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A one-degree-of freedom ankle rehabilitation platform

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Abstract. The ankle structure holds one of the most important role in the human biomechanics. Due to complexity of everyday activities this joint is the most prone to be injured part of the lower limb. For a complete recovery of the locomotor function, recovery exercises are mandatory. The existent ankle rehabilitation equipments allow only simple rehabilitation exercises, which cannot be used safely without the aid of a therapist. The introduction of robotic physical recovery systems represents a modern alternative to traditional recovery. Actuated devices are advantageous because they allow many types of exercises on same device, and also they accurate measure forces and angular motions. The purpose of this two paper is to propose a simple rehabilitation device, based on a one-degree-of-freedom mechanisms. Some structural, kinematic and designing aspects of this new ankle rehabilitation device are presented.

1. Introduction

Rehabilitation robotics represents a growing field in the past few years, in the attempt of speeding the process of recovery. The concept of rehabilitation robot can include a wide array of devices, from artificial limbs to personal assistance in hospitals and homes.

In case of lower limbs injuries ankle sprain have a high frequency, approximately between 15 and 20% of all sport injuries, [1]. This injury can also occur in daily activities as well, when a person steps on an uneven surface and the ankle is turned unexpectedly in any direction, beyond the normal limits of movement. The ankle injuries can be classified into grades, depending on the extend of physical damage of the ligaments: grade I (mild), grade II (moderate) and grade III (severe). Treatment of the ankle injury can be divided into three phases: first one includes prescribed medicine and reduction of the swelling, second is represented by the rehabilitation exercises and last is the functional phase where the patient prepares to return to normal activities.

Rehabilitation exercises are required in order to maintain joint mobility and promote muscle strength, after a period of immobilisation. The drawbacks of these exercises are represented by the long duration, the repetition and the low complexity devices that do not stimulate the patient to fully recover, [2]. Also, the lack of trained personal represents a major problem in performing the exercises under professional supervision. All of these factors stimulate innovation in the domain of rehabilitation devices, where the physical training effort of a therapist can be reduced to a simple



monitoring of the robot, [3]. This also allows to record and track the evolution of the exercises and patient's recovery.

The existing robotic rehabilitation devices can be divided into active or passive (depending on the help they offer to the patient). Also they can be grouped according to the rehabilitation principle they follow into: gait trainers, ankle rehabilitation systems and exoskeletons (table 1). Each category is also subdivided offering numerous versions, depending on the affection of the patient, [3-5].

Table 1. Category of rehabilitation robotic devices.

| Category | Subcategory | Examples |
|------------------------------|-----------------------------------|--|
| Gait- trainers | -Treadmill | LokoHelp |
| | -Foot-plate-based gait trainer | The Gangtrainer GT I, HapticWalker, GaitMaster5 |
| | -Overground gait trainer | KineAssist |
| | -Stationary gait trainer | MotionMaker, Lambda, AIST Tsukuba, Biodex Multi-Joint System |
| Ankle rehabilitation systems | -Foot-plate based systems | Rutgers Ankle |
| | -Orthoses | Anklebot, Knee-Ankle-Foot-Orthosis (KAFO) |
| Exoskeletons | -Treadmill-based exoskeleton | ReoAmbulator, Lokomat, ALEX, LOPES, POGO, PAM, University of Auckland system, MINDWALKER |
| | -Portable exoskeleton | ReWalk, Ekso, Indego |
| | -Exoskeleton with mobile platform | SJTU mobile robot, SUBAR, WalkTrainer |

In order to develop an ankle rehabilitation device, the overall motion of the ankle-foot frame must be studied. This motion is complex and occurs around three axes: plantar flexion and dorsiflexion, eversion and inversion, abduction and adduction presented in figure 1, [6]. As starting point of these movements we consider the right angle position formed between the shank and the dorsal foot.

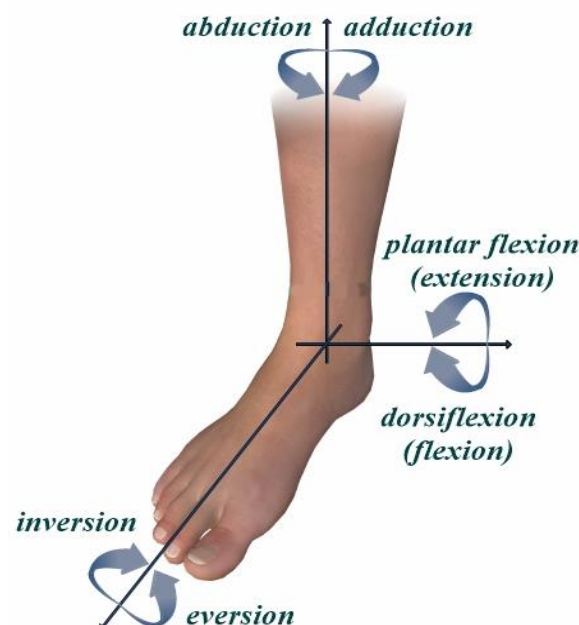


Figure 1. Ankle movements [6].

The plantar flexion (or extension) is the movement where the dorsal foot moves away from the shank while the dorsiflexion movement (or flexion) is the opposite (the dorsal foot moves closer to the shank). Inversion represents the movement where the plantar face of the foot is directed towards the medio-sagittal plan and eversion the opposite movement. Plantarflexion and eversion motion amplitudes range from 20-30 degrees and 45-50 degrees for dorsiflexion and inversion for a healthy patient, although clinical measurements are lower, due to ligaments and muscles restricting the motion, [2]. The abduction-adduction motion results from the previous ones combined, thus it is not required for a rehabilitation device.

In this paper an ankle-foot rehabilitation device with one degree of freedom is proposed. The system is based on wobble board concept, providing full rotation around a vertical axis. The rehabilitations exercises are designed for balance and increase of muscular tone. Also it increases ankle range of motion by exercising muscles that are not typically used while standing on boards that only tilt in two opposite directions.

2. Rehabilitation platform

In order to recover plantar flexion/dorsiflexion and inversion/eversion movements, a 2 degrees of freedom (DOF) mechanism is needed [7, 8]. It means that the moving platform (link) supporting the foot should have 2 independent DOF (figure 2). To drive the moving platform with 2 independent

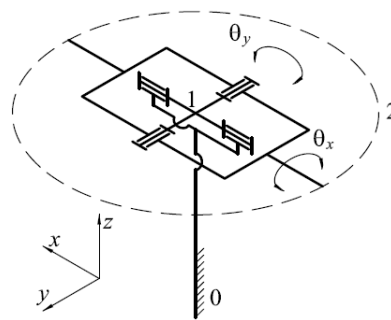


Figure 2. Simplified kinematic sketch of a 2 DOF platform.

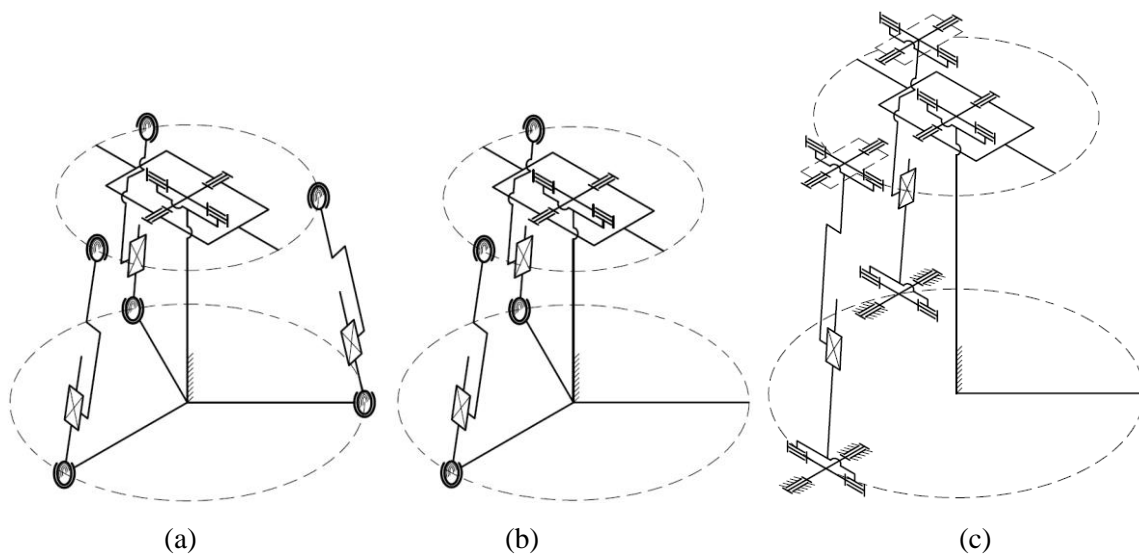


Figure 3. Possible driving solutions: a) 3-SPS/U mechanism; b) 2-SPS/U mechanism; c) 2-UPU/U mechanism [9].

DOF we may use an underactuated 3-SPS/U mechanism (figure 3(a)), a 2-SPS/U mechanism (figure 3(b)) or a 2-UPU/U mechanism (figure 3(c)), [9]. But these mechanisms need two or three actuators. A simpler driving solution proposed in this paper is the one shown in figure 4, using a mechanism with a single DOF (a single actuator). Its disadvantage is that the two DOF of the platform are not independent any more, the amplitudes of the rotation angles θ_x and θ_y have the same value ($\theta_x = \theta_y$).

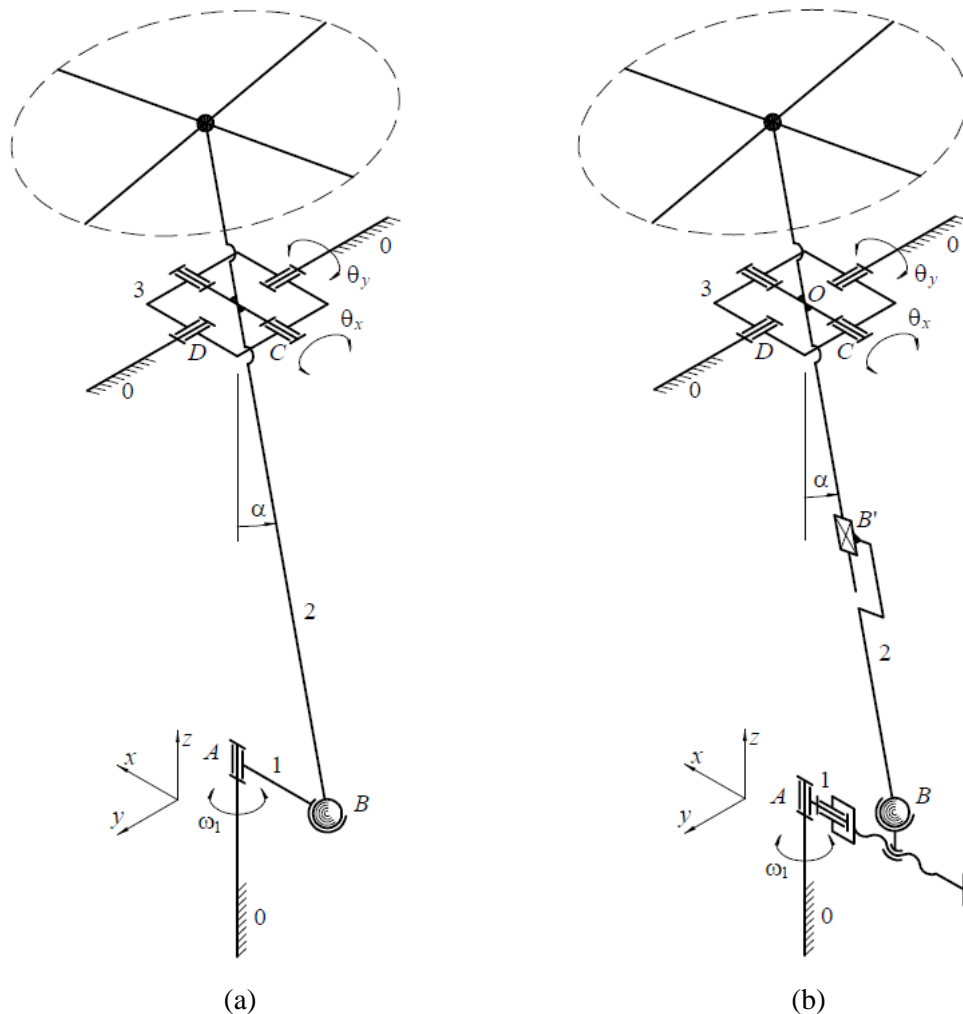


Figure 4. Platform kinematics: a) simplified sketch; b) real sketch, which allows the variation of α .

To compute their degree of freedom, we will use Kutzbach formula for a spatial mechanism. Not any link of these mechanisms will rotate around z axis (only five movements are possible). This is why will use the equation (1):

$$F = 5(n-1-j) + \sum_{i=1}^j f_i, \quad (1)$$

where n is the number of links (including the frame); j is the number of kinematic pairs (joints); f_i represents the degrees-of-freedom of the i th kinematic pair.

For our mechanism, $n = 4$, $j = 4$ (3 rotational joints - A , C , D - with $f = 1$ and 1 spherical joint B with $f = 3$). It means, (equation (2)):

$$F = 5(4 - 1 - 4) + (3 \cdot 1 + 1 \cdot 3) = 1, \quad (2)$$

which means that we need one actuator to drive the mechanism (A joint in figure 4) and the rotations with θ_x and θ_y angles of the foot platform are not independent.

The amplitude of the angles θ_x and θ_y depends on the value of α angle, which depends on the overall dimensions of the mechanism, equation (3):

$$\theta_x = \theta_y = \alpha = \arcsin\left(\frac{l_{AB}}{l_{BO}}\right). \quad (3)$$

In order to modify the amplitude of these angles, the length of the link 1 (l_{AB}) should be modified. This is possible using a nut-screw transmission (see figure 4(b)). It is only possible if the length of the link 2 (l_{BO}) is also variable. To make it variable, a passive prismatic joint B' will be introduced (see figure 4(b)). At the moment, the platform should be stopped to adjust the length l_{AB} (to modify the α angle), manually. In the future, this action will be possible automatically during platform operation thanks to a second motor that will drive the screw.

A CAD model of the platforms is shown in figure 5 and photos of the real platform are presented in figure 6.

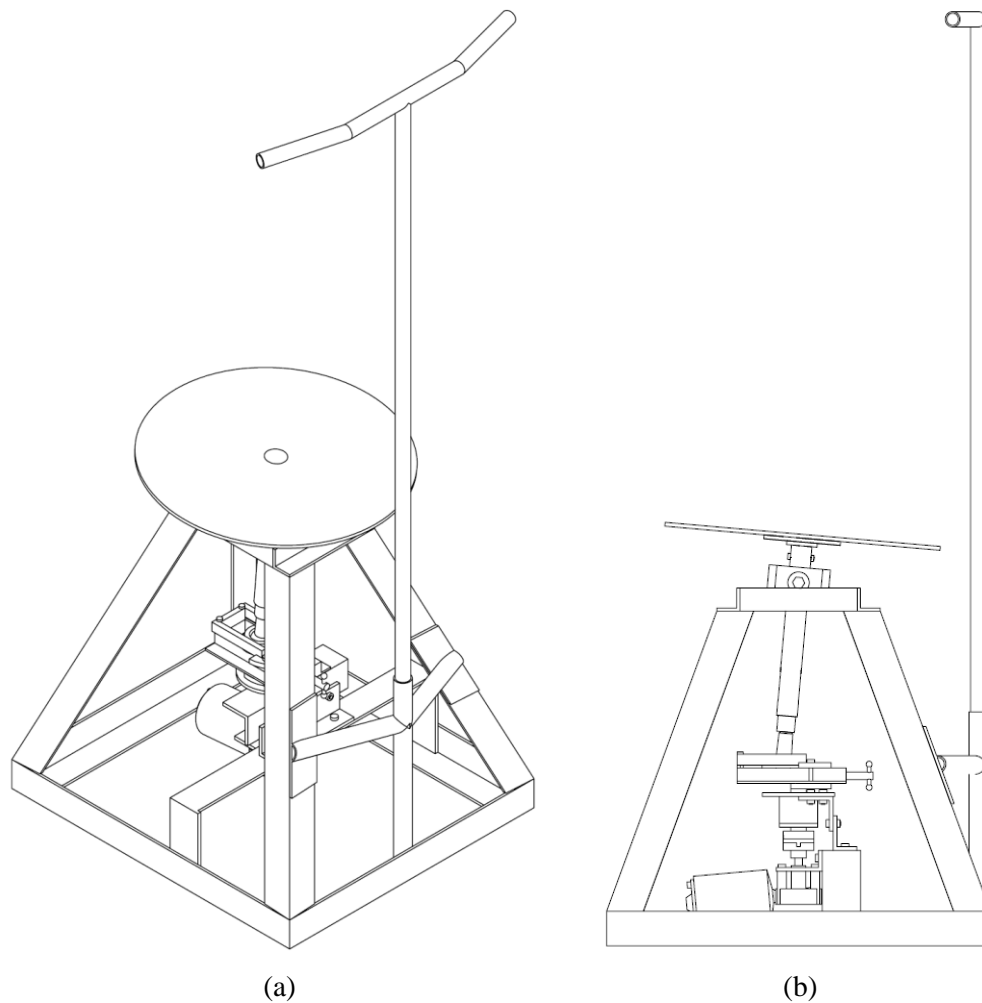


Figure 5. CAD model of the platform: a) 3D view; b) side view.

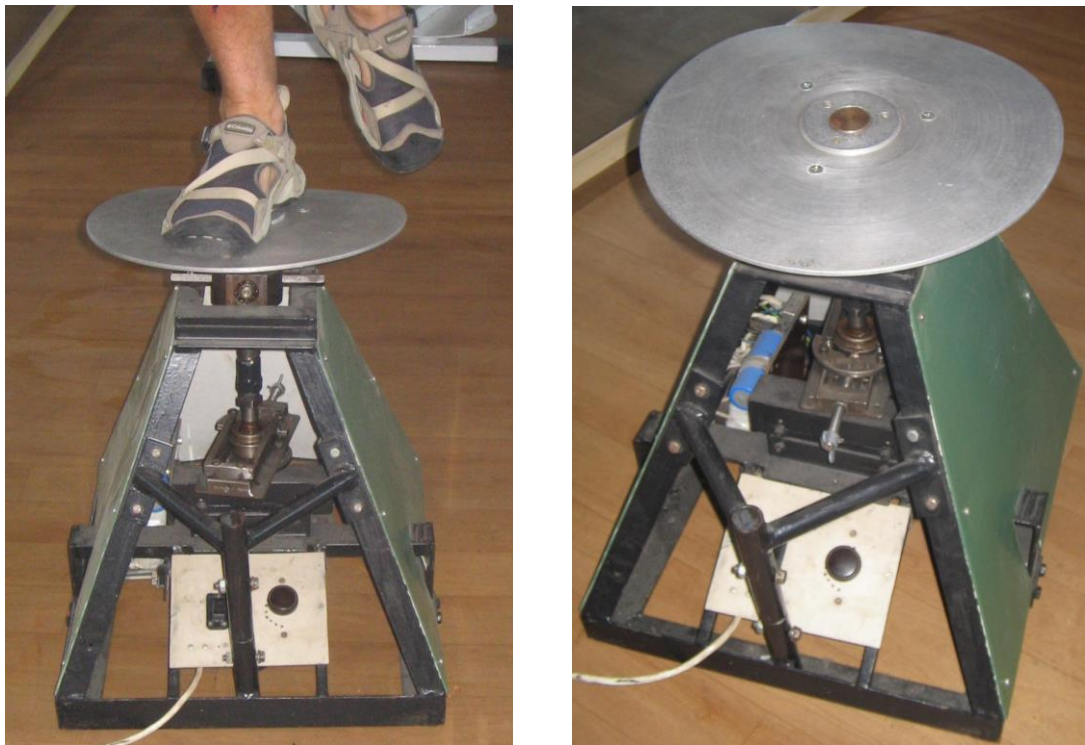


Figure 6. Photos of the real platform.

The general control architecture of the rehabilitation platform is shown in figure 7. The user may adjust the rotational speed and the direction of rotation of the driven link of the rehabilitation device.

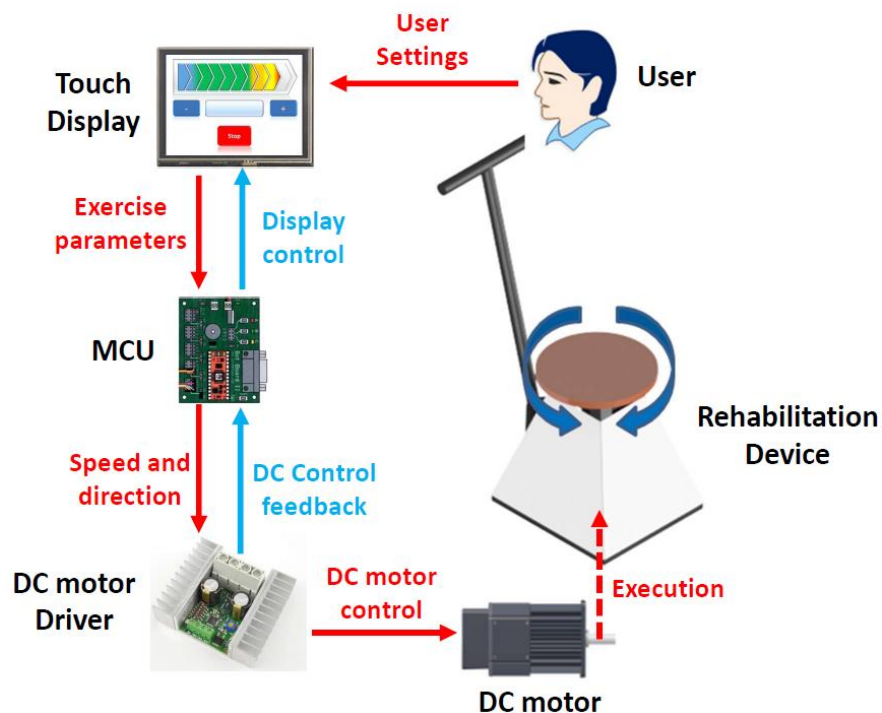


Figure 7. Control architecture.

3. Conclusions

The ankle joint plays one of the most important role in the human biomechanics. Due to complexity of everyday activities this joint is the most prone to be injured part of the lower limb. To complete gain back its function, recovery exercises are mandatory. The existent ankle rehabilitation equipments allow only simple rehabilitation exercises, which cannot be used safely without the aid of a therapist. The introduction of robotic physical recovery systems represents a modern alternative to traditional recovery. In this paper an ankle-foot rehabilitation device with one degree of freedom was proposed. Some structural, kinematic and designing aspects of this new ankle rehabilitation device have been presented. Future constructive solution will use the second motor, in order to modify the value of α angle without the need to stop the platform, based on a command of the user.

4. References

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