INTERNATIONAL CAE CONFERENCE

November 30 – December 4, 2020

3D-PRINTED ANKLE-FOOT ORTHOSIS: A DESIGN METHOD

Alberto DAL MASO, Francesca COSMI

University of Trieste, 3D Fab Lab, Department of Engineering and Architecture, Via A. Valerio, 1, Trieste, Italy, E-mail: cosmi@units.it

Objectives

Additive manufacturing technology offers several advantages where large-scale customizing is required. This is particularly common for certain medical applications such as orthopedics, in which the efficiency of a treatment is strongly connected with each individual patient's body shape [1].
An Ankle-Foot Orthosis (AFO) is an external medical device which helps a patient hold his/her ankle in the right position when the muscular/skeletal system is not sufficient (Fig. 1). The more the shape of the orthosis adapts to the patient's body, the more comfortable and efficient the treatment will be.
The aim of this work is to find a method to design a fully-customized Ankle-Foot Orthosis, taking advantage of 3D-scanning and 3D-printing techniques. This is done with the help of a voluntary patient, a 21-year-old woman who has difficulties in walking after wearing a plaster cast for three weeks; an AFO would aid her post-traumatic rehabilitation.

Fig. 1. Examples of standard Ankle Foot Orthoses.

Methods

The adopted design process can be divided into the following steps:

1. **Foot scan with photogrammetry.** To obtain the exact geometry of the ankle, the photogrammetry technique is chosen [2]. 150 photos of the patient's foot are taken from different angles and loaded into the Agisoft PhotoScan Pro™ software, which elaborates a mesh of the ankle in *.stl* format.

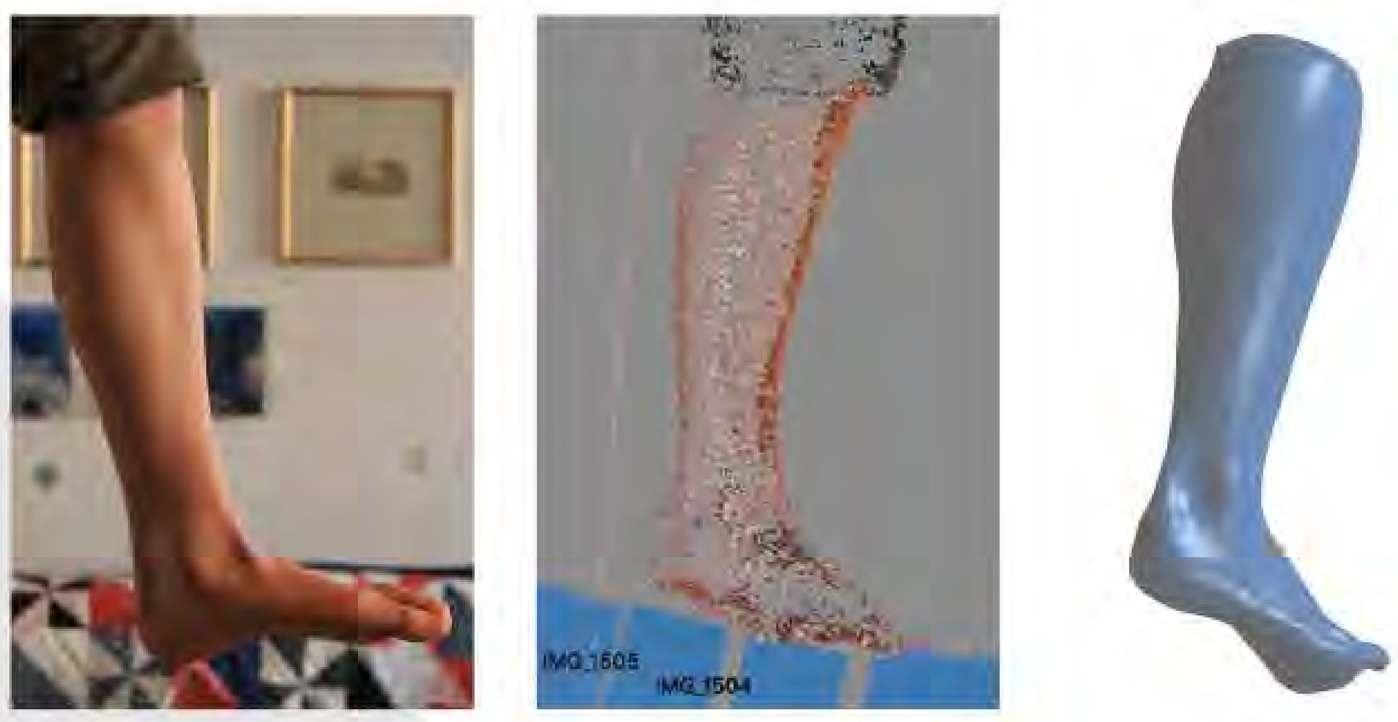

Fig. 2. From images (left) to point cloud (center) to 3D mesh (right).

2. **Data import in the CAD modeler.** In order to design the AFO around the scanned foot, it is necessary to import the mesh into a CAD modeler. SolidWorks™ Premium Edition 2014 CAD software is chosen for this purpose. Direct editing of large *.stl* (or equivalent mesh files) in SolidWorks™ is very complex, but thanks to the *Curve Wizard* and the *loft* features, it is possible to manually retrace the shape of the scanned foot, thus obtaining a fully-functional *solid body*.

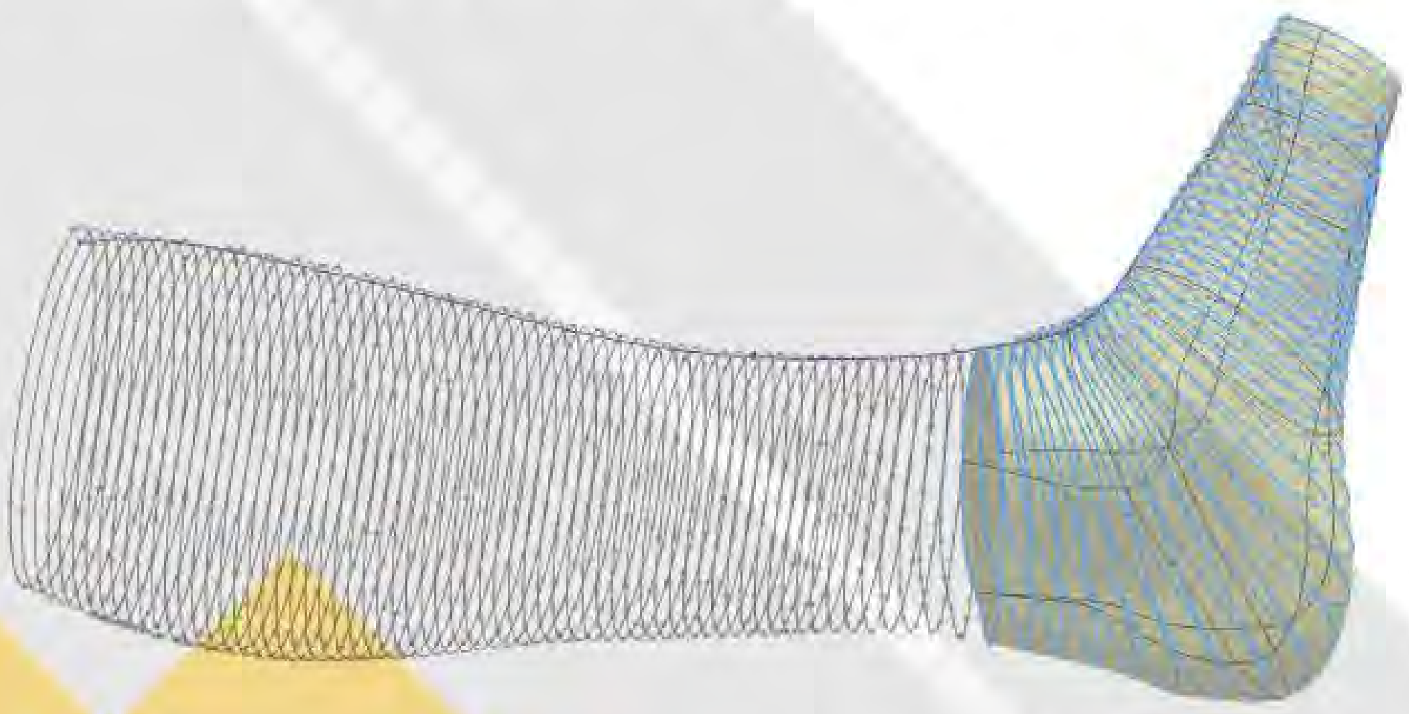

Fig. 3. *Loft* feature is used to obtain a *solid body* from the 3D mesh.

3. **AFO modelling.** The *Boundary Boss-Base* feature in SolidWorks™ allows the creation of a well-parameterized outer surface geometry. By performing an *extruded cut* with the desired shape, we obtain a first-draft model of the device.

4. **FEM optimization and 3D print.** Before 3D-printing the modelled AFO, it is necessary to adjust its thickness and outer shape in order to meet the structural requirements. Given the medical function of this orthosis, a verification of the device under the loads and constraints described in Table 1 is necessary. Fused Deposition Modelling (FDM) has been chosen for the print. The material used is PLA, whose mechanical characteristics after 3D printing have already been tested [3]. FEM structural analyses are performed in SolidWorks™ *Simulation*. After each analysis, the profile is adjusted to guarantee functionality in any problematic area. Once the orthosis is modelled and optimized, it can be 3D-printed.

Table 1. Loads and constraints applied to the AFO.

	Load	Constraint
Type and magnitude	Vertical force 50 N	Fixed geometry
Application area	Foot instep	Calf

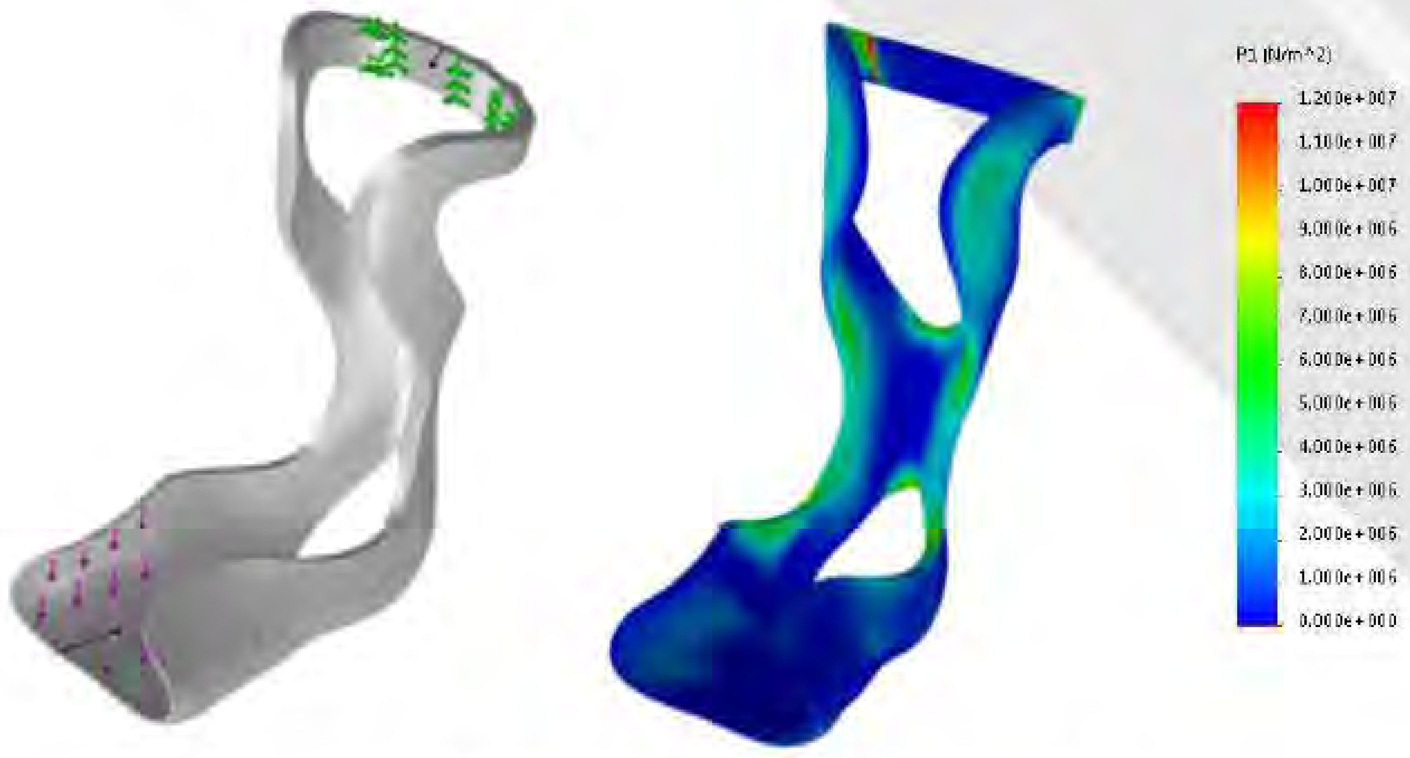

Fig. 4. Simulation setup (left) and results (right).

Results

The photogrammetric acquisition gives a very detailed output: thorough inspections show an excellent correspondence between the original mesh and the lofted body. The 3D-printed AFO has been tested on the patient and proved extremely comfortable and adherent.

Fig. 5. 3D-printed AFO (left) and test on patient's foot (right).

Remarks and conclusions

The advantages of a custom-designed 3D-printed orthosis on a standard-type or hand-crafted device can be summarized as:

- patient's comfort, therefore medical treatment efficiency [4];
- ease of automation for the manufacturing process, therefore lower costs;
- possibility of removing material in the less-stressed areas of the device, therefore weight reduction and breathability enhancement.

Future developments may include topological optimization of the AFO and studies on several patients. This procedure can be easily adapted to different kinds of orthoses, for example for the knee or the wrist.

References

1. Yong Ho Cha et al. *Ankle-Foot Orthosis Made by 3D Printing Technique and Automated Design Software*. J Applied Bionics and Biomechanics, July 30, 2017, Volume 2017 (2017), Article ID 9610468.
2. Mitchell H.L., Newton I. *Medical photogrammetric measurement: overview and prospects.* ISPRS Journal of Photogrammetry and Remote Sensing. Elsevier, Volume 56, Issues 5-6, 2002, pp. 286-294.
3. Dal Maso A., Cosmi F. *Mechanical characterization of 3D-printed objects.* Materials Today: Proceedings, 34th Danubia Adria Symposium, Trieste; Elsevier, 2017.
4. Mancini A., Morlacchi C. *Clinica Ortopedica*. Piccin, 2005, pp. 259-265.