RESEARCH ON THE DESIGN AND DEVELOPMENT OF A SMART KNEE ORTHOSIS

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ABSTRACT: The purpose of this research is to create a functional prototype for the lower limb orthosis, respectively the knee studied in the project "Bionic Orthosis for the Lower Limb", where a study of the existing needs on the market was carried out and several concepts were developed from which the optimal one was chosen. This research is about designing, manufacturing and testing a prototype orthosis and making it more useful by creating a mechatronic system that allows the patient to constantly observe his health.
The conclusion of this research is to obtain a functional prototype, who will be improved in a future research to reach an optimized version of the orthosis.

KEYWORDS: orthosis, 3D printing, mechatronic, prototype

1. Introduction

In recent years, there are more and more diseases and accidents that lead to the non-use of some limbs and to the mental state of the persons concerned. Among these diseases is diabetes, which in recent years has affected more people than in the past. Most people discover it too late, when their peripheral circulation has already been affected and they are in the stage of not being able to use a part of the limb.

The purpose of this research is to develop a product that will make life easier for people with various locomotor problems.

For the development of a bionic orthosis, various aspects regarding the market were analyzed, namely, opportunities, existing products and customers.

2. Concept model

Medical reports inform that orthoses for the lower limbs specifically for the knee, are a treatment for medical conditions such as: fracture, kneecap dislocation, damage to ligaments or cartilage, dissecting osteochondrosis. So, the orthosis for the knee must provide stability, allow some mobility, but not excessively, to align a correct position and resist external forces.

Living with a knee orthosis can take time to get used to, so doctors and engineers are constantly trying to develop and improve solutions to make patients' life easier.

After a more detailed analysis, was chosen an optimal concept for the realization of the orthosis. This is shown in Figure 1.

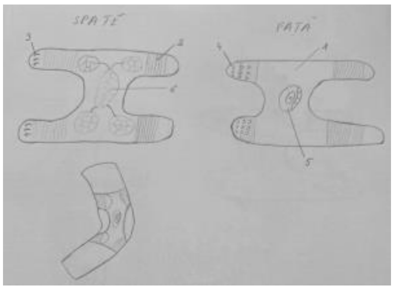

Fig.1. The chosen concept for the manufacturing of the orthosis

The lower limb bionic orthosis has the body (1) made of textile material. Adjustment of dimensions is made by elastic bands (2), by stretching them, obtaining values in the range of 30 - 85 cm. After adjusting the dimensions, both for the thigh and the calf, the orthosis is fixed using hooks (3) which are inserted into the rings (4), located over the entire range of dimensions. Depending on the doctor's recommendations, the treated area and the time of use is set through the mechanical system (5). A silicone pillows system (6) is placed on the inside of the orthosis for easy and comfortable wearing, which comes into contact with the wearer's skin, avoiding the risk of possible injury during use.

3. Modeling and 3D printing resistance structure

The schedule for wearing a knee orthosis is different for each patient, depending on the type and severity of their problem. Often patients have to go for regular physical examinations or perform therapeutic exercises and have to take off the orthosis. The orthosis also needs to be cleaned regularly.

Bearing these aspects an orthosis must be easy to use, without causing pain or scratching the skin.

Analyzing the textile material used for the orthosis, it has been established that a resistance part will be attached to the material.

To design the 3D model, anthropometric measurements of the person who will use the orthosis were used. The orthosis was designed in Inventor Software and 3D printed using HIPS material.

In figures 2 and 3 you can see the 3D model created for the orthosis.

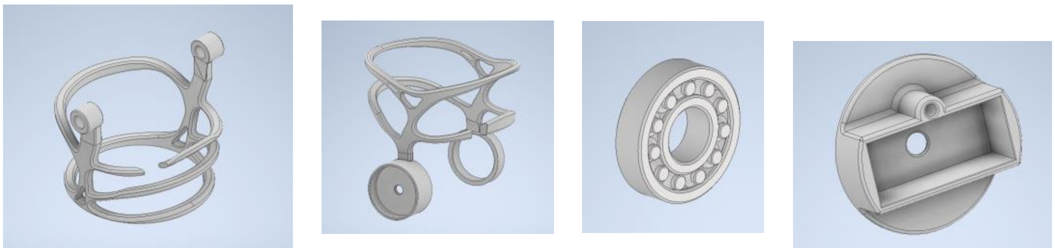

Fig. 2. 3D components models of the orthosis

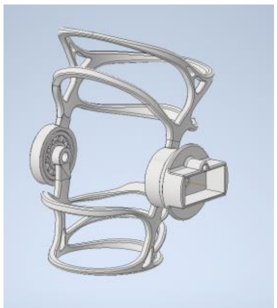

Fig. 3. 3D model assembled

The orthosis for the lower limb brings to the fore a more anatomical shape with large cutups that offers better mobility to the person. Both the cutups on the surface of the orthosis and around the joint offer the patient an easier wearing, making the orthosis to have a lower weight. In order to increase the patient's mobility, the joint was realized using a bearing, assembling both parts of the orthosis with it by tightening.

Moreover, for a more detailed check of the foot dimensions in the manufacturing of the orthosis, it was also used a human body scanning application "Nettelo" presented in Figure 4.

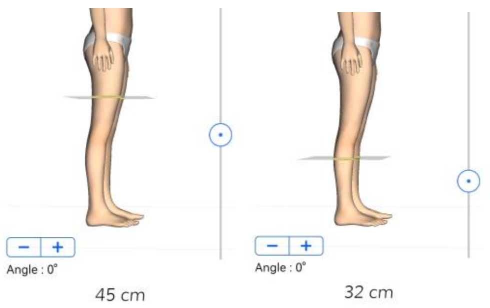

Fig. 4. Human body scan [8]

Several prototypes were printed for the orthosis and the optimal one was chosen to continue the study and to optimize the necessary elements. These are shown in figure 5.

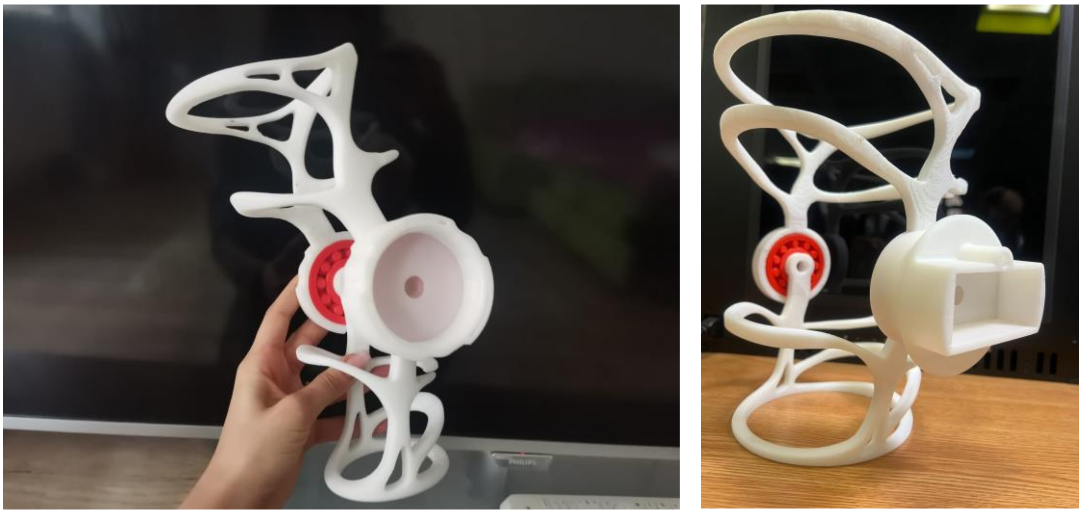

Fig. 5. Prototypes (from left to right): first functional prototype and second functional prototype

4. Materials

Choosing a material for 3D printing products has become increasingly difficult because the 3D printing market comprises a wide variety of materials. For the choice of the material used in the studied orthosis, a research was conducted on the following materials: PLA, ABS and HIPS.

PLA (Polylactic acid)

One of the most common thermoplastics in 3D printing is polylactic acid (PLA), an environmentally friendly, biodegradable polymer created from plant sugars from crops such as tapioca, corn and sugar cane.

Suitable for: applications in various fields, miniatures, cosplay, decorative pieces.

Pro arguments: low cost, easy to print, good hardness and mechanical strength, dimensional accuracy, biodegradable.

Contra arguments: can be brittle, oozing occurs, low temperature resistance, not UV resistant, degradation of prints over time.

ABS (Acrylonitrile butadiene styrene)

Acrylonitrile butadiene styrene (ABS) plastic is used in a variety of industrial applications for extrusion and injection molding, such as lego bricks. Its properties are well known, and the quality of the filament can be easily controlled during manufacture.

Suitable for: mechanisms, functional prototypes, functional parts for the automotive industry.

Pro arguments: high mechanical strength, impact resistance, water resistance, good temperature resistance, no oozing and stringing.

Contra arguments: special printing conditions, increased tendency to deformation, strong contractions, no UV resistance, unpleasant smell.

HIPS (High-impact polystyrene)

High impact polystyrene (HIPS) is a variation of styrene. HIPS has similar properties to ABS, but dissolves in limonene (a solvent derived from citrus plants). HIPS is a dissolvable backing material that is commonly used with ABS. When used as a backing material, HIPS can be dissolved in d-Limonene, leaving the print free of marks caused by backing removal. HIPS is not only excellent for supporting ABS prints, but it is also more dimensionally stable and lighter than ABS, making it an excellent choice for parts requiring lighter weight. HIPS filament is relatively new and its use is still experimental.

Suitable for: cosplay items, parts that need to be lightweight, protective housings.

Pro arguments: impact and water resistance, fine surface, lightweight material, can be used as backing material, dissolvable in d-Limonene.

Contra arguments: heated enclosure and platform, requires ventilation, high printing temperature, emits harmful particles in printing.

For a best comparison, each material characteristics are shown in Table 1 :

Table. 1. Material characteristics

Features	PLA	ABS	HIPS
Strength [MPa]	32	40	65
Rigidity	5/10	7,5/10	10/10
Sustainability	4/10	8/10	7/10
Temperature of extrusion [°C]	180-220	220-240	220-230
Bed temperature [°C]	20-55	80-110	50-60
Coefficient of thermal expansion [µm/m-°C]	85	68-110	80-90
Glass transition temperature [°C]	60-65	105-110	100
Price* [RON]	199,00	233,00	283,00

* Price refers to one ZORTAX 3D printer filament with 800g mass.

Because the orthosis material has to be stiff for best mobilization, but also light so as not to affect locomotor function and create discomfort for the user, HIPS material was used.

5. Mechatronic System

A mechatronic system consisting of sensors, an RGB LED and an LCD screen to help the patient use the orthosis more easily was also considered. The mechatronic system components are shown in Table 2.

Table 2. Mechatronic system components

Components name	Number of pieces
Arduino Nano Board	1
Mini Breadboard	1
RGB Led	1
Resistor 220 Ω	3
LCD display	1
Temperature sensor DHT11	1
Pulse sensor	1
The vibration module	1
Wires mom - dad	17
Wire dad - dad	1

To operate the circuit, the Arduino Nano board was placed on the mini breadboard and the other components were connected to it using mom-dad wires. The right pin of the temperature sensor was connected to the GND port of the board, the left pin to the 5V port and the middle pin to the digital port 7. The vibration module and the pulse sensor were connected in the same way, the difference being the change of ports from which they receive data. Thus, the pulse sensor was connected to analogue pin A0, and the vibration sensor was connected to digital pin 2. In the case of the RGB LED, the cathode was connected to the GND port, and the led pins for RGB colors were connected in series with a 220 Ω resistor and connected to the pulse modulated digital pins 9, 10 and 11.

A circuit was made on a normal breadbord to test the components and its operation before put it on the orthosis. This is shown in figure 6.

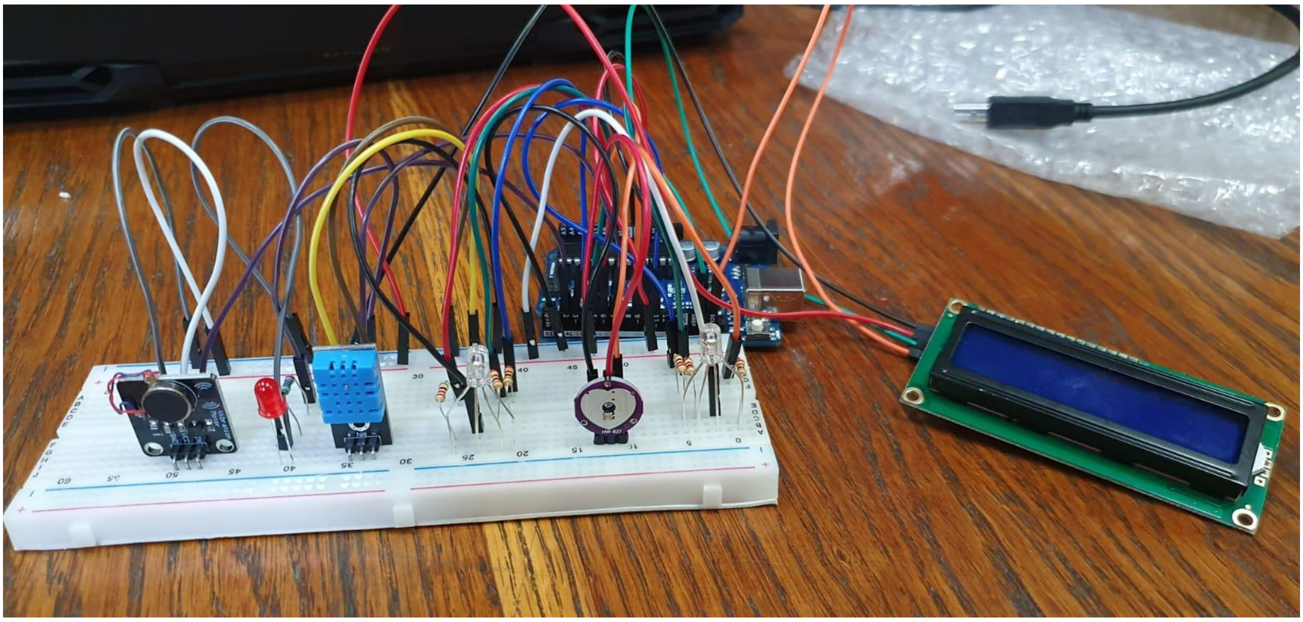

Fig. 6. The circuit for testing

The circuit principle of the operation consists in measuring the temperature and pulse of the patient, displaying them on the LCD screen and warning by light and vibration if the temperature is higher than 37ºC or the pulse is not within the normal range of 400-600 heart rate. A code was also developed to operate the circuit using Arduino software. Some sequences of it are shown in figures 7 and 8.

```
if(tempC >= 37){
 digitalWrite(r,255);
 digitalWrite(g,0);
 digitalWrite(b,0);
 digitalWrite(vibratie_pin,HIGH);
 delay(1000);
}
else{
  digitalWrite(r,0);
 digitalWrite(g,0);
 digitalWrite(b,255);
 digitalWrite(vibratie_pin,LOW);
 delay(1000);
}
```

Fig. 7. Code sequence for temperature sensor [9]

```
  if(val_puls < 400){
    lcd.setCursor(0,1);
lcd.print("Puls:");
lcd.print(val_puls);
    digitalWrite(r2,255);
   digitalWrite(g2,255);
   digitalWrite(b2,0);
   digitalWrite(vibratie_pin,HIGH);
   delay(1000);
   }
```

Fig. 8. Code sequence for pulse sensor [9]

6. Conclusions

In conclusion, with the help of this research, an efficient way of measuring pulse and temperature has been developed, including warning systems for the user in case of medical problems. A textile material and a 3D-printed pattern were also combined to ensure durability. The prototype orthosis is functional and useful for the patient. This can be seen in figure 9.

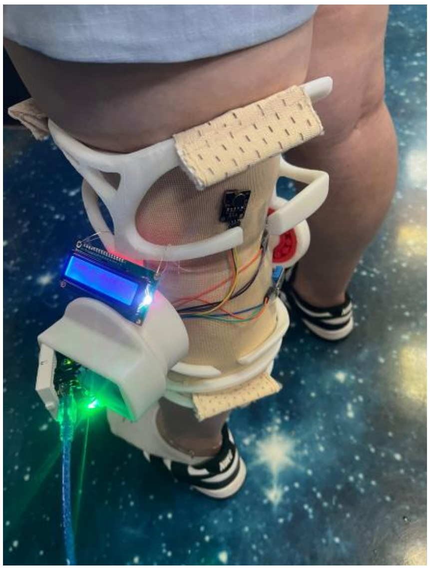

Fig. 9. Wearing orthosis functional prototype

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