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Towards Engaging Upper Extremity Motor Dysfunction Assessment Using Augmented Reality Games

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ABSTRACT

Advances in technology offer new opportunities for a better understanding of how different disorders affect motor function. Our aim is to explore the potential of augmented reality (AR) using free hand and body tracking to develop engaging games for a uniform, cost-effective and objective evaluation of upper extremity motor dysfunction in different patient groups. Based on the insights from a study with 20 patients (10 Parkinson's Disease patients and 10 stroke patients) who performed hand/arm movement tasks in AR, we created a set of different augmented reality games for upper extremity motor dysfunction assessment.

Keywords: Augmented Reality Games, Engagement, Upper Extremity Motor Dysfunction, Assessment, Parkinson's Disease, Stroke patients.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Interaction Styles; J.3 [Life and Medical Sciences]: Medical information systems.

1 INTRODUCTION

More and more people are affected by disorders that impair their motor function, e.g. neurovascular diseases, neurodegenerative diseases, and musculoskeletal pain conditions. As the majority of these people are elderly, it becomes a necessity to develop cost-effective evaluation methods for diagnosis, treatment and monitoring of patients with motor dysfunctions.

Currently, each medical discipline uses disease-specific clinical tests to assess motor (dys)functions, based on subjectively scored and low-resolution rating scales, qualitative video analysis, or cumbersome marker-based motion capturing. Current methods often consist of simple, repetitive tasks that may lead to loss of interest of the patients. Unfortunately, variations in tasks and environment are often not considered, despite being essential aspects of daily life. Moreover, adaptation of the tasks according to the actual physical and intellectual capabilities of each patient is difficult.

In this context, mixed reality (MR) interactive systems have a high potential in becoming a viable solution for the assessment of motor function in a simulated environment. MR environments present within a single display real world and virtual world objects together [17]. Virtual reality (VR) totally immerses a user in a completely synthetic world [17]. VR has already proven to offer great opportunities for rehabilitation of several patient groups [3], as it enables real-world situations to be simulated, thereby giving the therapist full control over parameters (e.g. sizes, distances, velocities, trajectories etc.) related to a specific movement of interest. The total visual isolation from the real world, however, may interfere with natural behavior of patients. This issue can be circumvented by using AR, which allows the user to see the real world, with virtual objects superimposed upon or composited with the real world [2]. AR thus supplements reality and provides patients with a more realistic experience that results in more intuitive natural interaction [11].

Interactive AR systems have already been successfully developed for rehabilitation of motor function of the arm and hand. Several AR systems have used a variety of interaction methods such as gloves [15], [19], real objects [1], [13], [14], small markers attached to the hand [11] and contact-less tracking [7], [18]. Thereby, different visualization styles have been used, such as monitors [7], [14], [18], [19] and 2D or 3D rendering in direct environment of the patient (2D: [11], [13], 3D: [1], [15]).

A game that engages players to participate is a strong tool that may transform repetition into a more pleasant activity [9], [10]. Also, an engaging game may motivate patients to make movements showing their full physical capacities, which otherwise they might not make. Most AR systems for rehabilitation involve exercises implemented as games in virtual worlds. These have proven to be an excellent tool to motivate [20] and engage patients to perform repetitive tasks [5] during rehabilitation. Moreover, the simulated environment offers high flexibility with regard to the shapes, positions and trajectories of objects, allowing for adaptation to the capabilities of each patient. Adaptable exercises in which patient's own performance is used to set the targets, are known to increase patient motivation [12].

Nevertheless, research to date has not focused on the use of virtual environments for objective assessment of the type and severity of arm and hand dysfunction. In our work, we design and implement AR games for assessment by translating tasks and movements from current assessment sessions (with real objects) into the virtual world, thereby exploiting the potential of AR in terms of engagement and flexibility.

The following section summarizes the insights that we have gained from different user studies on assessing upper body motor dysfunction using augmented reality games. Based on these insights, we present in Section 3 the design of three games that are meant to assess specific upper body motor dysfunctions. We close the paper with an outlook of future work and upcoming user studies.

2 USER STUDIES

Based on the consultation of 1 clinician, 1 movement scientist and 7 Parkinson's Disease (PD) patients, we designed the game "post office trouble" [6] which focuses on a simple but functional task, i.e., reaching and grasping an object. The game puts the player in the position of a post office worker who has to sort international packages while making as few mistakes as possible. The destination of the package can be determined by recognizing a well-known picture (see Figure 1).

A study on engagement and usability with 8 healthy elderly participants showed that the usability of the game is still quite low, but that there is potential for engagement [6].

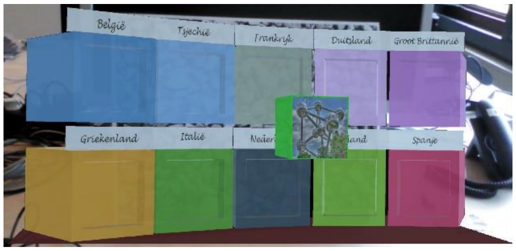

Figure 1: Post Office Trouble main view – the package, showing a picture of the Atomium of Brussels, has to be placed in the delivery box of 'Belgium' (upper left).

Following experiments with healthy users [8], [16], we conducted a study that specifically explored the usability and engagement of different puzzle types (colors/images), interaction modalities (grasping/pointing) and presence of visual feedback of virtual hand (yes/no) in augmented reality. In this study, 20 patients (10 PD patients and 10 stroke patients) performed hand/arm movement tasks in four different conditions in AR and one condition in real world (see Figure 2).

In this context, it was essential that patients were able to naturally interact with the virtual environment and to perceive the correct 3D position of objects around them. For this purpose, we used a Cinoptics AIRO II Optical See-Through (OST) head-mounted device (HMD) (2 OLED displays, each with a 1280×720 resolution, aspect ratio 16:9 and FOV ≈ 40° diagonal) for stereo visualization of virtual content, allowing for an accurate depth perception of virtual objects. We used the parameters of the HMD (e.g., screen width, screen height) and some average measures for humans (e.g., distance between the user's eyes) to position the two virtual cameras for stereo rendering of the virtual content for the left/right eyes.

The patient sat in front of an A0 sized tracking marker (see Figure 2) that allowed for an interaction space that was large enough to position virtual objects ipsilateral and contralateral to the tested arm, above and below shoulder level. We tested different backgrounds for the marker. The "stones" picture proved to be very robust in dealing with the occlusion problem due to the position of the hand in front of the RGB camera on top of the HMD.

Figure 2: Stroke patient during the experiment.

While playing the game in AR, the patient's movements were recorded to allow for objective, quantitative evaluation of their motor function. The patients' hand movements were tracked using the Intel® Realsense F200, which was mounted on top of the HMD. The patients' arm and trunk movements were tracked using the Kinect™ v2 for Windows, which was placed at a distance of 3 meters with approximately 45° angle relative to the left side of the patient (see Figure 2).

A comparison of movement characteristics revealed that moving a real object was more targeted and took less time than moving a virtual object. Moreover, movements in AR were characterized by reduced variability (in angle and velocity) of the upper arm and more pronounced trunk displacement for ipsilateral targets. It is plausible that these differences are largely attributable to the difficulties that many patients encountered in achieving natural interaction with the virtual content. The usability of our AR system was relatively low. Still, 24% of the SUS scores [4] were above the threshold value of 68 and, from our observations, these corresponded to the situations where the hand was correctly and robustly tracked (i.e., the hand was not erroneously identified as the contralateral hand and loss of hand recognition was minimal). This suggests that many barriers of the present prototype are due to technological limitations, rather than the AR setup itself. The AR game may be suitable for assessing the hand and arm function of mildly affected patients if usability can be further improved.

3 Game Design

Based on the above findings, the game design first aimed at improving usability. As a first step, we considered a different sensor for hand tracking (i.e. LeapMotion instead of the Intel® Realsense F200) to provide more robust hand tracking and more natural interaction, allowing recognition of more postures and gestures of the hand. In addition, we enlarged the interaction space by means of tracking multiple markers to offer more flexibility in the patients' movements.

We further used the feedback from our previous experiments and discussions with 1 clinician and 2 movement scientists to design three AR games that extend the set of movements required in the "post office trouble" game. These three small AR games are currently being tested both with PD and stroke patients and a control group.

In all three games, virtual hand visual feedback was provided to help patients interact with the virtual content. In Figures 3 - 5 the blue ellipsoid represents the index finger while the yellow one is the thumb.

Also, visual cues were provided as 3D lines between the center of the view of the HMD and the virtual object of interest, when this was located outside the view of the HMD. Depending on the hand chosen to solve the AR tasks, the whole virtual scene is mirrored.

3.1 Game 1 – Balloons

We define 4 virtual movement directions in front of the patient (i.e. upper left, upper right, lower left, lower right) by rotations with different predefined angles. The center of all rotations is the estimated position of the shoulder of the tested arm.

On each of the 4 directions a faraway balloon is displayed, and the patient is asked to touch (intersect) with the index finger the virtual line between the balloon and the shoulder (the green line in Figure 3), as far as they can. Thus, the 4 "corners" of the reachable workspace are determined.

Twelve balloons are then displayed (one at a time) at various positions and at random depths within the reachable workspace. The patient is instructed to touch the balloons as accurately and quickly as possible. To provide feedback and an engaging experience, the balloons explode when being touched.

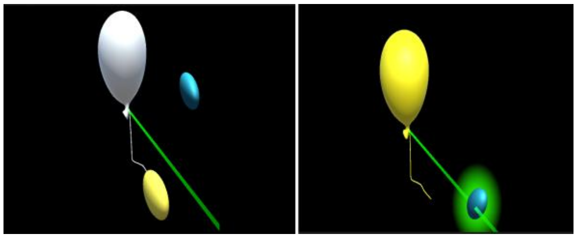

Figure 3: A screen capture in Unity3D with the AR scene for determining the reachable workspace of the patient. The dark grey background becomes almost transparent when displayed in the OST-HMD and it is practically invisible to the user.

The goal of the Balloons game is to determine the reachable workspace of the patient where 95% of daily life activities take place and to measure the speed and the goal-directedness of reaching objects within this space.

3.2 Game 2 – Melody Cubes

Twelve empty cubes with 3 different sizes are displayed in front of the patient, within their reachable workspace, as determined in game 1. The filled cubes, which can be grasped and moved, appear on the left side, one of each size at a time. Each cube color turns into a lighter shade when it is grasped (see Figure 4). When a filled cube is placed inside an empty one with similar color, another filled cube is generated until the maximum number of 4 is reached. Additionally, a 12th part of a well-known melody is played. Once all the empty cubes are filled, the complete melody is played as reward for completing the exercise.

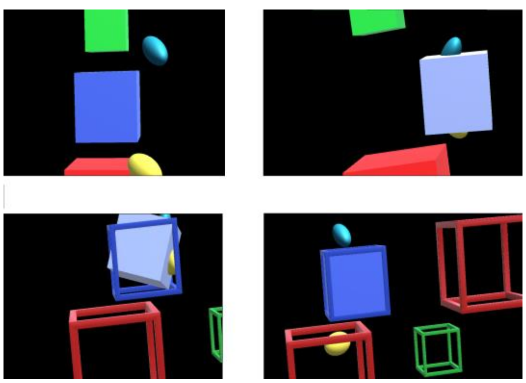

Figure 4: A screen capture in Unity3D with the AR scene for reach and grasp task

The goal of Melody Cubes is to evaluate the patient's ability to adjust hand opening (i.e., the distance between the index finger and the thumb) to objects of different sizes that have to be moved to a destination.

3.3 Game 3 – Hungry Squirrel

The major activity of the Hungry Squirrel game is to grasp and move walnuts into a basket while avoiding a squirrel (see Figure 5). Three situations are possible, each appearing 2 times for each of the two targets in front of the patient (one is above shoulder; the other is below shoulder), in a preset order:

a) No squirrel between the object and the target;
b) The squirrel appears from the beginning (no surprise element);
c) The squirrel appears after the patient starts moving the objects towards the target.

In cases b) and c) the squirrel is placed at half distance between the initial position of the walnut and the basket. The visual feedback provided for interaction can be seen when the patient grasps the walnut; when the walnut is placed into the basket or the walnut touches the squirrel (see Figure 5 lower left and right corner).

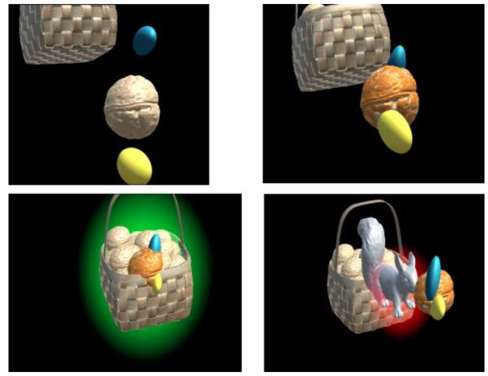

Figure 5: A screen capture in Unity3D with the AR scene for moving objects toward a target, avoiding obstacles.

The goal of the Hungry Squirrel game is to evaluate if and how patients are able to adjust their movement trajectory in order to avoid an obstacle in the way to their target.

4 Conclusion

Based on several user studies with healthy persons and patients, we designed a set of three games for upper body motor dysfunction assessment. The goal of the games is to provide an objective and quantitative measurement of human motor function in a controlled and engaging environment that offers the possibility to perform a variety of movements. Just from the initial observations while testing these games, we can say that they are more engaging and usable than our previous approaches. This is mainly due to a much more robust hand tracking, but also due to simple but funny game elements (exploding balloons, completing a melody, hungry squirrel). As future work, we will complete a large study involving in total 10 Parkinson, 10 stroke patients and 10 control persons. Based on the results of this study, we will consider different sensors including data gloves to further improve hand tracking, for a higher accuracy of the positions of the joints. In addition, enlargement of the interaction space (up to an entire room) will also be a necessary prerequisite for extending the capabilities of the current setup to full-body assessment, combining upper-body movement evaluation with gait analysis. Finally, we will consider using a Video See-Through HMD to achieve a more precise alignment of the virtual hand with the real hand, provided that patients do not get dizzy while wearing it. Also, the effects of Augmented Virtuality or VR for assessments of motor functions in different patient groups could be explored.

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