**Complex Control Systems**
**ISSN 1310-8255** **Proceedings of the International Scientific Conference "Robotics & Mechatronics 2023"**

# Autonomous Controller for an Active Elbow Orthosis

Emil Petrov[(1)], Silviya Angelova[(2)] , Plamen Raykov[(1)] and Yasen Paunski[(1)]

[(1)]Institute of Robotics, Bulgarian Academy of Sciences, Sofia, Bulgaria
[(2)]Institute of Biophysics and Biomedical Engineering, Sofia, Bulgaria

***Abstract*-This paper describes a prototype of an autonomous controller for an active elbow orthosis. Until now the experiments with such an orthosis were conducted with the permanent use of a personal computer as a means of parameterization and control of the execution. For its (orthosis) use as a real rehabilitation tool, it was necessary to develop an autonomous control device that allows both parameterization by a physiotherapist and independent work in the patient's home. This article describes a prototype of such a controller and its function in the two main ways - parameterization and autonomous operation, with or without electromyographic feedback. A parameterization dialogue is presented.**

***Keywords*—Active elbow orthosis, autonomous controller, electromyographic feedback.**

## I. INTRODUCTION

The statistics for 2021 indicate that there are 654 547 persons in Bulgaria with recognized permanently reduced working capacity or degree of disability [1]. Despite the high rate of disability in poor countries, it appears that they are the ones with the lowest allocation of health care resources [2]. Poor financing of health care leads to a number of problems with access to rehabilitation services, which, if any, are woefully inadequate. In the end, it turns out that the person in need receives most of the care from a family member who has to balance work and the dependent relative [3]. This support remains unsatisfactory as it is linked to specific needs.

Teasel et al. [4] made a randomized research that shows that 2/3 of rehabilitation approaches in the chronic phase after stroke (one of the most common diseases) are associated with improvement in motor function. In search of a solution to improve home rehabilitation of motor skills, not a few scientific groups provide technological solutions in the form of robotic movement devices. Most of them are passive [5],[6],[7], but the most modern technical devices for rehabilitation are the active ones – robots, active orthoses and exoskeletons. Elbow orthosis usually has one degree of freedom and allow performing flexion and extension. McBean and Narendran [8],[9] hold patents of several developed active orthoses. The first device could be used for upper and lower limb even with existing tremor and muscle plasticity. The control is proportional to the own surface electromyographic signals. The next mentioned device is controlled by EMG signals again and is directed for improving the functional capacity of the elbow joint. It also has feedback from at least one EMG sensor and can be used even when EMG signals of some muscle miss. Self-directed use of these devices undoubtedly benefits the patient, but personalized impact is key to addressing the individual sufferer's problems. Fregly et al. conclude that the biggest technical gap is in personalized neural control and recovery models [10]. For clinical practice where highly unique patient characteristics are involved during all the long cure, stereotypical treatment design is likely to yield variable functional outcomes.

For its use as a real rehabilitation tool, it was necessary to develop an autonomous control device (ACD) that allows both parameterization by a physiotherapist and autonomous work in the patient's home. The ACD for AEO is designed to control its mechanics in two modes - without using an electromyographic (EMG) feedback signal and on/off using an EMG signal from a single surface flexor muscle - muscle biceps brachii - to start the movement.

## II. ACD PROTOTYPE HARDWARE

The ACD consists of an integrated actuator of Dynamixel family [11] (Fig.1.), AEO microcontroller OpenCM 9.04 [12] (Fig 2.) located on the mechanics of the orthosis and a Power Interface Module located (PIM) in a separate box that can be placed on a desktop or attached to a patient's belt. The actuator and controller assembly has been described in [13] and will not be discussed here. PIM consists of a lithium-ion battery GENS ace B-25C-2200-3S1P-PT and interface elements, including:

- A mechanical structure (housing) allowing the emplacement of the battery and below-listed components in it and suitable both for placing on a desktop and for attaching to a patient's belt. A foil with text and graphic legends (Fig.3.) is placed on its front with explanations of the meaning of the elements located on it;
- Two-position latching switch with double contact system for turning on the power supply;
- Hardware LED indicator for power on;
- Two-position lever self-locking switch (ES) for submitting an execution command to the controller;
- LED indicator for work flow (WF) of ACD;
- Two-position lever self-locking switch for setting the way of use (WUS) of the ACD – parameterization or autonomous work;
- Two-position lever self-locking switch for setting the autonomous operation mode of the ACD – hard control without EMG feedback or On/Off control with EMG feedback;
- Potentiometer for determining the current threshold (CTP) for EMG control. Such a potentiometer is a must because the

surface EMG signal could be different: (a) when the electrodes are displaced, (b) applying the electrodes in a place even slightly different from that where they were placed by the physiotherapist, (c) interelectrode distance, (d) the quality of the electrodes used, (e) the condition of the skin under the electrodes, (f) the general physical and psychical condition of the patient, etc.;

- Connector for cable connection to the controller (power supply, digital signals, analog signal);
- Fuse 3.15A with holder.

To avoid the need to place special LED indicators and the corresponding communication cables with OpenCM 9.04, lever switches are used, so the direction of their levers indicates their current function marked on the foil cover.

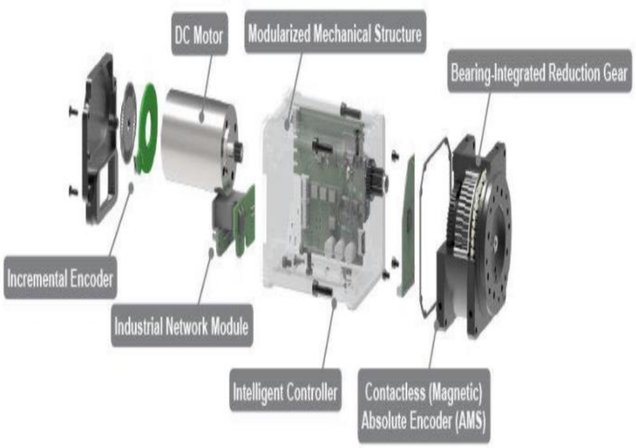


Fig. 1. Integrated actuator of Dynamixel family

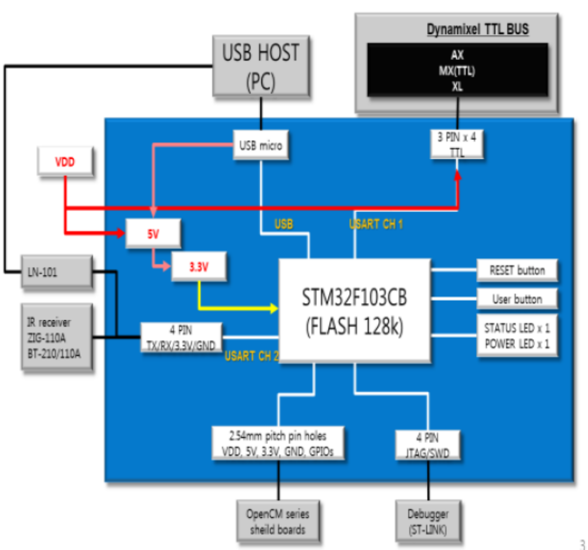


Fig.2. Microcontroller OpenCM 9.04 general structure

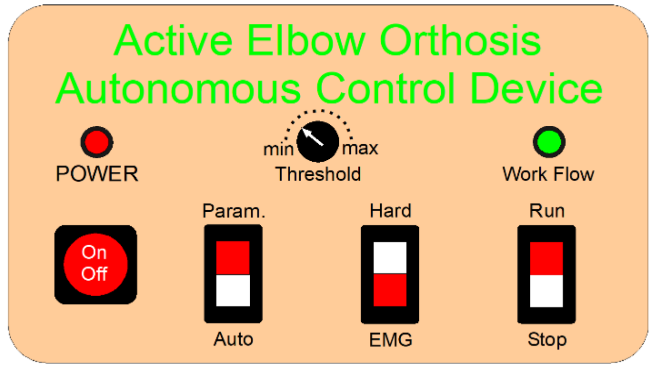


Fig. 3. Foil cover with explanations

## III. Ways of Use of ACD

It is noted that a patient will not perform very fast and precise motion. The purpose of the active orthosis is to force the elbow joint to move aiming rehabilitation. It should have a set of programs for several flexions and extensions with different speeds that the user can choose according to his own needs.

The mechanical parts of the proposed prototype of an orthosis were designed using CAD system (Fig. 4). The construction is light, as it should be worn and the patient should operate on it alone. 3D printing of the elements of the orthosis allows the construction of complex lightweight plastic parts. However, attention must be paid to the fragility of the fine plastic elements. It must be noted that the mechanic construction and drive system are constructed based on mean values of the segments of the upper human limb taken from the web page [14].

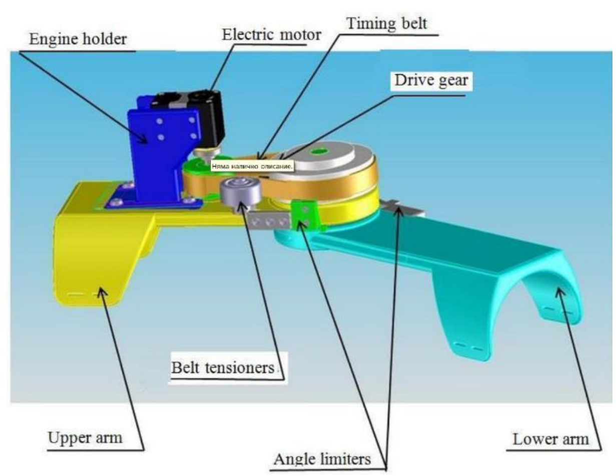


Fig. 4. CAD model of the active elbow orthosis

It is not necessary to make device links with adjustable lengths. This will destroy mechanical construction stability and reliability. Three prototypes of different lengths (basic, minimum and maximum) would be sufficient for patients of different sizes. The designed prototype (Fig. 5.) can be used for both left and right elbow, by changing the places of the switches at the end positions of the movable forearm segment and the mechanical restraints restricting the undesired movement of the arm. The actuator and the controller are placed on the unmovavble upper arm segment.

There are two ways to use the ACD.

*A. Parameterization*

It is activated when, before turning on the power supply of the ACD, WUS is set to "parameterization". A communication between the PC and the ALO controller is established. Through the console (text dialog mode) of the PC, parameterization is performed with subsequent recording in the non-volatile memory of the controller. The parameterization is carried out by a physiotherapist who determines:

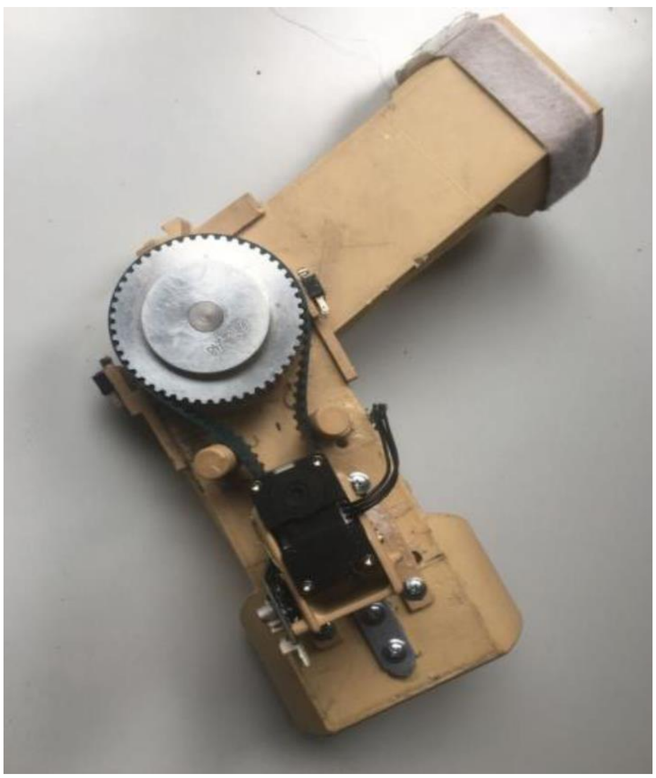

Fig.5. A photo of the assembled orthosis prototype

- The starting position of the orthosis (maximum extension for the specific patient);
- The final position of flexion;
- Rest time (between flexion and extension);
- The parameters of the subsequent autonomous operation modes – hard control or EMG control.

1) Mode without using EMG signal

Default values are shown and could be changed if necessary. They are set:

- Flexion/extension time;
- Number of cycles (one cycle = flexion+rest+extension).

2) On/off mode using EMG signal

Flexion/extension time is set. The physiotherapist indicates the places on the patient's arm to attach the EMG electrodes.

During parameterization the permissible values for the individual quantities are suggested, and either the set values from the previous parameterization or appropriate ones are implicitly set. The values entered in the EEPROM are protected by a checksum.

*B. Autonomous work*

It is activated when before turning on the power supply of the ACD, WUS is in "autonomous operation" position. After parameterization by a physiotherapist, the patient activates the ALO by himself, as described below. WF LED indicates the proper work or some malfunctions of ACD.

1) Mode without using EMG signal.

- The ALO power supply is switched on. ALO moves to the extension position defined by the physiotherapist;
- ALO is placed on the arm, ACD – on a desktop or belt;
- ES is placed in the "RUN" position (Fig.3.), WF lights up and ALO wait two seconds;
- ALO starts performing the movements set by the physiotherapist. After carrying out the set number of cycles ALO stops movement and can be removed and switched off – the physiotherapy is finished. To repeat the cycles, ES must be disabled and enabled again.

2) Mode using EMG signal for on/off control.

- The ALO power supply is switched on. ALO moves to the extension position defined by the physiotherapist;
- CTP is placed in the extreme right position - maximum trigger threshold of enabling ALO movement;
- ALO is placed on the arm, ACD – on a desktop or belt;
- On his arm, the patient places an EMG sensor in a place previously marked by the physiotherapist;
- ES is placed in the "RUN" position, WF lights up;
- The patient tenses his muscle (biceps brachii) and by the other hand slightly rotates CTP counterclockwise;
- Upon reaching the threshold currently set by the potentiometer, ALO is triggered and one cycle is performed with the parameters set by the physiotherapist. If more cycles are desired, the patient tenses his muscle, leaving CTP in the position in which the desired activation threshold is determined;
- To finish the physiotherapy, after the end of the cycle, the patient turns off ES, the power supply and removes the orthosis.

## IV. Conclusion and Future Work

The presented prototype of the ACD has been tested on real patients (Fig. 6.) and has shown sufficient functionality and convenience for autonomous use. The future work on ACD is mainly pointed in two directions:

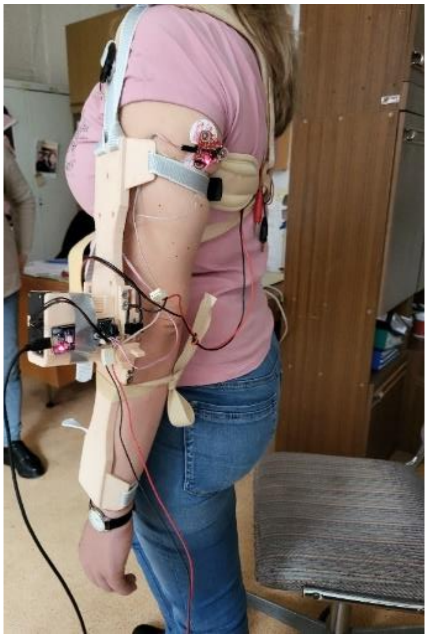

Fig. 6. Real test of ALO with ACD

- Development of a graphic interface for the parameterization of the rehabilitation procedures by the physiotherapist;
- The use of a microcontroller with a digital keyboard and indication in the ACD, which will give more options and make it easier for the patient to use the AEO, and also reduce the number of signals (cables) between the ACD and the AEO microcontroller.

## APPENDIX

*Parameterization dialogue - mode without using emg signal: Example*

*(ACD – Autonomous Control Device, Phis – Phisiotherapist)*

ACD: Elbow Orthosis ready for parameterization.
The old extension position is 6 deg. Press Enter to confirm or set new extension position.
Phis: 11
ACD: The new extension position is 11 deg.
The old flexion position is 137 deg. Press Enter to confirm or set new flexion position.
Phis: 125
ACD: The new flexion position is 125 deg.
The old rest time is 1500 msec. Press Enter to confirm or set new rest time.
Phis: 2000
ACD: The new rest time is 2000 msec.
The old autonomous operation mode is HARD CONTROL.
Set new autonomous operation mode: HARD CONTROL (Enter HARD) or EMG CONTROL (Enter EMG).
Phis: HARD
ACD: HARD CONTROL selected.
The old flexion/extension time is 3500 msec. Press Enter to confirm or set new flexion/extension time.
Phis: 5000
ACD: The new flexion/extension time is 5000 msec.
Set the number of cycles. The old value is 10. Press Enter to confirm or set new number of cycles.
Phis: 15
ACD: The new number of cycles is 15.

PARAMETERIZATION FINISHED

## ACKNOWLEDGEMENT

This study was financially supported by the Bulgarian National Science Fund, Grant No. КП-06-М47/6.

## REFERENCES

[1]https://nsi.bg/sites/default/files/files/pressreleases/Census2021-hd.pdf
[2] Papanicolas, I.,Woskie, L.R, Jha, A.K. Health Care Spending in the United States and Other High-Income Countries *JAMA.* 2018;319(10):1024-1039.
[3] State of health in the EU, България, Здравен профил за страната 2019.
[4] Teasell, R., Mehta, S., Pereira, Sh., McIntyre, A., Janzen, Sh., Allen, L., Lobo, L., Viana, R., Time to rethink long-term rehabilitation management of stroke patients *Top stroke rehabil*. 2012;19(6):457-62.
[5] Jensen, E., Raunsbæk, J., Lund, J., Rahman, T. Rasmussen, J., Castro, M., Development and simulation of a passive upper extremity orthosis for amyoplasia. *Sage*.2018; 5:1–10.
[6] Ates, S., Lobo-Prat, J., Lammertse, P., van der Kooij, H., Stienen, A., SCRIPT Passive orthosis: design and technical evaluation of the wrist and hand orthosis for rehabilitation training at home. In: IEEE 13th International Conference on Rehabilitation Robotics (ICORR). Seattle, 2013; 1-6.
[7] Rahman, T., Sample, W., Jayakumar, S., King, M., Wee, J., Setikatar, R., Alexander, M., Scavina, M., Clark, A., Passive exoskeletons for assisting limb movement. *Journal of Rehabilitation Research & Development*. 2006;43:583-590.
[8] McBean, J., Narendran, K, 8.7.2008. Powered orthotic device. US7396337B2.
[9] McBean, J., Narendran, K., 6.1.2015. Powered orthotic device and method of using same. US8926534B2.
[10] Fregly, B.J., Boninger, M.L., Reinkensmeyer, D.J. Personalized neuromusculoskeletal modeling to improve treatment of mobility impairments: a perspective from European research sites. Journal of NeuroEngineering and Rehabilitation .201;: 9(18).
[11] https://www.robotis.us/dynamixel/
[12]https://emanual.robotis.com/docs/en/parts/controller/opencm904/
[13] Angelova,S., Raykov, P., Petrov, E., Raikova, R. A prototype of an active elbow orthosis – problems of mechanical design and orthosis control. Series on Biomechanics.2021;.35(3):3-11.
[14]http://biomed.bas.bg/en/wp-content/uploads/2012/02/MassInertial.html