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Designing

Design and Control of an Active Wrist Orthosis for Rehabilitation

Zahra Vahabi[1], PhD; Ali Mokhtarian[2*], PhD; Mohammad Taghi Karimi[3], PhD; Faezeh Jahanshah[2], MSc; Reza Arefi[4], PhD student

[1]Department of Biomedical Engineering, School of Engineering, University of Isfahan, Isfahan, Iran
[2]Department of Mechanical Engineering, Khomeinishahr Branch, Islamic Azad University, Khomeinishahr/Isfahan, Iran
[3]Department of Orthotics and Prosthetics, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[4]Department of Mechanic Engineering, Babol Noshirvani University of Technology, Babol, Iran

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ABSTRACT

Background: In this study, an active orthosis has been designed to rehabilitate patients with weak wrist flexor and extensor muscles.
Methods: First, the mechanical design of the actuating mechanism with a linear servo motor to provide the desired wrist rotation, is performed in SolidWorks software. Also, to determine the force created by the actuator during flexion and extension of the wrist, the movement of the mechanism is simulated in Visual Nastran software. After molding the patient's wrist, the main body of the orthosis is made by forming the thermoplastic sheets on the mold, and the components of the mechanical part of the mechanism are installed on it. Then, the hardware part of the electronic circuits to drive the motor and to communicate between the control modules and the actuator is designed. For the programming of microcontrollers and synchronizing of deriver to the joystick, Bascom AVR software is used. The simulation of electrical circuit is performed in Proteus software and the printed board circuit is made in Altium Designer software.
Results: The results of applying this orthosis on the wrist of a healthy subject indicate its proper performance in creating an acceptable angle range for the wrist extension and flexion.
Conclusion: The use of the designed active wrist orthosis can improve the rehabilitation process of the patients with weakness in their wrist muscles.

Introduction

Weakness of the muscles of the wrist is one of the disabilities of the upper limbs that can be caused by stroke, spinal cord injuries and congenital diseases, as well as problems such as accidents and severe injuries [1, 2]. The proper rehabilitation of such patients is the result of the advances occurred in rehabilitation engineering and technical orthopedics in the field of designing and manufacturing orthoses. As known, orthoses are generally classified into active and passive categories [3-7]. However, the orthoses for rehabilitation of patients with inability to move their wrist are mostly passive. The NESS-H200 orthosis, the WREX orthosis and the WDWHO orthosis are the samples of such orthoses [8].

In this regard, Jahnsen et al. (1997) studied the effect of using a wrist orthosis on superficial electrography of wrist extensor muscles in healthy users during functional activities. They found that the use of wrist orthoses reduced the muscle activity of the extensor muscles (less than predicted) [9]. Johnson et al. (2004) examined the effect of wrist orthoses on forearm muscle activity. They showed that the wrist orthoses do not reduce the electrography activity of the flexor and extensor muscles

Corresponding author:* Ali Mokhtarian, Department of Mechanic Engineering, Islamic Azad University, Khomeinishahr Branch, Motahhari Street, Malek Shahr, Postal code: 8196797411, Isfahan, Iran. **Tel: +98 31 33660011-2333; *Email:* mokhtarian@iaukhsh.ac.ir, alimokhtarian@gmail.com

of the wrist during grasping the objects and doing works by hands [10]. Hu et al. (2012) evaluated the effects of an electromechanical wrist assisting robot with electrical neuromuscular stimulation for rehabilitation patients after stroke. The use of this robot improved movement accuracy. Also, electrical neuromuscular stimulation increased the activation of the wrist muscles and stopped the overactivity of the elbow muscles [11]. Arnold and Johnson (2017) designed a dinosaur-shaped wrist orthosis to restore the wrist extension and flexion range of motion to normal state [12]. Jackman et al. (2019) studied the immediate effect of a functional wrist orthosis on children with cerebral palsy or brain injury. They concluded that wearing a functional wrist orthosis does not immediately improve the ability of these children to grasp and drop objects [13]. Zhang et al. (2019) proposed a robotic assessment method for active wrist range of motion to determine progress in improving wrist function. This robotic system has an adjustable structure that allows multidimensional movements of the wrist [14]. Miller et al. (2019) studied the effect of repetitive magnetic stimulation combined with robotic training on wrist muscle activation after stroke. They observed the positive changes in the activation of the wrist extensor muscles [15]. Zhang et al. (2020) designed and analyzed the performance of a two-degree-of-freedom wrist rehabilitation robot driven by two pneumatic actuators. They showed that this robot can be widely used in the field of wrist rehabilitation [16].

Considering the available researches, very little research work has been done in the field of designing active wrist orthoses compared to classical and passive orthoses. However, the use of active wrist orthoses is inevitable for patients with severe weak wrist flexor and extensor muscles due to stroke, spinal cord injuries and congenital diseases, and problems such as accidents and trauma. According to a comprehensive search by the authors, no active orthosis that can cover both flexion and extension movements of the patient's wrist has never been designed and the existing active orthoses considering their mechanical structure and the electrical stimulus operation often cover only the wrist extension movement. In this regard, in the present study, the design and motion control of an active wrist orthosis with the ability to create wrist flexion and wrist extension of disabled people are conducted. An important feature of the proposed design is the wireless connection between the joystick and the servo motor deriver, which is created to facilitate the use of orthosis by the user. In the presented design, a mechanical mechanism and a thermoplastic body molded on the wrist are used to transfer and convert the linear motion of the servo motor shaft to the rotational motion of the wrist. The structural modeling and then the dynamic simulation of the motion of this assistant system has been performed in SolidWorks and Visual Nastaran softwares, respectively. Furthermore, the programming codes related to servo motor control and synchronization of system with the joystick are written in Bascom AVR software. Also, the electrical microcontroller circuit is simulated in Proteus software and the printed circuit board is created in Altium Designer and it is implemented on an actual board.

Methods

Mechanical Design of the Mechanism

Considering the allowable range of motion tasks of the wrist, the proposed orthosis should be able to create the rotation angle in the range of -40 to +40 degrees for the wrist [17]. In other words, assuming when the hand is in the direction of the forearm the angle of rotation is zero, it is necessary for the wrist orthosis to be able to rotate the hand 40 degrees below the forearm and 40 degrees above the forearm. For this purpose, a mechanism using a linear electrical actuator is designed to provide the desired rotational motion.

The optimal mechanical design of this mechanism, which means determining the position of the joints and the length of its arms, is conducted in SolidWorks software. The designed structural model with linear actuator is shown in Figure 1.

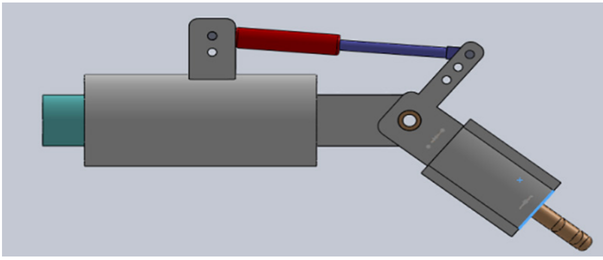

Figure 1: The mechanical model of wrist orthosis with actuator in Solid Works software

In the next step, the movement of the designed mechanism is simulated so that in addition to ensuring its efficiency, the minimum force and power required to move the wrist by the linear servo actuator is estimated. In this regard, the weight of the modeled orthosis (about 6 N) according to the density of the selected materials is calculated by the software and applied to the orthosis during the simulation. Also, using the anthropometric tables, the weight of hand is considered equal to 0.06% of total weight of body [18]. Ignoring the friction of the joints, the movement of the orthosis is simulated in the Visual Nastran software environment (Figure 2).

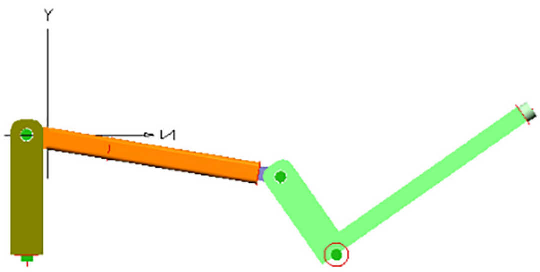

Figure 2: The view of orthosis motion simulation in Visual Nastran software

Figure 3 shows the force plot of linear actuator during wrist extension. During the simulation in this software, the actuating force reaches its maximum value in initial and final point of wrist extension phase. Actually, considering this value, the proper servo motor can be selected.

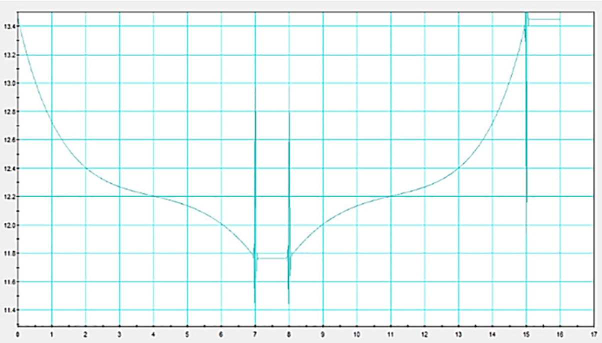

Figure 3: The force (Newton) applied by actuator versus wrist extension time (second)

As observed, the maximum value of force (about 13.5 N) is corresponded to initial and final points of time interval.

Obviously, in the case of wrist flexion, due to the positive effect of the earth's gravity and the creation of its torque in providing movement, a little force is required via the actuator.

Preparing the Mold and Making the Orthosis Body

In following, it is necessary to build the main body of the orthosis, which covers the wrist and the hand (The other parts of orthosis, including mechanical and electrical, are implemented on main body). For this purpose, the wrist and the hand as well as the forearm of user are first molded using medical plaster. After half an hour, the mold is gently released from the user by the relevant technician (such that it does not lose its shape) and prepared for the next step. At this stage, the inside of the mold, which is an empty space, is first filled with a mixture of plaster and water, and in order to facilitate the next steps of the operation, a rod is located inside the mold (Figure 4).

Figure 4: The prepared mold to form the thermoplastic sheet

After the mold is prepared, a thermoplastic (polypropylene copolymer type) sheet is formed around the specified parts on the mold shown in Figure 3. In this way, a 4 mm thick thermoplastic sheet is placed in a special heating device and heated to 180 degrees for a maximum of 7 minutes to become completely flexible. In the next step, the heated plastic sheet is wrapped around the mold and is tied with a cloth bandage to prevent air from entering until it cools down and takes the shape of the mold.

It should be noted that all the steps of molding and constructing of the main body of the orthosis have been performed in completely standard conditions in the orthotics and prosthetics laboratory of the Faculty of Rehabilitation Sciences of Isfahan University of Medical Sciences. After that, the orthosis body is cut into two parts, one part is attached and fixed to the forearm, and the other part is attached to the hand and it is movable. The connection of these two parts is done by using two suitable rotary joints on both sides of the wrist, so that the links of these joints are riveted on one side to the fixed part (located on the forearm) and on the other side to the moving part (connected to the hand).

Also, to hold the user's hand and forearm inside the orthosis, holding straps made of special adhesive fabric are used as shown in Figure 5.

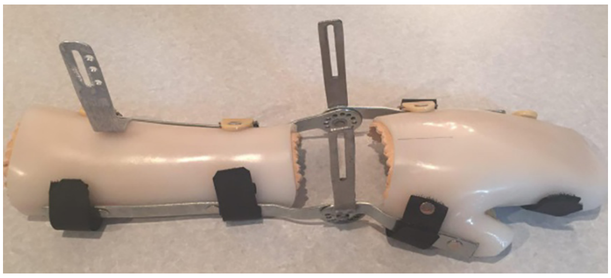

Figure 5: The main body of wrist orthosis with linkages and retaining straps

Design of electronic circuit

Two Atmega8 microcontrollers are used to control the linear servo motor of orthosis and to establish a wireless connection between the control unit and the driver.

To make it easier for the patient to use the wrist orthosis, a joystick handle with the ability to move gently in both up and down directions is considered, which is assembled on the control unit box of the orthosis (Figure 6). Utilizing the joystick handle, the user can control the wrist rotational movements during flexion and extension phases.

Figure 6: The joystick handle designed to control the movement of the orthosis (installed on control unit box)

The programming codes of servo motor control and joystick motion synchronization with the deriver are written in Bascom AVR software as well as the related electrical circuits are simulated in Proteus software. Also, the printed circuit boards are designed in Altium Designer software (as shown in Figures 7 and 8) then, they are implemented on an actual board.

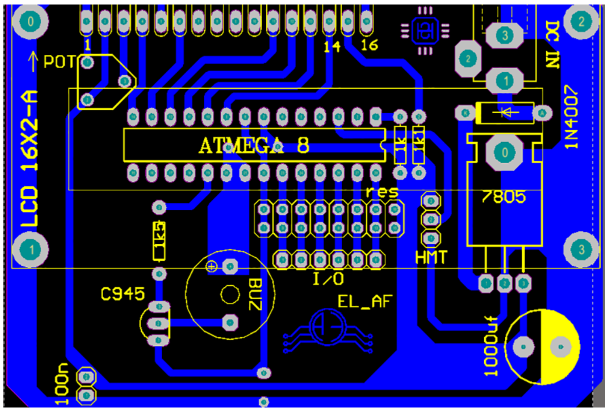

Figure 7: The printed circuit board of joystick motion synchronization with the deriver (installed in control unit box)

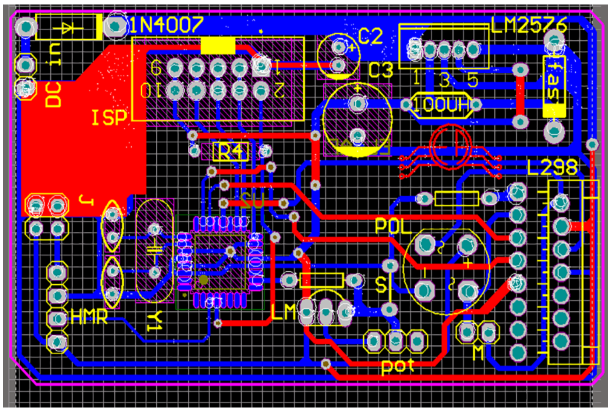

Figure 8: The printed circuit board of servo motor control (installed on orthosis body)

The electrical actuator installed on this orthosis is a linear micro-servo motor shown in Figure 9, that has the ability to be controlled linearly throughout its range of motion.

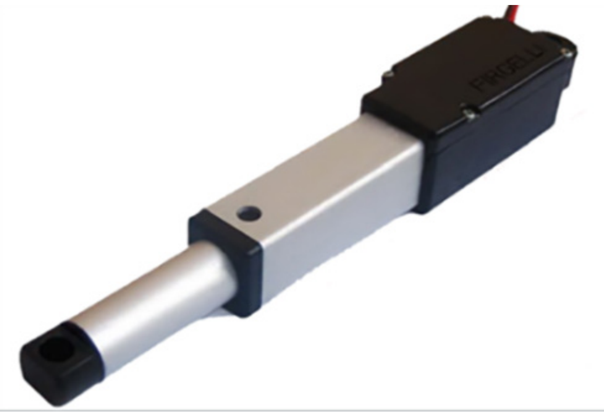
Figure 9: The linear micro-servo motor actuating the wrist orthosis

The movable shaft of the selected motor can be moved up to 5 cm relative to the fixed body. Also, this servo motor can apply force up to 5 pounds. The linear motion of the motor shaft and the relatively high force bearing due to have a gearbox with a conversion ratio of 1:63 as well as the appropriate physical dimensions are the reasons for using and choosing this type of actuator. Furthermore, the selection of servo motor is based on the maximum force and power (determined in Visual Nastran software) required to create the wrist extension and flexion throughout considered range of motion.

Figure 10 shows an image of the made prototype of active orthosis proposed in this study, with its electronic components.

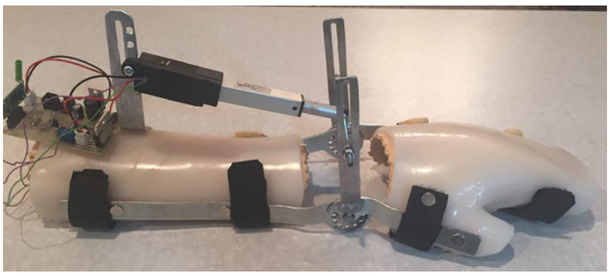
Figure 10: The proptotype of active wrist orthosis

In addition, a 16×2 character LCD display is installed on the orthosis control unit of the prototype to observe the direction of wrist rotation simultaneously with the movement of the motor shaft (Figure 11).

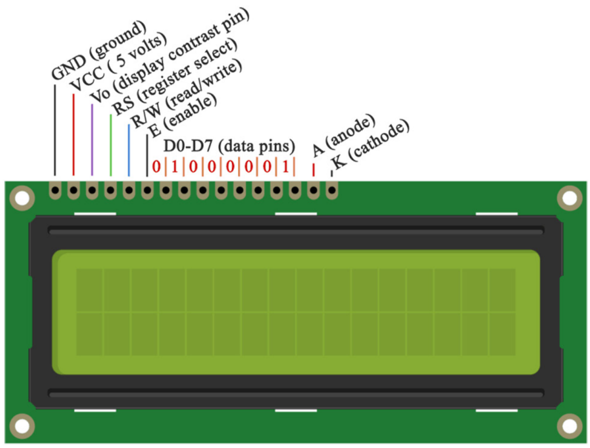

Figure 11: The 16×2 character LCD display (installed on control unit box)

Primary Evaluation

In this subsection, the experiments related to performance of device on the wrist of a normal subject (male, age 29 years, weight 70 kg, height 1.72 m) is described and the obtained results are examined. To do this, the orthosis is attached to the wrist of a healthy subject, and during two steps, the orthosis is moved in both extension and flexion directions of the wrist movement, and the final angle of the wrist rotation is measured using a conveyor. As shown in Figures 12 and 13, the provided orthosis covers the angle of rotation expected for the wrist correctly and completely in both the extension and flexion directions.

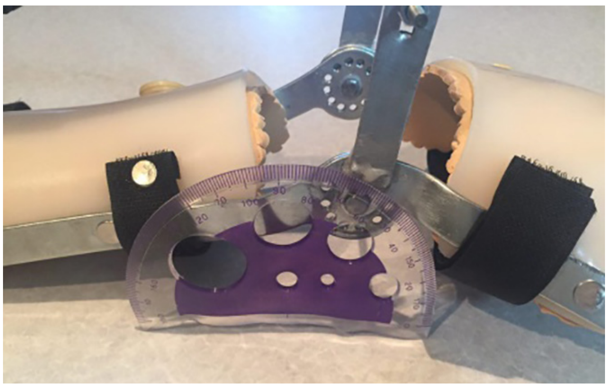
Figure 12: The measurement of the maximum orthosis rotation angle in the direction of wrist flexion

Figure 13: The measurement of the maximum orthosis rotation angle in the direction of wrist extension

Also, the performance of orthosis on wrist of healthy user is satisfactory and acceptable. Indeed, no unwanted interaction between wrist and orthosis is sensed by subject during flection and extension phases. In addition, as observed, the orthosis motion can be perfectly controlled by using joystick handle.

Conclusion

In this study, we designed, simulated, and constructed an active orthosis to rehabilitate and actually move the injured person's wrist in both flexion and extension directions. The active orthosis has the ability to be controlled and to be moved in two directions considering its biomechatronic structure. Also, in terms of ease of use, the system is designed and built in such a way that the patient can use this orthosis even at home or at work without the assistance of anyone.

In order to conduct research, orthosis was first designed and modeled in SolidWorks software. Then, the movement of the mentioned system was simulated in Visual Nastaran software and the required power of the linear servo motor was obtained and after optimizing the system structure, the appropriate actuator was selected. In following, the prototype of orthosis consisting of the main thermoplastic body and the components of the moving mechanism were made. In the next step, the orthosis motion microcontroller was programmed using Bascom AVR software and the electrical circuit was designed and simulated in Proteus software. Also, the printed circuit board was made in Altium Designer software and the required electronic components were assembled on the orthosis body. Finally, after completing all the above steps and eliminating a series of mechanical and electronic defects, the orthosis was placed on the wrist of a healthy user and the expected rotational movements of the orthosis were evaluated in both flexion and extension directions of the wrist. The results indicate the proper performance of the designed active orthosis on rotational motion of the wrist within the allowable range. As observed during the test, there is no undesirable interaction between user and orthosis, and the use of device with joystick handle is simple and comfortable for the normal subject. Also, the control of wrist motion can be perfectly performed by the user. Evaluating the use of this orthosis on the patients' wrist is one of the future research aims of the authors of this article.

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Conflict of Interests: None declared.

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