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Hercules: a low-cost sEMG based prototype to improve gait strength

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***Abstract*—This paper presents a prototype of a low cost exoskeleton for lower limbs capable of helping elderly or people with disabilities by improving their gait strength. A muscular signal circuit acquires the Surface Electromyography (sEMG) and an online analysis of the muscle activity is performed to generate features able to control two servo motors positioned in the person's hip and knee, responsible for the gait control. This study shows that the sEMG acquiring system and the mechanical structure proposed can provide acceptable results for building a low cost orthosis.**

I. Introduction

Human life expectancy has been growing in the world the past years and, as a consequence, the world population is getting older. Estimatives account that there will be a 200% increase of elderly in developed countries in the next decades. According to IBGE (Brazilian Institute of Geography and Statistics) [1], in Brazil, only in the past 60 years, 5% of the population joined the elderly group, what corresponds to 15 millions of individuals and this number is still growing. IBGE projections expect this number to double in the next 20 years.

A common problem in advanced age if the loss of muscular power (Figure 1), caused by muscular weakness [2]. One of the articulations that are relevant in this mobility impairment during aging is the hip due to its relation to the muscles that coordinate gait ([3], [4] and [5]), sitting down and standing up ([6]) and climbing steps ([7]). Falling is one of the greatest consequences of this process. About 6% of these falls cause fractures, 1% of them in the hip [8]. To avoid this kind of accidents that usually happen in daily activities, some people have used support mechanisms such as sticks and walkers.

Recently, robotics technology has been used to help minimizing the muscular weakness problems caused by aging through the development of robotic-powered exoskeletons and joint-adapted orthosis [9] [10]. Some of these projects include:

- Cyberdine HAL-5 [11] and [12]: Hal uses the EMG signal to determine its control signal. It is a full body assisting exoskeleton.

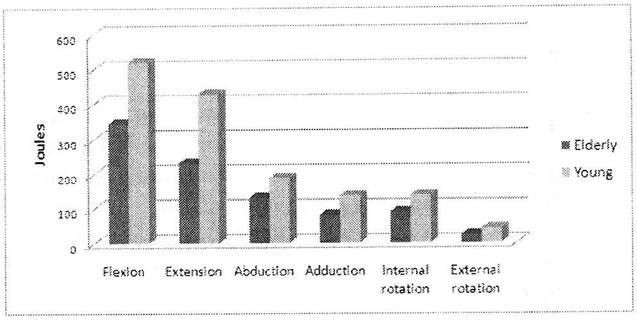

Fig. 1. Muscular Power Loss with Aging

- EXO-LL12 project [13], from UC Santa Cruz University, current research effort is focused on developing a semi active system for improving the ability of the operator to carry a payload.
- BLEEX project at U.C. Berkeley is a self-powered exoskeleton for strength and endurance enhancement of humans that is ergonomic, highly maneuverable, mechanically robust, lightweight and durable [14].
- Sarcos exoskeletons, recently bought by Raytheon, are artificial limbs that use sensors to detect the subtle skin or muscle movements and translate them into limb movement.
- Honda has two exoskeletons: an active and an experimental one. The first weights only 2.8 kg and can be manufactures in 3 sizes: Small, Medium and Large. Its battery allows two full hours of walking at a 4.5km/h speed. The second experimental walking assist device aims to help support bodyweight to reduce the load on the user's legs while walking, going up and down stairs, and in a semi-crouching position.

- Rewalk, by Argo Medical Technologies, is a wearable, motorized quasi robotic suit. It provides user-initiated mobility - leveraging advanced motion sensors, sophisticated robotic control algorithms, on-board computers, real-time software, actuation motors, tailored rechargeable batteries and composite materials [15].

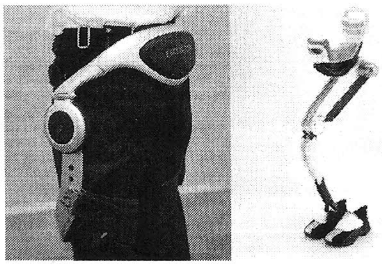

Fig. 2. Honda Assistive Devices

To have reliability on motion control, most of the projects in this area uses Surface Electromyography (sEMG) [16] to analyze the muscle activity and to generate a control signal capable of improving limited functions. [17] presents a real-time system based on Support Vector Machines to classify electromyographic signals in order to design decisions to control a robotic arm. The work of [18] and [19] represent a control system where information from EMG and angle sensors are used to provide the control signal. In the same approach, [20] proposes a neuro-fuzzy visual based system to correct the classification performed over sEMG signals whereas [21] uses Kalman Filter to produce estimates based on the EMG signals that will be used as input in the control module. The majority of these results are presented for upper limbs.

In this context, this work presents a prototype of a low cost sEMG-based exoskeleton for lower limbs capable of helping elderly and people with disabilities by improving their gait strength.

The paper is organized as follows. First the human gait study, relevant to the control process, is presented. Next, the prototype structure is described (both for motion and acquisition). Finally, we discuss the results and present proposes for further work.

II. Human Gait

In its standard representation, human gait corresponds to repetitive and symmetric consistent movements between the legs, from the period where there is surface contact, the **Stance Phase**, and the **Swing Phase**, where there is no contact between the floor and the foot (see Figure 3). The Stance Phase remains active while there is any foot/floor contact. It corresponds about 60% of the gait phase and it can be divided into 5 parts: a) contact, that positions the foot and starts disaceleration; b)loading, complete foot support for transferring weight; c) midstance, to aline and stabilize the knee; d) terminal stance, where acceleration restarts and and e) preswing, where there the foot leaves the floor.

The swing phase starts when the lower limb leaves the floor and it ends before it reaches back the support surface. It comprises about 40% of the gait cycle with: a) the beginning of losing contact and forward acceleration; b) when the movement passes the knee or the support leg and c) the return to the contact point and the desaceleration process.

In this way, to assure a close system working, a similar and parallel mechanism (for the sagital knee and hip plan) was selected to help holding the movement during stance phase.

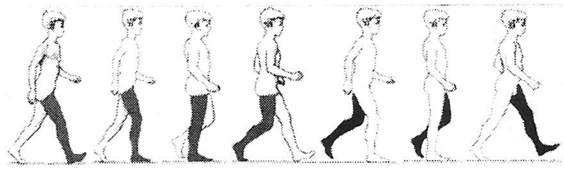

Fig. 3. Gait Cycle

III. Prototype

The prototype for the exoskeleton proposed is composed by a mechanical and an electronic set.

The mechanical set is based on the metal structure and the servo motors that will help perform the gait loop. The prototype was manufactured with aeronautical aluminium, due to its lower weight. Two motors were positioned in parallel to the hip and the knee in order to empower the most depreciated movements over aging (knee flexion and extension - Figure 1). Moreover, these two freedom angles are the ones that can not be disregarded when one intends to mimic human gait. There are 3 main parts in the mechanical structure: support structure, limb structure and motors. The support structure corresponds to the structure around the hip, tights and legs. They work as support points that are responsible for holding the necessary force applied to this joint. The limb structure refers to the link between hip and knee and the link between knee and leg. They are the fixation places for the motors that will perform the movements.

The electronic set is composed by: a) The data acquisition and processing unit (section III-A); b) a 8051 family microcontroller designed board that receives the data from the acquisition unit and process it to generate the control signal to be sent to the servomotors positioned in the exoskeleton (section III-B) and, c) the batteries that are responsible for powering the whole system. In order to avoid impairing the subject's natural hands and body moves, the electronic set is placed in the back of the hip support structure.

Figure 4 presents an overall scheme of the prototype.

A. Data Acquisition and Processing Unit

The EMG sensor is one of the most accurate measurement tools to determine human motion intensity [10]. Contrary to force sensors, it is not affected by the interaction between the

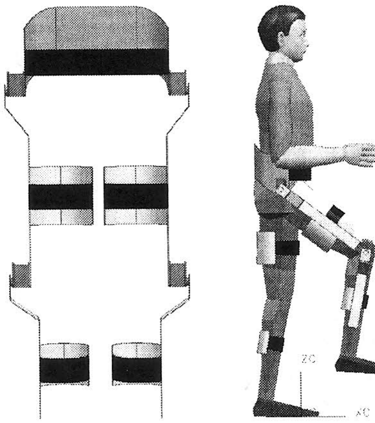

Fig. 4. Prototype Sketch

subject and the environment as it represents a direct reading of the subject's intention (in healthy individuals).

There are special transducers for electromyography that help reducing noise and that provide a better signal acquisition for sEMG. These transducers or electrodes have to be positioned in the desired muscle group to represent the electric power generated when the muscle's inner fibers respond. Muscle activation level indicates the neural activation in the motor neurons present in that region and its bio-potentials range from 0V to 10mV with a 0Hz to 500Hz bandwidth. However, its energy band relies between 50Hz and 150Hz.

The quadriceps is a large muscle group that includes the four prevailing muscles on the front of the thigh: Rectus femoris, Vastus lateralis, Vastus medialis and Vastus intermedius. All four quadriceps muscles are powerful extensors of the knee joint what turn them into good source of information regarding movement intention for flexion and extension. The study of [10] shows that for the start of the gait cycle, when there is intention of movement, Vastus Medialis is the quadriceps muscle that presents the most of the activation. Furthermore, [22] shows the importance of positioning correctly the sensors in the quality of control gait.

Then, to acquire the sEMG, one Noraxon [23] 2cm spacing dual electrode for signal acquisition and one single electrode for reference were positioned in the Vastus medialis. The detection starts in the beginning of the swing phase, where a contraction in vastus medialis occurs. This contraction, if passing a threshold, signals for a movement intention [24].

Figure 5 presents the data acquisition and processing system blocks responsible for transforming the raw sEMG signal into a movement intention one. Each block was designed as follows:

1) The instrumentation amplifier was implemented using the Analog Devices AD620 with adjustable gain varying in the range 200-400V/V.
2) The butterworth 50Hz high-pass and the 150Hz low-pass filters are 4 order filters with 2V/V gain.
3) The 60Hk Notch filter is used in order to reject the induced noise generated by the electronic devices and electric power.
4) The rectifier is a half-wave to allow only positive signal passing.
5) The 3Hz low-pass filter is applied to detect the signal envoltory. Figures 6 and 7 shows the resultant signal envoltory for quadriceps vasto medial flexion and extension.
6) The threshold detection is the part of the circuit that compares the minimum level that should fire the movement intention. This minimum level can be online adjusted to each individual. Figure 8 presents this threshold comparison process.

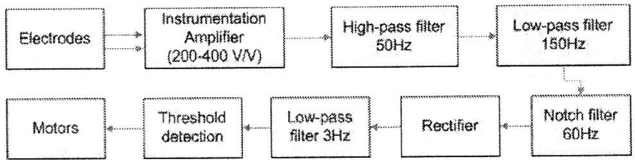

Fig. 5. Block Diagram of Acquisition System

In the current prototype, the intention detection is an on/off kind, i.e., if the comparison circuit identifies a movement intention, it fires for the control system, that takes control of the current gait (see Figure 8).

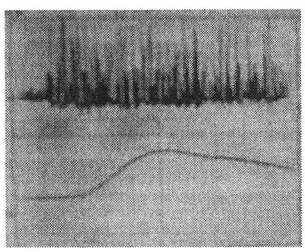

Fig. 6. Signal Envoltory for Quadriceps Flexion Maintained- Step 5

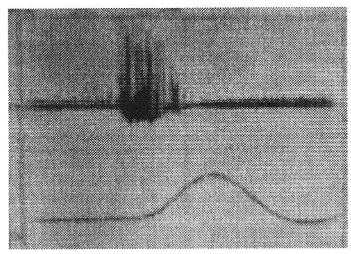

Fig. 7. Signal Envoltory for Quadriceps Flexion/Extension - Step 5

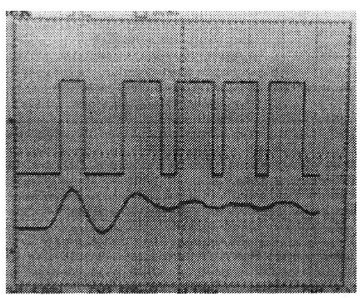

Fig. 8. Digitalized Signal

B. Movement Control

The quality of an orthosis or exoskeleton is judge on how well they control the lower limb during swing and stance phases. In the approach proposed in this work the movement control works as follows:

1) The movement intention is detected in the acquisition unit;
2) The digitalized signal is sent to the control board that, if not under a current movement, starts a new gait cycle;
3) The gait cycle speed can be adjusted by the subject online.

Due to its on/off nature and to avoid noise, the signal sent to the control board during a current gait execution is unconsidered and reestablishes control only when the feet are close to the floor and are able to gain force to start moving again. This allows the energy from one step to be transferred to the next step, thus taking advantage of inertia and momentum.

A pulse-width-modulation signal (PWM) is responsible for actuate the motors (Figure 9). The speed of the moves responsible for the gait cycle sub-phases depends on the speed selected by the subject. It is defined in such a way that the moves are as smooth as if the subject was not wearing the orthosis. The positions that the servos should reach in order to control the gait were pre-defined for each subject tested.

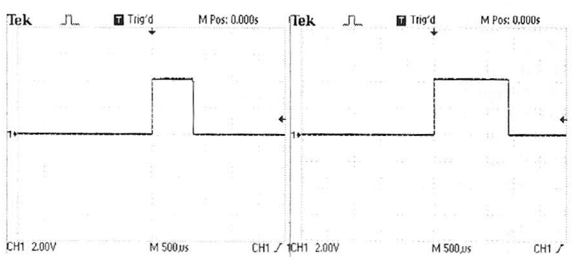

Fig. 9. PWM Generated for Different Angle Positions

IV. Results

Figures 10 and 11 present the final design of the proposed prototype. In the present, most of the anatomic requirements were unconsidered when related to material used.

As for the sEMG acquisition, the quality of the signal was maintained even when stressed with noise and in all cases the envoltory of the signal was successfully accomplished (Figures 6, 7, 8). One remark is in the fact that different subjects have different threshold levels. Currently, this level is adjusted online in a calibration moment.

Regarding the strength gain with the exoskeleton, it is directly proportional to the power of the motors used. According to [24], the required torque of the hip and knee motors to a 75kg patient wearing a 30kg exoskeleton and able of improving in 50% its gait strength is, respectively, 72Nm and 101.25Nm. For this prototype, we used motors that are only capable of maintaining the helping structure and the subject, as we aimed the study of the acquisiton/gait coordination. However, if the motors are changed, the same system can be applied.

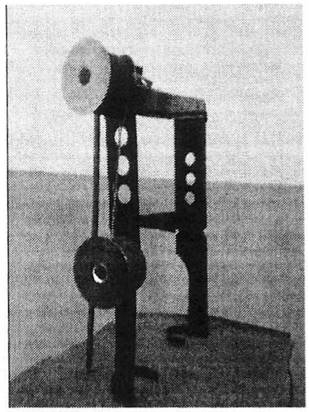

Fig. 10. Final Prototype - View 1

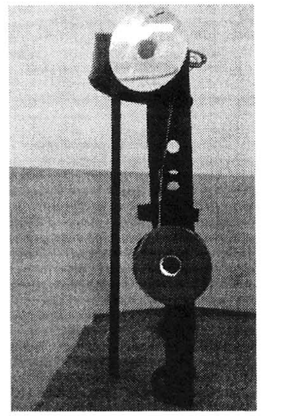

Fig. 11. Final Prototype - View 2

V. Conclusions and Future Work

Exoskeletons do not have specific pathologies targets but rather can benefit many subjects with different disabilities. Although they can be this relevant, only few are available in the international market for prices (about U$150,000.00) that are far away from most people's buying power, most of this caused by their complexity. The proposed system main goal is to help healthy people with muscle weakness to have better performance in their daily activities through a low-cost assisting mechanism for gait control.

Although the current acquiring system only uses one muscle group to detect movement intention, it has proved itself a good data source. However, to improve the system reliability and to be able to control every part of the gait cycle with the human interaction, we propose to use different muscles groups, such as hamstrings to check de-acceleration during swing phase. Moreover, we intend to use the derivative of the signal that represents the movement intention to automatically estimate the gait speed.

Some of the improvements proposed include:

- to extract features from the sEMG channels to define classification patterns that can be used for differentiated gait
- to use spiking neural networks as a classification instrument
- to move the last blocks of acquisition (integration and digitalization) to the software unit, thus eliminating the on/off characteristic of the system and giving more flexibility to treat the signal
- to change the material of the exoskeleton for anatomical sake
- to evaluate different motors and the actual power gain in the gait cycle for different subject groups.

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