# Quantitative Evaluation of the Kinect Skeleton Tracker for Physical Rehabilitation Exercises


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## ABSTRACT

Using video game technology in physical rehabilitation has shown many positive results in the past few years. The release of the Microsoft Kinect has presented many new opportunities for development in physical rehabilitation technologies. However, there have been questions about the Kinect's accuracy in actual experimentation. In this paper, we compare skeleton data obtained by a Kinect to that obtained by a VICON system in order to determine the accuracy of the Kinect while a tracked subject is moving their arm around. This is the first steps towards a much larger physical rehabilitation system.



## Categories and Subject Descriptors

I.4.8 [**Image Processing and Computer Vision**]: Scene Analysis – *depth, range data, motion, tracking*

J.3 [**Computer Applications**] Life and Medical Sciences - *Health*

## General Terms

Measurement, Reliability, Experimentation, Human Factors, Verification.

## Keywords

Kinect, VICON, Motion Tracking, Physical Therapy.


## 1. INTRODUCTION

Rehabilitation has two major goals: the enhancement of functional ability, and the realization of greater participation in community life. In terms of physical rehabilitation, the focus is to improve motor functions of various joins and limbs to improve the patient's daily life [1].Game based physical therapy has been shown to be useful. Patients who had had experiences with Virtual Reality integrated with their exercises have found the exercises more entertaining and had higher rates of recovery [2]. Also, work with other types of gaming technology have shown to be useful as well, such as the Nintendo Wii and the Microsoft Kinect [3, 4]. These type of systems prove useful because they are low cost and highly accessible.




PETRA '14, May 27 - 30 2014, Island of Rhodes, Greece. Copyright 2014 ACM 978-1-4503-2746-6/14/05...$15.00


But now comes the question of "If these systems are low-cost, then is there any accuracy lost due to decrease in cost?" In this paper, we present a validation system to analyze the accuracy of the Microsoft Kinect. We use the Microsoft Kinect's Skeleton Tracker to track a subject and compare it to a Vicon system that is tracking the subjects arm.

In this paper, we will first talk about some uses of the Kinect in other rehabilitation systems as well as other evaluation and validation techniques. Second, we will describe the equipment used and the experimental setup of how we collected data. Then, we will show the results of analysis done on the captured data between the two different systems. Lastly, we will describe our conclusions and future work.

## 2. RELATED WORK

The Microsoft Kinect provides a low-cost, markerless motion tracking system. This is attractive to rehabilitation systems for many reasons. Because of its low-cost, it can be used by almost anyone who can afford it. There is not the hefty price tag that very accurate systems such as a Vicon system can provide. This makes it so it can be widely used in many places, not just a scientific or laboratory setting. Other marker based systems have the disadvantage of requiring a set up time and accurate placement of the markers. A markerless system allows for a faster experience for patients and does not hinder the patient's movements in anyway [5].

The Kinect has already been used in a Kinerehab project [4, 6]. The purpose of this was to determine the number of correct motions made by a patient. Also, [7] uses a Kinect while having subjects play games made for rehabilitation. The main issue with these approaches is that there is no validation of the data obtained using a ground truth as reference.

Work has also been done to validate the depth sensor of the Kinect [8]. The work done here has shown that the Kinect can do well at performing depth analysis. However, this work was only done on static objects and not done on actual people or used with objects in motion.

Evaluation work has also been done in gait assessment [5, 9]. One approach had the Kinect stationary, while the other had it placed on a mobile robot while following a person. Both show promising results with the Kinect while comparing against a Vicon system. However, these approaches focused on gait assessment and did not focus on upper body.

Also, validation work has also been done when focusing on postural control [10]. This work also shoes that the Kinect has the potential to be used in clinical settings. They did mention some drawbacks that were found. One of limitations found was lack of access to joint rotations in the subject's limbs. This limits the amount of angular data that can be obtained from the joints.

# 3. EXPERIMENT

## 3.1 Equipment

### *3.1.1 Vicon*

The Vicon system is a motion capture system that was used as a ground truth in our experiments [11]. It is used for collecting highly accurate 3D coordinate positions of infrared (IR) reflective markers.

For this, we used the Vicon Tracker software to track markers placed on a subject's left shoulder, elbow, and wrist. Since Tracker only tracks rigid bodies, we made custom 3D printed mounts to place the markers in and taped them to the subject's body. They were placed in such a way to mimic joints in the Kinect SDK. Figure 1 shows the mounts and the placement on the body.

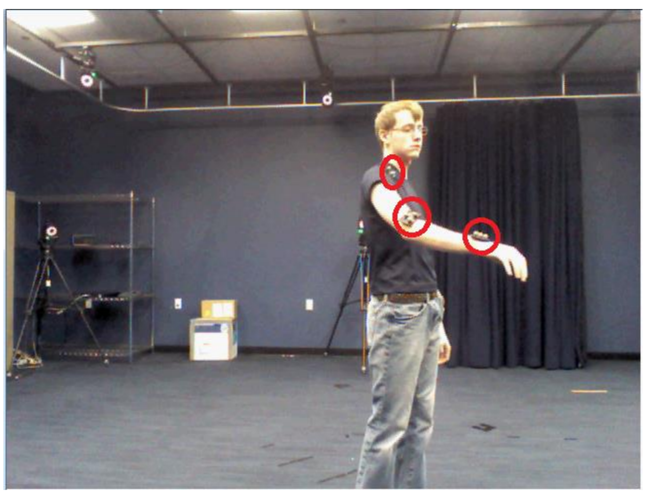

**Figure 1. Top)** Vicon markers placed in the 3D printed mounts. The left mount was placed on the wrist, the center was placed on the elbow, and the right was placed on the shoulder. Bottom) The mounts placed on the body.

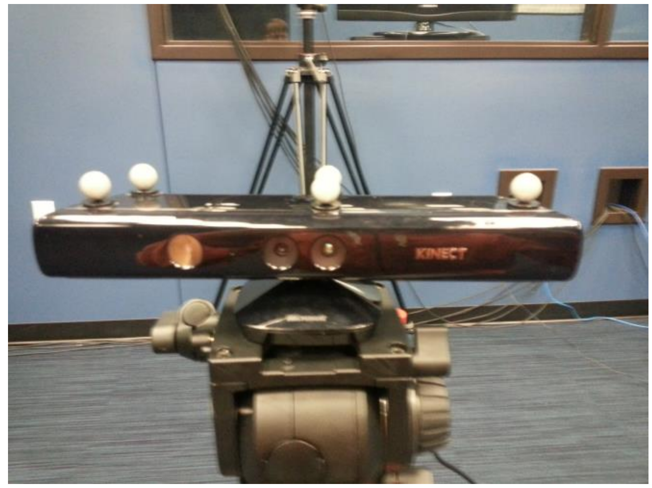

**Figure 2.** The Microsoft Kinect Sensor with Vicon markers placed on top.

**Figure 3.** Skeleton Tracker Model produced from the Kinect SDK.

### *3.1.2 Microsoft Kinect*

The Microsoft Kinect, as shown in Figure 2, is a low-cost sensor that captures motion data from an IR camera and a regular RGB camera [12]. We are using the Skeleton Tracker from the Kinect SDK to obtain the joint positions of the subject in 3D. Figure 3 shows an example of the model produced by the skeleton tracker.

## 3.2 Experimental Setup and Data Collection

For the experiment, our goal was to compare data from the Kinect Skeleton Tracker to that of the Vicon system. To start, we placed Vicon markers on top of the Kinect (Figure 2). This gives the position of the Kinect in the Vicon reference frame as well as the Rotation and Translation Matrices between the Kinect and Vicon reference frames. We then placed the Kinect on a tripod in a room with 16 Vicon MX cameras (Figure 4 Top). The subject then walked into the room with the markers attached to their arm. Figure 4 Bottom shows the view of the setup from Vicon Tracker.

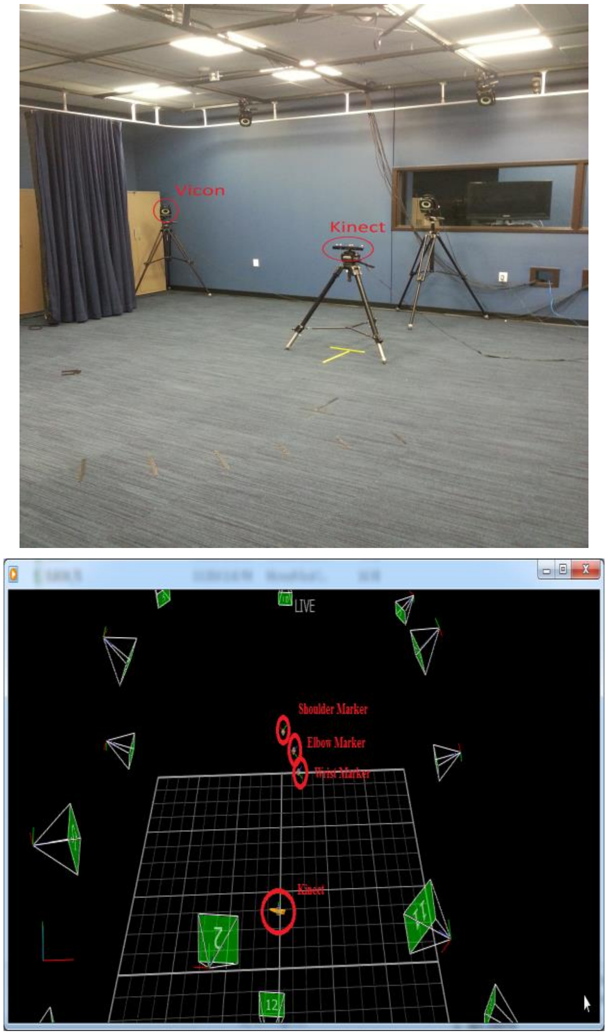


**Figure 4.** Top) Kinect placed in the Vicon Capture area. Bottom) Vicon Tracker view of the environment.

The subject walked into the room wearing the mounts on their arm. The subject was then asked to walk around and move their arm around to where the both the Kinect and Vicon would we the motion. The Kinect recorded all the X, Y, and Z coordinate position in meters, while the Vicon recorded the same values for the marker mounts. Timestamps of when the samples were taken were also recorded.  This is because the Kinect records at 30 frames a second, and Vicon records at 100 frames a second.  This allows us to find matching frames between the two systems.

## 4. RESULTS

The first step in order to compare the Kinect and Vicon data is to convert from points obtained from the Kinect reference frame to the Vicon reference frame. The Vicon system gives the rotation and translation matrices between the two systems, making the transformation trivial. Figure 5 shows an example of the obtained arm position data from the two different sensors.We then calculated the difference between the two sets of samples. Figure 6 shows the difference between the Kinect and Vicon for each frame taken. The reason for the different number of samples for each joint is that the Vicon system did not capture all the mounts in each frame. The reason for this is that the markers that were placed too close together, particularly on the wrist mount. The system saw two markers as one and recorded the value for that mount at [0, 0, 0] for some frames. Those frames were excluded from all calculations. The spikes at the end of the graph were caused by walking away from the Kinect where the Kinect's error increases greatly.

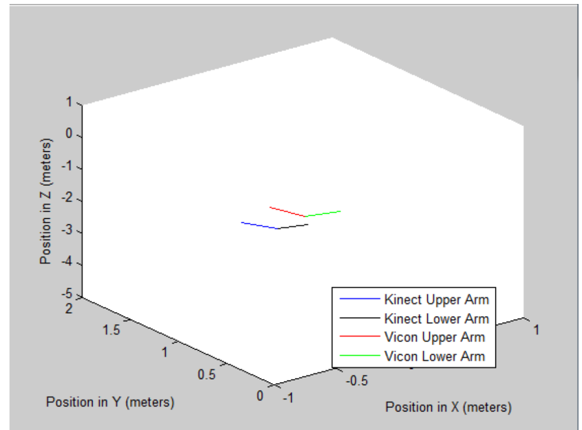


**Figure 5.** Visual comparison of the subject's arm from both Vicon and Kinect views.

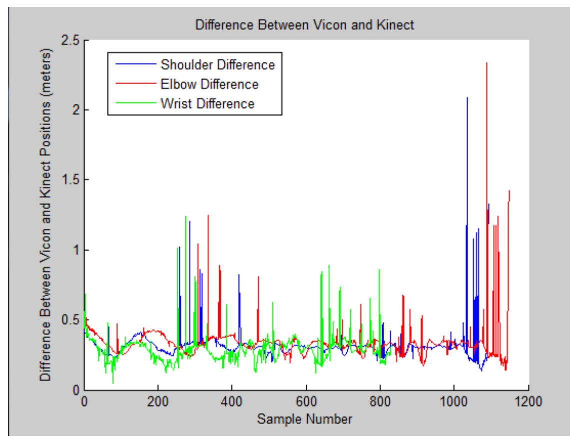


**Figure 6.** Difference of the joint positions between the Vicon and Kinect samples.

Table 1 shows the mean and the standard deviation of the joint positions between the two systems. There were some differences between the two, which were expected. This much of a difference was not. Other experiments that used Vicon for Kinect evaluation shown more promising results [5, 9, 10, 13]. Gait analysis has had average error of less 2cm [5]. [13] also tracked an subject's arm using a Kinect and a similar system to that of the Vicon. The error presented in their work was also significantly less than ours. All of these used markers placed on the body instead of using mounts. This has led us to believe that our issue with how the markers were placed on the body during our experiments. The fact that the markers were placed on top of the Kinect means that the Vicon system sees the Kinect slightly higher than where the principle point of the depth camera actually is. Also, the calculated center of the Kinect from Vicon may also not line up with the principle point. Another reason for the differences were that the mounts could have caused some deviation as well. While we tried to mimic the joint positions of the Kinect SDK Skeleton Tracker, the mounts may have been slightly off. Also, the mounts were a raised surface on the body, causing Vicon to see the mounts closer to the Kinect than the joint actually was.

**Table 1.** Mean and Standard Deviation of the Difference of Joint Positions between the Vicon and Kinect samples

| Joint | Mean (m) | Standard Deviation (m) |
|---|---|---|
| Shoulder | 0.302 | 0.138 |
| Elbow | 0.322 | 0.180 |
| Wrist | 0.284 | 0.178 |

Next we determined the above mentioned difference that was caused between these two systems and accounted for this. This significantly reduced our error, as shown in Table 2 and Figure 7. To remove the error, we measured the approximate distances between the position of the mounts and the Kinect joint locations, as well as the distance from the Kinect and the markers on top of the Kinect. When these were accounted for, we able to obtain much more promising results.

**Table 2.** Mean and Standard Deviation of the Difference of Joint Positions between the Vicon and Kinect samples after Correction

| Joint | Mean (m) | Standard Deviation (m) |
|---|---|---|
| Shoulder | 0.057 | 0.036 |
| Elbow | 0.079 | 0.061 |
| Wrist | 0.084 | 0.077 |

## 5. CONCLUSIONS

In this paper, we have shown a way to validate data obtained from the Microsoft Kinect Skeleton Tracker. We also compared this data to that obtained from a Vicon system while tracking a subject's arm. The Vicon system was used as a ground truth in order to determine the accuracy of the Kinect. The results that were obtained were not exactly expected. The difference between the two systems was somewhat significant averaging at least 5cm per joint, but parts of this were caused by the experimental setup. The fact that there are still differences seen means that further work needs to be done in order to further reduce this difference.

## 6. FUTURE WORK

The first step that has to be taken is to figure out how much error was introduced by the set up. Also, different marker formation in the marker mounts have to be made so that less frames have to be dropped. Finally, this would have to be applied to the whole body instead of just an arm so that full body tracking can be validated.

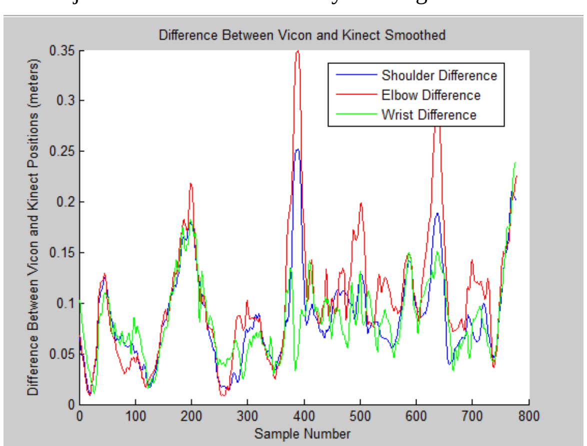


**Figure 7.** Difference of the joint Position between the Vicon and Kinect samples after error corrections.


## 7. ACKNOWLEDGEMENTS

This work has been partially supported by the following NSF grants: IIS: 1409897, IIS: 1258500, CNS: 1035913, IIS: 1041637, CNS: 1338118.


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