Proposal and Evaluation of Kinect-based Physical Training System for Special Needs Education

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Abstract- **Microsoft Kinect is a motion sensing device for video games with potential applications in rehabilitation or physical training systems. Many studies have shown the effectiveness of Kinect-based physical training systems, particularly for promoting concentration and movement in special needs education. However, the availability of such systems in the special needs education field in Japan is currently very limited. We developed a Kinect-based physical training system for special needs education and provided it to schools for evaluation. To clearly estimate the system efficacy, we developed a motion analyzer utilizing the open-source software OpenPose. Using the motion analyzer, we were able to evaluate the system's efficacy. In this paper, we report an overview of the system and the results of the evaluation.**

Keywords-motion sensor; Kinect; physical training system; special needs education; OpenPose.

I. INTRODUCTION

Recently, several motion sensor device types have been developed for use in video game systems, such as the Nintendo Wii Fit, Microsoft Kinect, and Leap Motion. These devices are also useful for rehabilitation or physical training assistance systems, and many research reports have been published on the efficacy of such motion sensor devices.

Lange et al. reported that Kinect’s high accuracy of tracking and feedback on performance was important in games developed as rehabilitation tools for adults with neurological injuries [1]. Kayama et al. focused on decreasing elderly adults' dual-task ability as a risk factor for falls [2]. They developed a game based on tai chi exercises using Kinect to improve dual-task ability and evaluated the game over a 12-week period in 41 elderly individuals. They reported that the exercise was effective in improving cognitive functions. Chang et al. reported that the Kinect-based rehabilitation system significantly improved motivation for physical training and exercise performance among young adults with motor disabilities [3]. Bartoli et al. adapted an on-the-market, motion-based touchless game for use with Kinect to assist the education of five children with autism and confirmed the efficacy of this teaching tool using standardized therapeutic tests [4]. Fu et al. evaluated the efficacy of a Kinect-based game system for the rehabilitation of 112 children with mental disorders. They compared the children’s’ pediatric evaluation of disability inventory scores before and after training [5] and found significantly improved results.

Few studies have specifically studied the use of such tools in the special needs education fields. Chang et al. compared the effectiveness of the Kinect system and the high fidelity OptiTrack optical system [6] and showed that Kinect was effective enough as a rehabilitation tool for use in both clinical and home environments. Altanis et al. also found that a Kinect learning game was effective for children with gross motor skill problems and motor impairments [7]. Boutiska et al. successfully used a game called “Kinect Adventures” as an auxiliary learning tool for teaching “Mnemonic Techniques” in children with autism [8]. Freitas et al. developed a Kinect-based motor rehabilitation game to analyze the evaluation feedback from users to repeatedly inform appropriate upgrades [9].

Kinect is most often used as a motion sensor device in such studies because of its low cost and usage possibility without extra attachment devices or markers. However, developing effective Kinect-based rehabilitation systems is not easy. This has led some researchers to use on-the-market games that might discourage continued use by individuals with special needs. Greef et al. discussed the efficacy of Kinect-based games as rehabilitation tools for children with motor skill problems [10], emphasizing that on-the-market games usually revolve around competitions based on mastery skills. Hence, on-the-market games for children with special needs may result in feelings of exclusion. To provide interesting games for such individuals, they recommend developing Kinect games designed according to user requirements. Contrarily, a commercial suite of Kinect-based educational games known as Kinems [11] already exists. These games are targeted at not only typically-developing children, but also at children with learning disabilities. Some researchers have already investigated the efficacy of these games. Kosmas et al. provided empirical evidence that Kinems games enhance motor performance in children with learning disabilities and motor impairments [12]. Kourakli et al. conducted analyses in inclusive classrooms at two primary schools with 20 children having special educational needs. They concluded that these games have a positive impact on children's academic performances and improve their cognitive, motor, and academic skills [13]. Tsiakalou et al. also showed that Kinems games can improve academic performance, motor skills, and executive functions like short-term memory, problem solving, concentration, and attention in children with special needs [14]. Some Kinems games have an embedded monitoring and reporting system that provides teachers the ability to enrich the quantity and quality of information about the children's specific needs. Retalis et al. used Kinems in a study involving children with ADHD learning disabilities [15] and found a statistically significant pre- to post game improvement in their nonverbal intelligence scores. Additionally, an in-depth examination of learning and kinetics showed an improvement in the children's executive functions and cognitive skills.

The Japanese Ministry of Education (MEXT) actively promotes the use of Information and Communication Technology (ICT) devices as educational tools [16]. Several studies related to special needs education have reported an excessive use of notebook and tablet PCs for communication training or rehabilitation; however, there is a limited mention of motion sensor devices such as Kinect. On the National Institute of Special Needs Education website [17], the discussion about ICT devices and their applications in special needs education does not include any information on motion sensors [11]. In 2013, Microsoft Japan and Tokyo University's Research Center of Advanced Science and Technology collaboratively developed the observation and access with Kinect (OAK) [12], a software that aims at supporting children with severe disabilities by identifying their tiniest movements and utilizing those as switches for electronic devices or communication needs. Although OAK can also be used for rehabilitation, it does not provide it's software development kit; therefore, it is impossible to adapt its function to other applications.

We developed a Kinect-based physical training system and provided it to special needs education teachers in seven classrooms of three schools for evaluation. Comments were gathered from the teachers and users, and the system was accordingly revised. Most comments were highly positive, and many teachers reported that the system promoted unusual physical movements that had not been previously seen among the children.

Besides such positive evaluations, numerical data is still required for evaluating the objective of the system. Numerical data was obtained by comparing the player's skeleton positions and the angles formed by connecting skeletons of two video images presented with or without the system. For this analysis, we developed a motion analyzer utilizing OpenPose [18], an open-source software that provides human skeleton position data from video images. We applied the system to a child with motor skill problems and evaluated the data obtained from the system.

Our design goals of this system is as follows.

For trainees (children with disabilities):

1. Inducing a trainee's motivation to move their body as much as they can.
2. Making the training with the system enjoyable for trainees.
3. Developing a trainee's potential ability of their physical body motormovements.

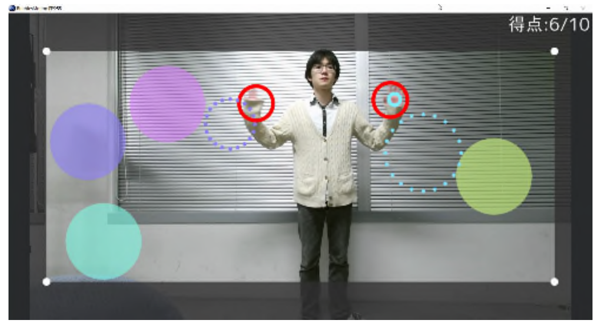


Figure 1. Application outlook

For trainers (special needs education teachers):

1. Easy to use - no need for training before use the system.
2. Easy to customize the system for each trainee condition.
3. Easy to recognize the effect of the training.

Based on these goals, we evaluate our system and specify the effectiveness and problems to be solved of the system.

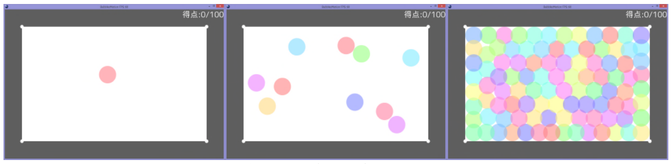
The structure of this paper is as follows. In Section 2, we provide an overview of the physical training system. In Section 3, evaluations and suggestions from several teachers who have used the system are presented. In Section 4, we describe an outline of the motion analyzer and the results applied to a child with motor skill problems. Finally, we provide concluding remarks and suggestions for future prospects in Section 5.

II. SYSTEM SPECIFICATIONS

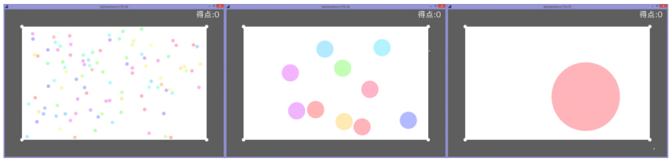
The Kinect-based system was developed to motivate movement in children with autism and mental disorders who are able to independently move around. The system displays a video image of the player captured by the Kinect camera with randomly allocated graphical targets, such as balls, other shapes or animals, superimposed on the screen. When the player touches a target, it disappears with a sound and a point is awarded. The game lasts until all the targets have been eliminated (Figure 1). To clearly identify the relationship between the touching motion and target elimination, the target changes its shape before disappearing. When Kinect recognizes the player, red circles appear on the players hands. The game can also be used without a finish point. For example, by selecting the target-manipulate mode, players can hit targets with a rock-shaped hand, break them with scissors, and catch them with paper. In this mode, recognizable pictures, instead of red circles, are displayed on the player's hand (Figure 2(g)).

The game can be customized according to the training purpose or the child's needs. The customizable parameters are listed below:

- Number of targets (Figure 2(a))
- Finish point
- Target size (Figure 2(b))
- Touch-area size (Figure 2(c))
- Type of targets (Figure 2(d))
- Size and position of target area (Figure2(e))
- Body parts used for touching (head, right or left hand, and right or left foot; Figure 2(f))



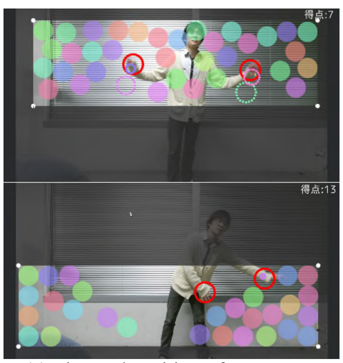
(a) Number of targets



(b) Target size

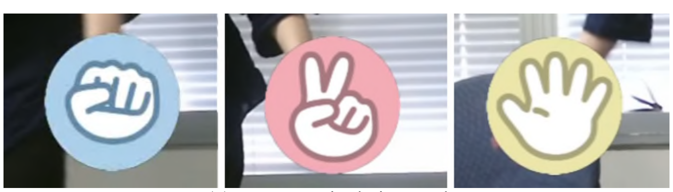
(d) Touch-area size

(e) Types of targets



(e) Size and position of target area

(f) Parts of body used for touching



(g)Target manipulation modes
Rock: catch, Scissors: break, Paper: hit

Figure 2. System specifications

As shown in Figure 2(e), the user can change the size and position of the area where the targets will appear. This function allows the player to concentrate on a specific area and move toward the area. The last parameter (Figure 2(f)) allows the player to use only the left or right hand or all body parts to touch the targets. These settings are saved as a text file for each player and are retained for the next time they play.

III. TEACHERS' EVALUATION AND SUGGESTIONS

The Kinect-based physical training system was provided to seven classes in three Japanese special education schools and reports were gathered on its usefulness and popularity. There were no questionnaires used because the evaluation criteria were expected to be different depending on the disability situation of each child, the aim of the session, and the education method of each teacher. The collected comments are given in the Appendix.

The teachers used large monitors, 50 inches or more, and each practice was 10 to 15 minutes depending on children's situation. The disability situations of the children of these classes were as follows.

- Case 1 contained two children: Child A, aged 10 years, with autism spectrum disorders and mild intellectual disability; Child B with cerebral palsy.
- Case 2 contained five children aged 15 years, four with developmental disability and one with autism
- Case 3 included five classes.

  Class (1) contained .three children aged 15 years, with intellectual and physical disability.

  Class (2) contained three 3 children aged 3with cerebral palsy.

  Class (3) contained three 3 children aged 7 years with severe multiple disabilities.

  Class (4) contained one child aged 8 years with cerebral palsy.

  Class (5) contained one child aged 14years with muscular dystrophy.

Here, we describe the teachers' comments**.**

According to the comments in the cases 1, 2 and (1), (2), (4), (5) of Case 3, children, who could move around by themselves and recognize that the targets disappeared when they touched them enjoyed the game intensely by extending their arms, lifting them over their heads, or jumping. All teachers commented that the children seldom used those movements. In class 3 (2), there was one child who was so energetic that he became exhausted. These comments show that the game system successfully induced children's motivation to move their body and most of them seemed to enjoy the training.

However, the comment of Case 3 (4) (see Appendix) identifies the difficulty of recognition of the target for a child with milder disability. In Case 2 and Case 3 (3), there was also recognition difficulty for children with severe disabilities. This explains the suggestion of making the targets static and showing them one at a time.

The first suggestion of Case 2 arises from the issue of Kinect sensor. The first version of Kinect recognized two people and the second version recognized six. But neither could distinguish each person. In order to distinguish each person frame by frame, we need to use markers of some kind.

The second suggestion of Case 2 pointed out that for hand shapes to be recognized by Kinect, it is necessary to have the hands face toward Kinect. This movement was one of the difficulties faced by most of the children. Even if they can fold their wrists, intellectual disability makes it hard to understand the function of Kinect. Some children were unable to make the scissor shape.

IV. RESULTS ANALYSIS

It is challenging to compare motions made with or without the system for evaluating the system performance. Although Kinect can easily recognize the position of human skeleton data, most special needs education schools and classes are not in a situation to use Kinect anytime they want. Thus, in some cases, we must use a video footage of the children's motion for comparison of motions made with and without the system. To help evaluate the system, we developed a motion analyzer that can compare differences in motion between two videos. The motion analyzer uses OpenPose, an open-source software that recognizes human poses and reports skeleton position data. OpenPose obtains position data from the base of the neck and both sides of the hips in each video, and superimposes the points by zooming from one to the other. Through this process, OpenPose can calculate the motion angles of the shoulders, elbows, or other joints and compare the difference in angles between the two videos (Figure 3).

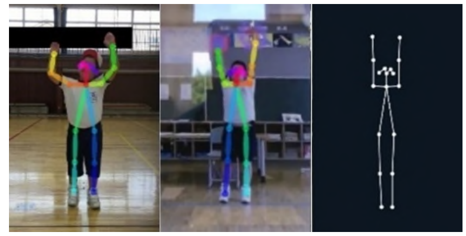
We used motion videos of a child with limb and trunk dysfunction caused by cerebral palsy and hydrocephaly. He also suffered from paralysis on the right half of his body. The child underwent a calisthenics training with a teacher for a year. This calisthenics training is very popular in Japanese compulsory education and it includes whole body basic motions with familiar rhythm and the words. At the beginning of the training, he could not move his body to the rhythm. After training, he was able to move to the rhythm; however, his ability to move his muscles showed no improvement, according to the teacher. The teacher used the Kinect system with the child for 15 minutes per week from April to July 2017. The two videos, with and without the system, were recorded in July 2017. Based on the rhythm of the calisthenics training, we fit the same timing of both video scenes. The motions with and without the system that were compared are listed in Figure 4 (a)–(d), and the angles of the shoulders and elbows for each motion are shown in TABLE 1. The "Standard" in TABLE 1 indicates the ideal angle for each motion and each percentage indicates the standard angle.

Step 1: Original videos — Step 2: OpenPose Output — Step 3: Motion Analyzer

Figure 3. Analysis process

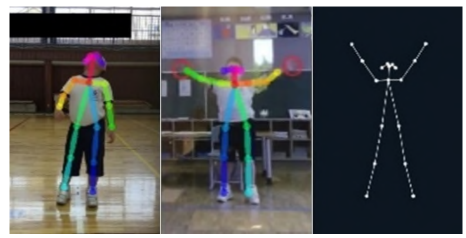
TABLE 1. ANGLES OF SHOULDERS AND ELBOWS DURING EACH MOTION

Joint	Pattern	Before	After	Standard
Right shoulder	A	120.3(67%)	167.4(93%)	180.0
	B	47.0(35%)	102.1(76%)	135.0
	C	37.9(28%)	120.8(89%)	135.0
	D	117.8(65%)	132.8(74%)	180.0
Right elbow	A	72.8(60%)	13.1(93%)	0.0
	B	5.0(97%)	5.4(97%)	0.0
	C	14.3(92%)	10.0(94%)	0.0
	D	56.1(69%)	24.4(86%)	0.0
Left shoulder	A	139.5(77%)	178.3(99%)	180.0
	B	21.3(16%)	119.9(89%)	135.0
	C	22.9(17%)	114.3(85%)	135.0
	D	141.1(78%)	150.8(84%)	180.0
Left elbow	A	58.7(67%)	2.8(98%)	0.0
	B	49.4(73%)	23.5(87%)	0.0
	C	6.6(96%)	15.2(92%)	0.0
	D	16.2(91%)	26.5(85%)	0.0

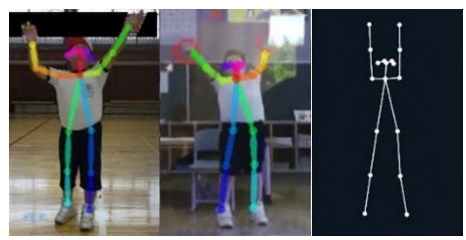


(a) Exercise Pattern A:
Raise arms next to the ears

(b) Exercise Pattern B:
Arms at shoulder level



(c) Exercise Pattern C:
Arms swinging above the shoulders



(d) Exercises Pattern D:
Raising arms and standing on toes
Left: before, Center: after, Right: standard

Figure 4. Motions with and without the system

Figure 4 (a) depicts that the child showed great improvement in extending his arms upward. As observed in

Figure 4 (b), his motion also considerably improved, except for his left elbow. However, as observed in Figure 4 (c) and (d), better results were obtained with the system.

The results support that the system induced the child's active movements and performance. The teacher informed that the child had never shown such extending actions before. In this study, we focused only on the upper half of the child's body. In future studies, it will be necessary to expand the analysis to whole body motion and to observe more number of children. We also need to revise the system to record the motion video and data directly.

V. CONCLUSION AND FUTURE WORK

We developed a Kinect-based rehabilitation system for special -needs education and provided it to schools for evaluation. In order to clearly estimate the system efficacy, we also developed a motion analyzer utilizing the open-source software, OpenPose. We then evaluated the effectiveness of the system efficacy using this motion analyzer.

The Kinect-based physical training system was provided to seven classes in three Japanese special education schools and reports were gathered on its usefulness and popularity. Many teachers rated the system as highly valuable for children with disabilities. The feedback and suggestions offered by the teachers provided insights into ways the system could be made more effective and more popular.

We also developed a motion analyzer using the open-source software OpenPose, which recognizes human poses and reports their skeleton position data. Using the analyzer, we analyzed videos of motions performed by a child with limb and trunk dysfunction, with and without the rehabilitation system. In most cases, the child's motions improved upon Kinect-based system usage. The child's teacher reported never having seen him make such movements before. It is clear that the system induced these active movements in the child.

In this research, we only analyzed the upper part of the body. In the future, we will need to analyze whole body motion. Additionally, we applied and analyzed the system to data for only one child. However, we have provided several schools with the Kinect systems as we mentioned in Section 3. We are going to request the teachers for gathering motion datas and share the analysis results for improving the system better and developing the best way of utilizing it.

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APPENDIX

- Case 1:

Child A: Aged 10 years; with autism spectrum disorders and mild intellectual disability.

Child B: Aged 10 years; with cerebral palsy.

Teacher's evaluation: Child A actively moved his body. While aiming at targets, he checked his body position and tried to touch them by his extending arms or jumping. Because child B had palsy affecting his left arm, which he usually does not use, his movement for touching was limited. He enjoyed the game a lot.

Suggestions: To reduce clumsy body motion because of disability, the children need synergetic motion trainings for their hands and legs, for example, by letting them touch static targets in turn.

- Case 2:

Five children, four with developmental disability and one with autism

Teacher's evaluation:

➢ It was clear that the child had visual field constrictions, which was evident from his movement during the game.
➢ By projecting the large screen (120 inches), children were well motivated.
➢ Trying to touch targets made children careful about their body positions.
➢ Using animal picture targets drew more attention.
➢ Children showed unusual motions like crouching down or taking long strides toward left and right.
➢ They played with more intention and for longer than other activities.
➢ Many children can play at the same time.
➢ Suggestions:
➢ When Kinect does not recognize a child, he is confused.
➢ For some children, making a rock, scissor or paper hand is difficult, particularly the scissor hand.
➢ Too many targets make it difficult for children to concentrate on a specific one.
➢ It would be useful to designate the positions and the turns of the targets as they appear.
➢ System preparation takes lot of time.

- Case 3: Comments were obtained from 5 classes.

(1) Three children aged 15 years, with intellectual and physical disability

Teacher's evaluation:

➢ Usually they tend to be inactive, but the game induced them to move independently, extending their arms or crouching down.
➢ One child could not understand the causal relationship between touching and disappearing targets; however, when the animal picture targets were shown, he understood the relation.

Suggestions:

➢ By fully showing targets on the screen, we may be able to find the child's gazing point and their visibility range.

(2) Three children aged 3with cerebral palsy

Teacher's evaluation:

➢ They very eagerly played the game and one child got exhausted.
➢ The game was used once a week for 5 weeks. Children became more active than before.

Suggestions:

➢ No suggestions.

(3) Three children aged 7 years with severe multiple disabilities

Teacher's evaluation:

➢ They could not recognize the targets and just slightly moved their hands.
➢ It was difficult for them to notice whether they touched the target or not.

Suggestions:

➢ In order to make the targets easier to recognize, make the targets blink or develop other strategies.
➢ It is difficult for the children to concentrate on the game if there are many things on the backdrop.
➢ Making the targets appear one by one would help children recognize each target.

(4) One child aged 8 years with cerebral palsy

Teacher's evaluation:

➢ The child actively played at first, but lost interest later.
➢ Recognizing the target did not seem easy for her.

Suggestions:

➢ Many such games should be developed.

(5) One child aged 14years with muscular dystrophy

Teacher's evaluation:

➢ He usually does not lift his arm above his shoulder, but here, he lifted his arm over his head.
➢ Changing the target site helps train children to move their arms in various directions.

Suggestions:

➢ No suggestions.