DEVELOPMENT OF THE JOINT POSITION SYSTEM FOR CONTROLLING THE EXOSKELETON BASED ON PNEUMATIC MUSCLES

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Abstract. *There is an increasing demand for equipments to aid human locomotion, due to the great number of people presenting restrictions to perform their daily life task. The present work is part of Assistive Technology development program of the UFMG at the Laboratory of Bioengineering (LABBIO). There are many pathologies affecting the locomotor system and causing modifications on the execution of the gait. Nowadays, there are about 20 million survivors of poliomielitis in the world who face a new challenge: the Post-Polio Syndrome, a set of motor incapacities produced by the polio that appear many years after the patient had contact with the virus of polio. The volunteer patient presents neuromotor deficit on lower extremities causing deficit on locomotion due to a lesion caused by the polio virus. It was developed an assisted system of locomotion using a hip orthesis to fasten the artificial muscles to assist the flexion movement of the hip for the task of walking. This work presents the development of an electronic device capable of controlling the drive of the artificial muscle by means of data acquisitions of the articulate position captured by the potentiometers fastened on the orthesis attached to the patient. A pattern of activation and deactivation of the artificial muscle was set based on the angular behavior of the hip joint according to the normal cycle gait. Tests performed at the Laboratory of Prothesis and Orthesis with the patient, demonstrated improvement of the gait pattern of the patient with assisted movement of flexion of the left hip during walking.*

Keywords*: Bioengineering, artificial pneumatic muscle, gait, potentiometer.*

1. Introduction

Insight into normal walking patterns can help practitioners improve the efficiency of persons with gait-related pathologies. Such knowledge may assist the clinician in the selection of orthotic or prosthetic components, alignment parameters and identification of other variants that may enhance performance (Ayyappa and Mohamed,1996).

Familiarities with gait terminology and function enable the prosthetist or orthotist to communicate effectively with other members of the medical team and contribute to the development of a treatment plan.

Gait characteristics are influenced by the shape, position and function of neuromuscular and musculoskeletal structures as well as by the ligamentous and capsular constraints of the joints. The applications of engineering and technology to the understanding of human walking received enormous impetus in 1945 when Inman *et al*. initiated the systematic collection of normal and amputee data on an instrumented walkway in their outdoor gait lab at the University of California—Berkeley (Saunders *et al.*,1953; Inman and Eberhart, 1953; Wagner,1954; Inman *et al.,* 1981).

Since that time, a number of researchers and clinicians increasingly have used the growing array of gait technologies to measure and analyze the parameters of human performance in normal and pathological gait (Perry, 1992; Sutherland, 1988).

The aim of the present study is the development of a joint position system for controlling the exoskeleton based on pneumatic muscles for people who have locomotors deficit. The exoskeleton is used by the patients who have Post Polio Syndrome - PPS that means a constellation of symptoms and signs that appear from 20 to 40 years after the initial polio infection and at least 10 years after what was once thought to be the "recovery" from polio. The typical features of PPS include unaccustomed weakness, muscle and generalized fatigue, pain, breathing and/or swallowing difficulties, sleep disorders, muscle twitching (fasciculations). The muscle problems in PPS can occur in previously-affected muscles or in muscles that were previously thought not to be affected by the initial polio illness. The aim of the exoskeleton is to help the hip flexion movement during the gait cycle.

1.1 Understanding gait function

Walking involves the complex interaction of muscle forces on bones, rotations through multiple joints and physical forces acting on the body (Chambers and Sutherland, 2002). The walking gait maneuver is the body's natural means of locomotion. Together with balance and stabilization, this convenient mode of travel represents personal mobility and thus, autonomy.

Normal human gait repeats a basic sequence of limb motions that progress the body along a desired path while maintaining weight-bearing stability, conserving energy and absorbing the shock of floor impact (Perry, et al., 1996).

1.2 Gait Mechanics

Understanding the mechanics of the normal gait cycle is necessary to better comprehend assessment and training procedures. The following is Perry's (1992) explanation of the normal gait cycle with a corresponding graphic description in Figure 1. The mechanics of walking are referred to as the gait cycle (i.e., a sequence of events between two sequential contacts by the same limb). Stance and swing are the two phases that compose the gait cycle. The stance phase, which constitutes approximately 60 percent of the normal gait cycle, is the interval in which the foot of the reference extremity is in contact with the ground. The swing phase, which makes up the remaining 40 percent of the gait cycle, is the portion in which the reference extremity does not contact the ground.

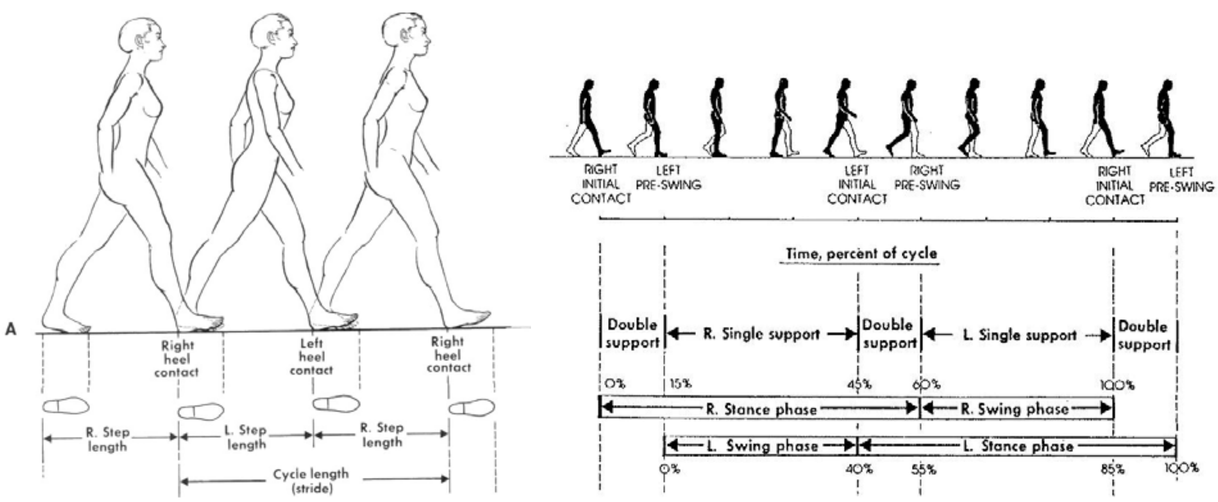

Figure 1 (a) Gait cycle – Stride; (b) Dimensinos of walking Cycle.

Stance is further subdivided into three intervals according to the sequence of floor contact by the two feet. Initial double stance begins the gait cycle and is the time both feet are on the floor. Single limb support begins when the opposite foot is lifted for swing. Here, the word support is preferred over stance to emphasize the functional significance of floor contact by only one foot. During the single limb support interval, the body's entire weight rests on that extremity. The duration of single limb support is the best index of its support capability. Terminal double stance begins with floor contact by the other, foot (i.e., contralateral initial contact) and continues until the original stance limb is lifted for swing (i.e., ipsilateral toe-off).

2. Methods

A pneumatic artificial muscle (Fig.2) was developed and constructed at LABBIO – Bioengineering at UFMG (Vimieiro, 2004; Nagem 2005) and it has the similar characteristics of the Mckibben muscle (Klute *et al.*,1999; Chou and Hannaford, 1996).

Figure 2 Pneumatic artificial muscle realized at LABBIO.

2.1 Determining the muscle size

The artificial muscle is fixed in the hip orthosis after having been adjusted by suitable equations that determine the position for optimizing the use of its power. Using the joint position (hip angle) the muscle is fixed in the orthesis using Cosine Law, as in Eq. (1), with this mathematical application it is possible to reach the relation between the joint and the muscle length.

$$C = \sqrt{a^2 + b^2 - 2ab\cos\alpha} \quad (1)$$

Legend:
C = muscle [m].
α = orthesis joint angle [degrees].
a e **b** Distances between the muscle and patient hip (a – from trunk to hip joint , b – from tight to hip joint) [m].

The distances are fixed using the model of orthesis for this specific patient (Vimieiro ,2004).
The value is a = 0,35 m and b = 0,20 m

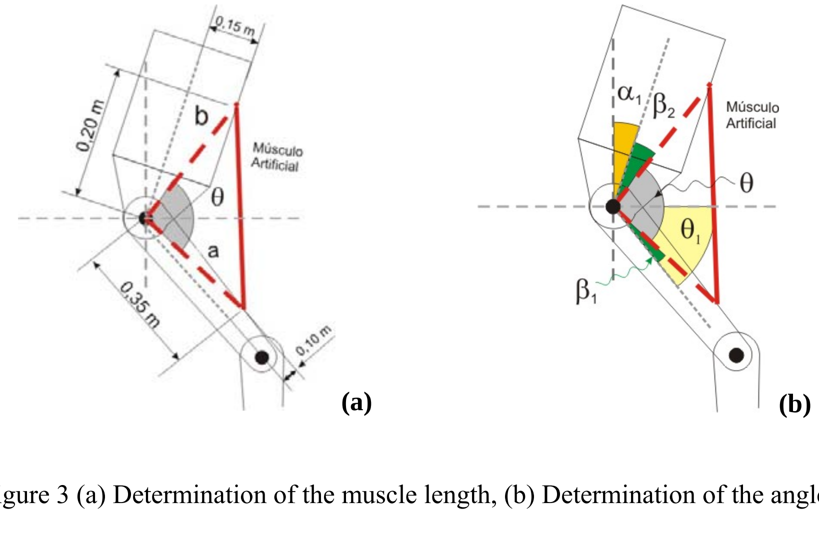

Figure 3 (a) Determination of the muscle length, (b) Determination of the angle.

The orthosis is divided in the two parts. There is an anterior part and another posterior for the trunk and also the tight part that can be adjusted independently; these parts are connected using Velcro (Fig. 3) in both sides (right and left).

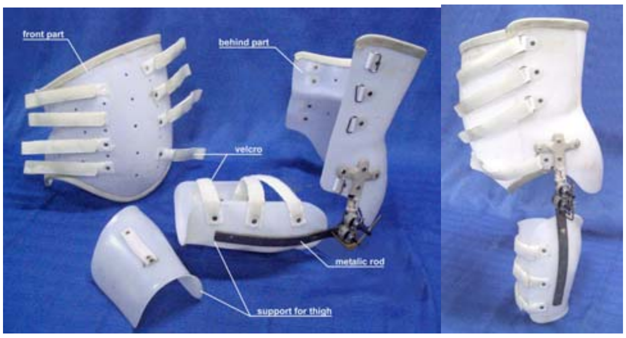

Figure 4 Photography of the orthosis for the hip with white tight support.

2.2 Electronic system of artificial muscle activation.

The electronic activation system is used for monitoring the joint angle continuously. A multimeter measures the resistance value related to the variation of a potentiometer fixed at the orthosis axis. This value corresponds to the movement of flexion-extension. This system receives the signal from the movement of the hip joint and sends it to a prototyping board which is configured to identify and process the signal executing the activation of the artificial muscle.

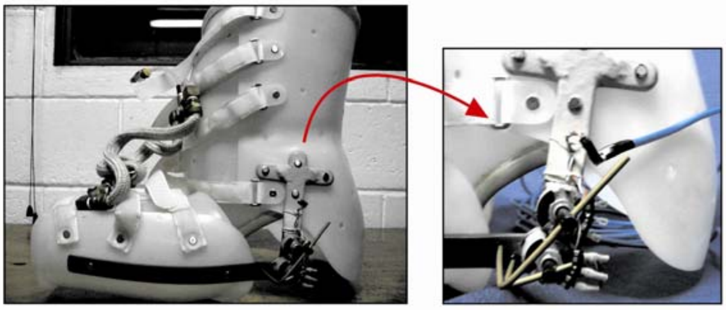

Figure 5 Potentiometers fixed to exoskeleton.

The electronic system of activation is performed by a variable resistance fixed on the orthesis that indicates the different position of the inferior limb during the hip joint movement. The potentiometer calibration curve was obtained by comparing the potentiometer variable resistances during the hip joint movement with the angle of the hip by using a goniometrer

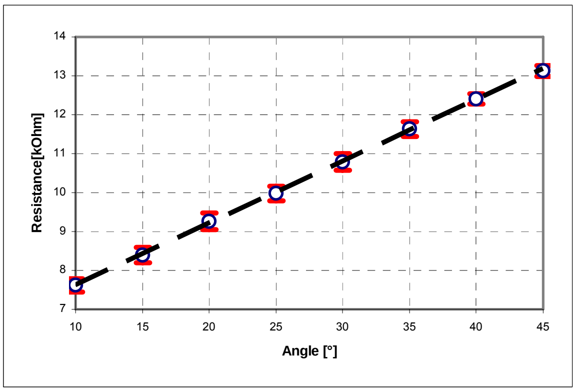

Figure 6 - Potentiometer resistance as a function of hip joint angle.

The interpolation curve of resistance as a function of hip joint angle was obtained by a fit of the calibration values as represented by Eq. (2),

$$\Omega = 0{,}078548\lambda + 7{,}9317 \quad (2)$$

$R^2 = 0{,}9987$

Where Ω is the potentiometer resistance [Ohm] and λ is the inclination angle of the orthosis [Degrees].

In order to make it easier to interpret the signal coming from the potentiometer, a known resistance was inserted in circuit. Thus, it was possible to convert the potentiometer readings into volts. Figure 6 schematically shows the circuit.

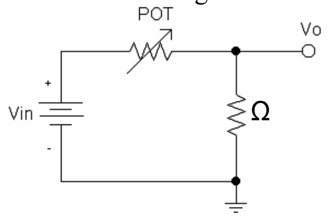

Figure 6 – Voltage Divider circuit.

V_{in} is the Input Voltage [V];
POT is the Potentiometer Variable Resistance [Ohms];
Ω is the knwon Resistance [Ohms];
Vo is the Output voltage [V]

These variables are combined in equation 3:

$$V_0 = V_{in} \frac{\Omega}{\Omega + POT} \quad (3)$$

Keeping the V_{in} e R values constant, equation 3 shows that V_O is inversely proportional to the potentiometer value, so this way the system will be able to register the variation of joint angle (FIG 5).

The system is composed by:

Voltage Comparator Block: This block is always verifying the values of the angleλ, by the sensor voltage. When the angle passes the reference value of theλ, the output turns high and start the timers blocks A and B. This procedure just could be done when the comparator enable signal is high. The comparator enable signal comes form the logic gate.

Timer A Block: When the block input is high, the timer output goes high for a period T_A from 0,4 to 5,7 seconds. On output high the valve is turned on. This block will finish the activation time of the artificial muscle and the time and the velocity of the walk will be realized based on the patient behavior.

Timer B Block: When the block input is high, the timer output goes high for a period T_B from 0,8 to 6,1 seconds. This block determine the time of muscular relaxation (t_C), that it is given by: $t_C = t_B - t_A$. Thus we verify that t_C only will exist if $t_B > t_A$. The value adjusted for t_B will in accordance with occur the walk realized by the patient.

Logic Gate: This block has as function to monitor the output of the timers A and B. Its output will be high only when both the signals in its inputs will be low. On this way, the output of the logic gate will be active only when don't have movement of the artificial muscle, or either, when contraction or muscular relaxation does not occur. It is important observe that the output signal is sent for the voltage comparator reset. Thus one will guarantee that another gait cycle will not be initiated without before it has finished, completely, the previous one.

Current Amplifier Block: The air flow in the artificial muscle is controlled by a valve. The timer A output cannot supply enough current to activate this valve. Then becomes necessary a current amplifier block to amplify the timer A signal.

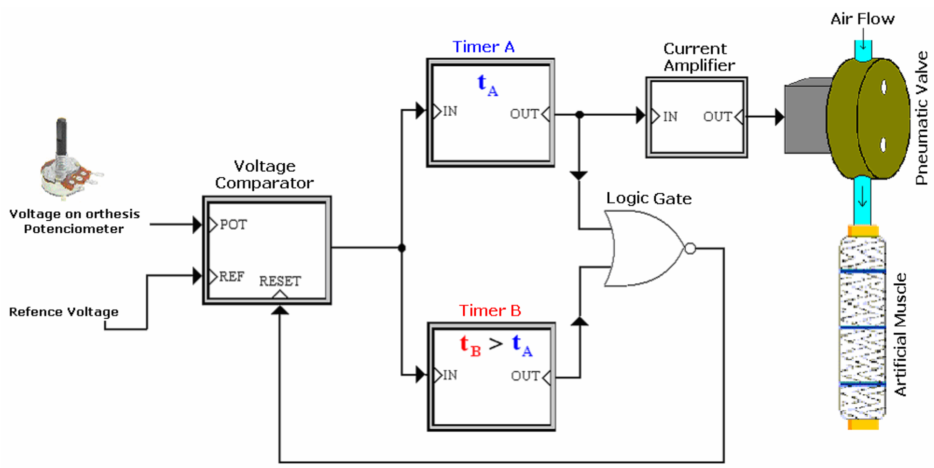

Figure 7. Block Diagram from the electronic system activation of artificial muscle.

The hip joint behavior during gait cycle executed by the patient can be monitored measuring the voltage signal on the potentiometer. Using Eq.3, it is reached the results for the following figure using the relation between voltage and resistance of the potentiometer.

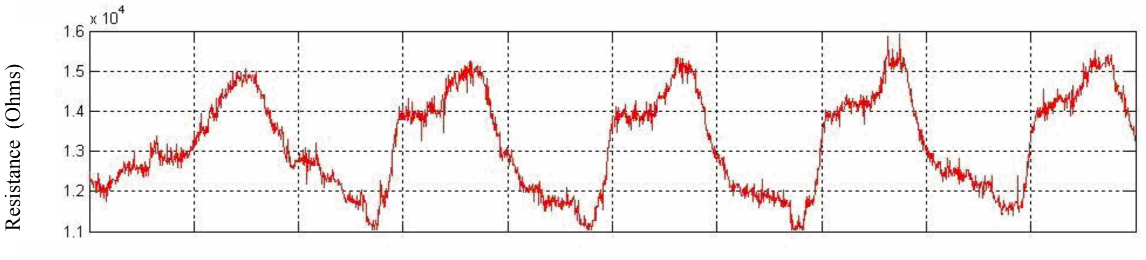

Figure 8 Potentiometer Resistance behavior during gait cycle execute by the patient

The fig. 8 shows the left hip movement of flexion an extension. During the initial phase the artificial muscle is on stretched position. At this moment the hip joint angle is around 37 degrees because the reference is the trunk axis and the patient has flexion deformity installed because of PPS. The data acquisition was made using a digital oscilloscope AGILENT 54622A 100MHZ.

Potentiometer signal is transmitted to the activation system and the valve is activated producing the flexion movement of the hip through artificial muscle.

2.4. Discussion and Results:

The system is able to execute the activation of the artificial muscle using the information of the hip joint motion. The data is processed during the gait cycle of the patient and produces the controlling of air supply resulting the activation of the artificial muscle fixed on the hip orthesis Fig. 9.

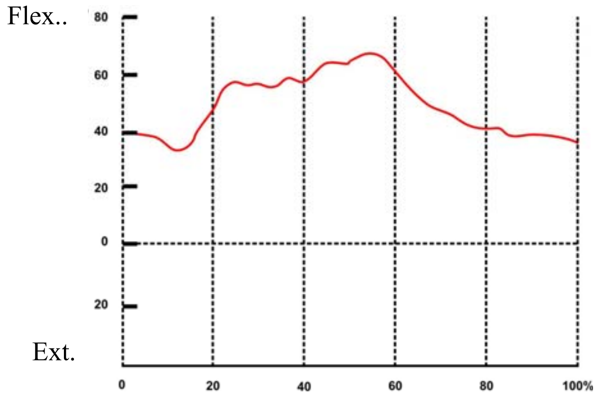

Figure 9. Hip Joint Moviment using exoskeleton

3. Acknowledgements

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4. References

Ayyappa E, Mohamed O. Orthotics and prosthetics in rehabilitation. In: Lusardi M, ed. Clinical assessment of pathological gait. Newton, Mass.: Butterworth Heinemann, manuscript submitted for publication, September 1996.

Chambers, H.G. and Sutherland, D.H. "A Practical Guide to Gait Analysis." Journal of the American Academy of Orthopaedic Surgeons, May/June 2002; 10 (3): 222-31.

Saunders JB, Inman VT, Eberhart HD. The major determinants in normal and pathological gait. JBJS 1953; 35-A:543-58.

Inman VT, Eberhart HD. The lower-extremity clinical study--its background and objectives. Artificial limbs, January 1955; 4-34.

Wagner EM. Contributions of the lower extremity prosthetics program. Artificial limbs, May 1954; 8-19.

Inman V, Ralston HJ, Todd F. Human walking. Baltimore: Williams and Wilkins, 1981; 1-128.

Perry J. Gait analysis; normal and pathological function. Thorofare, N.J.: Slack, 1992; 2-128.

Perry, J., et al. Observational Gait Analysis. The Pathokinesiology Service and The Physical Therapy Department, Rancho Los Amigos Medical Center, 1996.

Sutherland D. Development of mature walking. Philadelphia: MacKeith Press, 1988.

Chou, C.P. e Hannaford, B. Measurement and modeling of McKibben pneumatic artificial muscles. IEEE Transactions on Robotics and Automation, 12(1), 1996, Pages 90-102.

Vimieiro, C.B.S, Desenvolvimento de um exoesqueleto com aplicação de músculos artificiais pneumáticos em sua articulação, Dissertação de mestrado, Departamento de Engenharia Mecânica – UFMG, 69p, 2004

Nagem, D.A.P.; Desenvolvimento e teste de desempenho do musculo artificial de McKibben, Trabalho de graduação, Departamento de Engenharia Mecânica –UFMG 66p., 2002.

Klute, G.K; Czerniecki, J.M.; Hannaford, B: McKibben Artificial Muscles: Pneumatic Actuators with Biomechanical Intelligence IEEE/ASME 1999 International Conference on Advanced Intelligent Mechatronics (AIM '99) September 19-22, 1999 in Atlanta, USA.

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