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# Kinect v2 evaluation for in-home medical rehabilitation scenarios

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**Abstract.** The technology advancements greatly improved the medical services over time with virtual reality (VR) devices and applications. Currently taking advantage of these recent advancements is the medical rehabilitation field, heavily studied in past few years as a promising VR area. VR-based rehab brings several advantages over the traditional therapy and could deliver personalized in-home treatment without the need of a permanent dedicated supervisor. A device that could make this technology possible is the Microsoft's new Kinect v2, an improved motion capture sensor available at low prices for personal use. This promising high-tech device can track body movements without the need of additional attached devices that could prove unconformable and expensive. In order to evaluate the medical rehabilitation utility for in-home usage we conducted some research studies and practical experiments focusing on the upper-part of the body in a seated pose in front of a desk. Results indicate that the Kinect sensor can successfully track the body in the proposed scenario and showed great reliability. Occlusion interferences can highly impact the sensor's overall performance, but in a normal prepared in-home environment the sensor proves to be very efficient.

**Keywords**: Kinect v2, medical rehabilitation, human-computer interaction, RRIOC.

## 1. Introduction

Virtual Reality (VR) is nowadays a widely spread term, defining simulated environments in which users immerse themselves and interact directly with the environment by using various peripherals. Although the concept was developed mainly for entertainment purposes in the gaming industry, this growing technology has been rapidly adopted in other fields like medicine, education or military.

The last few years have shown great potential for the VR industry as there are a fast growing number of research projects in the field, many of them focusing on input/output devices in order to increase the interaction level of the user with the virtual environment. Head-mounted displays such as Oculus Rift, Microsoft HoloLens or Steam VR, motion capture sensors such as Kinect or Motion Leap and many other controllers are currently accessible to common users at affordable prices for home, personal or professional use. This way, VR can now be used in many more paradigms, leading to infinite research possibilities in order to assist users in daily actions.

The use of VR in the medical field has been intensively researched over the past years and it greatly improved so far the medical services with technology such as telemedicine or assisted surgeries. An interesting application in this field is the VR assisted rehabilitation or simply virtual rehabilitation. Typically, after an orthopedic condition, surgery or other problems like paralysis, a patient must undergo periodic rehabilitation exercises with repeated simple to complex movements until full or partial recovery. Thus, each patient must go to a rehabilitation center where he will have proper equipment and will be assisted by a specialized rehab medic or trainer each time. Still, there are a couple of problems that arouse:

- There is the need of a rehabilitation center with trained personnel;
- The patient must go each time to the rehab center in order to be assisted (hard to do especially for elderly or impaired people);
- The time slot is limited at the rehab center.

On the other hand, VR-based rehabilitation systems have greatly improved and can deliver home-use therapy following a personalized dynamic patient-specific treatment with visual and audio feedback, offering this way, possible solutions to all of the above mentioned problems of the traditional approach:

- The therapy can take place without the need of a permanent therapist. All the exercises are already recorded and the patient has clear instructions on how to handle them. Also, most of the systems provide feedback and scores that are connected to a therapist in order to be able to check the patient's progress;
- The therapy can be practiced at home without time constraints and also without the need to move to a remote rehab center.

Furthermore, these systems are already available at low-cost prices, using recent gaming technology devices in order to capture the movements or to interact with the patient. One of the most popular examples is the Microsoft Kinect sensor, available since 2010 in its first version. The Kinect sensor automatically detects the body of a person and allows the extraction of joint positions and orientations without the need of additional computer vision techniques. The Kinect sensor is a low-cost capture system already used at a large scale for gaming purposes and it requires only a PC or Xbox alongside the necessary drivers, allowing many researchers to take advantage of it. Thus, applications are researched and developed in various fields like healthcare, sports (Hesham et al, 2015), education (Fernandez et al, 2015), security (Sinha et al, 2013), 3D reconstruction (Yong et al, 2012), robotics (Fankhauser et al, 2015) and many others. Particularly, there are a great number of research articles treating rehabilitation systems using Kinect. Calin et al (2011), Su et al (2013), Khan et al (2014) and Gal et al (2015) are just a few Kinect-based rehabilitation systems that show a great potential for the home use of VR rehab systems.

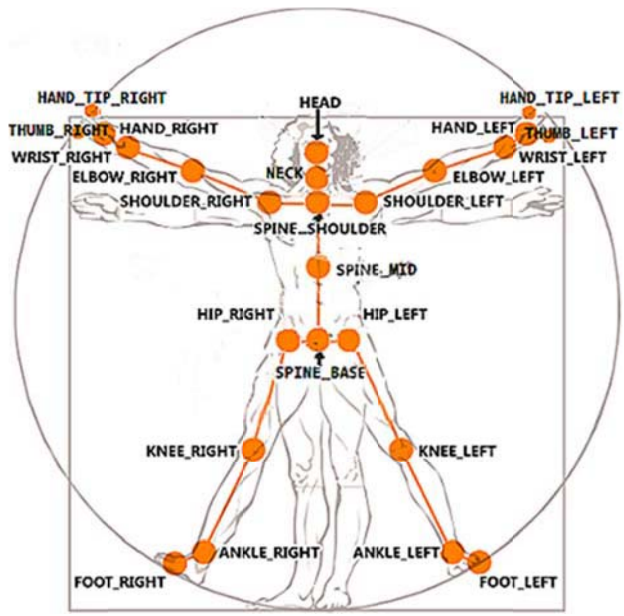


Figure 1. Kinect v2 skeleton positions relative to the human body

Featuring a new high resolution color camera (1920 x 1080) with a higher depth resolution (512 × 424), an improved depth sensor based on the Time-of-Flight (TOF) technology (Gonzalez et al, 2015) and with a 30fps audio-video simultaneously acquisition (Jungong et al, 2013), the new second version of the Kinect sensor tracks a total of 25 skeletal joints (Figure 1) and brings some great improvements from the previous version. According to Gonzalez et al (2015) the TOF system is an important innovation added to the Kinect v2 sensor and it measures the time it takes for a laser pulse to return to the sensor after hitting a target surface. Alongside the new built-in ambient light rejection, the Kinect v2 improved the capabilities of the sensor proving to be much more stable and precise as the range increases, compared to the Kinect 1 performances.

In this paper, we will focus on the reliability of the new Kinect V2 sensor usage for home medical rehabilitation taking into consideration some key factors:

- Distance
- Background
- Poses
- Occlusion
- Body part tracking

We will also try to make some recommendations regarding best practices in positioning the Kinect V2 sensor for different rehabilitation procedures, illumination, background and various occlusion conditions.

The paper will further present:

- some related works in evaluating the Kinect sensor, particularly regarding medical rehabilitation field aspects;
- our approach to build a system in order to assess the Kinect v2 sensor capabilities;
- the resulted system, technical challenges and the experimental prototype;
- experiments and results;
- conclusions, remarks, recommendations and also future work.

## 2. Related work

Since the first version of Kinect has been increasing in popularity among motion capture devices, especially for rehabilitation or therapy, there have been many researches focused on evaluating the Kinect sensor in order to better understand its capabilities and also the sensor’s limitations.

One of the most cited research article, Obdrzalek et al (2012), examined the pose accuracy of the Kinect showing that the tracking systems depend a lot on the body posture and has self-occlusion issues. Furthermore, having additional objects such as chairs in the scene could also interfere with the tracking capabilities. This could prove as unreliable for the rehabilitation patients that are seated in a wheelchair or in bed.

Shires et al (2013) presents some of the Kinect sensor characteristics and safety issues and some improvements to enhance the hand tracking capabilities provided by the Kinect SDK. The article also compares the Kinect sensor with a virtual glove Nintendo Wii hardware, proving same tracking capabilities, removing the need of physically attached devices that could obstruct movements, be uncomfortable or prove harmful for some patients.

Brook et al (2014) tested the accuracy of Kinect to measure motion in Parkinson's disease and found that the Kinect sensor is very accurate for large or gross movements such as sit-to-stand, but not for smaller or fine movements such as hand clasping. Still, it has potential to be low-cost, home-based sensor to measure movement.

Webster et al (2014) experimentally evaluated the Microsoft Kinect's accuracy and capture rate for stroke rehabilitation systems using thirteen different gross movements in comparison to the OptiTrack motion capture system, focusing on the upper extremities : wrist, elbow and shoulder joints. The results showed an acceptable level of accuracy and latency but with influence from various parameters such as angle and distance from Kinect.

Huber et al (2014) tested the reliability and validity of the Kinect sensor in comparison to a magnetic tracker and a goniometer. The study was aimed at the upper extremity joints for shoulder rehabilitation and it indicated that the Kinect sensor is reliable for frontal view captures, but has problems with occlusive poses.

Tseng et al (2014) explored the potential and also the limitations of the Kinect sensor in rehabilitation applications especially for home-usage. The result indicated a positive outcome in using the sensor for rehabilitation purposes by using interactive video-games. The paper also highlighted some of the Kinect sensor usage advantages such as easy configuration, low cost hardware requirements and minimal therapist involvement.

Summarizing, with hundreds of articles covering the Kinect sensor available, Hossein et al (2014) created a great review on the Kinect sensor impact on physical therapy and rehabilitation. The authors reviewed both studies that evaluate the technical aspects and reliability of the Kinect sensor in the researched field, and also clinically evaluated systems in order to prove that the Kinect can be a suitable tool for rehabilitation, showing significant clinical results.

Since the second version of the Kinect sensor is relatively new, there are fewer articles that evaluate the performance and the reliability of the new sensor, especially regarding medical rehabilitation. The new Kinect sensor looks more promising as it improves resolution and depth accuracy and has better image acquisition and processing algorithms (Gonzalez et al, 2015).

Wiedemann et all (2014) investigated the ergonomics of the new Kinect sensor at the place of employment and highlighted some guidelines for the placement of the sensor in order to achieve best tracking results mainly for seated poses. According to the authors, an inclination angle of 20° to 40° relative to the line of sight and a position of about 5cm above the table height are some ideal parameters for a robust track in case of a sitting person. Also, the authors mention that the distance from the subject should be minimized but the whole body should remain in the tracking field of view.

Furthermore, Wiedemann et all (2015) studied the Kinect V2 sensor accuracy compared to the golden standard, a marker-based system provided by Vicon. The article evaluates seated and standing body postures and concludes that the Kinect v2 seems inefficient in the calculation of the neck angle or upper body rotations while seated. Still, the research highlights the body posture as very important, as the efficiency of the Kinects sensor depends a lot on it. The authors consider that the Kinect v2 sensor has a lot of potential especially in non-laboratory environments and further studies should be considered, analyzing the accuracy for kinematic captures in both seated and standing postures.

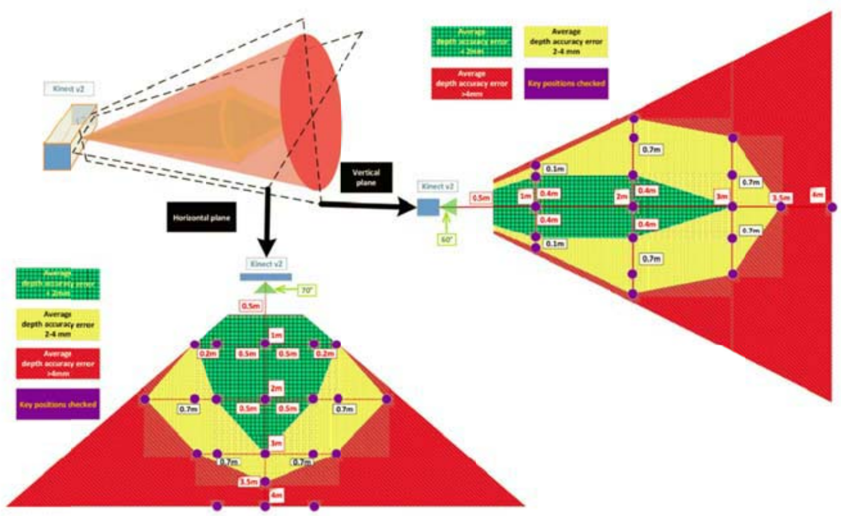


Figure 2. Accuracy error distribution of Kinect for Windows v2 (Yang et al, 2015)

Yang et al (2015) has an excellent study about the current version of the

Kinect, assessing the accuracy of the new sensor. Thus, the authors evaluated the accuracy distribution, depth resolution and depth entropy and also some noise issues. The article divided the space of accuracy error distribution in three regions with accuracy less than 2mm (green), between 2mm and 4mm (yellow) and more than 4mm (red). According to the authors, the error distribution satisfies an elliptical cone of 60°x70° angle parameters (Figure 2).

The same article mentions about several factors that are affecting the Kinect v2 sensor's performance, such as reflective materials or very high light-absorbing materials. Both mentioned factors could lead to problems in reflecting the light emitted by the Kinect sensor. Still, the authors conclude that the second version of the Kinect sensor provides acceptable performance at a very low price, showing great potential in fields like education or medicine.

To the best of our knowledge, there are no current studies that cover the reliability and the usage of the new Kinect v2 sensor in virtual rehabilitation applications, specifically that involve seated poses at a desk, thus we will cover in this article some experiments in order to evaluate the performance of the sensor focusing on these particular cases, often seen in rehabilitation procedures.

## 3. Our approach

Our purpose is to further explore the Kinect v2 capabilities in rehabilitation procedures starting from previous related work and experimental observations such as Yang et al (2015) and Wiedemann et all (2015). Our approach aims to capture and display sequences of medical rehabilitation exercises by using the Kinect v2 sensor and represent them on the screen using a 3D human avatar. The evaluation will be made by visual assessment, displaying side by side the skinned avatar using the captured joints values and the direct camera image, both provided by the Kinect v2 sensor in real-time. This way we can evaluate relevant performance issues regarding rehabilitation motions.

In order to achieve the article's purpose, we designed a program that should cover some of the following basic functionality:

- Capture joint information from Kinect v2 sensor;
- Display an animated 3D avatar;
- Combine the joint information into an animation and display it using

the 3D avatar;
- Display image camera feed alongside the 3D avatar.

## 4. System architecture and implementation

In the process of building our experimentation program application we evaluated some options for a fast development process. We considered programming from scratch in C# using the provided Kinect v2 SDK samples or using some graphics engines like Unity 5 or Unreal Engine 4 (UE). Taking into account some key factors like prototyping speed, Kinect v2 integration and documentation, scripting program and skeletal animation features, we chose UE as a starting point as it proved to be more suitable to our needs at the moment.

UE is a solid open-source, state-of-the-art 3D graphics engine that comes with a full suite of development tools. The engine is built mainly for gaming development purposes, but all kinds of other applications can rapidly be prototyped and deployed on various platforms.

Some of the most important features that made us choose UE were the Blueprints and the skeletal mesh animation system.

The Blueprint (Figure 3) is a visual scripting language provided by UE as a tool for fast development that helped us focusing on the actual needed functionality and achieving quick results.

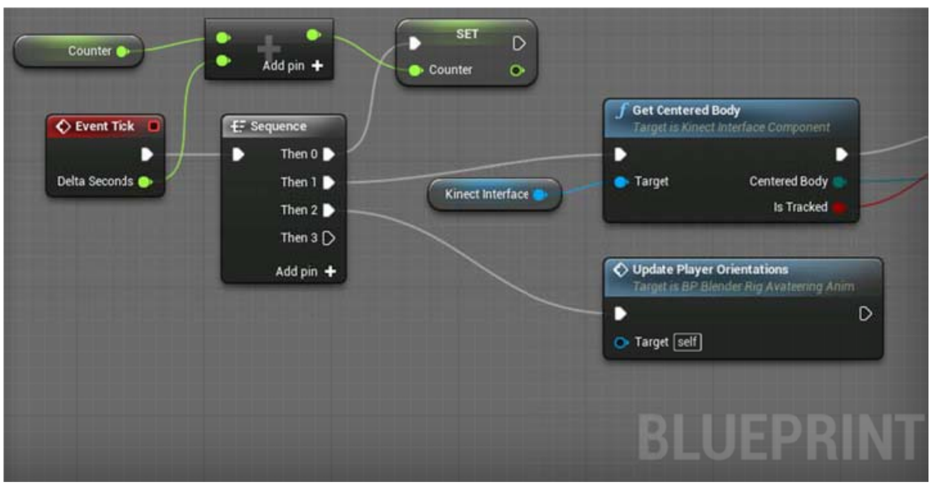


Figure 3. Unreal Engine 4 - Blueprint example

The skeletal animation system in UE represents joints as a simple tree list and attaches this list to a skinned mesh through the graphical interface, allowing for easy creation of an animated avatar (Figure 4).

In order to capture data from the Kinect sensor we used Kinect 4 Unreal (K4U), one of the free UE plugins that fully supports the second version of the Kinect. The plugin practically exposes all the Kinect v2 SDK functionality to the Blueprint system allowing for fast scripting development using all the power of the current Kinect sensor.

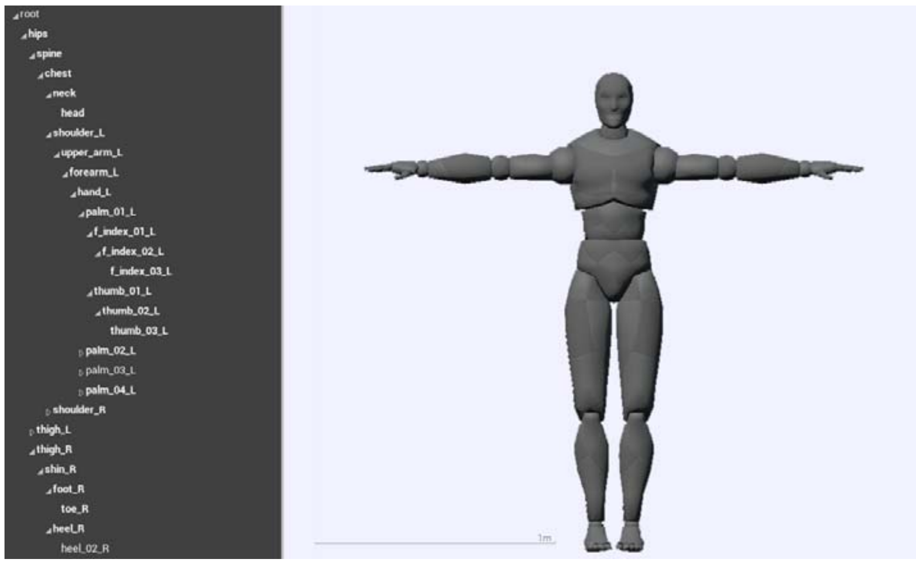

Figure 4. Unreal engine 4 - 3D avatar mesh with joint list

Processing the joint information received from the Kinect sensor in order to create a correlated animation was quite easy to achieve using Bone Transforms components to compute a final animation pose which is attached to a physical body mesh. Practically, each Kinect joint rotation contributes to one or more bone rotations so we collected all the joint values in a dedicated structure and assigned those values to the Bone Transform rotations. For the purpose of this experiment we will be focusing mainly on the upper body joints and especially on the hands, so we connected only the upper body part to the Kinect joints (Figure 5).

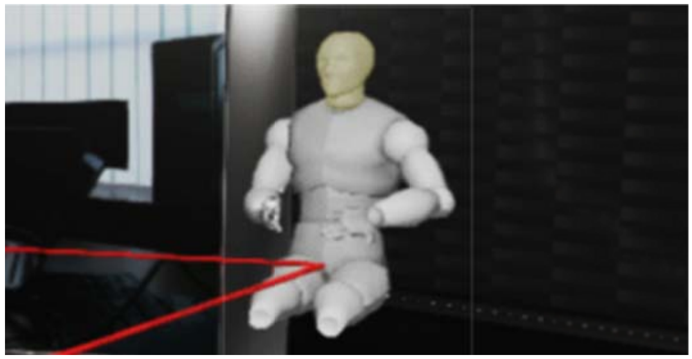

Figure 5. Upper body mesh controlled with Kinect

After importing a skinned body mesh 3D avatar and mapping all the Kinect information to it we already had a highly functional working prototype.

In the final step we used K4U to display a real-time video feed directly from the Kinect camera in order to have a visual comparison measurement method (Figure 6). We also displayed separate videos for infrared and depth feeds supplied by the Kinect SDK.

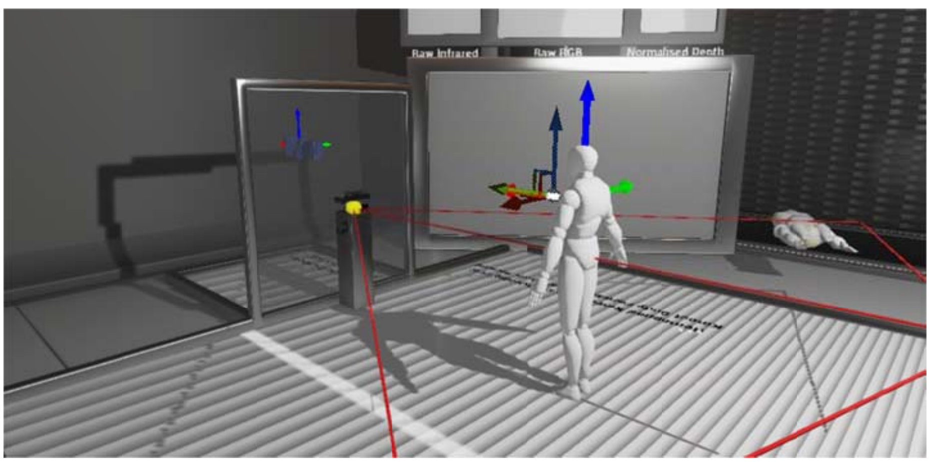


Figure 6. Prototype system and evaluation method

We also used some marker red lines to highlight the current horizontal plane (z==0) for the Kinect sensor and also the field of view (FOV) and the tracking range described in the sensor's specifications (70° FOV and 0.5m to 4.5m range).

## 5. Experimental results

After the prototype was prepared we had several experiments focusing on the above-mentioned key factors regarding medical rehabilitation: distance, background, poses, occlusion and body part tracking.


Figure 7. Kinect v2 accurate motion captures from different angles in a seated pose at a desk

For the experiment we used a simple setup consisting of a single standard Kinect v2 sensor with no additional calibration connected to the UE4 based prototype application running on a Windows 10 laptop device. All the tests were made in a private laboratory under both natural and artificial illumination conditions.

Figure 8. Kinect v2 motion capture in real-world home conditions (occlusion, reflective surfaces)

We tested multiple positions and distances for a seated pose at a desk, a very common scenario regarding medical rehab. Each test was executed taking into consideration and evaluating occlusion and self-occlusion, reflecting surfaces and over lighted backgrounds mentioned by Yang et al (2015), different distances and angles for the Kinect sensor in order to track individual body parts.

Our first test results in this scenario showed that the second version of the Kinect is a very promising capture device in the field of medical rehabilitation (Figure 7).

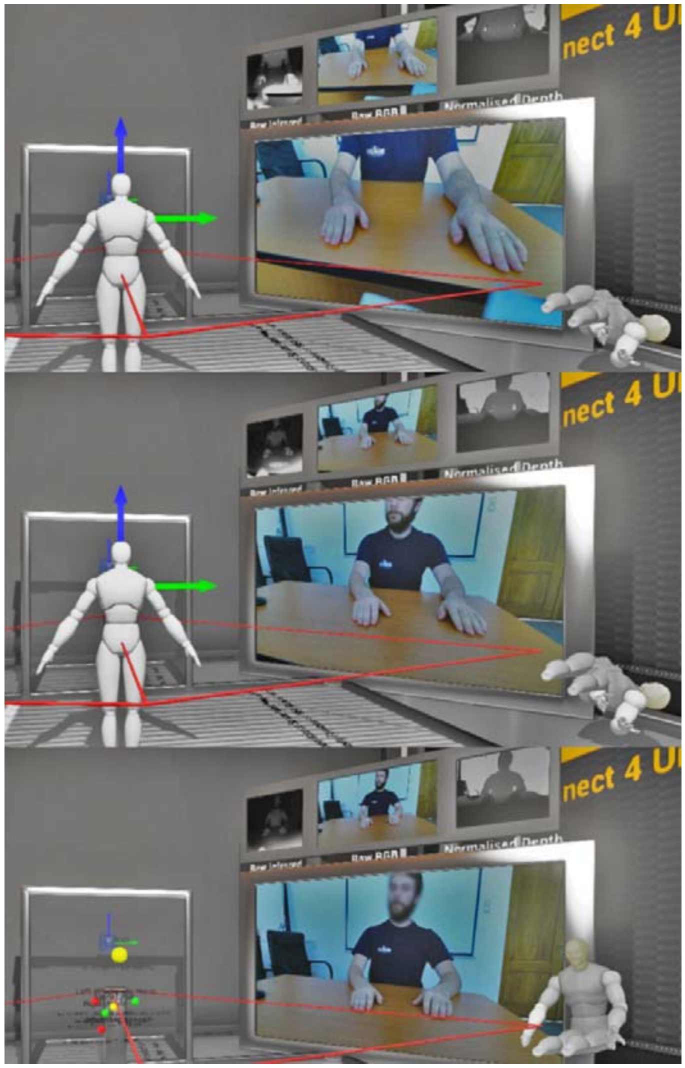

Figure 9. Kinect evaluation of body part capture

The captures show that the Kinect could track relevant moves with high accuracy from different angles and various background illuminations even when only the upper body is present in the FOV of the sensor.

With our next tests, we intended to simulate some home-usage conditions, with foreign object occlusion and different kind of materials (Figure 8). The results highlighted that occlusion interferences could impact the Kinect sensor performance. Medium reflective surfaces seems to impact the overall capturing performance so it's best to have opaque backgrounds if possible. One important mention could be that chairs with big backrests can influence and alter the body position and rotation and even some important joints, as seen in the figure.

Figure 10. Kinect evaluation for occlusion on a desk

We also made some tests to evaluate how much of the body needs to be in the FOV of the sensor in order to be captured by it (Figure 9). The results confirmed our expectations and show that the whole upper body is required to be in the camera's FOV in order to have joint motion recognition.

In the last set of tests, we tried to add some occlusion interferences directly on the desk where the subject is positioned (Figure 10). The results are better than expected: although for big objects the Kinect sensor had some issues, on common desk conditions (a desk with a bag, a thermos and a keyboard on it) the performance was great.

A small mention to keep in mind is that in order to correctly capture a body part, the joints contained in that body part must be completely in the FOV of the sensor.

Concluding, we experimented with many environmental conditions and setup based on the research of Wiedemann et all (2015) and Yang et al (2015), adding occlusion and other parameters in order to better simulate realistic home conditions. All the experiments are focused on a seated pose in front of a desk for which we considered both front and side tracking. We experimented various cloth versus background conditions, object occlusion, over-illuminated or reflective surfaces, distance setups. For each setup we considered a minimum of 10 different positions and we measured the approximate observable success rate for it.

The experimental data and the results are summarized in Table 1 for natural illumination conditions and Table 2 for artificial illumination conditions.

Table 1. Experimental data under natural illumination conditions

| Environmental Setup | | | Human subject | | Tests | Success rate |
|---|---|---|---|---|---|---|
| Distance | Background | Other | Capture | Clothes | | |
| 1m | Over illuminated | | Side | Black | 20 | 85% |
| 1m | Over illuminated | | Front | Black | 10 | 100% |
| 3m | Normal | Backrests chair | Side | Black | 10 | 80% |
| 3m | Normal | Backrests chair | Front | Black | 10 | 90% |
| 2m | Normal | Backrests chair | Side | Black | 20 | 85% |
| 2m | Normal | Backrests chair | Front | Black | 10 | 90% |
| 2m | Normal | Medium | Side | Black | 10 | 60% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Occlusion | | | | |
| 2m | Normal | Medium Occlusion | Front | Black | 10 | 80% |
| 1.5m | White Medium-reflective | | Side | Black | 10 | 50% |
| 1.5m | White Medium-reflective | | Front | Black | 10 | 90% |

Table 2. Experimental data under artificial illumination conditions

| Environmental Setup | | | Human subject | | Tests | Success rate |
|---|---|---|---|---|---|---|
| Distance | Background | Other | Capture | Clothes | | |
| 1.5m | White Medium-reflective | | Side | Black | 10 | 70% |
| 1.5m | White Medium-reflective | | Front | Black | 10 | 90% |
| 1.5m | Normal | | Front | Black | 10 | 100% |
| 1.5m | Normal | | Front | White | 10 | 100% |
| 1.5m | Normal | | Side | Black | 10 | 90% |
| 1.5m | Normal | Medium Occlusion on desk | Front | Black | 10 | 100% |
| 1.5m | Normal | High Occlusion on desk | Front | Black | 10 | 90% |

## 6. Conclusion

In this paper we presented some relevant researches related to evaluating the second version of the Microsoft's Kinect sensor and conducted some research experiments focusing on the medical rehabilitation use of this sensor's capabilities.

Our experiments evaluated a very common home-usage scenario of medical rehabilitation of the upper body, standing at a desk. The results are very promising, the new version of the Kinect sensor having great performance and stability outside laboratory conditions and could prove to be very efficient for in-home unsupervised rehab applications.

Although the Kinect sensor performance was acceptable from all positions we had the best results by positioning the sensor about 1.5m in front of the subject, with the horizontal plane higher than the desk. This also helps avoiding some of the self-occlusion problems. Also, the whole upper-body of the subject must be in the tracking FOV of the sensor.

Future work should include subjects with orthopedic conditions in order to better evaluate real rehabilitation scenarios in home environments.

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