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Experimental Testing of a Prototype of an Active Elbow Orthosis Based on *in vivo* Investigation of Elbow Flexion/Extension of Healthy Subjects

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Abstract: *Many people have problems with elbow joint driving because of different diseases, sport trauma, road traffic injuries, etc. A good way for restoring elbow motions is a self-rehabilitation using an active orthosis. It has to be light, convenient for daily use, active, easy to control by patients, and safe. The paper presents a prototype of an active elbow orthosis. The plastic details were designed using a CAD system and were 3D printed. The joint was driven by a Dynamixel actuator. To increase the joint moment, a reduction gear-belt drive was constructed and applied. Experiments with six healthy subjects were performed using a Noraxon measuring system, aiming to investigate elbow joint angles in natural movements with four different velocities of elbow flexion and extension without and with a load of 0.5 kg in the hand. The four velocities (from very slow to very fast) were controlled by a specialized PC application. In order to achieve similar motions of the orthosis, the angle profiles were approximated so that the motion was between 10° and 120° because of electro/mechanical and software safety stoppers. Experiments were performed with the orthosis following the given angle profile without load and with a load of 0.5 kg. The results show that the orthosis' forearm performs the given angle and angular speed profiles with enough precision.*

Keywords: *Elbow, Active orthosis, Rehabilitation, Flexion/extension, Human experiments.*

Introduction

Many people have problems with elbow joint driving because of different diseases (stroke, osteoarthritis, bursitis, Parkinson, etc.), sport trauma, road traffic injuries, etc. [17, 19, 23]. The consequences include a decreased range of motion, pain, spastic muscles, unusual way of motion performing, uncomfortable way of living, even invalidation. A good way for restoring elbow functioning is a self-rehabilitation using an active orthosis [3, 7, 15, 20, 21] in the early stage of problem occurrence. It has to be mentioned that in Bulgaria technical devices for rehabilitation are rarely used [4, 18, 24]. In contrast to passive orthotic devices, an active orthosis can use electromyographic signals (EMGs) from the surface muscles [5] of the patient for device control. In this way the natural neurological control mechanisms of the brain which are damaged can be used, restored, and improved [2].

The driving system of an active orthosis can be electrical, pneumatic, or hydraulic. In this paper only reported devices using electrical motors will be considered since such driving is more perspective nowadays. The orthosis can use a direct drive, or reduction gears can be applied so as to increase the moment in the joint and at the same time use a motor with less weight and size. A table with exoskeletons used for rehabilitation which are electrically actuated and have from 1 to 18 active degrees of freedom (DOF) is presented in [22]. The driving systems contain DC motors or servo. Usually, few details about the used electrical motors are reported. The main problem in choosing such a motor is the interrelation between its power (moment), size, and weight. If the motor is small and does not have enough power to move the forearm and hand, reduction gears have to be constructed and added. If the motor is powerful enough, it will be with larger dimensions and bigger weight, but it has to be placed on the proximal part of the orthosis, and this will impede the independent usage of the orthosis by the patients. Detailed information about used motors and gears in reported active orthoses and corresponding scientific papers is usually missing [8, 9, 13]. More often series of Dinamixel motors are mentioned [6]. The moments, which have to develop the electrical motors, are also very rarely mentioned [14]. Despite the fact that in [2] exoskeletons are considered, it can be noticed that in this paper a 24 V Maxon Amax 22 DC motor is used, with a 333:1 Maxon planetary gear and a 4:1 worm wheel gear. According to the authors, the used DC-drive can generate a torque of about 16 Nm.

Our intention has been to develop an active wearable elbow orthosis for rehabilitation with one DOF, light enough so that the patients could use it independently by themselves, driven by an electrical motor and with battery power supply. The orthosis has to be safe and have an easy to use set of programmes for rehabilitation, i.e., with a set of motions with predefined angle displacement and velocities and ranges of motions. The aim of the present study is to test the designed prototype of an active elbow orthosis performing flexion/extension motions with 4 different angle velocities (from very slow to very fast) in accordance with the angle trajectories experimentally recorded from natural experiments with six healthy subjects.

Materials and methods

Mechanical design of the orthosis

The elbow joint is a complex one and allows two independent motions – flexion/extension and pronation/supination. For the purposes of rehabilitation, an elbow orthosis can have only one DOF – flexion/extension, the natural range of which is around 150°. Pronation/supination can be limited by the device. The proposed prototype of an active elbow orthosis consists of two light ergonometric plastic parts – arm and forearm – designed using a CAD programme and printed by a 3D printer. The lengths of the arm and forearm of the orthosis are chosen according to mean values of human upper limb segments [10]. Their lengths are 241.6 mm for the arm and 229.5 mm for the forearm. The weights of the two parts (without motor, gear, etc.) depend on the material used for printing, and in the current variant they are 227 g for the arm and 203 g for the forearm. There is no option to adjust the current lengths according to the individual subject sizes. Three prototypes with three different sizes (small, medium, and large) are planned to be made in the future. The two parts form a rotation joint connected by a toothed-belt reduction gear, which provides reverse rotation movements induced by the motor

(Fig. 1). The gear ratio can vary, depending on the patient's needs, by changing the sizes of the gear wheels.

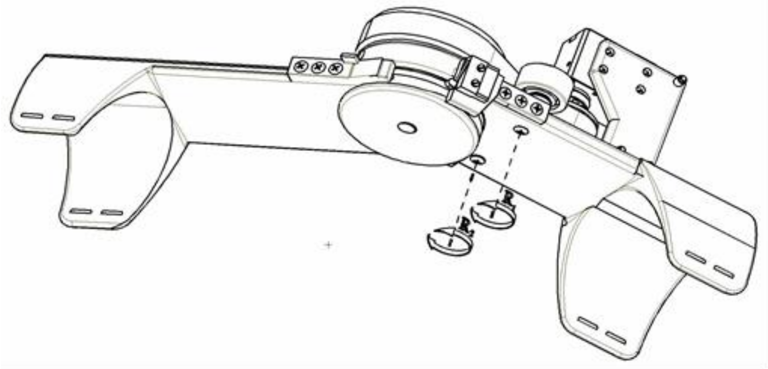
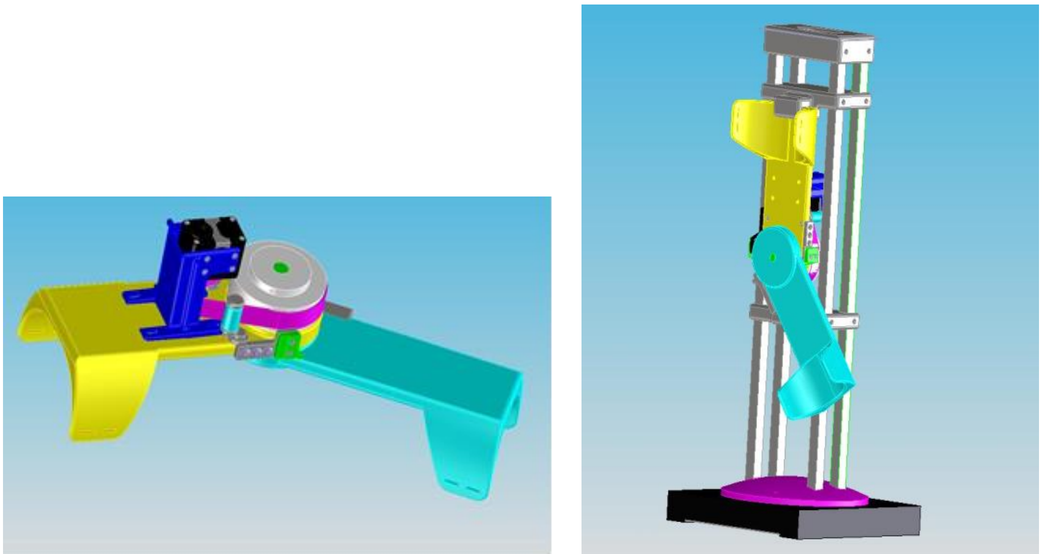


Fig. 1 A general view of the orthosis prototype
with marked movement of the eccentric compensators which stretch the belt

The orthosis is driven by an electric motor, which is placed in a specially designed holder (Fig. 2A) constructed in such a way that if some mechanical conflicts occur, it has to be broken. In this way the limb of the patient will be additionally protected from undesired loads and eventual trauma.



A) B)

Fig. 2 CAD views of the elbow orthosis:
A) the two parts (arm and forearm) with the gear and motor in its holder;
B) the orthosis on the stand.

One of the wheels of the rotation module is fixed on the motor axis, and another one is bearing with the help of a rotary node that consists of two radial bearings, thus aiming to remove all clearances of the bundle details. The two wheels are connected with a flexible timing belt. Two eccentric role compensators are added in the kinematic chain. Their role is to compensate optimally the length of the tooth frame. By adjusting these eccentric compensators, it is possible to adapt the orthosis to the respective patient by changing the gear ratio by replacing one or both gears, without a need to change the length of the timing belt (Fig. 1). A special stand was designed (Fig. 2B) in order to fix the orthosis when it is not in use, or when different experiments are performed.

The designed bundle has a maximal loading of 7.5 Nm and allows a working range from 10° to 130°. For safety, hard and electrical stoppers are installed at the two angle ends. All these details are installed on the device arm so that the orthosis forearm is able to move without additional loading within the angle limits (Fig. 2A). The two links of the orthosis are fixed to the human arm and forearm by Velcro; the axis of flexion/extension in the elbow coincides with the axis of the motor. There are special holes in the plastic parts for Velcro transmission and fixing. The orthosis can be used both for left and right arm by placing the stopper in different positions.

Control systems of the orthosis

The orthosis is controlled by a hierarchical three-level control system. The main requirements to such a system are:

- Safe-for-health voltages and currents;
- Additional safety to mechanics;
- Sufficient torque;
- Suitable dimensions and weight;
- Real time motion PID control;
- Easy access to orthosis position, speed, current, and other system parameters;
- A rich set of drive and operating modes;
- Precise control possibility in different modes.

Some of these requirements are described in [1, 16]. Each of these levels has its own microcontroller module with the appropriate software. The lower level of the control system is an electrically driven actuator Dynamixel XH430-W350-T, named below “servo” [1, 11]. The purpose of the servo is to drive the mechanics of the orthosis in accordance with the chosen motion law. It consists of a digital absolute encoder, a local controller with communication capabilities, a motor driver, a reduction gear, and a mechanical structure allowing easy installation and wiring. Its main features are:

- Power supply: 12 V DC;
- Stall torque: 3.4 Nm;
- Accuracy: 0.088 deg/encoder pulse;
- Weight: 82 g;
- Dimensions: 28.5 × 46.5 × 34 mm.

All low level software (firmware) is written by the manufacturer and is located in the servo flash memory. The access to the firmware is carried out through a serial link with a possible speed of up to 4.5 Mbps. A basic tool for servo programming is the control table. The control table is a structure that consists of multiple data fields to store the status or to control the device. Users can check the current status of the device by reading specific data from the control table with read instruction packets. Writing the instruction packets enables users to control the device by changing specific data in the control table.

Due to additional safety considerations, the current-based position operating mode has been chosen. The block diagram of the PID regulator is shown in Fig. 3 [11]. For the purposes of the experiment, as well as to ensure a smooth movement, a time-based profile with an S-curve for the angle profile and a trapezoid form for the velocity profile have been chosen (Fig. 4) [11].

The middle level of the control system is an OpenCM 9.04 microcontroller [1, 12]. The purpose of this level is: a) to communicate with the upper level for programming and data transfer, and b) to store the programme and data and to control the servo. It is available with Arduino IDE development environment that are offered with API functions, sufficient for lower level control. OpenCM 9.04 communicates with the servo through a TTL serial link and with the upper level via an USB.

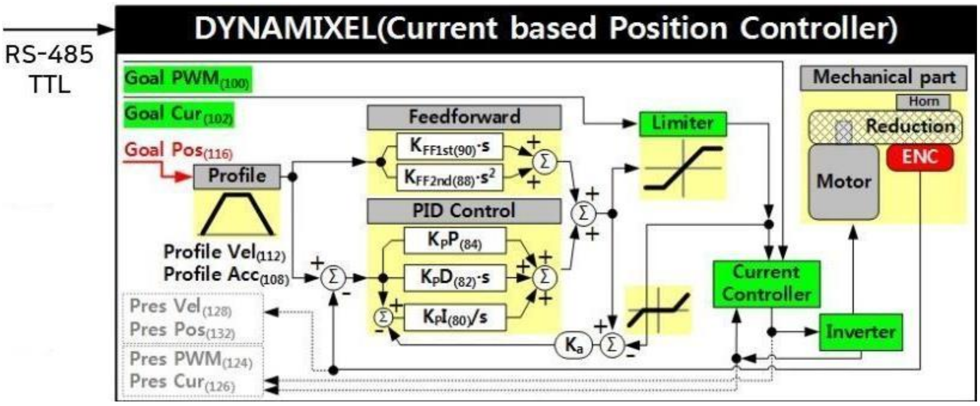


Fig. 3 Block diagram of the PID regulator (current-based position mode)

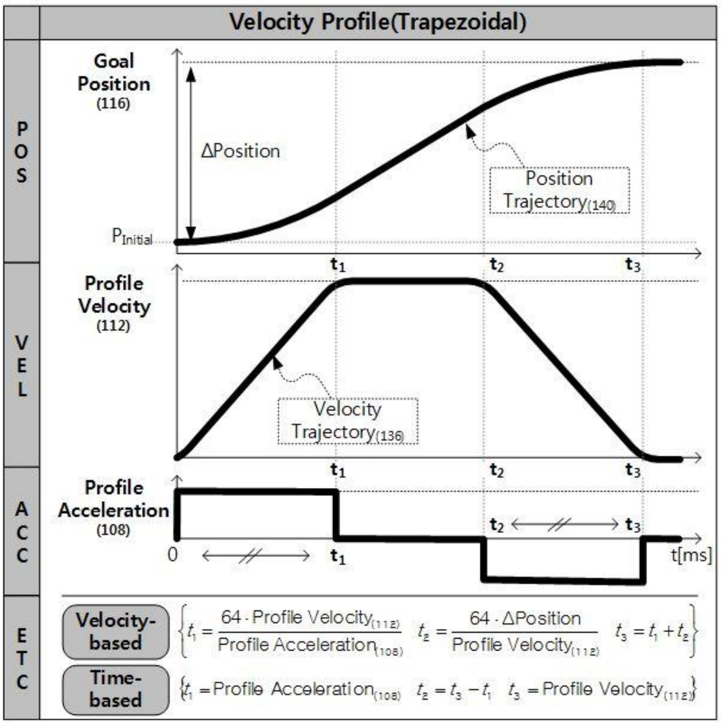


Fig. 4 Position, velocity, and acceleration profiles applied to XH430-W350-T

The upper level is a personal computer with installed Arduino IDE [1] with appropriate libraries. It serves for OpenCM 9.04 programming and for user interface. The user interface may be realized by any Windows/Linux/Android, etc., terminal application or by stand alone human-machine interface. After the start of the current experiments, data were collected every 100 ms. The experimental results were received and saved as "tab" separated values in text files.

In Fig. 5 the prototype of the orthosis together with the control module is shown. The weight of the orthosis together with the actuator and motor holder is about 1.150 kg.

Fig. 5 The orthosis prototype

Experiments with healthy subjects performing flexion/extension motions in the elbow joint with four different velocities

The aim of the experiments was to investigate the way the elbow angle changed during full elbow flexion/extension motions in the sagittal plane with different velocities – from very slow to very fast. Only healthy people were investigated.

A 2D flexible goniometer connected to the Telemyo system of Noraxon was used for the experimental measuring of the elbow joint angle. It was capable of measuring the angle in the range of -/+ 150° with an accuracy of 2°. Its two plastic parts were attached to the subject's arm and forearm by using kinesiotape. These parts were attached over the lower lateral third of the humeral bone and the upper third of the radial bone. The intermediate flexible part of the goniometer, which was sensitive to tension and bending, was placed over the elbow joint, which was slightly stretched. The signal from the goniometer was transmitted wirelessly to the computer and recorded for further off-line processing.

An experimental protocol had been set up to describe the number of motor tasks that should be performed, the number of repetitions, and the sequence of exercises. Each experimental record lasted one minute, and before starting the experiments, the goniometer was calibrated. Then, during this time period, as many as possible repetitions of elbow flexions and extensions in the sagittal plane were performed. For this purpose, the volunteers sat comfortably on a chair without armrests. The two feet were firmly placed on the floor, the shoulders were on the same level, and both arms were freely relaxed beside the body. At a sound signal, participants began to perform steady elbow flexion with a thumb pointing upward, held the final upper position for 5 s, and then again evenly and gradually released (extended) the limb to the starting position.

A specialized application on a PC with light and sound signals was run for each motor task. When a movement was required, the computer screen flashed in green, and when a posture was required, the screen flashed in red, and a counter counted down the seconds of the movement mode in reverse order. The movement task always started with a 5 seconds rest interval; then for 10, respectively 6/2/1 seconds the subject performed elbow flexion;

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after reaching the maximal angle, there was a 5 seconds interval for maintaining the final upper position; then again for 10, respectively 6/2/1 seconds the subject performed elbow extension, followed by 5 seconds rest in downward position. In this way four motor tasks with four different flexion/extension velocities were performed. Then the same protocol started again, but with an anatomically shaped weight of 0.5 kg attached to the right wrist.

Overall, six right-handed volunteers took part in the experiments. They personally filled in an informed consent form and declared that they did not have any neurological or traumatic disease.

To approximate the law for control of the motor of the orthosis from the recorded experimental angles, four points were calculated for one movement task with 4 different velocities – beginning of the motion, end of the flexion, beginning of the extension, and end of the movement task (Fig. 6). The same approximation was made for motor tasks with a weight of 0.5 kg. Based on these 6 curves, a mean curve was approximated (black bold line) and was taken as input for the control system of the motor. It has to be noted that the approximated curves started at 10° and ended at 120° in order to avoid the end stopper switching off. However, the figures given below start from relative zero angles for the forearm.

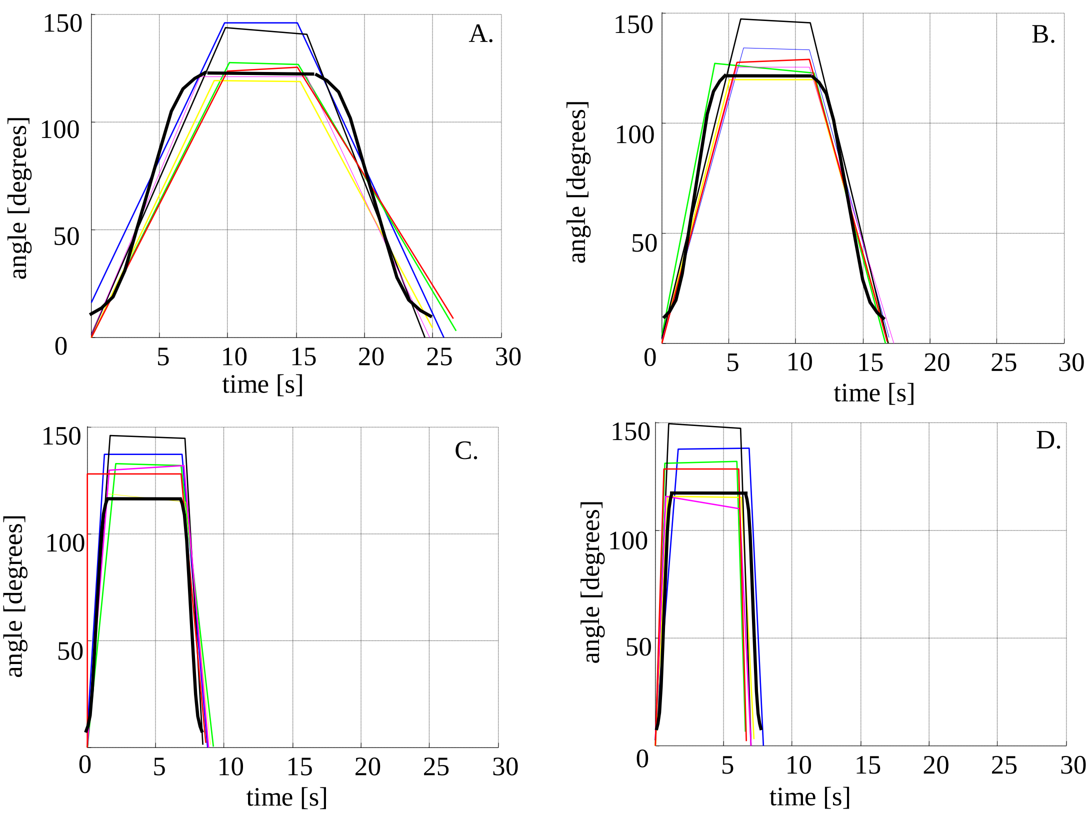
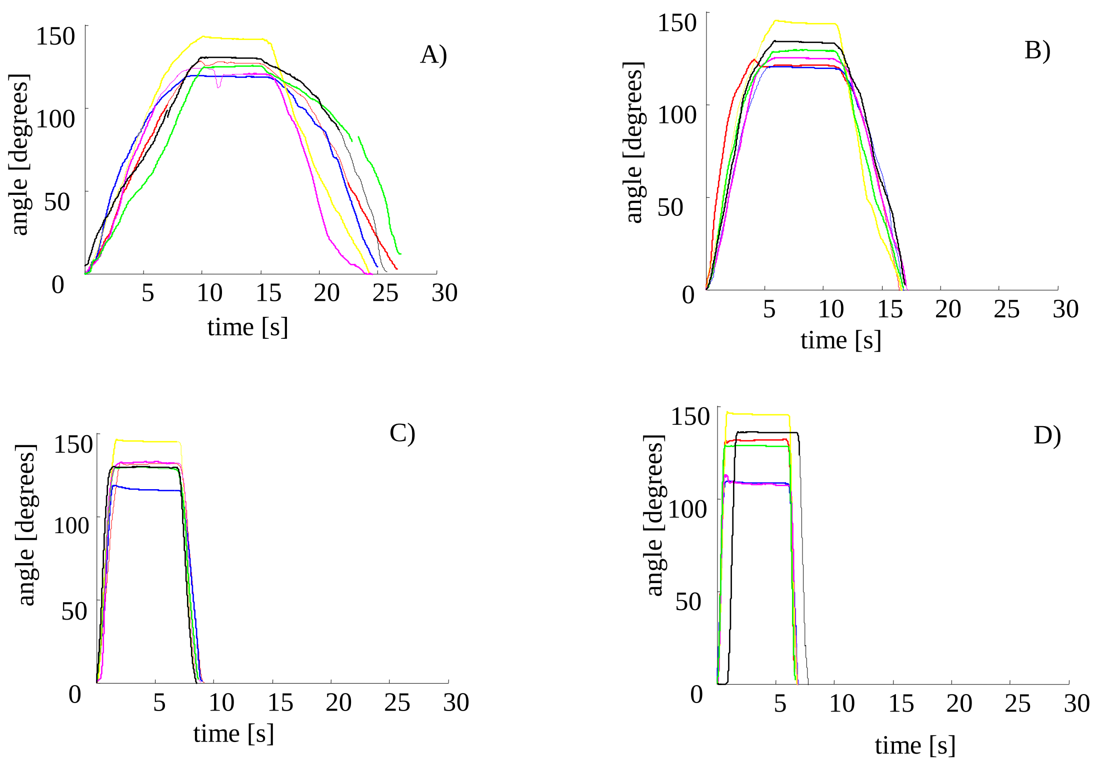


Fig. 6 Approximation of the law for angle change of the orthosis axis for the four flexion/extension velocities. Coloured lines represent data from the six experimental subjects. The bold black line represents the angle of the orthosis. A) 1st speed, B) 2nd speed, C) 3rd speed, D) 4th speed. All movements here are without load.

Results and discussion

Six healthy volunteers participated in the experiments – 3 males and 3 females. The mean age was 48 years. For each one-minute experimental record, only one movement task (flexion-rest-extension) was chosen visually and manually. The so chosen angle curves for flexion/extension motions with the four velocities given via the monitor, without and with load, are shown in Fig. 7. As can be seen, the different subjects performed the movement tasks similarly. The motions with fewer velocities were less graceful. The maximal range of the elbow motion was about 150°, and the mean value of the elbow angle was about 135°. During rest position in maximally flexed forearm, the angle became to decrease slightly, probably because of eventual fatigue. There were no visible differences between movements without and with load (Fig. 7) (first row versus second row).

However, the influence of the speed of motion was very well visible in Fig. 7. To illustrate this more clearly, the mean values are given in Fig. 8. The time for performing flexion and extension were nearly the same. These times decreased significantly when the speed of motion increased. A definite conclusion about the influence of the load could not be made. As for the mean values of the angle speed (Fig. 7B), there were more differences between flexion and extension. These values were higher for extension, probably due to the influence of the gravity forces, which tended to return the hand in vertical position, while during the flexion the muscles worked anti-gravity.



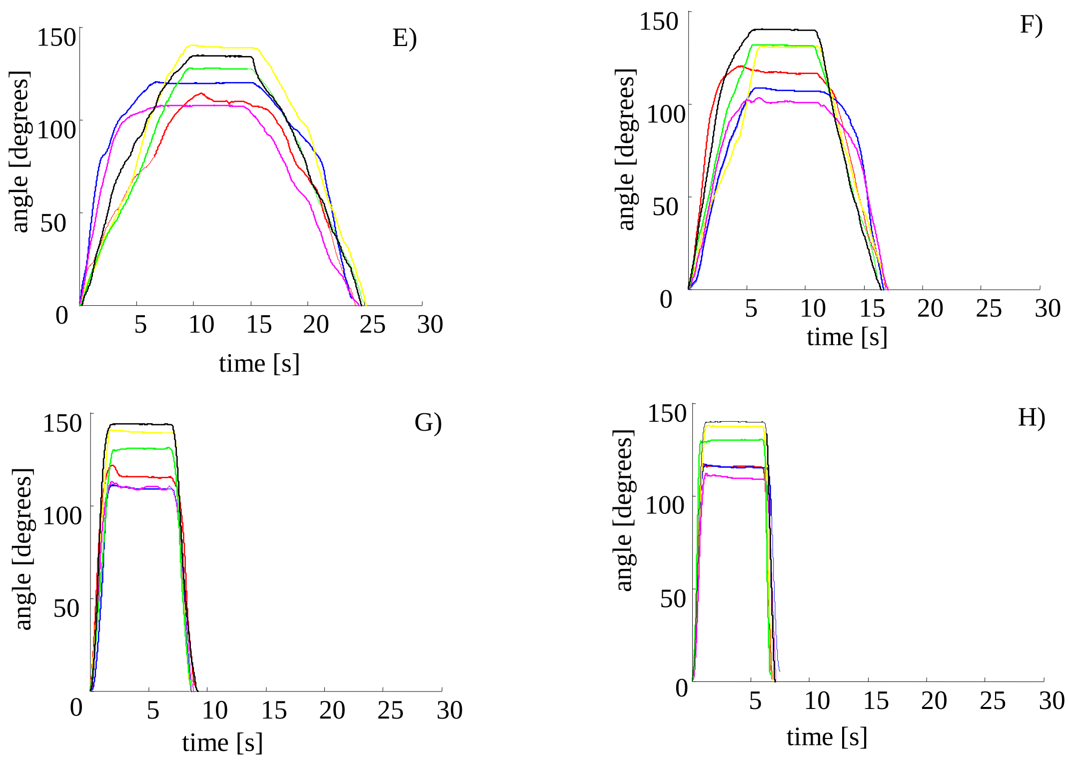


Fig. 7 The angle curves for the 6 experimental subjects (marked with different colours) during movement tasks with the four different velocities of the flexion\extension without load and with load of 0.5 kg. A) 1st speed, B) 2nd speed, C) 3th speed, D) 4th speed, E) 1st speed with load, F) 2nd speed with load, G) 3th speed with load, H) 4th speed with load.

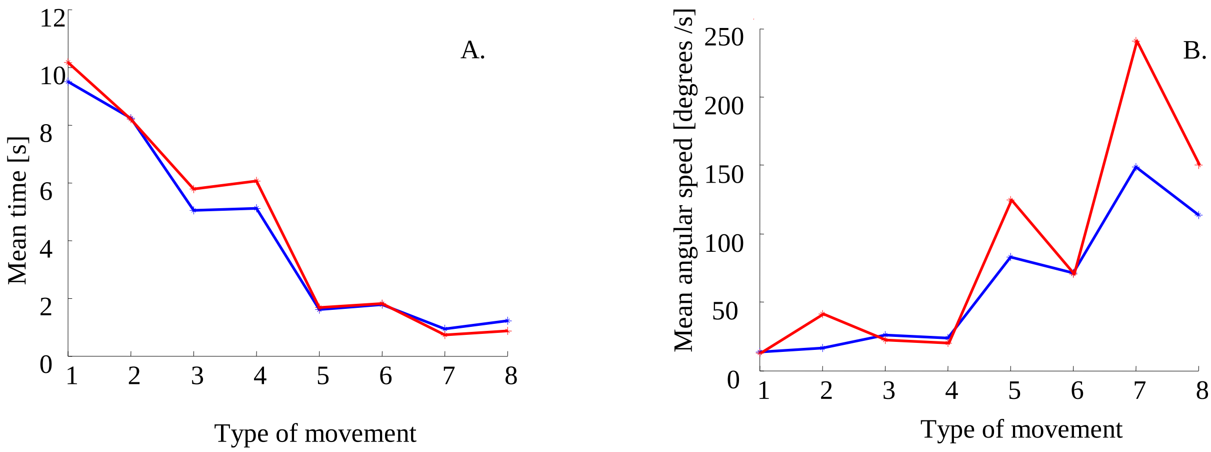
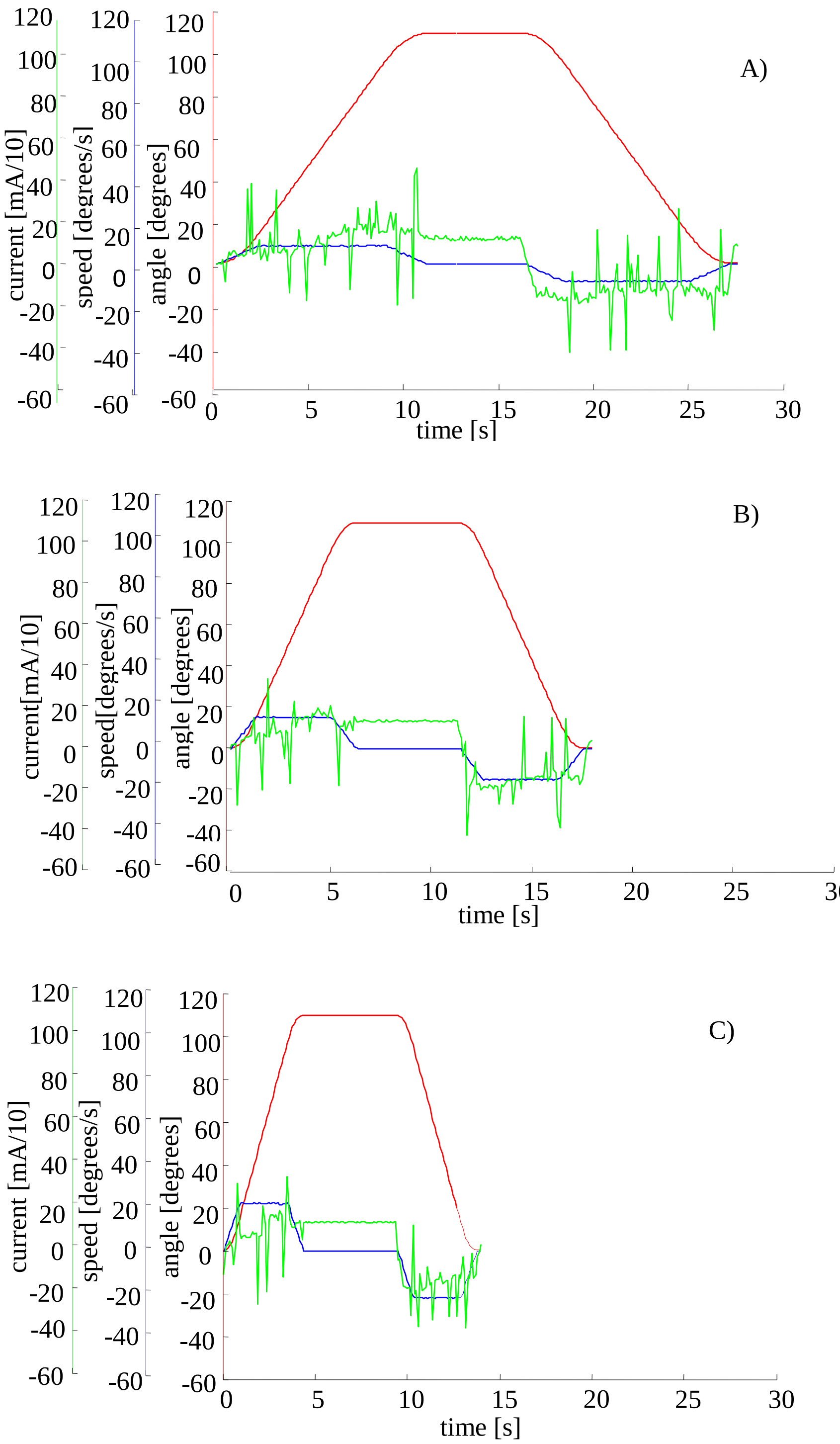


Fig. 8 Mean values for all subjects for different motion velocities without and with load:
A) – mean values of the movement time (flexion – blue, extension – red);
B) – mean values for motion speed (flexion – blue, extension – red). Horizontal axis: 1 – 1st speed, 2 – 1st speed with load, 3 – 2nd speed, 4 – 2nd speed with load, 5 – 3th speed, 6 – 3th speed with load, 7 – 4th speed, 8 – 4th speed with load.

In Fig. 9 the output data from the actuator are presented – angle, angular speed, and motor current. These data are presented for four different values of the time for flexion/extension.

The acceleration and deceleration times are 20% of the full time span. The data are given from a relative zero angle of the encoder (approximately 10° between the forearm and vertical axis). The forearm of the orthosis always stops at 120° and rests for 5 s. The data with load were very similar. It has to be mentioned that experiments with a load of 2 kg were also performed, but the smoothness of the motion was not satisfactory. As can be seen in Fig. 9, the angle trajectories are very smooth and approximate well the human motions (Fig. 9 versus Fig. 7). The angular speed curve is also graceful and in accordance with Fig. 4. Due to real time compensation of admissible clearances in the mechanics and the belt drive, the current has positive and negative peaks (green lines in Fig. 9).



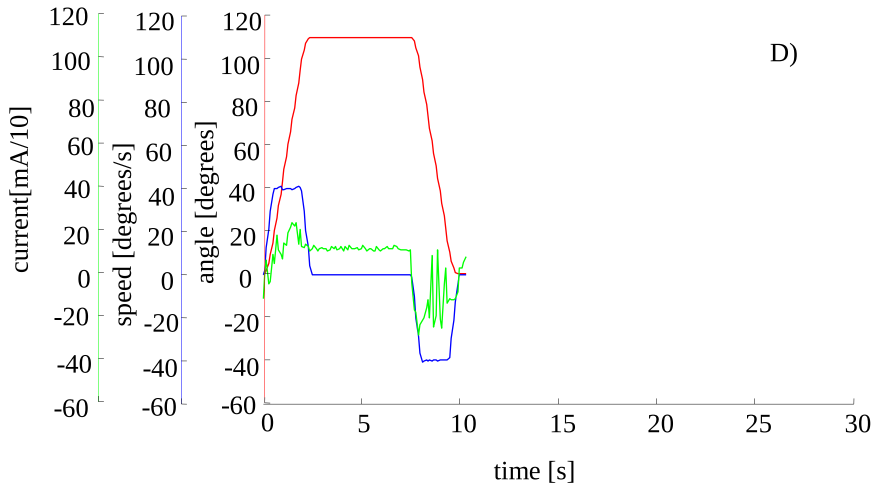


Fig. 9 Angle, angular speed, and current as output from orthosis motor for four different time durations: A) Motor task duration 11.5 s, time for acceleration and deceleration 2.3 s; B) Motor task duration 6.5 s, time for acceleration and deceleration 1.3 s; C) Motor task duration 4.5 s, time for acceleration and deceleration 0.9 s; D) Motor task duration 2.5 s, time for acceleration and deceleration 0.5 s.

Conclusion

The aim of the presented work was to verify experimentally the developed prototype of an active elbow orthosis driven by an electrical motor. The orthosis has one degree of freedom – flexion/extension, while the second degree in the elbow, pronation/supination, was not allowed. The lengths of the arm and forearm of the orthosis cannot be changed, but different means are provided for adapting the orthosis moment to the individual needs, such as eccentric compensators and different sizes of the reduction gear. This variant of the orthosis had a gear to increase the moment in the joint. The gear, however, provokes noise in the control system, and in future this will be avoided by removing the gear, since there already exist Maxon motors with similar weight and size but with bigger moment. It is also intended eventually to take electromyographic signals from the main elbow flexors and extensors and to use them as control signals after suitable processing.

The experiments with people performing flexion/extension motions in the sagittal plane, without and with a load of 0.5 kg, with four different velocities, have shown that all people perform these movements similarly. Such movements are basic for rehabilitation of the upper limb. The mean values of the duration of the flexion and extension and the mean value of the respective speed (Fig. 8) have allowed us to approximate well a trapezoidal law for motor speed (Fig. 4) and a respective S-curve for angle displacement. This ensures the graceful movement of the forearm of the orthosis.

Two of the output parameters of the encoder (angle and angular speed) are smooth and in accordance with our expectations. The current, however, has positive and negative peaks during acceleration and deceleration, which is unacceptable. It has to be noted that during the 5 s rest period the current is also smooth enough (Fig. 9). We think that the fluctuations in the current are due to the effects of the mechanical construction, mainly because of the presence of reduction gears. That is why, the next variant of the orthosis will be constructed with an actuator that is powerful enough so that the reduction gears will be avoided, and the forearm and hand of the patient will move even more easily and smoothly.

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References

1. Angelova S., P. Raykov, E. Petrov, R. Raikova (2021). A Prototype of an Active Elbow Orthosis – Problems of Mechanical Design and Orthosis Control, Series on Biomechanics, 35(3), 3-11.
2. Benitez L. M. V., M. Tabi, N. Will, S. Schmidt, M. Jordan, E. A. Kicherner (2013). Exoskeleton Technology in Rehabilitation: Towards an EMG-Based Orthosis System for Upper Limb Neuromotor Rehabilitation, Journal of Robotics, Article ID 610589.
3. Burgar C. G., P. S. Lum, P. C. Shor, H. F. Van der Loos (2000). Development of Robots for Rehabilitation Therapy: The Palo Alto VA/Stanford Experience, Journal of Rehabilitation Research and Development, 37(6), 663-673.
4. Chakarov D., M. Tsveov, I. Veneva, P. Venev (2018). Development of an Upper Limb Exoskeleton for Rehabilitation and Training, Series on Biomechanics, 32(4), 11-18.
5. Copaci D., D. Serrano, L. Moreno, D. Blanco (2018). A High-level Control Algorithm Based on sEMG Signaling for an Elbow Joint SMA Exoskeleton, Sensors, 18, 2522.
6. Dallali H., E. Demircan, M. Rastgaar (Eds.) (2020). Powered Prostheses. Design, Control, and Clinical Applications, Elsevier Inc., Academic Press.
7. Herr H. (2009). Exoskeletons and Orthoses: Classification, Design Challenges and Future Directions, Journal of Neuro-engineering and Rehabilitation, 6:21, https://doi.org/10.1186/1743-0003-6-21.
8. Hoppe-Ludwig S., J. Armitage, L. K. Turner, M. K. O'Brien, C. K. Mummidisetty, L. McGee Koch, M. Kocherginsky, A. Jayaraman (2021). Usability, Functionality, and Efficacy of a Custom Myoelectric Elbow-wrist-hand Orthosis to Assist Elbow Function in Individuals with Stroke, Journal of Rehabilitation and Assistive Technologies Engineering, 8, 20556683211035057, https://doi.org/10.1177/20556683211035057.
9. http://myomo.com/wp-content/uploads/2017/12/MyoPro-2-Motion-G-Full-Manual.pdf (Access Date June 6, 2022).
10. https://biomed.bas.bg/en/projects/motco/data/ (Access Date June 6, 2022).
11. https://emanual.robotis.com/docs/en/dxl/x/xh430-w350/#control-table (Access Date June 6, 2022).
12. https://emanual.robotis.com/docs/en/parts/controller/opencm904/ (Access Date June 6, 2022).
13. https://myomo.com/what-is-a-myopro-orthosis/ (Access Date June 6, 2022).
14. Kyrylova A. (2015). Development of a Wearable Mechatronic Elbow Brace for Postoperative Motion Rehabilitation, Ph.D. Thesis, The University of Western Ontario, https://ir.lib.uwo.ca/etd/3019/.
15. Lehneis H. R. (1968) Application of External Power in Orthotics, Orthotics and Prosthetics, 22(3), 34-45.
16. Petrov E., S. Angelova, P. Raykov (2021). Active Elbow Orthosis Actuator Control, Automation of Discrete Production Engineering, Technical University – Sofia, 3, 177-180 (in Bulgarian).
17. Picelli A., S. Tamburin, M. Passuello, A. Waldner, N. Smania (2014). Robot-assisted Arm Training in Patients with Parkinson's Disease, Journal of Neuro-engineering and Rehabilitation, 11, 28, https://doi.org/10.1186/1743-0003-11-28.

18. Raikova R., K. Tahtakov, V. Chakarov (2011). Technical Device for Prevention of Spinal Column Disorders. Pilot EMG Study for Estimation of Back Muscle Activity, International Journal Bioautomation, 15(2), 115-130.
19. Ravalli S., C. Pulici, S. Binetti, A. Aglieco, M. Vecchio, G. Musumeci1 (2019). An Overview of the Pathogenesis and Treatment of Elbow, Journal of Functional Morphology and Kinesiology, 4(2), 30, https://doi.org/10.3390/jfmk4020030.
20. Ripel T., J. Krejsa, J. Hrbacek, I. Cizmar (2014). Active Elbow Orthosis, International Journal of Advanced Robotic Systems, 11(9), 143, https://doi.org/10.5772/58874.
21. Rzyman G., J. Szkopek, G. Redlarski, A. Palkowski (2020). Upper Limb Bionic Orthoses: General Overview and Forecasting Changes, Applied Sciences, 10(15), 5323.
22. Tiboni M., A. Bordoni, R. Faglia, N. Pellegrini (2018). Robotic Rehabilitation of the Elbow Based on Surface Electromyography Signals, Advances in Mechanical Engineering, 10(2), 1-14.
23. Xu G., A. Song, L. Pan, H. Li, Z. Liang, S. Zhu, B. Xu, J. Li (2012). Adaptive Hierarchical Control for the Muscle Strength Training of Stroke Survivors in Robot Aided Upper-limb Rehabilitation, International Journal of Advanced Robotic Systems, 9(4), 122, https://doi.org/10.5772/51035.
24. Zahariev R., N. Valchkova, G. Angelov, Y. Paunski (2019). Robots for Help in Pedagogy and Rehabilitation: Cyber-physical Systems for Pedagogical Rehabilitation, 20th International Conference on Computer Systems and Technologies, CompSysTech'19, ACM Conference Proceedings Series, 1-7.

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