IOP Conf. Series: Materials Science and Engineering **444** (2018) 052021 doi:10.1088/1757-899X/444/5/052021

Novel rehabilitation system for the lower limb

M Mateas[1], C Moldovan[2], CM Gruescu[3] A Kis[4] and E-C Lovasz[5]

[1, 2, 3, 4, 5] Mechatronics Department, University Politehnica of Timisoara, Romania, 1 Mihai Viteazu, RO-300222

E-mail: marius.mateas@upt.ro

Abstract. A new structure and construction of a rehabilitation system for the lower limb is proposed. In many cases rehabilitation is suboptimal due to subjective and empirical choice of evaluation criteria, and therefore three new criteria are introduced. The test bed allows the measurement of three basic parameters (displacement, velocity and force), which are used to calculate the proposed criteria. The system is described in regard with structure, construction and data acquiring. In order to validate the design, a primary set of measurements are performed on the system driven by a healthy person.

1. Introduction

Leg rehabilitation is a very frequent case in the kinetic therapy following injury treatment, neurological diseases or post surgery treatment. The aim of the rehabilitation is the regain of all geometrical and kinetic indicators that characterise a normal leg movement.

In order to assess the efficiency of the rehabilitation and the leg geometrical and kinetic performances, one must perform measurements of displacement, force, velocity and temperature. It is important to correlate the results of the measurements in order to guide the treatment person-oriented.

There is a large data base of methods to measure different parameters linked to leg's movement, involving mostly the force and displacement dependency. The authors of [1] present an electro-mechanical system, which acquires data necessary to study the relation between force, velocity and electrical activity of muscles. Another type of method, as described in [2], uses an opto-mechanical system and foresees the measurement of the mechanical power of the leg during extension for a seated patient. More modern methods use image processing [3] and study the influence of more and more subtle parameters, such as the circadian rhythm [4].

2. Characteristic parameters

Based on previous researches of the authors in the case of leg rehabilitation one must take into account beside the main information regarding displacement, velocity and temperature some more parameters such as the heart rate and the pain degree of the involved person.

To rapidly asses the achievements and also to have an intelligible progress report readable by the involved person for the augmentation of his/her involvement in the treatment, the authors recommend the use of some assessment indicators divided into three classes:

- geometrical evaluation indicator
- kinetic evaluation indicator
- global evaluation indicator.

The **geometrical indicator** must contain information about the displacement of the leg and the angular values of the knee joint:

$$I_G = \frac{d \cdot \Delta\theta}{l \cdot p_m}, \qquad (1)$$

where:

I_G = geometrical evaluation indicator
d = displacement
$\Delta\theta$= angular displacement of the knee joint, $\Delta\theta = \theta_{max} - \theta_{min}$
l = leg length
p_m= pain level mark.

The **kinetic indicator** must contain information about the velocity of a leg-attached characteristic point, the pain level during the movement, the heart rate and the pushing force:

$$I_K = \frac{v \cdot F}{h_r \cdot p_m}, \qquad (2)$$

where:

v = velocity at the end of the leg
F=force at the end of the leg
h_r= heart rate.

The **global evaluation indicator** must combine the two above, taking into account the percentage participation of each partial indicator according to the given importance level. Therefore, based on the fact that velocity and force are not a primary task in rehabilitation, the authors consider to weight I_K with a 40 % participation to the global rehabilitation indicator:

$$I_R = 0.6 \cdot I_G + 0.4 \cdot I_K. \qquad (3)$$

In order to collect data to calculate the partial and global rehabilitation indicators a specially designed test bed is used.

3. Rehabilitation system

Considering that during the measurements the person involved must not suffer of additional movement impediments, the authors propose to acquire linear and angular displacement and also velocity of a leg-attached characteristic point by means of a non-contact measurement. The recommended method is based on photogrammetry and requires a calibrated CCD camera filming the entire leg movement during a rehabilitation exercise.

Figure 1 depicts a picture of the device together with a user, when the foot holder is maximally stretched.

1 – seat
2 – foot holder (with three markers of different colours)
3 – lower leg
4 – upper leg (thigh)
5 – return helical spring

Figure 1. Image of the leg rehabilitation device with an active patient.

The constructive design of the rehabilitation device is based on the average anthropometric leg dimensions [5]:

- length of element 4 (buttock-knee length): 613mm,
- length of element 3 (popliteal height): 444mm.

In the design process was also considered the position of the foot holder when legs are stretched and folded. In the stretched position the foot holder is positioned at 800mm with respect to the seat, and in the folded leg position, the foot holder is at 390mm from the seat, thus resulting in a travel (displacement) of 410mm.

This data is used in the calculus of the forces that appear in the rehabilitation device when considering the spring constant k.

The return force is generated by the helical spring (5) attached between the foot holder (2) and the seat (1), hence work is done only by the user's foot biceps muscle, the main muscle used for standing up motion. In this setup, using a spring, the return force increases linearly with the displacement of the foot holder, but the rehabilitation device can be modified to produce a constant force throughout the strike by attaching a weight and a pulley and replacing the spring.

Also, there can be observed on the foot holder the markers used for the video tracking procedure, but the rehabilitation device also offers possibilities to implement other types of measurement sensors, such as potentiometers or force sensors. The foot holder is mounted on a slider with ball bearings in order to reduce friction in motion.

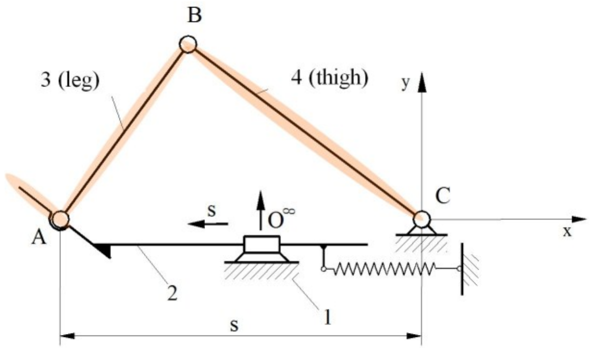

Figure 2. Kinematic schema of the rehabilitation device.

In figure 2 is represented the kinematic schema of the rehabilitation device together with the human using it. In this representation the following notations are used: 1 - frame of the device, 2 – foot holder, 3 - lower leg and 4 – upper leg. Since the foot holder (2) slides along the frame (1) the model contains the translational joint O, all other joints being modelled as rotational joints: A (foot holder, lower leg), B (lower leg, upper leg), C (upper leg, frame). The travel of the foot holder is noted with s, this parameter being measured through video tracking.

To determine the return force generated by the foot holder, and hence the load on the user throughout the rehabilitation process, it is necessary to know the spring constant k. This can be determined through simple measurement techniques.

4. Experimental measurements

In order to determinate indicators (1), (2), (3), it is necessary to measure the travel (displacement), the velocity and the antagonist force. To this purpose, it is proposed a photogrammetric method. Firstly, the movement of the patient leg is filmed on the rehabilitation test bed and then, using an image editor, the frames are extracted at a rate of 10ms. The markers on the foot holder are used to record the displacement. The processing of the video file uses the software application Fiji [6], which allows the determination of the displacement and velocity.

In order to determinate the antagonist force, the helical spring included in the test bed was calibrated.

The measurement performed on the test bed driven by a healthy person provided values of the parameters within the following intervals:

- travel of the foot holder: 336mm,
- force: 14.5N (start of travel) and 353.5N (end of travel).
- linear velocity: 452mm/s (start of travel) and 267mm/s (end of travel).

The angle between the spring and the travel direction varies in the interval (1.73…0.98)deg. Due to these low values, there is no significant difference between the spring developed force and the effective force component along the travel direction.

The evolution of the velocity, travel and force against time (step Δt= 10ms) during the filmed movement on the test bed is given in figures 3…5.

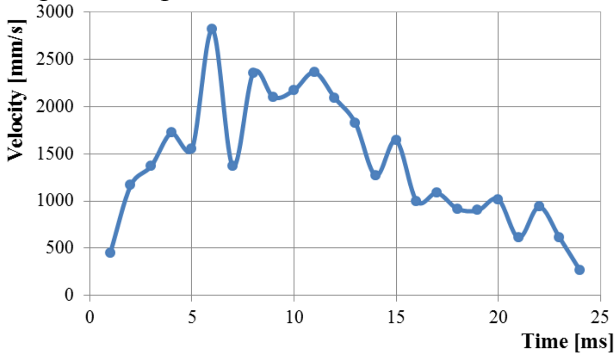

Figure 3. Velocity.

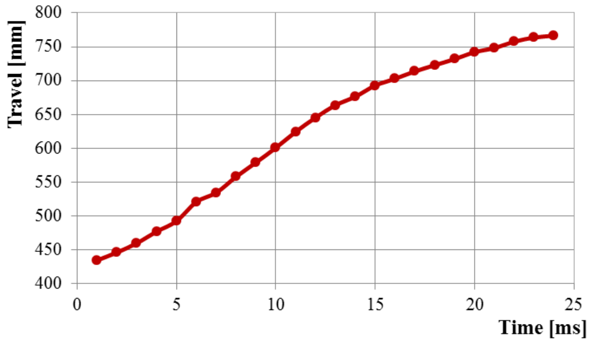

Figure 4. Travel.

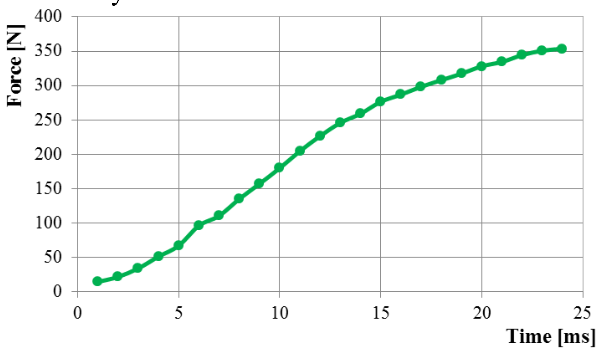

Figure 5. Force.

The measurements presented above were performed in order to validate the correctness of the structure and construction of the test bed, the accuracy of the image processing and to provide approximate values of the basic parameters, which are going to be used in the calculus of the indicators.

5. Conclusions

The test bed conceived for the rehabilitation of the human lower limb is correctly designed for recovering the mobility of the leg joints and allows the measurement of several basic parameters during the movement performed by the patient.

6. References

[1] Bigland B, Lippold CJ 1954 The Relation Between Force, Velocity and Integrated Electrical Activity in Human Muscles *J. Physiol*. **I23** 214-224

[2] Bassey, E.J. & Short, A.H. Europ. 1990 *J. Appl. Physiol*. **60**

[3] de Souza MV, Venturini C, Teixeira LM, Chagas MH, de Resende MA 2008 Force-displacement relationship during anteroposterior mobilization of the ankle joint *J. Manipulative Physiol Ther*. **31(4)** 285-92

[4] Souissi N, Gauthier A, Sesboüé B, Larue J and Davenne D 2004 Circadian rhythms in two types of anaerobic cycle leg exercise: force-velocity and 30-s Wingate tests *Int. J. Sports Med*. **25**(1) 14-19

[5] https://msis.jsc.nasa.gov/sections/Section03.htm

[6] https://fiji.sc/