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Comparing "Pick and Place" Task in Spatial Augmented Reality versus Non-immersive Virtual Reality for Rehabilitation Setting

Maryam Khademi, Hossein Mousavi Hondori, Lucy Dodakian, Steve Cramer, and Cristina V. Lopes

Abstract— **Introducing computer games to the rehabilitation market led to development of numerous Virtual Reality (VR) training applications. Although VR has provided tremendous benefit to the patients and caregivers, it has inherent limitations, some of which might be solved by replacing it with Augmented Reality (AR). The task of pick-and-place, which is part of many activities of daily living (ADL's), is one of the major affected functions stroke patients mainly expect to recover. We developed an exercise consisting of moving an object between various points, following a flash light that indicates the next target. The results show superior performance of subjects in spatial AR versus non-immersive VR setting. This could be due to the extraneous hand-eye coordination which exists in VR whereas it is eliminated in spatial AR.**

I. INTRODUCTION AND BACKGROUND

Medicine is one of the important application areas for virtual reality, leveraging it for games and scientific visualization [1]. The scope of VR applications in medicine has expanded over the recent years such that today it includes physical therapy (PT) and rehabilitation. VR has been found very effective for both mental and physical therapy.

One of the primary origins of disability in the developed countries is stroke [2]. It is a rapidly developing loss of brain function(s) resulting from lack of blood flow caused by either a blockage, or a hemorrhage [3]. Stroke often affects upper-extremity motor functions [4]. These impairments hold back stroke patients in performing ADL's severely. In an early stage after stroke, patients receive upper-extremity physiotherapy. This includes goal-oriented reaching and pick and place tasks which incorporate real object manipulation [5]–[7]. Methods of motor function assessment such as Purdue Pegboard Test, Fugl-Meyer, or ARAT are based on the subjects' performance in the above-mentioned tasks [8]–[10].

A. *Virtual Reality Therapy*

Unlike conventional and robotics-assisted technologies, Virtual Reality is a cost-effective alternative that let users interact with a simulated world using special hardware and software [11]. Besides, including VR into stroke rehabilitation caused a great increase in patients' motivation to more enthusiastically follow the rehab sessions [12], [13].

B. *Augmented Reality Therapy*

In contrast to VR, Augmented Reality superimposes a computer-generated image on a user's view of the real world. It not only preserves some benefits of leveraging VR such as fully controlled setting and measurable feedbacks, but also needs less computation time to model the 3D environment [14]. In AR, patients experience a more engaging and natural interaction rather than VR. Virtual objects can be manipulated in an intuitive and natural way to maximize learning ADL's [15]. The haptic feeling [16] of the real objects could bring on a more natural interaction. In addition, patients do not need to don external devices attached to their hand or body.

There is consensus amongst therapists that as the interaction of patients with the physical environment is reduced, their ADL's recovery starts to deteriorate [17]. Thus an essential factor to successful recovery is to increase the patient's level of interaction with their environment.

AR environments are flexible enough to provide customization in terms of complexity, required feedbacks, etc., of the exercises based on patients' particular needs [11]. This is especially important, considering that physical conditions of the patients change regularly, and thus adjusted systems should be easily provided.

In addition, augmented reality games have been reported highly engaging for patients undergoing therapy. As [18] investigated, about 65% of patients are likely to give up their physical therapy rehabilitation session. Further, Tinson [19] provided evidence that stroke patients within a clinical unit spent only 30 to 60 minutes per day for actual therapy while 40% of their time, they are not engaged with any activity. In stroke rehabilitation, it is a key factor to have the patient involved with the training exercises frequently; otherwise the desired level of recovery will not be achieved.

C. *Difference in Cognitive Perception of AR and VR*

To have effective interaction with real-world objects, the brain builds a spatial representation of them [20]. For target-oriented movements (e.g. pointing and reaching), the target's relative position to the hand should be converted to the

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body-centered coordinate. There is a transformation chain of reference frames that yields a common body-centered representation [21], [22]. The location of an observed target is coded in retinal coordinates. By considering the relative spatial information of the eye and head positions, we can transform the retinal coordinates to head-centered coordinates. This representation is required to be further transformed into body-centered coordinates by considering the head position relative to the body. When position of the observed target and hand are translated to the common body-centered reference frame, spatial difference between them is calculated which leads to forward plan of an action.

To interact with a non-immersive VR setting (which is widely used in stroke rehabilitation), the subject needs to perform at least one extra transformation to translate the virtual world's coordinate to the body-centered coordinate while it is not required in spatial AR. The extra transformation could be challenging to stroke patients while it may not even be necessary to recover their ADL's.

The paper's main contribution is thus studying the effect of the extra transformation on performance of the subjects in AR versus VR settings. By comparing the score of the subject while performing "pick and place" task in both AR and VR environments, we verify whether it varies at all.

The remaining of the paper is organized as follows: Section II describes the method including the procedure, setup, and subjects. The data analysis is presented in Section III. Finally, conclusion and future work are discussed in Section IV.

II. METHOD

A. Procedure

We developed a pick-and-place task in which a subject pick a cylindrical object and place it inside a virtual square that appears on a random location. The subject needs to reach for the square as if he/she is hitting a target with the object in his/her hand. As soon as the cylindrical object enters the square, it disappears while another target square appears in a different random position, meaning that the subject scores one and has to reach for the next target. The task continues non-stop for 30 seconds and the subject's score is announced at the end. This exercise aims at reaching highest number of targets within a given time interval.

The task of pick-and-place, which is involved in many activities of daily living (ADL's), is one of the main impaired functions stroke survivors most wish to recover. It includes training of primitive postures of the hand including reaching, tilting, and grasping which need control on various hand parameters such as: range, speed, and smoothness of movement. This helps us measure several important performance features that can be used to evaluate recovery of the patient. Giving dynamic audio/visual feedbacks on performance of the user throughout the task such as playing sounds when he/she hits the target and displaying the next square target in response to the patient, the system increases the quality of patient's interaction with it.

B. Setup

We have two setups: AR and VR. Both setups share a table on which the subject performs the task. There is a camera to capture hand movements of the subject connected to a conventional computer that processes the video feed and produces audio/visual feedback in real time. This setup has the potential to be used in clinical as well as home setting (as a tele-rehabilitation system).

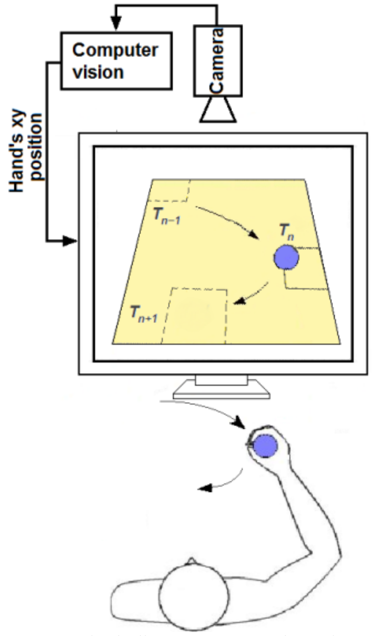

Fig. 1. VR setup including a camera and monitor display

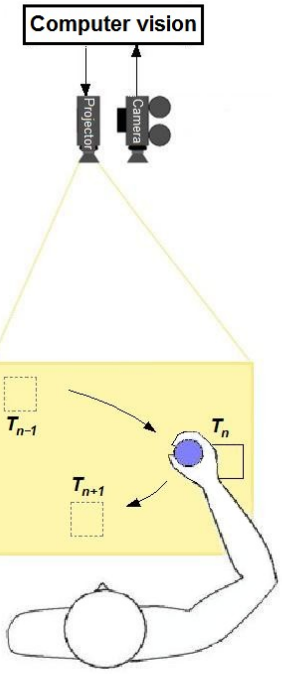

Fig. 2. AR setup including a camera and projector

1) VR setup: In the VR setup, the subject looks at a monitor, displaying random squares and a cursor which represents the subject's hand position while reaching the targets (Fig. 1). We developed a computer vision algorithm to locate and track a color marker attached to a cylindrical object which is held in the subject's hand.

2) AR setup: In the AR setup, instead of having a monitor, we use a projector to superimpose the virtual square targets on the tabletop. This is the same table that serves as a platform for the subject to do the pick-and-place task. Same as VR, the subject's hand movements are captured by a camera, while he is looking on the table and interact with the virtual objects superimposed on it (Fig 2).

Since the key intention of this study was to evaluate the cognitive effect of spatial updating in VR versus AR system, we developed both systems as simple and similar as possible. That is, for VR, we developed a non-immersive system where the subject needs to coordinate his hand movement in real world while his eyes follow the visual feedbacks (i.e., relative positions of his hand and the targets) on the monitor. For AR, we used spatial augmented reality where the 2D virtual objects are projected on the tabletop (i.e., the planar workspace of the subject).

The reason for using 2D AR and VR is that some of stroke patients have difficulty with depth perception of 3D interfaces. Fluet et al. [23] showed that the subjects performed worse with 3D glasses on while looking at a 3D screen as compared to naked eyes looking at a normal screen.

C. *Subjects*

We conducted a within subject experiment including 14 healthy subjects. There were 7 males and 7 females, aged 22 to 45 years old. All subjects performed the task with their dominant hand and they were instructed about the tasks before the experiment. They were told to hit the targets as fast as possible where hitting occurs as soon as the cylindrical object touches any edge of the target squares. They also had a trial test to get familiarized with the task and learn the task. Each subject was asked to play both AR and VR tasks.

III. DATA ANALYSIS

Performance of the subjects in both VR and AR tasks was assessed using the total number of targets that they could hit in a given time interval (30 sec). Fig. 3 illustrates the superiority of AR scores than VR's. Fig. 4 shows the average and STD of the scores, demonstrating that there is no overlap between extremes of means ± SD. The mean value of the AR scores is 19.81 with SD of 2.29. In VR score set, the mean value is 10.94 with SD of 2.41. The result of paired samples t-test analysis (p-value = 1.7291e-008, α=0.05) is statistically significant which rejects the null hypothesis; therefore the means of the samples are not equal.

In case of VR, directions of reaching trajectories of the hand toward the targets are not as accurate as AR. Hence in VR, after the reach is complete, the hand position has more often to be corrected. The source of this error is that in planning the forward command of reaching, precise position of the target is not perceived.

Fig. 5 shows monitored x-y hand position of a random subject while performing the VR task versus the respected target's center position. Note that the circles highlight the over/under shoots. After each over/under shoot, the subject has to take a fraction of a second to correct his hand position. As Fig. 6 illustrates, in AR, this phenomenon is not observed. The time spent to correct one's hand position accounts for different levels of performance in AR and VR. The subjects perceive the target position inaccurately in VR which might be due to the one extra spatial transformation that they have to perform compared to the AR task.

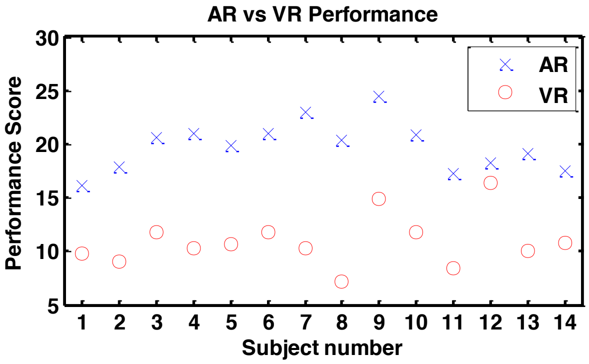

Fig. 3. Performance of the 14 subjects in performing AR and VR tasks

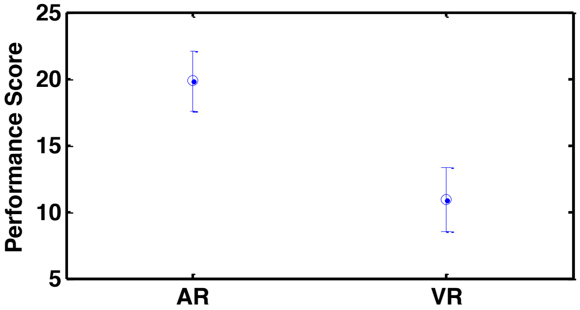

Fig. 4. Mean and standard deviation of the 14 subjects' scores in performing AR and VR tasks

IV. CONCLUSION

As discussed in Section I, there have been significant amount of effort to use VR for rehabilitation. However, learning in a virtual environment can be transferred to the real environment. Transfer of rehabilitation training into real-world ADL's is even easier to accomplish if the training is conducted in as close to the real environment as possible. Spatial representation of the world and how brain deals with it as a gaze-centered transformation is one of the motivations to accept that AR could be a better medium than VR for post-stroke rehabilitation. Besides, engaging in AR therapy seems to be a cost-effective alternative to other forms of therapy such as conventional, robotic, or VR.

We designed a task of pick-and-place that is representing one of the main ADL's that post-stroke patients need to master. This exercise consists of moving an object from point to point following a target. The results show superior performance of subjects in spatial AR versus non-immersive VR setting. This could be due to the extraneous hand-eye coordination which exists in VR whereas it is eliminated in spatial AR.

Future work includes performing this exercise on stroke survivors to warrant that AR can provide a great level of clinical evidence. Furthermore, we have investigated AR perception in healthy individuals under different AR presentations [24] which has to be taken into consideration in developing AR systems for stroke patients as well.

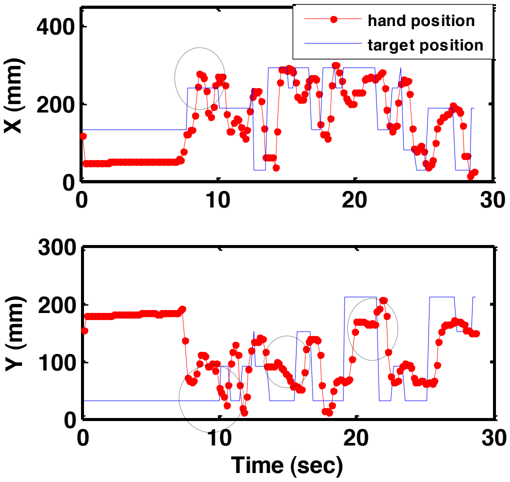

Fig. 5. Monitored x-y hand position of a random subject while performing the VR task versus the respected target's center position. Note that the circles highlight the over/under shoots.

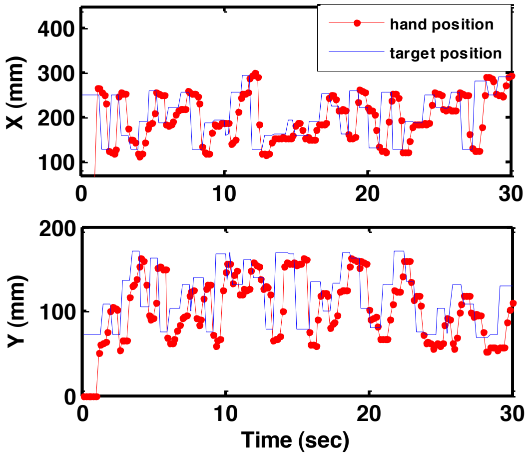

Fig. 6. Monitored x-y hand position of the same subject as Fig. 6 subject while performing the AR task versus the respected target's center position.

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