Title:
A CAD Tool to Design Bespoke Insoles for Severe Orthopedic Treatments

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Introduction:
During the last decades, the footwear sector was characterized by a strong computerization of the overall product development process, from the foot diagnosis to the shoe manufacturing. In such trend three main phases can be recognized:

- a foot diagnosis stage, in which dedicated 3D scanners are more and more used to achieve the virtual geometry of the foot;
- a footwear design stage, where the footwear and related accessories (last, upper, insole and outsole) are designed by customized CAD systems;
- a production stage, where CNC machines are employed to manufacture the shoe components.

The scientific literature of the last years presents frameworks of CAD [1] and CAM systems for customized insole [2]. The target was set on the insole modeling, considering the foot plantar pressure and foot geometry. However, the 3D shape of a bespoke shoe last is neglected. More advanced design systems are proposed in [3] and [4]. In these cases the foot pathologies addressed by the outcoming insoles are limited. For instance, there is no possibility to model insoles for severe deformities such as amputated feet or clubfeet. In conclusion, the insoles play a key role for the correct gait of the patient and they have to be designed starting from a custom made shoe last.

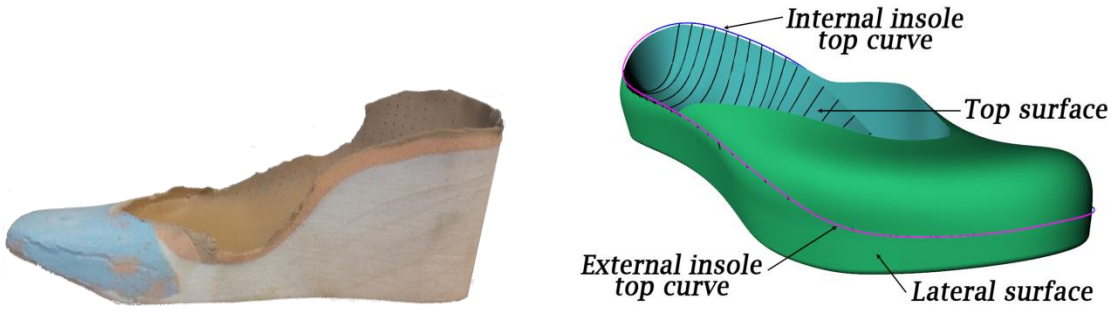

Fig. 1: A handmade insole for amputated feet (left) and the CAD structure of the models obtained from the proposed approach.

Main idea:
The paper presents a method and the related CAD tool to design bespoke footwear orthotics for patient with serious pathologies. The method accepts as input the 3D geometry of the foot as a triangulated mesh and the 3D geometry of the customized shoe last as NURBS surfaces. The foot is digitized using an innovative 3D scanner which allows the foot to be supported while scanned. The foot is fully supported by a shaped surface in order to position the foot with the same crimping profile as it would be assumed in the final custom made shoe. The shoe last is designed starting from this shape by using a dedicated design software tool, which address the foot pathologies presented above.
The outcoming insole volume is composed by three surfaces:

- the top surface in contact with the foot;
- the bottom surface which is in contact with the outsole and matches the last bottom surface;

- the lateral surface delimits the insole volume in order to be contained inside the last.

At first, the shoe last and the foot are superimposed. Then the foot plantar surface is sectioned with parallel vertical planes. This first group of curve network will be used to build the top surface of the insole. According to the type of insole to design (full plantar insole, ¾ insole, insole for an amputated foot), the section planes are drawn from the heel to the toes or from the heel to the metatarsal. Two curves are then manually input by the user. In this way, the designer has the possibility to choose the height of the lateral surface of the insole. The aim is to regulate how strong the insole has to support and hold the foot. During this step, the designer specifies the insole arch height as well. The two lateral curves are then blended together and projected to the last upper surface. The obtained result is a curve which represents the boundary of the insole top surface.
The curves are connected in order to create the top surface of the insole, as a network surface. This result is used to split the lateral surface of the shoe last and obtain the lateral surface of the insole. The obtained surfaces of the insole are merged with the bottom surface of the shoe last creating the insole volume. Finally, the volume is converted in a triangulated waterproof mesh in order to be correctly machined with a milling machine.
The method has been implemented as semi-automated commands in a plug-in of Rhinoceros (By McNeel), a general purpose CAD system, also diffused in the footwear sector. The developed software, called InsoleDesigner, has been fully integrated with another plug-in, called LastDesigner [5], in order to support the overall design process of the orthopedic shoe.

Conclusion:

The tool for the insole design has been tested within an orthopedic footwear company aiming at changing the traditional manual manufacturing process with a more innovative one, based on the use of 3D foot digitizers, design software tools and milling machines for the shoe components manufacturing. The challenge of the changeover was to implement a development process of the insole faster and more reliable than the traditional approach. However, the software tools were required to be flexible and easy to use by the technicians already in the company.
From the preliminary experimentation of the system, the average time saving to produce a couple of unequal insoles for a patient with an amputated foot is around 50% (from 55 to 28 minutes). Indeed, the system provides repeatability and attractiveness for unexperienced young orthotic makers.

References:

[1] Li, F.; Li, Y.; Wang, M.; Wu, J.: Research on Computer Aided Design of Customized Insoles, Computer-Aided Industrial Design & Conceptual Design, 2009, 1430-1433.
[2] Huang, C.-N.; Lee, M.-Y.; Chang, C.-C.: Computer-Aided Design and Manufacturing of Customized Insoles, IEEE Computer Graphics and Applications, 2011, 74-79. http://dx.doi.org/10.1109/MCG.2011.19
[3] Actis, R. L.; Ventura, L. B.; Lott, D. J.; Smith, K. E.; Commean, P. K.; Hastings, M. K.; Mueller, M. J.: Multi-plug insole design to reduce peak plantar pressure on the diabetic foot during walking, Medical & Biological Engineering & Computing, 46, 2008, 363–371. http://dx.doi.org/10.1007/s11517-008-0311-5
[4] Lochner, S.J.; Huissoon, J.P.; Bedi, S.S.: Parametric Design of Custom Foot Orthotic Model, Computer-Aided Design and Applications, 9(1), 2012, 1–11. http://dx.doi.org/10.3722/cadaps.2012.1-11
[5] Bernabéu, J.A. et al.: CAD tools for designing shoe lasts for people with diabetes, Computer-Aided Design, 45(6), 2013, 977–990. http://dx.doi.org/10.1016/j.cad.2012.12.005