Capítulo 5.

Prosthesis design through software tools and additive manufacturing

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Abstract

This document presents the methodology to design a hand prosthesis and orthotics. CAD tools and 3D printing were used to design the prototype and build the system. An acceleration sensor was used attached to the head of the user to control the movement of the prostheses. The system was evaluated by grappling common objects with different users. Index Terms—3D Printing, additive manufacturing, Industry 4.0.

Keywords: prosthesis; orthotics; 3D printing; additive manufacturing; industry.

Diseño de prótesis mediante herramientas informáticas y fabricación aditiva

Resumen

Este documento presenta la metodología para diseñar una prótesis de mano y una órtesis. Se utilizó herramientas CAD e impresión 3D para diseñar el prototipo y construir el sistema. También, un sensor de aceleración acoplado

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a la cabeza del usuario para controlar el movimiento de las prótesis. El sistema se evaluó mediante el agarre de objetos comunes con diferentes usuarios. Index Terms-3D Printing, fabricación aditiva, Industria 4.0.

Palabras clave: prótesis; órtesis; impresión 3D; fabricación aditiva; industria.

Projeto de prótese por meio de ferramentas de software e manufatura aditiva

Resumo

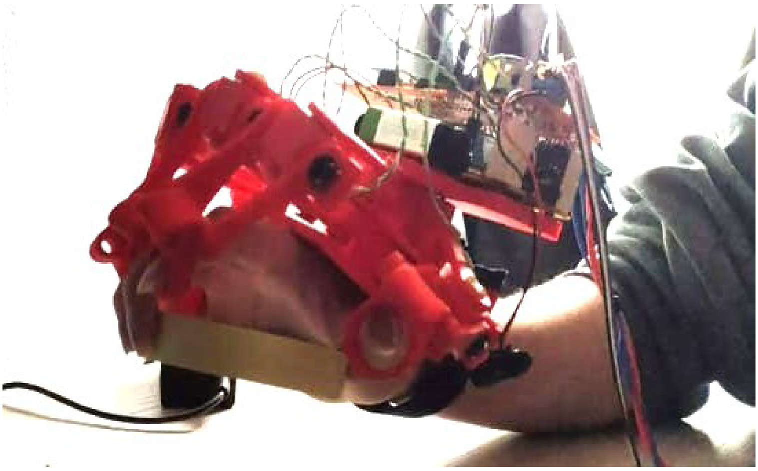
Este documento apresenta a metodologia para projetar uma prótese de mão e uma órtese. Foram usadas ferramentas CAD e impressão 3D para projetar o protótipo e construir o sistema. Foi usado um sensor de aceleração conectado à cabeça do usuário para controlar o movimento das próteses. O sistema foi avaliado por meio da manipulação de objetos comuns com diferentes usuários. Termos do índice - Impressão 3D, manufatura aditiva, Indústria 4.0.

Palavras-chave: prótese; ortopedia; impressão 3D; manufatura aditiva; setor.

Introduction

Figure 1

Orthotics controlled by an acceleration sensor



Industry 4.0 is defined as the integration of disruptive technology trends into supply chains. Some of the technology trends are cyber-physical systems (CPS), Internet of Things (IoT), Big Data analytics (BDA), cloud computing, fog, and edge computing, augmented and virtual reality (AR/VR), robotics, cybersecurity to semantic web technologies, and additive manufacturing (AM) (Bajic, 2020).

Industry 4.0 has aroused great interest in researchers, and the most developed countries in the world. The trend has been observed to create development plans that allow new technologies to be integrated into their production processes (Li Da Xu et al., 2018). Additive manufacturing is one of the key technologies for the development of Industry 4.0 (Dilberoglu et al., 2017). This technology is also called 3D printing and is defined as the process of construction of objects layer by layer (Rosalino and Belmonte, 2020). Plastic is typically used, although other materials such as metals (Dilberoglu et al., 2017) have also been used. In contrast, in subtracting manufacturing, the construction process begins with a solid material, and pieces of the material are subtracted until the object is found.

The origins of 3D printing date to 1951 with a patented technique called 'Photo-glyph recording'; later the technique of stereo-lithography was developed, opening the way to modern 3D printers (Gao et al., 2015). The components of 3D printers were invented many years ago, but it is until now that each component has been developed that the cost was lower enough to create desktop 3D printers. These printers are used in a wide range of applications such as automotive, aerospace, engineering, medicine, and biomedical systems development, among others (Gao et al., 2015). The needs of consumers have changed day by day due to the emergence of new technologies. Nowadays we seek to reduce the development time and design products according to the needs of the user (Lasi et al., 2014). Additive manufacturing presents the opportunity to reach these expectations, democratizes the manufacturing process, and at the same time, allows the creation of objects with complex geometries and multiple materials (Gao et al., 2015). 3D printing has been compared to disruptive technological trends such as digital books or music downloads since it allows consumers to create objects at home, designed to their needs (Berman, 2012).

One of the most important applications of 3D printing is the development of prostheses and orthotics. 3D printers allow the development of prostheses at low cost, tailored to the user, and explore new possibilities such as electronic control. Prostheses have previously been developed such as the one reported in (Sittiwanchai et al., 2014), where a transhumeral prosthesis has been designed using CAD tools. In this work, a control system has been developed using the electrical signals of the EMG muscles. However, they report that the device requires improvements to be used in daily life, because the device has been tested only in a controlled environment, and signal acquisition is a complex task.

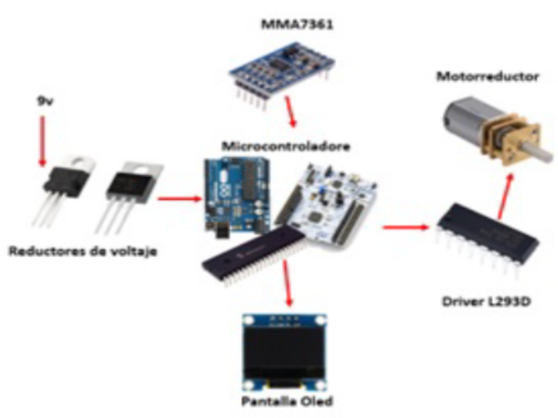
A second prototype using the same methodologies has been shown to be 80% effective (Sakib and Islam, 2019), where it is considered a success to close the prosthesis according to the electrical signals generated by the muscles. This prototype was tested on an amputee who in most cases achieved the movement of the prosthesis. The strategy for acquiring the signals has been evaluated to determine the most successful methodology. It has been experimented with wet and dry electrodes, finding better performance with dry stainless-steel electrodes (Alvarado et al., 2019). Other improvements made to prosthetic designs include coating 3D printed prostheses with skin-mimicking materials (Tavakoli et al., 2017), achieving better grip on objects.

At the Manuela Beltrán University in Colombia, there is the Ibero-American Center for Personal Autonomy and Technical Aids (CIAPAT). In this place, researchers and students develop technological aids that facilitate the lives of people with disabilities. Work has been done on the development of prostheses using 3D printers, however, it has been observed that electronic control methodologies are based on the acquisition of EGM signals from muscles, and it is difficult to distinguish when the order to move the prosthesis is sent. A solution to overcome this difficulty is the development of a prosthesis controlled by an accelerometer located in the user's head. This control mechanism allows greater reliability, since it requires less instrumentation, compared to the acquisition of EGM signals. The project was developed using CAD tools for the design of the printed circuits and the model of the prosthesis. A 3D printer was used for the manufacture of the prototype. Finally, some performance tests were carried out to verify its operation.

Hardware development

Figure 2

Diagram of the components of the system

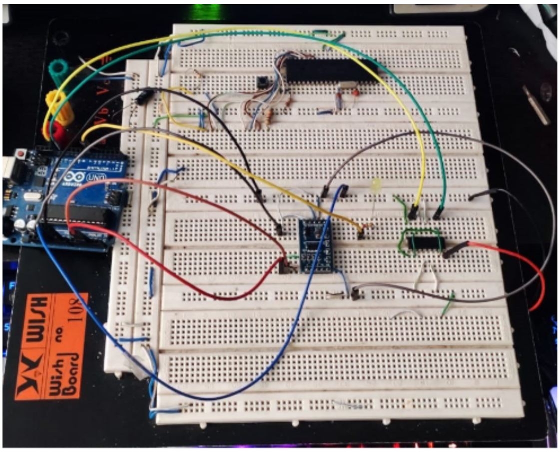


The system is formed by the elements of Figure 2. The MMA7361 acceleration sensor was used, which has three analog outputs to determine the acceleration of the sensor in three axes. A microcontroller picks up the sensor signals, displays on an OLED the inclination of the accelerometer, and determines the action to be performed by the motor that moves the prosthesis. Different software was designed for three microcontrollers: the ATmega328P, the STM32F411re, and the PIC18F455. To control the MR-1268 gear motor, the L293D driver was used, which consists of an integrated circuit with an H-bridge, allowing motor speed control. 5 V and 3 V regulators were used to power the system using batteries. The goal of the system is to control the movement of the prosthesis' fingers, according to the inclination of the acceleration sensor. Since the accelerometer is located in the user's head, the user can open and close the prosthesis, with the lateral movement of the head, and if he wants to block the movement of the system, it is necessary to move the head forward and backward.

Prototype design

Figure 3

Prototype design using a breadboard



The initial prototype of the system was developed on a breadboard as shown in Figure 3. On the board, the power supply was tested, the visualization of the data on the OLED screen, and the measurement of accelerometer signals. Once the proper functioning of the components was verified, the printed circuits are designed. A total of three printed circuits are designed; the first one supports the accelerometer located in the user's head 4; a second circuit contains the control circuit 5, and a third printed circuit with the power stage 6. Once the electrical design is finished, the mechanical design of the prosthesis is carried out. Thanks to the advancement of additive manufacturing, free software, and free hardware (Horvath and Cameron, 2014), we can find a large number of file designs with models of prostheses available on web pages. At the initial stage, a search for models of hand prostheses was carried out. Of the possible models, the one closest to the designer's needs was chosen, and modified to support the electronic components. The design of the prosthesis is seen in Figures 7 and 8, which corresponds to a skeleton located on the hand to help the movement of the fingers. These devices are also called orthoses. The device was built using an Ultimaker S5 printer with ABS-type plastic.

Figure 4

Printed circuit model for the acceleration sensor

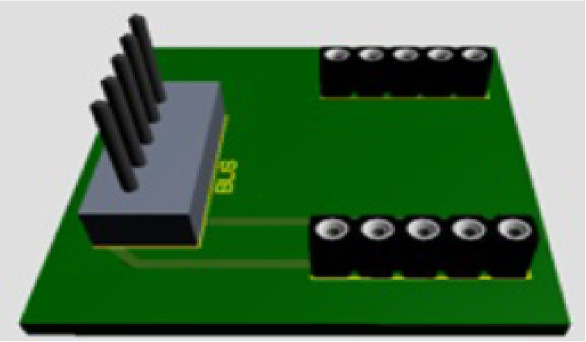


Figure 5

Printed circuit model for the control circuit

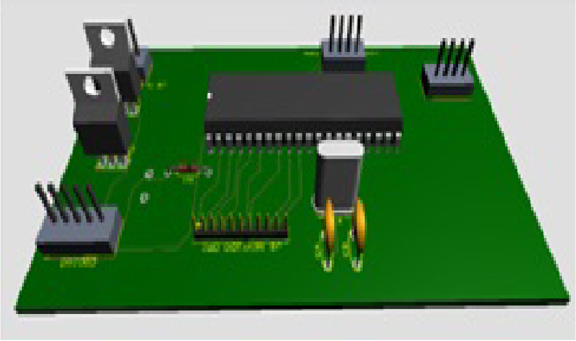
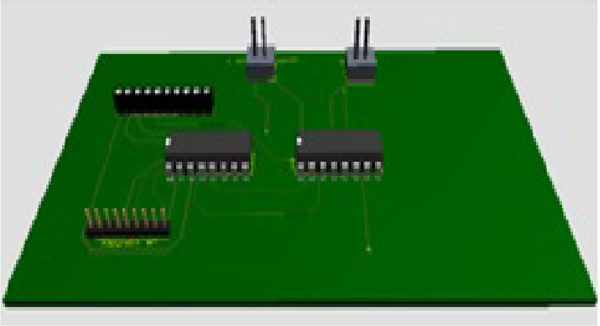


Figure 6

Printed circuit model for the motor control



Software development

Figure 9 shows the algorithm used to control the device. In the first stage of the software the angle of inclination of the user's head should be estimated. The Z and X axis of the accelerometer allows to determine the angle of inclination towards the sides of the user. By using the Y and Z axis it is determined whether you have tilted your head forward or backward to block the movement of the prosthesis. The angle of inclination is estimated using Equation 1:

$$\alpha = \tanh^{-1}\left(\frac{a_z}{a_x}\right) \qquad (1)$$

Once the microcontroller receives a percentage of inclination greater than a threshold, it must generate the signals that move the motor coupled to the fingers of the prosthesis. The system is in an open loop and does not have feedback. Therefore, the system has been controlled using timers. It has been estimated how long it takes to open and close the prosthesis, to fix the time the signal is applied to the motors. Finally, the OLED screen software has been adapted to visualize the percentage of head tilt and the direction. This process allows the designer to evaluate whether the prototype behaves according to specifications.

System Evaluation

The final device is shown in Figure 10. There are threads that pull the phalanges to achieve the opening and closing movement of the hand. Figure 11 shows the OLED screen corresponding to the graphical interface of the system. On this screen, a menu is displayed, and the user can configure whether to move the joints all at the same time, or a phalanx movement by phalanx is preferred. Once the system is started, you can see the percentage of inclination on the screen. The initial test of the system consists of moving the head and observing the movement of the hand in a vacuum. Figure 12 shows the prosthesis in a vacuum and closed. Then tests were carried out to try to take objects; punctually, two tests were carried out with common objects; the first trying to take a roll of tape; the second trying to take a glass; the first attempt could not be held correctly; however, after a time of practice the technique and grip were improved, and the subjects were able to grab the objects. A pair of pictures of the tests can be seen in Figures 14 and 15. Finally, tests were carried out with different test subjects, finding that at first, it is somewhat difficult to control the opening and closing by means of the accelerometer. Since the feeling of the orthotics is something completely new, the initial reaction is to contract the hand before the reaction of the system. However, the problem was corrected with training.

Figure 7

Model of the orthotics superior view

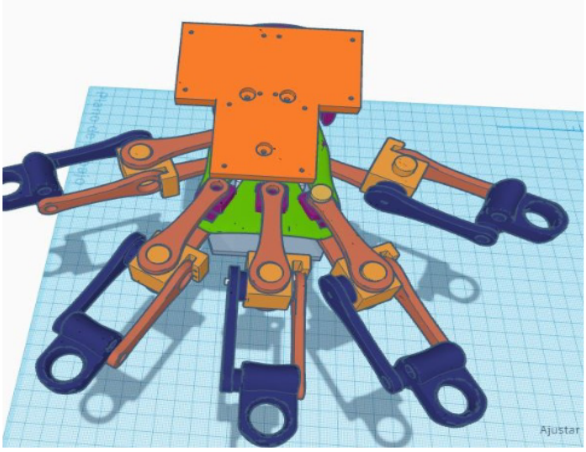


Figure 8

Model of the orthotics lateral view

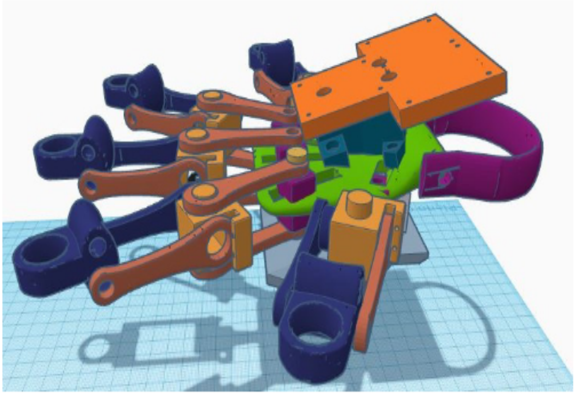


Figure 9

Flux diagram of the software

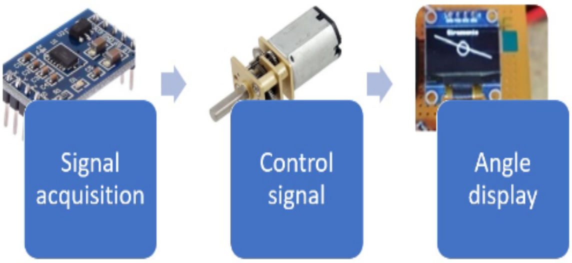


Figure 10

Printed orthetics. Superior view

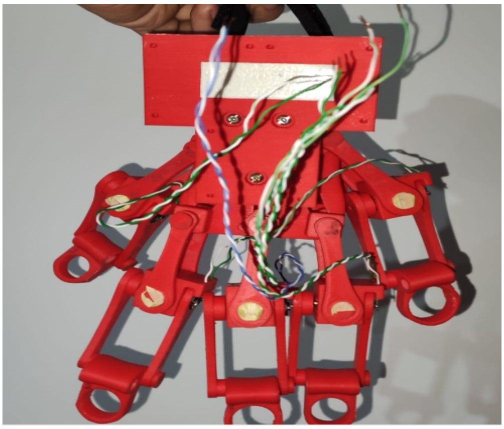


Figure 11

Menu displayed on the OLED screen

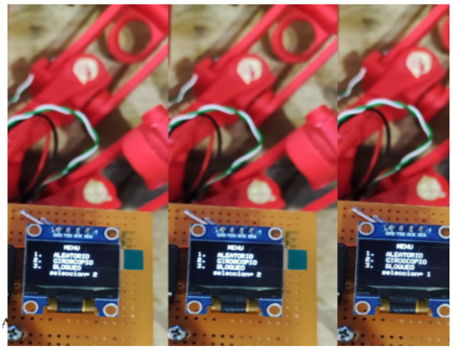


Figure 12

Inclination of the acceleration sensor displayed on the OLED screen

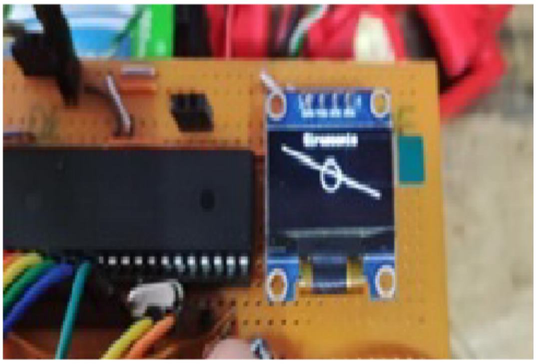


Figure 13

Closed position of the orthetics

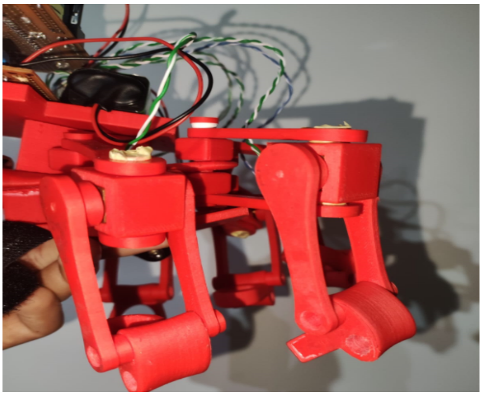


Figure 14

First test with common objects

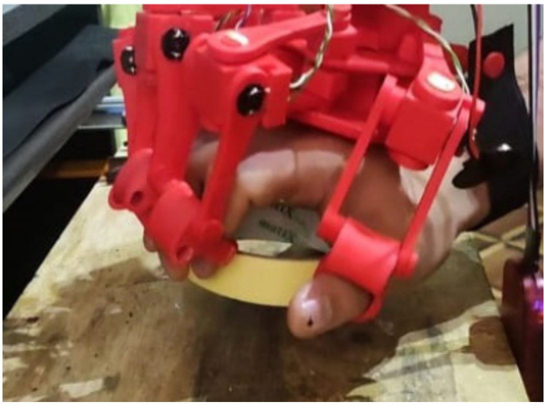
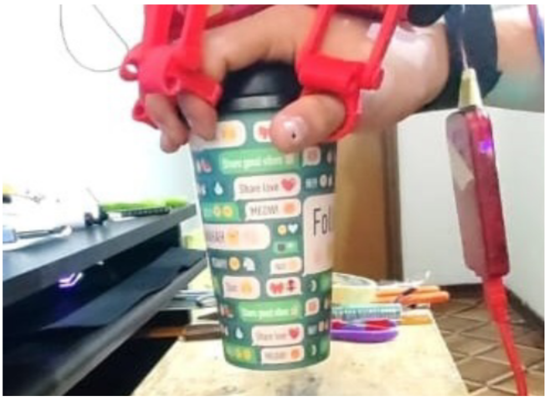


Figure 15

Second test with common objects



Conclusions

The new technologies of industry 4.0 like additive manufacturing is useful to design products adapted to the specific need of the customers. In this case, an orthotics was designed to support the movement of the fingers to grab objects. The cost of the prototype is less than 25 dollars, showing one of the advantages of 3D printing. Previously, similar systems were designed using sensors to detect the electrical signals generated by the muscles. In this work was demonstrated, that an acceleration sensor is also a reliable alternative, with fewer instrumentation problems. The designed system was useful to grab common objects, but in the beginning, some difficulties were shown. An orthotic is a device that helps to move some organs of the body; people without disabilities tend to move their fingers before the order of the microcontroller. With training, this problem is solved, and we expect this does not happen with people with disabilities.

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