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A Prototype System For Upper Limb Post Stroke Rehabiliation

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***Abstract*—This article presents the design of a complete system for patients' upper limp rehabilitation after stroke. After performing a thorough examination of the existing industrial and research solutions, a new, portable and low-cost system was designed. The system is comprised of an innovative mechatronic base electronically controlled and interconnected with a pc-based virtual environment within which gamified therapeutical exercises take place.**

Keywords—stroke; upper limb; rehabilitation; biomechanics; robotic arm

1 Introduction

At the first place, international literature was studied regarding the importance of stroke and its rehabilitation as well as the related existing technologies and methodologies [1-27].

Next, and as the first step towards the design of the proposed system was to undertake a deep literature review of the state-of-the-art of the existing commercial and research solutions. Table I indicates the exact solutions with their product names and their manufacturers' details.

TABLE I – EXISTING UPPER LIMB REHABILIATION SOLUTIONS

Number of Reviewed System	**Existing Stroke Rehabilitation Systems**	
	Product Name	***Manufacturer***
1	ArmeoSpring	Hocoma
2	Amadeo	Tyromotion
3	Armotion	REHA technology AG
4	MYRO	Tyromotion
5	PABLO	Tyromotion
6	DIEGO	Tyromotion
7	MOTORE	Humanware
8	ULTRA	Humanware

As a result of the above studies, the main specifications that a new system should integrate are portability, the easiness of use without the need for experienced assistant, low cost, versatility, and simplicity. From the technological perspective, ideally, the system must provide force feedback and zero gravity sense, gamification of therapeutical scenarios, and remote monitoring by medical experts.

The proposed system is comprised by the following main sub-systems:

a) mechatronic base,

b) electronic control,

c) software, and

d) 3D-based human-machine interface.

2 Mechatronic design

A mechatronic base was designed to support the limb of the patient allowing it to move at limited XY area. An innovative characteristic of the proposed system is that there is a Z simulation move integrated through the particular mechanical design of the base. Therefore, the base can be considered as to be a XYZ moving system. The overall view of the base is illustrated in Figure 1.

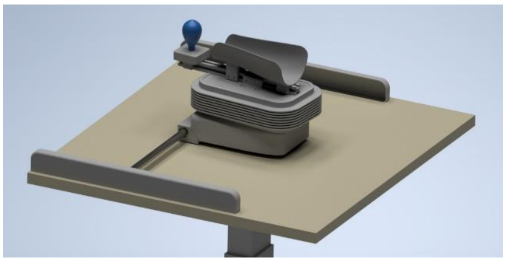


FIGURE 1. 3D design overview of the mechatronic base.

Figure 2 depicts the details of the mechanical design. Specifically, there are certain mechanisms for keeping users safe during the operation. Particular mechanisms for limiting the movement to specified areas have been integrated. All the functions of the mechatronic base were primarily designed and tested in CAD (Computer-Aided Design) environment to ensure optimal results.

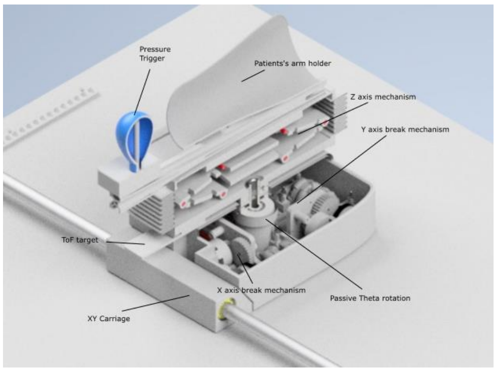


FIGURE 2. Details of the designed mechatronic base.

During the design and testing procedures, 3D printing (additive manufacturing) was performed using technologies of Nylon SLS/MJF and LCD SLA. Such approach helped reducing cost and time of design cycles.

Figure 3 illustrates the specific mechanism for limiting the movement area of operation in Y and X axes using rods, blocking parts and geared wheels (Figure 4). Such an approach keep the patient’s hand safe and secure.

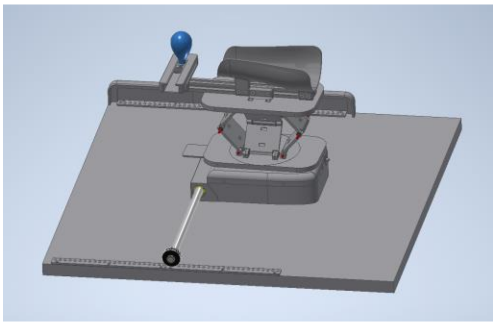


FIGURE 3. Movement limitation mechanism.

Figure 7 illustrates the details of the mechanisn of Y directrion of movemnt.

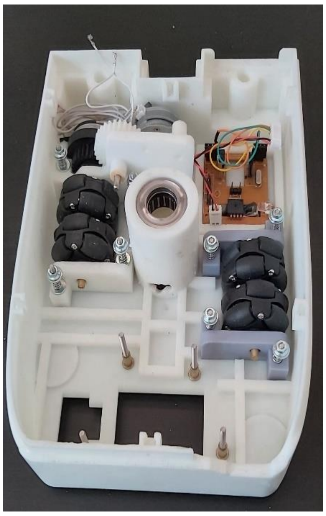


FIGURE 7. Mechanical design of the base part.

The brake operations was achieved by using multi-directional wheels in order to ensure entirely free movement at the opposite side of the exercise. Specific mechanisms have also be adopted so as to reduce the vibrations at the highest level possible (i.e. springs, suspension between base and table, etc.). Such details are depicted in Figure 8.

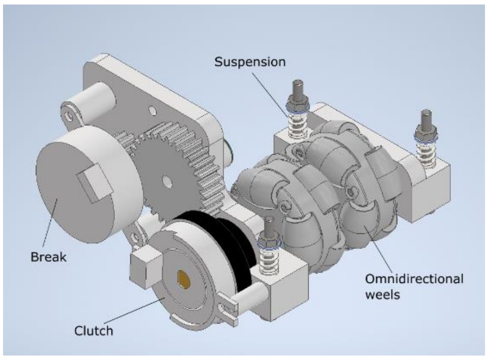


FIGURE 8. Details of smooth operation mechanisms design.

The resistance of the base movement was achieved by using a particular current-controlled magnetic mechanism. Further design details are shown in Figure 9.

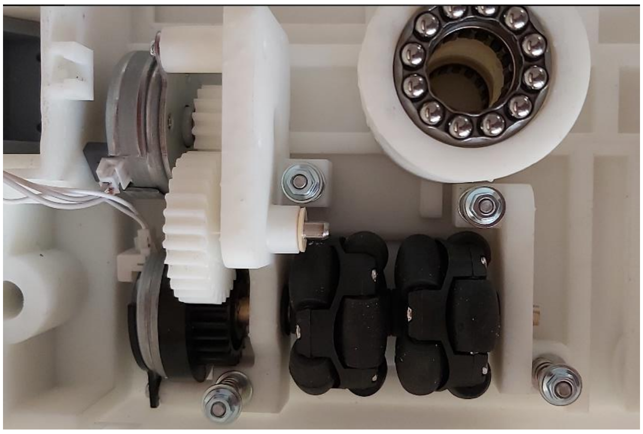
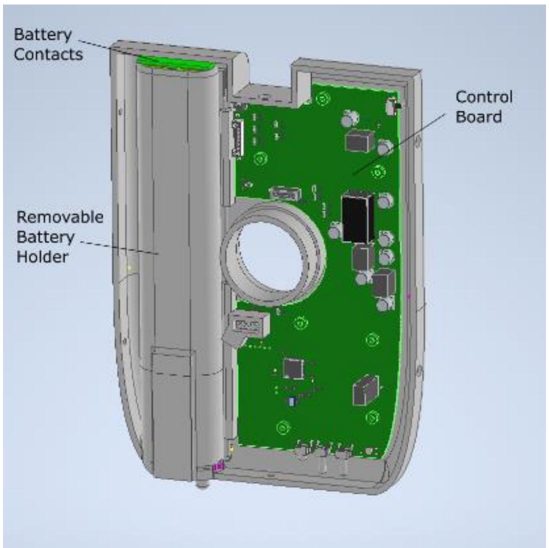


FIGURE 9. Design of special magnetic brake mechanism.

An extra brake in X axis was designed in order to ensure the stability of the overall device as it is shown in Figure 10.

FIGURE 10. The stability mechanism design.

The cover of the base hosts the printed circuit board (PCB) of the positioning control as well as the batteries compartment (Figures 11 and 12). Batteries ensure the operation of the system unplugged of the mains serving in this way to the maximum versatility of installation and usage.



FIGGURE 11. Base’s cover design.

FIGURE 12. Base’s cover and electronic controller.

Regarding the movement at Z axis, a particular mechanism was design, as it is depicted in Figure 13, which allows for a distance of 11 cm in total of movement having the patient’s hand in the best safe condition during the exercise. Patient uses a specific handle (small-ballon like) to signal the intention for movement up or down. This is controlled by an electronic circuit based on Time-of-Flight (ToF) sensor.

FIGURE 13. Z axis movement control mechanism.

Figure 14 illustrates the optical ToF sensor placement at the bottom of the Z axis trigger mechanism.

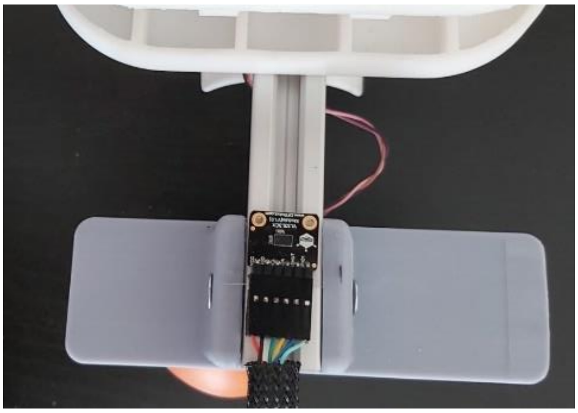


FIGURE 14. Time-of-Flight sensor for Z axis trigger control.

The details of the trigger design are given in Figure 15.

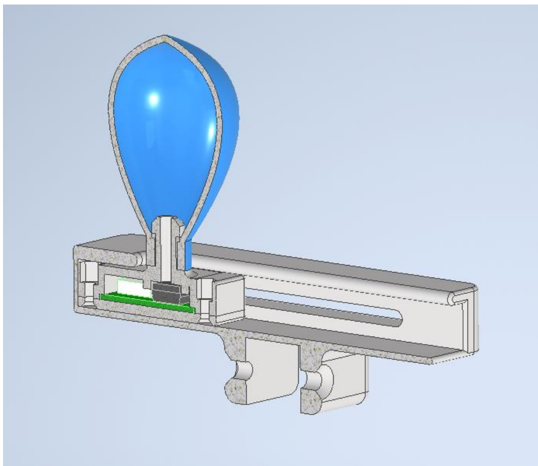


FIGURE 15. Details of the trigger design.

3 Electronic Control Design

The design of the electronic part of the system was kept as simple and low cost as possible. For the XY direction control, the PC pointing and positioning device concept has been adopted. For the Z direction trigger control a pressure sensor and a ToF-based distance sensor have been employed. The communication of the system with a personal computer is achieved by employing a Bluetooth radio module, namely the HC06. System doesn't include any kind of motor in order to keep it low-weight and portable. Instead, a magneto-rheological-controlled brake is used together combined with specific designed mechanical mechanisms.

The block diagram of the schematic of the electronic system is depicted in Figure 16.

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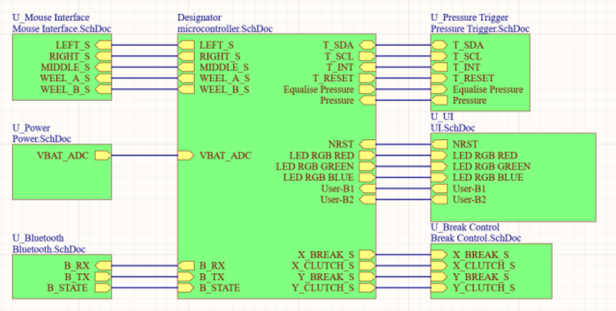


FIGURE 16. The electronic system's schematic design.

The microcontroller of the electronic system reads signals from the aforementioned embedded sensors and produce the necessary signal to drive properly the electronic brakes.

The design of the printed-circuit board (PCB) of the electronic system is shown in Figure 17 and Figure 18.

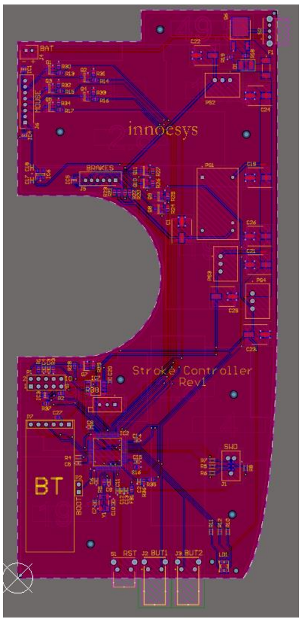


FIGURE 17. The design of electronic system's PCB.

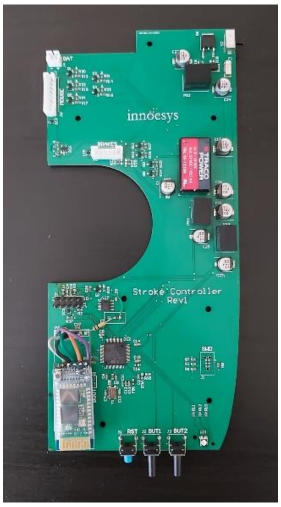


FIGURE 18. The electronic system with components soldered.

Additionally, the PCB for the sensors and battery connections were made as shown in Figure 19.

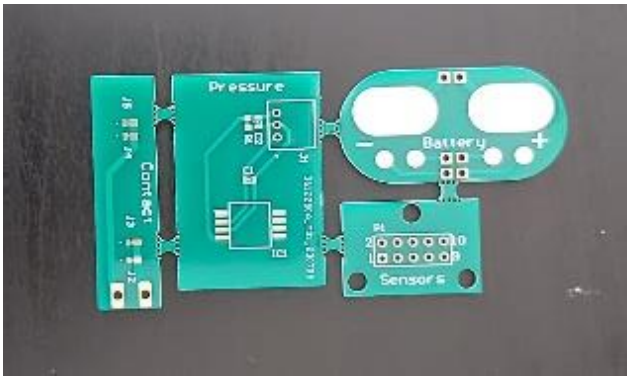


FIGURE 19. PCBs for batteries connection and sensors integration.

The detail given in Figure 20 depicts the installation of these PCBs in the cover of the bae.

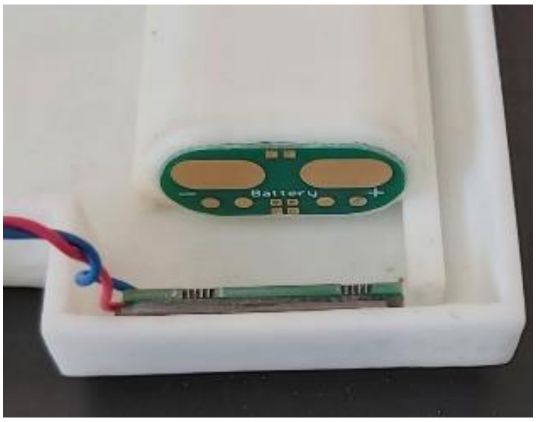


FIGURE 20. PCBs installed in the cover of the base.

Figure 21 gives an overall overview of the system fully assembled with parts and electronics.

FIGURE 21. Overall overview of the system.

4 Firmware and Software Desogn

4.1 Firmware Desogn

For the microcontroller's firmware the STM32CubeIDE of ST Microelectronics was used. The programming language was C. ST-Link programmer/debugger was also used during the phase of the development. Figure 22 illustrates the structure of the firmware.

FIGURE 22. Structure of the microcontroller's firmware design.

4.2 Software Design

The development of the PC software, namely the Stroke Rehab s/w, Delphi integrated design platform or Embarcadero was used. Specifically, this platform is based on Visual Pascal.

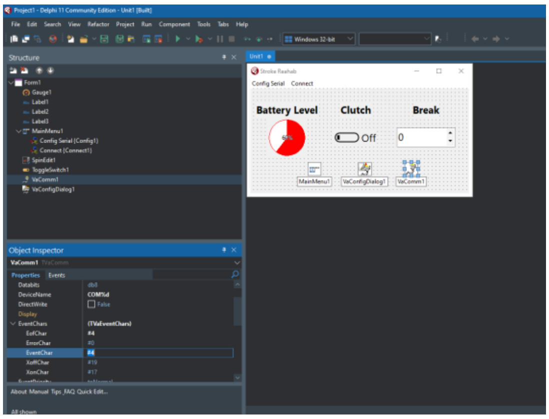
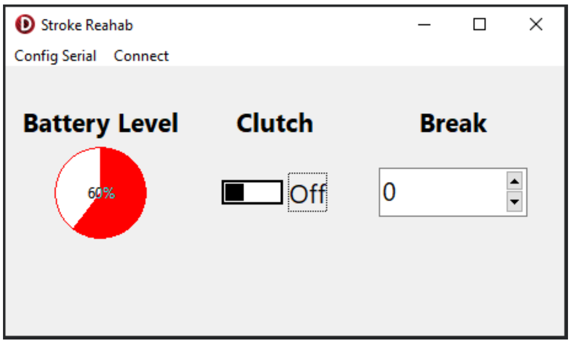


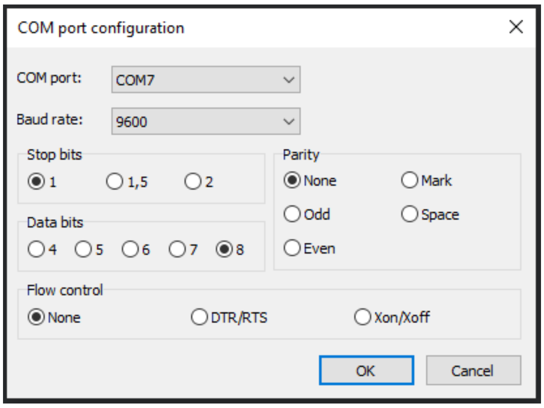
FIGURE 23. A view of the Delphi programming environment.

The Stoke Rehab s/w includes two main windows, one for operating the mechatronic system and a second to configure the communication parameters with the mechatronic system. These windows are illustrated in Figures 24 and 25 accordingly.



Battery Level 60%
Clutch Off
Break 0

FIGURE 24. Window for setting up the operation of the mechatronic system.



COM port configuration

COM port: COM7

Baud rate: 9600

Stop bits: ● 1 ○ 1,5 ○ 2

Parity: ● None ○ Mark ○ Odd ○ Space ○ Even

Data bits: ○ 4 ○ 5 ○ 6 ○ 7 ● 8

Flow control: ● None ○ DTR/RTS ○ Xon/Xoff

FIGURE 25. Window for setting up the parameters for communication with the mechatronic system.

All the information of the mechatronic system's operation feed the Stroke Rehab s/w in real-time through the Bluetooth wireless protocol.

5 3D Space Design

The proposed rehabilitation systems also include virtual reality (VR) functionalities in order to enhance the prospected results. A PC monitor is placed in front of the user to show various VR scenarios. These scenarios are closely related to each patient status and are synchronized with the operations of the user-driven mechatronic system. For the development of the VR scenario Unity platform was adopted due to its inherent ability to build Epics and Scenes. As an example of use, a VR scenario according to which the user can be exercised to reach and touch products placed in shelves at a super-market was developed (Figure 26).

FIGURE 26. A view of the VR scenario of reach and touch products.

During the exercise, the patient's movements are logged into the PC software in real-time. This is very important because this information shows the progress of the user's status and give the ability to experts to adapt their practices.

VR scenarios can be changed according to each patients record and status. In parallel, all the data collected by the software application of the system can be remotely monitored by doctors.

Figure 27 depicts a typical window of the developed s/w application display activity data in real-time.

Before you begin to format your paper, first write and save the content as a separate text file. Keep your

Activity Data	
Activity	1st
Target Duration (sec)	120
Catch Distance Difficulty (1-4)	4
Catch Click Difficulty (1-4)	3
Success	3/6
Actual Duration (sec)	106
Duration Difference	+13%

Per Attempt & Object Position	
Mean Distance Error (pixels)	-

Per Attempt	
Catch Pressure (1-4)	3.3

Position Of Object: Select
Attempt: 1

FIGURE 27. A typical window that displays activity data in real-time.

The developed s/w provides a broad range of parameters calculation such as:

- Activity
- Target Duration
- Catch Distance Difficulty
- Catch Click Difficulty
- Actual Duration
- Duration Difference
- zean Distance Errors (pixels)
- Catch Pressure
- Object Position for Catching

6 Conclusions

This article studied the state-of-the-art regarding the systems/solutions for upper limb post stroke rehabilitation and proposed the design of a new and innovative system. The detailed design of the mechatronic system, the electronic control system, the firmware and software, the VR-based scenarios, and the management software platform were thoroughly described.

The overall system is characterized by the low-cost, the highest portability, the highest versatility and robustness, the highest efficiency and effectiveness.

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Confict of Interest

There are no conflicts of interest.

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