Upper-body interactive rehabilitation system for children with cerebral palsy: the effect of control/display ratios

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ABSTRACT

We have developed a virtual reality rehabilitation system using upper-body interaction with Microsoft KinectTM. With the use of KinectTM, the system enables a patient a full-range of avatar movements to adapt the Control/Display (C/D) ratio of a limb’s position in 3D space. In this paper, we have explored the effectiveness of C/D ratios in our prototype application to analyze user performance, work load, and user enjoyment with university students without motor impairments. Our findings suggest that the C/D ratio is related to task difficulty, movement strategy, and user motivation.

1. INTRODUCTION

Cerebral palsy (CP) is a term that refers to various motor impairments caused by damage to the central nervous system during foetal development (Krageloh-Mann and Cans, 2009). This disorder affects approximately 0.3% of births (Krageloh-Mann and Cans, 2009) and often manifests itself during childhood as a difficulty to use one side of the body (hemiparesis). Motor deficits encompass difficulty in planning and executing movement. Children with impaired motor function need physical therapy in order to improve their movement patterns and to maintain the range of the affected arm and leg joints. Constraint-induced movement therapy (CIMT) if often used to improve upper limb function (Hoare et al., 2007). CIMT encourages the use of the affected hand by restricting the unaffected hand and asking for intensive movement with the impaired upper limb. To be efficient, this approach demands intensity. Having the “good” arm blocked for long periods of time can generate frustration in the child and might not be applicable in a long-term rehabilitation program. More “child-friendly” approaches are needed during the neuro-development of children with CP. For example, rehabilitation programs could offer therapeutic games that are specifically designed to encourage the child to use their affected limb.

The field of Virtual Reality (VR) has grown dramatically as an emerging tool that has great potential for use in rehabilitation (Le Gal et al., 2008). VR systems offer the capability to achieve rehabilitative goals through the use of real-time feedback and adaptive strategy/difficulty (Rose et al., 2000). Traditional CP therapy involves repetitive movement as a key means of motor rehabilitation. However, such traditional therapies are often of little interest to a child, affecting his motivation to continue such therapeutic activities (Schmidt and Lee, 2005). VR offers boundless variations of augmented feedback, objects, orientations, and creative environments. Likewise, all parameters of a Virtual Environment can be varied under repeatable conditions (Cikajlo and Matjacic, 2009) so that the VR remains motivating and entertaining (Rand, 2007).

The objective of this project was to develop a game, adapted to children with CP, that would encourage the child to use their affected hand and, thereby, to improve their movement and motor control of the limb. A rather simple task was chosen: to catch objects, traveling in various directions, with one hand using a Microsoft KinectTM sensor. A specialized algorithm was developed to aid the Kinect sensor in recognizing the paralyzed arm’s limited field of movement. Additionally, an application was developed to penalize the use of the unaffected arm to encourage the child to use the affected arm.
2. RELATED STUDIES

Virtual rehabilitation is conducted through the use of virtual reality (VR) and virtual environments (VE) within rehabilitation. VR and VE can be described as a multi-sensory, interactive, computer-based environment, that simulates a real world environment. Virtual rehabilitation has potential therapeutic benefits due to the immersive graphical nature and the realistic interaction techniques; it has attracted considerable attention in research and clinician communities (Halton, 2009). Besides its immersive nature, VR is able to provide motivation whereby individuals tend to have fun and are more motivated to continue rehabilitation (Berger-Vachon, 2006). In addition, the advantages associated with the use of Virtual Rehabilitation are that the same VR hardware can be used for various types of patients, as well as for various types of exercises (Burdea, 2003).

There are a few Virtual Rehabilitation systems for motor-learning rehabilitation using full-body interaction. IREX (Kizony et al., 2003) is a projected video-capture system. A single camera is used for vision-based tracking to capture the user’s movements. The captured video images can be displayed on a connected TV screen, corresponding in real time to his movements. Its suitability has been investigated for use during motor or cognitive rehabilitation (Kizony et al., 2002). The EyeToy game also uses a single camera to capture the user’s movements. Interaction with an on-screen user avatar can only track movements in a single plane and is not able to record body movements (Fitzgerald et al., 2007). The Cybex Trazer® employs a single infrared beacon which is mounted on a belt worn around the waist of the user. The user’s motion is captured by monitoring the sensor’s position by the tracker bar (Fitzgerald et al., 2007).

In the previously-mentioned studies, the investigated systems have limited working space visually since the user’s movement is directly projected on a screen via a tracking system, even though a patient with impaired motor function has a limited range of movement. If the programmed training is successfully conducted, a patient might feel confident since he feels his movement range gradually improving. However, in most cases the training takes place over a long time and we believe that these patients have difficulty keeping their motivation high until they see their improved movement. Furthermore, users’ limited working space may limit system capability such as task variation and interaction techniques for the rehabilitation task.

The goal of the project was to develop a full-body, interaction, virtual-rehabilitation system using Microsoft Kinect, which enables children with hemiparesis to improve their affected hand. Our purpose is to assist them in a full-range of avatar movements to adapt the Control/Display ratio of limb/joint positions in 3D space from the Kinect. In this paper, we begin to explore the effectiveness of C/D ratios in our prototype application to analyze user performance, work load, and user enjoyment with university students without motor impairments.

3. PROPOSED SYSTEM

3.1 Hardware configuration

Figure 1 illustrates the proposed system configuration, composed of one 60” TV monitor, one laptop, one Microsoft Kinect sensor, and one rehabilitation application running on the laptop. The application renders a visually-realistic 3D environment.
3.2 Virtual rehabilitation application

The rehabilitation application was developed to support rehabilitation for children with impaired motor functions. The application supports the rehabilitation of arm movements through natural, full-body interaction.

Figure 2 shows a screen shot of the main interface of the rehabilitation application. In the application, an avatar is displayed in the center of the TV monitor. The avatar represents a user’s full body movement. The user controls the virtual avatar and attempts to touch a virtual object that moves around within the virtual space. The application can change the properties of the virtual object such as direction, velocity, size, shape, and so on.

The application uses the Kinect sensor to obtain 3D positional data for the user’s left/right hands, wrists, elbows, and shoulders. However, the user’s avatar hand movements are represented alongside the circle which is displayed in the center of the screen. That is, the positional data is converted to 2D positional data and rendered in real time via the user’s avatar hence providing visual feedback to support the reduction of motor error.

Figure 2. Screenshot of rehabilitation application – C/D ratio is set up for both hands: 2.0 for the left hand, and 1.5 for the right hand. Both the left/right hand avatar disappear when the task begins. The degree of the object’s direction is rotated counter-clockwise.

In the training mode, the system supports two interaction techniques: One hand (only the left or right hand is used) and both hands (left/right hands are used simultaneously or independently). Each interaction technique trains the subject’s arm movements through a virtual-object touching task in which a user is required to touch a target object traveling in various directions within the virtual space using their activated hand (e.g. left hand if the selected interaction technique is left hand interaction).

3.3 Hand movements with a Control/Display (C/D) ratio

The Control/Display (C/D) ratio is a ratio between the amplitude of movement of the user’s real hand and the amplitude of movements of the virtual cursor (Dominjon et al., 2005). In most cases using a Virtual Environment, the C/D ratio may be set up based on the user’s physical working space where the user is able to move in the virtual work space with a full range of movements.

Since a patient with an impaired motor function has a limited range of movement, the system assists in full-range avatar movements to change the C/D ratio. As shown in Figure 2, two avatars are displayed simultaneously for each hand: The user avatar (UA), and the amplitude user avatar (AUA). The UA’s movement corresponds to the user’s actual limited movement. The AUA’s position is updated based on the C/D ratio. For example, if the C/D ratio is set at 2.0, then the AUA’s movements will be double the range of the UA’s movements.

3.4 Sample rate of the captured joint position

If the sample rate of joint positions is not frequent enough, the data would not provide enough information about a patient’s’ movements. The sample rate was simulated in each type of designed training mode. The sample rate data were collected while each mode is playing for 2 minutes. As a result of the simulation, the average sample rate was 20.67 Hz (SD = 2.51). According to the simulated average sample rate, the joint positions were recorded about 20 times per second.
4. SYSTEM EVALUATION

The purpose of this evaluation is to assess the effectiveness of a C/D ratio in terms of user performance, work load, and user enjoyment. In this paper, we assess the prototype system in the one-hand condition (only using the user’s dominant hand).

4.1 Participants

Twelve participants (9 male and 3 female), between 19 and 30 years (Mean, M = 24.3, Standard Deviation, SD = 3.3 years) were used from university students. All participants were right-handed, in good health, and had not used a game using Kinect.

4.2 Apparatus

One Kinect was used for training exercises and experimental tasks (see Figure 1). The Unity3D platform was used for graphic rendering. Kinect was updated to about 20Hz. All tasks were performed using a TOSHIBA laptop running on Windows 7 with an Intel Core i7 720QM processor and 4GB of memory. All subjects were at a distance of about 3 meters from the Kinect sensor.

4.3 Task Procedure

In this study, the independent variable is the C/D ratio. Three main tasks were conducted using three different C/D ratios: 1.0 (no amplitude), 1.5, and 2.0. To remove the sequence effect, the three main tasks were completely randomized. Each main task contains a training session, a trial session, and a questionnaire session.

The purpose of the training session is to learn how to play the object catching trial using Kinect. In the training session, the C/D ratio was set at the same value as the trial session. Between 20 and 40 objects were represented randomly from different directions to cancel the training effect. Each object was represented every 2 seconds. The subjects were required to catch the object with their dominant hand.

In the trial session, 60 objects were used. The subjects were required to use their dominant hand to catch the 60 objects. The applied direction of the object was visually different among the three C/D ratio conditions: [−40°, −5°, 60°] for C/D 1.0, [−25°, 27.5°, 125°] for C/D 1.5, and [10°, 60°, 190°] for C/D 2.0. Their degree was randomly selected and applied. However, every time an object with an even order number was applied, the subjects were required to put their dominant hand on their side, that is, to its initial position of −70°. Each object was represented every 2 seconds.

After concluding the trial session, the subjects were asked to complete a NASA TLX questionnaire, and a Physical Activity Enjoyment Scale (PACES) questionnaire.

5. RESULTS

Three dependent variables were used for analyzing the subject’s performance and the subjective data in the conducted tasks: Task success rate, work load, and enjoyment. A one-way ANOVA analysis was carried out to find the effects of the dependent variables. Table 1 shows the results.

Table 1. Results of variance analysis.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Task success rate</th>
<th>NASA TLX</th>
<th>Physical Activity Enjoyment Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-D ratio df(2,32)</td>
<td>F = 6.57**</td>
<td>F = 1.77</td>
<td>F = 2.67 †</td>
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<tr>
<td></td>
<td></td>
<td>F = 1.97</td>
<td>F = 0.84</td>
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<td>F = 4.01*</td>
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<td>F = 0.03</td>
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<tr>
<td></td>
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<td>F = 0.23</td>
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</tbody>
</table>

† p < 0.1, * p <0.05, ** p<0.01

5.1 Task success rate

The task success rate was defined as the user success rate which is the percentage of tasks that users complete correctly.
A significant effect was found, $F(2,32) = 6.57$, $p = 0.004$. Bonferroni follow-up tests revealed that the C/D ratio 1.0 condition (M = 99.72%, SD = 0.96%) was significantly higher than the C/D ratio 2.0 condition (M = 90.28%, SD = 10.77%). Furthermore, the C/D ratio 1.5 condition (M = 97.50%, SD = 3.51%) was significantly higher than the C/D ratio 2.0 condition.

5.2 Workload

The NASA Task Load Index (TLX) was used to measure the workload of the subjects. It contains six subscales: Mental demands, physical demands, temporal demands, performance, effort, and frustration. All items were rated on a 7-point scale. Concerning mental demand, physical demand, temporal demand, effort and frustration, a low value indicates less workload experienced, whereas higher values indicate more workload experienced. Concerning performance, lower values indicate better performance, and higher values represent poorer performance.

Concerning mental demand, physical demand, performance and frustration, there was no significant difference for the different conditions. For temporal demand, ANOVA revealed a significant trend for condition, $F\,(2,32) = 2.67$, $p < 0.1$, Bonferroni follow-up tests revealed that the C/D ratio 2.0 condition (M = 3.67, SD = 1.15) was significantly higher than the C/D ratio 1.0 condition (M = 2.67, SD = 0.98). For effort, ANOVA revealed a significant trend for condition; $F\,(2,32) = 4.01$, $p = 0.027$, Bonferroni follow-up tests revealed that the C/D ratio 2.0 condition (M = 3.41, SD = 1.24) was significantly higher than the C/D ratio 1.0 condition (M = 2.08, SD = 0.67).

5.3 Enjoyment

The Physical Activity Enjoyment Scale (PACES) was used to assess enjoyment (Kendzierski and DeCarlo, 1991). PACES is an 18-item questionnaire that measures an athlete’s perceptions of enjoyment derived from participation in a physical activity such as sport. Average value of the 18 subscales was used as the Enjoyment.

For Enjoyment, ANOVA revealed that there was no significant difference among different conditions.

6. DISCUSSION

The aim of the study was to explore the capability of the prototype application to assess user performance, workload, and enjoyment for the purpose of rehabilitation.

The results showed that there was a significant effect on task success rate and effort, as well as a significant trend on temporal demand. For the task success rate, performance in the C/D ratio 1.0 condition was significantly higher than that in the C/D ratio 2.0. Furthermore, performance in the C/D ratio 1.5 condition was significantly higher than that in the C/D ratio 2.0. These results indicate that the value of the C/D ratio affects task difficulty. Indeed, during the main task, the applied direction of the object was visually different among the three C/D ratio conditions: [-40°, -5°, 60°] for C/D 1.0, [-25°, 27.5°, 125°] for C/D 1.5, and [10°, 60°, 190°] for the C/D 2.0 condition. However, the user’s real hand movements are the same among these C/D ratio conditions. During interviews, a couple of subjects made a comment about the effect of the visual gap. That is, with a C/D 2.0 ratio they were required to make more of a cognitive plan for object targeting by controlling their hand movement speed, as well as adjusting hand position. This indicates that even if the real hand movement area is the same among different C/D ratios, the user’s behavior was different, that is, the user’s movement strategy for the task could change.

These effects were observed on the resulting workload. The temporal demand in the C/D ratio 2.0 condition was significantly higher than that in the C/D ratio 1.0 condition. Furthermore, effort in the C/D ratio 2.0 condition was significantly higher than that in the C/D ratio 1.0 condition. Due to the visual gap, subjects commented that they were required to make an effort to complete a task with a C/D 2.0 ratio as well as feeling time pressure with a C/D 2.0 ratio. Concerning frustration, we expected that users feel stress for avatar operations in C/D 1.5 and 2.0 ratio conditions. However, there was no significant effect depending upon the condition. According to the user’s comments, he felt comfortable for the C/D 2.0 ratio condition because of the speed of the avatar’s movement. For the C/D 1.0 ratio condition, he felt uncomfortable because the avatar’s movement was slow. However, there was also an opposite comment for this point of view.

Concerning enjoyment, there was no significant difference among these C/D ratio conditions. However, according to the users’ comments, the user could be challenged, excited, and motivated to perform the task with a C/D 1.5 and 2.0 conditions. Concerning the C/D 1.0 condition, the users commented that the
movement was realistic, natural, and simulated. This result indicates that user motivation can be changed with different C/D ratios. Pasch (2008) indicated that user motivation was related to movement strategies. They employed a Wii Boxing game for their study, hence the result was for a specific game scenario. However, our results take into consideration a more generic point of view since the effect was assessed on a primitive interaction level to change the C/D ratio. This finding could possibly be used for designing adaptive, motivational instruction for any kind of VR rehabilitation system.

7. CONCLUSION

In this study, we explored the effectiveness of C/D ratios in our prototype application to analyze user performance, work load, and user enjoyment with university students without motor impairments. The results show that the C/D ratio was related to task difficulty, movement strategy, and user motivation. Future work on different kinds of C/D ratios will be designed to better understand their effectiveness. In addition, other kinds of interaction techniques we have developed will be investigated using patients with impaired motor function.

8. REFERENCES

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