Human Gait Cycle Analysis Using an Adapted Mechanical Prosthesis

C. R. L. Moraes, E. M. Aragão Junior, R. J. R. S. Lucena, É. L. Cavalcanti, and M. A. B. Rodrigues

Abstract

The knee is a joint that acts in the process of locomotion of the human being. When a person, for some reason, loses this joint starts a slow and expensive process of rehabilitation for the reintegration of this person in society. With this mindset, this project aimed to compare normal gait and gait using an adapted mechanical knee prosthesis, in order to list parameters that in the future a dynamic control system can be used to act on a low cost knee prosthesis, capable of facilitating the process of rehabilitation, making it less traumatic. The tests were performed in healthy people using a device that had two accelerometers and two channels of electromyographic signal acquisition. After the tests, the data were analyzed and the following conclusions were observed: (a) gait with the prosthesis has a higher balance phase and is tiring and slow when compared to normal gait, and (b) there is the possibility of development of a control system for electronic knee prostheses using inertial sensors and electromyography only.

Keywords

Mechanical prosthesis • Accelerometry • Electromyography

1 Introduction

The knee is one of the joints of the human body most important for performing the movement, allowing humans to move at small distances. When a person loses this joint, being amputated or for congenital defect, in addition to being a traumatic situation physically and mentally is also the beginning of a cycle of adaptations, which will require patient willpower, patience, dedication and above all a multiprofessional qualified team to follow this process.
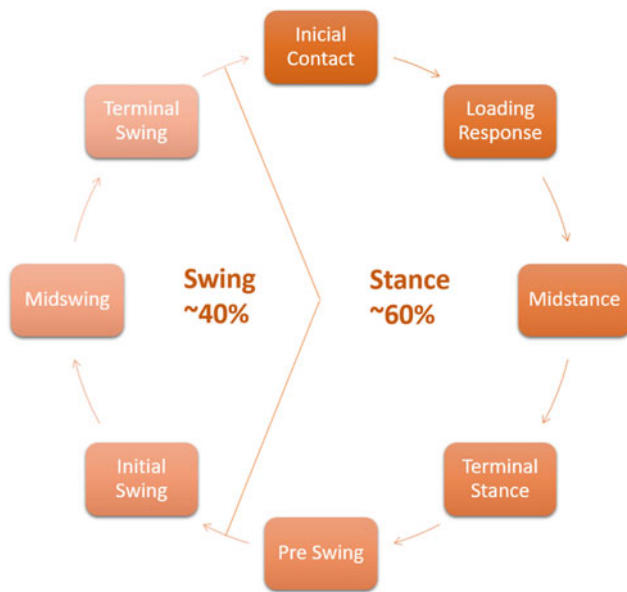
The Brazilian Institute of Geography and Statistics (IBGE) reported in its 2010 Census report that about 23.92% of the Brazilian population has at least one type of disability (auditory, visual, motor or intellectual), and that among those 29.09% has a motor deficiency. Still according to the Census, in the state of Pernambuco, little more than 22% of its resident population has some degree of motor deficiency [1]. However the IBGE does not report how much of these motor deficiencies are due to amputation, nor the level of these amputations. Thus the data on this subject are imprecise and only estimated in the literature.

It is estimated by the literature that 85% of the amputations are lower limbs [2]. Of these, approximately 80% of amputations occur due to vascular diseases and/or diabetes. The second major cause of amputation occurs due to trauma (20% of amputations, with 75% of these occurring with men), being the main reasons automobile accidents and wounds of gunshot [3].

Considering the difficulties faced by people who do not have the knee joint, such as the reduction of mobility in space, this study intends to compare the normal gait with gait using an adapted knee mechanical prosthesis 3R15 Ottobock. The purpose of this comparison is that from this information can be developed a control system for an electronic knee prosthesis. In the data collection, we used inertial sensors and an equipment of acquisition of electromyography (EMG).

1.1 Analysis of the Gait Cycle

The gait is considered normal when a person can perform a sequence of synchronized movements of the lower limbs that in turn moves the body forward without losing the stable posture. This process is commonly called gait cycle, being divided in the stance phase, 60% of the cycle, and the swing phase, 40% of the cycle (Fig. 1) [4–6].

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Fig. 1 Phases of gait observing [4]

Fig. 2 Components of the adapted mechanical prosthesis. Adapted fitting in L shape, fastened to the user by Velcro straps, mechanical knee 3R15, Ottobock adapter tube and Ottobock SACH foot
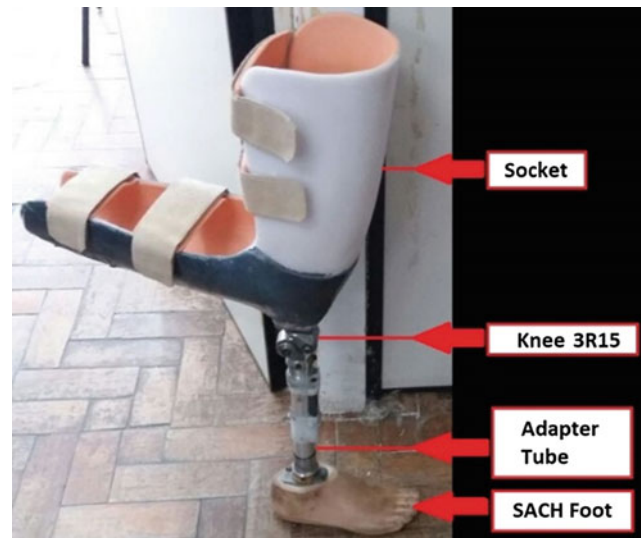
The stance phase corresponds to the period during which the foot is in contact with the ground. This phase is divided into five subphases: initial contact, load response, midstance, terminal stance and pre-swing. The swing phase represents the remainder of the cycle and refers to the period when the foot is raised above the surface. This phase is divided into three sub-phases: initial swing, midswing and terminal swing. The precise duration of these intervals varies with the individual's walking speed [5, 6].

2 Materials and Methods

The study was carried out in the Post-Graduate Program in Electrical Engineering in conjunction with the Post-Graduation in Biomedical Engineering of the Federal University of Pernambuco—UFPE. The following equipment and software are used: Microsoft Kinect, notebook, adapted socket, 3R15 knee mechanical prosthesis and Ottobock SACH foot, equipment developed by GPEB/UFPE, silver chloride surface electrode with saline gel and Reability software for analysis of the data.

As it is a study for the development of a prototype that in this first moment will not be used volunteers with amputations above the knee but the researchers themselves, being used the Ethics Committee with CAAE 2,695,690. Later, when the process is already consolidated and does not present any type of risk to the patient will be used amputated patients, which is not scope of this work.

In order to solve the problem of the lack of amputated individuals, the prosthesis received an adapted socket (Fig. 2), thus enabling the use by the researchers.

The GPEB/UFPE developed equipment consists of two inertial sensors model MPU-6050, an EMG acquisition sensor, a bluetooth HC-05, a microcontroller with low power consumption MSP430G2553, a battery charging system and a 9 V battery (Fig. 3) [7]. Currently this device supports up to four EMG channels and two inertial sensors. However, in this work, only one EMG channel and two inertial sensors were used, since it is intended to use the minimum of sensors, in order to obtain the lowest possible cost.

For the data analysis, the software Reability was developed, developed by GPEB/UFPE. This interface is intuitive and easy to use (Fig. 4). This software allows the real-time visualization of the signals and the possibility of recording and saving the data in the computer for later analysis, together with the video during acquisition [7].

Like Cavalcante et al. [7], it was decided to use Microsoft Kinect in the acquisition of images, since it is an equipment capable of detecting when a person exists in their field of action and of identifying when there is a movement. The synchronization of the video is done automatically with the acquisition of the data and the identification of the gait phases was performed with the aid of a physiotherapist.

The signs were acquired in the laboratory, first without the use of the adapted prosthesis and then with it. The purpose of these tests is to analyze the walk, with and without prosthesis. The protocol was based on the individual walking by nine meters, aiming to enter into a cyclical regime, and recording is only done during the last three meters. This exercise was repeated three times without the prosthesis and three times with the prosthesis.

Before the beginning of the tests, there was more than 40-h training with the adapted prothesis, assisted by

Fig. 3 Equipment used during
testing
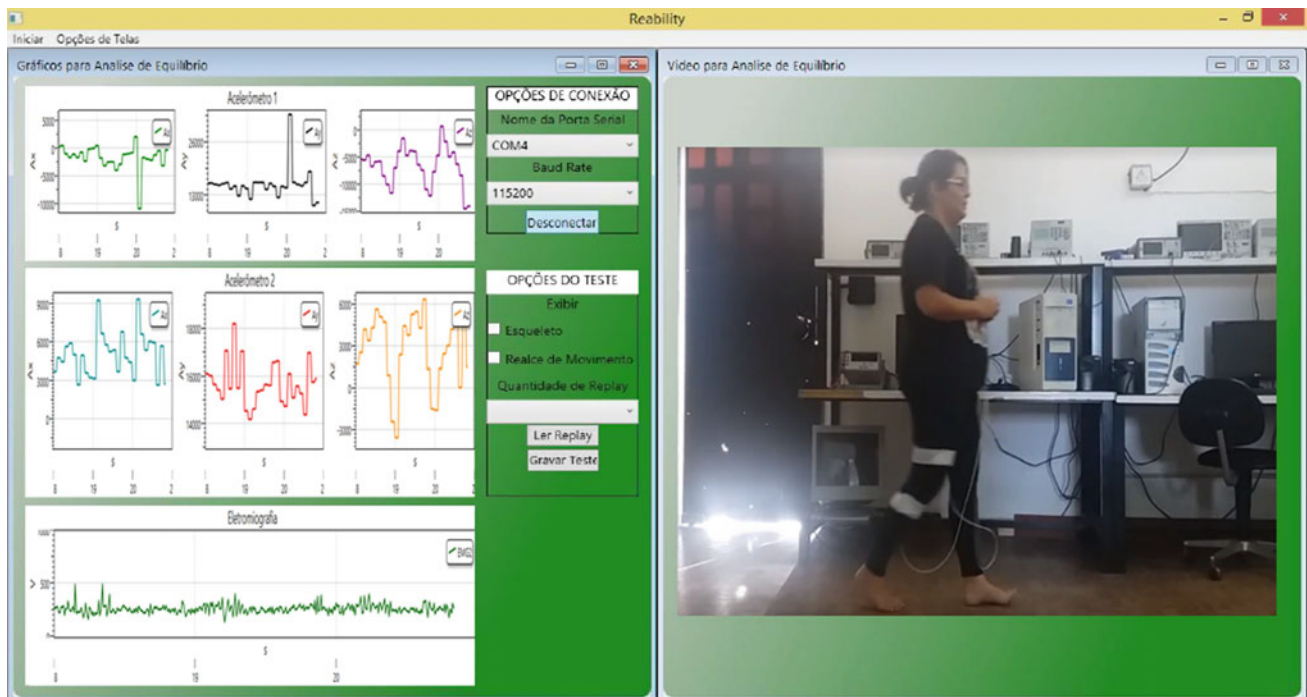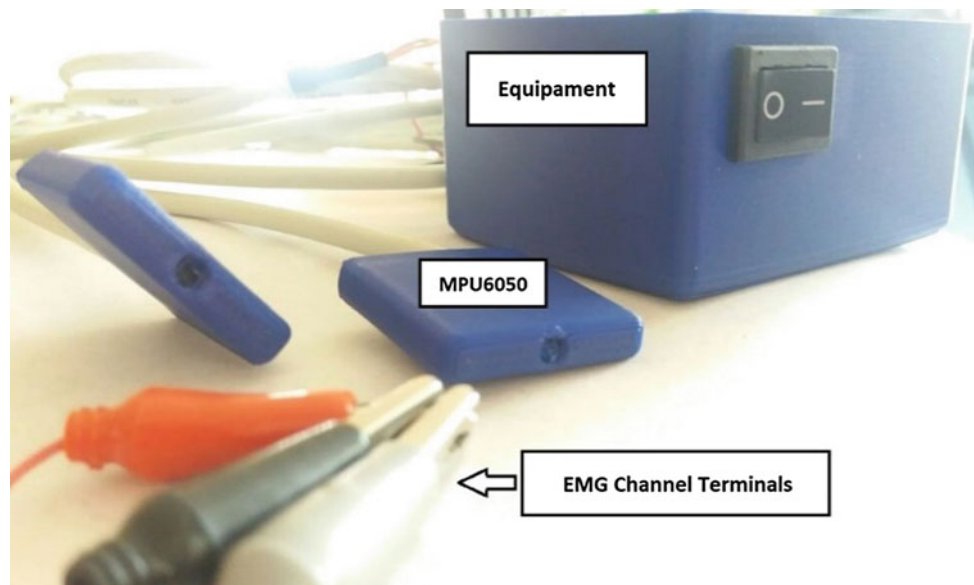
Fig. 4 Platform Reability. On the left side the graphs are visualized. In the first row the graphs of the first accelerometer are shown, in the second line the graphs of the second accelerometer and in the third row the graph of the electromyography; and on the right side the video

physiotherapists at the AACD (Association of Assistance to the Disabled Child), in Recife-PE, as the amputee needs to train during the rehabilitation, researchers need to relearn to walk, understanding their difficulties and limitations imposed due to lack of a member.

The position of the electrodes followed the SENIAM (Surface Eletromiograph for the Non-Invasive Assessment of Muscles) protocol for the lateral quadriceps femoris muscle of the left leg located in the anterior region of the thigh and the accelerometers were positioned in the right leg

with the X axis facing for horizontal with positive direction to the right side, vertical Y axis with positive upward direction and Z axis facing the user. Accelerometer 1 should be centralized at the thigh 10 cm above the knee and accelerometer 2 centered at the leg 10 cm below the knee.

3 Results

The first test performed, without the use of the prosthesis, is intended to make a brief analysis of the gait of a person without disability. Three tests were performed. Table 1 shows the time and speed of each test and in Fig. 5 a representative figure of the test performed.
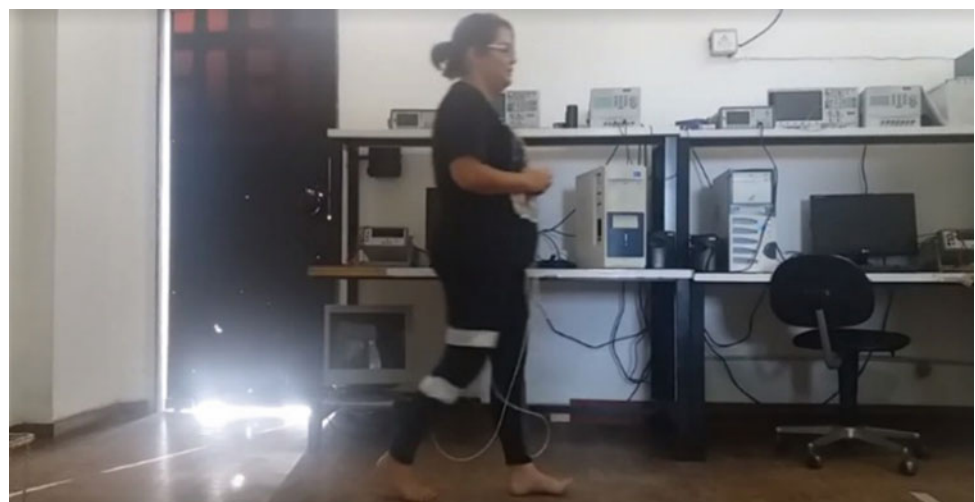
The EMG and accelerometry data are shown in Fig. 6. The muscle activation signal is highlighted within the red rectangles in the first line. The yellow and purple rectangles were used to highlight two more phases of gait, obtained through the observation of the footage made in conjunction with the presented graphics. The data within the yellow rectangles are in the period from the initial contact to the midstance, in the purple rectangles of the midstance to the pre-swing, in the reds the swing phase and the black rectangle represents that at the end of the gait the user remained standing and resting on both feet.

The acquisition of the signs with the mechanical prosthesis 3R15 were performed in a similar way to the test performed without the use of prosthesis, having the same

intention as the previous test. However, this analysis is used to make a comparison between the two gears and for the subsequent design of a control system for an electronic knee prosthesis. The time and speed data are presented in Table 2 and in Fig. 7 a representative figure of the test is presented.
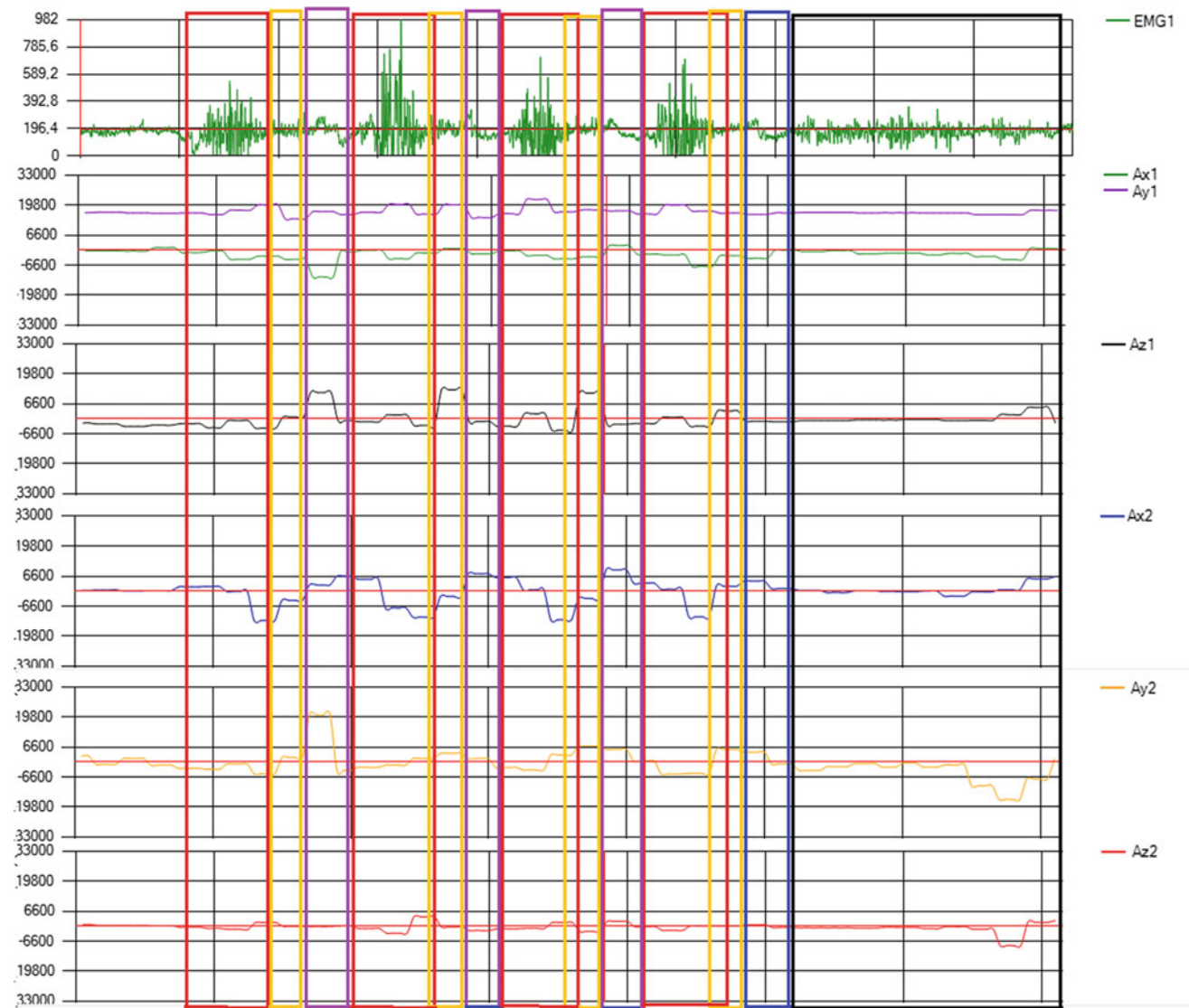
The EMG and accelerometry data are shown in Fig. 8. As in the previous test, the muscle activation signal is inside the red rectangles on the first line. The green and yellow rectangles were used to define two more stages of gait and were done observing the footage made in conjunction with the presented graphics. Since the data within the yellow rectangles are in the period from the initial contact to the midstance, the purple rectangles of the midstance to the pre-swing and the red ones in the swing phase.

4 Discussion and Conclusion

This research, although it is not a new topic in the scientific community, is part of a larger work that seeks the development of a low cost equipment for monitoring and control of the gait of people transfemorally amputated. Therefore, it was decided at the first moment to not use people who had above-the-knee amputations to perform the tests with the prosthesis, given that it is difficult for researchers to understand the difficulty that users in the first stage of rehabilitation suffer, and how they face daily difficulties after the rehabilitation phase.

This stage of understanding for the researcher is of fundamental importance, because as the researcher deeply understands the difficulties and problems that arise for the users of knee prosthetics, they are able to propose solutions that will improve the quality of life of these users.

During this training phase it was noticed that one of the main limitations of this model of mechanical prosthesis is that when initiating the initial contact phase the knee of the

Table 1 Data acquired during the tests without the prosthesis

Tests	Time (s)	Speed (m/s)
Test 1	5	0.60
Test 2	5	0.60
Test 3	4	0.75

Fig. 5 Test without the adapted prosthesis

Fig. 6 Graph of the data. First line EMG signal. The second, third and fourth lines are respectively the X, Y and Z axes of the first accelerometer. The fifth, sixth and seventh lines are respectively the data of the X, Y and Z axes of the second accelerometer

Table 2 Dados adquiridos durante os testes com a utilização de prótese adaptada

Tests	Time (s)	Speed (m/s)
Test 1	12	0.25
Test 2	12	0.25
Test 3	11	0.27

prosthesis must be fully extended, because in case there is minimal flexion when the weight of the user is transferred in the phase of response to the load, it will flex at once, which can cause fall.

For the acquisition of the electromyography signals, electrodes were used that were placed in the quadriceps lateral femoralis muscle, using the SENIAM protocol,

positioned contralaterally to the leg that was amputed. This was necessary because the quadriceps femoral muscle of the thigh that was with the adapted prosthesis was always in the relaxed state, due to its positioning (Flexed to 90°). However, it is believed that in people who have amputation above the knee and who were protected immediately after amputation, they have electromyographic signals that are sufficient to be used as classifiers in a control system of an electronic knee prosthesis [8–10].

During the normal gait tests (Fig. 6), it was found that the Y and Z axis graphs on both accelerometer 1 and accelerometer 2 were not stabilized and were not cyclical in all tests performed. These graphs were expected, with rotation on the Y axis indicating a slight external rotation of the knee whereas rotation on the Z axis indicates a slight lateralization of the

Fig. 7 Test with the adapted prosthesis

movement (abduction/adduction movement). This phenomenon was also observed in gait with the adapted prosthesis (Fig. 8), however its variations were greater in accelerometer 2, which is explained by being more distant from the hip.

The rotation on the X axis has the purpose of extending and flexing the knee and is the only axis that has cyclic movement and standard in both gears, being thus like in the other axes more intense in the accelerometer 2. This is explained, therefore when observing the gait it is noticed that the leg executes movements with amplitudes greater than the thigh.

Regarding the data in Tables 1 and 2, it is possible to notice that gait with the prosthesis is slower than normal, and this result was already expected. When using the prosthesis the researcher, spent more energy and made more effort in carrying out the walk and this was perceived with the increase of the amplitude of the EMG signal when the muscle should be relaxed, prolonging the time of the stance phase. The EMG signal, as shown in Fig. 8, has a longer activation time than the signal shown in Fig. 6, indicating that the leg stance phase is larger than that of the leg with the prosthesis, i.e., that the swing phase of the prosthesis is smaller. This phenomenon is explained by the literature, since the user does not have total confidence in the prosthesis leg [2, 11].

Based on all the data acquired during the tests, it is concluded that it is possible to create a control system for an electronic knee prosthesis, using the same equipment that was apply in the gait analysis phase. The equipment used is portable and has bluetooth communication, which allows in the future the creation of a mobile application that will receive signals coming from the prosthesis.
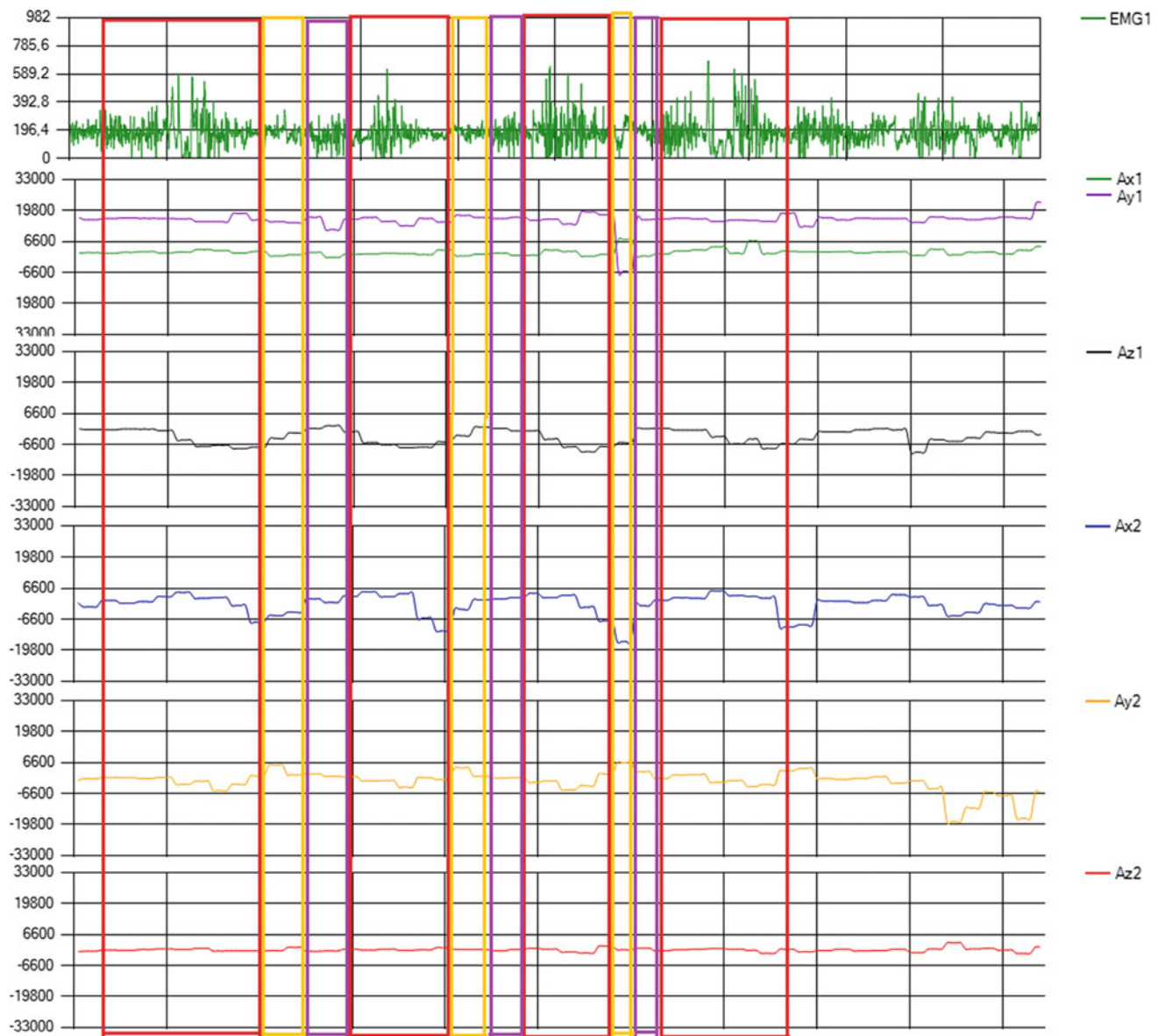
Fig. 8 Graph of the data. First line EMG signal. The second, third and fourth lines are respectively the X, Y and Z axes of the first accelerometer. The fifth, sixth and seventh lines are respectively the data of the X, Y and Z axes of the second accelerometer

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