Using Kinect V2 to make the OSAS system more time efficient and accurate: a pilot study

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ABSTRACT
This paper challenges a new way of validating movements according to the OSAS system based on OSAS Quality Criteria, by using a Microsoft Kinect V2 Depth Sensor. Currently accessing movements with the OSAS system is very time consuming. In cooperation with a rehabilitation center, this research is focused on making the process of assessing more time efficient. Within this study several pilot tests are conducted to create a baseline measurement in using the Kinect V2 for the OSAS system. A pilot test has been conducted by applying Kinect V2 into the OSAS assessment activity. The data of the joint positions of the upper extremity was gathered and the activity was recorded during testing. The data of the Kinect V2 is inspected by comparing it with the recorded video. Since the highest accuracy of detecting a movement during the pilot test is 63,0%, it is argued that the Kinect V2 is a system with potential, but it needs future research to be a sufficient addition to the OSAS system.

Author Keywords
OSAS system, Kinect V2, Cerebral Palsy, Body Detection.

1. INTRODUCTION
Cerebral palsy (CP) is the most common motor disability in the childhood which is caused by brain damage. It is a neurological disorder that affects a child's movement, motor skills and muscle tone [1]. Monoplegia is a type of unilateral spastic cerebral palsy, which causes a paralysis of a single limb, usually an arm and an affected hand [2]. This group of children, who encounter arm-hand function problems and restriction of bimanual tasks, use their affected hand as an assisting hand. Often, they do not use their arm-hand to its full potential in bimanual tasks [3]. Therefore, the stimulation and observation of bimanual tasks is very important in the rehabilitation process of children with monoplegia [2].

To observe and assess a patient suffering from CP a commonly used method by Adelante [4] is OSAS (Observational Skills Assessment Score) [3]. OSAS, is an assessment method that consists of a set of tasks that the participant has to perform. Thereby, the performance of the participant is assessed by a therapist according to the OSAS Quality Criteria, which represent the degree of CP of the participant [5]. This method uses a set of cameras to collect footage of the patient's movements. This video footage will then be assessed based on the benchmarks stated in the research of Speth, L. et al [3]. The OSAS assessment method is often used by therapists in the Netherlands [personal communication, April 19, 2019] because of the accessibility and simplicity of the measurement setup. However, (1) the therapist has to evaluate the full length of the recorded video footage second by second based on the OSAS Quality Criteria [5], which takes approximately 45 minutes, and (2) not all minor movements can be observed by this video footage. Therefore, the process of assessing the movements of a child is very time consuming. Also, it is a type of relatively subjective assessment, which is conducted by traditional visual inspection method. This assessment is error-prone with the increase in workload and work speed of therapists [6]. Taking these disadvantages into consideration, new methods for measurement should be examined. This study will examine if the Kinect V2 is able to improve the accuracy of the system as well as reduce the time consumption of the assessment for the therapists.

When it comes to measuring the change in body gesture there are several sensors that are used for a comparable application. Since there are multiple previous studies [7,8,9,10,11] about the use of the Kinect Version 2 Depth Camera that seem promising to use as an addition in the OSAS system, this paper focuses on the use of the Kinect V2. Another reason for using the Kinect V2 is the fact that the Kinect V2 has no physical contact with the body of the child. Therefore the Kinect Depth Camera is a sensor that will not impact the execution of the exercise.

This study will first focus on the wrist joint to verify if the Kinect V2 is a valuable addition. The wrist joint is chosen based on the following findings; (1) large, less precise joint movements are easy to track with Kinect as proven in previous studies [8,12] and (2) according to the OSAS Quality Criteria and stated by a therapist [personal communication, April 19, 2019] the wrist is the most used joint for accessing the movements during the exercises. Table 1 shows how often the therapist classifies each joint of the upper body.

Once the level of accuracy of a Kinect V2 is determined by tracking joints of the human body, a second test is conducted in order to verify whether the Kinect V2 is able to track the right point of the human body while executing one of the OSAS exercises [Appendix A]. In this test, joints of the right upper extremity are tracked by the use of the Kinect V2. Afterwards, gathered data of the Kinect V2 is analysed to determine whether it is valid.

Body part	Amount of classifications
Trunk	5
Shoulder	6
Elbow	6
Wrist	20
Hand	10
Fingers	8
Thumb	8

Table 1, Amount of classifications per joint according to OSAS Quality Criteria [5].

2. Related works

2.1. Current technologies for assessment of body rehabilitation

Accurate assessment of body rehabilitation is required in order to ensure the patients perform their rehabilitation exercises well and receive the correct assistance plan from therapists. Traditionally, the information-collecting and evaluation steps are conducted by therapists, this way of assessment is very time consuming and error-prone when the work speed and workload are increased [6]. Nowadays, many technologies play an assistant or even a dominant role in evaluating the quality of posture and gesture activities [13]. Gesture monitoring technologies show great benefits of supporting rehabilitation assessment, especially for the CP and stroke patients. There are two main technical methods for gesture monitoring: (1) wearable sensor-based systems [14] and (2) vision-based/depth camera-based systems.

The wearable sensor system is usually built upon a hand kinematics assessment glove with attached flex-sensors and position-sensors (accelerometer) [14]. Though gloves with position sensors provide accurate measurements of the hand, they are cumbersome to wear and connected by wires [14]. The above-mentioned drawbacks are not applicable for the OSAS system due to the special case of the affected hand of CP children. The wearable devices have an influence on the stress level of children during testing, which could affect the testing results [personal communication, April 19, 2019]. Additionally, it is time consuming for the therapists to set up the wearable sensor for each patient.

In comparison to the wearable sensors, the vision-based/depth camera-based technology provides a cost-effective solution for clinical use due to low costs and high robustness [15], it can support the therapists for the diagnosis and monitoring evaluation with an easy setup [15]. Another significant advantage of depth camera-based technologies is the fact that it is non wearable, which does not stress children with sensors that they have to wear during tests.

There are several widely applied vision-based technologies like Microsoft's Kinect device and Leap Motion [8]. Kinect is able to recognize the full body movements while Leap Motion is specially for small gesture tracking [16]. The decisive advantages of the Kinect system over the Leap Motion, in our case, is the whole upper body tracking capacity.

The OSAS system focuses on the assessment of the functionality of the upper extremity during daily life activities of a child. Also the coordination between the affected and non-affected arm and hand is assessed. The Kinect system can be used as a motion sensing device that offers a suitable alternative to OSAS, supporting the therapists with the diagnosis and evaluations by reducing subjectivity, imprecision and make the process less time consuming.

2.2 Kinect V2 in the rehabilitation field

Compared with traditional cameras, the added value of Kinect V2 for the rehabilitation is its depth sensor that is able to retrieve the 3D information and real-time skeletal tracking [17].

The most valuable advantage of the depth camera for action recognition and human motion detection is the improvement of segmentation. It tracks by combining the color- and depth-camera to resolve the difficulty of the interpretation of the complex variations in human body movement [18].

Due to the mentioned benefit as well as the reasonable price, the use of Kinect technology has been supported and applied in the area of rehabilitation of people with CP and people who had a stroke as a potential posture and gesture analysis tool [19].

There are two types of the Kinect sensors, Kinect Windows V1 and Kinect Windows V2. This research uses Kinect V2 for the following reasons. Firstly, comparing with Kinect V1, the Kinect V2 is able to define six more skeleton joints, which include hands and thumb tracking that are essential for application in the OSAS system. Moreover, Kinect V2 uses the 'time-of-flight' method to compute depth, which is more stable, precise and less prone to interference than the Kinect V1 [20].

Research related to the Kinect V2's ability to accurately capture upper extremity movements is consistently reported as sufficient for clinical use regarding the elbow and wrist motion tracking. In the comprehensive measurement about the accuracy and reliability of the Kinect V2 by Karen Otte, 2016 [10], results of the research lead to the assumption that the Kinect V2 is accurate enough to measure clinical parameters in the healthcare context. Karen Otte's research results show that the wrist, hand and shoulder have high accuracy in the vertical movement components. As one of the conclusions of that study, the upper body including the hand, elbow and shoulder can validly be used for general movement analyses and calculations of clinical parameters. Other works for the application of upper extremity function analysis [21], and assessment of balance disorders [22] also concluded the accuracy of the Kinect V2 is sufficient for related assessments. However, it is still in the early application stage for the Kinect-based rehabilitation methods, because there are limitations and possible errors such as occlusion and noise in skeleton tracking [7,8,11,12,21,17], and there is a lack in clinical evaluation [17].

Based on the above conclusion from several publications, the Kinect V2 is assumed to be a robust and reliable sensor for the OSAS system for the affected arm assessment of the CP children.

2.3 Limitations of Kinect V2

Although great results on human body tracking and body gesture recognition can be achieved by Kinect V2, it still has a challenging problem to monitor fine motions. This problem occurs with small body parts like the hand and fingers, which have more complex articulations and are more easily affected by segmentation errors [23].

As a vision-based sensing system, Kinect has a serious limitation on generating skeleton poses due to self-occlusion [22]. This problem has to be considered into our study since the detected body parts are the affected arm and hand of CP children, which may build up the difficulty of the measurement. A solution for this problem could be using multiple Kinect sensors to detect the target from different perspectives which relates to a complex data fusion by combining the measurements from all of the Kinects [12], but this is out of our expertise and scope of the study to put into practice. The future work section provides a discussion about this topic.

3. Methodology

As shown in figure 1, wrist movement can be divided into six types of movements [25] (1) flexion, (2) extension, (3) radial deviation, (4) ulnar deviation, (5) pronation, (6) supination. According to the OSAS Quality Criteria the therapists are not interested in pronation and supination. Therefore this study focuses on detecting and assessing the (1) flexion, (2) extension, (3) radial deviation and (4) ulnar deviation. Also according to the OSAS Quality Criteria it is not important to know the precise angle of individual joints, hence the detection of the wrist motion is sufficient enough to make an assessment according to OSAS [3].

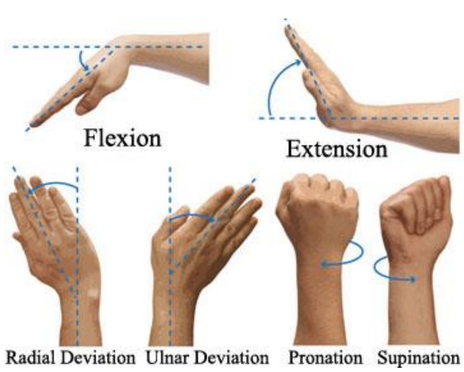

Fig. 1 Wrist motion [24].

To be able to analyse the movement of the wrist, X-, Y- and Z-values of the (1) trunk, (2) shoulder, (3) elbow, (4) wrist, (5) center of hand and (6) the top of the hand are collected in real-time by the Kinect V2. These three values for each point can be detected as coordinates of the joint. Knowing the position in space for each of these joints makes it possible to show the body gestures by analyzing the change in values. To ensure the Kinect V2 is able to track gestures of the wrist stably, a benchmarking test was conducted.

3.1 Kinect Windows V2

In this research, a Kinect V2 was used for tracking the body movement. The Microsoft Kinect device contains a depth sensor, a color (RGB) camera and a four-microphone array. It uses infrared (IR) light to generate depth images that can give a 3D representation through reconstruction [7]. In terms of software development support, the Kinect can be programmed in C++, Java, C#, and many other programming languages [8]. The process of the data acquisition is based on the visual skeleton tracking and collecting the 3D position of the joints without markers [15]. The maximum frame rate for the Kinect is 30 fps, and the active measurement range is from 0.5 to 4.5 meters, the closer to the sensor the higher the precision tracking is, as long as the body parts are fitted the frame rate [9].

This study uses the KinectPV2 library for Processing [26]. This library is used in combination with the Kinect V2 to visualize the skeleton point of the elbow, wrist, hand and fingertip (middle finger) of the right upper extremity and to generate the X-, Y-, Z-values of the wrist and hand.

By using the mean shift algorithm, skeletal tracking is enabled. Therefore, the target body joint is tracked by the Kinect V2 sensor and represented by its 3D coordinates in real time [12].

3.2 Test setup

The Kinect V2 is mounted on a tripod to place the Kinect V2 at a fixed height of 170 cm from the table to the bottom of the Kinect V2. The Kinect V2 is placed in a downwards angle of 52 degrees. The distance between the Kinect V2 lens and the center point of the view is 198 cm. With this distance the Kinect V2 has a Horizontal Field of View of 484 cm and a Vertical Field of View of 415 cm [27] at the reference point of 198 cm. The distance between the Kinect V2 and the end of the table is 215 cm. The Kinect V2 recorded the test at 30 fps. During all the tests the Kinect V2 uses its camera to record video footage and its depth sensor to track the joints of the participants body.

Similar to the table OSAS system uses [3], one table with the size of 140x70x76cm is used for the benchmarking test. For the final test three tables are used with the same size of 140x70x76cm. Since the light-intensity can influence the accuracy of the data [13] parameters in the test environment should be contained. Therefore, the test was conducted in a controlled environment.

3.3 Participants

In this pilot-study, three participants were sampled by convenience. The test group consists of one woman and two men respectively 23, 24 and 24 years old. The participants have no disabilities.

3.4 Benchmarking test

The goal of this test is to determine whether the Kinect V2 is capable of detecting wrist motions (1-4) in the most standardized form. The participant was asked to fully flex and extend the wrist ten times. Afterwards the participant was asked to move from a radial to an ulnar deviation ten times as well. An accelerometer was placed on the center of the hand of the participant which was also tracked by the Kinect V2. By doing so the gathered data of the Kinect V2 can be validated with the data gathered by the accelerometer. The used accelerometer is a MPU6050 [28]. The Kinect V2 was placed at a height of 110cm with a distance of 110 cm to the participant. In so doing, the axis of the Kinect V2 and the accelerometer match. As shown in figure 3, the Kinect V2 is tracking the elbow, hand, center of the hand and the top of the hand. Only the data of the center of the hand is used in data analyses. The other joints were tracked to increase the stability of the Kinect V2. In figure 2 and 3, it is shown how this test was conducted.

3.5 'Making a sandwich' test

In order to assess whether the Kinect V2 is able to add value to OSAS, this study mimics one of the tasks that a child with CP has to perform. There are several activities for different age groups in the OSAS system. Since the tools that are necessary for one of the tests are basic household products and because of the importance of mimicking the exercise precisely, it is decided to use the 'Making a sandwich' [Appendix A] task for this study. The 'Making a sandwich' test is used by Adelante's therapists to assess children between 7 and 12 years old. During this activity, a child needs to open a jar of his favorite paste and spread the paste across a sandwich that lies on a plate. Afterwards another sandwich is placed on top of the spreaded bread and cut in half. The two slices of sandwich are placed on another plate. The child is allowed to use both hands to conduct the task, their affected hand is usually used as an assistant hand.

The used materials in the OSAS assessment test, 'Making a sandwich', are (1) a knife, (2) four plates, (3) two slices of bread and (4) a jar of chocolate paste. Next to the specific materials for this task, the rest of the set-up is the same as described in Test Setup. As shown in figure 4 and figure 5 a test setup was built.

To make sure the exercise was conducted in the correct way, instructions were given to the participants. After describing the task of the test, following additional instructions were given:

- Start when the start sign is given;
- Start with waving your right arm around until a stop sign has been given. (the Kinect V2 tracks the arm);
- For a duration of two seconds, hold your arm still above (to make a reference point in the data);
- Try to move like you normally do;

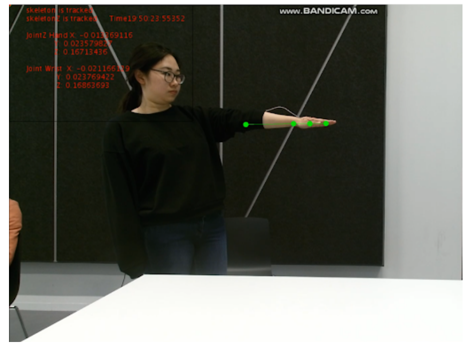

Fig. 2 Film still - Benchmarking test

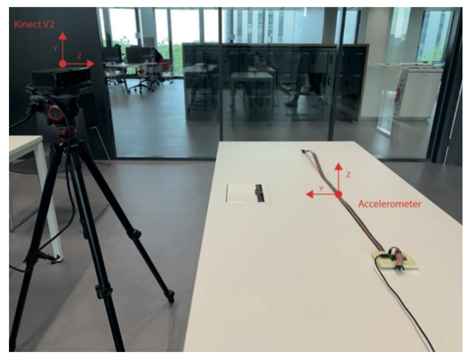

Fig. 3 Side view - Benchmarking test

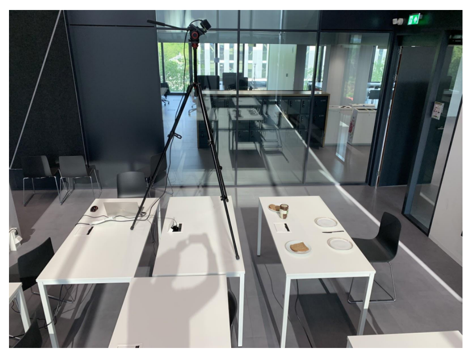

Fig. 4 – Side view – Making a sandwich test

Fig. 5 – Top view – Making a sandwich test

3.6 Data validation

All assessments in this study are executed by one of the authors. Afterwards the assessment of the first author is validated by a second author. During the 'benchmarking' test an accelerometer was used to validate the data of the Kinect V2. The accelerometer was placed on the center of the hand in order to match the Z-axis of the accelerometer to the Y-axis of the Kinect V2 as shown in figure 3. Since the raw data of the Kinect exists of very small numbers, the raw data is multiplied by a value of 3000. In so doing, the raw data has a similar data range as the raw accelerometer data and therefore it becomes more convenient to validate. Once the both data sets are plotted in a graph, the data is validated by looking for similarities in the graphs. This study determines the similarity of both datasets to be true; when the accelerometer data represents a peak (½ sinus wave) in the same time frame as a slope (¼ sinus wave) in the Kinect dataset.

In previous research [10] the accuracy of the Kinect V2 in a highly controlled environment is determined. During the 'Making a sandwich' test, it is seen that adding objects (in our case: tables, knives, plates, etc.) can cause noise in the data. Next to that, the accuracy depends also on the system that is used. Therefore, this study conducted its own calibration tests. Six tests in which the two participants did not move for ten seconds were conducted. The results of this test are called 'baseline measurements'. Based on this measurement, it is determined when a change in the data is considered to be a movement. Since the Kinect V2 and the program that was used in this study did not give the same amount of data points each second, the corresponding data of the given timestamps of the Kinect V2 (± 1/40 of a second) is analysed.

The validation of the 'Making a sandwich' test has been done in three steps. Analysing the video recording to determine at what timestamp the participant performs a movement is the first step. This analysis has been done for each body part of the upper extremity. Secondly it has been checked whether the Kinect V2 was tracking the joint on the right point on the body, by analysing the video recording for each timestamp. Finally, once the participant performs a movement and the Kinect V2 tracks the right point, the data of the Kinect V2 is assessed. This assessment has been done by analysing the graphs of the X, Y and Z-coordinates of each joint to see if the Kinect V2 was tracking the movement at the right time and in the right direction.

4. Results and Data analysis

4.1 Benchmarking test

The data from the accelerometer MPU6050 [28] is used as reference data to validate the accuracy of the Kinect V2.

Data shown in figure 7 represents the displacement (center of the hand) on the Y-axis over time. The data in figure 6 represents the acceleration (center of the hand) over time on the Z-axis. Important to note, the Y value of the Kinect V2 can be compared with the Z value of the accelerometer because they are at the same orientation, as shown in figure 3. The Y value visualized in figure 7 is a sample of the data collecting by the Kinect V2 when a participant was performing ten times the wrist flexions and extensions respectively. Figure 6 shows a sample of the Z value data of the accelerometer with the same timestamp as in figure 7.

4.4.1 Wrist flexion and extension

By analysing both datasets by flexion and extension of the wrist, similarities can be found. As seen in the sample in figure 6 and 7, similarities are marked green. Unmarked areas represent a mismatch between both datasets. In table 2 the amount of detection is shown.

	Accelerometer	Kinect V2	Similarities
Extension (n=)	76	60	78,9%
Flexion (n=)	76	65	85,5%

Table 2, Detection of wrist movement

4.1.2 Wrist deviation

In the wrist deviation test, the orientation of Z from the Kinect corresponds with the Y of the accelerometer, which is supposed to indicate the wrist deviation movement. However, it is hard to notice any similarities in the Y data graph of the accelerometer to indicate the repetitive movement of wrist deviation. By comparison in figure 8, the Kinect data graph of Z value starts and stops to fluctuate regularly at the same timestamp as wrist deviation starts and ends in the video footage. Under these circumstances, the X value of the accelerometer are shown as auxiliary reference data to validate if the Kinect data is correct or not.

The red line in figure 9 is the visualization of the X value of the accelerometer from the wrist deviation test. From this figure, there is similarity noticeable between both graphs. When the values go up in the X direction of the accelerometer, the wave goes down conversely in the graph. In this case, the data variation of the Kinect Z value could be matched with the accelerometer, but inversely and with low consistency.

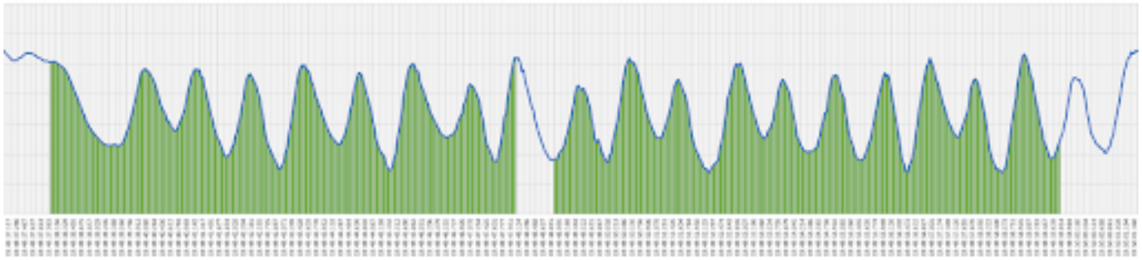

Figure 6 , The Z value data graph of Accelerometer during the wrist benchmarking test

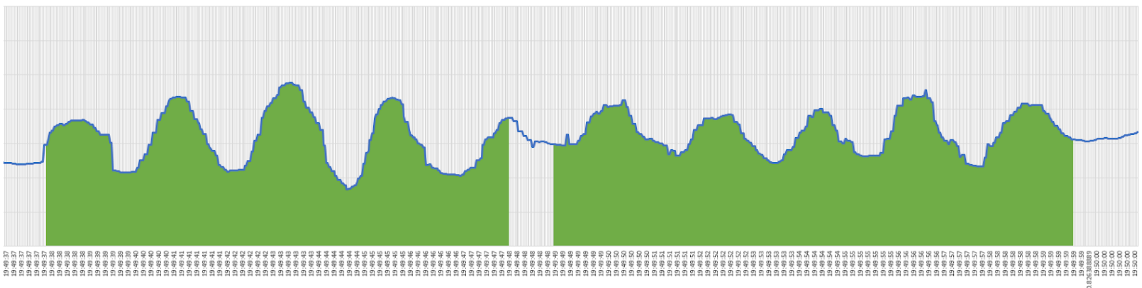

Figure 7 , The Y value data graph of from Kinect during the wrist benchmarking test

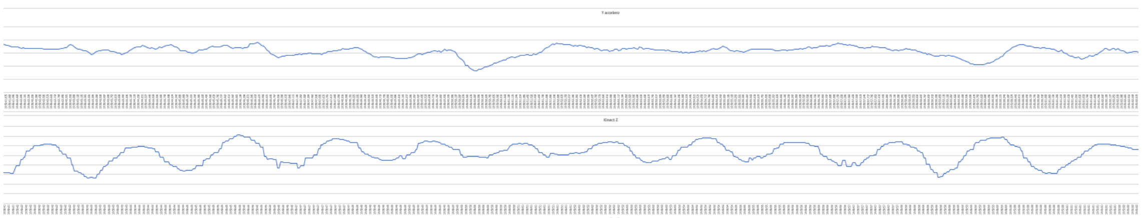

Figure 8, The comparison graph of Kinect Z (the bottom) and Accelerometer Y (the top)

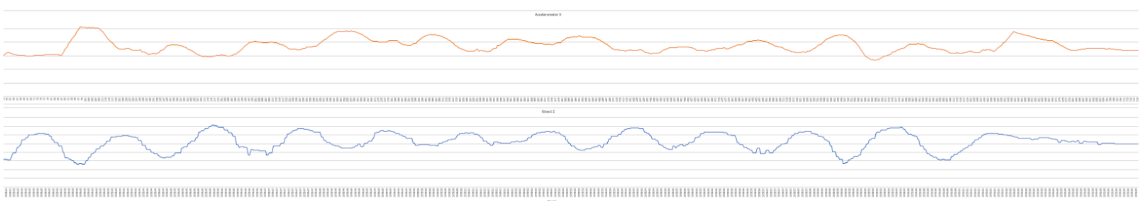

Figure 9, The comparison graph of Kinect Z (the bottom) and Accelerometer X the top)

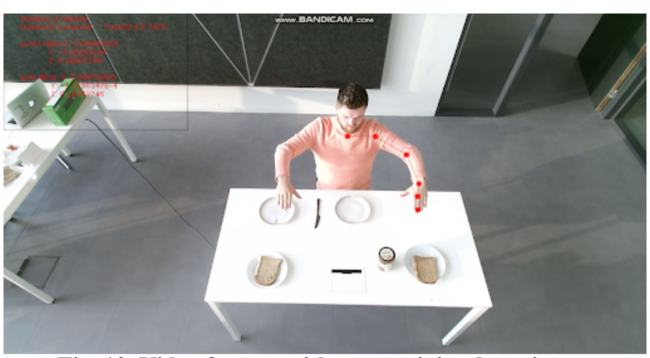

Fig. 10, Video footage with correct joint detection.

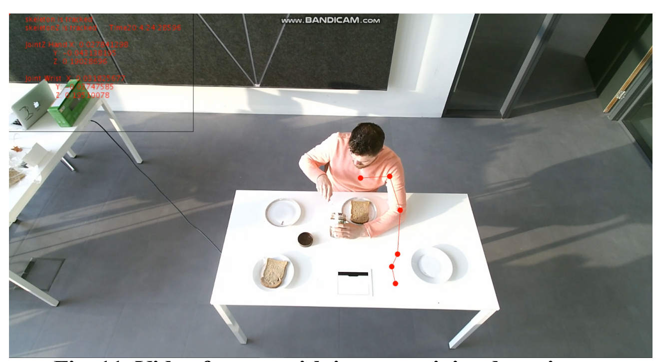

Fig. 11, Video footage with incorrect joint detection.

4.2 Making sandwich test

During this test, the points of the coordinates of each joint is printed on the video footage as shown in figure 10. A total of 67830 timestamps divided across six joints were analysed across three tests by video. In table 3 are the percentage of correct joint detections ('True') of the Kinect V2 shown. The amount of wrong joint detections is stated as 'False'. An example of a 'False' detection of joints on the participants body is shown in figure 11.

Six tests, in which the two participants did not move for ten seconds, were conducted. Within these tests the highest difference between the maximum value and the minimum value of the joints was different for each coordinate of each joint. In table 4 is shown what the difference per coordinate of a joint is. Higher values then stated in table 4 are considered to be a movement in this study. The point of the top of the hand is excluded from this assessment since the detection accuracy is only 23,6%. The center of hand (with an accuracy of 35,2%) is included because of the importance of assessing the wrist joint.

Table 5 shows how many percentages the Kinect V2 detected movement in the right direction at the right time. When a movement is validated during the video assessing as a true movement (table 3) and the Kinect V2 detected this same movement in the right direction we call it a 'True' movement in table 5. If it is not, we call it a 'False' movement.

	Trunk	Shoulder	Elbow	Wrist	Center of hand	Top of hand
True	11160	10439	10396	5674	3679	2668
False	145	866	909	5631	7326	8637
True in %	98,7%	92,3%	92,0%	50,2%	35,2%	23,6%

Table 3, Correct joint detections

Baseline measurement	Trunk	Shoulder	Elbow	Wrist	Hand
X-axis	1,83	2,61	1,72	1,52	4,21
Y-axis	0,54	1,31	2,24	2,01	5,74
Z-axis	4,53	3,93	3,45	3,45	6,81

Table 4, Movement baseline measurement of Kinect V2

	Trunk	Shoulder	Elbow	Wrist	Hand
True	7124	6659	6853	5711	4629
False	4179	4645	4451	5593	6675
True in %	63,0%	58,9%	60,6%	50,5%	41,0%

Table 5, True and False movement detection of Kinect V2

5. Discussion

A pilot-study with three participants is executed. By conducting a benchmarking test, using a Kinect V2, wrist movement is visualised. In this test, objects (table, knife, jar, bread and plate) that are required for the 'Making a sandwich' test, had minor influence on the detection of body joints. As seen in figure 6 and 7 flexion and extension of the wrist is matched in the dataset based on time, and thereby it is presumed that the Kinect V2 is able to produce valid data for detecting the flexion and extension. When assessing the wrist deviation, the shapes of the graphs did not seem to show some similarity. However, considering the video analysis the Kinect V2 does produce an interval similar to the (real) movement of the participant. Thereby it seems that the Kinect V2 did detect the correct movement. This leads to the assumption that the accelerometer was either not sufficiently attached to the center of the hand or the range in ulnar/radial deviation of the wrist is less represented in accelerometer data because of its smaller range of movement [29].

In extent to the benchmarking test, the 'Making a sandwich' test resulted in detecting data of Kinect V2 with a stronger link to the OSAS system criteria. The detection rate of the Kinect V2 decreased in this test significantly. Especially the detection of points on the human body was lower than expected. A plausible reason for the decrease in accuracy could be the distance between the target joint and the background (in this case the table). As shown in figure 7 the joints resting on the table (wrist, hand and top of hand) are closer to the background (the table) and are clearly detected less accurate, this theory [30] has been supported by calibration tests as well. The fact that the benchmarking tests, in which the distance from the wrist to background is significantly larger, has a higher accuracy supports this plausible argument. In this case, measuring (with Kinect V2) from different (multiple) angles could offer a higher accuracy. Although the detection of joint points on the body was lower than expected, more than 50% of the joints that were detected correctly in fact did have the correct direction, start- and finish time. Considering this is a pilot-test, in which data analysis is for some part based on human eye detection, the Kinect V2 shows some potential in detecting trunk, shoulder and elbow movement.

Based on the results of this pilot-test the link between Kinect V2 and the OSAS Quality Criteria [5] can be made to some extent. As shown in figure 6 movements in the trunk, shoulder and elbow can be detected with significant accuracy compared to hand and wrist movement. Since OSAS is not only about the wrist but the whole upper extremity with a focus on the affected arm, it is presumable that the Kinect V2 can be an addition to the OSAS system after tackling the lack in accuracy.

Looking back on the executed tests and their results some limitations of the study can been seen. Since the participants in this study were adults with no disability similar to CP, it is recommended to arrange a test with children suffering from CP in future work. It is assumed the Kinect V2 will work in the same way but that can not be confirmed within this study. The objects during the 'Making a sandwich' test did interfere with the Kinect V2. This study can not determine on what level the objects interfere. It is recommended to use non interfering object or no objects in future work.

Once future research is done, resulting in an increased accuracy of the Kinect V2, the OSAS Quality Criteria could be filled in automatically based on the data of the Kinect V2. Hereby the system will be more time efficient, since the therapist is no longer needed to assess the exercise. However, considering the need of video footage to discuss the exercise with the parents of the patient and/or third parties, it is recommended to remain collecting video footage of the OSAS exercises. In this case, video footage can always be used for verification and improvement of the Kinect system. Moreover, implementing an option for the therapist to select a certain time frame enables a more time efficient procedure [personal communication, April 19, 2019].

6. Conclusion

Within this study, tests have been conducted to find out whether a Kinect V2 is able to be a valuable assistant for the therapist in the OSAS system. First a benchmarking test is executed in order to verify if the Kinect V2 is able to track human gesture and generate data without the interference of objects near the participant. Further, tests to determine if the Kinect V2 is able to detect flexion, extension, ulnar- and radial deviation of the wrist is executed. Later a final test, where an actual test of the OSAS system is imitated, is done in order to determine if the Kinect V2 is a promising addition for the system.

After the tests we can say the Kinect V2 is able to detect the flexion (accuracy of 86%) and the extension (accuracy of 66%) of a wrist joint. The ulnar- and radial deviation can not be determined as accurate by this study. Since the highest accuracy of detecting a movement during the final test 'Making a sandwich' is only 63,0% we do not recommend the Kinect V2 for replacing the current camera setup, but it can be a promising addition to the OSAS system. Movements related to trunk, shoulder, and elbow can be assessed by the Kinect V2 in order to reduce the workload of therapists to be a less time consuming solution. Since it is assumed that the accuracy is slightly influenced by interfering objects during the exercises, the Kinect V2 seems a more promising system when changing the OSAS exercises to exercises without the use of objects. Therefore we do recommend to conduct future research.

6.1 Future work

From our perspective, there are a few approaches in order to improve the application of a Kinect V2 into the OSAS system. Based on the results and conclusion of this study, the following future researches are worthwhile to be conducted. Firstly, it is suggested to apply Kalman filtering or sensor fusion [17] which can partly solve the problem of the noise in hand and fingers tracking.

The second improvement is creating a more advantaged algorithm which can provide the more relevant segmentation results and focus on the detection of the needed gestures and movements. In doing so it is recommended to research the use of multiple Kinects to cope with the depth errors once performing exercises with objects.

Another way of reducing error in hand tracking is subtracting the background [31]. It is assumed that this technique will make skeleton tracking more stable.

By tracking fine motions on the wrist, hand, thumb and fingers by Kinect V2, the Leap Motion [8] could be a more suitable option than the Kinect V2. Therefore, it is considered as a good combination to make the Kinect V2 and Leap Motion working together.

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Appendices

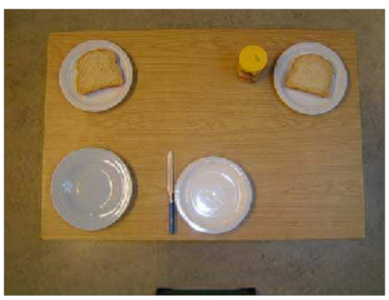
Appendices A. - Making a Sandwich

Making a sandwich
Age 7 - 12 years

Setting
Quiet room
Rectangular table with a hard tabletop that is adjustable in height
Table and chair adjusted to the correct height of the child
Webcam 1 stands in front of the table and provides a mid frontal view, approximately on shoulder height of the child: head, trunk, arms, hands and the entire working space come on screen
Webcam 2 is mounted on the ceiling above the table for a cranial view, both hands are visible.

This set-up is valid for children with a right unilateral pareses.

Cranial view



Frontal view

Material
Plate (white) without anti-slip, exactly in front of the child
Knife (IKEA, bistro cutlery with bleu handle) on the non-affected side of the child
Two sandwiches, divided over two flat plates (white), within reaching distance of the child to the right and to the left in front of the child.
A new jar of chocolate paste with screw lid (jar content 400 gr.). Make sure the foil is removed and the lid can be screwed open easily. The jar is placed on the affected side, within reaching distance of the child.
Set one extra plate for the sandwiches that are ready -on the non-affected side-
To keep in reserve: a piece of cloth for dirty fingers.

Starting position
The child sits behind the table with both arms on the table. Chair and table are adjusted to the right height of the child. Both feet are on the floor or on a footrest. The child's upper body is undressed or is dressed in an undershirt.
The sandwiches and the chocolate paste jar are positioned as described above.

Instruction to the child
The assessor tells the child that he/she is going to make sandwiches;
"You are going to make sandwiches. Put some chocolate paste on the sandwich and make sure the whole sandwich is covered with paste. Put another sandwich on top and slice the sandwich in half. Put the sandwich that is finished on the extra plate. If you are ready, close the chocolate paste jar and push the jar away from you. You may start when I say go".
The assessor counts down; 3-2-1-go, at three the video is recording, at 'go' the child starts with the task.

The video recording is ended after the child has pushed the jar away from him/her.

Video instructions in case of problems

- The child cannot open the chocolate paste jar:

First give extra verbal instruction (e.g. turn the lid the other way around). If the child is still not successful, the assessor helps a little by opening the lid.

- The child forgot what he/she is supposed to do:

Repeat the instruction and if necessary show the child how to slice the sandwich.

- Do not commend on the use of hands.

- After the task is finished, the child is allowed to eat the sandwich if he/she wants to.

Maximal time: 5 minutes
If the child is not going to finish the sandwich in time, give a warning signal after 4.5 minutes to close the chocolate paste jar and to shove it away.

Scoring:
According to the quality criteria.

Appendices B. – Reflection Daan Noordman, studentnr. 1388436

Starting this project deficiencies in my competence, according to the FTC, encouraged me to complete this research project in a considered direction. Derived from the knowledge I would potentially gain from the assigned pre-master courses, my previous design experiences and my future career interests I defined my goals for this project. As described in my vision (PDP) I believe data will play a larger and valuable role in the field of industrial design, developments like IoT will shift the role of a designer. Therefore, I want to be progressive in exploring this field and want to develop my expertise in 'Math, Data and Computing' and 'Technology and Realisation' in this project. These expertise areas, including 'Creativity and Aesthetics' correspond to the squad I chose. Other expertise areas I like to focus on in this project are 'User and Society' and 'Business and Entrepreneurship'. Within the topic of this research project I did not see enough opportunities to develop my competence on C&A. Therefore, I decided to contact Bart Hengeveld. In consultation with him I defined two exercises focused on 2D and 4D design to improve my skills in this area.

This research project had a rough start, as the project had no clear direction. To me this was relatively new as I was used to be pushed in a certain direction in my previous study. This unclarity asked for a new approach in which I had to analyse the wishes of stakeholders within the healthcare business and determine where this project could add value in the field. This was an interesting process for me, as I improved my professional skills in collaborating with therapist and representatives of Adelante.

As our research developed a more focused topic, I gained a more in-dept knowledge about the related users of OSAS. Children with CP are a vulnerable user group that need a particular approach, by observing this user I learned to have patients and noticed how intrusive products or applications can discourage this user group. Previously I had little experience in working with children, therefore this was a valuable experience.

Multiple iterations of the research goal led to implementing the Kinect in a rehabilitation environment with CP children. Using a Kinect was for me an unfamiliar field of technology. Digging deeper in this technology, I can say it was a valuable learning experience. By exploring (future) possibilities of motion detection techniques, I developed an understanding of coding in the language of C# (in visual basic) and java (in processing) which were unfamiliar to me prior to this project. Developing my experience in such technology was one of my main goals, and therefore I took charge of writing the final processing code that is used in the tests. As Kinect generated large data sets, this was an opportunity to gain knowledge in data analysis. Working with large realistic data sets, I learned the interpretation of different kinds of datasets, creating a step-by-step data analysis/validating process and how to deal with errors and mismatches in datasets.

Writing a research paper in academic language was new for me, thereby I rapidly improved my vocabulary in the English language. I did not experience writing in an academic manner as very difficult as my writing style is rather condensed and detailed. However, I noticed that writing in this way is at the expense of my writing speed. Thereby, I learned that working in a group I could add value in checking other people's work.

As described in my personal identity I often function as a mediator in a project group. Thereby, within project discussions I like to come to a considered result, sometimes this leads too lengthy discussions which does not benefit the progress of the project. Considering this I learned to bring group discussion more to the point and improved my collaboration skills in the project.

Looking back at this project, I can say it was a rocky road. Especially defining the research scope and executing a considered research process did not always go as fluent as we hoped in our project group. Nevertheless, I think this has resulted in more learning opportunities, as I can say with certainty that I gained valuable experience in data analysis, a new field of technology, a new user group and business structure in the Healthcare sector. But above all, I will be able to conduct research in a more efficient and thorough way.

Appendices C. – Reflection Wiebe Audenaerd, studentnr. 1407546

During the last half year I created an additional knowledge on top of my Bachelor in order to be permitted to the Master Industrial Design. My goal during this half year, as written in my PDP and pointed out by the DAC, was expanding my knowledge in the following EAs; (1) Technology & Realisation, (2) Business & Entrepreneurship, (3) User & Society and (4) Math, Data & Computing. Because of my Bachelor in Product Design from the HKU, I left the EA Creativity & Aesthetics slightly underexposed for this half year.

Developing an understanding in conducting scientific research was one of the main learning goals I set for myself. Since I had never done this before I found it difficult to start. During the past half year I arranged many meetings with lecturers where I learned how to start and how to give direction to a research project. Within the course Creative Electronics, I have unexpectedly learned that I need to keep the bigger picture of a project in mind, in order to feel confident along a project. With this developed skill, I now have the ability to create this helicopter view for myself. This will help me to become the designer I want to be. Another learning goal was the understanding of the language English. During this project I read many related scientific papers which helped me to enlarge my vocabulary and grammar. By reading the related work I developed a thorough understanding in conducting scientific research and how to write a clear structured paper. This acquired skill helped me during the writing of the paper of this project, as well as the final report for other courses.

As written in my PDP, one of my goals was to develop an understanding in collecting, analysing and concluding based on data. Within the project, I learned how to collect data in a scientific way with a Kinect and an accelerometer. When programming the Kinect, I developed a basic understanding in the program languages C#, Python and Java. I used my acquired knowledge of the course Creative Electronics in order to program and build the accelerometer which we used to validate the Kinect data. This process helped me to gain an in-depth knowledge in the program language C++. During the course Making Sense of Sensors I learned how to deal with data and how to validate it. I could immediately apply this gained knowledge into the project. In doing so, I expanded my knowledge on this topic and learned how to compare such datasets.

During the project I learned a lot about the healthcare sector and how such innovations should be addressed. By maintaining contact with the stakeholders (Adelante's researcher and therapists) I developed my professional skills in communication within a professional context. During this project, I hoped to develop communicational skills with the user (in this case, the patient). Since we were not permitted to interact directly with the user, I could not develop this as previously hoped for. This is something I want to develop in the upcoming projects.

One of the biggest lessons learned during the project at the Health squad, was that the EAs could benefit from each other if I was able to make the connection between them. Throughout the project I learned how the connection can be made and how to approach this. The EA Business & Entrepreneurship remained underexposed during the research project. Therefore, as written in my PDP, I decided to focus on the other three areas during the project. To still develop myself in Business & Entrepreneurship I implemented my previously acquired skills (within the course: Designing with and for Multiple Stakeholders) to my own company. A new goal for future projects is including this EA into the project.

Also, during the project I spent a lot of time in investigating what EAs and squads most fit me as a designer by talking with both lecturers and students. I noticed that I really missed the EA Creativity & Aesthetics during last half year. In the upcoming years I will ensure I will involve this EA more into the projects and courses. I also noticed that my vision on design is slightly shifted towards an interest in sustainability and the well being of the planet Earth. I am curious to what extend this interest will develop in the upcoming years and how it will be combined with my current vision about the future world and how everything is more and more connected with each other, without harming the environment of humans.

Appendices D. – Reflection Jing Li, studentnr. 1362909

This research project together with other four courses are my premaster program. It is not the first research project for me as a student graduated from industrial design. But it is the first research I have conducted on a highly scientific and technical level. There are several aspects of this research project which are different with my previous research projects. Firstly, we made a working prototype to conduct our research. By means of programming a Kinect for achieving our research purpose that is detecting the aimed joints and printing the data in real time. This is a very technical step for me since I am still pretty new in programming field. Even though there were lot of open resource and nice libraries from online about Kinect programming, it still required a lot of basic knowledge of different computer language as well as high level of debugging. Luckily, the electives alone with the squad project, such as creative programming and creative electronics, did provide me a vision to get started. Moreover, these squad members as well as experts provided a lot of valuable suggestions and help on our prototyping step. During the technical prototyping step, I gained the knowledge in the technology and realization domain by understanding the working principle and utilized different technologies such as the depth sensor and the accelerometer for my own research purpose.

The second main difference which is also challenging for me is to create the scientific and rigorous methodology for conducting research. In my previous design research, the traditional user research methods such as interview, observation, user testing were used most of time. Since the Kinect research is a complex case related to data validation and analysis in later stages, the user testing in this case is a scientific pilot test which requires a calibration or a benchmark to examine the data validity. In order to design an appropriate mythology, in-depth research on human hand movement combining with analyzing the requirements from the clients who are the therapists in our case, as well as the needs of the target group (the CP children) has been done. By doing so, I put myself into the position of the target group and clients to understand their needs better. Also, I learned how to create methodology for different research purposes based on the basic user research methods.

This scientific research includes a big amount of data which requires rigorous data analysis skills. Our data are mainly numeric coordinates. In order to analyze them, the first step is data visualization, then the data validation which is done by comparing row data with calibrated data. It is the most difficult part for me in the entire research process duo to the high complexity of mathematical logic. For overcoming this difficulty, we brainstormed within the group and sought advice from experts for the professional knowledge about machine learning for data analyzing, and finally generated the solution. This research process is arduous, but it ended successfully. The data analysis with the methodology parts need to be structured logically to implement data validity that developed my math, data and computing area of expertise. But, since the research is more about the computer engineering or medical engineering field, I have to admit it is not same as ordinary design research. For example, I feel I missed the chance to develop my creativity in this case. For example, we applied, adjusted the exist technology and validated the results instead of creating a new concept and new prototype for a future design solution.

After finishing the pre-master program, my professional research skill as a designer in terms of scientific research and academic writing were leveled up. In the group work, I played to my strengths on the expertise area of User and Society to dig into the problem of clients and found out the design requirements, as well as generating the solution of the professional user testing by creating the methodology. As a professional researcher, I did self-studying proactively on different fields related to our research such as human movement and machine learning besides joining in group work. I realized the future responsibility as a professional designer is to bring the technology and integrating it with daily life and being the bridge between the scientists and engineers with the clients, offering a design solution to cross the gap between them. For achieving these goals, I am aware that I need to expand my expertise area and develop my skill on data, computing and technology in the master program.