KINECT Applications for The Physical Rehabilitation

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Abstract— This report presents the results of KINECT applications used in physical rehabilitation tests. Aoyama Gakuin and Kitasato universities collaborated on this project, which is supported by SCOPE. The applications, following standard tests, are for the timed “Up & Go Test”, the timed “10-Meter Walk Test” and for a Joint “Range of Motion” Measurement; test results are given. The implementation, evaluation and advantages of a proposed “Real-time ROM Measurement” are also given. The proposed KINECT application will be useful for enhancement of KINECT technical capabilities and for further advancements in medical care.

Keywords— Kinect; Physical Rehabilitation; Joint Range of Motion Measurement; ROM styling

I. INTRODUCTION

KINECT is a sensor box initially developed for the Xbox games console. Its Windows interface has also been commercialized by Microsoft. KINECT has a video camera, together with a depth sensor, that makes it possible to measure the distance between an object and the KINECT box.

KINECT covers 3D space about 4 meters in depth and an angular field of view of 30 degrees to right and left. Its distinguishing feature is the provision for skeletal and joint structure tracking to be captured by the camera. KINECT sensors do not work extremely well for recording movement. Even so, its affordable price means that it will have potential for a wide variety of applications.

The KINECT-based physical rehabilitation research project supported by SCOPE (Strategic Information and Communications R&D Promotion Programme) is being developed over the 2011-2012 financial year. Aoyama Gakuin University is responsible for developing applications and Kitasato University is contributing to provision of physical rehabilitation training schemes for application development. Kitasato University provides evaluation and improvement proposals for the applications.

This paper reports the results of four types of KINECT-based physical applications. The applications measure either walking time or joint angle ranges. The applications are not for training patients but for measuring training effectiveness. The paper then explains why there are difficulties with the implementation of on-going manual measurement processes. Then it proposes a “Real-time ROM Measurement”: a real-time measurement process that reflects the advantages of KINECT.

II. THE TIMED UP & GO TEST

A. Measurement

Podsiadio D and Richardson S explains in the paper [1]: “This study evaluated a modified, timed version of the "Get-Up and Go" Test (Mathias et al, 1986) in 60 patients referred to a Geriatric Day Hospital (mean age 79.5 years). The patient is observed and timed while he rises from an arm chair, walks 3 meters, turns, walks back, and sits down again. The results indicate that the time score is (1) reliable (inter-rater and intra-rater); (2) correlates well with log-transformed scores on the Berg Balance Scale (r = -0.81), gait speed (r = -0.61) and Barthel Index of ADL (r = -0.78); and (3) appears to predict the patient’s ability to go outside alone safely. These data suggest that the timed "Up & Go" test is a reliable and valid test for quantifying functional mobility that may also be useful in following clinical change over time. The test is quick, requires no special equipment or training, and is easily included as part of the routine medical examination.”

The timed “Up & Go” test is one of the most commonly used rehabilitation tests in Kitasato University. The university has two big hospitals. It was decided to implement the KINECT application following the manual describing how to take measurements.

B. Software Implementation

A marker pole is put 3 meters in front of the chair where a patient sits at the beginning. KINECT is put on a desk in an extended line nearly 4 meters from the chair. KINECT sends VGA pictures and 3D (three dimension) coordinates data (X,Y,Z) corresponding to each VGA pixel and the person’s skeletal and joint structure to a PC via USB interface. The PC software measures the time: starting from when the patient stands up, as he goes around the pole until he sits down again. The software has algorithm to detect a patient getting up from the chair and sitting back down in the chair.

A number of algorithms are implemented to judge the accuracy of the time measurement, i.e., first, judging from the height of a patient’s head position, next the height of his crotch position etc. Another idea was also tested: this was to define the cubic space around the chair and to draw conclusions from the number of included joints that the KINECT skeleton-tracking structure reported. The location of KINECT was changed to evaluate the accuracy of the patients’ “getting on and off the chair” detection algorithm.

The KINECT box was moved from directly in front of the chair, to the side of the chair and to above the chair-looking down on it. There were some errors in each case. In the end the best position

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selected was for the KINECT to be placed directly in front of the patient 4metres from the chair.

C. Evaluation and Discussion

Evaluation of the software was done by comparing an examiner’s stop watch time record with the KINECT test program. Table 1 shows the result. Here the test sample were healthy, mostly University, students. The time difference average is 0.33 seconds. An accustomed expert in physical rehabilitation pointed out that even hand-operated stop-watch measurements are subject to small errors, so the time difference shown in Table 1 is acceptable for adapting the KINECT system in a hospital. The result shows KINECT-based time counting for the timed “Up & Go” test is acceptable for normal individuals.

But there are issues to be resolved. When a KINECT video-camera has only one person (i.e., a patient) in range it works well. But if two people appear in the range of the video-camera, a false report goes to the PC. When the timed “Up & Go” test is being administered, generally speaking, an assistant walks beside the patient, so at least two people are captured by the KINECT camera. When two people do a U-turn at the marker post which is about 50cms from KINECT (so, very near to it), sometimes the video-camera could not follow correctly. When this happens, the test program waits for the “sitting down again” of the wrong person; this means that the time measurement is incorrect.

The second issue is that the KINECT system, as so far developed, could not get the timing right for “getting up from the chair” or for “sitting down again”. A geriatric person moves very slowly when standing up or sitting down. When a stop-watch is used, an examiner starts the watch for a patient who is getting up from a chair when the patient’s hip moves away from the chair and is no longer touching it. This small movement is rather difficult for KINECT to detect. The same type of slow movement when the patient sits down is equally difficult for KINECT to detect. But it is very likely that improved KINECT technology will soon be available to resolve these issues.

III. TIMED 10-METER WALK TEST

A. Measurement

Oberg T. Karsznia A. and Oberg K. describe in the paper “Basic gait parameters: Reference data for normal subjects, 10-79 years of age” [2]: “Basic gait parameters were extracted from 233 healthy subjects—116 men and 117 women, 10 to 79 years of age. The measurements were made in a gait laboratory on a 5.5 m walkway. The results are presented in a series of reference tables for slow, normal, and fast gait. Mean, standard deviation, coefficient of variation, 95% confidence intervals, and 95% prediction intervals were calculated. Significant sex differences exist in all gait parameters. In a two-way analysis of variance (ANOVA) model, there was a statistically significant age-variability for gait speed and step length at normal and fast gait, but not for step frequency. In the step length parameter there was a significant interaction effect of age and sex at normal and fast gait. The reference data are considered valid in an outdoor laboratory situation.”

See [3] for a definition of the timed “10-Meter Walk” test and for the test method of how to evaluate a person’s ability to walk. The test used in our project has a modified scheme. There is a 10-meter walkway with 2-meter approach strip and a 2-meter ending strip at the ends of the 10-meter walkway. A start line and a finish line are marked on the walkway. A patient walk is performed at a preferred walking speed (normal comfortable speed) or a fastest possible speed (maximum speed trial). The test collects the times from three walks and records the time taken (seconds) between the two lines. In the case of the manual test, an assistant walks with a patient and starts and stops a hand-held stop-watch. The assistant also counts a patient’s steps.

B. Software Implementation

To get the time recorded both at the start line and at the finish line, two KINECT boxes are located on desks together with two PCs. (Fig.1) The two PCs are 10 meters apart and connected via Ether hub and cable. Thus, at the PC display near the start line, two videos captured by both KINECTs are shown. Timing detection requires a line that the PC software can identify as a person crosses it. The line is defined and drawn beforehand manually, consisting of a vertical line on KINECT-captured figures both at the start line and the finish line.

To check that the system is working, the PC makes a warning sound when a person crosses the start and finish lines. The timed “10-Meter Walk” test [3] defines the start timing as “when the toes of the leading foot crosses the 2-meter mark”. KINECT does not clearly identify the toes so our software algorithm identifies the line being crossed by using a person’s centre of gravity.
C. Evaluation and Discussion

Table 2 shows the results of the evaluation test. The average time difference for the two sets of results (examiner and KINECT) is 0.15 seconds. So, from the point of view of measured time, the KINECT-applied system is acceptable for practical use.

Here, also, there are issues to be resolved. Firstly, a patient is accompanied by an assistant. The assistant is responsible for preventing any problem for the patients. So the KINECT video camera captures two people simultaneously. It is not easy to distinguish a patient from an assistant, unless extra measures are taken, for example: an identifying mark on the assistant's clothes.

Secondly, two KINECTs work together to measure time between a start line and a stop line, so some rule is required to identify the patient as the same object captured on both lines. One method is to ask the patient to walk on the near side about 1-meter from KINECT and the assistant to walk on the far side. This resolved the first issue.

The third issue is the complexity of installing two KINECTs together with PCs and LANs. In addition, for more detailed testing, it's necessary to count steps. This requires a new KINECT which sees the foot and reports toe-joint movements. Since the foot is a vital element in walking, I expect that in the near future KINECT for the structure of the foot joint will become available for physical rehabilitation.

IV. JOINT RANGE OF MOTION MEASUREMENT

A. Measurement

The CDC website [4] states in “Normal Joint Range of Motion Study” that “People with bleeding disorders, such as hemophilia and Von Willebrand Disease may develop chronic joint disease from repeated bleeding into their joints. Over time, the joint disease results in decreased mobility of the joints. People without bleeding disorders also lose mobility in their joints with ageing. However, there are very few studies of joint mobility over time in people without bleeding disorders. Data from the Joint Range of Motion study provide a baseline to learn more about loss of mobility due to joint bleeding.”

The page shows a photo of a lady with a protractor manually measuring the elbow angle of a man lying on a bed. The idea is to apply KINECT for measuring the joint range of motion, to replace manual measurement with automatic measurement. Range of Motion (ROM) is a key term in rehabilitation care. It should be pointed out that KINECT is not able to measure all angles accurately. However, the KINECT system will be very useful for an upcoming ageing society because of how easily it can provide data on bone relationships. Table 3 lists the candidate joints which can be measured by KINECT, extracted from the paper of The Japan Association of Rehabilitation Medicine [5].

When caring for a patient, the joints where ROM is applied are selected depending on rehabilitation requirements. When the range of the measured joint is extended, then the rehabilitation is judged to be effective. During measurement a patient sits on a chair, stands or lies down on a carpet depending on the ROM test region. When necessary, an assistant helps to carefully move the joint being measured.

Fig.2 shows photos of manual ROM measurement for shoulders and crotch.
B. Software Implementation

For calculating ROM, the following are required:
- Selected target joint
- Two joints with one bone link to the target joint
- Body direction that defines a norm plane for calculating angle

The norm plane is a frontal plane that is estimated from two shoulder joints and a centre of body, i.e., navel.

When a person’s movement is detected within a camera angle, KINECT provides skeletal joint structure tracking to a PC. Its 3D location information is limited to joints involved in large body movements. The software shows the skeletal joint structure tracking. [Fig.3]

If more than one person is captured by KINECT, the display shows their skeletal joint structure together. In manual measurement, generally speaking, an assistant is nearby, so the assistant’s skeletal joint structure tracking is also shown. The software developed shows ROM values digitally on a display. An assistant (examiner) measures the ROM value with a protractor, and reads the value. Both KINECT and manual values are recorded. Table 4 shows the result of comparing both sets of values.

C. Evaluation and Discussion

The issue first discussed is whether KINECT-measured ROM values are useful. For some joint cases it is valuable. Generally, even with manual ROM measurements there can be slight differences in the values of 5 -10 degrees. Table 4 shows the joints where the values measured by KINECT can replace the manual ROM measurement: for the upper limbs this is possible but for the lower limbs it is difficult. Thus the developed application is useful for shoulders and elbows where the movement range is wide. But it is not useful for the crotch and knee with the present KINECT. At the same time several issues to be resolved are clarified.

The printed manual for ROM measurement [5] explains the posture of a patient as lying down on a carpet when the target joints are crotch or knee. This posture results in KINECT receiving and producing erroneous information as it cannot be positioned normally and tracking results are unstable. Being positioned “normally” means that KINECT is placed on a table about 70 cm from the floor, and the angle direction is horizontal. In attempting to resolve the issue, KINECT was moved about and placed in different positions, for example: 2 meters up, looking down at an angle of 45 degrees; a stable accurate tracking could not be achieved. Hopefully, a solution will soon be found with future advancements in KINECT technology.

In ROM measurement an assistant teaches a patient how to move hands and elbows before taking measurements manually. So, when the experimental measurement was carried out, the same thing was done for the KINECT application. This means that two people are captured by a KINECT camera, resulting in two skeletal joint structure trackings on the PC display. When two people are overlaid, an unstable state occurs. The manual [5] does not expect the

<table>
<thead>
<tr>
<th>Joint</th>
<th>Principal Reference Axis (*)</th>
<th>Measured Angle Range (Degrees)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examiner</td>
<td>KINECT</td>
<td>Examiner</td>
<td>KINECT</td>
</tr>
<tr>
<td>Flection</td>
<td>Vertical line passes extension</td>
<td>160</td>
<td>166</td>
</tr>
<tr>
<td>Extension</td>
<td>45</td>
<td>41</td>
<td>9</td>
</tr>
<tr>
<td>Abduction</td>
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<td>152</td>
<td>2</td>
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<tr>
<td>Adduction</td>
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<td>12</td>
<td>-</td>
</tr>
<tr>
<td>External rotation</td>
<td>Vertical line to coronal plane passes elbows</td>
<td>60</td>
<td>59</td>
</tr>
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<td>Inner rotation</td>
<td>60</td>
<td>55</td>
<td>8</td>
</tr>
<tr>
<td>Flexion</td>
<td>Upper arm bone</td>
<td>150</td>
<td>154</td>
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<td>Extension</td>
<td>0</td>
<td>8</td>
<td>-</td>
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<tr>
<td>External rotation</td>
<td>Vertical line passes patellae</td>
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<tr>
<td>Extension</td>
<td>0</td>
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</tbody>
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(*) Measure plane is frontal parallel plane
measurement to be made without an assistant, thus measurement of lower limbs such as crotch, knee and legs is particularly difficult as help and advice are needed from an assistant.

KINECT-applied ROM measurement attracted the interest of many medical field workers. They say the foot joint structure tracking and ROM are useful for rehabilitation. Also KINECT capability is tried on a baby but here skeletal joint structure tracking does not show up. Probably it is because a baby dole does not make much movement or because KINECT itself has no information about a baby. It is certain that KINECT for a baby will also be useful in nursing.

V. PROPOSAL OF REAL-TIME ROM MEASUREMENT

A. Experienced Issues

As described, three types of KINECT applications for physical rehabilitation have been developed, tested and evaluated. These are summarized as follows:
- KINECT provides relatively stable skeletal joint structure tracking together with joint 3D coordinate data (X,Y,Z) when it is set up to capture one person who is standing in front of the equipment.
- KINECT captures more than one person in its video windows and it provides tracking of all skeletal joint structures. When these figures are in contact position or they are overlaid on each other, KINECT is not able to create stable skeletal joint structure tracking.
- KINECT provides 3 dimensional coordinate data (X,Y,Z) with about from 0.5 to 1.0 cm margin of error.
- KINECT detects depth distance (Z axis) with infrared; therefore it works within a room but is not applicable for the outside. The possible measurement dimension is approximately from 0.5 to 4.0 meters.
- For detecting a person within a video camera range KINECT works according to a person’s movement. It can sometimes incorrectly identify a person because of, for example: a curtain moving in the wind.

KINECT has a number of issues which limit its application in rehabilitation at the moment, but the following characteristics show the advantages it will have for future application.
- Machine-learning technology allowed KINECT to find a person within a captured video. It may be possible to apply the technology to a variety of objects other than a person. So a variety of new applications will be possible.
- Depth distance (3D coordinate data) corresponding to each VGA pixel is measured by KINECT. From the 3D information it is possible to create 3D objects. A created object has the structure of an extruded plane. The object can be rotated on a PC display. In some cases, the picture of the rotated object shows the depth information more easily, making it simpler to see and recognize the relative distance among 3D objects.
- KINECT creates skeletal joint structure tracking of a person. This function is useful for medical care, particularly in rehabilitation. KINECT has been a useful learning tool in Europe and with its development and application in Japan there it will result in better estimation of joint 3D coordinate data.
- Results indicate that KINECT development based on rehabilitation manuals could be inappropriate. Rather, it is better to consider the advantages of KINECT. Therefore Real-time ROM Measurement is proposed.

B. Software Implementation

As described, while admitting the restrictions of the present KINECT specification, a Real-time ROM measurement application has been developed. A designated-joint ROM with figures and an angle degree is digitally displayed on a screen.

The measurement process implemented by the application follows. Development has been done with a Windows PC applying KINECT SDK and Visual Studio C++.

- Before starting the measurement, the assumption is that one patient is standing in front of KINECT. If an assistant stands beside the patient, it is acceptable as long as the two people do not overlap on the screen.

- Starting the application creates three windows on a display. One window tilted at an angle displays a title and project name for 1 second, and then it disappears. The left-hand window shows the skeletal joint structure tracking of the patient together with the joints. The right-hand window shows the measured degree of the indicated joint in real-time.

- KINECT identifies a person when a patient moves, then it displays his skeletal joint structure on a screen. Two ways of skeletal joint structure tracking are implemented, i.e., KINECT original and medical education style at Kitasato University. Fig.4 shows the latter.

- As shown in Fig.4 possible joints for measurement are indicated with a circle. In Fig.4 the circle has a dot at the centre but the photo is not clear. When a mouse is overlaid on the circle, a small pull-down menu opens. It shows a menu to select measurement types such as flexion/extension etc. A click on it starts ROM measurement.

- When it starts, the left-hand window displays the angle of the joint being measured. At the same time in the left-hand window, ROM angle measurement is displayed with a pink fan shape at the left elbow (Fig.4).

- Measured degree values are displayed with large number fonts in the right-hand window. (Fig.5) This display shows a real-time operation. The patient can see both windows while moving his joint, corresponding hand or legs and so on.

- The right-hand window displays maximum and minimum angles while measuring. Its function is to observe an angle and display it at times selected manually. This function is implemented as an examiner selects the right timing from looking at the patient’s moving joint position.
C. Evaluation and Discussion

With a combination of a KINECT and a laptop PC with a 17-inch display it is possible to make Real-time ROM Measurements. It allows a patient on his own to know his ROM measured angles by moving joints while standing facing KINECT. An assistant, if necessary, can select joints, record ROM results and assist the patient. Further improvements to this application should allow for a patient’s personal record management of ROM data and its visualization by chart.

The project established that this KINECT application has advantages for medical care especially in the field of rehabilitation. The KINECT currently available has limitations: measurable space is limited, 3-dimensional X,Y,Z coordinate data have relatively large differences of 1 cm, the VGA picture is small, and its skeletal joint structure tracking often becomes unstable. But with KINECT technology advancement, surely these current limitations will be overcome in the near future.

VI. RELATED WORKS

Google Scholar listed 759 items with the searching words “KINECT applications for rehabilitation” on March 15 2013. This shows so many researchers are interested in the field. By adding searching words to the phrase the result number decreases. In case “range of motion” it is 658 and “game” is 734. When “the timed up and go test” is included the number decreases down to 42. No paper has discussion about “timed 10-meter walk test”.

Two types of searching key words combination follows. The first one has “KINECT applications for rehabilitation” plus “joint range of motion, the timed up and go test, limb, shoulder, elbow, angle measurement”. This resulted in 4 papers but one paper excluded it has no KINECT terminology. The titles are listed in [6][7][8].

The second combination has plus “joint range of motion, limb, shoulder, elbow, flection, extension, abduction, adduction, external rotation, inner rotation, angle measurement”. Google Scholar listed 6 papers. The titles are [9]-[14].

Paper [9] reports a comparison study of the precision in the computation of joint angles between Kinect and an optical motion capture professional system. It describes the results obtained about a range of disparity that guarantees enough precision for most of the clinical rehabilitation treatments prescribed nowadays for patients.


Paper [6] describes the findings suggest that the Kinect can validly assess kinematic strategies of postural control, therefore become a useful tool for assessing postural control in the clinical setting.

VII. CONCLUSION

As a tool for 3-dimensional image processing, KINECT has been selected for the development of a number of applications to measure the effects of training. Its practical utility has been confirmed through evaluation experiments. Even though there are a lot of limitations for KINECT, Real-time ROM Measurement has been proposed and its practicality proved by implementation and evaluation. It is foreseen that KINECT technology will be widely applied in medical care fields.

REFERENCES