Development and Evaluation of a Rehabilitation Program using Kinect™ Motion Capture Technology

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***Abstract*—A rehabilitation program was developed and applied using the recent development of Kinect motion capture technology. We tested the use of Kinect in the rehabilitation of people with physical disabilities (the elderly in our case). The rehabilitation takes advantage of Kinect without requiring a controller and the intuitive use of Kinect through physical gestures. Evaluation of an improved program in a second test identified new ways of using Kinect in future tests and as an exercise aid for the test subjects. Survey results collected following the tests indicate that many subjects were interested in the program as a new application, and the program encouraged exercise by reminding the subjects of when they were young.**

***Keywords*—Rehabilitation Program; Motion Capture; Kinect; Elderly; Nursing**

I. INTRODUCTION

A. Background

In recent years, it has become increasingly common to use motion capture technology for the movement of characters in three-dimensional (3D) movies and video games. This technology allows for the movements of humans in real life to be read by a computer. Since these data are a reproduction of the movements of actual humans, the recorded movements are extremely real.

Motion capturing is performed by attaching sensors to joints of the human body. Receiving sensors, such as those in cameras, record signals from the attached sensors and send them to a computer to be converted into digital data. By assigning the movements of each sensor to the joints of a computer-created person, it is possible to make the computer-created person move in the same way as an actual human.

However, using motion capture technology requires a wide space for filming and much technical machinery, such as cameras and computers, and it is thus not easy to use from a financial point of view.

In 2010, the public started using Kinect™ [1]. Once the potential of Kinect, which uses motion capture technology, was identified, Kinect was modified for use on computers.

The Kinect for Windows® software development kit (SDK) was officially released as a tool for personal computer (PC) development, on the prerequisite that it was not to be used for commercial purposes. As a result, Kinect is currently being used as a motion capture technology in various research fields, e.g., research on games and video, nursing and medical care.

B. Kinect

Kinect is an interactive system that allows the control of video games without the use of a controller. It is a peripheral for the Xbox 360 released by Microsoft that allows for intuitive control using gestures and voice recognition as shown in Figure 1. The word “Kinect” is a combination of the words “Kinetics” and “Connect”.

Figure 1. Kinect Source: XBOX360 Kinect [1]

Kinect was released by Microsoft in 2010. At that time, the Nintendo Wii, which was released in 2006, had opened up a new games market with its controller that used physical motions for controls. Users then found alternative uses for the interactive game systems. One of the biggest differences between Kinect and the Wii is that Kinect does not require the player to hold a controller, and it is possible to move characters in the game simply by making physical motions. Both consoles use motion capture technology. The Wii reflects the player’s movements in the game by performing detection along three axes: pointer movement (through acceleration), changes in movement and inclination via the motion sensor built into the controller and pointer detection using infrared light. Kinect uses a number of sensors and processors and does not need to attach markers to the body. Therefore, it can reflect movements in the game by estimating and constructing indirect parts on acquired skeletal images and using these to track movements in real time.

C. Past research

Much research has been performed in the medical field employing motion capture technology that uses Kinect.

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1) Navigation support for the visually impaired

The Human-Computer Interaction group of the University of Konstanz in Germany is conducting a navigation support project for the visually impaired [2]. The project aims to provide aid for the blind as they walk down hallways, ascend and descend stairs, and open doors, using Kinect as a sensor.

This project involves scanning an environment with Augmented Reality using Kinect and then recognizing that environment. A system voice then tells the person wearing the device the distance to the next object (such as a door or staircase). By tying a device containing a vibration motor linked to the Kinect around the waist, it is possible to prevent the wearer from bumping into obstructions by physically (tactually) notifying them of danger, using vibration that becomes increasingly strong as the wearer approaches the obstruction in question.

2) NAIST Ballpool

Hiroyuki Funaya of the Doctor's Course in Information Science and Technology at the Nara Institute of Science and Technology developed an application (app) called "NAIST Ballpool" [3], taking advantage of the fact that Kinect does not require a controller or the user to own a videogame console or computer. This app provides an exercise in which Kinect is used to move a robot displayed on a screen to touch a ball. The app was used in a retirement home [4] by residents aged 80–90 years. When asked what they thought of the experience, they said it was "fun". Kinect is used to reflect physical movements on a screen, allowing the body to move freely in a virtual sense. However, the retirement home residents reported problems in implementing Kinect. First, "when using the Kinect for input-based controls, 3D input is not necessarily appropriate for two-dimensional display." For example, when Kinect is used *in lieu* of a mouse, the arms must be continuously raised to perform input commands. This activity is tiresome compared with using a mouse controller, which allows easy input using only the fingers. Second, "when using the Kinect, there is nothing for the user to touch, so there's no physical feedback." This is because physical movements are reflected on a screen and there is no sense of being in control as there is no tactile feedback.

D. Kinect for Windows SDK and the Sample Shape Game

Microsoft initially stated in the Kinect instruction manual that Kinect should not be used to control a PC itself, but they acknowledged the use of Kinect on PCs for non-business purposes, provided that the internal algorithms would not be altered and that Kinect would not be used for the manipulation of Xbox games. Microsoft officially released a beta version of "Kinect for Windows SDK" (a program development kit for running the Kinect on a PC) on June 16, 2011 [5][6].

Kinect for Windows SDK contains a "Skeletal Viewer" and "Sample Shape Game" as sample programs. These were constructed in a basic program that allowed Kinect to be used on PCs, and provided a simple experience demonstrating the abilities of Kinect.

The Skeletal Viewer allows the display of depth images and color images, recognition of two people and indirect recognition of each person. Thus, source code from the Skeletal Viewer allowed users to study the basics of how to program and use Kinect for Windows SDK.

In the Sample Shape Game, the player must touch falling objects with his/her body to score points. It also supports voice recognition, allowing the player to control the game with commands such as "Reset" and "Faster". However, to make use of the voice recognition function, a voice recognition framework must be installed.

E. Purpose and approach of this paper

The purpose of this paper is to evaluate the effectiveness of Kinect application as the rehabilitation program. Subjects in a nursing home played the Sample Shape Game program included in the Kinect for Windows SDK. We then asked which areas of the game they would like to see improved using questionnaire. Based on their request we made improved version of application and then had them play the improved version. After they experienced improved version, we asked questionnaire again to evaluate the effectiveness.

F. Composition of this paper

The first section covers the background that brought us to undertake our present study, existing challenges, past research, and the objective of the paper. The second section introduces the developed program. The third section discusses how an evaluation test was conducted. The fourth section presents the results of each test performed in the third section. The fifth section discusses observations related to the results obtained in the previous section. The sixth and final section summarizes the work and discusses future research.

II. DEVELOPED PROGRAM

A. Development environment

We installed Kinect for Windows SDK on a PC so that Kinect could be controlled using the PC. The development/implementation environment was as follows.

PC System: FMV - F8370
CPU: Intel® Core™ 2 Duo CPU T8100 (2.1 GHz)
Memory: 2.00 Gb
OS: Windows 7 Professional

Furthermore, we used Microsoft Visual C# 2010 Express as a development tool to implement improvements in the

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Sample Shape Game program used in this test. Improvements were made according to survey results collected after test 1 (described below).

B. Falling objects

The size, type and drop rates of falling objects were not originally programmed with our test subjects in mind, so we made the objects simpler and bigger and reduced the drop rate. The program was changed as follows.

```
    public void SetSize(double f)
{   baseShapeSize = f
    shapeSize = sceneRect.Height*
                    baseShapeSize / 1000.0;  }
public void SetDropRate(double f)
{   dropRate = f ;  }
```

- Changed underlined value:
  - 1000.0 → 500.0
- Increased size of falling objects
  - dropRate = f → dropRate = f/2

To simplify the objects, we changed the poly types to circular objects, such as circles and bubbles. Figure 2 shows the results of our changes.

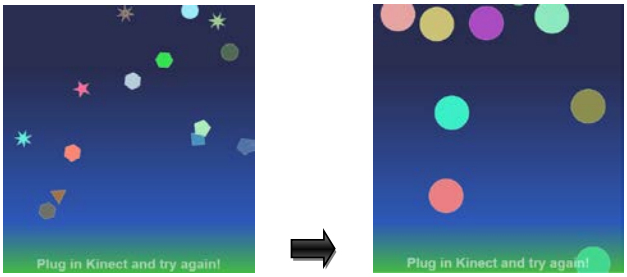

Figure 2. Screen captures from the original program (left) and the changed program (right).

C. Projecting the player on the game

Originally, the top right of the main game window displayed a tiny player image entered via the Kinect camera. We decided to make the player image the same size as the full window by overlaying the player image on the main game window. When we superimposed the Kinect camera image of the player on the game window, we encountered a problem that only the camera image was being displayed, and the game screen was not visible. Therefore, to make it look as if the player was transported into the game, we made the image from the Kinect camera semi-transparent and superimposed the camera image onto the skeletal frame-based image. The program was changed as follows.

```
<Image Name="video" Opacity="0.5"
  Margin="12,50,12,12" HorizontalAlignment="center"
    Width="504" Height="550"
    VerticalAlignment="center" />
```

By changing the opacity value from 1.0 (non-transparent) to 0.5 (semi-transparent), the player image was projected onto the game window. The semi-transparency meant that the screen images were slightly difficult to observe, but the result was adequate for our purposes.

D. Final program

The results of the changes and improvements of the program in Sections 2-B and 2-C are shown in Figure 3.

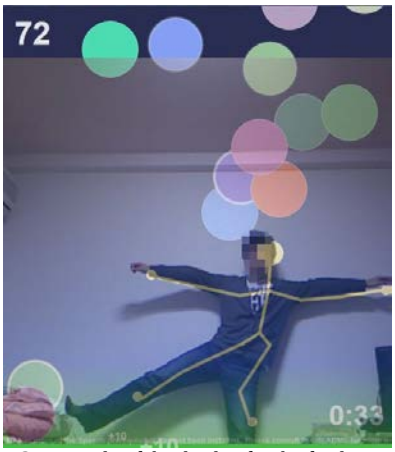

Figure 3. Example of the display for the final program.

We were, thus, able to improve the program in terms of the falling objects and the superposition of the player image from the Kinect camera onto the game screen. The improved program was used and evaluated in test 2 (described below).

III. EVALUATION

A. Test 1: Sample Shape Game experience

1) Purpose of test 1

Elderly people living in nursing homes who do not usually exercise and people who require day services were asked to participate in the test. Both the subjects and their exercise instructors played the Sample Shape Game. This formed the basis of the test. We asked the subjects and their exercise instructors for their opinions and thoughts on how the program should be improved for test 2.

2) Test subjects

Seven people receiving day services and one exercise instructor were enrolled from the Suwa Central Hospital Union Nursing Home *"Fureai no Sato"*.

3) Materials

The following materials were used.

– Kinect
– one laptop PC

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– one projector
– the Sample Shape Game.

4) Procedure

On the day of the test, people who receive day services in the nursing home facility were asked to play the Sample Shape Game for about 30 minutes. We then asked them which aspects of the program they would like to see improved.

5) Comments and Opinions of the subjects

The thoughts/opinions/requests we received from the people who experienced the game were as follows:
– The game should display the actual person as recognized by the camera, not just a skeletal frame.
– The falling objects should be more interesting (e.g., money or strawberries).
– The falling objects should be larger.
– There should be recognition of wheelchairs (which are not detected properly).
– There should be selectable levels of difficulty.
– There should be familiar music (without music, there is little desire to play).

B. Test 2: Playing the improved Sample Shape Game

1) Changes from test 1

The following changes were made to the Sample Shape Game:
– Changes were made to the falling objects.
– Changes were made to the size of the falling objects (they were made twice as large).
– Changes were made to the type of falling objects (they were changed from squares, triangles, and stars to just circles).
– The falling rate was reduced and the intervals between falling objects were increased (by a factor of 2).
– The players themselves were projected into the game by superimposing the player image captured by the Kinect camera (originally displayed in a small window at the top right of the screen).

2) Purpose of test 2

We made changes to the Sample Shape Game according to the feedback we received from test 1, and we had the subjects play the improved version and take a survey afterwards. We used the results to study the usefulness of a program using Kinect in rehabilitation.

3) Test subjects

Seven people receiving day services (different subjects from test 1) and one exercise instructor were enrolled from the Suwa Central Hospital Union Nursing Home "*Fureai no Sato*".

TABLE 1. NUMBER OF SUBJECTS THAT VISITED FOR DAY SERVICE CATEGORIZED BY AGE AND NURSING LEVEL.

Age	**Number of subjects**
70–74	1
75–79	2
80–84	5
85–89	7
90–94	3
Nursing level	**Number of subjects**
1	2
2	4
3	4
4	4
5	2
Support Required	2

On the day of the test, as shown in Table 1, 17 people came to the facility to receive day services. Seven subjects and one exercise instructor experienced the program.

4) Materials

The following materials were used:
– Kinect
– Two laptop PCs (one for connecting the Kinect, and the other for connecting speakers and playing music)
– The improved version of the Sample Shape Game produced by our group
– Two audio speakers
– One projector
– One music compact disc (the best of Bon festival dance)
– Survey forms
– Writing material

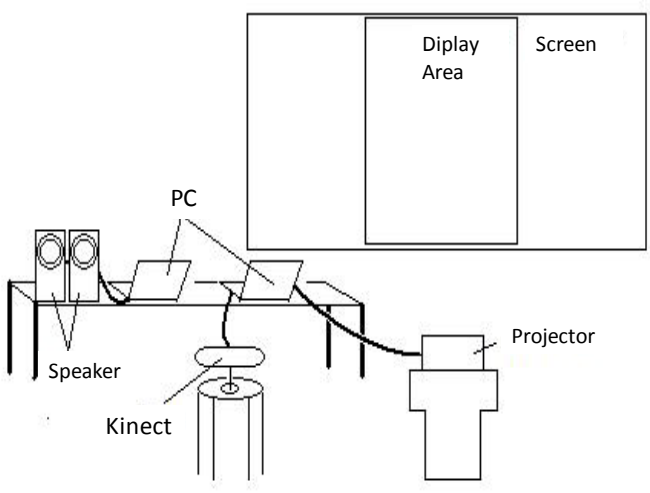

Figure 4. Configuration.

The speakers were connected to one PC to play music, and the other PC was used to connect the Kinect and the

projectors as shown in Figure 4. The projector was used to display the combination of the game screen and the image obtained from the Kinect camera on the main screen.

5) Procedure

We returned to the facility where we performed test 1 so the subjects could experience the improved Sample Shape Game. In test 2, we played music during the test, in response to the subjects' opinions in test 1. Since we used different subjects for test 2 and the testing time was restricted, we did not compare the program before and after improvements.

Figure 5. Test subjects experiencing the improved program.

Subjects used the improved program, as shown in Figure 5, and then filled out a survey, in which they were asked to provide a five-level evaluation (from "I agree" to "I disagree") in response to five statements: "The game was easy to use", "The game helps me exercise", "I want to play again", "There should be music" and "The size of the objects was appropriate".

IV. TEST RESULTS

A. Results and observations for test 1

As stated above, the thoughts/opinions/requests we received from subjects who played the game in test 1 were as follows:

– The game should display the actual person as recognized by the camera, not just a skeletal frame.
– The falling objects should be more interesting objects (e.g., money and strawberries).
– The falling objects should be larger.
– Wheelchairs should be detected properly.
– The player should be able to select the level of difficulty.
– Familiar music should be played.

Subjects wanted to see themselves projected in the game instead of a skeletal frame, suggesting the skeletal frame, which appeared inorganic, did not make them feel as if they were directly participating in the game.

Some subjects wanted more interesting objects to fall, but since the original program only contained very simple shapes such as circles and triangles, it was difficult to change the shapes into specific objects; we thus decided to use only one shape. The size of the objects was changed by adjusting some values in the program, but since this would increase the density of objects on the screen, we changed the speed and number of falling objects accordingly.

During the survey to determine which points required improvement for test 2, we encountered a problem not directly related to the program. Some subjects were wheelchair users, and they experienced problems in terms of being recognized by the game. Probable causes for this are that the game was not played within an area most suitable for using Kinect and that the armrests of the wheelchairs were mistakenly recognized as human arms.

We did not think of using music when we designed the test, but subjects suggested that music was necessary to make them want to exercise. Therefore, we decided to use traditional Japanese Bon festival music, such as "Tankō Bushi", to provide music familiar to people of the subjects' age.

B. Results and observations for test 2

Test 2 involved a survey with a five-level evaluation (from "I agree" to "I disagree") in response to five statements: "The game was easy to use", "The game helps me exercise", "I want to play again", "There should be music" and "The size of the objects was appropriate". The results are given in Table 2.

TABLE 2. SURVEY RESULTS

	Evaluation				
Item	**5**	**4**	**3**	**2**	**1**
Game was easy to use	5	1	0	1	0
Game helps me exercise	2	3	2	0	0
I want to play again	5	1	0	1	0
There should be music	7	0	0	0	0
Size of objects was appropriate	7	0	0	0	0

The results are summarized as follows.

1) The game was easy to use; mean score: 4.4

The controls were simple, as the subjects only had to move their arms and legs to score points, and the subjects were thus able to get used to the game relatively quickly. Sometimes the skeletal frame was not properly detected, resulting in the subjects not being able to control and play the game.

2) The game helps me exercise; mean score: 4.0

This statement referred to the question of whether the subjects felt the game helped them exercise. The results varied slightly, but several subjects felt that the game would be a good incentive for exercise.

3) I want to play again; mean score: 4.4

Several subjects mentioned that the game reminded them of being younger and that they would like to play again.

4) There should be music; mean score: 5.0

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We did not use music during test 1, but in response to the opinions received during test 1, we played songs the subjects were familiar with, such as Tankō Bushi and Sōran Bushi, during test 2, resulting in the subjects being more motivated in their participation.

5) The size of the objects was appropriate; mean score: 5.0

We doubled the size of the falling objects in the original program to make them easier to recognize. There did not seem to be any particular problem in recognizing the objects and there were no negative opinions.

Comprehensive evaluation of the five statements demonstrated that the game was easy to control and that it enabled the subjects to exercise by being reminded of when they were younger. It also demonstrates that playing music leads to more motivated participation and that feedback was generally positive.

When evaluating the desire to play again, it is important to take into account that the skeletal frames were not always properly detected and that the subjects might become bored with the game over long periods. We did not survey this point in the study.

The following positive and negative comments were made by the respondents outside of the five-level evaluation.

Positive points

– The game is a good incentive for exercise.
– The game reminded me of my younger self.
– The game gives me something to focus on.
– The game enabled me to move my hands again by reminding me of when I was younger.
– The game is nice in that the colors change.
– The game reminded me of when I played basketball.
– The game is good for exercise.

Negative points

– I was not used to the game, so the movements were a bit difficult.
– I did not have a good impression of the game because it did not display me properly (the skeletal frame was not properly detected).
– The game responded too slowly.
– It would have been nicer if the game moved in accordance with the music (permitting dancing).
– There should have been more variety in the falling objects.

One opinion that was particularly prevalent was that the game reminded the subjects of being younger, allowing them to move their bodies freely again. It is likely this was due to (1) increased motivation to move associated with their interest in new things (the Kinect system) and (2) music they were familiar with was being played.

Some subjects were not able to evaluate the game properly because their skeletal frame was not correctly detected. Most of these subjects were wheelchair users, implying that the problem was due to Kinect not being able to distinguish armrests from arms and therefore failing to recognize a proper skeletal frame.

V. OBSERVATIONS

The nursing home facility usually has a 45-minute recreation session in the afternoon, where the elderly exercise by participating in bread-eating contests, playing balloon volleyball in which they move their arms in fan-like motions, or playing on a Wii (Wii Sports, Wii Fit). They also perform exercises that involve balancing, stretching, getting up and walking as a pastime while waiting for other people to finish their morning baths. In contrast to the kind of rehabilitation performed at hospitals, which is aimed at recovering a person's motor functions (such as going to the bathroom alone) by practicing movements necessary for daily life, at the nursing home, rehabilitation involves the functions the person still possesses. Regarding the differences between the two kinds of rehabilitation, we received comments from the exercise instructors including "It's good that they can use their whole bodies without the use of objects" and "The movements have been made slower, so it is different from things that are made for slightly younger people, like the Wii, and it provides a more comfortable exercise for people who cannot move quickly, such as the elderly." As these comments show, the game was more playable for the elderly subjects in test 2 than those in test 1 by adjusting the rate and speed of the falling objects to be lower than those in the original program.

Next, we considered the opinions received in the survey. These opinions suggested that some of the subjects required a long time to get used to the controls, but since the movements were very simple, it did not take long to understand the game in general. Many subjects also stated that being able to remember their younger selves made them able to move their bodies again. It is likely that the music played at the time played a large part in this. Subjects stated that this program offered a new experience for the subjects, and we were able to get them interested and move their bodies actively because of this. However, this only reflects their evaluation of the program when first experiencing it. It is possible that they will be less interested with the program, if they use it numerous times. The program itself involves touching round objects that fall from above to earn points, but there is no fixed play time, and the same objects fall down (even if they change color). Therefore, there is not a lot of visual variety and subjects may become easily bored with the game when playing it repeatedly or for long periods. Regarding detection of the skeletal frame, recognition was insufficient during test 1. Several people experienced problems in having their skeletal frames detected because the distance from Kinect to the subjects had not been adjusted to the number of people present, and the test location was too bright. Also, sometimes Kinect had trouble discerning between the armrests of a wheelchair and the arms of the person in that wheelchair. However, in test 2,

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detection of the skeletal frames was improved, because we had a better understanding of the optimal distance between Kinect and the test subjects.

A comprehensive evaluation of the results from test 2 showed that most suggestions received in test 1 were properly implemented in the revised program. Thus, test 1 allowed us to improve the game so that subjects could perform reasonable exercise, and disregarding the problem of experiencing the same program continuously, the program was fresh and new and stimulated the subjects. In addition, the game was relatively easy for the subjects to understand because of the intuitive controls of Kinect.

When comparing our program using Kinect with the Wii, we suggest that Kinect is more useful for rehabilitation programs, because it is easier to perform exercise with the easy controls, and because the movements can be slowed to the subjects' requirements.

VI. FUTURE WORK

We asked the instructors who participated in test 2 what they would like to see changed in the future. The following comments were received:

– The program should change as time passes.

– It might be fun if the objects came in from the sides as well from above.

– There should be more room for competition.

– The game should stimulate the subjects to bend their bodies and stretch their arms sideways by having the objects center on the subjects at first and then gradually fall in from the sides.

VII. SUMMARY

The purpose of this study was to develop and apply a rehabilitation program using the recent development of Kinect motion capture technology. We performed tests making use of the Kinect's innate features of not requiring a controller and allowing intuitive play through physical gestures for the rehabilitation of people with physical disabilities, such as the elderly. Evaluation of the developed program in test 2 suggested new ways of using Kinect as an exercise aid for the test subjects.

Kinect was originally used for playing games and creating 3D images on PCs using motion capture technology. However, this study demonstrates that our revised program can be used with Kinect to offer rehabilitation to elderly people with physical disabilities.

Results of surveys taken after the tests indicated that many people were interested in the program and it yielded favorable impressions as a means of exercise by reminding the subjects of when they were young. In addition, playing music that the subjects were familiar with helped encourage subjects to participate.

However, some subjects could not use the program because their skeletal frames were not detected properly. This suggests it is necessary to alter the sensitivity of the skeletal frame detection program specifically for the environment used. In addition, the program should be enhanced to prevent the subjects from becoming bored during the long-term use required for rehabilitation.

Surveys results for problems with our program and suggested improvements demonstrated that Kinect can be used for rehabilitation programs. Therefore, future research should investigate the development of rehabilitation programs using Kinect. This study shows that the revised program in conjunction with Kinect was enjoyed by elderly people and it invoked their desire to exercise.

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