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PREFACE

The First International Conference on Advanced Research in Engineering – CARE 2020 is organized by the "Academician Radu Voinea" Doctoral School of the Faculty of Mechanics from the University of Craiova. It aims to provide a platform for researchers, engineers, PhD students and postdoc students, involved in the area of mechanical engineering and industrial engineering as well as robotics, mechatronics and interdisciplinary fields, to meet and share the latest developments in their research field.

The main objective of CARE 2020 is to promote excellence in research, to establish partnerships and collaborative relationships through the exchange of knowledge and expertise and to respond to new trends and challenges in doctoral research in engineering.

CARE 2020 covered important areas of research, development and innovation in robotics, biomechanics, industrial engineering and automotive. Papers were solicited in topics related to new theories, advanced design and applied mechanics, including but not limited to the following:

- Advanced processing technologies in industrial engineering
- Applied Thermodynamics, Heat Transfer. Thermal Systems
- Automotive. Engine and Transmission. Road Safety
- Biomechanics
- Biomedical engineering
- Computer-aided design and manufacturing
- Experimental mechanics
- Mechanisms and Machines Design
- Mechatronics
- Modeling and simulation in mechanical engineering
- Robotics
- Modeling, analysis and simulation of the manufacturing processes
- Technology and engineering management

The accepted papers have been grouped in four technical sessions: (I) Robotics, (II) Biomechanics, (III) Industrial engineering, (IV) Automotive.

The content of this thematic book admirably reflects the complementary aspects of theory and practice, which have taken place in the last years. Certainly, the content of this book will serve as a valuable handbook to those who work in research and development of advanced robotic devices, biomechanics, modelling and simulation in mechanical and industrial engineering, advanced processing technologies or innovative materials.

We would like to express our gratitude to the 90 authors for their interest in participating in CARE 2020 and for writing 36 excellent papers in a timely manner, allowing this conference to become a reality in a short period of time. The conference represents the effort of academics and researchers from the main Romanian universities: Bucharest, Brașov, Craiova, Cluj-Napoca, Iași, Galați and Pitești, but also from universities in Italy and the United States of America.

We thank all the reviewers and members of scientific committee, for their outstanding work, which allowed the conference papers to be published as scheduled.

We would also like to thank the keynote speakers, experts with outstanding international recognition in their fields, who come from top universities in Europe and the US, such as Johns Hopkins University, Princeton University, Auburn University, Indiana University, Technical University of Lisbon, West Saxon University of Zwickau, Technical University of Cluj-Napoca, University of Craiova.

They presented at the opening of the conference the latest trends in research in their expertise fields, from Enabling Technology Safe Robot-assisted Retinal Surgery, Image-Guided Robotic System for Medical Applications, New Challenges in Medical Robotics, to Dynamics of Equine Locomotion, Auto-Mobility for the Future-Functional and Technical Development , Numerical simulation of an over-moulded plastic injection part, and Self-Organization and Robustness in Biological Systems; Insights for Bioinspired Design, making the conference a real success.

Editors

October 2020

ROBOTICS

Design and Control of Recover Rehabilitation Parallel Robot

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Abstract. This paper presents the design of the parallel robotic rehabilitation system in order to achieve a proper design of the experimental model of a robotic rehabilitation system targeting the rehabilitation of the lower limb joints such as hip, knee and ankle to be healed medically. The robotic system consists of two linked parallel modules, one designed to train the hip and knee, and the other-for the ankle joint. The control system has been developed to perform gait training from a supine position of the patient.

Keywords: parallel robot, rehabilitation, stepper motors, hip, knee, ankle

1. Introduction

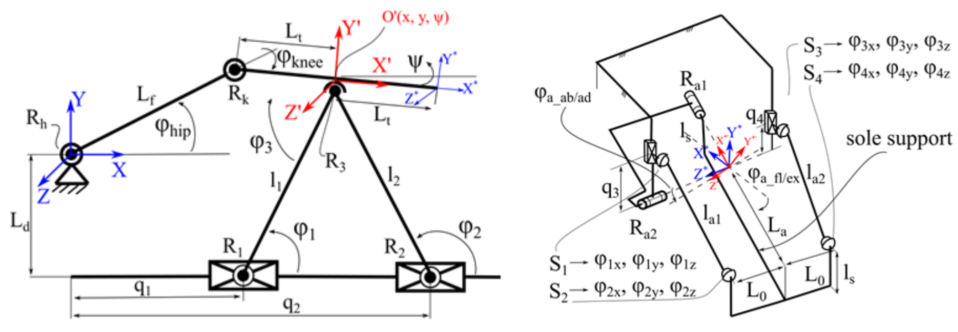
The average occurrence of strokes in the developed world is about 180 per 100,000 inhabitants [1]. Research into robotic therapy has expanded steadily and the number of therapeutic rehabilitation robots has risen significantly over the last two decades. Robotic rehabilitation therapy may provide high-dose and high-intensity training for patients with stroke or spinal cord disorders [2]. These devices ensure healthy, comprehensive and task-oriented rehabilitation for people with mild to severe motor disability following stroke. From a neuromuscular perspective, the use of interactive bio-feedback will reliably track the amount of support or resistance during movement, ensure good repeatability, and increase the motivation for training [3]. Passive physiotherapy is often a preferred method in the early stages of therapy to reduce swelling, alleviate pain, and restore range of motion. This consists of moving the limb while the muscles remain inactive and regularly includes such devices as Continuous Passive Motion (CPM) machines [4]. In recent years, orthotic systems [5-6] exoskeletons [7], or robot structures [8-9] are increasingly used to rehabilitate human gait or the movements of damaged human joints. Lower limb rehabilitation, movement therapy and muscle strength training can be used with parallel robots [10]. The parallel rehabilitation robotic system presented in this paper allows early treatment of patients who have had a stroke and are bedridden and there is no need for the patient to be placed upright to begin the rehabilitation.

2. The kinematical description

The parallel rehabilitation robot at RECOVER is a parallel structure composed of two parallel chained structures. The first helps in the training of hip- and knee joint motions rehabilitation and the second is a parallel structure which helps in the medical recovery of ankle joint.

The hip-knee module parallel structure has three kinematic chains, the first chain K_{chain0} is RR type having revolute joint R_h and R_k with free rotation for every joint and links L_f and L_t. The second and third kinematic chains are the PRR type, actuated by q_1 and q_2 respectively. The first chain K_{chain1} is composed by R_1 and the link l_1 having rotation in R_1 and K_{chain2} that is composed by R_2 and link l_2 having rotation in R_2, both mentioned chains are intersected in R_3.

The ankle module is a parallel structure as well is composed by three chains. The first chain A_{chain0} is a RR linkage having two revolute joints Ra1 and Ra2 with orthogonal axis that intersects at the source of both fixed and moving coordinate frames. The second and third chains A_{chain1} and A_{chain2} both are PSS type symmetrically assembled with respect X*Y* plane.



a) b)

Fig. 1. Rehabilitation parallel robot (a) kinematic scheme of knee-hip module; (b) kinematic scheme of ankle module [11]

3. Recover mechanical design

The Recover is a parallel robotic system designed for training rehabilitation of the lower limb with the goal of training hip flexion / extension, knee flexion, ankle adduction / abduction and ankle eversion / eversion. The design takes into consideration the anthropometric measurements of the human upper limb, the design begins from the knee-hip module considering the stroke of the active prismatic joints q1 and q2 shown in the above figure, these lengths give the total length of the table where the active joints are placed.

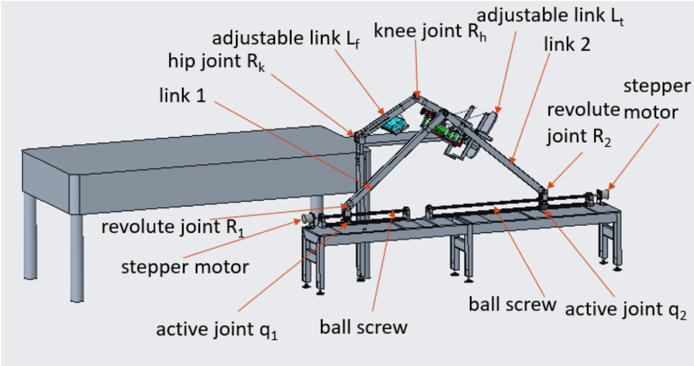


Fig. 2. Recover rehabilitation parallel robot CAD design

These values were chosen based on an approximately 1800 mm high human male. Length of upper leg is 430 mm having a correspondence link of robot L_f with adjustable dimensions between 390-440 mm, the length of lower leg of 480 mm [11] having possibility to adjust the position of ankle module situated on L_t link on X and Y axes, putting a limit (q1-q2)/2200 mm. Taking into account the height of the bed, Ld=435 high this dimension can be also adjusted between 380 to 455 mm to adapt to the height of different beds , the dimensions of links l1 and l2 are equals l1 = l2=855mm. The whole translation process is mounted on the long table, with the length of 2000 mm being a solid frame made of welded steel bars. The mechanical links are designed to be made from square pipes 40x40x2 of Al alloy (AW 60820, which have good structural strength and lightweight). The translational mechanism is materialized using 16 mm ball screws with 5 mm thread pitch, the strokes length for q1 is approximately 550mm and q2 is around 1050 mm. The active joints q1, and q2 are actuated using stepper motors HY-200-2222-D6 with 1.8°/step. The ball nut mechanisms are guided on the linear guiding rails HGR20. The revolute joints are built using two radial bearings per joint giving a better rotation in revolute joints. The ankle module is mounted on the lower leg support and is mostly made of Al alloy in combination with ONYX (3D printed material).It is a parallel structure able to perform flexion/dorsiflexion through the two identical PSS type kinematics chains, having one active prismatic joint and two passive spherical joints per chain, when the prismatic joints q_3 and q_4 performs translation motions in the same direction with the same speed. Therefore, due to the motion of q_3 and q_4 mentioned above, the revolute joint Ra1 is driven, so that the ankle module is subject to motion of flexion / dorsiflexion motion. The eversion/inversion motion is accomplished when motions in the opposite direction are performed by the prismatic joints actuating the R_{a2} rotation joint. The ankle module frame is built preponderantly from Al alloy profiles, the revolute joints are equipped with radial bearings. Translational motion q_3 and q_4 are made by using trapezoidal screws and nuts Tr10 having 2 mm pitch.

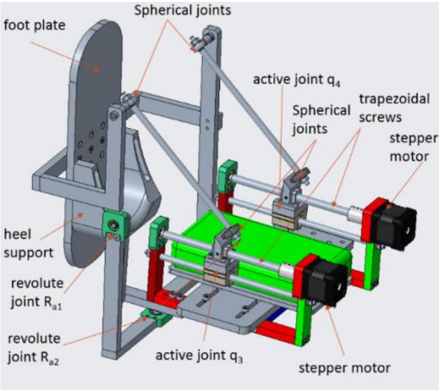


Fig. 3. Recover rehabilitation parallel robot ankle module CAD design

The current status of the experimental model of the Recover robotic device, which consists in the hip-knee assembly, is shown in Fig. 4, next to it is the stepper motor control electrical setup experiment illustrated in the next paragraph of this article.

a) b)

Fig.4 a) Recover experimental model; b) The setup of stepper motors control

4. The approach of stepper motors control

The RECOVER control system has been developed using stepper motor drivers, which allows independent or computer-assisted control of the four motors. No matter how complicated the drives are, a simple device that only controls one motor at a time is enough. In complex drives, several independent or interdependent events take place, which, according to a particular and well-developed algorithm, must be controlled simultaneously by the human operator or a computer system, but even in this case a simple control system is very helpful, which offers power of only one drive motor at one time.

4.1. Hardware description

The system's key element is the microsystem Arduino. For practical implementation an Arduino board, type "Pro-Micro-v11," was selected, one of the family's simplest variants, to which we attached four control modules, type "TB6600 Stepper Driver." Because of its simplicity and versatility, this type of driver is highly valued in stepper motor control, the large range of motors that it can handle having implemented almost all established control modes. The operation of the system is ensured by a d.c. power supply taken from a laptop that supplies 18.5 V at a maximum current of 6.5 A. An LCD display with I2C control type "LCD 1602 IIC / I2C" of 16 characters on 2 lines and a set of 4 microswitches for the generation of commands was also attached for independent use of the microsystem. The electrical diagram of the designed and constructed device is shown in Fig. 5.

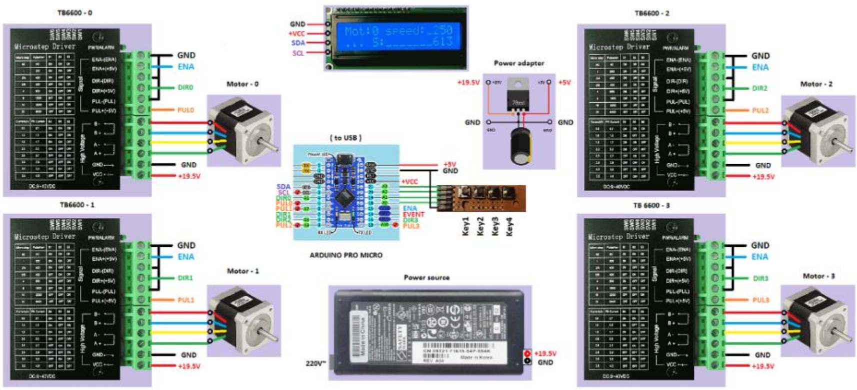


Fig. 5 The electrical and control connection scheme for stepper motors

4.2. The operation of the motor control system

The operation of the system is ensured by a program elaborated and tested from the IDE 1.8.13 Arduino environment, a program of "Menu" type in which different sequences can be chosen with the help of the defined buttons key 0 … key 3. This determines the drive controls of the selected motor (0 …3) so that, when the corresponding button is pressed, it rotates clockwise or counterclockwise (click key1 or key2).

The simplicity of defining the "PUL" and "DIR" commands for the 4 motors used is the way in which they are declared through a vector, as well as the way in which the 8 normal working speeds are generated and stored. The basic sequence for controlling the motors is the routine named smtr (from the "stepper motor"), which involves all control functions, the direction of rotation, the number of steps to be taken, and the speed of operation. For the implementation of the manual control actuation, it was decided in the convention that the value 0, as the number of steps to be performed, would describe this control mode. When checking the status of the control buttons (key1 and key2) before one of them is pressed, the active (selected) motor will rotate at the chosen speed in the specified direction.

In the current and presented version of motors control, each command given manually from the buttons is displayed on the LCD display and also sent as information on the selected serial line to a computer for monitoring. On it can follow the execution of an actuation command, the command parameters, and the result represented by the display of the number of executed steps. Also, on this serial line can be defined commands to execute. The control of critical situations in actuation is performed in principle by the actuation modules "TB6600" through the signal "ENA", authorizing the module. Thus, "end-of-stroke" protection systems can be implemented by electrically controlling this input only, without the need to implement in the main program of the Arduino system or the higher control program (PC).

4.3. User interface and development of a communication protocol C# Arduino

The purpose of this paragraph is to expose a possible interface and development of communication protocol between C# and Arduino for Recover rehabilitation robotic system, this interface allows communication using a Windows Forms interface on a computer as can be seen in Fig. 6.

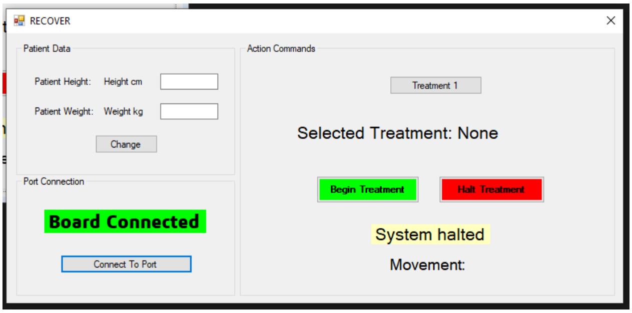


Fig. 6. The windows interface screen display

The calculation and transmission of input data for the Arduino program takes place in this program. To connect the application to the COM4 serial port (port to which the Arduino board is also connected) click on the "Connect To Port" button. After selecting the procedure by pressing the "Treatment 1" button, to calculate and transmit the data, click the "Begin Treatment" button.

The three sections of the program interface are: the Patient Data group, the Port Connection group and the Action Commands group. The Patient Data group inserts the weight and height of the patient who will use the robot, This data is stored in two variables: HeightData string and WeightData string. To ensure the connection to the COM4 port of the program, use the “Connect To Port” button in the Port Connection group. The control and selection of the treatment procedure is performed in the Action Commands group which currently contains: a button for selecting the treatment, a label showing the selected treatment, two buttons for starting or stopping the treatment, a label to signal the working status of the robot and a label to signal the movement of the robot. When the program is initialized, the following functions are executed: Form 1 where the Thread command initializes a thread to run the check Arduino function while the program runs without freezing or blocking the interface of the application and other functions that need to be executed. The check Arduino () function is used continuously in a separate generated thread which allows this function to be executed without blocking the execution of other functions which run simultaneously. Initialize Port function is responsible for the development and initialization of the COM4 communication port to which the Arduino board is connected. The function declares a new serial port of communication called "arduinoPort," the data transfer speed of 9600 bit / sec, designated "COM4," the date length of 8 bits / byte, and the standard number of stopbits / byte. Then the port of arduinoPort opens to transmit or receive data.

An important function which can be exposed is function **calculateQ ()**. For each set of movements, calculate new values for uk, uh and ug and transmit to the calculated functionQ (uk [j], uh [j], ug [j]): where uh1 = uh[j - 1]; uk1 = uk[j - 1]; ug1 = ug[j - 1]. The **calculateQ ()** function calculates the coordinates of the vector

$$Q = [q1\ q2\ q3\ q4] \tag{1}$$

$$q_1 = q_{1-1}; \tag{2}$$

$$q_2 = (2\sqrt{((l^2 - (y_1 + l_4 + (\frac{y_2}{2}))^2 + q_1} \tag{3}$$

$$q_3 = (l_g^{\ 2} - cg^2 \cos(ug)^2)^{\frac{1}{2}} + cg \sin(ug); \tag{4}$$

$$q_4 = q_3 - dg\,tan(\,eg); \tag{5}$$

The calculated coordinates are transmitted to the sendData function (pos1.ToString (), pos2.ToString (), pos3.ToString (), pos4.ToString ()). At the end of the calculations and the transmission of the data to the Arduino board, the C# application will signal the fact that the treatment procedure has ended.

5. Conclusions

The paper has presented the final design of the RECOVER parallel robotic system for rehabilitation. The design has been used to build the experimental model. The control system has been also developed and implemented using stepper motors, as an effective low-cost method to achieve the desired motion trajectory using an Arduino device. The independent control of all four motors has been implemented and tested and the user interface has been developed using previously developed mathematical model. The next steps consist in testing the robotic system using healthy subjects and the ergonomic optimization of the device.

Acknowledgments

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