# Custom Built Device for Spasticity Evaluation Associated to Spinal Cord Injury

## *A Redundant Signal to Electrogoniometer in Pendulum Test*

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Keywords: Spasticity, Pendulum Test, Biomedical Engineering, Electrogoniometer, Goniometry, Accelerometer, Spinal Cord Injury, Clinical Evaluation.

Abstract: The proposal of this project was the development of a more objective system to evaluate spasticity, dysfunction often presented by spinal cord injured people. As result, it will be possible to follow patient's progress in moments before and after any treatment, drawing comparisons through the acquired data. One accelerometer was added to the original pendulum test, providing redundant and alternative signal to the electrogoniometer, even in critical situations. Also, tests were performed in patients during treatments, what confirmed the feasibility of the present system in this method of evaluation.

## 1 INTRODUCTION

There are many causes of spinal cord injuries. Among them are: automobilist accidents, fire guns and diving into shallow waters. Non-traumatic causes, as nervous system diseases, can also lead to injury.

When spinal cord injury occurs, communication between the brain and body is affected, consequently, conduction of motor and sensory information is impaired.

### 1.1 Spinal Cord Injury Levels

Injury can be complete, when there is an absence of sensory and motor function in the lowest sacral segments; or incomplete, when there is preservation of any sensory and/or motor function below the neurological level that includes the lowest sacral segments (Kirshblum et al., 2011).

Paraplegia refers to impairment or loss of motor and/or sensory function in the thoracic, lumbar or sacral (but not cervical) segments of the spinal cord, consequent to the damage of neural elements within the spinal canal. With paraplegia, upper limb function is preserved, but, depending on the injury level, trunk, lower limbs and pelvic organs may present functional losses (Kirshblum et al., 2011).

Tetraplegia term refers to motor or sensory dysfunctions of spinal cord cervical segments due to damage of neural elements within the spinal canal. Tetraplegia results in impairment of function in upper limbs as well as typically in trunk, lower limbs and pelvic organs (Kirshblum et al., 2011).

Certain time after the occurrence of the spinal cord injury, movement disorders tend to appear, what hinders these people's lives and can induce pain.

This study focus on one of these disorders: the spasticity.

### 1.2 Muscle Tone and Spasticity

Each motoneuron, that originates from spinal cord, innervates many muscle fibers. As the muscle fibers do not contract themselves without the existence of a real action potential to stimulate them (except in some pathological situation), skeletal muscle tone is totally dependent of nervous impulses originated from spinal cord. Muscle tone is a state of partial tension of the muscle at rest that allows the contraction to start immediately after receiving a nervous impulse, besides of defining the strength with that the muscle resists to being strained. These


Manzano Maria R., Alonso K., Ferreira Braga Machado de Azevedo E., Varoto R. and Cliquet Jr. A..
Custom Built Device for Spasticity Evaluation Associated to Spinal Cord Injury - A Redundant Signal to Electrogoniometer in Pendulum Test.
DOI: 10.5220/0004234001200126
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (BIODEVICES-2013), pages 120-126
ISBN: 978-989-8565-34-1
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impulses are controlled in part by impulses transmitted by the encephalon to the correspondent motoneurons and in part by impulses originated from muscle fuses localized in the proper muscle (Guyton, 1997).

The increase of muscle tone characterizes the spasticity. In physical exam, spastic limbs present an increased resistance to passive movement, which is more accentuated with the increase of the amplitude and speed imposed. The increased resistance to stretching is greater at the beginning of the movement, and decreases thereafter. (Leitão et al., 2006).

As spasticity affects the quality of spinal cord injured people's lives, since it causes functional difficulties, besides pain and contractures, some specific treatments can decrease these effects in some muscle groups. Treatment is often considered essential to prevent deformities, improve function and release stressing symptoms (Miyazaki et al., 2008).

## 1.3 Rehabilitation

Some treatments are more used in rehabilitation programs, aiming the reduction of patient incapacity. Kinesiotherapy, Locomotor Treadmill Training, Functional Electrical Stimulation, use of orthoses and medication treatments are examples with satisfactory results (Lianza et al., 2001).

According to Dietz (2008), complete spinal cord injured individuals are beneficiated by gait training, mainly by atrophy prevention and spasticity reduction.

Patients can perform treadmill gait training associated to neuromuscular electrical stimulation (NMES). They are assisted by partial body weight support (BWS) (30-50%, to allow heel strike), and by physiotherapists that help them move their legs. During treadmill gait (at 0.14-0.39 m/s), the 4-channel electrical stimulator is also used to provide NMES to aid the stance gait phase (through quadriceps muscle activation) and the swing phase (stimuli to the fibular nerve) (Carvalho et al., 2006; Abreu et al., 2009).

## 1.4 Existent Evaluation Methods

The increase of new methods in spasticity treatment has driven forward new mechanisms to quantify its degree, measuring progression and success of these methods. In fact, there is a trend towards more objective measurements in order to make possible more precise and exact analysis.

In spasticity assessment, quantitative and qualitative indicators are used. They are used to identify intensity and influence on functional performance, being useful for indication of therapeutic interventions and analysis of assessment results (Leitão et al., 2006).

Scales are common clinical measures of muscle tone, among them are Ashworth Scale, Modified Ashworth Scale and Spasm Frequency Scale. Besides the patient's influence, scales are also a very subject grading method and do not allow smaller degrees identification.

The use of tonus as a resource to establish neurological diagnoses is possible through pendulum test that evaluates muscle tonus of the quadriceps. Data obtained in this test present minimum variability and high precision, require minimum patient cooperation and, the most important, they have significantly correlation with clinical results. This test has been used to evaluate spasticity in patients that presents hemiplegia, multiple sclerosis and spinal cord injury and also to evaluate the efficacy of antispastic drugs and muscle training (Salmela et. al., 2002).

Electrogoniometers and tachometers were used as instrumentations to pendulum test of spasticity (Bajd and Vodovnik, 1984).

Procedure involving computerized video motion analysis was applied as an alternative to goniometer in pendulum tests (Stillman and McMeeken, 1995).

Linear accelerometers were used as an alternative strategy to measure knee joint angle, what allows unlimited movements of the patient (Yakamoto et al., 2012).

Accelerometer was also combined to gyroscope in the development of a motion sensor system, in order to estimate joint moments in human dynamic analysis (Liu et al., 2010).

Alternative tests are available also to upper limb, as the use of a hand-held myotonometer for measuring tone, elasticity and stiffness of the muscle simultaneously, by applying a brief mechanical impulse, followed by a quick release to the muscle through acceleration probe (Chuang et al., 2012).

This project applies a common sensor (used in motion analysis) to the original pendulum test: the accelerometer. It provides information of thigh tremor during the test execution.

As redundancy, one electrogoniometer is also positioned in the patient to measure knee angle during the balance.

# 2 DEVELOPMENT

## 2.1 Transducers

### 2.1.1 Accelerometer

A piezoelectric accelerometer was chosen to quantify thigh tremor. The ACH-04-08-05 Accelerometer Analog Test PCB (Measurement Specialties, Inc., Norristown, PA, USA) used in this system, presents adequate features for this application. This unit consists of the ACH-04-08-05 accelerometer with thermal shield, a low-power operational amplifier, resistors and capacitors that provide signal conditioning (Figure1) (Measurement Specialties, Inc., 2001).

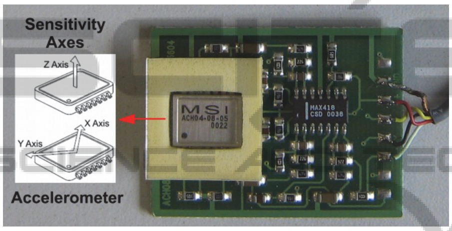


Figure 1: ACH-04-08-05 Accelerometer Analog Test PCB.

The accelerometer contains three cantilever beams composed of a metal substrate with a piezoelectric polymer element affixed to one side. The beams are oriented to simultaneously measure acceleration in three orthogonal, linear axes (X, Y and Z). The X and Y axes are at a 45$^{o}$ angle relative to the accelerometer package. Each beam is supported at one tip while the opposite tip is free to flex in response to acceleration. This flexion strains the piezoelectric material that generates a charge proportional to the applied acceleration. The accelerometer responds over a frequency range from 0.3 Hz to 5.0 kHz, as a result of the integrated electronics and the damped sensing elements. The sensitivity of axes is 1.8 mV/g (Measurement Specialties, Inc., 1998); (Measurement Specialties, Inc., 1999).

The ACH-04-08-05 Accelerometer Analog Test PCB provides three simultaneous analog outputs, one for each axis. Moreover, the circuit has a gain of 47.8, a high-pass filter (0.34 Hz) and a low-pass filter (185 Hz). The entire circuit requires +5 V power supply and drains 13 μA for all three axes (Measurement Specialties, Inc., 1998); (Measurement Specialties, Inc., 2001).

Tremors, as vibration signal, are usually composed of many frequencies that occur simultaneously. Vibration amplitude can be quantified in many ways: peak-to-peak level, peak level and root mean square (RMS). RMS value was chosen as an indicator because it shows the mean energy contained in the vibration movement. It is calculated according to the equation 1.

$$x_{RMS} = \sqrt{\frac{x_1^2 + x_2^2 + \ldots + x_N^2}{N}} \tag{1}$$

$x_{RMS}$ is the effective value of the vector analyzed, $x_1 \ldots x_n$ are its values and N is the vector size.

### 2.1.2 Electrogoniometer

Goniometry is one of the most used techniques by cinemetry, which allows the assessment of joint range of motion, and the description and comprehension of adjacent segments movement, providing a quantitative analysis about pathology and functional capacity rehabilitation (Esteves et al., 2007).

The S700 Joint Angle SHAPE SENSOR (Measurand, Inc., Fredericton, NB, Canada) was used to measure joint angle. This transducer has one degree of freedom and it consists of two cases attached to both tips of a 200 mm vinyl-covered metal cantilever (Figure 2). The cantilever has plastic optical fiber along the length on both sides, and the fiber is treated on one side to lose light proportional to bending. Thus, the angle between the two cases determines the amount of light traveling through the fiber.

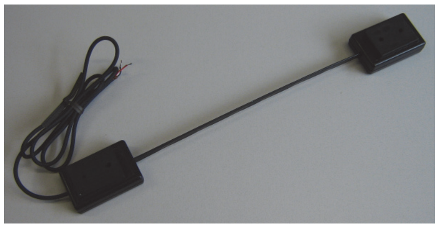

Figure 2: Electrogoniometer Shape Sensor S700 Joint.

One case contains the electronic circuit that converts the light signal from the sensor to an electrical output. The transducer output is centered on 2.5 V (sensor is straight, for +5 V power supply and 5 mA of current draw) and it is linear and usable without further processing. The output range is ±1.0 V for an angle range of ±90$^{o}$. The other case is used for mounting (Measurand, Inc., 2001).

## 2.2 Hardware

Hardware was built based on data acquisition

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through a microcontroller responsible also for analog to digital signals conversion, as well as their transmission to a computer through serial communication.

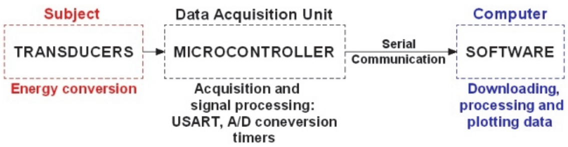


Figure 3: Global system diagram. Analog signal acquired from the transducers is converted to digital signal by the microcontroller and sent through serial communication to the software in the computer.

Basically, the data acquisition unit consists of PIC18F258 microcontroller (Microchip Technology, Inc., Chandler, AZ, USA), MAX232 dual driver/receiver (Texas Instruments, Inc., Dallas, TX, USA), 9V battery as power supply with 5V voltage regulator and support circuit for PIC (crystal and capacitors).

An alternative way to the serial port communication, not always available in many computers, is the use of a USB-Serial converter cable.

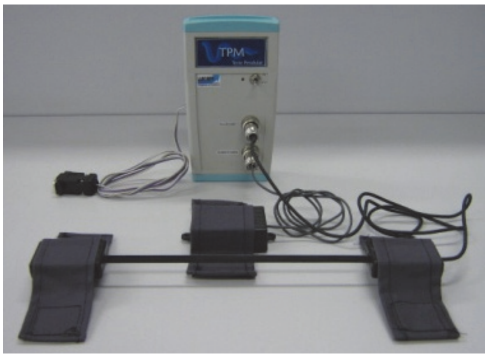

Figure 4: Complete system. Transducers, serial cable and equipment.

## 2.3 Firmware and Software

The microcontroller acquires data from transducers, realizes analog to digital conversion and sends these data to computer via serial communication. Libraries, corresponding to the PIC, USART, Timer, A/D converter and delays, were defined in the program of microcontroller; ports used and their I/O functions were also set up, and timing and clearing USART buffer functions were declared.

The software built to user interface was developed in LabVIEW 8.6 (National Instruments, Austin, TX, USA) platform, using graphical programming called G language.

Figure 5 shows the data acquisition screen. Transducers data are shown in real time during test.


Figure 5: Data acquisition screen.

The data is stored by an identification given to the patient at the capture moment. Figure 6 shows the screen where the user can see historical data.

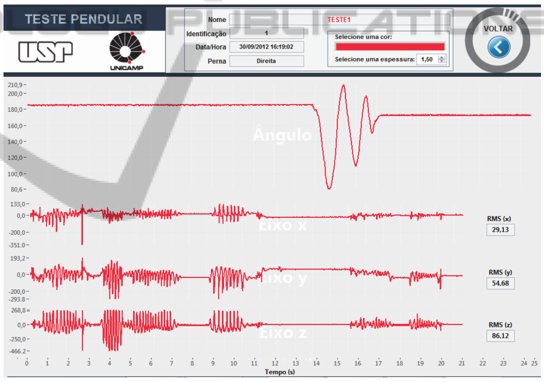


Figure 6: Historical data screen.

The electrogoniometer can also be calibrated. To this project, 180º corresponds to the leg completely extended, and 90º to the end of the balance. A linear equation is created using values acquired by the system, making a relation to determine the angle.

Other way to calibrate is setting the coefficients A and B of the equation. This mode is indicated when the calibration equation of the transducer is already known.

The accelerometer data are not converted to engineering units because they are just used to quantify the intensity of fractionated movement patterns.

# 3 METHODS

Tests were performed at Laboratory of

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Biomechanics and Rehabilitation of the Locomotor System – UNICAMP, with spinal cord injured patients (SCIs).

The SCIs volunteers are integrants of the rehabilitation group that realizes treadmill gait training with NMES. Tests were performed by two patients (both legs), as presented in Table 1.

Table 1: SCIs volunteers characteristics.

| Patient | 1 | 2 |
|---|---|---|
| Gender | Male | Male |
| Neurological Lesion Level | C5 | T3 |
| Asia Scale | AIS C | AIS A |

The patient is positioned in supine position, in a way that his leg may have free balance when released. A triangular lumbar support (45°) is placed under the patient to not induce spasticity.

As shown in Figure 7, the electrogoniometer is positioned laterally to the patient's leg and the accelerometer, above the leg (quadriceps direction).

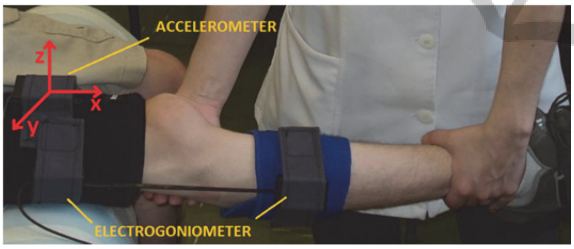


Figure 7: Sensors position.

At the beginning, the physiotherapist extends the leg and released it, letting it falls freely until it stops. Data are acquired and stored by the software.

Tests were performed three times consecutively for each leg, before and after the treadmill gait training with NMES.

## 4 RESULTS

For reference purpose, signals from healthy volunteer were acquired (Figure 8). First graph refers to the electrogoniometer signal, similar to a damped pendulum movement during the balance, presenting no abrupt signals or interruptions. Signals from three axis of the accelerometer can be also observed in Figure 8.

As a more quantitative way of interpretation, RMS from each repetition is calculated. The mean of the 3 axis are shown in Table 2. Values indicate few thigh tremor during the balance.

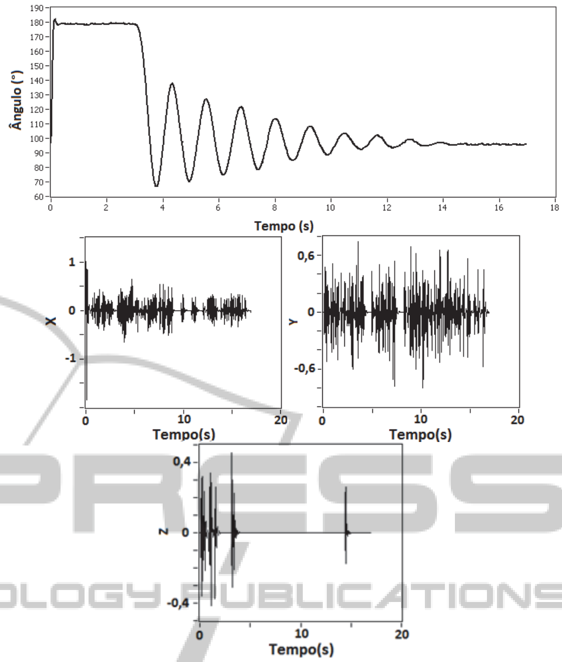


Figure 8: Data from control patient.

Table 2: RMS values of reference signals.

| $\overline{RMS(x)}$ | $\overline{RMS(y)}$ | $\overline{RMS(z)}$ |
|---|---|---|
| 0,16 | 0,16 | 0,07 |

SCIs test results are shown in Figure 9, before training, and in Figure 10, after training.

Mean of the three repetitions ($\overline{RMS(x)}$ $\overline{RMS(y)}$, $\overline{RMS(z)}$) of each leg was extracted in both moments, before and after. Then the difference between these two moments was calculated (Table 3).

Table 3: Differences of RMS mean values corresponding to instants before and after treadmill gait training.

| Patient | Leg | $\Delta\overline{RMS(x)}$ | $\Delta\overline{RMS(y)}$ | $\Delta\overline{RMS(z)}$ |
|---|---|---|---|---|
| 1 | Left | 2,22 | 1,23 | 2,44 |
| | Right | 1,39 | 0,86 | 1,95 |
| 2 | Left | 18,63 | 10,86 | 8,03 |
| | Right | 1,86 | 2,89 | 0,69 |

It is possible to observe that there is a significantly decrease of RMS value in the three axis signals of the accelerometer, when both instants are compared.

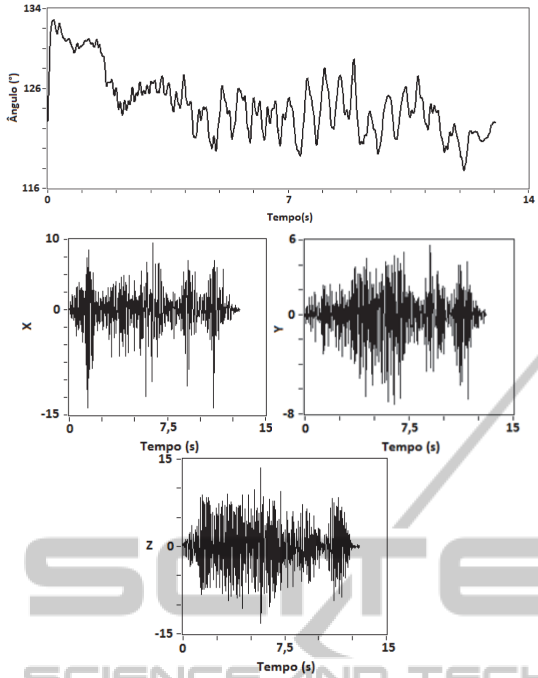


Figure 9: Data before training.

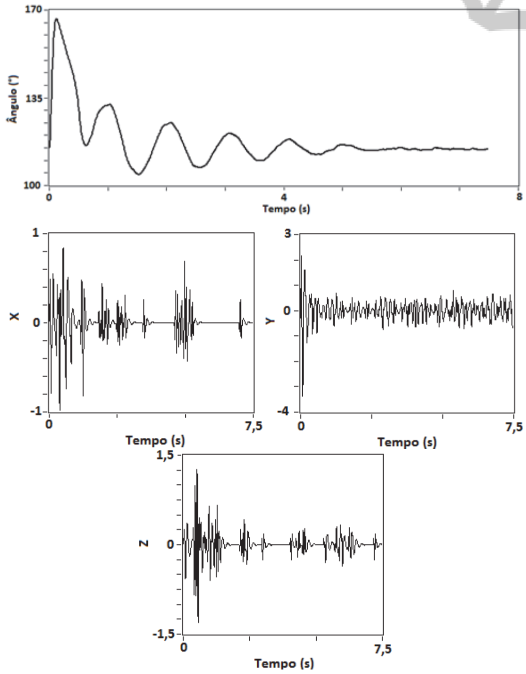


Figure 10: Data after training.

Measuring in three axis are made to improve the spatial sense compared with the electrogoniometer.

Figures 11, 12 and 13 allow a visual understanding of these data and make possible the evaluation the redundance of the sensors when used in pendulum test.

Besides that, it is possible to notice that instants after the training, the movement tends to be similar of a pendulum one, as occurs with the control signal obtained initially. This means that the spasticity has decreased significantly.

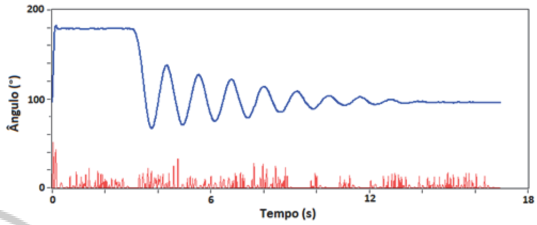


Figure 11: Angle x Vibration – Control signal.

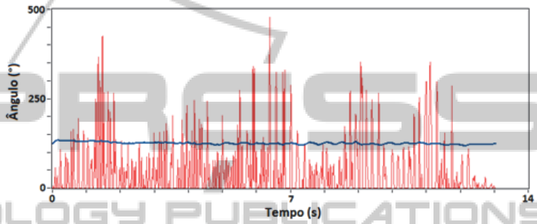


Figure 12: Angle x Vibration – Before training signal.

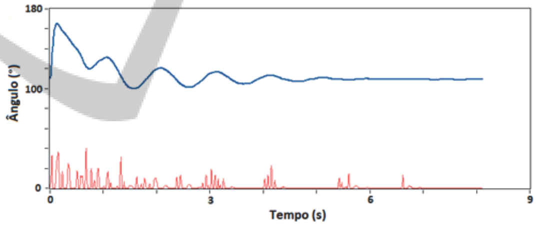


Figure 13: Angle x Vibration – After training signal.

## 5 CONCLUSIONS

Along the study, the feasibility of the accelerometer use in spasticity quantification was verified, since the tremor is certainly present during the pendulum test. Besides, it was possible to obtain RMS values as parameters to quantify spasticity.

Electrogoniometer, usually used in pendulum test, maintains its functionality as a redundant and complementary signal.

However, in severe spasticity, as the electrogoniometer signal does not allow parameters calculation, due to irregular signal shape, the use of signal provided by accelerometer is more appropriate.

Future works are encouraged by adding new accelerometers in different positions, proportioning not only acceleration values, but also, velocity and position.

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