ON THE DESIGN AND VALIDATION OF A PARALLEL ROBOT FOR LOWER LIMB REHABILITATION

IULIU NADAS[1,2], PAUL TUCAN[1], BOGDAN GHERMAN[1], ALEXANDRU BANICA[1], VASILE REDNIC[2], GIUSEPPE CARBONE[3], DOINA PISLA[1]

Abstract. This paper focuses on the enhancement of the design of a parallel robotic system for lower limb rehabilitation for bedridden patients following a stroke. The robotic system consists of two parallel robotic modules, each one targeting specific patient's joints, namely the hip-knee module and the ankle module. A FEA has been performed on the main elements of the robot to identify the most suitable profile to be used within the final design of the mechanism. An evaluation of the robotic system's user acceptability was also undertaken within laboratory tests conducted with healthy subjects to determine the overall level of satisfaction regarding the robot's performance.

Key words: parallel robot, robotic rehabilitation for lower limb, robot design, robotic system testing, finite element analysis.

1. INTRODUCTION

Stroke is the main cause of long-term disability and mortality in the United States and Europe [1]. Many patients who have had a stroke suffer from hemiparesis or partial paralysis of one side of the body, which limits their ability to undertake ADLs like walking and eating. Rehabilitative physical therapy is one of the most popular treatment options to help patients regain lost abilities and thus improve the overall life quality [2–4]. Motor therapy after a stroke is generally acknowledged to have an important role in lowering the patient's physical impairment [5]. Centered on the neural plasticity and the way it affects the human brain, rehabilitation treatments addressing motor impairments after stroke are based on reorganizing the brain's neuronal connections [6]. The number of individuals requiring post-stroke therapy is increasing on a yearly basis, while the overall

[1] CESTER, Technical University of Cluj-Napoca, 400114 Cluj-Napoca, Romania
[2] National Institute for Research and Development of Isotopic and Molecular Technologies; Cluj-Napoca, Romania
[3] DIMEG, University of Calabria, 87036 Cosenza, Italy

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expenses for post-stroke rehabilitation is expected to rise significantly in the upcoming years [7]. Conventional rehabilitation procedures, particularly for locomotion therapy, are very time-consuming, often necessitating upwards of three practitioners working together to support the patient's torso and legs [8]. Rehabilitative robots based on physical therapy and rehabilitation training techniques may aid patients with reduced motor function by providing thorough and cognitive training [9]. Because of its capacity to automate laborious, time-consuming treatment required to achieve positive patient results, robotic and electromechanical devices have recently attracted the attention of the rehabilitation field [10].

Lower-limb rehabilitative robotic systems have been developed in past years to improve the motor function of stroke survivors' impaired limbs. There are two types of lower-limb rehabilitation robotic systems: exoskeleton robots and end-effector robots [11].

Furthermore, robotic systems may also fall under the category of static systems, like those that manipulate a patient's lower limb while the patient is lying down or sitting up and the system is not supporting the body and robotic systems capable of supporting a patient's bodyweight and moving the patient in a variety of places, such hospital rooms, residences, and even outside [12].

The rehabilitation systems for the lower limbs might be classified into three categories:

i) systems that use treadmills and footplates. Robotic systems that employ treadmills and those that use footplates are both included in this category since they both maintain the patient in an upright posture. Lokomat is an example of robotic system based of treadmill and footplates. It is a commercial system developed by Hocoma AG [13]. Certain disadvantages can be mentioned, for example, it takes a while to set up and can't be used on patients who have had a severe stroke that has left them unable to stand on their own. LokoHelp [13] it is treadmill and footplate rehabilitation system. The patient's stability may be uncertain if he or she is strapped into a harness with two hooks attached to a pulley-based support system, which is one of the disadvantages that can be mentioned. Active Leg Exoskeleton (ALEX) [14], is a powered limb orthosis designed to help the patient on an as-needed basis. One problem of this robotic exoskeleton is that it is challenging to mount this exoskeleton to a user's lower limbs, as well as to control its therapeutic motions with linear actuators. G-EO-System is treadmill and end-effector based; it is able to perform virtual stair-walking as well as floor-walking [15]. Virtual reality training isn't available here. The Gait Trainer [16] helps patients restore their ability to move around independently by lowering their own weight and gradually increasing the speed. This rehabilitation technique has the drawback of requiring a therapist to focus solely on the knee motion.

ii) overground training systems, in most cases, the Overground gait Trainers devices are battery-powered exoskeletons that help patients to walk and are used in various areas (clinics, training facilities, and other places of residence are included). A post-stroke locomotor training system, the knee ankle foot [17] can assist in rehabilitation motions as ankle dorsiflexion and plantarflexion, knee flexion/extension. It has certain limitations, such as not covering hip mobility or its weight. Hybrid Assistive Limb (HAL) HAL-5 [18] is an exoskeleton that is used in everyday routines which has withstand clinical trials. It is rather heavy; it can't be used on patients who are immobilized because of its reduced torque magnitude and is also quite heavy. KineAssist [19] incorporates an omnidirectional moveable base that leverages cobot technologies. Since it cannot provide aided motion on lower limb joints, it cannot be used for stroke treatment for patients in the acute stage.

iii) Stationary training systems are suited for bedridden patients; the individual is seated on a treatment bed or chair while his/her lower limb is manipulated utilizing an end-effector or exoskeleton method.

The first example of a stationary training system is The MotionMaker™ [20] made by Swortek S.A. Its technology allows an active involvement of paralyzed limbs in workout regimens. The MotionMaker can fit individuals from 150 to 190 cm. The limbs are coupled to orthoses simply at the foot area to simulate natural ground response forces. The Lambda, [21], generates movement for lower limbs in the sagittal plane, together with a supplementary rotation for ankle movements with an extra wire-driven lower limb therapy equipment [22]. The design of this parallel structure is easy because it is based on one permanent frame that integrates the linear transmissions, motors, and a rudimentary lambda-category kinematic framework to transport motion from the motors to the feet. The inability to produce isolated movement of a certain lower-limb joint, such as the hip or knee, is one drawback that can be mentioned. Another interesting stationary gait trainer is RAISE [23–25], dedicated to bedridden patients, consisting of two parallel modules, each with two DoF. The robotic system can perform hip flexion/extension and abduction/adduction, knee flexion/extension, plantar flexion/ankle dorsiflexion and inversion/eversion of the ankle.

This paper focuses on the design improvement of RECOVER [26–34], a stationary training system. A particular emphasis has been placed on the hip-knee module, whose design has been submitted to a finite element analysis (FEA), while the validation of RECOVER has been performed using a User Acceptance Test (UAT).

The rest of paper is organized as follows: section 2 provides a brief illustration and description of the RECOVER modular architecture and its functionality; section 3 focuses on the hip-knee rehabilitation module FEA of the most important elements, considered critical in the final design of the robot; Section 4 provides a brief overview of the RECOVER robot validation tests that were conducted in laboratory conditions to assess the overall acceptance degree of the robot by the participants, as healthy subjects.

2. KINEMATIC DESCRIPTION OF THE PARALLEL ROBOTIC SYSTEM

RECOVER addresses the bedridden patients, those who have suffered a stroke and cannot stand on their feet. A robust construction is provided by a basic frame built of steel profiles, while the active joints of the hip-knee module can operate at high speeds and accelerations without creating vibrations that might interfere with the operation of the robotic rehabilitation system. Motions of the lower limb joints can be performed by the robotic system in both a synchronous and isolated manner.

It is a parallel robot consisting of two chained parallel structures which can work together or separately. The first module is dedicated to the mobilization of hip and knee joints and the second one is designed to help in the rehabilitation of ankle joint. The hip-knee module was designed to perform hip flexion/extension and knee flexion/extension.

Figure 1 shows the hip-knee module's three kinematic chains. The first kinematic chain K_{chain1}, consists of two revolute joints, R_h (hip joint) and R_k (knee joint), which are connected by the link L_f. The final element of this kinematic is the link L_t, following the revolute joint R_k.

The next two kinematics chain have similar structure: the chain (K_{chain2}) is of the $\underline{P}$RR type, with q_1 active prismatic joint, R_1 revolute joint, and l_1 link to the revolute joint R_3; the third kinematic chain (K_{chain3}) is also $\underline{P}$RR type, with q_2 active prismatic joint, R_2 and R_3 revolute joints connected by the link l_2. Thus, both links that belong to second and third kinematic chains l_1 and l_2 intersect in the revolute joint R_3. Therefore, the hip and knee motions are achieved by the individual motions of the active joints q_1 and q_2.

The ankle module of RECOVER parallel robot is dedicated to the ankle rehabilitation motions. It is mounted on the L_t link on the support of the lower leg so that the patient's foot is properly positioned with the heel in the heel support, Fig. 2. The ankle module consists of three kinematic chains: the first kinematic chain (A_{chain1}) is of RR type with two passive rotation joints R_{a1} and R_{a2} with an orthogonal axis that meets at the point in which both fixed and mobile coordinate frames originate; the second and third kinematic chains (A_{chain2}, A_{chain3}) are of $\underline{P}$SS type and are symmetrical with regard to the *OXY* plane. The A_{chain2} and A_{chain3} kinematic chains have the active prismatic joint q_3 and q_4 respectively connected to a "T" shaped movable platform (consisting of L_a and $2 \times L_0$) through links l_{a1} and l_{a2} respectively by the passive prismatic joints $S_1 - S_2$ and $S_3 - S_4$ respectively. It is important to note that plantarflexion and dorsiflexion motions are achieved when prismatic joints q_3 and q_4 move in the same direction with equal speed. When the two prismatic joints q_3 and q_4 move in opposing directions with equal speed, inversion and eversion of ankle are performed.

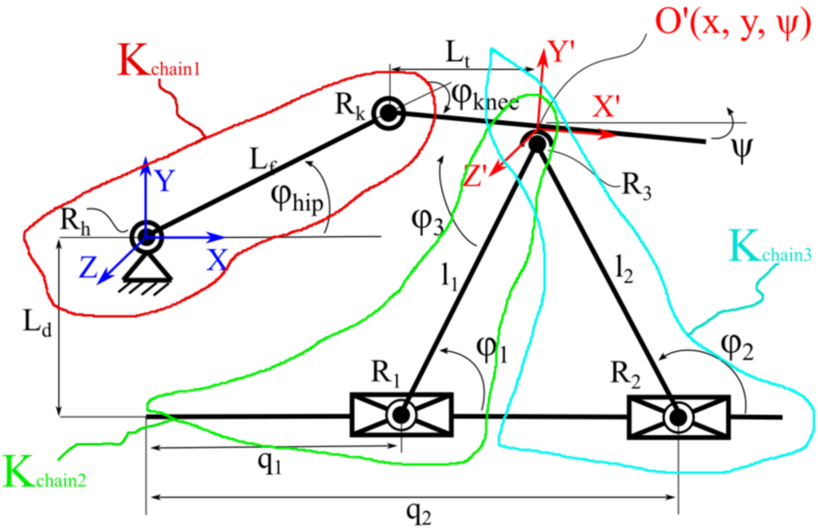


Fig. 1 –Hip-Knee module kinematics.

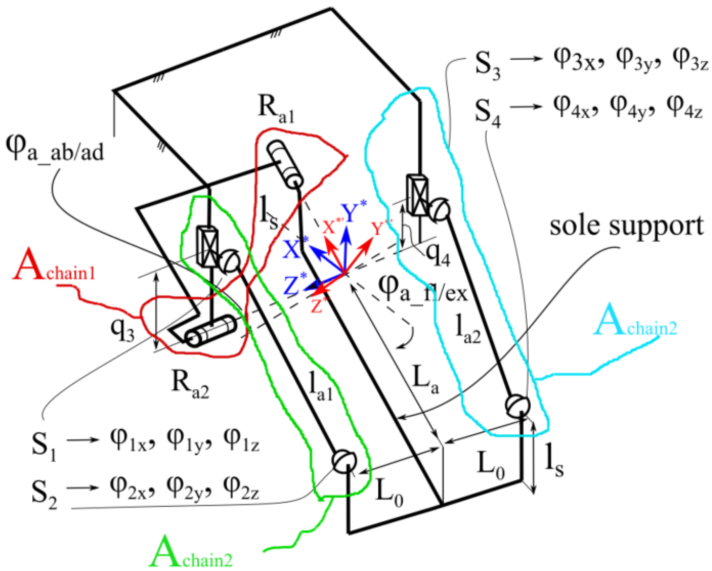


Fig. 2 – Ankle module kinematics.

3. DESIGN ANALYSIS OF HIP-KNEE PARALLEL MODULE

3.1. DIMENSIONAL OPTIMIZATION

RECOVER has been designed to fit adult patients with heights 1.50 – 2.00 m, so the dimensions of the L_f, L_t and L_a geometric parameters have been chosen according to [35], to fit the lengths of the thigh, leg, and foot. Fortunately, due to the design advantages, the ankle module does not need to be adjusted to the patient's foot size, so the L_a geometric parameter is constant. The L_f and L_t geometric parameters can be adjusted continuously to fit the anthropometric parameters using the following limits: $L_f = 370 \div 440$ mm and $L_t = 206 \div 226$ mm. Considering that the hospital bed height can vary between 400 and 600 mm (which directly influences the L_d parameter - the hip height), the l_1 and l_2 parameters have to be determined in strict relation to the active joints coordinates q_1 and q_2 the motion ranges of the rehabilitation training exercises. According to the specific medical requirements, φ_{hip} and φ_{knee} sweep the following motion range: $\varphi_{hip} \in [-\pi/6; \pi/2]$, while $\varphi_{knee} \in [0; +\pi/2]$. For a simplified geometric model (and thus a simplified control system), the l_1 and l_2 parameters are considered equal, which is why $l_1 = l_2 = l$. To avoid singularity configurations [29], the angle φ_1 values should have the following range: $\varphi_1 \in (0; \pi/2)$. Having all these premises, and using the geometric model presented in [29], equation (1), fig. 3 presents the pseudocode for the implementation of a Monte Carlo simulation using MATLAB [36], which leads to the approximate dimension of the l parameter of RECOVER and finally the stroke lengths for q_1 and q_2.

$$\begin{cases} h_1 : L_f \cdot \cos(\varphi_{hip}) + L_t \cdot \cos(\varphi_{hip} - \varphi_{knee}) - (q_1 + \cos(\varphi_1) l_1), \\ h_2 : L_f \cdot \sin(\varphi_{hip}) + L_t \cdot \sin(\varphi_{hip} - \varphi_{knee}) - (-L_d + \sin(\varphi_1) \cdot l_1), \end{cases} \tag{1}$$

where

$$\begin{cases} \cos(\varphi_1) \cdot l_1 = \dfrac{q_2 - q_1}{2}, \\ \sin(\varphi_1) \cdot l_1 = \sqrt{l_1^2 - \left(\dfrac{q_2 - q_1}{2}\right)^2}. \end{cases} \tag{2}$$

The following parameters have been used for the simulation: $\text{nsamples} = 1\,000\,000$ has been used to generate the values for the φ_{hip} and φ_{knee} angles using uniform distribution, while for the L_f, L_t and L_d parameters a normal distribution has been used, Fig. 4.

$\mu_{L_f} = 405;\ \sigma_{L_f} = 35$
$\mu_{L_d} = 400;\ \sigma_{L_d} = 100$
$\mu_{L_t} = 216;\ \sigma_{L_t} = 10$
$nSamples = 1000000$
while $(i < 20)$
    while $(j < nSamples)$
        $\varphi_{hip}(j) = -\pi/6 + (\pi/6 + \pi/2) \cdot random$
        $\varphi_{knee}(j) = (\pi/2) \cdot random$
        $L_d(j) = \sigma_{L_d} \cdot random + \mu_{L_d}$
        $L_f(j) = \sigma_{L_f} \cdot random + \mu_{L_f}$
        $L_t(j) = \sigma_{L_t} \cdot random + \mu_{L_t}$
        $\varphi_1(j) = (\pi/2) \cdot random$
        $l\_sample(j) = \left(L_f(j) \cdot \sin\varphi_{hip}(j) + L_t(j) \cdot \sin\left(\varphi_{hip}(j) - \varphi_{knee}(j)\right) + L_d(j)\right)$
    $l_{cycle}(i) = median\left(l\_sample(j)\right)$
$l = mean\left(l_{cycle}(i)\right)$

Fig. 3 – The Monte Carlo simulation pseudocode.

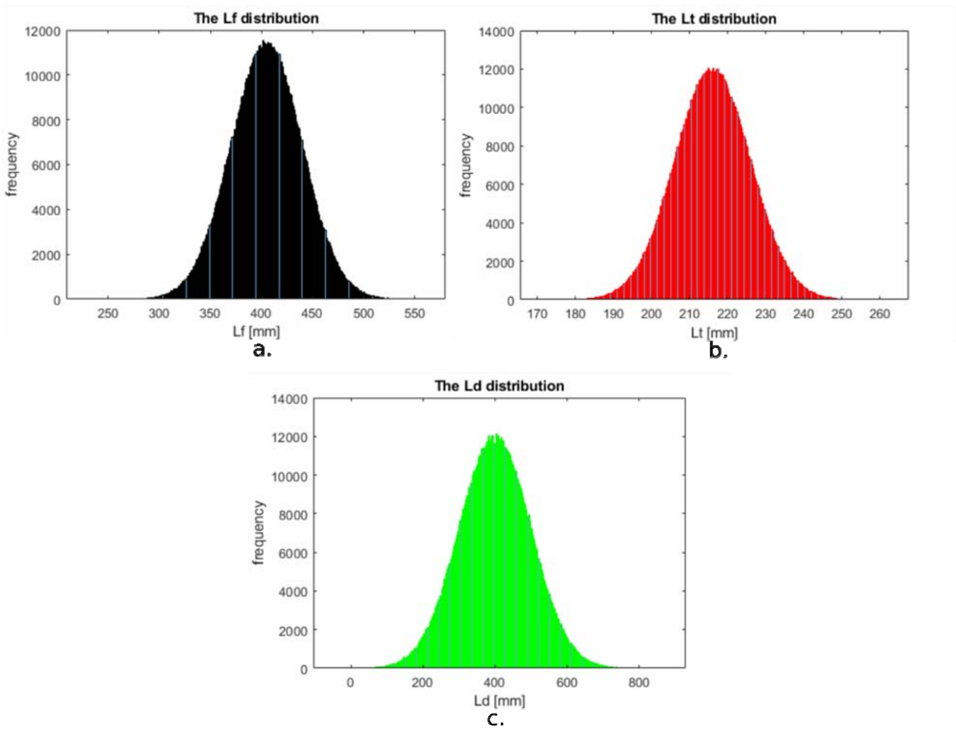


Fig. 4 – The normal distribution of the: a – L_f normal distribution; b – L_t normal distribution; c – L_d normal distribution.

The simulation has run for 20 cycles and the median value has been stored (for each cycle). Finally, the mean value of all stored median values has been computed, yielding $l = 830$ mm.

Using (1), the q_1 and q_2 stroke limits have been determined as follows: $q_1 \in [-440;190]$ mm, yielding a total stroke $q_{total\ stroke} = 630\,\text{mm}$ and $q_2 \in [-10;+780]$ mm, yielding a total stroke $q_{total\ stroke} = 790\,\text{mm}$.

3.2. FEM ANALYSIS

Fig. 5 presents the main elements of the RECOVER parallel robot. All the translation mechanisms of the robot's hip-knee module are placed on a base structure (1). The first prismatic joint is actuated by the first motor (2), while the second prismatic joint is actuated by the second motor (22). Translation parts include sledges (3), (19), rails (7), (20) and ball screws (5), (17). The links (6) and (15) are placed on the translational parts, each link is connected on translation parts through the rotational joints (4), (18). The hip link (9) is positioned on a steel support that is adjustable being able to modify its height by employing a telescoping mechanism in elevating and reducing the support height to adjust the hip joint position on Y axis. The thig link (10) is attached to hip joint (9) via a revolute joint. The femoral link (14) is coupled with thigh link via the revolute joint (12) and the femoral link is joined along with links (6) and (15) through the revolute joint (13). The ankle module (16) is attached to the femoral link (14).

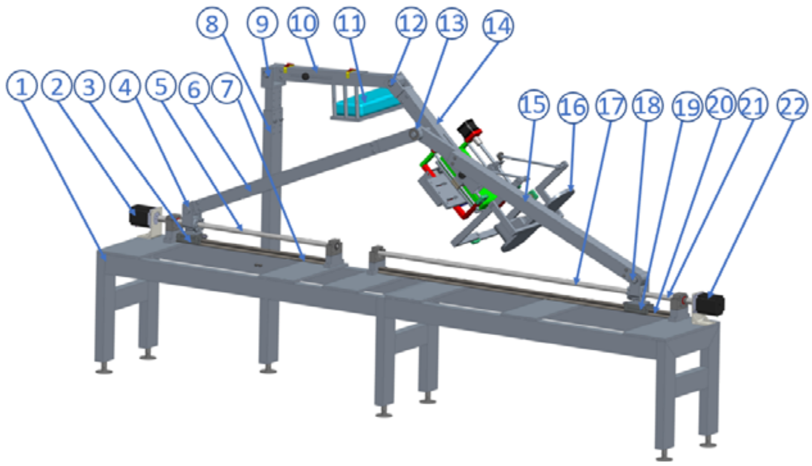


Fig. 5 – The main elements of RECOVER robot.

Deformation of structural parts that might impair accuracy and functionality must be considered to develop a comprehensive robotic structure solution. To achieve an accurate measurement of the critical components of the robotic construction, various Al alloy pipes of different thicknesses and profile sections were considered throughout the study. A variety of major structural components were examined for this utilizing Ansys 17.1 Static Structural module.

Because the parallel robot's structure supports the whole patient's foot weight plus the weight of the ankle module during rehabilitation exercises, the subassembly consisting of the two links l_1 and l_2, and their intersection axis (the axis of the revolute joint R_3) around which these two links rotate was statically analyzed because it was considered critical for the strength of whole assembly.

Within the FEA simulation, components have been isolated from the rest of the robotic system. The type of material of the analyzed component was specified for the analysis, as was the constrained portion within the studied assembly and the constraint region within the analysis of a single part. A 200 N force magnitude was applied in a specific section of the analyzed part. The research also considered the force generated by gravitational acceleration. The links were connected to the ground where the rotational joints R_1 and R_2 were supposed to be. The force was placed on the shaft circumferential surface where the shaft would be attached in the link L_t. The applied force is significantly larger than the typical human leg weighs around 15 kilograms [37], as well as the 5.5 kilograms of the weigh ankle module and the links L_f and L_t.

FEA of key subassembly of hip-knee modules. The subassembly evaluated using FEA, shown in Fig. 6a, is the one with links l_1 and l_2 made from Al alloy pipe with circular profile with 18 mm diameter and 1.5 mm wall thickness. A force was applied on the far end of the shaft to simulate the forces exerted in the true setting, which included the weight of the patient's lower limb and the rest of the robotic structure composed of links L_f and L_t, as well as the ankle module weight. The outcome was a maximum deformation of 11.651 mm implying an inappropriate deformation that happens during the static analysis, which concludes that this variant is not a suitable solution.

The next analyzed subassembly is seen in Fig. 6c) was built on pipes of 18 mm diameter with a wall thickness of 2 mm. While this is an improvement, the maximum deformation of 8.1139 mm does not meet the acceptable requirements.

A pipe made of an aluminum alloy with a diameter of 20 mm and a thickness of wall 2 mm is recommended for the subassembly investigation like in Fig. 6e. This simulation showed a maximum deformation of 7.6478 mm, which is inadequate for the robot task.

The next profiles studied are 20×20×1.5 mm squared pipes, comparing to the previous study shown in Fig. 6e, the total deformation of 4.7143 mm illustrated in Fig. 6b has decreased, but not enough to be considered as a viable solution.

Although the maximum deformation 3.9549 of the 20×20×2 Al alloy pipes presented in Fig. 6d is lower than that of the previous model, it is still insufficient to serve as a solution for the robotic design.

A rectangular Al profile 30×20×2 was also investigated; the maximum deformation obtained was 3.05 mm Fig.6f, which was better than the previous deformations.

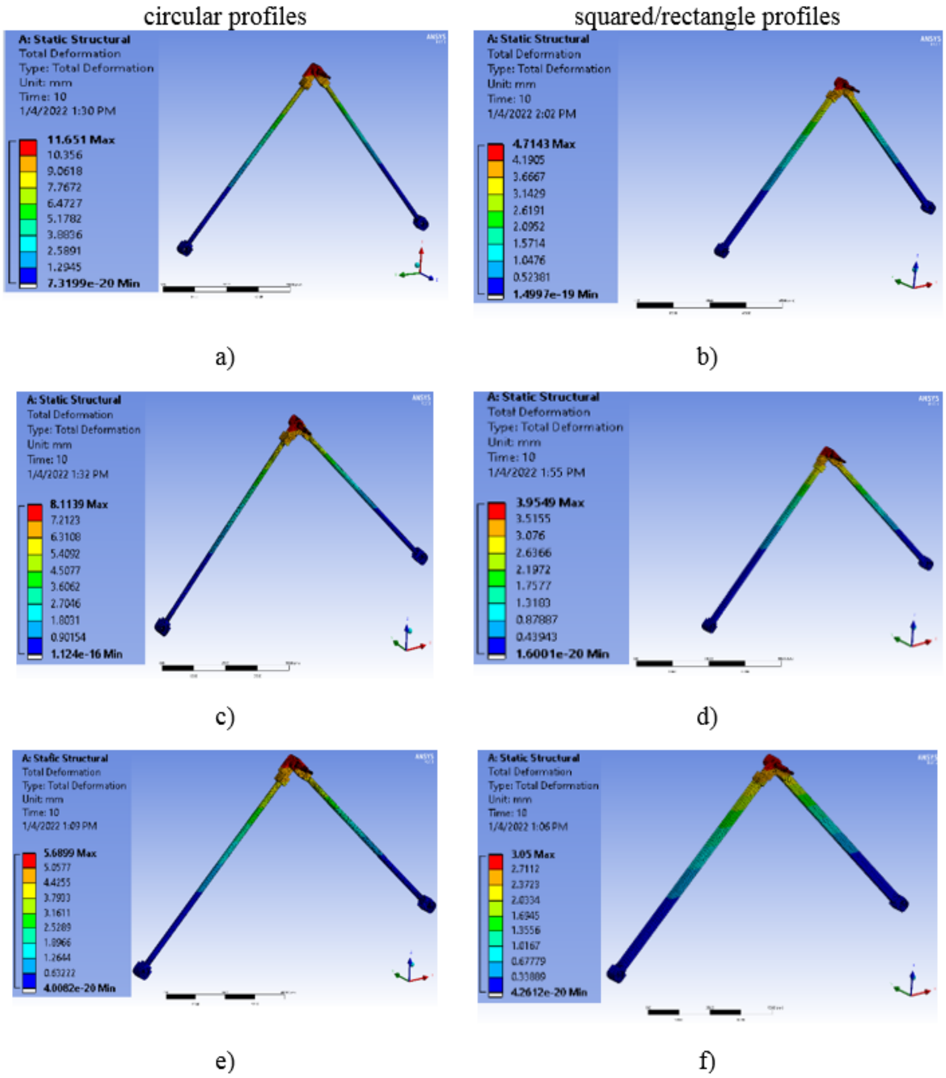


Fig. 6 – The FEA of hip-knee module subassembly made from Al alloy profiles: a) 18 mm diameter 1.5 mm wall thickness; b) 20×20×1.5 mm; c) 18 mm diameter 2 mm wall thickness; d) 20×20×2 mm; e) 20 mm diameter 2 wall thickness; f) 30×20×2 mm.

However, to ensure that deformation does not impair the robot's functionality and given the length of each link's two links is 895 mm, a square profile 40×40×2 was investigated in order to achieve the desired outcomes. The resulting deflection has no effect on the robot's performance, as shown in Fig. 7 below, where the greatest entire deflection of the subassembly is 0.764 mm at 895 mm gross length of links l_1 and l_2 .

Therefore, a squared profile 40×40×2 Al alloy profile was chosen in the final design of robot, its geometry yields robustness and stability during the training motions loaded with the human lower limb.

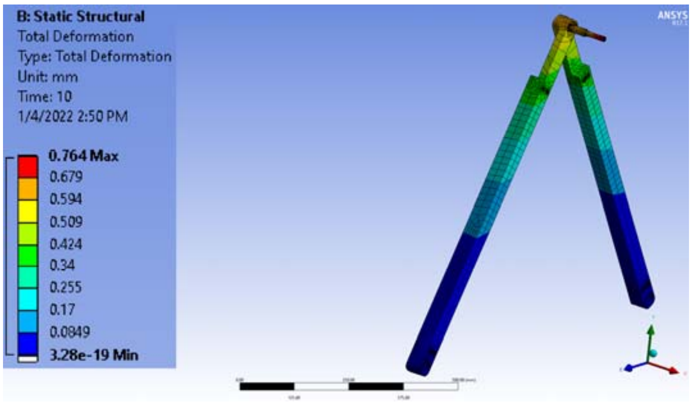


Fig. 7 – The FEA of chosen hip-knee module subassembly

4. THE USER ACCEPTANCE TEST OF THE REHABILITATION ROBOT

The experimental model of RECOVER was tested in laboratory conditions after the mechanical improvements. Figure 8 depicts the configuration. The tests were performed on ten individuals who were in good health (5 males and 4 females).

The RECOVER robotic system was used to perform the following motions during the testing phase: a) flexion/extension of hip; b) flexion/extension of knee; c) plantarflexion/dorsiflexion and d) inversion/eversion of ankle. The participants of tests were healthy subjects.

Repetition and familiarity with the robotic system helped the participants become more at ease with the technology [35]. The patient's condition was constantly monitored by the physiotherapist throughout the trial.

A written consent form explained how the robot operates and what rehabilitation motions are required prior to the procedure. The experiments could not be carried out until all participants had been told and signed the consent form. Figure 9 shows a robotic system during the hip and knee tests with a test participant connected with the robot illustrating flexion/extension of hip and flexion/extension of knee.

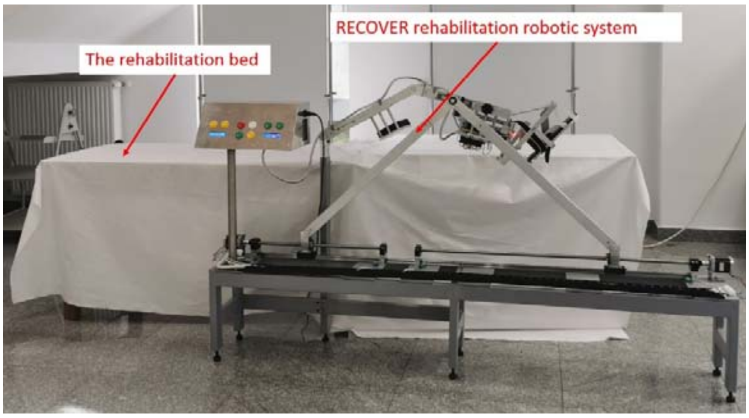
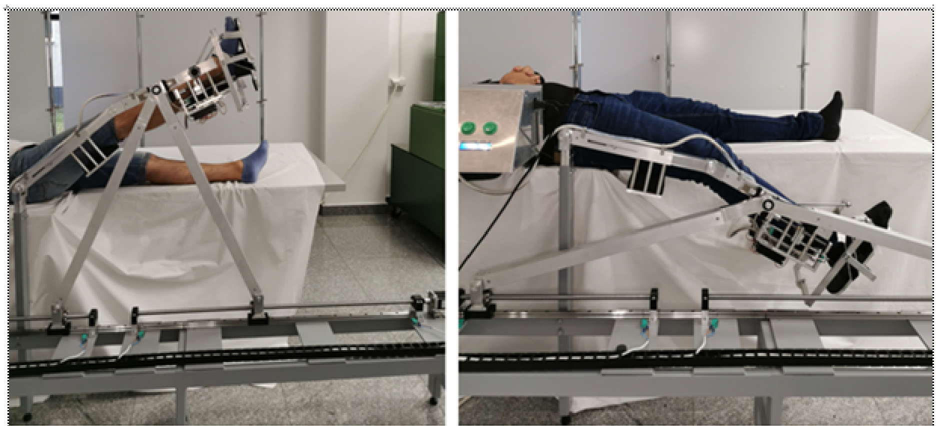


Fig. 8 – The RECOVER experimental setup.

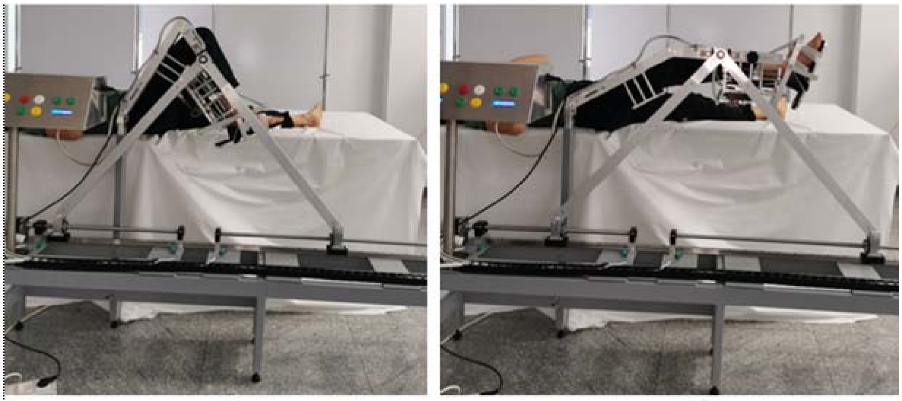
Table 1

The main aspects of participants

Subject	Gender	Age	Weight(kg)	Height(m)
1	Female	45	52	1.62
2	Female	37	56	1.72
3	Male	30	68	1.73
4	Male	34	70	1.78
5	Male	40	76	1.75
6	Male	31	89	1.84
7	Female	35	53	1.63
8	Male	42	80	1.84
9	Male	38	85	1.83
10	Female	39	60	1.64



a) b)



c) d)

Fig. 9 – Screenshot of RECOVER parallel robot for hip and knee rehabilitation during the test: a) hip flexion; b) hip extension; c) knee flexion; d) knee extension.

In Fig.10 are illustrated the ankle motions during the tests performed by RECOVER parallel robot for rehabilitation

Fig. 10 – Screenshot of RECOVER parallel robot for ankle rehabilitation during the test: a) plantar flexion; b) ankle dorsiflexion; c) ankle eversion); d) ankle inversion.

Since the 1990s, the acceptance of a new technology has been thoroughly studied [38]. User acceptance is characterized by their demonstrated willingness and capacity to make use of new technology [39] and how people perceive, embrace, and adapt technology usage [40]. The failure of new technologies to gain user acceptance is a major problem [41]. Models are employed in the literature on technology acceptance to describe how people utilize or accept the technology. Psychology, data management, and sociology all contribute to the development of these models. It is widely accepted that the user acceptability is a vital success element for implementing new technology. Taking into consideration the features of the people, technology, and organizational environment, this component may be adequately described, reliably forecasted, and efficiently controlled [42]. A technology's acceptability may be predicted using the models that have been described.

User acceptance methods. A total of ten test participants were divided into two equal sample groups, who were used to evaluate the RECOVER rehabilitation robot, were asked to give feedback about their experience. Participants were asked to complete a survey at the conclusion of the robotic treatment based on the results of the tests described above. A number of items regarding the robot-human interaction during the tests, including *comfort*, *absence of ache*, *tiredness*, *enjoyment*, *benefits* and *the desire to continue*, are addressed in the questionnaire. The form consisted in the following questions:

i. Please tell me if the robotic treatment made you feel comfortable(comfort)?
ii. The remark that you didn't feel any pain throughout the robotic training is true for you (absence of ache)?
iii. Did you become exhausted from the robotic training that you had received (tiredness)?
iv. How did you like working with the rehabilitation robot (enjoyment)?
v. Do you think the sessions with the robot therapist were helpful (benefits)?
vi. Would you be interested in doing more testing with the robotic system (wish to continue)?
vii. Do you recommend using the robot for stroke rehabilitation (recommend to anybody)?

Each participant was requested to rate each of the seven aspects using 0 to 7 scale, as follows: Disagree = 0; 1 = reasonably disagree; 2 = in some measure disagree; 3 = a bit disagree. Agree = 4; 5 = in some measure agree; 6 = reasonably agree; 7 = firmly agree. Table 2 presents the grades awarded to each sample group member by answering the seven questions that were included in the questionnaires.

Table 2

Table 2 how the participants rated the questions in the survey

Subject	Gender	Age	i.	ii.	iii.	iv.	v.	vi.	vii.
First sample group									
1	Female	44	5	7	3	4	6	5	6
2	Female	36	6	7	2	5	7	6	6
3	Male	30	7	7	1	6	7	6	7
4	Male	34	6	7	0	5	6	5	7
5	Male	40	7	7	0	7	7	6	7
Second sample group									
6	Male	31	6	7	1	6	7	7	7
7	Female	35	7	7	1	5	7	6	6
8	Male	42	7	7	1	6	7	6	6
9	Male	38	6	7	0	7	7	7	7
10	Female	39	6	7	2	4	6	5	6
Notations: i.= comfort; ii. = absence of ache; iii. = tiredness; iv. = enjoyment; v.= benefits; vi. = wish to continue; vii. = recommend to anybody									

Table 3 summarizes the averaged data from the survey on the participants' satisfaction of the robot- rehabilitation training first and second sample groups.

Table 3

Table 3 shows the results of the questionnaire that was given to participants in the study

	i.	ii.	iii.	iv.	v.	vi.	vii.
First sample group	6.2	7	1.2	5.4	6.6	5.6	6.6
Second sample group	6.4	7	1	5.6	6.8	6.2	6.4
Average	6.3	7	1.1	5.5	6.7	5.9	6.5
Notations: i.= comfort; ii. = absence of ache; iii. = tiredness; iv. = enjoyment; v.= benefits; vi. = wish to continue; vii. = recommend to anybody							

These findings demonstrate that patients in the first and second sample groups embraced and tolerated robot-assisted rehabilitation efficiently. Based on test findings, it yields a more than reasonably comfort feeling. Following the testing with the rehabilitation robot, none of the subjects mentioned any pain. During the experiments, several of the individuals found it enjoyable to interact with the robot. Based on their experience with the rehabilitation robot, the participants almost unanimously agreed that it provides benefits, and on the basis of their desire to repeat the experience with this robotic system, they agreed moderately and strongly expressed their desire to recommend it in stroke rehabilitation.

During the procedure, there were no incidents of any kind, and no individuals had to be removed from rehabilitation bed.

4. CONCLUSIONS

The developed robotic rehabilitation system can execute all the rehabilitation motions for which it was designed. Using six different profiles, the optimal profile was selected after extensive testing and finite element analysis of the robot links l_1 and l_2, which are the main parts that are subjected to static loading forces.

It was shown in a laboratory environment with ten healthy persons that the robot was effective in executing the proposed rehabilitative motions, according to the results.

To assess their experience with the rehabilitation robot, each participant completed a questionnaire at the end of the trial, in which they were asked to answer seven questions concerning their interaction with the robot. To establish the degree of acceptability of the robotic system among users, it was necessary to examine the grades provided by participants based on the questionnaire.

Attempts are being made to go ahead with clinical trials as soon as possible because of the excellent results obtained in laboratory testing, as well as favorable comments received from individuals who have undertaken rehabilitation activities of the lower limb utilizing the robotic system.

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