THERAPEUTIC FOOTWEAR VIRTUAL PROTOTYPING BASED ON GAIT ANALYSIS DATA

Aura Mihai, Catalin Dumitras, Mariana Pastina, Catalina Marta Harnagea
“Gheorghe Asachi” Technical University of Iasi, Romania
amihai@tex.tuiasi.ro

ABSTRACT

The paper presents partially obtained results of the SIMSANO project, within the framework of Romanian Second National Plan for Development and Research. The project aims to scientifically produce therapeutic footwear for those with locomotors disabilities inflicted by diabetes and arthritis. The project has an interdisciplinary research approach (Engineering, Material Science, Information Technology, Bioengineering, Medicine and Chemistry), and its immediate practical results can be transferred towards orthopaedic footwear manufacturers.

Key words: virtual prototyping, footwear, biomechanics, finite element analysis

1. INTRODUCTION

The foot comfort can be reached if the footwear, by means of its shape and components, is optimized from biomechanical point of view, so that it can simultaneously act as a support that takes over the body weight without deforming the foot and also it can reduce the plantar pressures in the risk areas. Plantar pressure measurements and gait analysis data offer a range of useful criteria for designing prototypes as lasts, orthopaedic components or entire therapeutic footwear. Several studies have been recently reported in this area of research [1, 2]. The 3D foot scanning procedures, the new pressure measurements with computer techniques, as well as the CAD interactive software solutions which have been developed lately, allow for the reassessment of designing the footwear or footwear components, and also provide useful data for predicting the behaviour of the products under various stresses and conditions while walking.

2. METHOD AND RESULTS

The research undertaken within this paper aims to study a complete solution for virtual prototyping (VP) of therapeutic footwear by combining the biomechanical data, which characterize the specific gait pattern for a patient affected by arthritis, with data obtained through 3D foot scanning and 3D interactive modelling of the new last. Virtual prototypes for lasts have been obtained and analysed. The method of Finite Element Analysis (FEA) is used for simulating the behaviour of therapeutic footwear during walking.

2.1. Data obtained from gait analysis and plantar pressures measurements

There were registered plantar pressures as part of barefoot statics and dynamics for a female subject aged 55, having visibly affected foot by arthritis. For measuring the plantar pressures, the Footscan 2D Gait Scientific System of RSScan Company was used.

The high values for peak pressures of the middle foot and metatarsal areas are determined by the arthritic foot structure, while both the foot structure and its function during walking determine increases of the pressure under heel and hallux (fig.1). The force/ time graphics
indicate values for forces developed during walking under different areas of the foot (fig.2). Also, the gait analysis offers information about walking pattern of the subject, about gait parameters, walking phases and their timing (fig.3). These values have been registered and they have been used in a later stage for simulating the behaviour of the proposed footwear.

**Figure 1.** Pressure distribution on statics. The red areas indicate high values of plantar pressures.

**Figure 2.** Force/time curves for different foot areas

**Figure 3.** Walking phases and their timing (Initial Foot Contact, Initial Metatarsal Contact, Initial Forefoot Flat Contact, Heel off, and Last Foot Contact)

### 2.2. Data obtained from 3D foot scanning

At this stage, the shape and anthropometric parameters for both left and right foot of the same female subject have been collected by 3D scanning techniques using the INFOOT USB Standard Model IFU-S-01, with eight progressive cameras of 1/4’ CCD and four lasers of 1M class. The data obtained from 3D scanner have been exported under .stl format so that it could be recognized in the CAD interactive software (fig. 4).

**Figure 4.** The scanned arthritic foot
2.3. Interactive 3D modelling of the new last

An initial last from database has been chosen. By using the Compare module of OrthoLast-Delcam Crispin software, the 3D shapes for both foot and initial last have been imported and alienated in the same working plan. The procedure of interconnecting the two shapes continues as far as the most points of tangency between them have been found. The initial last is modified according to the shape of the foot by following some specific measurements: length, toe girth, instep girth, toe allowance, toe spring, heel height. A personalized last is obtained, which will allow for accommodation of the structural modification of the patient with arthritic foot (fig. 5).

![Interactive 3D modelling of the last](image)

Figure 5. Interactive 3D modelling of the last

2.4. Predicting the behaviour of the virtual prototype during walking - Finite Element Analysis

The Finite Element Analysis-FEA offers multiple simulation solutions in different application areas. Several virtual three-dimensional models of the foot have been elaborated through 3D reconstruction and the finite element non-linear analysis, starting from the images obtained by scanning with the help of a tomography computer [3, 4]. Also, the finite element analysis (FEA) can be a very strong element in the studies of biomechanics of the foot, as well as for the improvement of the last form and of the footwear product. The complex behaviour of the footwear, in case of mechanic solicitations that appear during the walking, as well as the need to obtain certain results to be experimentally validated, involves an adequate modelling of its three-dimensional form and of the structures of materials that form it.

The analysis hereby has been made in order to simulate, for above mentioned patient with arthritic foot, a situation which appears during the walking act, when shifting one’s weight from one leg to the other and the entire weight of the body is distributed on one leg only, considering that this is the most unfavourable situation for the footwear.
The area of the Von Mises distortion (fig. 6) leads to the forecast of the values of 0.64-1.29 mm in the area of repeated bending and of the instep in case of the upper sides of the footwear and on the sole of 3.88 mm in the area of the end of the 5th metatarsal bone and in the repeated bending area, towards the external part of the sole. Values of distortion, up to 4.52 mm, are obtained in the extreme posterior point of the footwear, where the rigid stiffener is positioned on the upper sides, respectively in the extreme posterior point of the heel. The obtained values correspond to the situations noticed in practice, when we can see that, after a certain period of wearing a footwear product, the wearing level of the material is more pronounced in these regions.

Figure 6. The area of the Von Mises resultant distortion

4. CONCLUSIONS

- A complete solution for Virtual Prototyping (VP) of a last for therapeutic footwear is presented. Following steps are proposed: obtaining data from gait analysis and plantar pressures measurements, obtaining data from 3D foot scanning, interactive 3D modelling of the new last
- Finite Element Analysis (FEA) is used to simulate the behaviour of the new prototypes during waking act.

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REFERENCES