. To achieve these requirements, we decided to develop an EL framework based on a collaborative learning environment with a humanoid avatar which is a virtual agent controlled by an artificial intelligence (AI) technique.

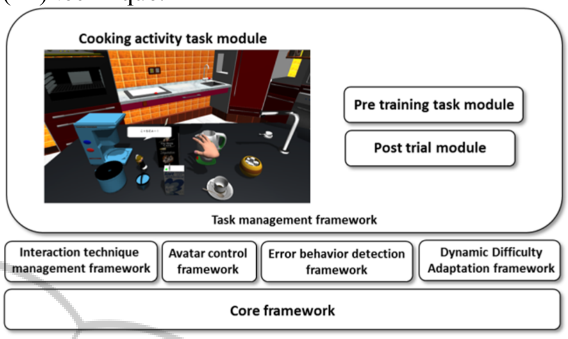

Figure 1: System framework of the proposed VK system.

Humanoid agent has a capability of supporting learning activities through improving learner's emotional state such as engagement as well as motivation (Soliman & Guetl, 2011). Using collaborative learning with the avatar, requirements (1), (2) can be achieved. In terms of requirement (3), error behaviour detection framework is considered. Concerning requirement (4), dynamic difficulty level adaptation framework is considered (Figure 1). In addition, we revised the interaction technique with the proposed VK platform using Leap motion device, which is a sensor device that supports hand and finger motion as input, to facilitate natural communication with the humanoid avatar.

2.2 System Framework

The prototype system is composed of a desktop PC, a PC monitor and Leap motion controller (Figure 2). In this paper, four main frameworks are described in detail such as a *Task management framework*, an *Interaction technique management framework*, an *Avatar control framework*, and an *Error behaviour detection framework*.

2.2.1 Interaction Technique Management Framework

This framework enables to control a hand avatar which tracks the user's hand gesture using the connected Leap motion controller. The position and orientation data of the user's hand are updated at about 125Hz. However, since the data confidence of the Leap motion becomes low due to a tracking error and self-occlusion, the orientation data of the user's hand avatar is fixed while grabbing some manipulable object to improve the usability of the hand avatar.

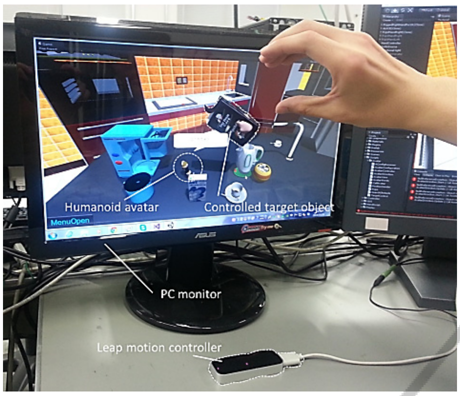

Figure 2: System configuration of the VK system.

2.2.2 Task Management Framework

This framework currently enables to manage a coffee making task. The screen shot of the coffee making task is shown in the Figure 3. The coffee making task contains seven manipulable visual objects such as a coffeemaker, a coffee filter, ground coffee, a coffeepot, a water pot, sugar cubes, and a milk carton. These seven objects can be manipulated with the hand avatar. To finish the tasks, a total of 10 manipulations were required as shown below.

1. Press the blue button on the coffee maker to open the filter door.
2. Set a coffee filter in the filter door.
3. Pour the ground coffee into the filter door.
4. Press the blue button again to close the filter door.
5. Pour the water from water pot into the coffee maker.
6. Set the coffee pot on the warming plate.
7. Press the red button on the coffee maker to make coffee.
8. Pour the coffee from the coffee pot into the coffee cup.
9. Put a cube sugar from the sugar plate into the coffee cup.
10. Pour the milk from the milk carton into the coffee cup.

2.2.3 Avatar Control Framework

The humanoid avatar in the VK platform is controlled by AI technique which is running on the *Avatar control framework*. Figure 4 shows that information flow between AI and the environment. AI is running on the background of the main task. AI has a sensor module which allows obtaining environmental parameters such as a current task status, task success/failure, distances to each object, as well as position/orientation of the user's hand avatar.

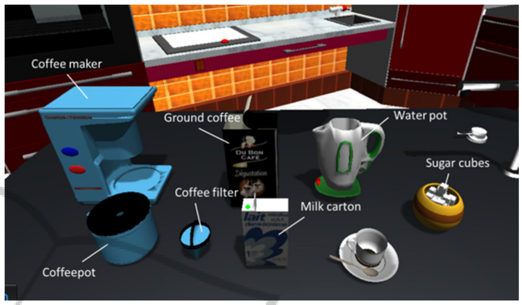

Figure 3: Screenshot of the coffee making task.

The AI control module consists of three components such as a Knowledge making component, a Decision making component, and a Motion making component. Obtained information through the sensor module is recognized in the Knowledge making component to analyse patient's behaviour as well as current task status. The result from the Knowledge making component is updated in the Database to share it with other components.

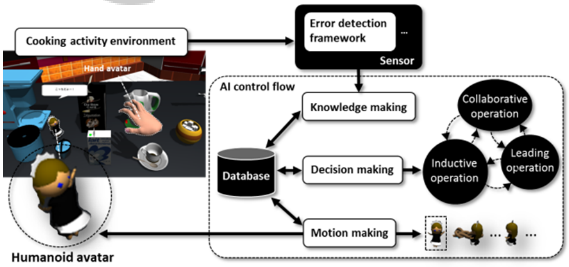

Figure 4: Information flow between AI and the virtual environment.

Depending on the result from the Knowledge making component, next operation of the avatar is decided by the Decision making component as well as by the Motion making component to update an operation mode of the avatar which consists of three operation modes: a Collaborative operation mode, an Inductive operation mode, and a Leading operation mode. In fact, these operation modes could be a key concept for designing collaborative learning environment.

The *Inductive operation mode* is a set of avatar's behaviour that allows indicating the next task for a patient to achieve. When a task begins, the avatar immediately moves to a target object. For example, if the applied task is the trial 2 (See 2.2.2 section), the avatar moves to the coffee filter and then performs an inductive behaviour (the avatar jumps up and down, or shakes the hand) to encourage a patient to conduct the target task. When it succeeds to indicate patient's attention to the target task, the avatar's behaviour is changed to the *Collaborative operation mode*.

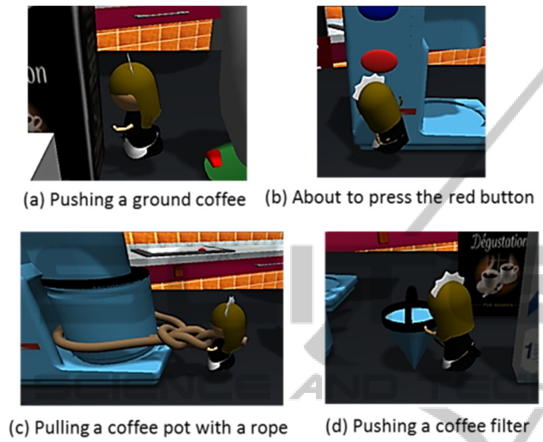

Figure 5: Collaborative operation of the avatar.

When the avatar is in the *Collaborative operation mode*, first, the avatar tries to achieve a target task alone (Figure 5). For example, if the target task is trial 2, the avatar tries to push the filter, however it does not move after all. In this situation, the avatar is asking for somebody's help. This situation actually was designed to encourage patient's helping behaviour to the avatar. With this approach, we designed a natural situation in which a patient to be motivated into an applied task. If it fails to indicate patient's attention to the target task, the *Leading operation mode* is applied to demonstrate a model prompts of the target task by the avatar.

2.2.4 Error Behaviour Detection Framework

This framework is independently working as part of the sensor module in the *Avatar control framework*. This framework enables to analyse hand avatar's trajectory as well as velocity distribution to predict error behaviour of a patient. According to the motor control theory, arm movement can be estimated using minimum Jerk model. We simply integrated this model to estimate avatar's trajectory.

3 SYSTEM EVALUATION

The goal of this evaluation was to explore how different eye movement patterns can inform us about cognitive activities between subjects with and without the avatar communication during the coffee making task. The following section describes the selected participants, the materials, the procedure and the data analysis of this evaluation.

3.1 Subjects

15 men and 1 women aged 21 to 25 were recruited through the Tokyo University of Science to participate in this study (age M = 22; SD = 1.20). All subjects were used to handle computers; however none of them had experience playing video games.

3.2 Material

The experimental setup consisted of a PC (Intel Core i7-4770 CPU with 3.40 GHz) with a 21.5" BenQ screen (1920x1080), and a leap motion controller. The virtual environment was developed using the system Unity 4.5 which was the game development platform. Tobii X2-30 eye tracking system was used to measure their eye movement patterns during the experiment. The eye tracker was attached under the display.

3.3 Procedure

Each participant tried out all two coffee making tasks with/without the avatar communication in a counterbalanced order. The subjects were seated in front of a screen monitor and first received general verbal information about the evaluation, the learning method, and the use of the VK system.

The subjects received two pre-training sessions to familiarize them with the method (i.e., with the avatar or without the avatar). They were in the same condition as the learning condition. The pre-training sessions were designed to familiarize them with the use of the Leap motion controller and the visual instructions. After these two pre-training sessions, the subjects were given a learning session, during which a task was performed using with the avatar or without the avatar. During the learning session, their eye movements were measured by using the eye tracking system.

4 RESULTS AND DISCUSSION

Eye movement pattern during the virtual coffee making task with/without the avatar was measured. Figure 6 shows that the example of the observed eye movements in the case of the task with the avatar.

The dashed line box represents an area that is set to count how often a fixation point were appeared to calculate a state transition rate of the fixation point. These areas were focused on the manipulable objects, instruction area, the avatar, as well as avatar's message which is represented on the avatar.

The average state transition rate was calculated using the obtained eye movement data during the conducted experiment. However, the data of the three subjects out of the 16 subjects were removed from the analysis since there was missing value on their raw data.

Table 1 shows that the average state transition rate of the fixation point in the coffee making task (in without avatar condition). Where, the *others state* in the table is a transition rate counted when the subject's fixation point is out of the focused area in Figure 6.
The result shows that the most frequent transition in this case was 30.89 %, namely the transition from the *Target object state* to the *others state*. In opposite transition direction the result was also high: 28.54%.

Figure 6: Example of the observed eye movements.

In fact, when the task begins, first of all, a subject paid attention to the instruction on the screen. Then if the subject correctly understands the applied task, he/she may take a look at the target object. From the results, however, the subjects mostly see the other objects (11.86%) after the instruction disappeared from the screen. Table 2 shows that the average state transition rate of the fixation point in the coffee making task with avatar. The result shows that the most frequent transition in this case was 10.09 %, namely the transition from the *Avatar state* to the *Target object state*. The transition from the *Target object state* to the *Avatar state* is also high: 10.02%.

After the instruction on the screen disappeared, most of subjects paid attention to the others as same as without avatar condition. However, the transition rate of the *Target objects state*, and *Avatar state* are also respectively high.

Table 1: Average state transition rate (%) of the fixation point in the coffee making task without avatar.

		A pre-transition state		
		Instruction	Target object	The others
post -transition state	Instruction	0.00	5.28	15.15
	Target objects	8.28	0.00	28.54
	The Others	11.86	30.89	0.00

Table 2: Average state transition rate (%) of the fixation point in the coffee making task with avatar.

		A pre-transition state				
		Instruction	Avatar	Message on the avatar	Target object	The others
post -transition state	Instruction	0.00	0.47	1.26	0.81	4.13
	Avatar	1.32	0.00	5.02	10.02	7.44
	Message on the avatar	0.52	5.74	0.00	5.59	5.24
	Target object	1.80	10.09	4.66	0.00	9.76
	The others	3.02	7.23	6.02	9.87	0.00

According to some subject's comments, he/she felt his/her mind-wandering during the experiment in without avatar condition. The mind-wandering is a state of decoupled attention. In this state, usually task-unrelated thoughts also occur.

In contrast, with avatar condition, most of subject reported that they felt friendly toward the avatar, as well as the avatar encouraged a helping behaviour.

5 CONCLUSIONS

We proposed a newly revised Virtual Kitchen system to integrate a new approach of errorless learning (EL) framework using collaborative learning with a virtual agent. In this paper, we described a concept of the proposed system, as well as conducted an evaluation to explore the effectiveness of the proposed EL framework. As the result of the evaluation using eye movement pattern analysis, we found that subject's visual attention was successfully induced by the avatar. In addition, according to the subjective report, we found that the possibility to prevent user's mind-wandering using the proposed framework.

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