Standing Mobility Exoskelton Device

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***Abstract*—This paper presents the development of an exoskeleton mounted on a mobile base to assist people in the Sit-to-Stand action and focused in the rehabilitation of the hip and knees joints. The prototype consists of linear actuators distributed in such a way that they assist the movements of extension and flexion, in the sagital plane, in the hip and knee joints; also, the mobile base allows the transport of a person of up to 90kg. The interaction between the user and the exoskeleton is carried out by processing EMG signals from the user via a Myo Armband and using a classifier to recognise five hand gestures that, in combination of them, generate the instructions to the exoskeleton. A PID control law was programmed in a microcontroller use as slave attached to an embedded computer for tracking the trajectories obtained from the Capture Motion System. The dynamical model of the system is presented in the paper as well as simulation and experimental results.**

***Index Terms*—exoskeleton, control, PID, tracking, EMG.**

I. Introduction

There are a large number of people around the world with injuries and diseases affecting the normal development of the muscles of the lower limbs. The people affected may develop circulatory as well as metabolic problems due to their obliged sedentary way of life. Rising from a sitting to a standing up position is one of the most frequently performed human activities, restoration of this action is essential for an independent living [1]. Many prototypes have been proposed to solve the problem of the positioning of a disabled person, the one by Yoshikazu Mori [2] designs a straight style transfer equipment for the lower limbs disabled. This design comprises three modules: a pair of elastic crutches, a powered lower extremity orthosis and a pair of mobile platforms. Other projects like Levo AG [3] and Superior ME [4] consists of wheel chairs that allow standing up transportation of the patient using a mechanical array. The idea of using a passive exoskeleton and a mobile platform is treated by Yosuke Eguchi [5] in which prototype incorporates a gas spring to assist the exercise of standing and support in the intermediate positions; at the same time, its prototype also has a mobile platform controlled by an inertial measurement sensor; finally, the Segway [6] and Winglet [7] projects that are robotic platforms based on a self-balancing robot for personal transportation that do not consider disabled lower limbs people.

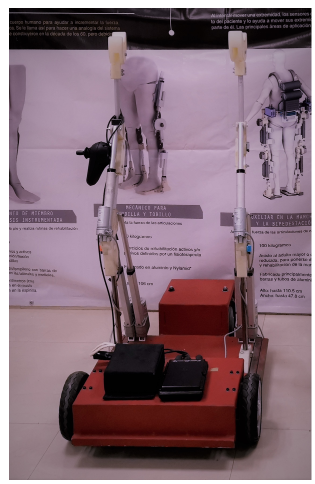

Fig. 1. Exoskeleton prototype built in the Cinvestav, can assist the Sit-to-Stand and Stanf-to-Sit tasks. The prototype can lift a person up to 90 kg using six linear actuators and can go over 30 km thanks to it's LiFePo battery.

This paper describes the design of an exoskeleton to assits Stand-to-Sit and Sit-to-Stand tasks. In Figure 1 shows our experimental platform build in our laboratory. The device is proposed with the aim of assisting the patient in standing and sitting exercises and then, become a technical support to allow movement of those with reduced mobility due to physical injury or an illness that affects the walk of the user.

The work of a nurse who must moving a patient from bed to wheelchair or, from wheelchair to a toilet, is a difficult task because she/he has to carry the weight of the patient and this can be very dangerous and very tiredly, besides inconveniencing the patient taking away the privacy of going to the toilet by him/her-self. The prototype proposed in the paper is not just a motorized chair aiding the sitting down and the standing up actions, it is rather an exoskeleton that also

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allows the user to move from one place to another without the risk of being hurt avoiding any discomfort to the nurse.

A novelty is that the control commands are generated by hand gestures that are interpreted by a Myo Armband [8]. This band is placed on the arm and senses electromiography signals and with the help of a classifier is able to recognize five hand gestures used to generate the instructions for the movements of the prototype. This is a great advantage as it allows the patient to have his hands free of any kind of remote control adding more safety and comfort because the patient can hold or even use his hands for other tasks, opposite to what happens when a wheel chair is employed, limiting the capabilities of the user.

The light weight but sturdy structure of the set-up has linear motors that generate the necessary torques in the joints to produce the different movements of the patient. It also has angular position sensors to measure the angular position of the joints. This information is crucial for the PID controller used to track the predefined trajectories of the movements of the exoskeleton.

II. Platform description

The exoskeleton was designed to suit a person with a height of 150 cm and a weight up to 90 kilograms. Them main objective of the exoskeleton prototype is assist the bipedestation action. The prototype supports the individual by the armpits and is fastened to user's legs and hip using three belts of different sizes as shown in Fig.3. It has a special class of linear actuators placed in such a way that the torque they produce is sufficient to perform the changes of position that the user requires. In Fig.2 the CAD model of the exoskeleton prototype is shown. The device's joints are made of nylamid, a plastic with a rigidity similar to aluminum's but lighter than it. About the platform, it's made of steel and adding motor wheels in front and free wheels on the rear, allows the user's transportation.

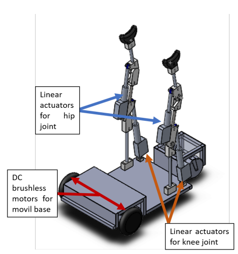

Fig. 2. CAD model of the exoskeleton to assist bipedestation.

III. Exoskeleton's dynamical model

The bipedestation system is a 6-DoF robot composed by 2 subsystems: the exoskeleton and the mobile base. An important consideration is that the exoskeleton has two members, left and right, that are parallels, for that reason the dynamical model of exoskeleton can be obtained as 2-DoF robot. Also, we consider that exoskeleton's tasks are going to perform while the mobile base is in repose state and it's dynamics

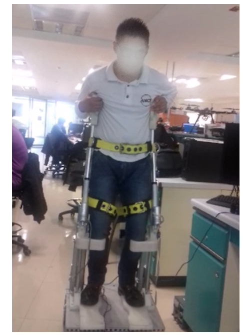

Fig. 3. Use of the exoskeleton prototype. The exoskeleton holds the user by the armpits, a belt fastens the user's hip to the exoskeleton and also two belts fastens the user's legs to the exoskeleton.

can be despised. The free body diagram of the exoskeleton is shown in Figure 4.

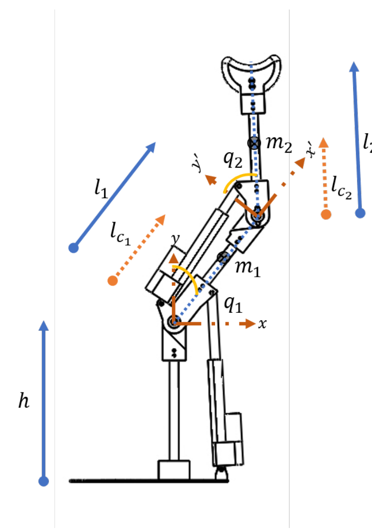

Fig. 4. Exoskeleton's free body diagram that shows the basic elements to obtain the dynamical model.

The dynamical behavior of the system is described by the following equations:

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + F(\dot{q}) = \tau \tag{1}$$

where $M(q)$ is the inertia matrix given by:

$$M_{11} = m_1 l_{c_2}^2 + m_2 l_1^2 + m_2 l_{c_2}^2 + 2 l_1 m_2 l_{c_2} cos(q_2) + I_1 + I_2$$
$$M_{12} = m_2 l_{c_2}^2 + l_1 m_2 l_{c_2} cos(q_2) + I_2$$
$$M_{21} = m_2 l_{c_2}^2 + l_1 m_2 l_{c_2} cos(q_2) + I_2$$
$$M_{22} = m_2 l_{c_2}^2 + I_2$$
$$M(q) = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \tag{2}$$

$C(q,\dot{q})$ is the centripetal and Coriollis forces matrix, that can be written as follows:

$$C_{11} = -m_2 l_1 l_{c_2} sin(q_2)\dot{q}_2$$
$$C_{12} = -m_2 l_1 l_{c_2} sin(q_2)\dot{q}_1 - l_{c_2} sin(q_2)\dot{q}_2$$
$$C_{21} = m_2 l_1 l_{c_2} sin(q_2)\dot{q}_1$$
$$C_{22} = 0$$
$$C(q,\dot{q}) = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \quad (3)$$

$F(\dot{q})$ is the effects of the friction forces matrix, this matrix includes the viscous and coulomb frictions, i.e.:

$$F(\dot{q}) = \begin{bmatrix} 1.95\dot{q}_1 + 1.95sign(\dot{q}_1) \\ 0.95\dot{q}_2 + 0.95sign(\dot{q}_2) \end{bmatrix} \quad (4)$$

$G(q)$ is the vector that includes the gravitational forces as follows:

$$G_{11} = -(m_1 l_{c_1} + m_2 l_1) g sin(q_1) - m_2 g l_{c_2} sin(q_1 + q_2)$$
$$G_{21} = -m_2 g l_{c_2} sin(q_1 + q_2)$$
$$G(q) = \begin{bmatrix} G_{11} \\ G_{21} \end{bmatrix} \quad (5)$$

and τ is the vector of torques defined as:

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} \quad (6)$$

Where τ_1 and τ_2 are the knee and hip torques respectively; m_1 and m_2 are the masses of links 1 and 2; l_1 and l_2 are the lengths of each link; l_{c_1} and l_{c_2} are the distances from the start of the link to its center of mass; q_1 and q_2 are the angular positions of the links; and I_1 and I_2 are the moments of inertia of each link.

IV. Simulation

To perform simulations, we can get $\ddot{q}$ form Eq.1 as follows:

$$\ddot{q} = M(q)^{-1}\left[C(q,\dot{q})\dot{q} + G(q) + F(\dot{q}) + \tau\right] \quad (7)$$

where τ is the control input. A PID control startegy is proposed in this paper. This kind of controller works with the error dynamics, the general form of the PID controller is shown in the next equation:

$$\tau = k_p e(t) + k_d \frac{de(t)}{dt} + k_i \int e(t)dt \quad (8)$$

where $e(t)$ is the angular position error given by:

$$e(t) = q_d(t) - q(t) \quad (9)$$

with $q_d(t)$ as the desired reference for $q(t)$, k_p, k_d and k_i is the proportional, derivative and integral gains respectively. Replacing Eq.8 in Eq.7 we get:

$$\ddot{q}(t) = -M(q)[C(q,\dot{q})\dot{q} + G(q) + F(\dot{q}) + k_p e + k_d \dot{e} + k_i \int e(t)] \quad (10)$$

Stability proof of PID controller only exist in the regulation problem, for the tracking problem is an open problem, for that reason we dont includes in this paper.

Using Optitrack Fig.5, a motion capture system, we obtained the desired trajectories for the knee and hip joints. A person wears an anti-reflective suit and we place reflective markers on it, after that, the system generates a 3D model of the person's body and the user performs the Sit-to-Stand tasks, once the software process data we are able to access the goniometry of knee and hip joints. In future work will add the necessary studies including several motion captures of volunteers to obtain a better pair of trajectories and extend the purposes of this article.

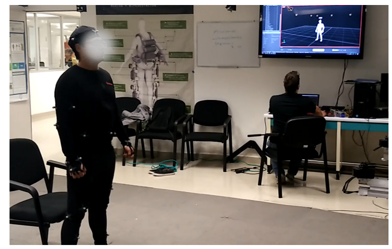

Fig. 5. Optitrack, motion capture system. A healty person wears an antir-refelctive suit, a markers set is positioning in the body and the system automatically generates a model from which can be extracted the corresponding trajectories for knee and hip joints.

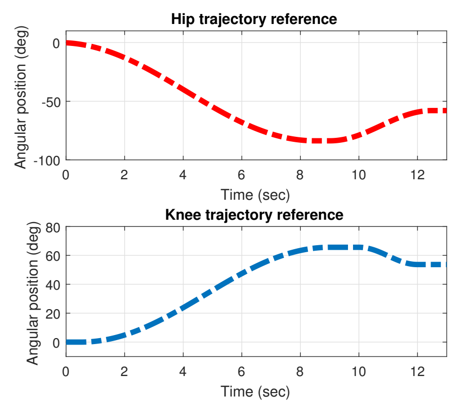

Fig. 6. Reference trajectories obtained from Optictrack. Once the software process all data, we can access the goniometry of knee and hip joints.

The obtained trajectories are shown in the Fig.6

In Table I the values of the parameters of the system to be simulated are presented. These values are actual values corresponding to the prototype that is being built in our laboratory.

We have two important tasks, standing to sit (st2sit) phase and sitting to stand (sit2st) phase, these phases of the motion are shown in Fig.7.

A. Simulation results in the Sit-to-Stand task

Keeping the balance of the user to avoid a fall depends on the good tracking of the desired trajectories. The trajectories

TABLE I
SYSTEM PARAMETERS

Parameter	***Value***	***Unit***
m_1	0.750	kg
m_2	0.500	kg
l_1	0.350	m
l_2	0.310	m
l_{c_1}	0.175	m
l_{c_2}	0.175	m

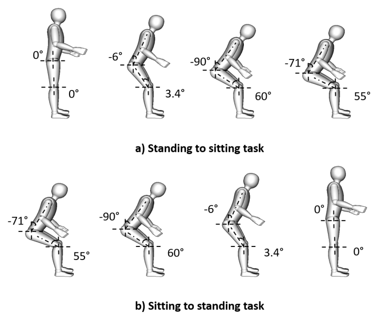

Fig. 7. 3D model of the human body showing the transitions in the a) Stan-to-Sit and b) Sit-to-Stand tasks

are such that the users center of mass is bounded to move within certain limits to avoid a fall. Fig.8 shows the behavior of the hip and knee joints in the sitting to stand task, and Fig.9 shows the error dynamics.

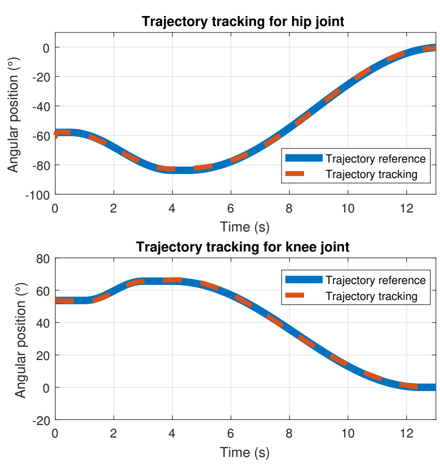

Fig. 8. Trajectory tracking in the Sit-to-Stand task.

B. Simulation results in the Stand-to-Sit task

Fig.10 shows the trajectory tracking of the hip and knee joints. Fig.11 shows the error dynamics of hip and knee joints.

Note that the error is not bigger than 0.007 degrees in the hip joint and no bigger than 0.003 in the knee joint. Thus it can be concluded that the trajectory tracking for the sitting to standing task is adequate. Simulation results show that the PID controller is appropriate for performing the required task.

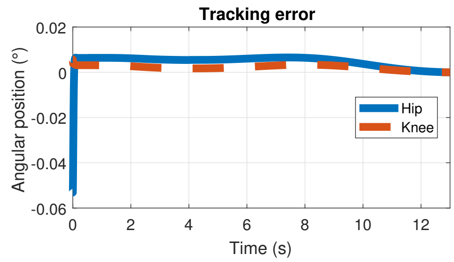

Fig. 9. Error in the Sit-to-Stand task. The blue line shows the tracking error for hip joint while red line shows the tracking error for knee joint.

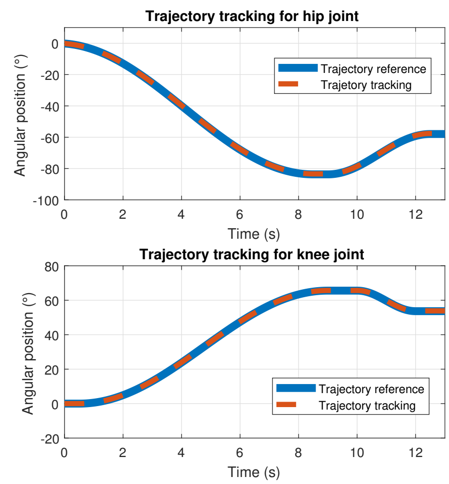

Fig. 10. Trajectory tracking for the Standing-to-Sit task.

V. EXPERIMENTAL RESULTS

The entire system shown in the Fig.12, functions is described below:

The way the different components of the exoskeleton interact or work are described next.

- The Beaglebone Black (BBB) [10] is an embedded computer, its system operative is Debian, which is a Linux based operating system.
- The Myo Armband is connected via Bluetooth to the Beaglebone Black.
- The Myo Armband implements an electromyography, and sends the data via Bluetooth to be processed by the BBB.

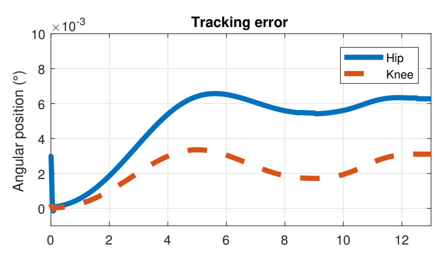

Fig. 11. Error in the Stand-to-Sit task. The blue line shows the tracking error for hip joint, while red line shows the tracking error for knee joint.

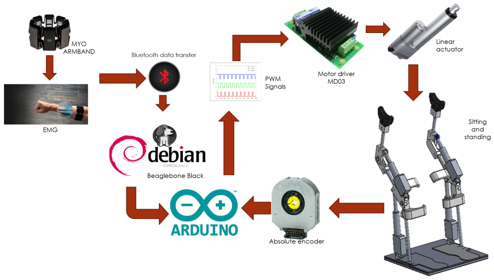

Fig. 12. Exoskeleton's elements. The main objective of the system is lift a person up to 90 kg, to achieve this objective, we use six linear actuators to generate a torque in each joint and obtain the angular position using an absolute encoder.

- We preinstalled the PyoConnect2.0[11] library on the BBB, this library allows to access the data sent by the Myo, for our purpose we recognize five hand gestures as shown in Fig.13.
- Because the process of the data on the BBB requires all the resources of himself, an Arduino Uno [12] is added as slave of the BBB, this platform receives data via serial port from the BBB depending on the hand gesture recognized by the BBB.
- The Arduino Uno interprets the data received; four hand gestures are used: Double tap to unlock the Myo, Fist as a safe key to prevent the interruption of tasks, Wave out for the standing to sitting task and Wave in for the sitting to standing task.
- Once a task is chosen, the Arduino computes the necessary trajectories to be executed by the hip and the knee joints, reads the absolute encoder via SPI communications, compare this lectures with the corresponding trajectory and generates the necessary PWM control signals of the actuators that produces movements on the hip and the knee joints.

Fig. 13. Hand's gestures recognized by the Myo Armband. From left to right: Unlock (double tap), Fingers Spread, Wave In, Wave Out and Fist.

To prevent the interruption of tasks or undesirable behavior the following process was implemented: if the first gesture received is "Unlock" the system notifies the user, through vibration, that the system is waiting for the second gesture for three seconds, if this time is exceeded the system will automatically blocks discarding all transactions; if the second gesture coincides with "Fist" the EMG sensor vibrates again indicating to the user that the system is ready to receive the task command, this may be "Wave In" or "Wave Out", if the second gesture does not match, the transaction is canceled and the system is locked. This form of decision making is implemented in the experimental platform.

The PID controller gains of the experimental platform are:

$$k_p = \begin{bmatrix} 20 & 0 \\ 0 & 20 \end{bmatrix}$$
$$k_d = \begin{bmatrix} 1.5 & 0 \\ 0 & 1.5 \end{bmatrix}$$
$$k_i = \begin{bmatrix} 0.20 & 0 \\ 0 & 0.20 \end{bmatrix} \quad (11)$$

A. Experimental results in the Sit-to-Stand task

The graphs of Fig.14 shows the trajectory tracking of the hip and knee joints on the experimental platform in the sitting to standing task. The red lines are the actual angular position obtained from the encoders in the respective joints, while the blue lines are the reference trajectories. Fig.15 shows the error, i.e. the difference between the reference trajectories and the actual position for the hip and knee joints. The error between these signals must be minimal to ensure, among other things, that the center of mass of the exoskeleton remains in its equilibrium region, avoiding the risk of fall of the user.

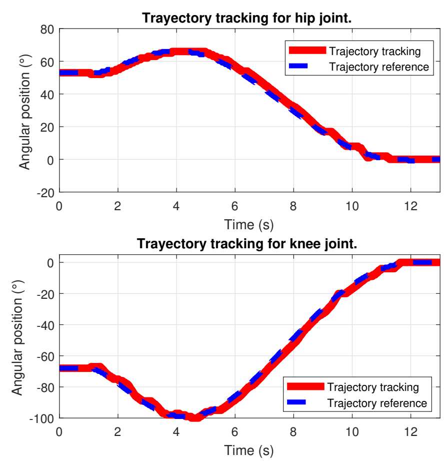

Fig. 14. Trajectory tracking in the Sit-to-Stand task.

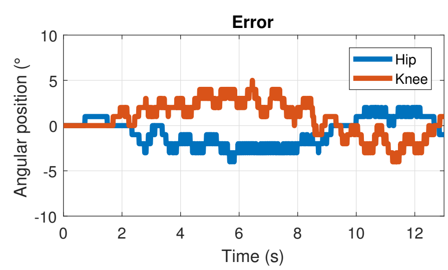

Fig. 15. Tracking error in the Sit-to-Stand task.

B. Experimental results in the Stand-to-Sit task

Fig.16 and Fig.17 are the equivalent ones to Fig.14 and Fig.15 but corresponding to the standing to sit task. As in the previous subsection, the tracking performance is good because ensures the minimal risk of fall of the user.

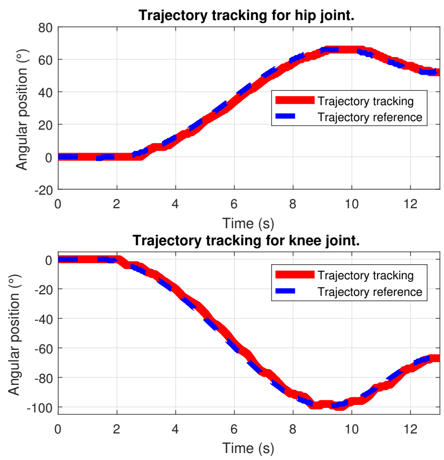

Fig. 16. Trajectory tracking in the Stand-to-Sit task.

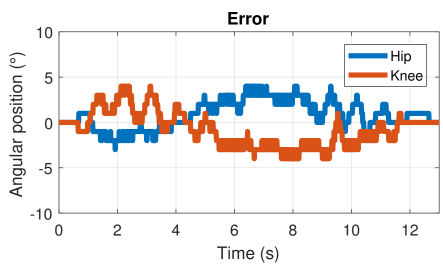

Fig. 17. Tracking error in the Stand-to-Sit task.

One important thing to say it's that the user of the exoskeleton needs a previous treatment to recover or strength his upper limbs, including the hands movements, because as we can see in Fig.18 and Fig.19 the hand's gestures are used to activate the exoskeleton's tasks.

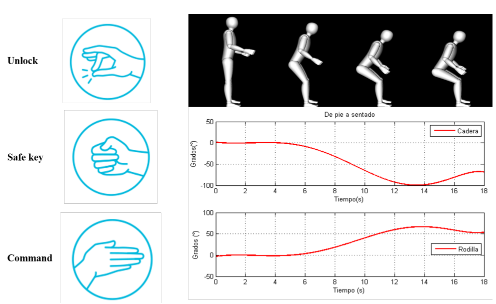

Fig. 18. Activation of the Sit-to-Stand task; first, unlock the Myo Armband, make the fist gesture as safe key and finally, Wave Out gesture to select the corresponding task.

Assuming the exoskeleton is locked, although the band is already placed on the arm of the user, to mobilize the exoskeleton the following steps are required: Make the gesture "Unlock", this unlocks the band and keeps the system alert to receive the next gesture; make the gesture "Fist", this indicates that soon will be given a next instruction, it can be to stand or sit; make the gesture "Wave In" or "Wave Left", this indicates

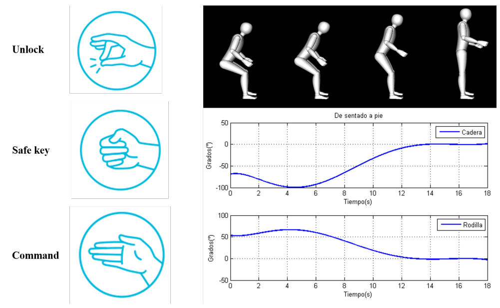

Fig. 19. Activation of the Stand-to-Sit task; first, unlock the Myo Armband, make the fist gesture as safe key and finally, Wave In gesture to select the corresponding task.

a movement in the exoskeleton (stand or sit) depending on the gesture shown in Figures 18 and 19.

VI. Conclusions

One of the main contributions in this work is the use of the EMG device to activate the exoskeletons tasks; using the Myo Armband in our platform has the advantage that the user has both hands free for other activities or in an emergency, unlike in a wheelchair that require the use of both hands for transportation. Thinking mainly about safety, the exoskeleton is programmed to never move until a user activates it via a Myo Armband by performing the adequate hand gestures, also the use of a motion capture system to extract the reference trajectories ensures the user's minimal risk of fall. The mobile platform where the exoskeleton is mounted, was designed to comply with the construction standards of ramps and designated places for people with disabilities, also allow users to move around in small areas, providing comfort and safety to the user in their daily activities. In the future will be reported new control estrategies to improvement the behavior of the exoskeleton an also, new forms to control it.

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