https://dx.doi.org/10.22161/ijaers.75.23 ISSN: 2349-6495(P) | 2456-1908(O)

Orthosis and Prosthesis Development for Large and Medium Animals using reverse Engineering and Additive Manufacturing Techniques

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***Abstract*— *Nowadays, the search for innovative techniques for Veterinary Medicine has been constant. Problems such as laminitis, that causes hoof pain in large and medium-sized animals, foot fractures that occur by trampling or even hoof breaking, can impair the productive or functional development of the animals, even leading to their sacrifice. The aim of this research is to use reverse engineering and additive manufacturing technologies to contribute to the development of orthoses for these animals that need help to be rehabilitated back to their environment, with a more adequate comfort. As a result, it was possible to digitize the lower limb of a calf that had an open fracture using reverse flight time engineering technology with the Kinect One equipment and thus digitize the paw to create a fixation and immobilization orthosis for the member. The orthosis was produced by additive manufacturing technology to immobilize the lower limb of the fractured calf. Thus, it is concluded that reverse engineering and additive manufacturing technologies can greatly assist in the area of veterinary medicine.*

***Keywords*— Fracture, additive manufacturing, orthoses, reverse engineering.**

I. INTRODUCTION

Nowadays, the search for solutions to assist in the treatment of fracture, laminitis, broken hooves often caused by trampling of other animals confined in the same environment, injuries, among other pathologies, has been increasing. Dairy-producing animals such as cows, when presenting problems such as paw fractures or chronic hoof problems, impair productive development and are usually euthanized. Given the various events like these, in the area of Veterinary Medicine, the search for solutions to propose an improvement to the animal or allow a more comfortable living condition is a great achievement. Currently, two innovative technologies have stood out and demonstrated an evolution in this area. The first of these is Reverse Engineering, that allows you to digitize objects at full scale and digitally transform them into a virtual three-dimensional biomodel without having to draw the model from scratch. The second technology is Additive Manufacturing, which allows you to transform the virtual biomodel created by Reverse Engineering and transform it into a real biomodel, printed by a 3D printer.

The aim of this research was to develop an orthosis with immobilization function of the lower limb of a medium size animal to replace the locking pins that are not showing improvements or satisfactory results. This orthosis was created by Reverse Engineering Flight Time and Additive Manufacturing techniques by a 3D printer using the fused deposition modeling (FDM) technique.

REVERSE ENGENEERING

According to Raja, (2007); Sokovic and Kopac, (2006), Reverse Engineering is a technology that allows you to reduce product production cycles, so you don't have to draw an object using a computer-aided design program. According to Raja (2007), Reverse Engineering goes through 3 phases: point digitization; stitch processing and application. Reverse Engineering can be applied in several areas such as Medicine, Architecture, Engineering, Design, among others. Santos (2017), comments that in the area of orthopedics, it is possible to create custom orthoses for each type of patient, so that the immobilizers fit the limbs more properly, avoiding problems such as discomfort and poor positioning in immobilization. The Reverse Engineering applied in medicine as anatomy study, prosthesis creation, implants, among others, has shown much benefit. For Vinesh and Kiran (2008), Noncontact Reverse Engineering is classified into two techniques, Reflective and Transmissive. An example of a reflective technique used is the Time Of Flight (TOF) scanning method. This technique has the principle of measuring the amount of time it takes a light pulse to travel to the object and make a return [Bellian et al., 2005; Dion; Bertone, 2004; Sekimoto et al., 2003].

ADDICTIVE MANUFACTURING

For Canciglieri et. Al (2015), Additive Manufacturing has its manufacturing processes based on liquid, solid and powder. According to Volpato (2017), nowadays there are more than 20 types of Additive Manufacturing systems that manufacture objects by adding layers. Objects are made of simple or complex freeform geometries, which in turn eliminate mold tools. According to Ahrens (2007), this technique allows the manufacture of molds, parts, objects using a virtual three-dimensional model, and can have its simple or complex geometries. One of the techniques that stands out for its easy access and cost effectiveness is fusion and deposition modeling. According to Volpato (2017), the principle of material extrusion technologies occurs through the process of depositing the material in the form of small diameter filament, which is obtained by the principle of extrusion in a calibrated nozzle. Basically the head is mounted on a system with controlled movements in the X and Y plane. This system usually operates on a construction platform made up of a mechanism that moves upwards towards the Z axis. At the end of every fusion and deposition layer, the process of building the next layer is repeated again until the object is ready, it means that it is built layer by layer until the part is constructed.

ORTHOSES

The purpose of the orthoses is to help and improve the conditions of patients who require support or have dysfunction of the body segments. They can be internal as: stents, valves, plates, etc.; or external as: glasses, plaster casts, splints; walking sticks. among others. According to Carvalho (2006), the orthoses can correct the posture and allow movements to a certain extent, being able to totally or partially immobilize the movements.

II. MATERIAL AND METHODS

For the development of this project all the computational processes developed were made in a Dell Brand Inspiron 15R 7520 Special Edition Notebook. To scan and capture the lower limb points of the animal we used the equipment Kinect One + Computer Adapter developed by the company Microsoft. The point capture process was made through Reverse Engineering technology using the Flight Time technique, as shown in Fig. 1.

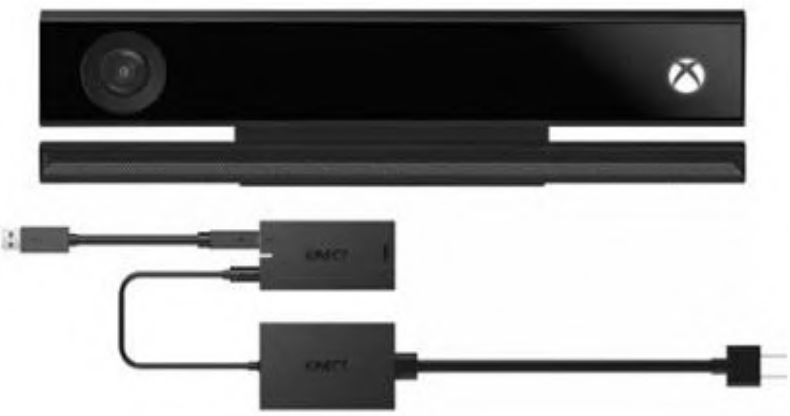

Fig. 1 – Kinect One device and computer connection adapter.

According to Raja's methodology (2007), Reverse Engineering captures points, performs their processing and applies the meshes. For this methodology, the free version of the Kscan3D program was used, as shown in Fig. 2.

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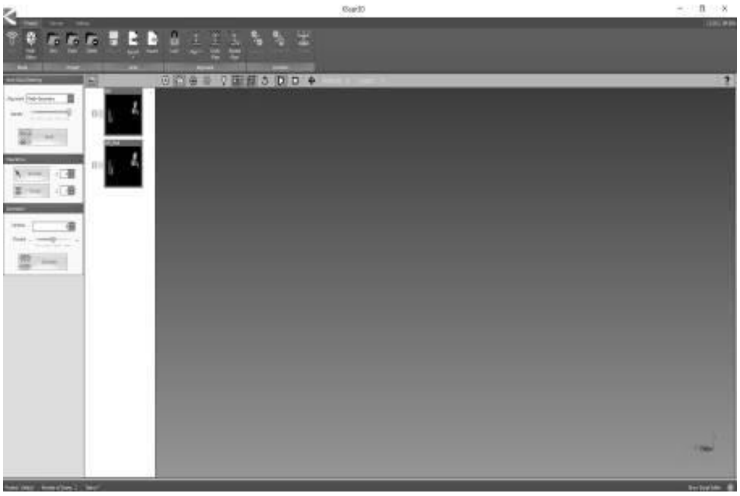

Fig. 2 –Kscan 3D program used to capture, process and apply points by Reverse Engineering technique.

For adjustments, three-dimensional design creation, cleaning of unwanted artifacts and modeling, the program used was *Meshmixer* version 3.5.474. This software was developed by the company *Autodesk* and is also a free program. Fig. 3 illustrates the program screen interface.

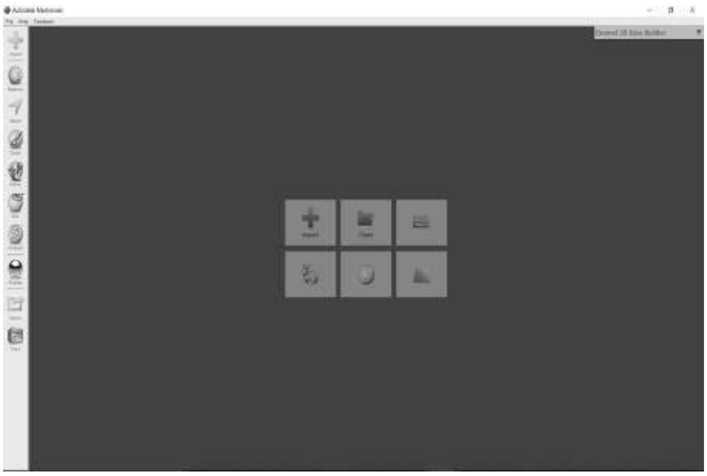

Fig. 3 – Autodesk Meshmixer program used for modeling.

The 3D *ZONESTAR DIY 802QR2* printer was used to make the immobilizer. This printer has been assembled for the immobilizer making through a mounting kit that has two extrusion nozzles at XZ-axis and the heated working table at Y-axis, according to Fig. 4.

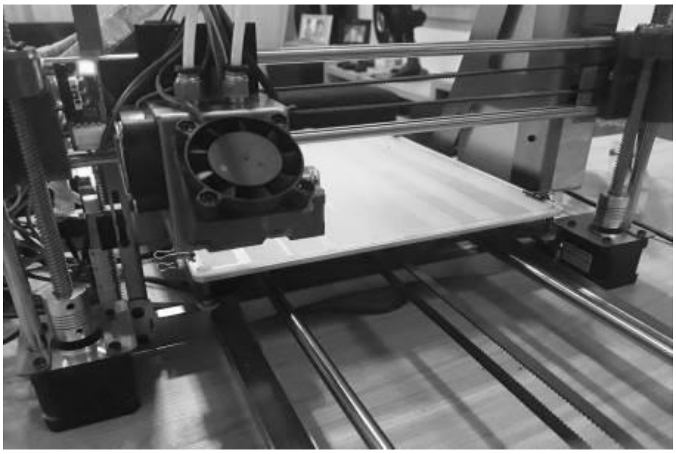

Fig. 4 – 3D Zonestar Diy 802QR2 printer with the technique of Deposition Fusion Modeling.

The printer comes with a free program called *Repetier-Host*. This program is responsible for slicing the three-dimensional design developed by Reverse Engineering technology into layers and converting it to the 3D printer using the *gcode* language. Fig. 5 illustrates the interface of the *Repetier-Host* version 2.1.3 program.

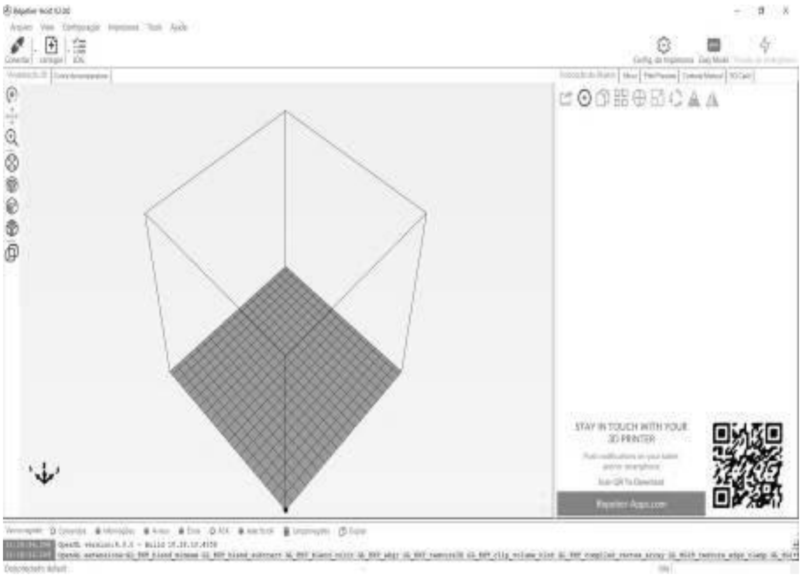

Fig. 5 – Repetier-Host program used to slice three-dimensional objects for 3D printing.

For the printing of the orthosis we used on average 250 g of a 1.75 mm diameter filament in Metallic Blue color, 3DFila brand. The composition of the material is Poly (Glycol Ethylene Terephthalate) - PETG, as shown in Fig. 6.

Fig. 6 – PETG Filament Roll used for the manufacture of immobilizing orthoses.

As an initial procedure, the fractured calf's leg had the treatment, cleaning and care procedures before starting the stitches scan. For the following procedure, it was necessary to define an appropriate positioning for the Reverse Engineering technique to be started. After the care performed, the professionals stabilized the paw in the correct position for the beginning of the digitalization. Fig. 7 shows the position of the paw to be digitized.

Fig. 7 –Lower limb being prepared and positioned for digitization of points by Reverse Engineering technique.

As scanning began, the Kinect One device scanned the lower limb points through Reverse Engineering flight time and sent it to the Kscan 3D Program to process and triangulate each point thus forming a mesh as a surface and turning it into a three-dimensional biomodel, according to Fig. 8.

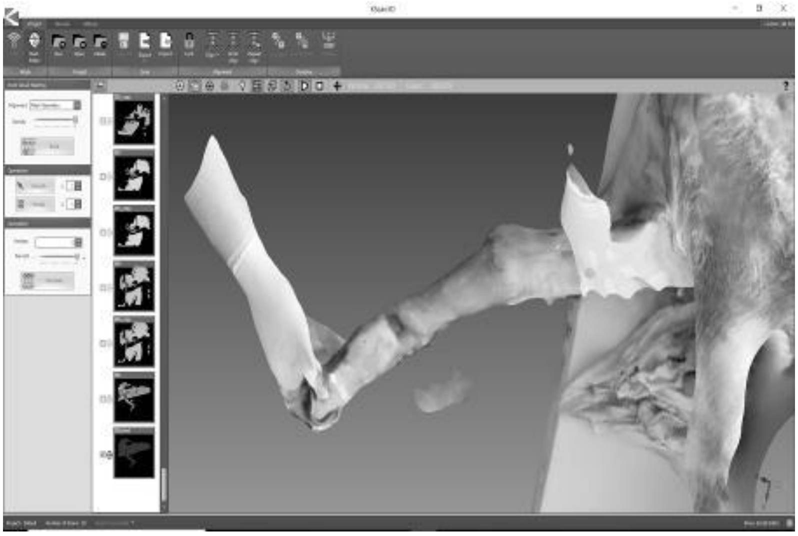

Fig. 8 – Creation of the three-dimensional biomodel through Reverse Engineering.

After digitization, the virtual biomodel was exported to the Meshmixer program, which allowed the modeling of the orthosis using the biomodel as a base reference. The program allowed the modeler to delete unwanted artifacts that were scanned along with the lower limb and also corrected defects or parts that were not captured. Fig. 9 illustrates the preparation of the orthosis volume and the division into two parts to allow the calf's foot to engage. An open hexagon design had also been developed to allow ventilation and give greater mechanical strength to the orthosis.

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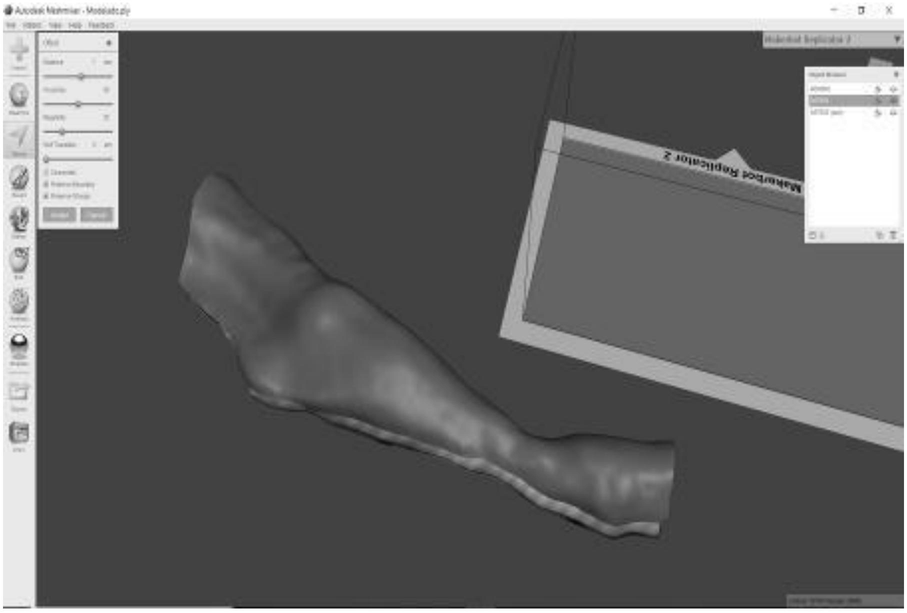

Fig. 9 – Modeling and adjustments in the virtual three-dimensional biomodel using the Meshmixer program.

Finally, with the orthosis modeling ready, the file was exported to the Repetier-Host program to perform the virtual biomodel slicing, thus producing, by the Additive Manufacturing technique, a physical biomodel and an orthosis to analyze and check possible scale failures and dimensions. Fig. 10 illustrates a biomodel with the fracture position markings and a small orthosis for fitting and position matching.

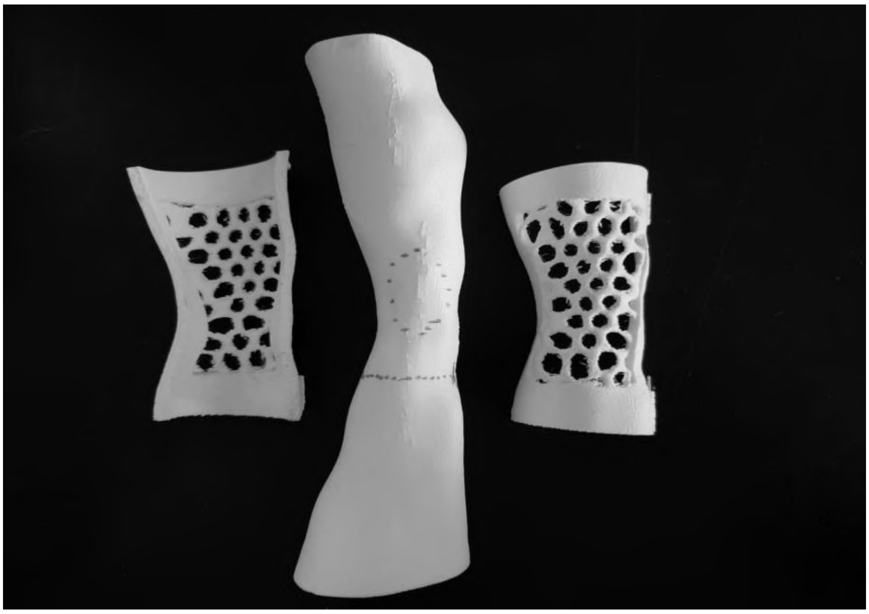

Fig. 10 – 3D printing of a Biomodel and part of the orthosis for conferences and analysis.

It is possible to analyze in Fig. 11 that the biomodel was the appropriate measurements and acceptable with the test orthosis. Both fit and allowed to check the orthosis in the animal to validate the orthosis and thus print the definitive for use.

Fig. 11 – Result of biomodel fitting and test orthosis for analysis.

After approval of all studies and analyzes between the Biomodel, the test orthosis and the animal's limb were made for orthosis for use on the calf's fractured paw. Fig. 12 shows the 3D printing of the ZONESTAR printer producing the immobilizer that was used on the animal.

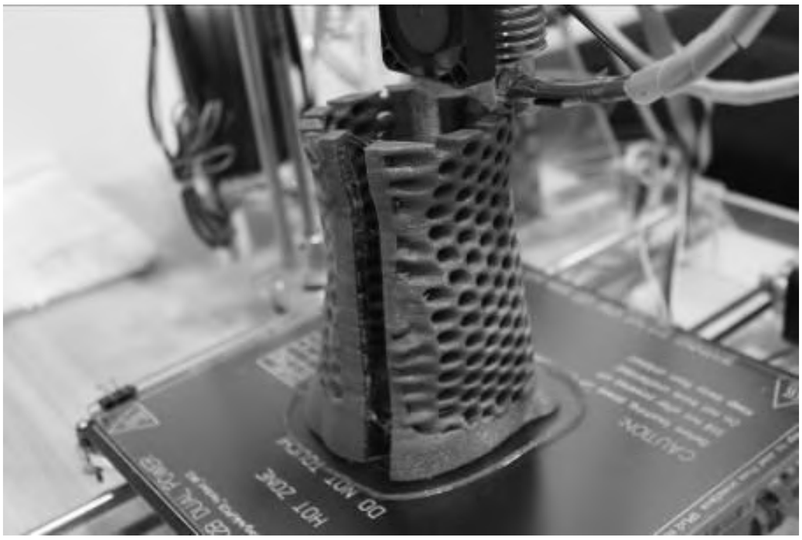

Fig. 12 – 3D printing of an Orthosis by the technique of Additive Manufacturing.

III. RESULTS AND DISCUSSIONS

As a result, it was possible to digitize the fractured calf member and convert it to a virtual three-dimensional model for reference in creating the custom orthosis. The result obtained by the Additive Manufacturing technique was approved by the team because the immobilizer demonstrates sufficient mechanical resistance not to break and also by the correct fit of the orthosis with the fracture paw, as shown in Fig.13.

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Fig. 13 – Analysis of the orthosis printed by the 3D printer with the fractured calf's foot.

After the orthosis test with the paw and the analysis of the dimensions of the socket, the animal underwent a last surgical procedure to remove the pins that were not having an immobilization effect. Finally, the immobilizer was used to fix the lower limb for not allow the movement of the bone that suffered the fracture in order to calcify in the correct position. Fig. 14 shows the animal in a normal posture walking through the grass.

Fig. 14 – Animal with immobilization orthosis walking through the grass.

The device has demonstrated satisfactory results due to the recovery of the animal and the form that it has presented in its movement, touching the paw more firmly in the soil and allowing its movement.

IV. CONCLUSIONS

Through Reverse Engineering technology, it was possible to digitize the lower limb by the reflective technique Flight Time to use as a virtual biomodel in orthosis modeling. After digitization, the designed orthosis was printed without problem by Additive Manufacturing technology. According to the results obtained by 3D printing, the pins implanted in the fractured limb of the animal that did not obtain satisfactory immobilization results for the bone to be regenerated were removed, so the orthosis applied to the calf's paw was able to immobilize the limb with a satisfactory result. The orthoses locked the fractured parts as well as allowed the animal to have its movement regularized and be able to walk again. This project opened the door for new research that may use Reverse Engineering and Additive Manufacturing to assist in the area of Veterinary Medicine that is still little explored. It is possible to create Prostheses for bovine and equine hooves with laminitis problem, jabutis hooves, bird nipples and many other applications.

ACKNOWLEDGMENT

We thank Paulista State University "Júlio de Mesquita Filho" - UNESP, the University of Rio Verde - UniRV and CAPES for their support and encouragement to this project.

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