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Development of a Functional Neuromuscular Stimulation System for Independent Ambulation of Patients with a Spinal Cord Injury

Alejandro Garcia Blanco, Gildardo Jiménez, Pedro Ochoa Moreno

Abstract— **This paper proposes the use of a controlled assistive device, aimed as a support for the impaired individuals to allow a limited ambulatory function. The aim of the overall project is to develop a simple, portable and economically accessible device that permits the limited movement of the inferior extremities on patients with lumbar spinal cord injuries. The scope of the present investigation is limited to not perform medical investigation direct on patients. For the purpose of testing it is planned to use a mechanical model. As the input control interface it will be used a dataglove for the right hand**

Index Terms— **Functional Neuromuscular Stimulation, Neural Networks, Spinal Cord Injury**

I. INTRODUCTION

When a person, generally as a result of a severe traumatism, suffers an interruption of the neuronal connection in the spinal cord at a lumbar level, it loses control on its inferior extremities. This affects the capacity to develop in society. Between the most evident it is the ability to walk and being able to displace by itself. For a couple of centuries the traditional solution has been the use of a wheelchair. This has allowed the movement of people with different capacities when using the still functional superior extremities. Nevertheless, although the wheelchair is a solution widely used is not a complete answer, in comparison to the faculties that the patience previously had. To begin with, the person is sitting, limiting his reach to low relative heights. The movement is limited to the places through where the wheelchair can pass. Lately it has been seen a greater awareness of the population. Every time it is seen most frequently in public sites the installation of facilities for wheelchairs. In advanced countries many improvements have taken place in the market of the wheelchairs. Between these are motorized chairs, which do not need manual impulse. Others have movable wheel axes, which can even raise stairs. All these options can be only considered like improvements to the traditional present solution of the wheelchair . In the last decades there have been some investigations in regards to the Functional Neuromuscular Stimulation or direct electrical stimulation of muscles [1] - [8]. At the moment there are a few products in the market based on this technology, but only the Parastep system has obtained the approval of the American government for its sale [9].

This system consists of a control box, external electrodes for the legs, and some other minor accessories. It only allows taking small steps, to rise and to seat. This system has a commercial cost of around $12.000 USD, way ahead of the scope of an economic product that this work has as a desirable goal. The first step in any investigation involving the human body is a study of its anatomy. It was performed a study to determine the main bone structures, articulations, and muscular groups involved in the common normal gait of a person.

II. THEORETICAL MODEL

Based on the results of the anatomy study, it was resolved to use a simplified theoretical model. The reason of the simplification resides in the use of the minimum possible degrees of movement for a reasonable gait.

The following restrictions were assumed based on the use of the minimum degrees of movement:

- The tibio-tarsal joint or the ankle is considered rigid. Although this joint is important to walk, it's not essential. For this work it is not intended that the patient recovers all the previous abilities, like the possibility to run. The aim is to only give back basic independent ambulatory capabilities.
- The axis of the foot drawn from the heel to the fingers, respect to the axis of the leg will have a natural angle of around 90º. This can be easily made with rigid boots, widely used in orthopedics, extreme sports and other activities.
- The rotatory movements made by the feet were also not considered. Like the joint of the ankle, these are not essential for basic mobility. The leg and foot can be considered like two rigid ends without turning on their own axes.
- Also the rotational movement over the axis of the femur on the coxofemoral joint or hip joint was not considered essential for the ambulatory basic movement
- By not having rotatory movements in the coxofemoral joint or hip joint over the axis of the femur, nor in the tibiofibula on the axis of the leg, this has only one degree of movement or point of flexion located in the knee. Its axis of movement is perpendicular to the sagital plane, having movement of extension and flexion of the leg towards ahead and back respectively.

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Alejandro Garcia Blanco is with the Connected Home Solutions Division of Motorola Inc, Nogales Mexico (Mex 01-631-311-1100, USA 1-800–343-4566; e-mail: alex_g_blanco@hotmail.com. Alejandro.garcia@motorola.com).

Gildardo Jiménez is with The Chamberlain Group in Nogales Mexico, and also is a part time professor in the Instituto Tecnologico Nogales (Mex 01-631-311-1400; e-mail: gildardo_jimenez @hotmail.com).

Pedro Ochoa Moreno is full time professor for the Instituto Tecnológico de Nogales (Av. Tecnológico # 911 Nogales, Sonora, México 01-631-311-18-70 e-mail: pedro.ochoa.moreno@gmail.com).

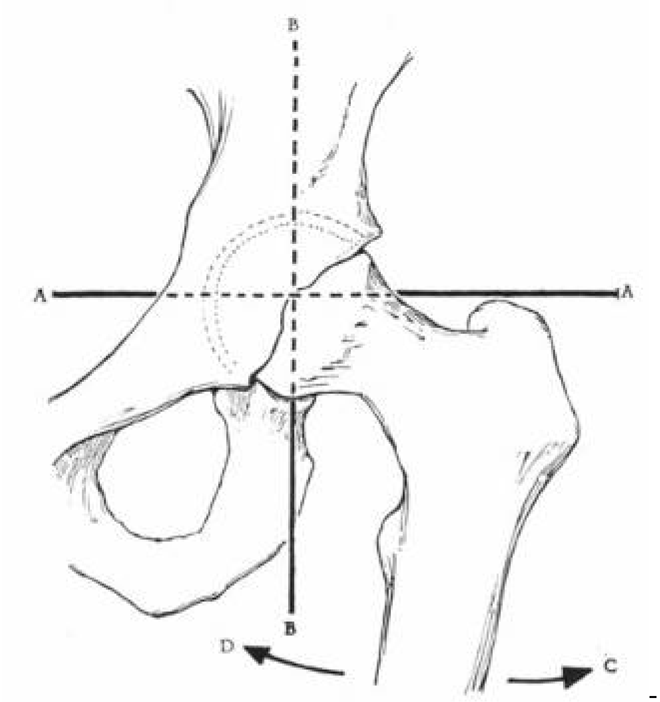


Fig 1 – Axis of the left coxofemoral joint.
A – A axis of flexion and extension of the muscle over the pelvis; B – B axis of rotation inside out of the muscle over the pelvis; C movement of abduction; D movement of adduction

III. AXES

Based on these restrictions, it was determined to limit the movement to 3 axes or degrees of freedom, as known in Robotics.

3 axes of movement are marked, with base in the main joints, in which the measurement is made by angular displacement on the axes. These are related to the Sagital Plane. This is an imaginary plane that, seen from the front cuts the body in two identical parts. Therefore the nose and the belly are crossed by this plane, and the eyes are close to it. The 3 axes are based on the 3 most relevant joints for the natural gait of a person. Fig 2 illustrates these axes

- Coxofemoral joint - axis perpendicular to the sagital plane. This axis crosses the body by the waist from side to side. Also it marks the movement of the thigh from front to back
- Coxofemoral joint - axis parallel to the sagital plane. This axis crosses the body on each leg by the waist, from the front to back. Also it marks the movement of the thigh towards the sides
- Joint of the knee - axis of the knee. This axis passes through the knee side to side, marking the movement of the leg from front to back.

IV. MOVEMENTS

Over each of the 3 mentioned axes, 2 equivalent and opposite forces are present on each axis named on the basis of the movement that is performed

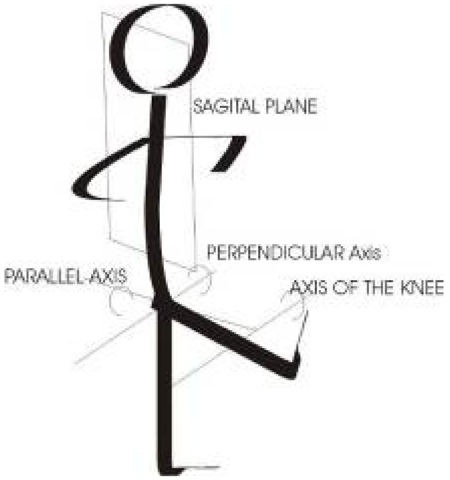


Fig 2 – Movement Axis

- Coxofemoral Movement of Flexion: In this movement, the thigh bends towards with respect to the hip. Being stand up, it raises the thigh. The main action of the Pectineal muscle is required for this movement
- Coxofemoral Movement of Extension: In this movement, the thigh extends backwards with respect to the hip. Being stand up, it lowers the thigh. The main action of the muscular group of the Gluteus is required for this movement (maximums, mediums and minimums Gluteus)
- Coxofemoral Movement of Adduction: In this movement, the thigh bends inside with respect to the hip, toward the sagital plane. When making this movement in both thighs it joins them. The main action of the muscular group of the Adductive ones of the thigh is required for this movement
- Coxofemoral Movement of Abduction: In this movement, the thigh moves outwards with respect to the hip, moving away of the sagital plane. When making this movement in both thighs it separates them. The main action of the muscle of the Tensor Fascia Lata is required for this movement

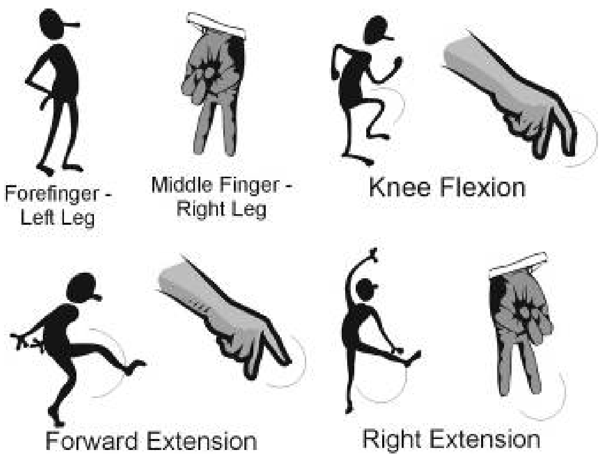


Fig 3 – Mapping of the movements

- Movement of the knee of Flexion. In this movement, the leg bends backwards with respect to the thigh. Being stand up, it raises the leg backwards. For this, the main action of the muscle Crural Biceps is required.

- Movement of the knee of Extension. In this movement, the leg extends forwards with respect to the thigh. Being stand up, it extends the leg forwards. For this, the main action of the muscle Quadriceps is required.

V. MAPPING OF THE MOVEMENTS

From the theoretical model previously delineated, it is given off that 3 axes of movement by each extremity are required. In order to control each extremity independently the middle and forefinger from the right hand were chosen. Respectively, the forefinger controls the left leg, and the right leg is controlled by the middle finger.

For mapping purposes, the hand is considered horizontal, with the palm downwards. Fig 3 illustrates the mapping described

- For the coxofemoral joint, or hip joint, the theoretical model points out that are necessary two degrees of movement or axes for their control. This coxofemoral joint is mapped to the metacarpus-phalanges joint, or to the base of the finger with the palm. The movement of extension of one thigh towards the front must corresponds to the movement towards in front of the finger related to his leg. Thus, if the finger is lowered (remembering that the palm is horizontal), the thigh will be also lowered.

- With respect to the movement of lateral abduction of the thighs, when separating the fingers the extremities must move the same. For example, when moving towards outside the forefinger, the left thigh will also have to extend towards outside and left.

- In the case of the joint of the knee, this one is mapped to the interphalangic joint of first and second phalanges, or the middle part of the respective fingers. As with the thighs, the movement of the knee must react to the movements of this joint. For a flexion of the finger it corresponds to a flexion of the knee, and an extension of it to its respective movement.

VI. GENERAL MODEL OF THE CONTROLLER

In theory, the model of the controller by itself is in open loop. The input interface is the movement of the user through the dataglove. And the exit, for the purpose of this work is the control for the physical model to construct.

It is left for future work the interfaces for direct functional neuromuscular stimulation, possibly with over-the-skin electrodes to direct stimulate the muscles.

Since the controller at itself is in open loop, the feedback of the system as a whole is given through the senses of the patient. That is, for questions of balance, position of the extremities, applied force, and compensation of effort due to muscular fatigue, the required compensation is left to the criterion of the patient. In this way, the overall system closes the loop by letting the feedback go through the patient senses.

Fig 4 – Dataglove

With the right training and therapy the patient will be able to make the necessary compensations.

Since the controller does not have feedback of the position of the extremities (as explained before), instead of relating absolute position of the fingers with absolute position of the legs, it is best to map the position of the fingers with force to be performed by the muscles. On this way, a greater flexion of finger, the more force is performed by the corresponding muscles. Thus the patient has control on the force to apply, allowing the handling of the feedback of the system to the user to compensate factors like fatigue and balance.

As for the control system, by not handling position feedback, gravity sensors, and a lot of other factors left to the patient, it simplifies the system to be built.

VII. DATAGLOVE

The development of any human interface outside the traditional keyboard and mouse is always related to the last advances within the field of the Virtual reality. It is in this science field where the greater advances in the matter of human interfaces can be found.

One of the new features that were introduced in the early 80’s to the consumer industry was the Atari Dataglove, invented by Tom Zimmerman. It was first just a glove that processed data, but in fact, it gave birth to what it is known today as Virtual reality.

By Definition a Dataglove is understood as an Electronic Glove that allows interacting through the computer with a world and its Virtual objects, by means of sensors and pressure actuators, which acquire the form of the object that is called on to give to the sensation of pressure in the hands of the user.

In 1983 the industry of the video-game suffered serious economic losses that lead to a temporary recess, and all investigations and advances became paralyzed.

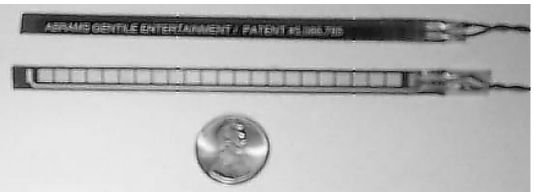


Fig 5 – Flexion Sensors

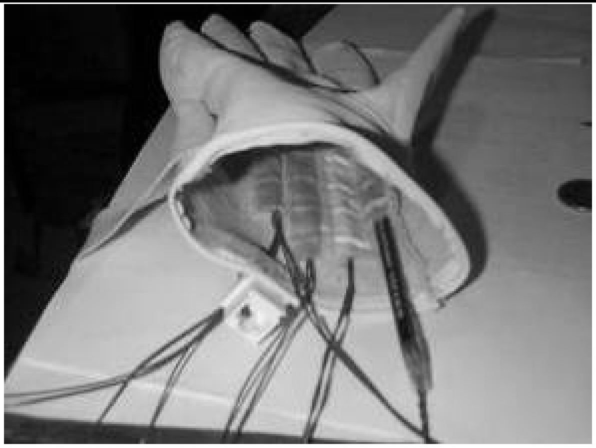


Fig 6– Inside Sensors

The Dataglove was sold to the NASA. Later a great part of the rights and secrets of Atari were acquired by their collaborators like Konami and Sega, among others, beginning the second part of the revolution of the video-games.

VIII. FLEXION SENSORS

First it was conducted an investigation to know commercially available alternatives already developed. Among the few options found, the most popular one between electronic hobbyists is a glove developed by the Nintendo Company, called indeed dataglove. This device contains a flexion sensor for each finger and a system of ultrasonic three-dimensional positioning, which allows the location of the hand in a plane xyz. This option was rejected since the present project requires two sensors by finger, middle and forefinger. In addition it is not necessary the location in the plane xyz.

Continuing with the search, it was found that the electronic hobbyists that have developed interface gloves, almost all use the same sensors used by the Nintendo dataglove (already discontinued). These are widely recommended by all, besides of its economy.

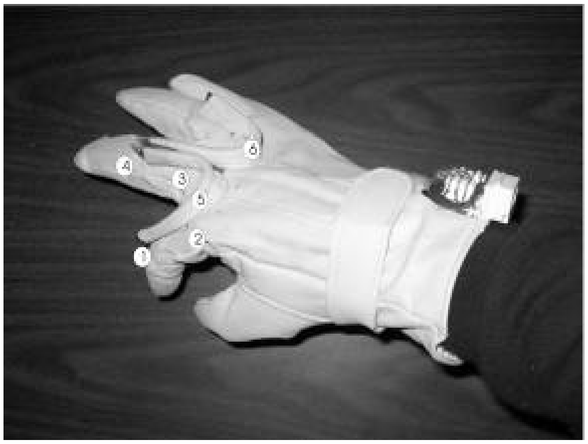


Fig 7 – Dataglove – Input Order

Of these works done by hobbyists, most of them used a sensor by finger. There were required 6 sensors total for the middle & forefinger. For the construction it was used a commercial glove of sheep skin.

The sensors were sewn to the internal part using light-strips of fabric to the glove. A RJ45 connector was added for the 6 sensors signals plus gnd/Vcc. Tests were done using a capture system DI-194RS from DATAQ Instruments. This system consists of 4 A/D capture channels. It was possible to be stated that each sensor is working, in response of the flexion of each finger.

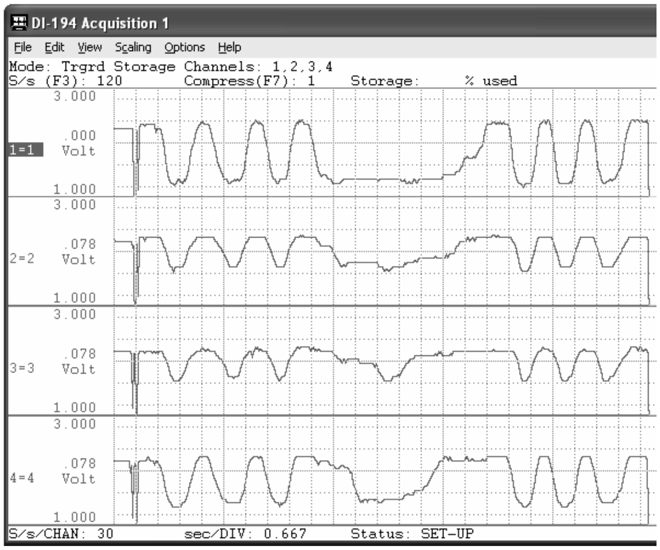
IX. INPUTS

There are 6 flexion sensors total, three for each finger. Two of the sensors are placed in top of the fingers to sense the corresponding flexion action. The other two are placed between fingers to sense the lateral movements of these, to correspond to the legs movements to the sides.

The inputs and its associated movements are

1 - Interphalangic joint of the forefinger – Flexion / Extension of the Left knee
2 - Metacarpus-phalanges joint of the forefinger Coxofemoral Flexion / Extension of the Left thigh
3 - Metacarpus-phalanges joint of the middle finger Coxofemoral Flexion / Extension of the Right thigh
4 - Interphalangic joint of the middle finger – Flexion / Extension of the Right knee
5 - Sensor between forefinger and middle finger - Coxofemoral Adduction / Abduction of the Left thigh
6 - Sensor between middle and ring finger - Coxofemoral Adduction / Abduction of the Right thigh

In Fig 8 it is shown the 4 sensors were used in the middle finger and forefinger. The curves at the left and the right of the plot show the moments when all the hand is closed and opened consecutively. In the middle part are the movements of the fingers in sequence.



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Mode: Trgrd Storage Channels: 1,2,3,4
S/s (F3): 120        Compress(F7): 1    Storage:      % used
S/s/CHAN: 30         sec/DIV: 0.667     Status: SET-UP
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Fig 8 – Sensors behavior by finger

The first plot is the sensor located at the middle of the forefinger. Second one is at the base of the forefinger. Third one is the middle finger's sensor at the base also. Four one is the middle fingers' sensor, at the middle part of it.

X. INTERFACE DEVELOPMENT

Based on the data captured with the DATAQ system it was determined the output max-min ranges from the dataglobe. The overall outputs needed are in the range of 0.5 and 4.5 volts, being this 10% to 90% of a range 0 to 5 volts. This range correspond to the input window of the available ADC embedded in the microcontroller. The 10% to 90% input range is to avoid excess voltages that the ADC may not see or even damage the IC.

Table I– Resistance values

CH#	R1	R2	RF
1	18k	10k	36k
2	20k	10k	100k
3	20k	10k	100k
4	18k	10k	47k
5	36k	22k	120k
6	36k	22k	120k

From the mentioned data, gain and offset required for each input was calculated to match the required range. It was used an opamp adding circuit based on LM324 ICs. The resistance values were determined individually for each channel. Table I and Fig 9 describes the circuit

XI. MECHANICAL MODEL

Since it is not the objective of this work to do medical research with real patients, it is planned to use a mechanical model for the test and development of the entrance interface (dataglove) and the controller. This mechanical model is planned to imitate the basic functions delimited by the raised theoretical model. This way, the only joints to consider are the coxofemoral or hip joint and of the knee. All others as the ankles will be fixed. For this, it is planned to use a wood doll articulated of the waist and knees.

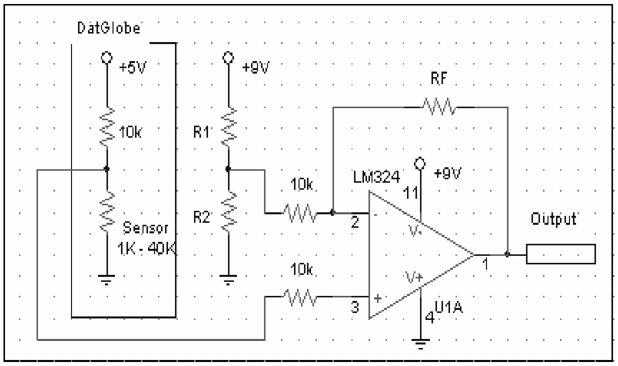

Fig 9– Circuit by channel

From the theoretical model, six important muscular groups for each leg were identified, for a total of 12. For this model it is planned to make correspond the actuators with each muscular group to give the realism necessary for the project.

The outputs and its associated movement and muscular group are

A1 - Extension of the knee – Left muscle Quadriceps.
A2 - Flexion of the knee – Left muscle Crural Biceps
B1 - Coxofemoral Flexion – Left Pectineal muscle
B2 - Coxofemoral Extension – Left muscular group of the Gluteus
C1 - Coxofemoral Flexion – Right Pectineal muscle
C2 - Coxofemoral Extension – Right muscular group of the Gluteus
D1 - Extension of the knee – Right muscle Quadriceps.
D2 - Flexion of the knee – Right muscle Crural Biceps
E1 - Coxofemoral Adduction – Left muscular group of the Adductive ones of the thigh
E2 - Coxofemoral Abduction – Left muscle of the Tensor Fascia Lata
F1 - Coxofemoral Adduction – Right muscular group of the Adductive ones of the thigh
F2 - Coxofemoral Abduction – Right muscle of the Tensor Fascia Lata

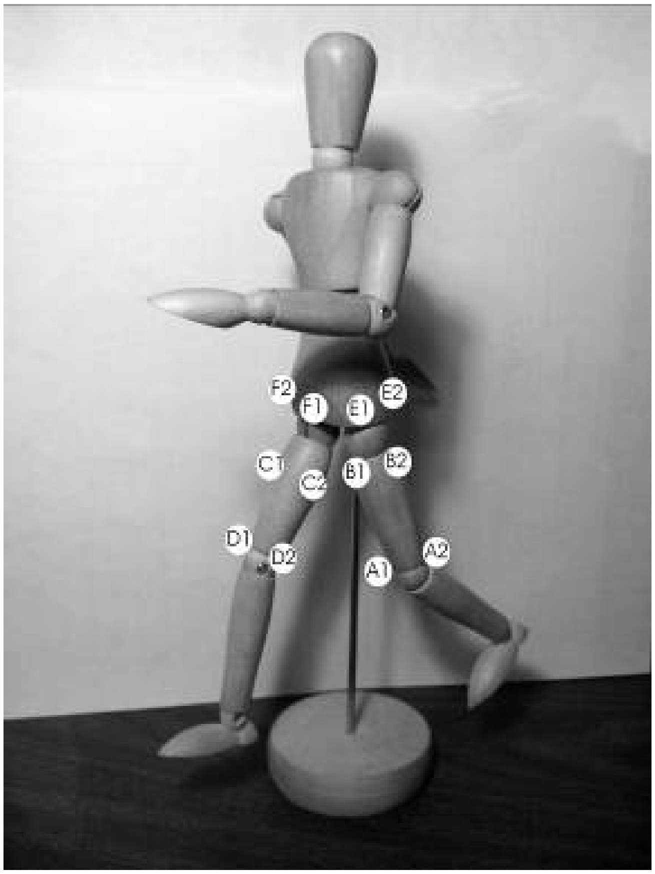

Fig 10– Outputs on the mechanical model

XII. ACTUATORS

It is planned to use muscle wires as the actuators. These actuators are of low voltage, economic, and of low speed but moderate force for their scale.

Muscle Wires are thin, highly processed strands of a nickel–titanium alloy called Nitinol – a type of Shape Memory Alloy that can assume radically different forms or “phases” at distinct temperatures.

At room temperature Muscle Wires are easily stretched by a small force. However, when conducting an electric current, the wire heats and changes to a much harder form that returns to the “unstretched” shape – the wire shortens in length with a usable amount of force.

Muscle Wires can be stretched by up to eight percent of their length and will recover fully, but only for a few cycles. However when used in the three to five percent range, Muscle Wires can run for millions of cycles with very consistent and reliable performance.

Muscle Wires contract as fast as they are heated – in one thousandth of a second or less. To relax, the wire must be cooled, which depends on the conditions surrounding the wire, and its size.

Compared to motors or solenoids, Muscle Wires have many advantages: small size, light weight, low power, a very high strength-to-weight ratio, precise control, AC or DC activation, low magnetism, long life, and direct linear action. The power needed to activate a wire depends on its diameter, length, and the surrounding conditions.

XIII. OUTPUT SIGNAL CONDITIONING

Within the limitations of the project, it was settled down to map the flexion of the fingers not with position of the legs, but with force to apply, leaving the compensation of fatigue balance and position to the patient.

This implies for effects of the model, to a greater input the greater force will have to exert the actuators. For the muscle wires a greater electrical current the greater mechanical contraction with respect to their position of rest.

With this at sight, a conditioning will be necessary to map the input signal to greater or smaller force, with the action of the actuators to greater or smaller displacement.

The Normalized output of the Neural Network is in the range 0 to 1. The actual output of the controller box can be either voltaje or a Pulse Width Modulated signal. In either case, 12 channels are needed.

These are almost entirely independent. There is an inverse relationship between opposite actuators in each legs, although this is not always constant due to other factors such the Force Compensation input and the network self training.

The output voltage is set to 10% to 90% of a TTL signal, or a range from 0.5V to 4.5V. This in order to avoid saturation due to transitories. Since the Muscle wires uses current, a voltage to current translator is needed.

If the PWM signals are selected as output, also 12 signal conditiones will be neeed to translate it to the necessary current signals.

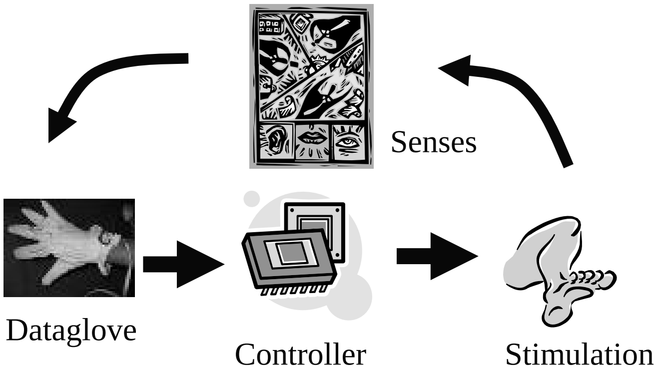

Fig 11– General Model of the Controller – Feedbacks

For the PWM signal type, the range would be related 0 to 0% and 1 to 100% of the pulse. The actual output of the controller box would be in a TTL form. The job of the signal conditioning module of the controller in this case will be to translate the maximum 100% PWM pulse to the top current that the muscle wire can hold. With this action the complete range linear translation from PWM percent to current is assured.

XIV. CONTROLLER SYSTEM

The whole system as talked before, is a closed loop system. In the understanding as the overall system are the user or patient, interfaces and electronic controls.

When the patient emits a control action, this action is gathered by the sensors of the input interface, processed in the electronic controls and sent to the output interface to make an action in the actuators.

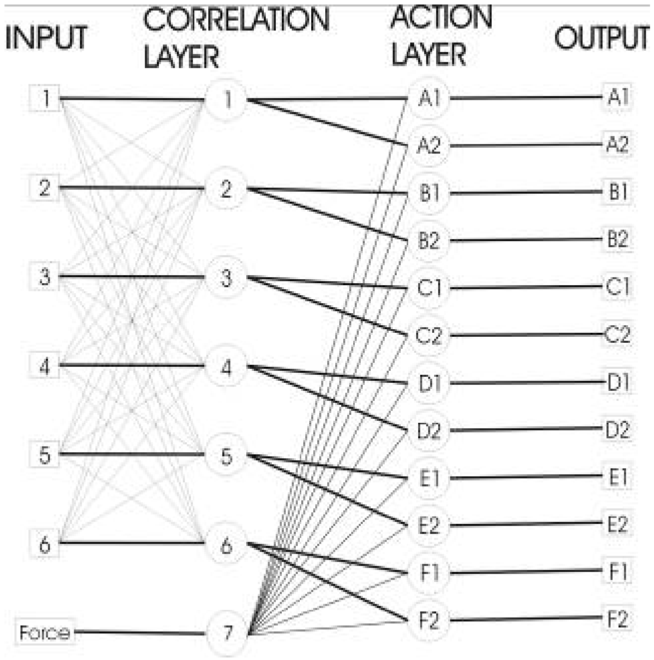

Fig 12– General Model of the Controller – Input Output diagram

The feedback in form of the legs position, muscular response by fatigue, and balance of the patient will be given directly to the patient through its own senses as it is the tact, seeing, balance and others.

The electronic controls by itself does not receive direct feedback of its acts, it works in open loop. The compensation or feedback comes in the perceptions that the user or patient receives from its own senses. This allows for an economic and accessible solution to a greater population.

XV. CONTROL LOGIC

In total there are 7 inputs, three by each finger representing each leg, and each one of these three for each joint to control. Plus an adjust for more or less force, to compensate for fatigue and individual characteristics of each patience such as weight, muscle force and others.

Each input action has a pair of opposite output actions associated, with the exemption of the force compensation which is associated to all outputs.

The outputs from the flexion sensors were found to not be individual for each finger movement. For any particular single movement, all 6 flexion sensors have some output present in a more or less form depending of the finger movement performed.

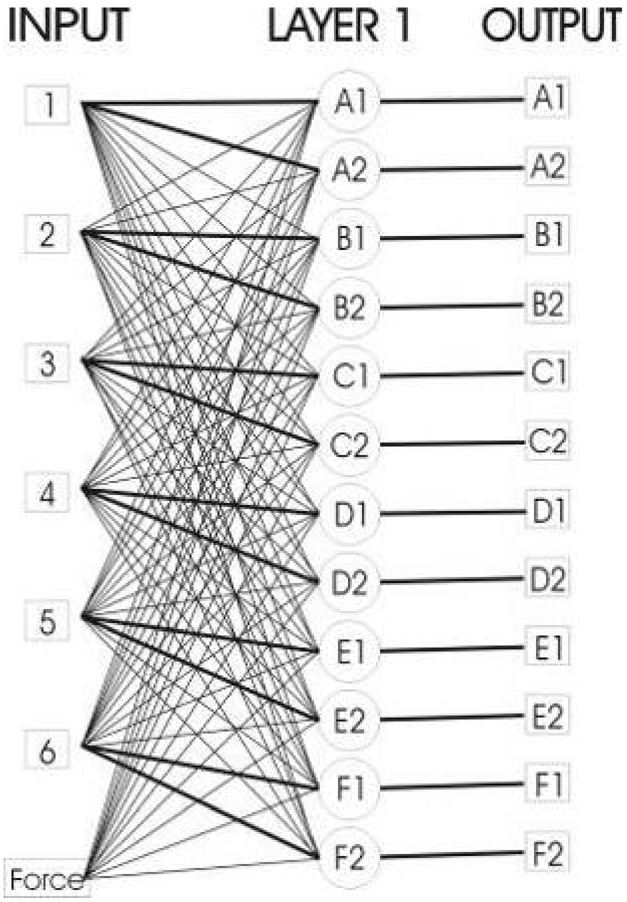

Fig 13 – General Model of the Controller – Neural Networks

It is necessary to incorporate a stage that separates these inputs and delivers clean independent signals for each action required.

The figure of the controller shows the 6 inputs and the correlation layer to individualize these inputs. Once the inputs have individual actions, these are associatd to their corresponding pair of outputs.

The most viable way to individualize this actions is to substract (add the negative) from the principal action the other signals. Correlation Layer performs this action by using pounderated sumatories for all inputs

Once the inputs are independent, the output layer generates the output pairs of actions corresponding to the actuators mentioned before. These are also ponderated between 0% to 100% via the Force input.

For the output, there are 3 pairs of actuators for each leg, representing the mayor muscular groups involved. Each pair corresponds to complementary actions of Flexion - Extension for every joint. Three pairs one for each joint, times two legs as it was mentioned conforms 12 outputs total.

XVI. NEURAL NETWORK

From the diagram, it is shown that each input has associated two outputs, with the exception of the force which is related to all outputs. Each one of these associations is a linear proportional relationship, and each node is the sum of all the actions associated with it.

These actions resemble the structure of a Neural Network with two layers. The Correlation layer is the equivalent of the first hidden layer of a neural network. The Output layer would be also the output layer of a NN.

The second layer basically only generates two almost-opposite outputs for each of the nodes for the correlation layer. These outputs are then modified with the Force input.

Due to the simplicity of this layer it is merged to the previous one. The result is a twelve node layer, which inputs are the mentioned 6 signals plus the force compensation.

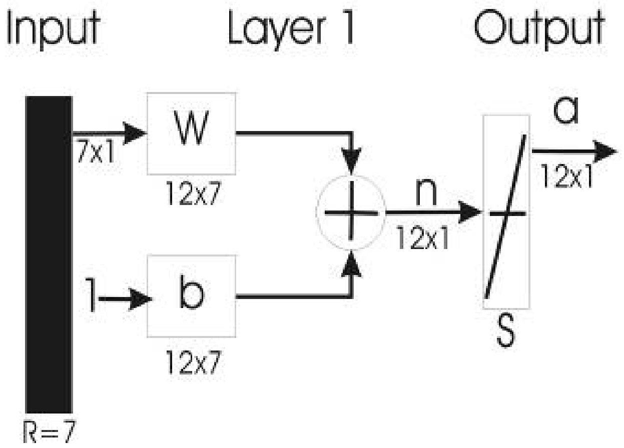

Fig 14 – General Model of the Controller – Neural Networks

XVII. TRAINING DATA

The data set comprises 6 inputs with a minimum and a maximum values. This max and min are in the Flexion (F) and Extension (E) actions, besides the Left (L) and Right (R) movements. This gives 2^6 or 64 sets of data.

Also there is a minimum and a maximum Force (F). The minimum (0) is translated to a 0 output and a maximum (1) is a full scale output.

The output of the dataglove for these actions is in the range of 0.5 to 4.5 volts. These signals are normalized to the range 0 to 1 to feed the Neural Network.

The expected action is also in the minimum to maximum range. This range normalized is in the 0 to 1 range. The output is returned to the 0.5V to 4.5 volts.

For training purposes a complete set of minimum and maximum data will be feed to the Neural Network. This is done to have all the input correlations present during training, to have the network learn to distinguish between inputs, clean them and separate each one.

As verification data another set is generated, but with middle points. That is, the training was performed at maximum and minimum. The verification is to be done with calculated data at intermediated points, such as a flexion of 30% for the forefinger and 75% for the middle finger

The verification data resembles the actual performing of the overall system, due to most of the time the system will not be at maximum (or minimum) points, but at an intermediate value.

Table II– Training Data (Example)

ACTIONS					**INPUTS**			**IN Normalized**		
	1	**...**	**6**	**F**	**1**	**...**	**6**	**1**	**...**	**6**
0	X	...	X	0	0.0	...	0.0	0.0	...	0.0
1	E	...	L	1	0.3	...	1.0	0.1	...	0.2
2	F	...	L	1	1.8	...	2.3	0.4	...	0.5
...	...	...	...	...	...	...	...	...	...	...
63	E	...	R	1	1.7	...	2.7	0.3	...	0.5
64	F	...	R	1	1.1	...	0.1	0.2	...	0.0

OUT Normalized			**OUTPUT**		
A1	**...**	**F2**	**A1**	**...**	**F2**
0.0	...	0.0	0.5	...	0.5
1.0	...	1.0	4.5	...	4.5
0.0	...	1.0	0.5	...	4.5
...	...	...	...	...	...
1.0	...	0.0	4.5	...	0.5
0.0	...	0.0	0.5	...	0.5

XVIII. CONCLUSION

One of the first questions to answer related to the viability of this project, is the capacity of the input interface to deliver the necessary control signals. So far, this question has been answered in a favorable way. There is still a need for some signal conditioning, but the actual measurements and simulations at this point have demonstrated a good relationship between the movements of the fingers to the output signals delivered.

Next milestone is the translation of these signals into the needs of movement of the mechanical model, and in a posterior work in the needs of a real patient. So far this milestone also seems to be in a favorable condition.

REFERENCES

[1] Centers for Medicare & Medicaid Services, “Coverage and Billing of Sacral Nerve Stimulation”, Transmittal AB-01-177 November 15, 2001.

[2] Jader A. De Lima, Adriano S. Cordeiro “A Low-Cost Neurostimulator with Accurate Pulsed-Current Control”, IEEE Transactions on Biomedical Engineering, VOL. 49, NO. 5, MAY 2002

[3] James J. Abbas, and Howard Jay Chizeck, Neural Network Control of Functional Neuromuscular stimulation Systems: Computer Simulation Studies, IEEE Trans Biomed Eng, 1995. 42(11): p. 1117-1127

[4] Yamaguchi, Gary T, Zajac, Felix E, “Restoring Unassisted Natural Gait to Paraplegics via Functional Neuromuscular Stimulation: A Computer Simulation Study “IEEE Transactions on Biomedical Engineering. Vol 37 no 9. September 1990

[5] Temple University, “Temple Using Stomach Pacemaker To Provide Relief For Chronic Nausea And Vomiting Associated With Gastro paresis” Temple University Health Sciences Center newsletter, 2000-12-11

[6] Niall Galloway, MD, FRCS, Jenelle Foote, MD, Cindy Sanders, “Bladder Pacemaker to Improve Quality of Life for Incontinence Patients” , Emory University Hospital newsletter, 05 November 2004

[7] Hesse S, Malezic M, Lücke D, Mauritz KH “Value of functional electro stimulation in paraplegic patients” Nervenarzt 1998 -69:300-305 Springer-Verlag 1998

[8] Hugues Barbeau a, David A. McCrea b, Michael J. O’Donovan c, Serge Rossignol d,1,Warren M. Grill e, Michel A. Lemay “Tapping into spinal circuits to restore motor function” Elsevier, Brain Research Reviews 30 1999 27–51

[9] SIGMEDICS, INC. “ The Parastep I System ”, Product Brochure, January 2005 Available http://www.sigmedics.com/index.htm

[10] Demuth Howard, Beale Mark, Hagan Martin, “Neural Network Toolbox for use with Matlab”, The Mathworks Inc, 9th edition, 2006

Alejandro Garcia Blanco received the BS degree in Electronic Communications Engineering from the Instituto Tecnologico y de Estudios Superiores de Monterrey (ITESM), Monterrey Mexico in 1997. He is currently studying the MSCE in the Tecnologico de Nogales, Nogales Mexico

From January to December of 1997 he worked as Transmissions and Maintenance Assistant on the Virtual University division of the ITESM. From 1998 to 2003 he worked as Electrical Designer for the Zenith / LG brands on the design of video stages for televisions. Since 2003 he is working for Motorola – Connected Home Solutions division in the New Product Introduction area. He also has worked as part time professor for the Universidad Tecnológica de Tamaulipas Norte and the Universidad Del Atlántico in Reynosa Mexico. His areas of interest are Multimedia Communications, Automatization Systems, signal and image processing

Gildardo Jimenez received the BS degree, Electronic Engineer, from Universidad Autonoma Metropolitana, Mexico City in 1980, the MSEE from Brunel University, London, UK, in 1987, and the MBA/TM at the University of Phoenix, Arizona, USA, in 2001.

From May 1981 to April 1997, he was an Electronic Engineer at the Instituto de Investigaciones Electricas, Cuernavaca Morelos, Mexico. From October 1986 to March 1987 he worked as Laboratory assistant at the Electrical Engineering and Computer Sciences Department at Brunel University, London, UK. From June 1988 to April 1997 he was a part time assistant professor at the Centro Nacional de Investigación y Desarrollo Tecnológico (CENIDET), Morelos, México. From June 1992 to April 1997 he was a part time assistant professor at the Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM), Campus Morelos, México. In April of 1997 he was employed as Electrical Engineer at Otis Elevator Company, Nogales, Sonora, Mexico. Since February 2005 he joined as an Electrical Engineer at Chamberlain Group, Nogales, Sonora, Mexico. Since 2003 he joined as a part time professor to the Instituto Tecnologico de Nogales Sonora, Mexico. His current areas of interest include Automatization Systems, signal and image processing, speech recognition, and tactile recognition.

Pedro Ochoa received the BS degree, Electronic Engineer, from Instituto Tecnológico de Durango, Durango, Durango, Mexico in 1980, the MSCE from University of Texas, Odessa, Tx. US, in 1984

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From January o1981 to July 0f 1981 he was employed as Electronic Engineer at Alcatel Company, Nogales, Sonora, México. From September 1984 t December 1986 he was a part time Electronic Engineer at Alcatel Company, Nogales, Sonora, México. Since 1984 he joined as a full time professor to the Instituto Tecnológico de Nogales, Sonora, Mexico. His current areas of interest include Analog Electronic, Optoelectronic, Automatization Systems, Multirate Controller, Real Time System.