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DESIGN AND DEVELOPMENT OF A LOAD CELL IN AN INTELLIGENT ELBOW CRUTCH FOR AN EXOSKELETON

Felipe Matias Cortez Trigueiro
Márcio Valério de Araújo
Laboratório de manufatura, Departamento de Engenharia Mecânica, Universidade Federal do Rio Grande do Norte (UFRN).
Campus Universitário, Lagoa Nova, 59078-970, Natal, RN, Brazil
fmctrigueiro@hotmail.com, marcio@ct.ufrn.br

Abstract. *This work presents the development of a smart elbow crutch equipped with a load cell and an embedded electronic system. This crutch is used by users of a robotic exoskeleton for lower limbs, besides the function of assisting in the balance and safety of the user, it is used as a Human Machine Interface (HMI) capable of sending a series of high level commands to the robotic exoskeleton called Ortholeg, like for example sitting, standing up, down stairs, among others. All these functions will be based on the force measured by the load cell at the time of the use of the exoskeleton, which upon reaching a predetermined value, will make the embedded computer interpret as being a command to be performed. The load cell was designed to be coupled to the crutch and for this purpose stress analyses were performed on the crutch in normal use condition. The measured efforts are sent to an A/D converter which then sends the data to a microcontroller. All information measured on the crutch is transmitted via Bluetooth to the embedded exoskeleton computer. The tests showed the functioning of the measurement, acquisition and shipment system, as well as the simulation of the loads on the crutch.*

Keywords: *Exoskeleton, microcontroller, crutches, load cell.*

1. INTRODUCTION

The great increase in the world of people with Spinal Cord Injury (SCI) since the 70's is shown in Ho et al. (2007), in this work we can observe that this lesion has varied greatly with age and causes over time, mainly causing losses in the control and the sensitivity of the limbs, because it affects the central nervous system. The regions that suffer from the trauma are located below the injury site and may totally preclude the passage of nervous stimulus through the spinal cord at its most severe occurrence.

These data are important in order to ensure an increasing number of studies aimed at providing assistance to those people suffering from physical problems arising from SCI, with the main support of technological advances in medicine with the intention of reducing the limitations imposed on patients and providing an improvement in their lifestyles.

The SCI has as one of its main consequences the fact that the person usually has difficulty locomotion, so patients suffering from this injury need a more adequate monitoring, as well as equipment, from the simplest to the most complex and modern, capable of somehow help those limitations that appear in this scenario.

One of the most commonly used assistant to human gait is a crutch. They are used to provide greater freedom of movement and independence while helping balance the user who has some difficulty in locomotion (Armstrong and Cipriani, 2001). Its use provides a considerable reduction of load on the lower limb joints, relieving joint pain and compensating for weakness or injury.

There are basically 2 types of crutches: the axillary, which are cheaper, however, are uncomfortable and difficult to use, because the incorrect use in the armpit support can cause nervous or vessel compressions; and the elbow (or forearm), this has a support for the forearm, which allows the hand to be free without removing the crutch, being more comfortable than the axillary. Even with these differences, users have a similar energy expenditure when using both crutches, as shown in Iwami et al. (2001).

The crutches can be applied together with other devices that help the human gait in order not only to serve their basic functions but also to add new functions that interact with this other equipment, among these other ways of using it, we can mention one that is growing a lot on the current world scenario because of its great potential in the rehabilitation of people with SCI, which are exoskeletons.

This work aims at a development of the previously done projects on the robotic exoskeleton for lower limbs, Ortholeg, as shown in Glober et al. (2015). For the new designed structure, it was thought of a load cell system capable of providing the application data of the forces present in the user's movement with the robotic exoskeleton. This analysis by the cell represents a stimulus for the embedded computer, which will interpret the values obtained to perform a certain function.

2. EXOSKELETONS

Exoskeletons began to be studied in developed countries (Guizzo and Goldstein, 2005) and gained increasing importance, because it makes possible a great reinforcement in the locomotion of people who suffered with some accident in the marrow that culminated in the partial or total loss of the inferior movements, as demonstrated in Can et al. (2015), which the sit and stand up action is modeled and analyzed for its power distributions when using an exoskeleton.

With the technological development were created several other models of exoskeletons able to help paraplegics in their rehabilitation. Among the new equipment found in the lecture, we see the use of crutches as something recurrent in the research. These projects commonly use crutches to increase safety and ensure individual balance, but it is also possible to use them as a HMI to communicate with the computer system. Two examples of the use of crutches in this context are: from Ochanomizu University in Tokyo, Japan (Ohta, et al., 2007); And The Robotics and Intelligent Systems Laboratory of the Institute of Advanced Technology in Shenzhen, China (Shaomin, et al., 2015).

Another good example of this is in the HAL exoskeleton (Hassan, et al., 2014), which the crutch serves as an interface to the exoskeleton (Fig. 1), that has several sensors for detecting the intention of movement and control of the user, allowing analysis capable of providing more appropriate responses of the orthosis to each situation.

Figure 1. HAL exoskeleton with interface to crutch and sensors (Hassan, et al., 2014)

Currently, some companies are investing in this technology, one of the largest in the area is the Israeli Argo Medical Technologies, which develops the exoskeleton called ReWalk (Technologies, 2017) (Fig. 2), it is able to allow the user to up and down stairs, stand up and sit, all this is chosen in a system located on a bracelet used by the user who sends the instructions to the embedded system. It also has sensors capable of starting functions, such as walking while inclining the body.

Figure 2. ReWalk Exoskeleton and its Components (Technologies, 2017)

Exoskeletons are also a study center for some researchs that attempts to measure its impact and importance for a SCI user. An article using the ReWalk exoskeleton as the basis of the research was done by the Department of Industry and Mechanical Engineering of the University of Brescia (Italy) (Lancini, et al., 2015), which analyzes all loads applied to the crutches during the use of this system (Fig. 3).

Figure 3. Measurement of loads in the use of ReWalk exoskeleton (Lancini, et al., 2015)

The Ortholeg Project has as a pillar the creation of the robotic exoskeleton for lower limbs based on the studies already done and the equipment already developed by its predecessors (Glober, et al., 2015). From the beginning, the main purpose of the project is to enable people to take regular actions, such as walking, sitting, standing up, up and down stairs.

The Ortholeg robotic exoskeleton (Fig. 4) is powered by an electric motor accompanied by reducers capable of providing a smoother and closer movement of the real to the user, also using an embedded electronic system capable of controlling motor functions and doing the acquisition of data during the use of the equipment. Its parts are made with various materials such as carbon fiber, special polymers and aluminum alloys. It is portable and lightweight (16 Kg) making it easy to carry, has great resistance and fits well to the wearer's body when dressed.

Figure 4. Robotic exoskeleton Ortholeg design

3. METHODOLOGY

In this topic will be present the characteristics of the main elements that compose the system proposed in the project, which are the crutch, the load cell and the Strain Gauges.

3.1 Crutch

For this project, for the reasons presented previously, the elbow crutch was chosen to be used in it, both for the functions already mentioned and also as Human Machine Interface (HMI) capable of communicating with the embedded system of the exoskeleton. In this context, one of the crutches has a load cell, responsible for measuring the efforts made by the user when using the crutch, which will provide high level commands to select some movements.

The crutch used in the project (Fig. 5) is articulated and its specifications are:

• Anodized structural aluminum body
• Polypropylene arm support
• It has arm cuff for the articulated forearm
• Anti-noise system inside
• Quick release coupling
• Retractable spring system for easy adjustment
• Tip 3/4 in natural rubber
• Can efficiently support a person up to 90 kg
• It has a maximum adjustment height of 117 cm and a minimum of 96 cm

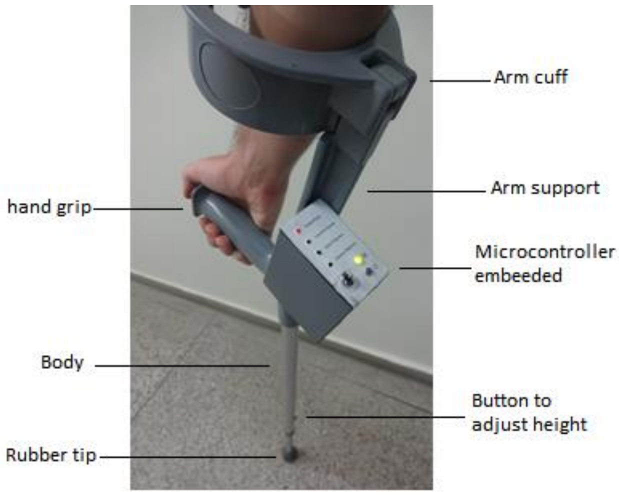

Figure 5. Image of the articulated crutch used in the project

3.2 Load cell

The load cell had the collage of two Strain Gauges in the half bridge format. This configuration will allow measurement of the comprehension forces used during the user's walk with the exoskeleton.

The body of the load cell in Fig. 6 is made of aluminum, has 35,3 g of weight and is 5.7 cm of height. In the center of the cylinders a through hole was made so that the cables connected to the extensometers could pass.

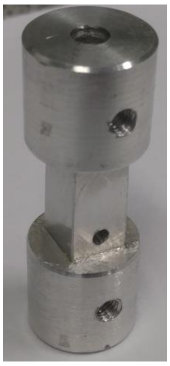

Figure 6. Load cell after machining

3.3 Strain Gauges

The Wheatstone bridge consists of four resistors connected in the form of a square and excited by a power supply V_i, producing a voltage signal V_0. The load cell used in the project has two Strain Gauges in the configuration of half bridge, name given by them for replace 2 resistors in Wheatstone to be able to measure the new voltage variation, because with this format it is already possible to receive the necessary data of the crutch compression (Balbinot and Brusamarello, 2007). The Strain gauges used in this project are HBM-1-LY43-3/350 (Fig. 7). The configuration of it is presented in Tab. 1 and have been taken from the HBM catalog for Strain Gages (HBM, 2017).

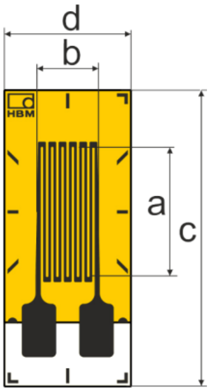

Figure 7. Schematic image of the extensometer used in the project (HBM, 2017)

Table 1: Specifications of the strain gauge used in the project (HBM, 2017)

Strain Gauge - HBM-1-LY43-3/350							
Type of material	Nominal resistance (Ω)	Dimensions (mm/inch)				Max. Permissive effective bridge ex. voltage (V)	Solder terminals
		Measuring grid		Measuring grid carrier			
		a	B	C	d		
aluminum	350	3(0,118)	2,5(0,098)	10,9(0,429)	5,9(0,232)	9	LS 5

4. EXPERIMENTAL PROCEDURE

To dimension the load cell, a previous study (Fig. 8) was made to verify the average force required for a person to stand up of the chair using the crutches. The tests were done with several people of different masses to obtain a range of load values representing the efforts made by the user on the exoskeleton crutch during its use. This was important because it guided the beginning of the design of the load cell.

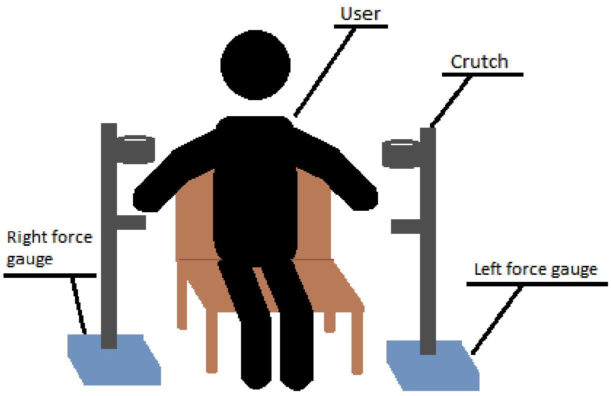

Figure 8. Experiment set for measuring the average force when a person is performing a sit to stand movement

A CAD software was used to design and dimension the load cell (Fig. 9) that was implanted on the crutch. After the process of machining, two strain gauges were collage to it in the half bridge configuration (Fig. 10), capable of analyzing the main axial and bending stresses applied to the crutch by the exoskeleton user.

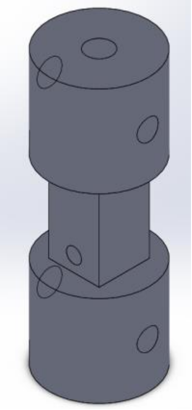

Figure 9. Isometric image of the CAD design of the load cell

Figure 10. Load cell after bonding the strain gauges

The strain gauge generate low-amplitude signals, so their amplification is required, then it is sent to the conversion module, which in addition to filtering and amplifying the generated signal, also performs a 24-bit resolution A/D converter, providing such as measurements for the microcontroller which processes the data and converts in high level commands to the embedded exoskeleton system via Bluetooth. Figure 11 shows the basic flowchart from a force measurement until the high level command generation.

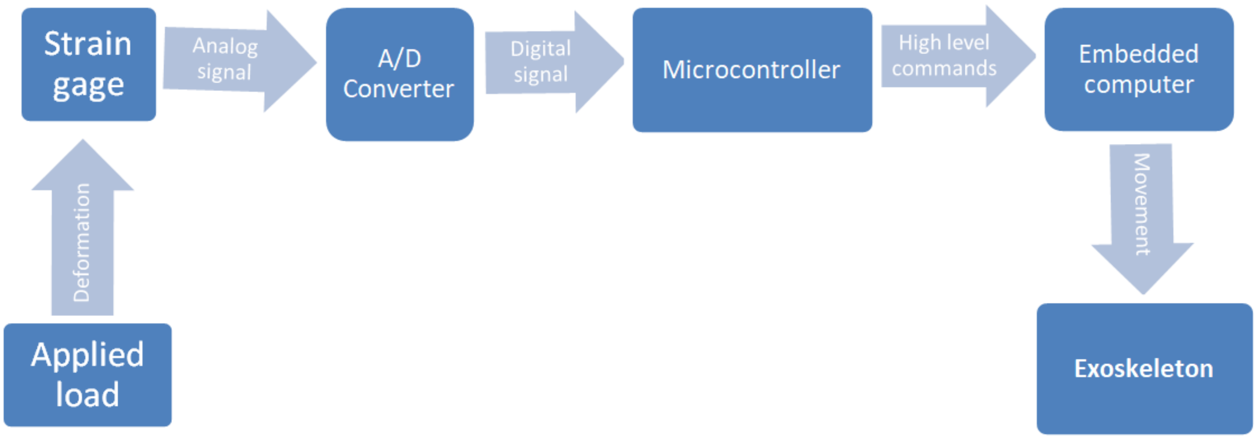

Figure 11: Flowchart showing the basics for data acquisition.

Subsequently, a computer program was created to receive the data from the strain gauges and save the information from the load cell while using the crutch, the data was in milivolts (mV).

Thus, the load cell calibration was done in the Metrology Laboratory of UFRN, then a structure was placed to compress the cell gradually (Fig. 12), because a hook was placed to fasten the assembly where the loads would be varied with the placement of standard masses of 5 Kg, value of the measurement interval that started with 5 kg and was progressively increased up to 50 kg, value above the established limit of force applied on a crutch during its use. The measurements of the proposed interval were repeated 6 times, according to the principles of measurement of metrology.

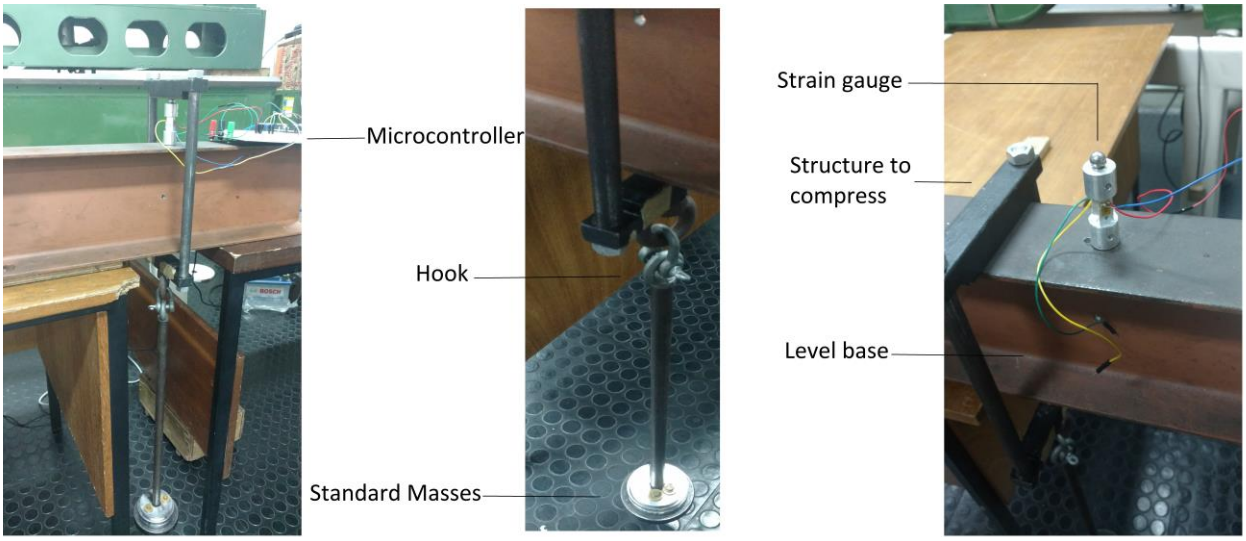

Figure 12. System used for load cell calibration

The analysis of the results of the calibration process resulted in the appearance of a graph that relates the value of the voltage (mV) measured in the load cell and the corresponding value of load (N) applied to it. With the graph it was possible to generate an approximate straight line equation for the points, called the calibration equation, capable of associating the voltage values with the actual load values applied in the cell.

It was then possible to deploy the load cell on the crutch and begin testing to produce data with the forces applied by users of different masses using the crutch, so it would be confirmed that the cell would be functioning correctly and measuring exact values for its use.

5. RESULTS AND DISCUSSION

The Fig. 13 represents the graph for the average force values that several people with different body masses apply to stand up of a chair. The masses are within the range of design values established for the exoskeleton, ranging from 55 to 75 kg.

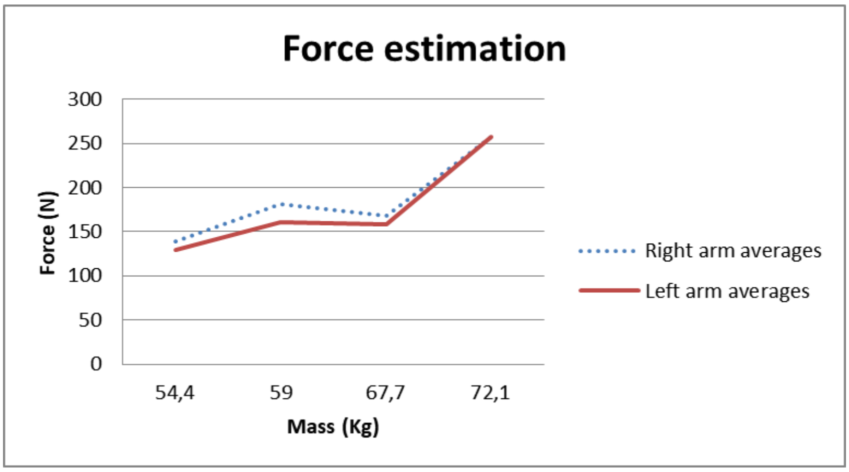

Figure 13. Graph with average values of applied force for the person to stand up

The values presented in the test are very important because they present an average load that each crutch will support maximum during the use by the patient. These data are important for locating the range of loads applied during the calibration of the system and was the beginning of the analysis of the design of the cell, as it also indicated the load that it would have to bear when placed on the crutch.

The initiation of the load cell design showed a limitation by where it would be placed and the need for its tips to fit into the inner cylinder of the body of the crutch (Fig 14), leaving the cell with a simple geometry. After this initial design, it was necessary to perform a stress analysis in the design with the maximum load value already obtained in the initial test.

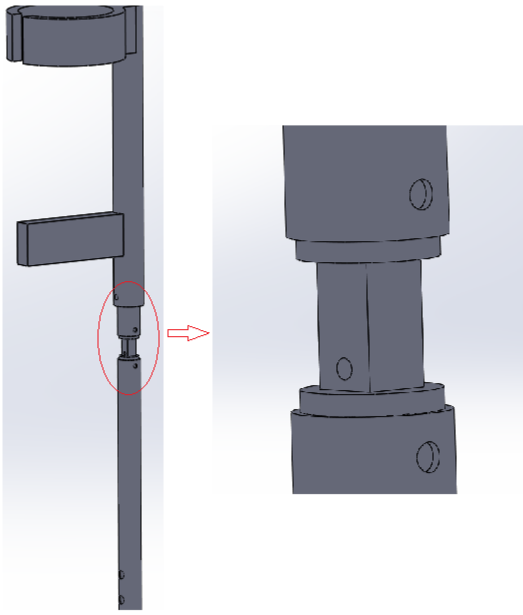

Figure 14. Marking the region where the load cell will be placed on the crutch

With the stress analysis that was performed to observe the safety of the project, it was possible to identify the load cell as the place with the highest stress, the analysis shown in figure 15. As can be seen, the maximum yield strength value analyzed does not exceed the material value of the structure.

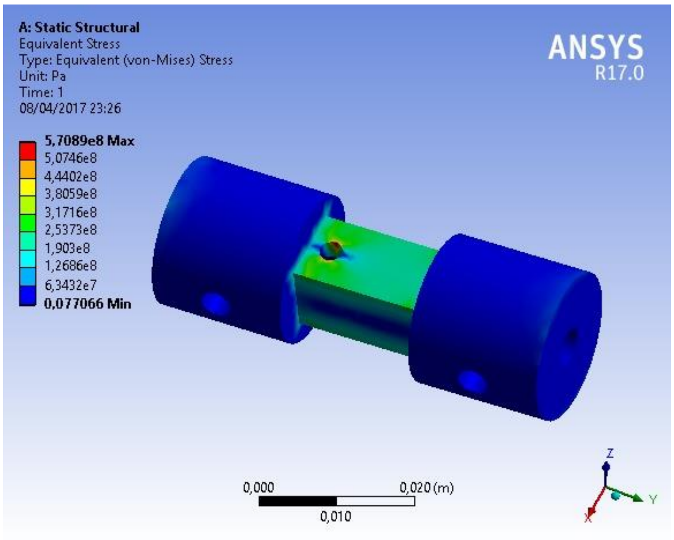

Figure 15. Voltage analysis in the projected load cell

The calibration of the load cell allowed the appearance of a graph that relates the measured voltages (mV) and the applied load (N) to it, its analysis enabled the appearance of a calibration equation (straight equation) to the system from the interpolation of his points.

The tests with people of different masses using the crutch with the load cell (Fig. 16), performed after the calibration, showed acceptable values for the actions performed, since the deformations presented on the crutch are able to correctly vary the measured values in the cell.

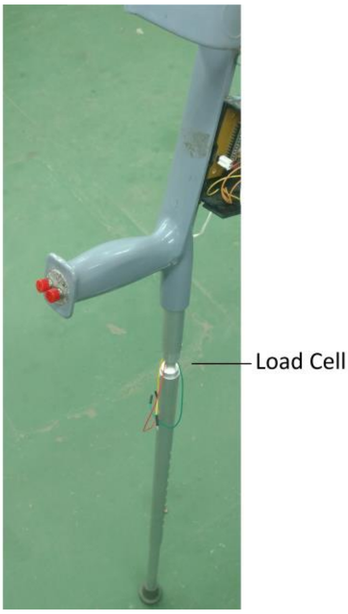

Figure 16: Crutch with load cell

6. CONCLUSION

With the analysis of this work, it is possible to perceive that the functionality of the load measurement system based on a load cell, as well as the processing and transmission of the signal coming from it, occurred in a correct way, allowing analyzes of values close to the real ones during the use of the crutches. The load cell structure implanted in the crutch responds well to the axial and bending forces resulting from the forces applied thereto by the user.

In this way, the system can be effectively incorporated into the Ortholeg robotic exoskeleton design, allowing various analyzes to be incorporated into the embedded computer that controls the actions of the set and create other ways to select a certain function simply with the user load stimulus on the crutch.

After this work, it will be possible to improve this system to monitor the loads applied by people over a period of time. By analyzing these periodic values, it will be possible to develop ways of using the crutches more comfortably to the patient and establish an average energy consumption in a defined time interval for the patient.

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