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Exoskeleton for gait rehabilitation of children: Conceptual design

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Abstract— **This paper presents the conceptual design of an exoskeleton for gait rehabilitation of children. This system has electronics, mechanicals and software sections, which are implemented and tested using a mannequin of a child. The prototype uses servomotors to move robotic joints that are attached to simulated patient's legs. The design has 4 DOF (degrees of freedom) two for hip joints and other two for knee joints, in the sagittal plane. A microcontroller measures sensor signals, controls motors and exchanges data with a computer. The user interacts with a graphical interface to configure, control and monitor the exoskeleton activities. The laboratory tests show soften movements in joint angle tracking.**

I. Introduction

The present research addresses one of the most relevant topics in biomedical engineering, it is exoskeletons. Exoskeletons have been defined as devices adapted to physical structure of the human body that can support movements, increasing the capabilities or facilitating the development of potentialities of certain members of the human body [1].

However, the construction of these mechanisms requires applying concepts of electronics, computer science and mechanics. In the electronics field, instrumentation and control are recognized as fundamental parts of the system: The instrumentation is responsible for collecting the useful information to be sent to the central processor, which contains the control strategies necessary to decide per the information received [2].

On the other hand, the design of exoskeletons arose in 1960 for combat in military applications, this because soldiers must carry equipment that exceeds his weight and requires greater mobility, also for long walks avoiding physical exhaustion when he reaches his destination and needs to perform operations. [2]

Furthermore, there are different research projects about development of exoskeletons for gait rehabilitation. For example, the wearable exoskeleton for physical treatment of children with quadriparesis made by Elena Garcia and others, who did a laboratory proof of concept with motion in the sagittal plane [3]. Other example is the H2 robotic exoskeleton for gait rehabilitation of Botole and others, which has six actuated joints and a force control system that enables longitudinal overground training of walking [4]. Moreover, there is a study assessing changes in cortical organization due to the usage of exoskeletons for free walking in suspension; this suggests a direct effect of robotic rehabilitation on the gait relearning process [5].

Moreover, nowadays it is possible to get commercial gait rehabilitation robots, as the ZeroG, an overground gait and balance training system installed on the celling, which allows patients to practice different activities in diverse rehabilitation environments [6-7]. As for exoskeletons, the Re-Walk system allows mobility to its users giving them some functions such as standing, walking, ascending and descending stairs [8], the Lokomat is a less versatile but it is successfully used in rehabilitation centers by adults and children [9].

This paper presents an initial concept design of an exoskeleton for gait rehabilitation of children. The design contains electronic, mechanical and software sections. From a technical point of view, each actuator is aligned with the corresponding human body joint and its actuation permits to support the joint rotation. The actuators are servomotors controlled by a microcontroller, which is connected to a computer. Finally, all the system is monitoring and regulating by a GUI (Graphical User Interface).

II. Methods and Materials

There were some particular characteristics taken into account for the design of the exoskeleton, such as:

- The system had to be simple and small. In consequence, the exoskeleton was designed with only four joints, two for each leg. They give motion to hip and knee joints in the sagittal plane.
- The maximum joint angles were selected to avoid any extremely wide leg movements. Then, 40° for knee joint and 20° for hip joint were defined as maximum values.
- The links between the joints had to be adapted to a mannequin with similar dimensions to a two years old child.
- The motors for joints had to be safety. Therefore, the design has small servomotors, one for each joint. The torque from these actuators gives joint movement but without an excessive or dangerous force for a child.
- As an initial prototype, the system should allow to select different motor velocities and number of repetitions, in other words, the number of wanted steps.

In order to follow the restrictions, a design is proposed, which contains electronic, mechanical and software sections that are described below.

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A. Materials

The hardware section uses a microcontroller DsPIC 30F4013 (Microchip, USA) [10]. This chip controls four servomotors: two TGY-1501MG (Turnigy, USA) [11] and two SG5010 (Tower Pro, USA) [12]. Each exoskeleton leg has two servomotors, the first one is on the hip join and the second one is on the knee join. Besides, the electronic system has light indicators, an on-off switch, an emergency push-button, a connector for supply and an USB connector for programming.

Besides the servomotors, the mechanic system requires links and a robotic base. There is an acrylic base for the electronics and the robotic legs, and each motor has a connected link. The design incorporates Velcro straps for attaching each simulated patient's leg to the links and the patient's back to the acrylic base.

For the software section, there are two algorithms built, a microcontroller algorithm and a computer one. These include communication protocols, controller systems, sensor lecturer and a GUI.

Finally, the robotic exoskeleton uses a child mannequin in order to simulate a patient.

B. Methods

The communication protocol starts with a hardware system detection by USB port from the GUI. Then, the microcontroller answers with a confirmation code and the communication is stablished. It permits select many options in the GUI such as: the leg or legs to move, number of repetitions, velocity, rotation angles. When the user presses a start button in the GUI, the hardware receives the configuration data and it can start the mechanical movement process. The movement process protocol has five stages, which are:

Stage 1: it starts the communication and receives data about desired robot configuration. Each variable has a specific code into the microcontroller. If the configuration is correct the protocol continues to stage two, else it is reseted.

Stage 2: it defines the joints to control by the hardware and a specific number of repetitions between 10, 20, 30, 40 or 50. Then the protocol moves to stage three.

Stage 3: it sets the velocity parameter as 5, 10, 15, 20 or 25, which is going to control the revolutions per minute of servomotors.

Stage 4: it limits the joints movement range depending of the parameters selected by the user and the kind of joint (hip or knee).

Stage 5: it controls and displays the entire process using sensors data to feedback a control system. This control helps to track the joints movements desired by the user. The process can be finished pushing a stop button in the GUI.

However, while the exoskeleton is moving, the system acquires data from each joint angle and displays them in real time. Because of that, the user can monitor the robot actuation and decide to stop it if he observes something dangerous.

III. Results

A. GUI

The GUI, named C.S.One, permits an easy interaction between the user and the exoskeleton system. Figure 1 shows the GUI with a section to connect with the hardware, other to configure the rehabilitation process, a central space to draw sensor signals and a big stop button.

Figure 1. Graphical User Interface.

Each variable has different options in its menu, which are displayable when the user clicks on it. By the other hand, when the system is operating, a graphic is shown with color lines. Each joint has a color: right knee on blue, left knee on red, right hip on green and left hip on purple. Finally, it is possible to select a motors' velocity from 5 to 25 RPM, the default value of velocity is the lowest possible; it prevents strong movements of the patient limbs. Although these velocities are related with gait velocities, this relation has not been measured.

B. Physical device

Figure 2 shows the electronic box that contains the microcontroller and all necessary circuits. Externally it is possible to see light indicators, an on-off switch, an emergency push-button, a connector for supply and an USB connector for programming.

Figure 2. Electronic box.

Figure 3 shows the exoskeleton with its aluminum legs, the patient's back support made in acrylic, the servomotors with their links, and the mannequin attached to the system by Velcro straps.

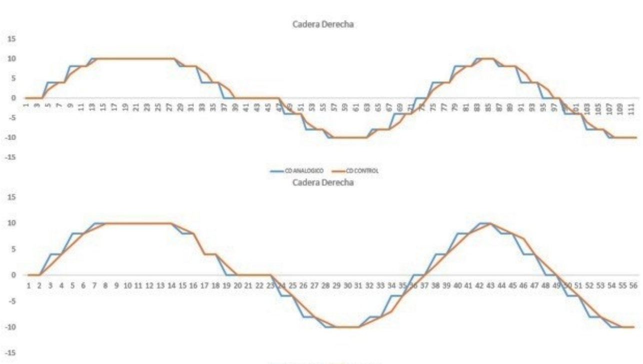
Figure 3. Exoskeleton picture.

C. Control

The control system implemented is proportional. It changes the control signal width of servomotors depending of the amplitude of error signal. This signal is calculated resting joint sensor data from desired user angle. Each joint control system was tested using sinusoidal signals with different periods. As an example, Figure 4 shows a tracking test result for the right hip joint where the rough line (blue) is the desired angle signal and the soft line (orange) is the controlled angle signal. Then, the joint control systems permit a trajectory tracking to different velocities and help soften joint movements. After all joint tests, error signal magnitude varies between 0º and 3º for the hip joints and between 0º and 2º for the knee joints.

Sennosides signals for a walking in suspension were used to probe the controller. As Belforte and others [5] say, it is possible to have a significant rehabilitation result applying this methodology, but a treadmill could be added below the patient to give him a tactile feedback.

Figure 4. A tracking result for the right hip joint.



Compared with other exoskeletons for gait rehabilitation of children [3] [9], the proposed design is simpler, smaller and with a control error acceptable if it is seen as an assistant robot that helps the patient to do movements.

IV. Conclusions

A conceptual design of an exoskeleton for gait rehabilitation was developed. This device contains electronics, mechanicals and software sections, which were tested using a mannequin of a child. All sections are interconnected by protocols that permit control and security in communications.

The graphical interface is friendly and easy to use. The user can control all the exoskeleton system through it, and he has real time information about movements and control processes of the machine.

Two hip joints and two knee joints are implemented. This four joints have soft movements thanks to the proportional joint control systems. It permits tracking trajectories at different velocities with an error less than 3º by joint.

In order to simulate different patient's weight, more laboratory tests are going to do using gait trajectories and variable link masses.

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