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DEVELOPMENT OF A SYSTEM FOR HUMAN GAIT ANALYSIS USING KINECT V2

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Abstract. *This paper presents the development of a system that quantifies the parameters of the human gait using the Kinect V2. The human gait parameters are used to identification and rehabilitation procedures. In Physiotherapy Clinics are used expensive methods with cameras around the patients or sensors placed on their legs. This results in expensive and inaccessible treatments to the most part of the population. Thus, this paper has the objective of development a low-cost device/software using the Kinect V2 that results in reliable data of the human gait parameters.*

Keywords: *Gait rehabilitation, Kinect V2*

1. INTRODUCTION

There are many health diseases that cause problems in human gait like: Parkinson's disease; Stroke; muscular dystrophy; etc. (Pirker et al., 2017). Besides those diseases, others factors can disturb the way that a person walks, like car accidents, different legs length or even psychological disturbers (Gonçalves and Carvalho, 2012; Gonçalves et al., 2015; Gonçalves and Krebs, 2017; Barbosa et al., 2018; Gonçalves et al., 2019).

There is an area dedicated to the treatment of patients with gait problems: the physical therapy. It seeks to address or at least minimize deficiencies in the way in which the patient walks, avoiding complications of health and in some cases, seeking the reintegration of the individual into society (Pirker et al., 2017; Khobkhun et al., 2014). The treatment begins with the diagnosis in the motor failure of the lower limbs. Often only the physiotherapist's vision is not enough for a reliable diagnosis, therefore methods/devices were developed to facilitate this (Mikolajczyk et al., 2018; Solanki et al., 2018).

Many of the methods developed benefit from robotic structures, sensors and cameras capable of help in diagnosis (Thewlis et al., 2011; Ye et al., 2015; Auvinet et al., 2011). However, the methods used are expensive, require constant maintenance, and skilled labor, since they are complex (Solanki et al., 2018).

Some parameters used to identify problems in the human gait are the angles of hip, knee and heel joints throughout the gait cycle. Thus, this paper investigates the use of the Kinect V2, a low-cost device, to quantify the human gait joints.

2. HUMAN GAIT AND KINECT

Human gait is defined as a method of locomotion encompassing the use of the two legs, alternately, to provide support and propulsion (Kharb et al., 2011). Figure 1 shows the gait cycle.

The Motion Capture systems (MoCap) applied in rehabilitation are generally used to record kinematic data to be post-analyze and assist health professionals with clinical evaluation and treatment planning. These systems can be divided into two main groups: optoelectronics and non-optoelectronics (Hondori et al., 2010). The non-optoelectronics sensors include magnetic systems, inertial sensors, wearable systems and mechanical systems. More information about these sensors can be found in existing literature (Hondori et al., 2010).

The optoelectronics may or may not use markers to track kinematics. When markers are used, they are attached to the body to represent skeletal segments and joints of the interest in the study. The optical system is composed of a camera and software post-processing vision system which tracks the markers placed at the patient and obtains information about body segments, joint position and orientation (Mundermann et al., 2006). In comparison, the markerless systems uses image features such as color, shape, image edge and/or image depth to obtain information about body segments, joints position and orientation (Hondori et al,, 2010).

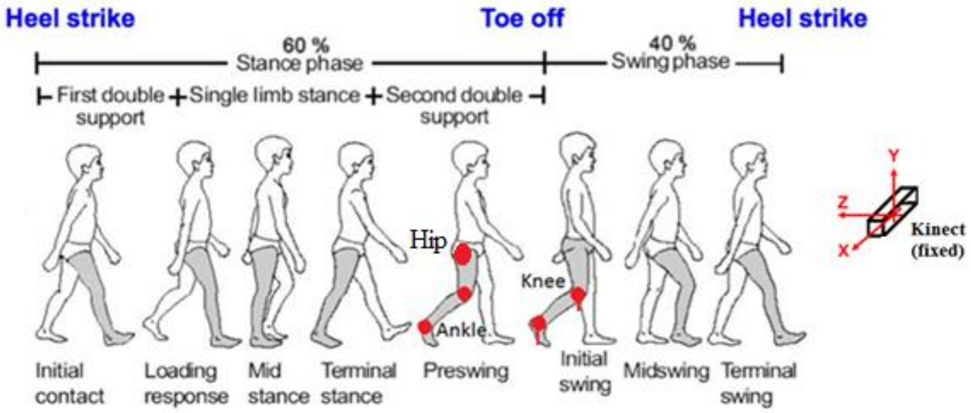

Figure 1. Gait Cycle (Adapted from Perry, 1992) and the Kinect reference.

In the case of marker system, after acquiring the image, processing techniques (Mundermann et al., 2006) are utilized to obtain the coordinates of the marker(s) to provide information for serious games or feedback during rehabilitation.

The markerless systems generally use the image depth to obtain and track the skeletal outline. The most widely used markerless system in the industry is the Microsoft Kinect device (Hondori et al., 2010) which provides a free Software Development Kit (SDK) with the ability to record real time body joint positions and orientations. The Kinect has two versions available, however this paper will focus on version 2 (V2). A comparison and description of the two Kinect versions can be found elsewhere (Liu et al., 2016).

The Microsoft™ Kinect® V2 (Kinect) is a low-cost markerless motion caption system designed for the Microsoft Xbox™. The Kinect has shown promise in clinical and biomechanics studies (Mundermann et al., 2006; Hondori et al,, 2010; Liu et al., 2016; Gonçalves et al., 2017a; Goncalves et al., 2017b; Springer et al., 2016). It can track three-dimensional (3D) movement through its depth sensor and produce the location of 25 joints in 3-D space at 30Hz (Ahmed et al., 2015).

3. METHOD TO ANALYZE THE HUMAN GAIT WITH KINECT

The method to analyze the human gait with Kinect V2 was developed using image acquisition and processing Matlab toolbox (Image, 2018), in addition to math resources.

The Kinect V2 libraries chosen were the Infrared Image and the Body Track (Skeleton). The first returns an infrared image and was used with circular reflectors, while the second is a library that locates the human joints.

3.1 Infrared Image

An infrared image is produces by an issuer in the Kinect and reflected by the objects in the environment. Some objects have ability to reflect greater than others, so the principle of to use this type of image, was necklace eight circular reflectors in the leg and trunk to highlight at the image and to be detected by the image processing algorithm.

To acquire the infrared images the Kinect was placed about 1.6 meters from the left of the treadmill, with the front face parallel to the direction of the movement. A holder was used for the Kinect to stand 0.5 meter in height. Two marks were fixed on the trunk, two on the thigh, two on the shin and two on the foot, to simulate the limbs in the side image. Figure 2(a) shows a scheme of how the marks were fixed.

The Matlab Kinect software used provides a support hardware that can be used to capture images of the sensor. However, only two image types are available: Depth and RGB. Thus, another communication between Matlab and Kinect became necessary. To solve this problem, a Mex file (MEX, 2018) was used to enable/acquired the Infrared image in the developed software, Fig. 2(b).

The next step is process the acquired infrared image. Using the Matlab function *imfindcircles* the marks on the leg patient will be detected. The function returns a matrix with the center of all circles detected, but the order of the elements lines is random, so a routine to organize the points in ascending order was developed. The organization was necessary to know which center point each line of the matrix corresponds.

With a vector math, is possible to procedure to the gait cycle analyzes. Subtracting a point of the trunk from the other, the result will be a vector relative to trunk, the same with the thigh, shin and foot. To find the hip angle, a scalar product is applied using the trunk vector and the thigh vector. The knee angle is obtained with a scalar product of the thigh vector and the shin vector, and finally, to obtain the ankle angle, a scalar product is calculated using the shin vector and the foot vector, as shown in Fig. 2(b).

Figure 2. (a) Schematic of the marks; (b) Vectors limbs.

3.2 Body Tracking (Skeleton)

Different from the Infrared image, Matlab provides a direct connection with the Kinect, so is not necessary a Mex file to acquire the depth and body tracking images. The joints points are detected by the Depth Image. Figure 3 shows the Depth image with the Body Track obtained by the Kinect V2.

Figure 3. Kinect V2 Depth image with Body Tracking (Red Lines).

The used MatLab Kinect library give an array with the joint position with the coordinates in meters, X, Y and Z respectively, Fig. 1.

The joints used in this research, is the 2 (spine mid), 13 (hip left), 14 (knee left), 15 (ankle left) and 16 (foot left) (Springer and Seligmann, 2016). Like in the Infrared image, a vector is built for each limb subtracting the points. To obtain the angles joints we simplified the movement to the side view using the Y and Z coordinates. Like in the infrared image analyzes, a scalar vector will return the angle between the limbs.

To acquire the Depth and Body tracking images, the Kinect position is frontal of the patient on the treadmill, and it was positioned 1.5 meters of the front treadmill and 1 meter in height. To filter the angle curve, is used a moving average filter, eliminating peaks common in this type analyze.

4. VALIDATION AND RESULTS

Fifteen males young adults (age: 21.93 ± 3.59 years, height: 1.78 ± 0.08 m, mass: 73.17 ± 11.58 kg) without any history of musculoskeletal or neurological disorder and three Parkinson's patients volunteered to participate. The ethics committee on human research at UFU (CAAE 84561618.3.0000.5152) approved the study.

To test the accuracy of measured angles, a Miotec® digital goniometer with a published accuracy of ±0.05° that acquires 2000 samples by second was used. Three of these equipment's were used, one in each joint analyzed, Fig. 4.

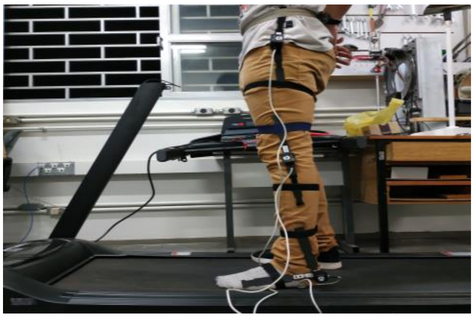

Figure 4. Experimental setup with the digital goniometers.

The experimental tests with healthy subjects were divided in two parts. The first, consist in a training session with the treadmill to ensure they were familiar with the device during 2 minutes. In the second part the healthy subjects were instructed to walk on a treadmill routinely with three speeds: 0.28 m/s, 0.44 m/s and 0.67 m/s, while the image acquisition was accomplished during 1 minute.

Figures 5 to 7 show the graphs with the means joints movements to gait cycle in function of the speed to healthy subjects.

Table 1 presents the absolute error in function of the gait cycle percentage. These errors were calculated by the difference between the system developed and the reference goniometer.

Table I. Error Table for the experimental tests with healthy subjects. The data unity is in degrees (º) and BT is the Body Tracking and IR is the Infrared results.

Cycle	**Ankle**						**Knee**						**Hip**					
	0.28 m/s		**0.44 m/s**		**0.67 m/s**		**0.28 m/s**		**0.44 m/s**		**0.67 m/s**		**0.28 m/s**		**0.44 m/s**		**0.67 m/s**	
	BT	**IR**	**BT**	**IR**	**BT**	**IR**	**BT**	**IR**	**BT**	**IR**	**BT**	**IR**	**BT**	**IR**	**BT**	**IR**	**BT**	**IR**
0%	-	2.967	-	0.357	-	4.598	3.413	3.929	7.272	4.811	2.606	2.932	13.942	0.073	3.867	4.709	2.608	0.966
10%	-	0.045	-	2.131	-	0.482	3.739	2.734	9.568	3.278	9.397	6.900	7.747	1.483	1.796	1.775	0.829	5.317
20%	-	0.281	-	3.300	-	0.390	1.630	1.482	6.493	1.215	6.374	1.989	4.865	0.044	6.441	1.553	0.268	7.927
30%	-	0.234	-	2.773	-	0.032	2.179	4.128	2.869	3.944	1.234	0.042	8.715	4.480	5.356	2.471	3.839	1.491
40%	-	1.383	-	0.423	-	0.166	2.378	5.544	0.455	1.241	0.002	8.730	7.583	3.745	3.859	1.459	0.375	0.109
50%	-	1.924	-	3.256	-	1.902	7.957	2.577	2.845	5.541	0.310	7.145	6.401	0.935	1.950	0.442	1.935	2.656
60%	-	4.426	-	2.619	-	1.213	1.305	2.023	10.242	10.162	7.631	10.992	8.409	2.747	3.543	1.049	4.688	5.813
70%	-	4.789	-	5.405	-	9.538	8.835	7.335	9.007	1.840	16.798	3.814	2.089	3.767	6.350	2.077	23.299	1.646
80%	-	6.009	-	2.899	-	6.190	22.108	23.756	6.129	3.676	7.589	6.220	11.639	6.784	11.131	1.537	15.812	0.055
90%	-	1.091	-	4.758	-	2.726	8.190	7.681	3.919	9.589	14.102	3.421	23.003	11.005	5.977	4.924	0.929	7.774
100%	-	6.939	-	1.624	-	3.874	7.373	2.830	7.656	8.642	7.658	3.363	19.468	7.644	7.895	8.103	4.196	7.159

The experimental tests with the three Parkinson's patients (mean age 70.6 years), to meet special needs, were performed in 30 seconds to accommodation follow to 30 second acquisition for each speed (0.33 m/s; 0.44 m/s and 0.5 m/s).

Figures 8 to 10 show the graphs with the means joints movements to gait cycle in function of the speed to Parkinson's patients.

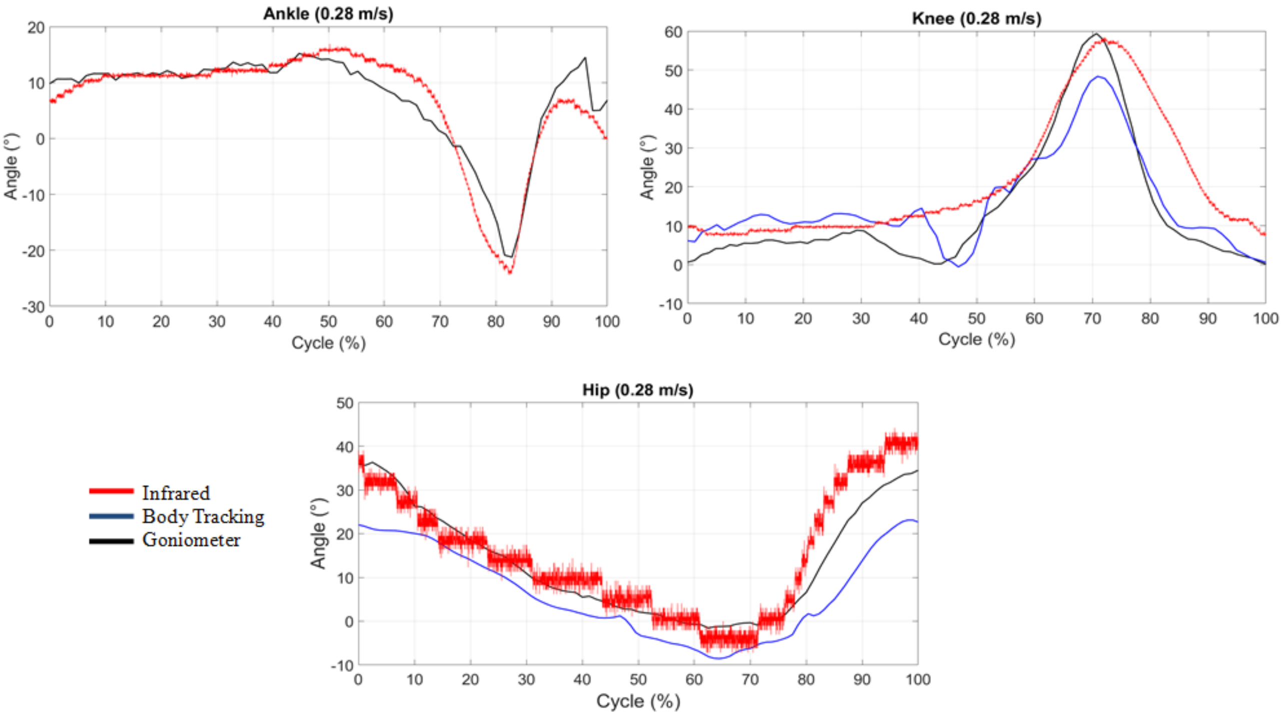

Figure 5. Means joints movements to gait cycle to 0.28 m/s - healthy subjects.

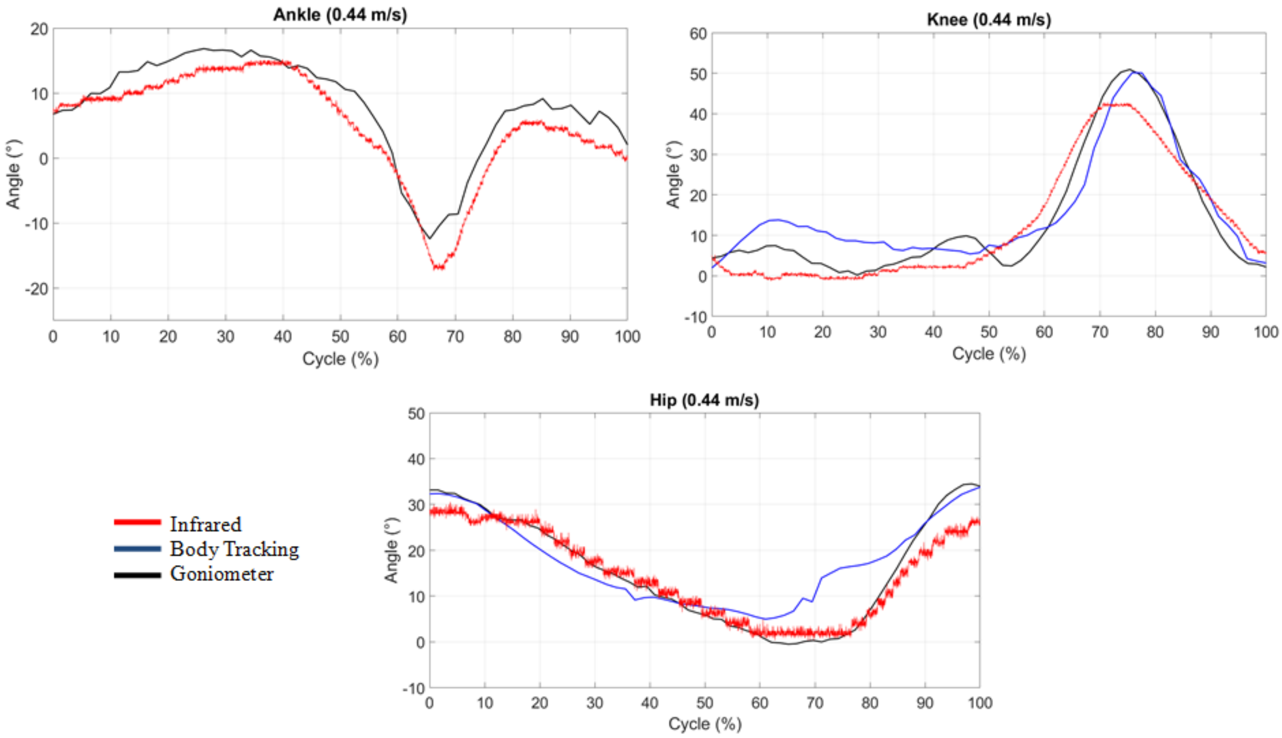

Figure 6. Means joints movements to gait cycle to 0.44 m/s - healthy subjects.

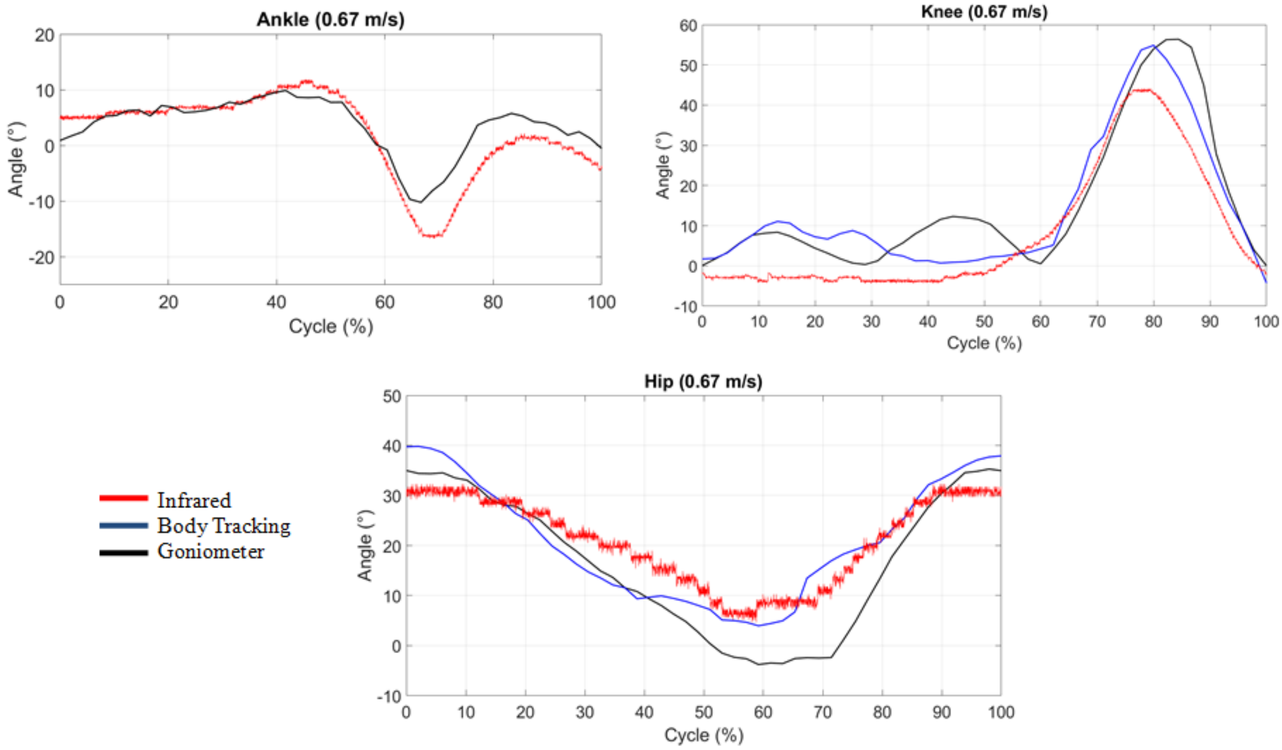

Figure 7. Means joints movements to gait cycle to 0.67 m/s - healthy subjects.

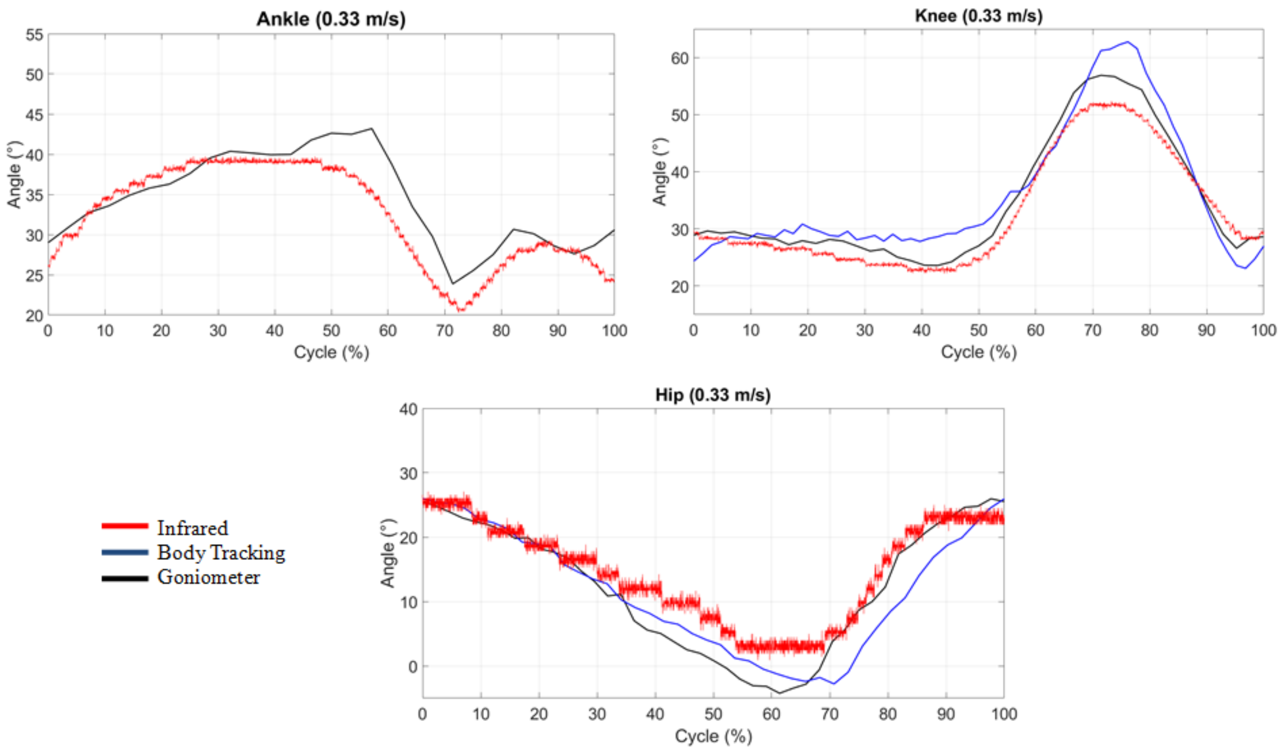

Figure 8. Means joints movements to gait cycle to 0.33 m/s - Parkinson's patients.

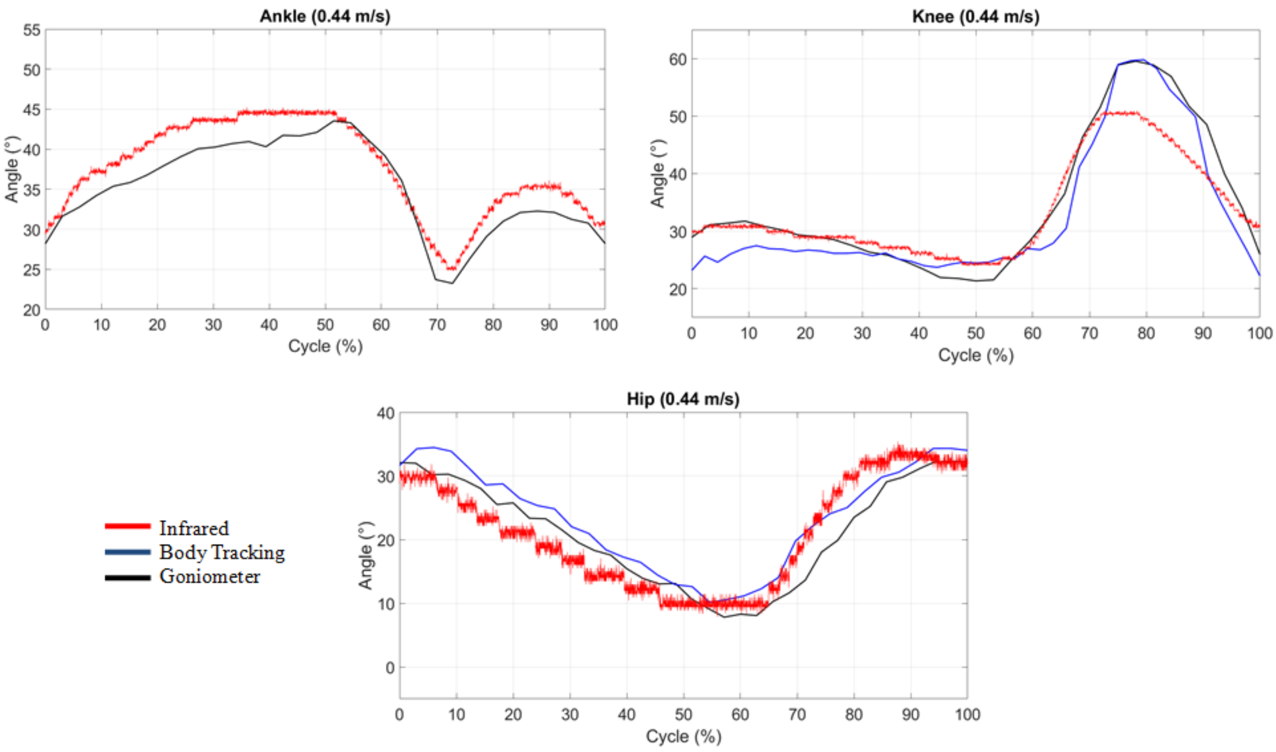

Figure 9. Means joints movements to gait cycle to 0.44 m/s - Parkinson's patients.

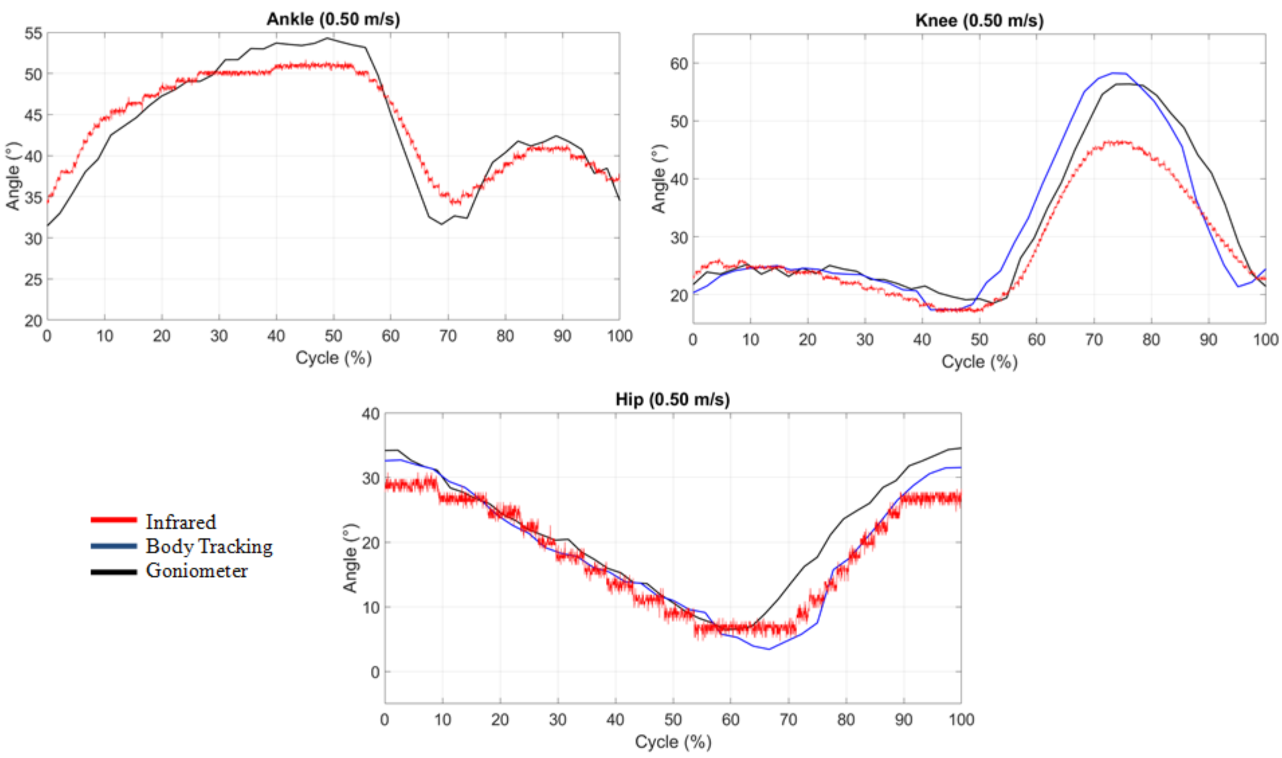

Figure10. Means joints movements to gait cycle to 0.50 m/s - Parkinson's patients.

It is evident that the curves obtained by the infrared and body tracking algorithms developed in Kinect V2 follows the curves obtained by the digital goniometer. Despite some deviations, the three are similar. Visually, it is observed that the largest deviations occurred at the peaks. Somehow, this was expected, since peaks represent a sudden change of motion and the Kinect has lower frame rate than the goniometer, about 30 Hz.

In this paper was not possible to do an ankle analyze using the Body Tracking. After several tests, it was concluded that Kinect has difficulty to detect the ankle joint, probably because of closeness with the treadmill. Therefore, the validation graphics and the Table 1 do not contain the Body Tracking analyze of the ankle.

Table 1 shows what was stated above. Major errors are common in peaks. It can also be stated that the beginning and end of the cycle are presented with a small error. The same can be said of the general amplitude, that is, the amplitude of the analysis done by Kinect tends to be close to the amplitude of the reference system.

The Kinect Infrared algorithm presented in the majority of cases better results than the Body tracking algorithm.

It is important to note that Kinect was able to track gait movement for Parkinson's patients, Figs. 8 to 10.

The statistical tests (hypothesis tests) were performed to confirm the accuracy of the results obtained to the gait cycle. Using a significance level of 5%, the rejection of the null hypothesis was obtained for all cases. Therefore, the values obtained are statistically significant.

5. CONCLUSION

The results obtained in this paper were expected in function of the literature, but in this paper were compared together the Kinect Infrared and Body tracking with the digital goniometer.

The results were similar between the two algorithms developed with the use of Kinect V2. A comparison between the digital goniometer and the Kinect price evidence for a big cost difference to errors acceptable.

Since the Kinect V2 maintain the curves format and close values, it is possible to diagnose and follow the evolution of the patient treatment.

Among the suggested future work are: adding computational resources, like Deep Neural Network to identify gait diseases; a serious game to increase the interaction between the system and the patient, so the patient may accompany you own evolution and understand better where is the problem. The Microsoft has closed the production of Kinect V2, but a new version is expected coming soon.

6. ACKNOWLEDGEMENTS

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