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A Haptic Serious Augmented Reality Game for Motor Assessment of Parkinson's Disease Patients

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Abstract

In the clinical community there is a need for assessment tools that allow for objective, quantitative and valid measures of motor dysfunction. In this paper, we report on the design and evaluation of a serious game that engages patients with Parkinson's disease in upper extremity (hand/arm) movements. The game employs augmented reality to show virtual movement targets, i.e. candies falling from a conveyor belt, and a haptic game controller to catch the candies, that is able to acquire quantitative data about the patient's movement. This paper first describes the design process of the game and the system components. Secondly, we present results of our small quantitative evaluation study (N=11, age: 26-60, healthy persons) regarding the usability of the system, the task load and user experience of the game. Our findings show that the system has a relatively good usability and the game is engaging, but there is still need for technical improvement with regard to tracking the controller in 3D space.

Keywords: Augmented Reality, Optical See-Through Head Mounted Display, Haptic Device, Serious Game Design, Assessment of Upper Extremity Motor Dysfunction, Parkinson's Disease.

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.

1. Introduction

Quantitative, objective and valid assessment of motor dysfunction is important for selection and evaluation of treatment as well as monitoring disease progression of various neurological conditions, such as Parkinson's disease (PD). Currently, every medical discipline uses its own disease-specific clinical tests, which mostly involve subjectively scored, low-resolution (i.e., insensitive) clinimetric assessments. These evaluation methods focus on "body functions and structures" (e.g., range of motion [ROM] or stiffness) or "activities" (e.g., ability to perform functional tasks like grasping an object or pouring water into a glass within a prescribed time), often without considering variations in task and environment that are encountered in daily life. Therefore, there is a need for development of new assessment methods that provide objective, quantitative measures of upper body motion dysfunction while the patients perform natural movements in a challenging and engaging environment.

To this end, we explore interaction modalities for patient-adaptive assessment tools that motivate patients to use their affected upper extremity to its full capability, which may ultimately lead to better insight into motor dysfunction. A well designed game that engages the player to participate, is a strong tool [5] that may encourage patients to make the movements necessary for assessment of motor dysfunction, and so enabling the doctor to make the right clinical decision.

This paper focuses on the design of an Augmented Reality (AR)-based serious game in which a user reaches for virtual targets while holding a haptic game controller. The game is implemented in the Unity3D game engine [13] using an Optical-See Through Head Mounted Display (OST-HMD), which shows the virtual content. Our choice for an OST-HMD was determined by the patients' safety, especially for future scenarios when they may wear the HMD while walking around. Because the game controller is directly visible through the OST-HMD and thus exist in both virtual and real spaces, the alignment between the virtual augmented world and the real world has to be taken into account. Therefore, the haptic game controller is fitted with visual markers that determine the location of the virtual equivalent. In addition, the controller can be equipped with sensors (e.g., accelerometer and gyroscope) to allow for objective, quantitative measurements of upper extremity movements in PD patients.

Section 2 of the paper describes the design of the game and the controller. In Section 3 a technical description of the whole system is presented, followed by a study on usability and game experience in Section 4. The paper ends with a conclusion in Section 5.

2. Game Design

Motivating users to make movements at the limit of their physical capabilities is a challenging goal. Motivating patients to move their affected limbs might be even more difficult, but is essential for assessment of motor dysfunctions. However, applied games have the potential to increase user motivation for physical activity to its limits. For instance, dance is recognized as a potential effective therapy for people with PD [4] and immersive virtual reality games seem to reduce pain experience during wound care and rehabilitation [9]. Theoretically [10], applied games change the real-world experience of a user into an engaging game-world experience. When a user is engaged in a game, i.e. experiencing a game-world, real-world limitations are typically diminished in favor of game-world challenges and motivations (cf. pain reduction in virtual reality immersion). Subsequently, the user experience in game worlds is used in serious game to facilitate realization of aimed-for transfer goals in the real world. For instance, "exergames" can be used to increase the health-related transfer effect of elderly [7].

For the present project, our aimed-for transfer effect was motor assessment of PD patients. In order to design a context-fitting game that is motivating for our end-user, we applied a user centered design approach in which medical experts were interviewed as to the details of the transfer effect and PD patients as to their game world preference and cognitive/physical capabilities. In a previous game design and implementation [2,3], we focused on simple functional tasks of the upper extremities, i.e. tasks that allow for

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determining the reachable workspace of a patient. We used free hand tracking for the game interaction. However, this led to an unnatural hand movement, due to the fact that the optimal pose for the hand tracking was with the palm facing the sensor on top of the HMD [2,3]. The present design incorporates a haptic game controller for interaction to allow users to make more natural hand movements.

Thus, based on our earlier experiences and interviews with medical experts, for the present project our transfer effect is detailed as to motivate PD patients to perform arm and hand movements for reaching an object. In order to design a game world that fits the end user, we interviewed 4 PD patients at the Leiden University Medical Center. All patients had experience playing simple games and indicated that the difficulty or pace of games should not create stress as it would result in the worsening of symptoms. We aimed to create a challenging and engaging game world that involves reaching movements.

Based on these findings of experts and end-users, we developed a simple concept game that could be implemented using the OST-HMD. The game is situated in a candy factory where conveyor belts move the candies to be collected in a basket. The objective of the game is to catch the candies before they reach the front edge of the conveyor belt and fall into a digital void (see Figure 1). The player manipulates the game controller (see Figure 2) that determines the position of a virtual basket (see Figure 1). When this controller is held in front of the RGB camera mounted on top of the HMD (see Figure 2), it will be recognized and a virtual basket will appear in the virtual world, overlaying the top part of the controller.

The first level of the game is basically a tutorial, teaching the user how to play the game and allowing them to get used to the technology. In this level there is one conveyor belt. When the basket is placed in front of the conveyor belt, a candy piece appears at the back of the belt and will slowly move towards the player. When a piece of candy is successfully caught the game controller will slightly vibrate and a "positive" sound is heard; otherwise a "cartoony" falling sound will be heard.

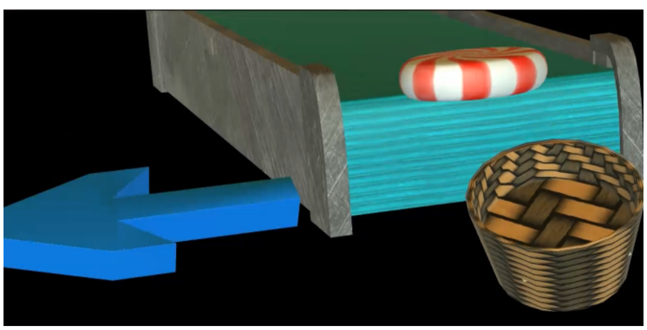

Figure 1: Screen capture with Level 2 of the game as seen by the user. The black background becomes almost transparent when displayed in the OST-HMD and it is practically invisible to the user. All the virtual objects (conveyor belt, arrow, candy and basket) are superimposed on the real world seen directly through the OST-HMD by the user.

In the second level, the difficulty of the game is increased by introducing two conveyor belts. The game starts when the basket is placed between the two conveyor belts. Then candy pieces appear at random time intervals on one of the conveyor belts. Because of the limited field of view (FOV) of the OST-HMD it is necessary to "look around" to see both conveyor belts. To reduce inconvenience related to the limited FOV, an arrow (see Figure 1) points to the direction of the conveyor belt where the next candy piece will appear. After catching ten candy pieces, the level is completed.

3. System Architecture

For our system, we use AIRO II OST-HMD from Cinoptics (2 OLED displays with a resolution of 1280x720, aspect ratio of 16:9 and FOV of ~ 40° diagonal). On top of the AIRO II an Intel® RealSense F200 Camera is mounted so that the angle between it and the head mounted display is approximately 12 degrees. We used this value together with the parameters of the HMD (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 game is implemented using Unity3D running on a laptop (CPU Intel Core i7-3630QM, 8GB, GPU AMD HD 7970M). The Vuforia Target Tracking API [11] was used for two different purposes: first, the recognition of a big 2D marker (an A1 size picture of rocks) to provide a reference point for placing the virtual content in the real world; and secondly, detection of a 3D cube marker to track the movement of the haptic game controller and to augment it with the virtual basket. Thereby, the tracked movements of the game controller are collected and stored for later motor dysfunction assessment.

The haptic game controller consists of a 3D printed handle with a cube that featured five tracking images (one on each side, except the bottom side). Inside the controller, there is an Arduino mini pro 3.3Volt 8 mHz ATmega 328 in combination with an Adafruit Bluefruit EZlink bluetooth module and a coin vibration motor (3V/70mA) to give haptic feedback to the user. An Ultrafire 18650 3000mAh 3.7 Volt lithium-ion cell is used to power the controller. The device also contains a MPU-6050 chip with accelerometer and gyroscope to collect further objective and quantitative information for motor dysfunction assessment.

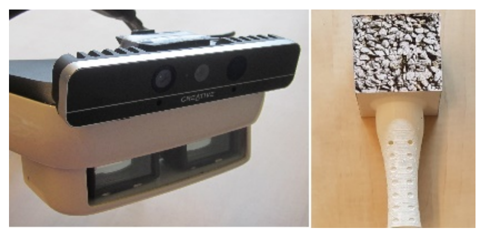

Figure 2: (Right) the OST-HMD and (Left) the controller used to play the game.

4. Study on Usability and Game Experience

We conducted a study on usability and game experience with 11 healthy people (7 male and 4 female, aged between 26 and 60, M=36.91, SD=12.36). The participants had to play the two different levels as described in Section 2 (see Figure 3).

Figure 3: Participant playing the game during the experiment.

Afterwards they were asked to fill in three validated questionnaires on a 5 point Likert scale: the Game Experience Questionnaire (GEQ)[8], Task Load Index (TLX) [6] and System Usability Scale (SUS) [1,12].

For the SUS, a score above the threshold value of 68 points represents good usability. The scores in our experiment ranged from 47.5 to 95 (M=70.7, SD=14.6). Six out of 11 participants scored the system above the threshold value, suggesting that the usability of the system was decent. However, it means there is ample room to improve usability. Participants indicated that biggest problems with usability were related to the limited FOV of the OST-HMD and the fact that the tracking of the controller was lost frequently, especially during fast movements or when the controller was held far away from the RGB camera mounted on the HMD.

The GEQ questions are grouped in seven categories [8]: competence, sensory and imaginative immersion, flow, annoyance, challenge, negative affect and positive affect. The results for each category are summarized in Figure 4. The game scored high on competence, flow and positive affect, indicating that the users enjoyed playing the game, felt absorbed by the game and had the overall feeling that they were successful, skillful in completing the game. The lower score on negative affect indicated that the users did not feel bored. Mixed reactions on annoyance, challenge and sensory and imaginative immersion, indicated that the game can be improved aesthetically and should feature various difficulty levels for different skill levels. Users indicated that annoyance was mainly related to the system losing track of the game controller.

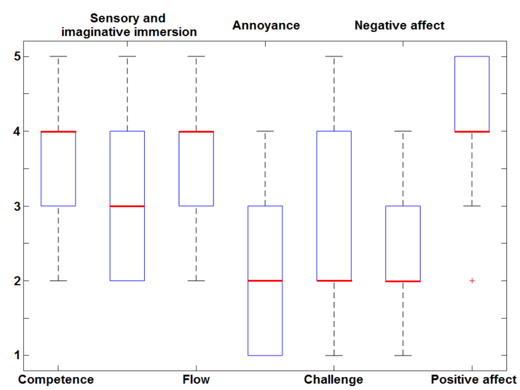

Figure 4: Results for each of the 7 dimensions of GEQ.

Scores on the TLX, displayed in Figure 5, indicated that participants did not feel irritated, discouraged, insecure or stressed and felt overall successful in accomplishing the task. Mixed reactions on the mental demand, physical demand, pace of the task and the amount of work put into the task indicated that the game difficulty was not fit for every participant, being considered sometimes too easy or too difficult.

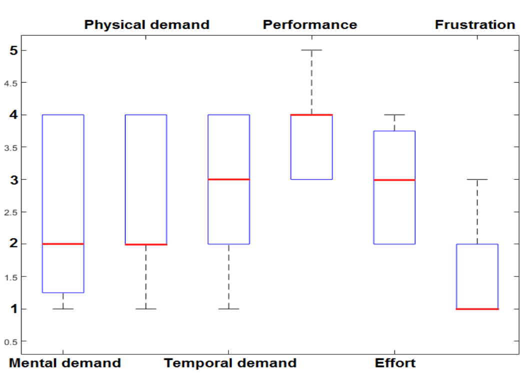

Figure 5: Results for the TLX questionnaire.

5. Conclusion

The results indicate that the designed game and the haptic controller are a successful first attempt in developing a game that motivates users to move their shoulder, arms and hand. The system incorporates a haptic controller equipped with sensors that may be used for the objective, quantitative assessment of people with PD. Alternatively, future use of the design may be self-monitoring of patients at home, but more work on the extraction and medical interpretation of the acquired data is needed.

However, results of the present study suggest that tracking performance of the controller was not always sufficient for smooth interaction, resulting in a longer learning curve and annoyance. Future research should indicate whether other types of tracking technology, like LED tracking, can provide better performance. Further developments of the game should be tested in the target group (i.e., PD patients).

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