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# KINECT AND WEARABLE ROBOTS

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***Abstract.*** *Exoskeleton and wearable robotics provide potentially helpful tools for gait therapy in stroke patients. To evaluate outcomes, one might employ motion capture systems to analyze gait parameters. Here we report our efforts to employ a cheap motion capture system, Kinect, to capture data on three healthy subjects while wearing our Anklebot. Results showed that the default Kinect body tracking software failed in some frames to identify some of the human joints. Thus, we developed an alternative using infrared markers fixed to the lower limb of the patient to calculate the kinematic parameters of the human gait in the sagittal plane from the use of Kinect. We characterize the performance of this vision system as showing errors of less than 4% compared with a digital protractor.*

***Keywords:*** *rehabilitation robotics, stroke, lower limb, Kinect, Anklebot.*

## 1. INTRODUCTION

Stroke is essentially a static (non-progressive) brain injury; presently, an estimated 6.6 million Americans have survived a stroke (Mozaffarian D., et al., 2016; Edward et al., 2015), the majority of whom will experience some motor deficits (Disa et al., 2004). One way to ameliorate and reduce the consequences of central nervous system injury is physical or occupational therapy delivered by clinicians and potentially augmented by robotic tools (Marc, 2011) like end-effector or exoskeleton robots. The goal of lower extremity stroke rehabilitation is to restore gait and allow patients to accomplish daily mobility tasks (Catherine et al., 1996; Susko et al., 2016).

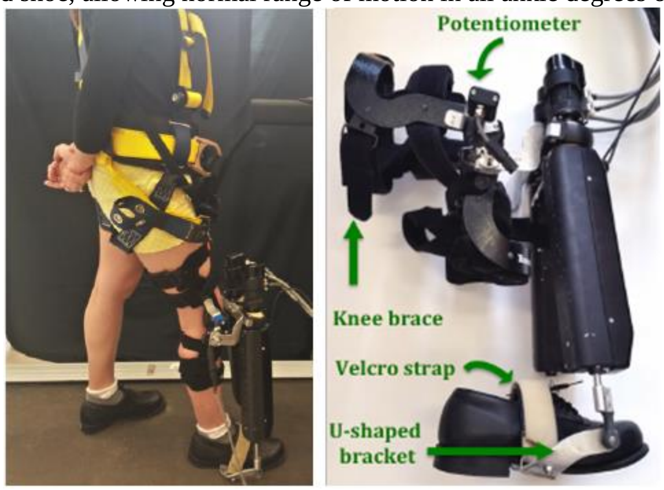
While robotics for the upper extremity has demonstrated added benefit when compared to usual care, lower extremity robotics is still just a promise (Susko et al., 2016). To assess the impact of new devices in gait rehabilitation, one might employ a Motion Capture system (MoCap). A cheap, portable, and easy to use MoCap system is the Microsoft Kinect. When applied to rehabilitation, the goal may include recording kinematic data (Springer and Seligmann, 2016).

Here we tried to employ the Kinect to measure in real-time joint angles of subjects while wearing the Anklebot (Roy et al, 2009). As we observed tracking errors, we developed an alternative solution utilizing the infrared images acquired from Kinect using six passive infrared marks fixed in the lower limb.

## 2. METHODS

## 2.1 Anklebot

The Anklebot is a wearable device designed to enable multi-variable mechanical interaction with the ankle in the sagittal and frontal planes (Roy et al, 2009). The Anklebot consists of two highly back-drivable linear actuators attached to the leg via a knee brace and a customized shoe, allowing normal range of motion in all ankle degrees of freedom (DOF), Fig. 1.




(a) (b)

Figure 1. (a) Unimpaired subject wearing the Anklebot. (b) Main parts Anklebot (Ochoa et al., 2016).

## 2.2 Kinect

In this paper, we employed the Microsoft™ Kinect® V2 (Kinect) that is a low-cost, markerless motion caption system. The markerless system uses the depth image to estimate and track the skeleton (Lun and Zhao, 2015). The Kinect provides a free Software Development Kit (SDK) open source which records in real time the joint position and orientation (Lun and Zhao, 2015).

The Kinect V2 has shown promise in clinical/biomechanics studies (Springer and Seligmann, 2016). It can track 3-D movement through its depth sensor and estimate the location of 25 joints in 3-D space at 30Hz (Lun and Zhao, 2015). The sensor and the SDK allow us to easily acquire 2D color, infrared (IR), 3D depth image, and 3D skeletal/body frames.

Some papers employed the infrared markers and Kinect to identify the gait parameters. In (Zhu et al., 2017) eight markers bars, fixed in the surface of the lower limbs, were used to measure the variation of these joints angles and compared the results with those of a patient using an exoskeleton. In (Sun et al., 2014) eight IR circular markers, fixed in the front lower limb, were used to make the gait analysis from the horizontal distances acquired by the Kinect.

Here we attempted to determine whether we can utilize the Kinect sensor and 3D skeletal/body frames "as is" to acquire joint coordinates while subjects wear the Anklebot. The Kinect was developed for gaming when the player does not wear any peripheral equipment.

The Microsoft SDK enables users to develop complex computer interface motion tracking applications in real-time. The complete process to obtain the body/skeleton estimation can be found in (Hansard et al., 2012). It tries to extract/identify a human body composed of two arms, two legs and a head. That said, Microsoft considered accessibility allowing people with disabilities to play some games. For example, amputees can play the games with the use of prosthesis that closely resemble human body limbs like "realistic-looking prosthesis" (http://support.xbox.com/en-US/xbox 360/accessories/accessi bility-kinect). Reflective surfaces must be covered to minimize problems with skeletal mapping. However, if a subject is using a cane the system might identify it as an extension of arms.

We explored first the potential of using the default Kinect SDK body tracking system without placing additional markers and capturing data in real time while subjects wear the Anklebot. After, we explored the use of infrared markers tracked by the Kinect.

## 2.3 Participants

Three young adults (32.67 ±4.04 years, 70.67 ±20.03 kg and 1.71 ± 0.14 m) without any record of musculoskeletal or neurological disorder volunteered to participate. The study was approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES).

### 2.4 Experimental setup

The experimental setup is divided in two parts. The first describes the use of Kinect with the real time body/tracking object and the Anklebot. All subjects participated in these experiment. The second part describes the experimental setup to acquire the images using the infrared markers. It was conducted on a single subject.

Prior to the trials, subjects were given a brief training/explanation session with the Anklebot to ensure they were acclimated to the device and the smart treadmill (Susko et al., 2016). Subjects walk in four different conditions: at two pre-selected speeds wearing or not the Anklebot. We selected low speeds corresponding to the range of typical stroke patients (0.223 m/s and 0.447 m/s). The subjects used the Anklebot on the right leg, Fig. 2. We captured the color image, depth image and body joints. The infrared images were also acquired for the third subject.

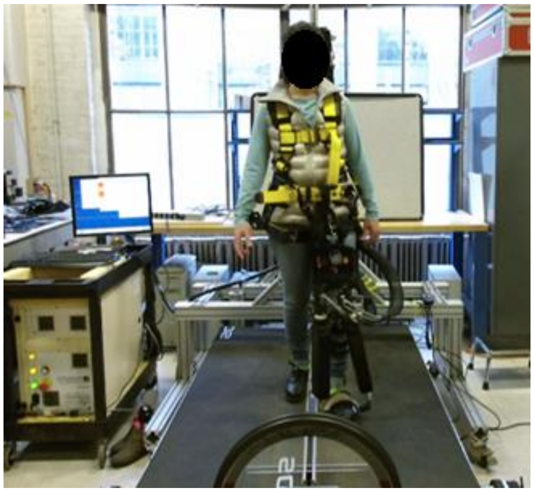
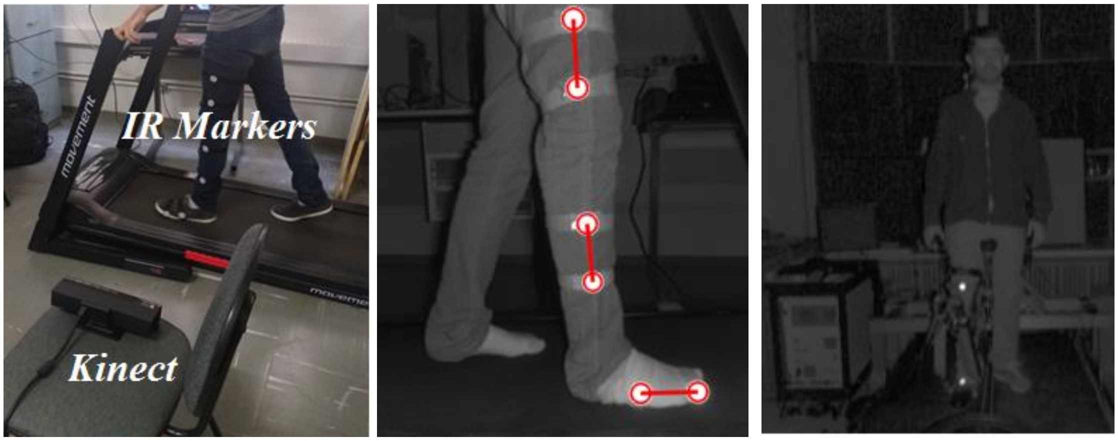


Figure 2. Color mirrored image acquired from Kinect showing the subject on the MIT-Skywalker wearing the Anklebot.

In the second part, we developed a motion tracking method employing passive infrared markers. The use of infrared markers ensures that the vision system sees only the areas of interest without having to control the background, which is important in a cluttered clinical environment (Susko and Krebs, 2014). For the gait analysis in the sagittal plane six passive infrared markers with 26mm diameter, Fig. 3(a), were used. The two IR markers on the thigh were used to estimate the angle of the hip, the two markers on the shin were used in conjunction with the hip angle to estimate the knee angle. Another two infrared markers were fixed to the foot, see Fig. 3(b). The Kinect was placed in front of subject's leg with 1m distance and 0.55m high in relation to the ground. We implemented in Matlab our algorithm to identify and track the markers. For details on the algorithm see (Susko, 2015).




(a) (b) (c)

Figure 3. (a) The setup to acquire the infrared markers without wearing the anklebot; (b) The scheme properly identifies the markers in (a); (c) Two IR markers identified when using the Anklebot.

To test the accuracy of measured angles, a Miotec® protractor with a published accuracy of ±0.05°, Fig. 4(a), that acquires 2000 samples per second was mounted in front of the Kinect, Fig. 4(b). The protractor was moved from 0° to 90° and 10s measurement for each position were acquired by the protractor and the IR vision system using the Kinect.


(a) (b)

Figure 4. (a) Miotec protractor; (b) experimental setup to measure static angle data.

## 3. RESULTS AND DISCUSSION

Figs. 5 and 6 summarize the results using the body/skeleton Kinect tracking. The color figure with body/skeleton frames shows that in some frames the default SDK Kinect software failed to identify the skeleton correctly. Fig. 5 showed four selected frames in which the Kinect failed. Fig. 5(a, c and d) identified the ankle joint as part of Anklebot actuator. Fig. 5(b) shows a frame in which the identification of both ankles failed.

(a) (b) (c) (d)

Figure 5. Color image with body/skeleton. (a) The algorithm identified the side actuator as the ankle joint; (b) The algorithm identified the two actuators as the subject ankles; (c) the algorithm identified the side left actuator as the ankle joint; (d) the algorithm identified the side right actuator as the ankle joint.

The right ankle joint's function was the most affected when wearing robot, mainly in the coordinate *X*, horizontal movement, Fig. 6. The Kinect setup and referential system used in the experimental tests were described in (Gonçalves and Krebs, 2017).

In this paper two speeds were employed and in both cases the Kinect failed to track the joints in some frames.

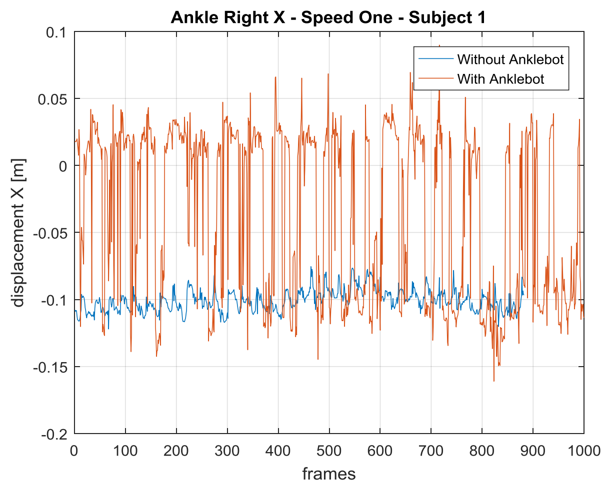



Figure 6. Displacement in direction *X* of ankle coordinate to subject one.

Thus, the use of wearable robots can present difficulties to the default SDK Kinect software in tracking the human body. Hence, we tested on the third subject the use of infrared markers and the wearable robot. Figure 3(c) shows the two markers in frontal plane clearly identified by Kinect when the subject used the Anklebot.

Table 1 shows the results obtained using measured static angles with the protractor and with the Kinect, Fig. 4. From Table 1, both measuring systems are equivalent when a t-test with 0.05 significance level is applied.

Table 1. Experimental static angle measures.

| | Protractor | | Kinect | | |
|---|---|---|---|---|---|
| Nominal Value | Mean (°) | Std (°) | Mean (°) | Std (°) | Error (%) |
| 10° | 9.75 | 0.18 | 10.12 | 0.15 | 3.80 |
| 20° | 19.84 | 0.37 | 20.31 | 0.11 | 2.36 |
| 29° | 28.70 | 0.55 | 29.08 | 0.10 | 1.32 |
| 42° | 41.65 | 0.86 | 41.63 | 0.10 | 0.05 |
| 52° | 52.42 | 0.94 | 52.51 | 0.11 | 0.17 |
| 61° | 61.31 | 1.08 | 61.93 | 0.20 | 1.01 |
| 77° | 76.61 | 1.43 | 76.87 | 0.12 | 0.34 |
| 80° | 80.25 | 0.78 | 81.00 | 0.33 | 0.93 |
| 90° | 89.78 | 1.20 | 90.12 | 0.45 | 0.38 |

## 4. CONCLUSIONS

This paper presented the use of a wearable Anklebot together with the Microsoft Kinect to acquire joint information. Tests performed with healthy subjects showed that the Kinect failed in some frames in identifying the correct human body joint, confusing the human lower shin with the side actuator of the Anklebot. Here we demonstrated that including IR markers eliminates these occurrences. This system was validated against a commercial angular measuring system.

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H. I. Krebs is a co-inventor in several MIT-held patents for robotic therapy. He holds equity positions in Interactive Motion Technologies, the company that manufactures this type of technology under license to MIT.

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