TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 64, Issue I, March, 2021

# EXPERIMENTAL EVALUATION OF A PARALLEL REHABILITATION ROBOT FOR NEUROMOTOR IMPAIRMENT

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***Abstract:*** *The paper presents the experimental evaluation of a new parallel robotic system with modular architecture developed for lower limb rehabilitation, for patients suffering from neuro-motor deficits. The robotic system, entitled RAISE, aims to target the acute post-stroke rehabilitation stage for bed-ridden patients. Within this paper, an analysis of current state of the art technologies in lower limb rehabilitation is presented, followed by a definition of the development stages starting from medical task definition and up to the experimental testing of the innovative robotic structure. The experimental measurements for robot task definition are presented, and the robotic structure is validated following a series of experimental tests with the system in laboratory conditions.*

***Key words:*** *parallel robot, rehabilitation, neuro-motor deficit, lower limb, experimental evaluation*

## 1. INTRODUCTION

At present, the majority of motor rehabilitation exercises are carried out with the active assistance of medical specialists in the field (Kineto-therapists). Unfortunately, this will not be viable in the future [1] as the expanding target groups for neurological disorders (due to increasing lifespans and unhealthy lifestyles), will lead to an overcrowding of the medical system with patients requiring rehabilitation thus having a negative influence on their recovery, social reintegration and independent living capabilities. This imposes a need to automate the rehabilitation procedures, through the use of robotic devices that must be capable of fulfilling the rehabilitation tasks, at the very least in an equal manner to a physical therapist.

Due to the inevitable shortage of medical personnel in relation to the increasing number of patients, many devices intended for rehabilitation have been and are being developed, which also results in a paradigm change in rehabilitation, while also granting kinetotherapists the option of treating multiple patients simultaneously [2]. Despite all of this, the technology is relatively new and is not frequently implemented in clinics and hospitals, mainly due to the costs of acquisition and implementation of such technologies being high.

The MotionMaker [3] developed by Swortec SA, is a fixed robotic system that allows the execution of lower limb exercises, from a sitting position, focusing mainly on gait training. The device has real-time sensory output and controlled electrostimulation, which can be adapted based on the patient requirements. The device is currently in the experimental stages of development.

The LokoHelp developed by the LokoHelp Group is a device developed for gait training in patients that have suffered a brain injury. The device is mounted on a treadmill and acts as a body weight support system as well as the patient needs to be in a standing posture. Clinical trials have been carried, proving the robot's capability to be as efficient as manual rehabilitation. This device is currently available on the market. [4]

The Gangtrainer GT I, a system sold by Reha-Stim, [5] is a device that aims to help patients regain the lost freedom of movement, by

removing the burden of their own weight and using foot plates that simulate stance and swing. The device requires the patient to be standing and following clinical studies it has been proven

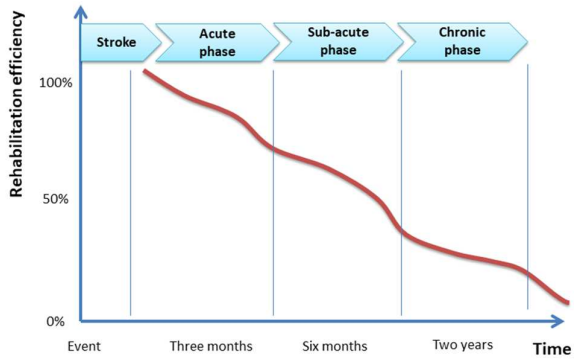


**Fig. 1** Rehabilitation efficiency over time

to be as effective as manual rehabilitation.

Following a state-of-the-art study a white spot has been identified in the rehabilitation of the lower limb, more specifically there are few devices available that are capable of treating patients in what would be considered to be the most critical stage of rehabilitation, specifically, the acute stage. In this stage patients are constrained to hospital beds, with almost zero control over their limbs. Additionally, it has been shown that the efficiency of rehabilitation is greater, the sooner it begins in relation to the occurrence of the neurological event (e.g. stroke) (Fig.1) [6].

The current paper is structured in accordance with the following sections:

**Development stages of robotic systems for neuro-motor rehabilitation**, where a description of the development process for a parallel robotic system for lower limb post stroke rehabilitation is presented, including the steps necessary to be followed to reach experimental testing;

**Experimental motion characterization for the lower limb**, where the detailed analysis of the motion amplitudes of the targeted rehabilitation motions is presented, following measurements done on healthy subjects;

**Description of the RAISE parallel robot**, where a novel modular parallel robotic system intended for the lower limb rehabilitation of patients in the acute stage of rehabilitation, is presented.

**Experimental tests based on medical protocols,** where the procedures and results of experimental testing procedures carried out in laboratory conditions on healthy subjects with the RAISE robot, are presented, thus validating the device functionality.

## 2. DEVELOPMENT STAGES OF ROBOTIC SYSTEMS FOR NEURO-MOTOR REHABILITATION

The development process of a robotic device used in medical applications requires a close collaboration between engineers and medical specialists. A robotic device used in neuro rehabilitation is tasked with manipulating a person's limbs. As a result of this it is highly necessary that the development process of a device that has to interact with these patients is capable of offering a safe, pleasant and rewarding experience both for the patients and the operators/medical professionals.

For this purpose a flowchart was made (Fig.2) that serves as a roadmap for the development process of a neuro-motor rehabilitation device. As it can be observed, a harmonious cooperation between medical professionals and engineers is necessary and must be encouraged if there are any valid results to be obtained.

Referring to (Fig.2) the first step of the development process is the **medical task definition**. This task falls entirely on the medical personnel, as they are the ones that are the most knowledgeable on the subject. During this stage inputs necessary for the development of a robotic device are defined. In the case of rehabilitation, these inputs are motion amplitudes, motion trajectories of the human limb, anchoring and counter-anchoring points (which are necessary to determine robot to human contact points), the specific exercises that are executed in manual rehabilitation procedures, the effectiveness of each exercise, the duration of rehabilitation sessions etc. At the end of this step, a clear robotic medical protocol should be defined. The second step would be **motion characterization**, the responsibility for this falls onto both doctors and engineers, as the motions that need to be reproduced by the system must be clearly defined, as well as the ranges of motion that need to be respected and

the means by which the robotic device would be able to achieve these motions safely and efficiently, while also ensuring that the entire experience is pleasant. At the end of this, the targeted joints and motion amplitudes should be clearly defined. Following the previous stage, the **concept definition** should begin. This task is approached by the engineering staff, and needs to use all previously obtained information to propose several robotic structures that could at least at the first sight fulfill the defined task, properly. Upon choosing a viable solution, the **mathematical modelling** of the system can begin. This task is highly important as it infers the clear definition of the robotic structure and its capabilities, with the outputs of kinematics, workspace and singularity analysis playing a central role in the pre-validation of the design, justifying the robot's capacity to achieve the medical task. Next is the **design and control stage** which is highly necessary in obtaining a working experimental model, that is able to fulfill its task freely (not in a real rehabilitation procedure), if the device is functional and fulfills all of the tasks defined in the first two tasks, then the robot can enter the **experimental testing** stage, at which point the device can be validated in a valid medical environment on actual patients, if all goes well this can lead to medical validation, which means that the robot is capable of doing its task and is a viable solution that can be implemented.

After these steps are complete, the manufacturing, and commercialization process for the device can begin.

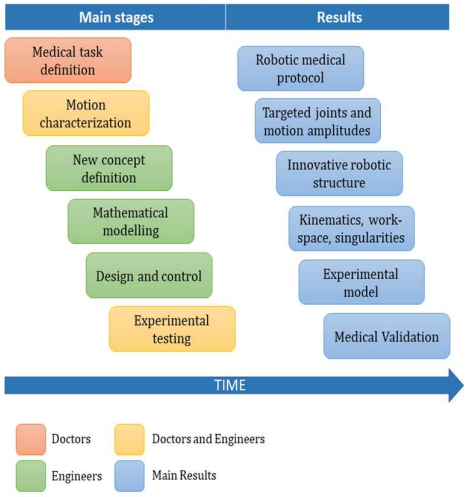


**Fig. 2** Stages of development

## 3. EXPERIMENTAL MOTION CHARACTERIZATION FOR THE LOWER LIMB

An ideal scenario in the development process of a robotic rehabilitation device is a 1:1 motion transmission ratio between the robotic arm motions and the patient leg motions. In reality every person is characterized by different anthropometric dimensions [7], and keeping a rigid mounting of the lower limb would only increase the potential for harming the leg. This can mainly occur due to disparities, when compared to the ideal leg movement, in the joints muscles and due to changes in posture during exercises.

A possible way of ensuring the proper robot functionality is to use sensors for real-time measurements [8], and systems that can characterize the motion of a healthy limb while also registering the discrepancies that occur in comparison with the ideal motion model of the human limb. For this purpose two methods have been used.

The **first** method, involved the use of a skin-mounted sensor system on a number of five healthy subjects (4 males and one female with ages ranging between 26 and 39 years old), which were asked to reproduce the respective motions used in the medical rehabilitation of the lower limb [9]. The sensor system, manufactured by **BIOMETRICS Ltd** [10] (Fig. 3) is comprised of a computer (1) used for signal processing, twin axis goniometers for motion amplitude recordings in different planes (2), signal transmission device (DataLog) (4), connection wires (5), and medical adhesive tape and elastic bands (3) for fixing the goniometers onto the subjects.

The Biometrics system is usually used to collect, process and analyze the experimental data in the field of human biomechanics [11,12] or clinical medicine, especially in the field of rehabilitation of human movements [9, 13, 14] .

The motions which were studied here are hip flexion/extension and abduction/adduction, knee flexion and ankle dorsi-/plantar flexion and abduction/adduction. The hip motions were measured using a bi-axial goniometer (SG150) which allowed the registering of motion

amplitudes in two perpendicular planes. The same type of goniometer was also used for the knee, here, due to the mechanically constrained motion of the knee joint only one axial measurement was registered, and for the ankle a bi-axial (SG110A) goniometer was used, to register amplitudes in two planes as in the case of the hip. The sensor mounting can be further observed in (Fig.4), which also depicts the starting position with the subjects laying on their back in a bed. The measurement procedure had the subjects perform the motions on their own without any kind of assistance and the subjects were asked to achieve the motions within what they personally considered to be comfortable motion ranges. For each motion, a number of ten repetition were carried out. In the case of the studied hip motions, the leg was raised within the sagittal plane (flexion/extension) and while being maintained in the sagittal plane, lateral hip motions were reproduced within the coronal plane (abduction/adduction). For the knee flexion, the leg was also raised using the hip, within the sagittal plane at a range close to 90 degrees and from there knee flexion was achieved. As for the ankle motions these were achieved while laying down.

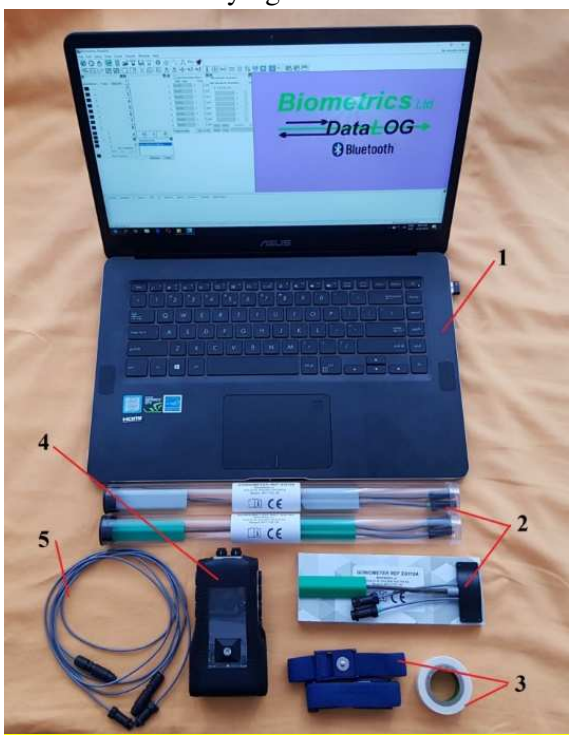


**Fig. 3** Biometrics instruments [10]

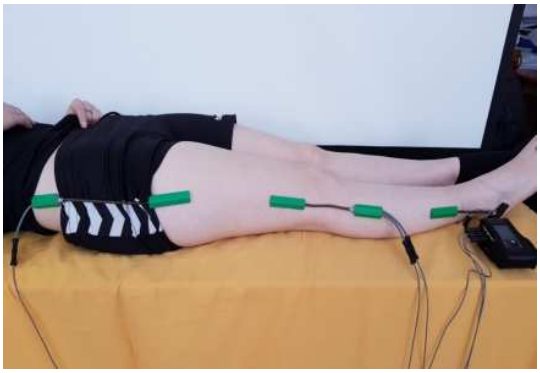

**Fig. 4** Sensor mounting

The motion amplitudes registered during the measurements were organized in table 1.1.

*Table 1*

**Experimental data from biometric sensors**

| **Hip motions** | | | | | |
|---|---|---|---|---|---|
| **Flexion/Extension** | | | | | |
| **Sub.** | **Min.** | **Max.** | **Avg.** | **Med.** | **Std.** |
| **1** | 55.26 | 61.82 | 57.99 | 58.05 | 1.98 |
| **2** | 38.07 | 47.63 | 44.12 | 44.28 | 2.82 |
| **3** | 42.98 | 56.42 | 48.03 | 47.14 | 3.89 |
| **4** | 29.51 | 37.27 | 34.11 | 35.31 | 2.67 |
| **5** | 46.91 | 61.02 | 53.92 | 53.03 | 4.37 |
| **Abduction/adduction (1)** | | | | | |
| **Sub.** | **AvgC** | **Std** | **AvgS** | **Std.** | |
| **1** | 13.3 | 3.16 | 30.39 | 3.58 | |
| **2** | 27.29 | 1.26 | 16.74 | 2.16 | |
| **3** | 6.67 | 1.01 | 20.52 | 2.68 | |
| **4** | 14.83 | 3.49 | 11.13 | 2.07 | |
| **5** | 16.07 | 2.19 | 31.83 | 1.37 | |
| **Abduction/adduction (2)** | | | | | |
| **Sub.** | **AvgC** | **Std** | **AvgS** | **Std.** | |
| **1** | 17.9 | 5.2 | 40.93 | 1.68 | |
| **2** | 23.16 | 4.19 | 34.73 | 4.77 | |
| **3** | 6.85 | 1.71 | 27.23 | 1.08 | |
| **4** | 10.23 | 1.34 | 17.17 | 1.93 | |
| **5** | 34.08 | 2.01 | 53.34 | 2.25 | |
| **Knee Flexion** | | | | | |
| **Sub.** | **Min.** | **Max.** | **Avg.** | **Med.** | **Std.** |
| **1** | 108.02 | 110.39 | 109.57 | 109.63 | 0.6225 |
| **2** | 94.77 | 102.89 | 98.41 | 97.35 | 2.7074 |
| **3** | 115.66 | 117.62 | 116.38 | 117.37 | 0.6144 |
| **4** | 96.19 | 99.41 | 97.71 | 97.96 | 0.9554 |
| **5** | 122.84 | 126.28 | 124.13 | 123.89 | 1.1633 |
| Ankle Motions | | | | | |
| **Dorsiflexion/plantarflexion** | | | | | |
| **Sub.** | **Avg.** | **Std.** | **Avg.** | **Std.** | |
| **1** | 25.85 | 2.44 | 31.18 | 0.98 | |
| **2** | 17.28 | 2.47 | 29.47 | 4.19 | |
| **3** | 16.66 | 1.83 | 44.16 | 4.23 | |
| **4** | 26.07 | 3.81 | 30.43 | 6.87 | |

| | | | | |
|---|---|---|---|---|
| **5** | 14.53 | 0.91 | 40.43 | 0.87 |
| **Adduction/abduction** | | | | |
| **Sub.** | **Avg.** | **Std.** | **Avg.** | **Std.** |
| **1** | 58.5 | 1.2419 | 8.28 | 1.5267 |
| **2** | 59.7 | 1.87 | 9.48 | 2.014 |
| **3** | 56.91 | 1.558 | 12.57 | 1.874 |
| **4** | 51.25 | 1.697 | 7.88 | 2.058 |
| **5** | 55.4 | 2.358 | 8.11 | 1.557 |


**Fig. 5** SIMIR measuring system

Real time data could also be collected remotely as given in [16]. The experimental measurements have clarified several characteristics of the studied motions. Consequently, during hip flexion/extension, low values of lateral deviations were observed, as for hip abduction/adduction, the motions should be reproduced with the leg raised from the horizontal plane in order to allow larger motion amplitudes and less joint stress. Knee motions as mentioned before are constrained by the knee joint and negligible deviations were observed. When referring to the ankle motions, it has been noted that during the neutral/starting position, each subject presented an inclination of the foot, from the vertical plane, most noticeable upon studying the averages registered for dorsiflexion, as for the lateral motions it has been determined that maximum angular amplitudes can only be achieved if the rotation in the perpendicular plane to the plane of motion, is not constrained.

The **second** measurement method involved the use of a cable driven robotic device. SIMIR (Fig. 5) is a system comprised of six wire tensioners with analogue functionality, organized in pairs of three, which provide two anchor points mounted on the limb segments connected by the targeted joints. The signal acquisition, control, and post-processing interfaces were created using a National Instruments integrated solution, and the graphical user interface, where tension and cable length variations can be observed and logged, was developed using the LabView environment. As in the **first** method, the same 5 healthy subjects were used. In the case of this method, the leg motions from a standing position, were studied (Fig. 6).

**Fig. 6** SIMIR leg mounting

The data collected using the SIMIR system (Fig. 7-9) presented similar signal oscillations to those observed with the Biometrics system, further supporting the notion of using signal behavior for determining the motion ranges of the targeted joints.

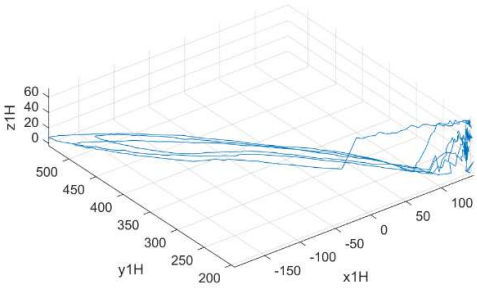


**Fig. 7** SIMIR knee trajectory

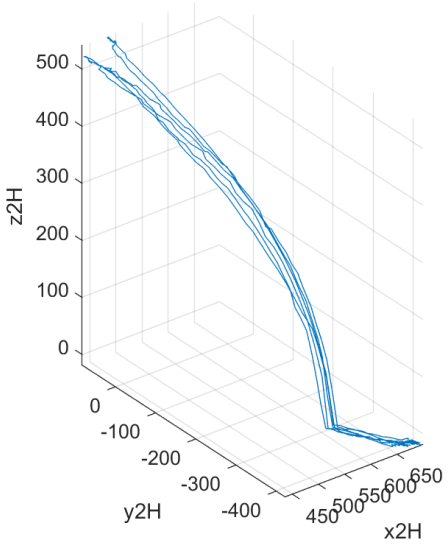


**Fig. 8** SIMIR ankle trajectory

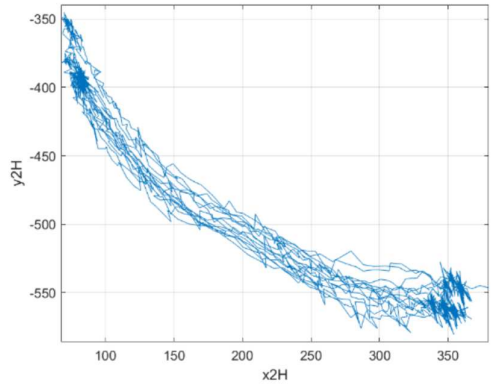


**Fig. 9** SIMIR Leg trajectory

## 4. DESCRIPTION OF THE RAISE PARALLEL ROBOT

The solution which has been developed for the motor rehabilitation of the lower limb, following the experimental data presented in Section 3, is **RAISE**, a 5 DOF (degree of freedom) modular parallel robot [15] (Fig. 10). The device is capable of providing active assistance in the reproduction of the clinical rehabilitation motions and by joint division it is capable of achieving:

- **Hip** flexion/extension and abduction /adduction
- **Knee** flexion
- **Ankle** plantar-flexion/ dorsi-flexion (extension) and abduction/adduction.

The robotic system's maximum motion amplitudes have been chosen to be slightly below the values recorded on the healthy subjects, to ensure the safety of the patients, as it was demonstrated through multiple clinical studies that the initial exercises are performed with lower-than-normal amplitudes. (Table 2), during the measurements presented in Section 3.

**Fig. 10** RAISE robotic system CAD model

*Table 2*

**Motion amplitude capacities of RAISE**

| | Ankle Joint | Knee Joint | Hip Joint |
|---|---|---|---|
| **Flexion** | 35 (deg.) | 80 (deg.) | 55 (deg.) |
| **Extension** | 20 (deg.) | 0 (deg.) | 0 (deg.) |
| **Abduction** | 20 (deg.) | - | 30 (deg.) |
| **Adduction** | 20 (deg.) | - | 0 (deg.) |

The robotic device itself consists of two modules. The **first module** (Fig. 11), is the **hip-knee module** (Fig. 12), is responsible with the hip and knee joint. The module performs the hip joint based motions in the vertical and lateral planes which are perpendicular to one another, and it performs the knee joint based motion in the vertical plane. The **second module,** is the **ankle module,** performs ankle joint based motions in two perpendicular planes similarly to the hip module but with motion amplitudes

corresponding to the capabilities of the ankle joint.

The parallel construction of the hip knee module implies the use of three active translational joints which transmit the motion to the passive joints that are connected to the human limb and aligned with the targeted joints for hip flexion/extension and knee flexion rehabilitation and hip abduction/adduction. More specifically there are two passive rotational joints, which have perpendicular rotation axes, that allow the reproduction of the hip motions, as mentioned previously, and another passive rotational joint for the knee.

**Fig. 11** RAISE hip-knee module

For the ankle module, there are two active rotational joints, with axial perpendicularity similar to the hip joints, which actuate the foot support, while maintaining the center of rotation coincident with the center of the human ankle joint.

As with any robotic device, during the kinematic modelling of RAISE, a total of three singularity cases were identified [13], all three of these involving the hip-knee module.

The **first singularity** has been identified to occur when the patient's leg is completely straight, this would mean that the robot only has one starting position, this has been accounted for by introducing a distancing element within the robotic structure limiting the amplitude of motion (Fig. 10), marked with a red circle.

**Fig. 12** Raise ankle module

The **second singularity** can occur if the patient's hip is flexed at a value of 90 degrees. This posturing of the leg does not coincide with the necessities of the medical specialist's recommendation for rehabilitation therapy [7], therefore it does not affect the device's capability of achieving its medical task and has been dealt with by limiting the actuator strokes. The **third singularity** has been identified to occur if the lower limb segment (encompassing the tibia) stands at an angle of 90 degrees downwards, parallel with the vertical axis, the solution to this was preventing this particular configuration from occurring directly from the control system.

Regarding the **anthropometric adaptability** of the device, the position of the passive rotational joints within the hip module can be altered along the connecting rigid segments as to allow a wider range of patients (based on limb segment length) to benefit from the robot's capabilities. The modular construction dividing the device into a hip and ankle module, allows the repositioning of the ankle module to satisfy different limb lengths. Concerning the varying thickness of the limb segments, the patient is mounted onto the device using textile straps to secure each limb segment in position. The patient's leg does not enter in direct contact with the passive joints and links connecting these, instead, 3D printed supports were manufactured and then padded with soft breathable material, to ensure that there is no possibility of damage to the patient's epithelium and that no discomfort is caused due to unwanted friction or sweat, during the rehabilitative procedure.

## 5.EXPERIMENTAL TESTS BASED ON MEDICAL PROTOCOL

An important step in the development of robotic devices involves the carrying out of tests and assessments beyond theoretical and virtual environments, in the real world. For this purpose RAISE was included in an initial experimental procedure, where its capacity to reproduce medically relevant motions was verified. The experimental procedures were done within the CESTER research center at the Technical University of Cluj-Napoca center where, the device was placed in an experimental setup reproducing what will be encountered in clinics and hospitals (Fig. 13).

The experimental procedures were done with the participation of five healthy and willing subjects aged 25 to 40, and the testing was done in accordance with the Helsinki declaration (albeit not necessary due to laboratory conditions), and each subject gave their written consent following a detailed explanation of the procedure, instruments, motions reproduced, duration of the experiment, and possible risks involved.

The tests were done while carefully following a predefined medical protocol regarding patient safety [17], data collection and robot operation. This protocol has been organized by a series of steps (Stp):

- **Stp1** The subject has to lay down on they back on the adjustable bed and place their right leg parallel to the RAISE robot (Fig. 14);
- **Stp2** Following a sterilization of the elements that enter into contact with the subject, the participant was asked to correctly and comfortably mount their leg on the device;
- **Stp3** Limb segments were secured onto the robot via elastic bands;
- **Stp4** Following successful subject mounting the, robotic device begins to reproduce hip flexion by lifting the subject's leg in the sagittal plane (Fig. 15);
- **Stp5** The device performed hip abduction by moving the patient's leg within the coronal plane (Fig. 16);
- **Stp6** Robotic device returns to homing position;
- **Stp7** The robotic device reproduced knee flexion, by flexing the leg in the sagittal plane (Fig. 17);
- **Stp8** The device returned to homing position;
- **Stp9** The device performed ankle dorsiflexion/plantar flexion from a starting position (Fig. 18a) by moving the foot in the sagittal plane (Fig. 18b,c);
- **Stp10** The device performed ankle inversion/eversion by moving the foot within the frontal plane (Fig. 18d);
- **Stp11** The device returns to homing position and the subject was dismounted from the device.

The device was returned to a homing position (Fig. 14) while switching between different types of motions. For each motion a number of 10 repetitions was achieved. Between each different motion, the subjects were granted a one minute resting period.

During these tests the robotic device was granted set values for the angular amplitudes used in rehabilitation (Table 3).

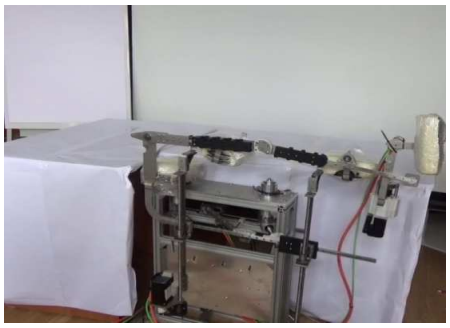

**Fig. 13** RAISE experimental setup

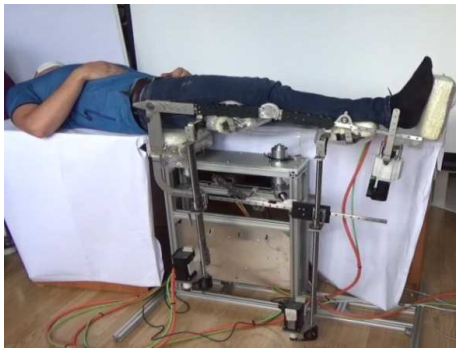

**Fig. 14** Experimental Homing Position

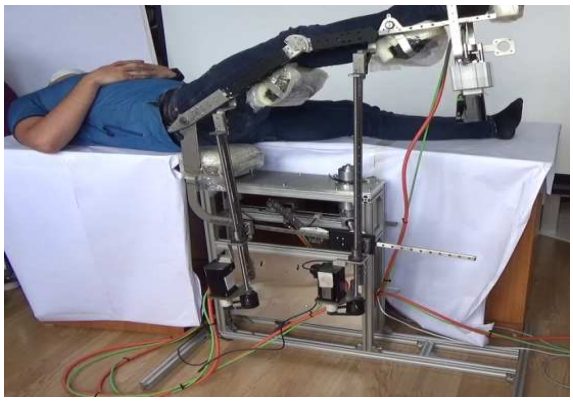

**Fig. 15** Hip flexion

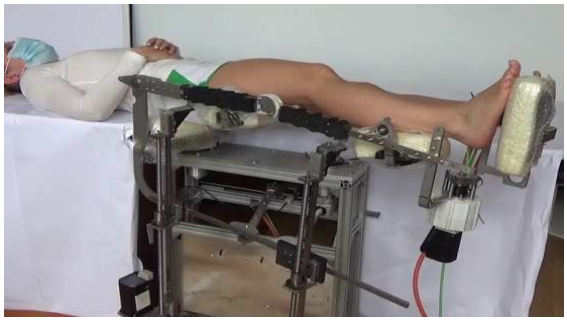

**Fig. 16** Hip Abduction

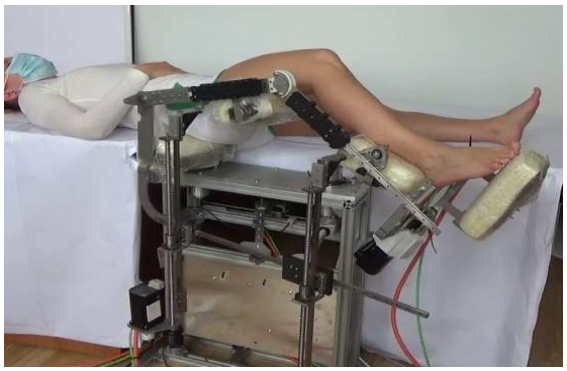

**Fig. 17** Knee flexion

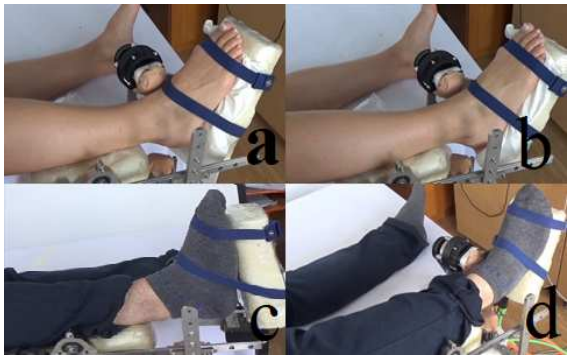


**Fig. 18** Ankle motions

*Table 3*

**Angular amplitudes used in the experimental stage**

| Motions | Amplitudes (deg) |
|---|---|
| Hip flexion | -25 |
| Hip extension | 80 |
| Hip adduction | 0 |
| Hip abduction | 25 |
| Knee flexion | 0 |
| Knee extension | 80 |
| Ankle dorsiflexion | -25 |
| Ankle plantar flexion | 25 |
| Ankle inversion | -25 |
| Ankle eversion | 25 |

Additionally, an experimental test was done, where the robotic device reproduces a sequence of six combined and simple motions on two subjects. The reasoning behind this was to study actuator behavior based on varying anthropometric data. The geometric parameters of the device were modified to fit the anthropometric characteristics of each subject. The subjects were one 160 cm high, 50 kg female with a thigh length of 440 mm and lower leg length of 430 mm and one 180 cm high and 81 kg male with a thigh length of 490 mm and lower leg length of 450 mm.

Following this experiment it was determined that the motion parameters of the active joints are independent on the limb length variations of the two subjects, with only a small variation of less than 1% observed in the active joint acting upon the lower limb segment (Fig. 19). This experiment stood to prove that the RAISE experimental model can be easily adapted to different anthropometric values without suffering any changes in its behavior.

## 6.CONCLUSIONS

The RAISE parallel robotic system was developed to address a white spot in research for lower limb rehabilitation systems, it being as far as the authors are aware the only device developed for bed-ridden patients.

Experimental measurements were carried out on healthy subjects to better study the motion planes in which rehabilitation exercises take place, and consequentially to increase efficiency and safety during the acute post-stroke

rehabilitation, as the ability to feel discomfort and pain is lost or greatly reduced during this stage. This can make patients unaware of any strain upon their joints and muscles.

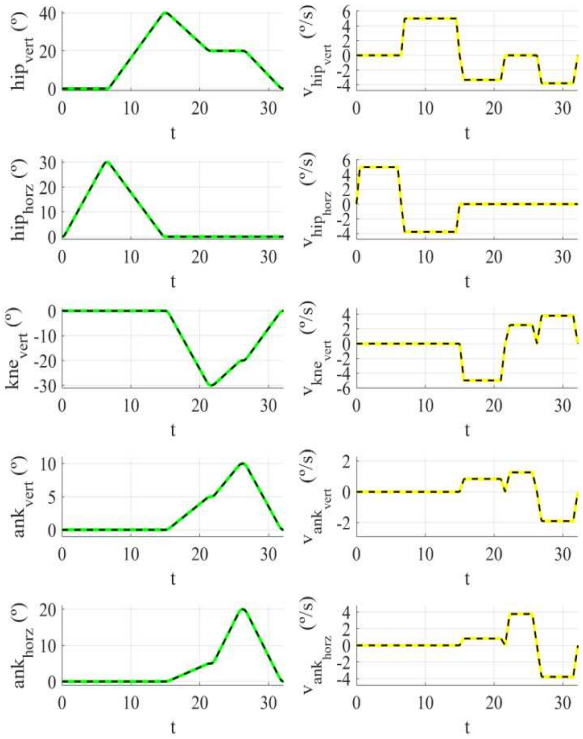


**Fig. 19** Joint motion amplitudes/speeds for the two subjects

RAISE, the parallel robotic device used in the rehabilitation of the lower limb, was proven to be capable of executing the flexion of the hip, abduction of the hip, flexion of the knee, ankle plantar flexion/dorsi-flexion and ankle inversion/eversion. This totals in a number of 7 simple rehabilitative motions, respecting the defined medical protocol.

Experimental studies carried out in laboratory conditions, on healthy subjects, served to validate the device's functionality and capability of executing the targeted rehabilitative motions safely and efficiently, in accordance with the protocols defined by medical specialists. Additionally a set of complex motions were reproduced by the device on healthy subjects with major differences in anthropometric characteristics which proved the device's viability in working with a varied array of patients without having any impact on the device or patient safety.

A highly important step for the future development of the RAISE robotic device would be the validation of its viability and performance within a dedicated post-stroke rehabilitation environment, which hopefully will be possible as soon as the Covid-19 crisis dims down and internal medical centers procedures will allow this type of experimentation.

## 7.ACKNOWLEDGEMENT

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project number PN-III-P2-2.1-PED-2019-3022/546PED/2020 (Neuro-Assist), within PNCDI III. The paper presents also results from the research activities of the project POCU/380/6/13/123927 – ANTRE-DOC, "Entrepreneurial competencies and excellence research in doctoral and postdoctoral studies programs", project co-funded from the European Social Fund through the Human Capital Operational Program 2014-2020.

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# EVALUAREA EXPERIMENTALĂ A UNUI ROBOT PARALEL DE REABILITARE PENTRU DEFICIENTE NEUROMOTORII

**Rezumat:** Lucrarea prezintă evaluarea experimentală a unui nou sistem robotizat paralel cu arhitectură modulară dezvoltat pentru reabilitarea membrelor inferioare, pentru pacienții care suferă de deficite neuro-motorii. Sistemul robotizat, intitulat RAISE, își propune să vizeze stadiul acut de reabilitare post-AVC pentru pacienții restricționați pe patul de spital. În cadrul acestei lucrări, este prezentată o analiză a stadiului actual al tehnologiilor robotizate de reabilitare a membrelor inferioare, urmată de o definiție a etapelor de dezvoltare începând de la definirea sarcinilor medicale și până la testarea experimentală a structurii robotice inovatoare. Sunt prezentate măsurătorile experimentale necesare pentru definirea sarcinii robotului, iar structura robotică este validată în urma unei serii de teste experimentale, cu sistemul, în condiții de laborator.

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