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Design and Development of a 3D Scanner Using Photogrammetry for the Generative Design of Low-Cost Hand Prosthesis Using Rapid Prototyping Technologies

Jonathan Morales[a], Roberto Moya-Jiménez[a]
[a]Engineering Physical Sciences and Mathematics, Universidad Central del Ecuador, Ecuador

Abstract

This study focuses on design and development of a 3d scanner using photogrammetry as the principal technique to build hand prostheses. This work also applies generative design principles, manufacturing knowledge and industrial design concepts to optimize the development of the final product in comparison with existing typologies on the market. The construction of this 3d scanner prototype responds to the necessity of facilitate the creation process of hand prostheses. This device takes advantage of the use of cameras to capture information about the hand features. After that, the 3d scanner digitalizes the information, avoiding wasted time on digital modeling or traditional methods to elaborate hand prostheses. This 3d scanner prototype aims to optimize time, development processes and the cost of hand prostheses through the use of rapid prototyping (RP).

Keywords: *3D scanner, Computer-aided design, Generative Design, Industrial Design, Photogrammetry, Rapid Prototyping.*

Introduction

The RP technologies make it possible to optimize certain processes such as, molds manufacturing, part's digitalization, costs reduction and production times for prosthetic devices (Morillo, 2015). By 2020, the use of RP and reverse engineering have evolved in the last 30 years, beginning to be part of human's daily life. These technologies also generate new opportunities of improvement in different areas for example, medicine, prosthetic development, videogames, product development, art, agriculture, archeology, biology, robotics, among others (Abdel-Bary, 2011). The World Health Organization (2017) indicates that more than 1 billion people suffer some type of disability in the world. it means around 15% of the world's population. In addition, the OMS mentioned that disability is greater in low-income countries than in higher-income ones. So insufficient funding for their requirements and needs is one of the main obstacles faced by this vulnerable population (OMS, 2011). Ecuador, being a developing country, has implemented three workshops for

the production of prostheses. These workshops are equipped with RP technologies, nevertheless, they don't meet current demand that is around 226.000 people with disability in Ecuador (CONADIS, 2020). And it is estimated that around 15.000 people require a prosthesis (GK, 2019). The price of these devices in Ecuador ranges from USD 300 to USD 25.000. And the prostheses construction goes from three days to a week, it depends of what kind of prosthesis is required (El Comercio, 2010). Therefore, it is considered difficult and delinquent to obtain this object.

Technological advances have considerably improved in prostheses manufacture, by replacing traditional methods with faster and more efficient ones. The traditional method uses clay or plaster to create models that are matched to the dimensions and aesthetics of the patient's original upper or lower limb. This allows to the specialist to create a similar model, but it requires too much time and, in some cases, direct contact with the patient, which is not feasible (Silva, Muñoz, Garzón, Landínez, & Silva, 2011). However, CAD programs, Reverse Engineering (RE) and existing machines, such as the 3D scanner, have allowed a non-contact measurement of these extremities, which is why it has taken an important role in the construction of prostheses. Even so, one of the drawbacks of this technology is its cost and acquisition in the country.

This work focuses its study on the process of making prostheses, what has been found in the development of RE and RP projects. Linked to the making of prostheses, has been, for example, the application of ER and RP by Ferreira, Alves & Bartolo (2004) in the development of a hand prosthesis for a person who has lost all 5 fingers of his hand. In this study, good results are obtained using ER through the use of Computed Tomography (CT), a laser scanner for digitization and finally the implementation of RP through 3D printing. However, one of the risks presented by this study was the radiation presented by the CT scans. The sockets, components of the prosthesis to secure and fit it, have also been the focus of application of reverse engineering, in this case, for lower limb prostheses.

Ecuador has not been one of the countries with a broad development in regards to 3D scanners, nevertheless in the last five years, some projects have been developed in Universities. One of them is the low-cost, turntable 3D scanner developed by Casignia and Perugachi (2017). This prototype captures objects between 0.6 - 1.75 meters in height, in an estimated time of 3 minutes. However, this scanner is not very stable and it has a design not consistent to compete with the international market. The Project carried out by Vilatuña (2019), at the Central University of Ecuador is a 3D optical scanner that uses photogrammetry, a technique that allows them to capture images from different angles. The results obtained when they scanned a building were good, however, the device is not designed

in its entirety, since it adapts a cellphone to a drone and only certain parts are modeled by their own.

Once the state of the art existing has been analyzed, and the problems that affect a vulnerable population with scarce resources in Ecuador. The objective of this project is based on the design of a 3D scanner applying photogrammetry for its implementation in the design of hand prostheses, through generative design.

Conceptual Framework

2.1. 3D Scan

3D scanning is intended to collect data from a real-world object or environment and recreate it in the form of a 3D digital model. There are two ways to create a 3D modeling object, one of them is conceptualizing the design from scratch, with its measurements and shapes, while the other way is 3D scanning. When you scan an object, you get a point cloud, usually millions of points in a Cartesian coordinate system in the shape of the scanned object. 3D scanning devices can generally be divided into two main groups (Curless, 2000).

2.2. Photogrammetry

This method, which is going to be implemented in this project, belongs to the non-contact scanning methods. It is a technique used to measure objects through photographs. Around 80 to 120 images are taken, depending on the size of the object and the desired resolution, this technique allows the creation of three-dimensional models from photographs (Ávila, 2016).

2.3. Design Process

There are some design processes where the main idea is to develop a solution that satisfies a necessity or resolve a problem. This project follows the Proyectual Methodology of Bruno Munari. This methodology divides on 3 phases: exploratory, development and validation phase. The first step is an investigation, where the problem is defined and the requirements. Finally on this phase it is clear the users and what kind of users the project will have. After that, it starts the development phase, where the main objective is to work on the solution, and finally get a prototype. The last step is the validation phase, where the solution is tested in real situations with real users and scenarios. After that, the product can be commercialized.

Methodology

In the first phase, an investigation was carried out at the Specialized Comprehensive Rehabilitation Center (CRIE). A prosthesis manufacturing center belonging to the Government of Ecuador. Also, as mentioned above, the existing problem in the country was analyzed. There was an interview with CRIE workers, specially with Alexandra Almache (responsible of CRIE) and Miguel Guerrero, specialist on prosthesis elaboration. They told

us that the main method to build prosthesis on CRIE is the classic one, a contact method. Also, they said that even that they have a 3D scanner, they don't use it because it takes a lot of time to scan the patient. And sometimes the person moves which develop on errors on the 3d scan and they have to start again all the process. Another problem is the cost and the maintainance of those machines, they should be calibrated in periods of time and they need a specialist that haven't come in two years. Where did the issue arise: How does the lack of up-to-date printing and reverse engineering technologies affect access to hand prostheses? Concluding that the existing machinery in the country is imported. So, its cost is high, even affecting the cost and time of making prostheses.

Two types of users were defined, a direct and an indirect user, and their respective profiles are created to have a better approach to their way of acting. The direct user is the person who requires an analysis and is going to be subjected to a 3D scan, which in this case would be the scan of their hand. While the indirect user, becomes the specialist who uses the machine to collect patient data. Once each type of user had been defined and studied, the requirements of each one began to be defined, which are presented in Table 1. These requirements are made based on the interaction that this type of user would have with the product.

Table 1. User Requirements

User Types	Requirements
Direct (Person who requires a prosthesis)	Comfortable Stable Nice to look at Intuitive Accessible price Fast in the process
Indirect (Specialist)	Quick to use Easy to use Easy to repair Stable Precise Good lighting Light Nice to look at

Font: Own creation, 2020.

Once the requirements were defined, we proceeded with the creative design phase. Where various shapes and designs were analyzed based on techniques such as biomimicry or the bad idea technique. This design process goes hand in hand with the requirements specified above, to make a suitable product. The Fig. 1 shows the first design proposals.

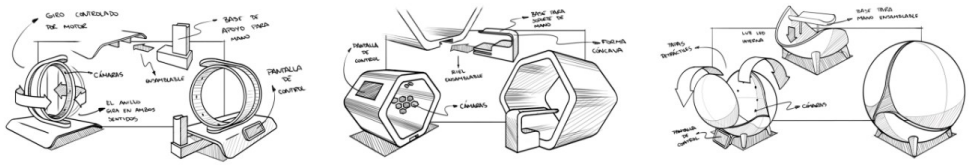

Fig. 1 First 3D scanner designs that use photogrammetry, LED light and a touch screen.
Font: Own creation, 2020

In the development of the first designs, the materials needed for the production process were recorded, as well as a technical sheet that allows understanding the specific operating characteristics of the product. Some materials that are used in this project are; PLA plastic, plastic sponge, cotton fabric and steel. In the other hand, some components are: Raspberry Pi 4, Pi Camera, Arduino Uno and a stepper motor. These characteristics were achieved thanks to constant validation with the different users in the design process. In addition, to performing a typological analysis with similar scanners on the market. Having analyzed all the previous characteristics and materials, we proceed to analyze the scanning process that should require the elaboration of hand prostheses. The development of prostheses with the aforementioned process will be carried out more efficiently and precisely, working with updated and not so expensive technologies. This is what the development of the 3D scanner seeks, which plays a fundamental role in the development of prostheses when acquire data from hand.

Results

For the development of the final product, the different parts were modeled in SolidWorks™. In Fig. 2 the final design is presented, which is based on the biomimetics of the scorpion, clearly referring to its morphology. While, in operation, it has a turning ring with cameras in different positions inside. This system controlled by Arduino and a stepper motor, allows the cameras to be positioned at different angles and rotate, surrounding the object to be scanned, which in this case is the patient's hand. In addition, the turning system optimizes the time to capture images of the hand. The interior light of led light strip, allows to control the lighting for a better quality in the image's capture. While the support serves as sustenance for the patient, so that he can rest his hand and keep it as fixed as possible.

Inside, it can be seen in figure 2, how the components are distributed. Where the Pi cameras are distributed in the ring and semi ring of the scanner.

Fig. 2 . EYES 3D scanner.
Font: Own creation, 2020

In this way, the design of the 3D scanner has been carried out considering the functional, economic and aesthetic requirements provided in the survey and interview carried out with the users raised in this work. By validating it with the different users, it was confirmed that it meets the functional, economic and aesthetic requirements of the product. By using a different scanning technique such as photogrammetry, you mostly reduce the cost of components, programming, and process that other types of scanners require.

Conclusion

The development of the 3D scanner was mainly focused on the elaboration of hand prostheses, for which its measurements, techniques, and components were designed for this objective. However, there are other applications that could use the scanner, such as the scan of feet, for the manufacture of prostheses, or scanning objects that do not exceed the scan area specified above. As Ecuador is a country that does not have its own industry that develops this type of devices necessary for various areas of production and research. This 3D scanner represents a great opportunity to start its development in the country, in addition to being below the economic price of similar scanners for these purposes.

The limitations found in this project were the number of cameras to be used and the rotation system used to optimize the process, because photogrammetry requires stability and precision to capture the images. So, this process can cause certain scanning difficulties in case there are strong movements that distort the image. The importance of this work lies in the lack of research and projects related to Industrial Design, Engineering, 3D scanner and prostheses in Ecuador. Since in the research carried out, there are projects that focus mainly on the engineering and techniques for the development of these devices. Fully complying with functional aspects, which in some cases are not desired because its design concept, because users do not see it as a product that can be used or related to it, as they do not see it attractive.

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