ASSISTED SIMULATION STATIC AND DYNAMIC BEHAVIOR STANDPOINT FOR SOME ACTIVE ITEMS COMPOSING ADAPTIVE ORTHOPEDIC INSOLES

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Abstract: *The paper presents a flexible and efficient method for plantar insoles components behavior analysis, in terms of their mechanical resistance. The research proposed to develop and to test an application as a software interface for the assisted simulating of the orthotic elements, as core items, that could be manufactured from different materials (plastics, high density or silicone). It is envisaged, first of all, the main orthotic components as core items, composing different types of plantar orthotic insoles with corrective role in case of any foot deformities. The main issue of the proposed and developed software interface is to make more efficient and objective the results in terms of the orthotic components behavior in case of different static and dynamic loads, simulating the most encountered situations (standing, walking, running, dancing, driving, jumping etc.).*
Keywords: *plantar, component, sole, programming, deformation*

1. PLANTAR SUPPORTERS FOR STABILITY AND LOCOMOTION

Body stability and safety during locomotion could be considered as crucial aspects related to life style, daily activities and working yield [1], [2]. If upper and lower limb prostheses in the event of an accident are really indispensable in many situations, leg and foot orthoses play also a very important role, especially in stages of rehabilitation therapy. One example could be envisaged by post operatory rehabilitation locomotion standpoint. [2], [3]. Not just a few cases were those in which different foot diseases or deformities have led to stability and locomotion problems, making people unable to carry on safely and in good conditions many of their daily activities. Also are known many situations in which, due to this causes persons otherwise fit and healthy had to be exempt from military service or certain sports activities that would have been beneficial to their health. This is why it has proven to be so important to solve such problems by adopting the solution to use prostheses or orthotics (especially in the lower limbs) with a correctional role and recovery of the locomotor function and body equilibrium and balance improvement [4], [5], [6], [7].
Customizing on cases of foot deformities (Hallux, Valgus, flat foot, hollow foot etc.), the solution to adapt foot insoles as plantar orthoses, inside the shoes proved to be not very difficult and very efficient one. For this reason, in the present, in this field, a lot of solutions have been developed, such as the use of special equipments. One of these consists in using integrated systems that allow feet fingerprinting, CAD model transmission and special insole prototyping, considering both the feet conformation and also the need for its correction [8]. Moreover, in the last years, there have been developed modern technologies for foot insoles creation, having inserted sensorial elements for locomotion parameters continuous monitoring during sportive activities. There are even solutions through which such of feet insoles could contain also acting items for locomotion stimulation and improvement [9], [10], [11], [12].
Based on these considerations, one of the great challenges of our research was to find a low cost and flexible solution to prototype adaptive feet insoles having progressive correction role in case of different feet deformities [13], [14]. In the paper there is described an important aspect related to our research, namely to simulate the behavior of any prototyping components, different materials (mechanical standpoint) in order to prototype such of feet insoles.

2. IMPORTANCE OF FOOT INSOLES

The importance of the foot insoles is well known, taking into account that they not only improve shoe comfort, but also could have a medical or orthopedic role [11], [12]. Thus means to improve the body posture, equilibrium, balance or even to correct some foot deformities (flat foot, pronounced arch etc.) that could cause

injuries at the level of the knee or hip joints. Comfort standpoint, corrective orthopedic foot insoles could include a core (manufactured from hard materials), wrapped in several layers from soft and antiperspirant materials, conformable to the foot sole surface [8], [15], [16].
Starting from these considerations, as post-doctoral research stage, it was envisaged to develop some flexible and efficient prototypes of progressive foot insoles, meant to correct step by step deformities like flat foot of pronounced arch, due to wearing shoes containing such orthotic insoles. For this reason several models were developed, each one containing a core (containing removable items both hard and soft materials), having correction role and simple antiperspirant insoles, soft materials. For the core, there were used ABS plastics and rubber or silicone items, as main materials, each of which can be 3D printed (ABS) or handmade (rubber, silicone). The reason for which such of materials were envisaged to be used is that the ABS is lightweight and it could be at high density 3D printed while the silicone is also lightweight and highly deformable. Thus means that a core including one or several ABS and one or several silicone items, proved to be very efficient in terms of the compromise comfort – correction [17].

2.1. Applied procedure

One of the main issue during developing research was to manufacture all necessary items composing the insole's core, so that the envisaged materials resist in case of different static and dynamic loads, simulation real conditions (like standing, walking, running, dancing, driving or jumping). For this reason, the items behavior via static and dynamic simulation for different dimensional prototypes proved to be very important. This is about developing several models for male, middle-height, aged between 20 and 40 years old.
For simulation, a static and dynamic analysis was achieved, using the finite element modeling (FEM) method.
To make this procedure to be easier to be applied, more proper and more efficient, in advance, the problem has been raised to make an analytical determination for prototyping items sizing, taking into account their resistance and deformation in case of static and dynamic loads. More exactly, it was established that for both categories of materials, the mechanical tension obtained in static and dynamic regime in different situations to be compared with the maximum admissible tension, specific to each category of material. For example, if the determined mechanical tension for the simulated item is proved to be greater than its maximum admissible mechanical tension, it must be resized so that it could resist in case of such of static or dynamic loads. The most important aspect to be considered is to compare the maximum admissible tension for the concerned material to the determined mechanical tension, the first parameter being expressed in relation (1). The maximum admissible mechanical tension is specific to each material.

$$\sigma_c = \frac{F_{c\_max}\, h}{E\, A} \quad (1)$$

where:
- σ_c represents the determined value of the mechanical tension of the item for each situation;
- F_{c_max} is the maximum admissible load in case of compression (or bending) for the orthotic item;
- h – the averaged thickness of the orthotic item;
- E – longitudinal elasticity modulus (of Young) for the material of item;
- A – the approximate surface of the orthotic component.

One of the most important aspect of the research was to develop (by programming) a software interface, which, starting from the resistance calculus algorithms in static and dynamic mode, to be able to display the results in any situation regarding the orthotic items using inside the insole's core. The main parameters to be considered for results obtaining are: the regime (standing, walking, running etc.), displacement speed and the estimated time of the acceleration after foot soil separation (Table 1).

Table 1: Input parameters as casuistic to be considered for the calculus algorithms

Regime	Displacement speed of the concerned person (v) [m/s]	Estimated time of the acceleration after foot soil separation (a) [m/s^2]
Standing	0	0
Normal walking	1.5	0.5
Running	8	0.2
Dancing	4.5	0.25
Driving	6.5	0.2
Jumping	0	20

The values presented in Table 1 (as example) mean the estimated speed and acceleration values for all real cases for an adult person.

3. SOFTWARE APPLICATION DESCRIPTION

To obtain more efficient and more accurate the results in terms of orthotic items resistance for static and dynamic loads, one of the main issues was to develop (via programming) a virtual instrument (as software interface), *Simulation for insole items behavior.vi*. The application was developed in Lab VIEW, being described at the paragraph 3.2.

3.1. The interface role

The main role of the developed software interface is to help on pre-simulation items dimensioning in order to have ideal condition referring to loads, constraints and size when using FEM method for simulation, before their 3D prototyping by printing. Another advantage is that once created, this software interface can be easily adapted for all types of prototyping items and for different situations, meaning static or dynamic loads. In terms of efficiency, the interface allows obtaining very quickly (in a few minutes) all results and necessary information on items dimensioning and simulation conditions, its running being user friendly.

3.2. Software interface describing

The interface is structured to contain two main of text – boxes, the first one in red, referring to input data and the second, in blue, referring to the generated results and information. The input data are divided in 4 categories, as follows: the first meaning the conditions in which the simulation must be performed, referring to the person who will wear such of orthotic items inserted. Related to this kind of input data, the information on simulation conditions are found (in blue), as information to identify the conditions regarding the orthotic items loading (figure 1):

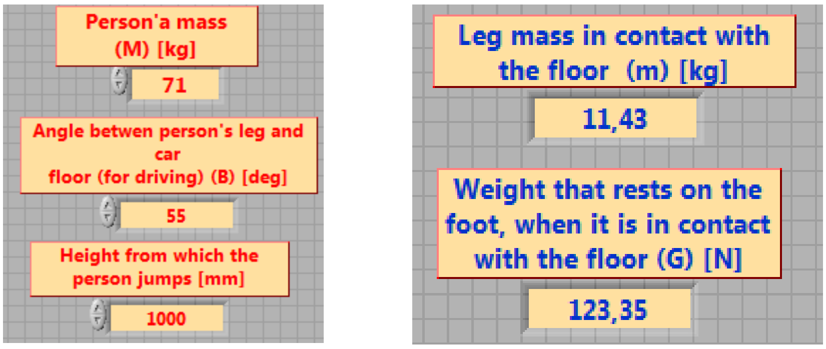

Figure 1: Simulation condition related to the concerned person

The next category of input data refers the plantar area, destined for specific orthotic items to be dimensioned (composing the insoles core) (Figure 2). The input text boxes mean to choose from list on situation, referring to the concerned foot area, the invoked activity and also the type of wear shoes:

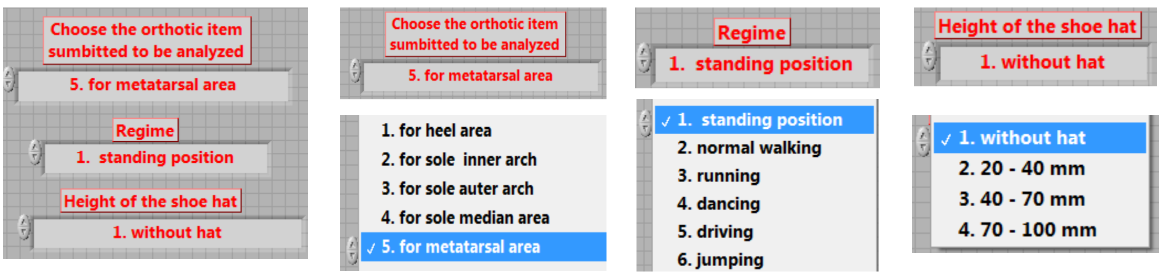

Figure 2: The dialog boxes, with selection, specific to the plantar area, type of activity for which the simulation must be performed and type of wear shoes

In terms of programming, related to this kind of input text dialog, for results obtaining, several Case-switch structures, including other Case-switch structures have been defined and applied to establish the calculus algorithm for each one of the cases (Figures 3 and 6). For each one of the cases, inside the case structure, the calculus algorithm was defined as resistance calculus parameters. Some aspects have taken into account empirical considerations and simplifying assumptions (e.g. leg's distribution mass, height for jumping, speed for displacement) (Table 1).

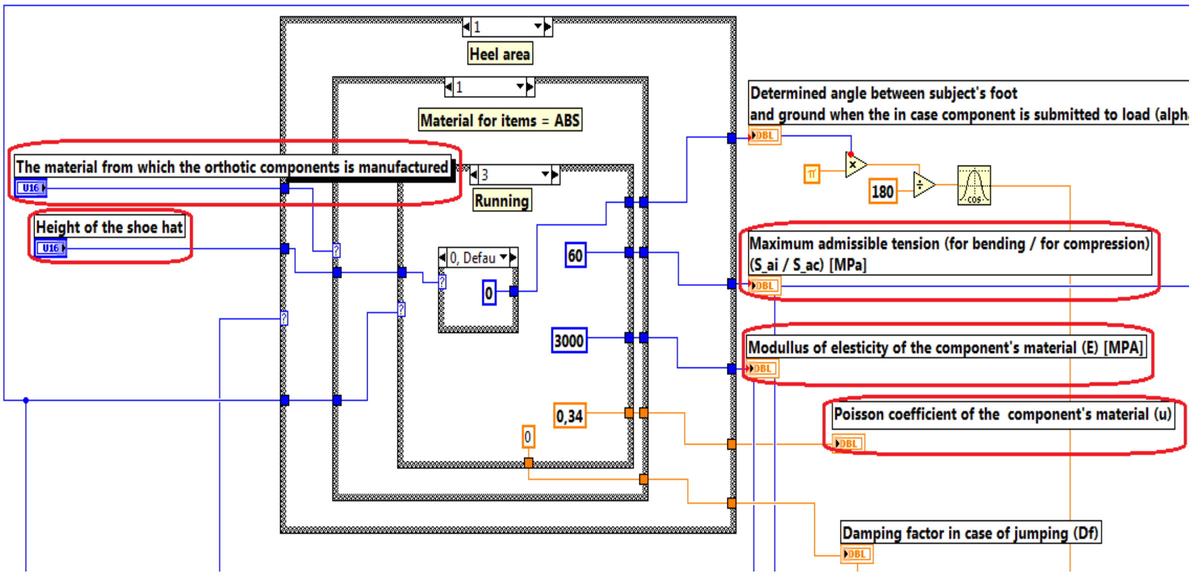

Figure 3: Example of programming diagram, including three Case structures, to define the algorithm for several resistance parameters determination, related to the prototyping orthotic items

As output information, several important resistance parameters can be determined to be displayed (Figure 4), useful to check if the component (item) must to be re-dimensioned or not.

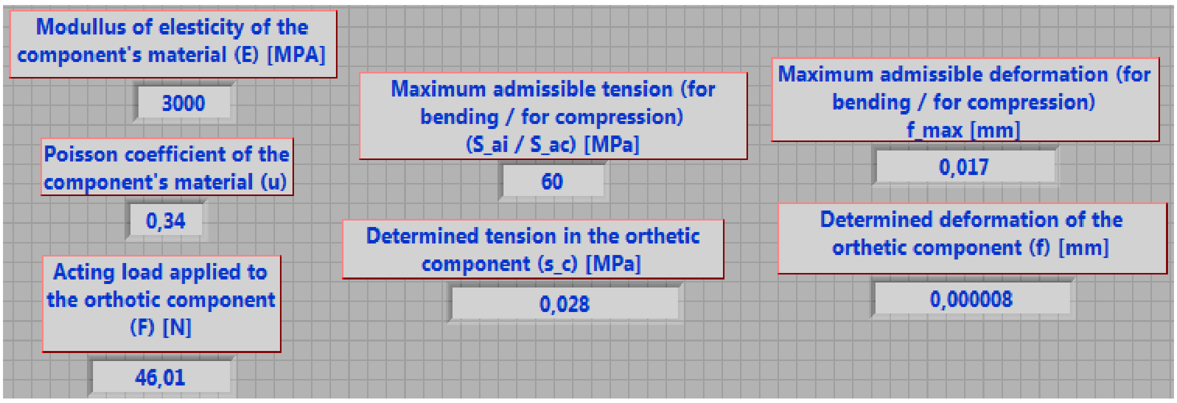

Figure 4: Example of main resistance parameters displayed as result in the analyzed item

Finally, the most important information mean the verdict if the analyzed item is well dimensioned (in case of different simulation conditions) or not. Thus is illustrated due to a LED of state (Figure 5), meaning a comparison function between the determined maximum admissible mechanical tension and the mechanical tension in the orthotic component for each case.

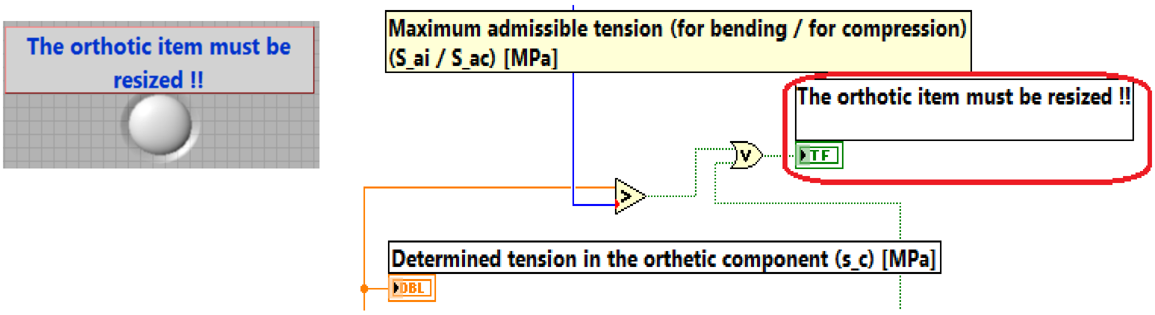

Figure 5: Displaying the most important information, as final verdict on analyzed item

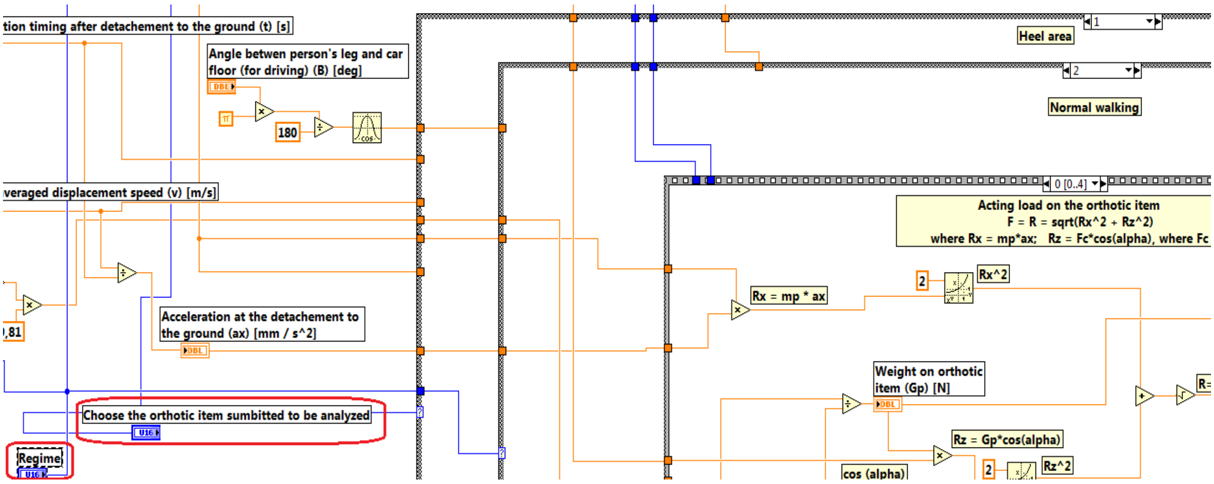

Figure 6: Example of programming diagram, including Case structures, to define the algorithm the determination of maximum admissible deformation and simulated deformation, related to the prototyping orthotic items

3.3 Software interface running

When interface running, the main steps to be follow refers to complete all necessary data inputs (in red), meaning that for each orthotic item, in all situation the results are given properly and quickly. Beside the necessary information on the item dimensioning, the results on mechanical tension, simulated deformation can be used into EXCEL tables to have an overview of all simulated cases (Figure 7).

Nr. of item	Item type	Regime	Tipe of loading	Load acting on the orthotic item (R) [N]	Determined mechanical tension (σ) [MPa]	Maximum admissible mechanical tension (σ_a) [MPa]	Determined deformation (f) [mm]	Maximum admissible deformation (f_{max}) [mm]
1	*For heel area*	Standing	static compression	43.68	0.029	60	0.000122	0.254
		Normal walking		54.37	0.036		0.000151	
		Running		459.26	0.301		0.00128	
		Dancing		210.34	0.138		0.000585	
		Driving		25.05	0.016		0.00007	
		Jump from 100mm	dynamic compression	13.981	9.175		0.0389	
		200 mm		19.772	12.975		0.055	
		300 mm		24.215	15.892		0.0674	
		400 mm		27.962	18.35		0.0778	
		500 mm		31.262	20.516		0.087	
		600 mm		34.246	22.474		0.0953	
		700 mm		36.990	24.275		0.1029	
		800 mm		39.544	25.951		0.11	
		900 mm		41.942	27.525		0.1167	
		1000 mm		44.211	29.014		0.123	
2	*For inner sole arch*	Standing	static compression	89.43	0.029	60	0.000083	0.1734
		Normal walking		95.78	0.031		0.000089	
		Running		465.91	0.149		0.000431	
		Dancing		224.37	0.072		0.000208	

Figure 7: Example of obtained results on resistance parameters for different orthotic items, after using the described software interface

4. CONCLUSION

Due to developed software interface, the collected data were placed into an EXCEL table, which were later used for the FEM simulation, before item 3D prototyping. This stage of research proved to be very useful and efficient, due to the fact that it were able to identify and solve in a timely manner some problems regarding the orthotic components dimensioning, related to their mechanical resistance in case of static and dynamic mode.
The application proved to be very useful and efficient for different types of orthotic items, so it proved to be flexible one, could be successfully used for different kind of foot insoles cores.

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