ASSISTED SYSTEM FOR SPASTICITY QUANTIFICATION

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Abstract. *Spasticity is a common and complex motor disorder that affects more than 12 million persons in the world. There are several studies on spasticity quantification on the literature but there is still a need for measurements improvements. This paper presents the preliminary study on the design of a assisted mechatronic device for spasticity quantification, in joint of ankle, elbow and knees. This approach is based on the velocity dependent increase in the tonic stretch reflexes, proposed by Lance (1980). The relevant variables, the measurement range and the adequate measurement systems are selected. The data acquisition system, board and software, are also defined. The first results obtained allow us concluding that the developed assisted system is reliable and well adapted to Spasticity quantification.*

Keywords*: Spasticity quantification; Stretch reflex, Mechatronic device*

1. INTRODUCTION

Spasticity is a complex motor disorder due to a supra-spinal inhibition, resulting from a hiper-excitability of the stretch reflex. Spasticity affects more than 12 million persons in the world and it interferes in the natural movements of the patients Decq *et al.* (2005), Calota *et al.* (2008), Le Carvozin *et al.* (2002). Some of the common symptoms are: a change in the recruitment of limb´s segments and a severe mal-functioning of the tendons reflex. The Ashworth Scale (AS) and the Ashworth modified version (MAS) are the common scales in clinical quantifications of spasticity, despite expert agree that both scales may not measure the characteristics that distinguish spasticity from other tonus disorders. Although the scale is useful in determining the amount of resistance felt in the passive displacement of the limbs, it does not quantify the dependence to speed, which is the feature that differentiates spasticity (Levin, 2005). This scale has a low reproductive rate, a lack of validation in all muscle groups, usually affected by spasticity and an inability to differentiate the mechanical stiffness from the reflective stiffness, Le Cavorzin *et al.* (2002).

In spite of knowing that they do not meet the criteria of a standard definition, AS and MAS scales are still used.

Hence, there is still a need for a device that meets these requirements. The correct quantification of spasticity has been under an extensively study by the scientific community, but it still does not exist a well-accepted standard method for spasticity determination and quantification. The literature presents several devices for spasticity quantification, but none of them is fully accepted, duo to various reasons Calota *et al.* (2008), (Levin, 2005), Bernhard *et al.* (1995): the approach of traditional measures are based on the phase and magnitude of the tonic stretch reflex and the resistance to passive stretch. Nevertheless, this measure is not correlated to the clinical impression of the spasticity degree and the implementation of the device is still complex; also, the measurement does not meet the criteria of the known theory Le Carvozin *et al.* (2002), (Levin, 2005), Bernhard *et al.* (1995).

Lance (1980) defined spasticity as: “spasticity is a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes (“muscle tonus”) with exaggerated tendon jerk, resulting in hyper excitability of the stretch reflexes, as one of the component of the upper motor neuron syndrome”. This definition is still accepted nowadays; it includes some important aspects: it refers spasticity as a symptom, as a disorder in the somatic motility, related to the high tonic component of the stretch reflex; it is due to the spinal reflex; it is one of the symptoms of the upper motoneuron syndrome; the tonic stretch is associated to the exaggerated tendon jerks, and reflects the physical component of the stretch reflex; the reflex of the tone stretch is the basis of the tonus; it is referred that the excess of the reflex depends on the stretch velocity Decq *et al.* (2005). This last statement is the key issue for spasticity quantification Calota *et al.* (2008).

This paper presents the preliminary study on the design of a mechatronic device for quantification of all levels of spasticity, in joint of ankle, elbow or knees. This approach is based on the velocity dependent increase in the tonic stretch reflexes, according to the criteria of spasticity definition proposed by Lance, to establish the relationship, for clinical evaluation, between all levels of spasticity.

The article is divided in five sections: section one introduces the spasticity concept; section two presents an overview on the existing methods for spasticity quantification; section three shows the device proposed approach and section four details its specification. Finally, section five resumes the conclusions.

2. OVERVIEW ON SPASTICITY QUANTIFICATION METHODS

The key issue is to determine which variables are necessary to correctly quantify this disorder. A correct measure to quantify spasticity must follow the physiological mechanisms related to the stand-up position control and the movement in healthy individuals and/or must detect possible deficiencies in any of these mechanisms that lead to motor disorders. For the acceptance of the method, their approach must be in accordance with a standard spasticity definition. In order to quantify spasticity, in literature, a vast number of variable measurements have been presented Bernhard *et al.* (1995), (Levin, 2005). Some of the existing methods are described in the following sections.

2.1. Isokinetic device with torque generator

This method consists of applying a torque motor to promote passive stretch of limbs, ensuring a constant velocity stretch. Increasing the tonic stretch reflex, it increases the resistance to stretch, promoted by the torque motor. This method determines the force exerted to move members in a given angle, affected by the resistance induced by the increased stretch reflex (torque), the angle where an increased electromyography (EMG) activity (threshold). The EMG signal also allows for assessment the muscular tone. This method allows quantifying the changes in phase and activity of the tonic stretch reflex of muscles affected by spasticity Calota *et al.* (2008), Bernhard *et al.* (1995) (Figure 1).

Figure 1. Isokinetic device with torque generator Calota *et al.* (2008).

2.2. Pendulum Test

The pendulum test is a technique well documented in the literature. In this method, patients are installed in the supine position and the passive stretch is promoted by the free fall of the legs and registered with an electrogoneometer placed in correspondence to the knee joint. The activity of the muscles, agonists and antagonists, is recorded by surface electromyography. The data is automatically processed in order to estimate the rate of relaxation.

This method is based on the quantification of resistance of muscles to passive stretch. Although considered a reliable method, it has some limitations as: resistance to stretch may be due to factors other than spasticity, such as the changes in properties of muscle tissue due to lack of use. Also, a limitation of this method is that it can only be used to evaluate the muscles of the knee joint Bernhaed *et al.* (1995), Le Cavorzin *et al.* (2002) (Figure 2).

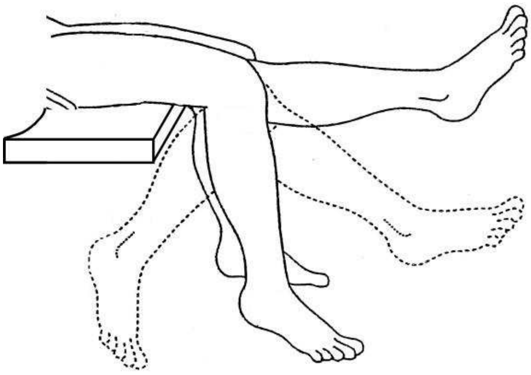

Figure 2. Pendulum Test (Le Cavorzin *et al.* (2002))

2.3. Device based on the excitability of motoneurones

The research performed with animals and patients after stroke, suggests that the measurement of stretch reflex threshold meets the criteria of the definition of spasticity, proposed by Lance (1980), and it is more suitable than the processes described above for the spasticity quantification.

The stretch reflex threshold depends on the speed of stretch. Promoting a passive stretch at different speeds, it allows determining the Dynamic Stretch Reflex Threshold (DSRT), defined as the joint angle and the velocity value corresponding to the time when the electromyography signal increases above the line average at rest.

The tonic stretch reflex threshold (TSRT) represents a specific value of DSRT to stretch a speed equal to zero (at rest). In this approach, the DSRT and the TSRT are expressed in velocity and angular coordinates values, i.e., the speed and joint angle in which the muscle activity starts.

Representing DSRT points in a coordinate system in two dimensions, angular velocity versus angle, it is possible to determine TSRT value by extrapolating the regression line through the points of DSRT when velocity value is zero, which corresponds to the coordinate angle at rest (TSRT). Previous studies suggest that when spasticity is present, TSRT curve lies within the range of biomechanics’ joint and when spasticity is not present, TSRT lies outside this range Calota *et al.* (2008).

3. PROPOSED APPROACH

The objective of this work is to develop a device for the quantification of all levels of spasticity, which can be accepted by scientific community. For this propose this device is based on the velocity dependent increase in the tonic stretch reflexes, according to the criteria of the standard definition of spasticity, as previously described. It aims to develop an universal device, that allows the evaluation for the joint of ankle, knees or elbow.

In this approach, it is determined the angle of biomechanics range and the angular velocity when occurs an increase in electromyography activity, for further data processing, by a program developed especially for this propose. Most of the daily life activity, requires joint angles of 45º for ankle, 140º to full flexion to the knee (Febiger, 1980) and 120º for elbow Ennnis *et al.* (2008). These ranges should be considered to ensure the assessment of movement in the whole biomechanical range, recruited in daily life. Andrea Calota *et al.* (2008), in their study of patients with stroke, detected an increase of activity of the EMG signal in Biceps Brachia, due to stretching the elbow joint, at angular velocities of 51º/s, 161º/s and 430º/s; this demonstrates the dependence of velocity of stretch reflex, in muscle affected by spasticity. The measure describe above will be obtained using sensors that ensure the described requirements. The sensors used in this approach were then selected in order to consider the range mentioned.

For spasticity quantification, there are three measuring methods of interest: electromyography, the angle at the limb’s moment and the velocity of movement. In the following sections, the method for the experimental determination of each variable is detailed.

Table 1 resumes the parameters and the measuring ranges for the proposed equipment.

Table 1. Variable measuring range in the proposed approach.

Parameters	**Measuring range**
angle	180º
electromyography	20-500 Hz
force	100 Kgf
angular velocity	500º/s

4. PROPOSED DEVICE

This section presents the proposed device for spasticity determination. It details the overall system proposed, the sensors and actuators to be used as well as the user interface to be developed.

4.1. Overall system

When designing a new laboratory or industrial prototype, a preliminary study on the relevant variables to be measured and the corresponding devices commercially available must be performed. The measurement data collected from the physical world must be further analyzed and mathematically processed.

The proposed system, shown in Fig 1, includes the following sub-systems:

- Sensors/transducers;
- Signal conditioning (amplifiers, filters, converters, ...);
- Interface between the signal from the conditioning system and the computer;
- Computer;
- Software for data processing and user interface.

4.2. Electromyography

Electromyography records the electrical activity of muscle, and it is a powerful tool in the analysis of human muscular system. When the muscles are active they produce an electric current generally proportional to muscle activity. EMG studies the muscle function through the interpretation of bioelectric signal produced by the muscle (Delsys, 2003).

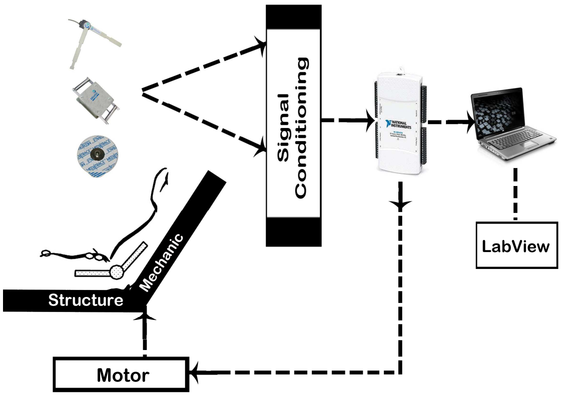

Figure 3. Diagram of shear modulus versus frequency at 303 K

To measure the EMG signal, surface or needle electrodes are used, depending on the muscle type, superficial or deep. Passive surface electrodes have no amplification in the electrode; active surface electrodes have a signal preamplification system before being sent to the conditioner, which enable a noise reduction.

In this approach, passive surface Ag/AgCL electrodes are used which do not cause pain to the patient. The SENIAM Hermens *et al.* (2000), recommends the use of electrodes Ag/AgCl, together with a conductive gel to reduce signal noise by ensuring a better contact between the electrode and the skin. The signal muscle when measured using surface electrodes has amplitude to 5mV. The frequency range of the EMG signal for the correct analysis is limited between 20Hz and 500Hz, since frequencies below 20Hz tend to fluctuate and to be unstable (Delsys, 2003).

The electrodes have a bipolar configuration, enabling a high rate of common mode rejection, and easily eliminating/reducing signal noise. They should be placed in a 20 mm distance from each other. A surface cleaning gel should also be used in order to reduce the impedance skin/electrode.

4.3. Goniometric

The angle that the member is, at any given time, is an important information in the study of spasticity, to determine the point where there is greater intensity of spasticity.

Goniometry is an evaluation technique widely used in physiotherapy. The movement of a joint is the result of movement of a joint surface in relation to the other. Goniometry is able to measure the range of motion with the use of a goneometer.

The goneometer should have one axis free at least 180º; it can be 1D or 2D (Table 2).

The 2D version for the DELSYS is the option chosen due to allowing the angle required, and the fixing system is more efficient.

Table 2. Comparison of two Goneometer models

Specification	**goneometer 1D GN360 MIOTEC**	**goneometer 2D DELSYS**
Free axis	360º	180º
Precision	0.5º	0.5º
Fixing method	Neoprene	Adhesive

4.4. Angular velocity

The angular velocity, at which the limb moves, directly influences the study of spasticity. Thus, for the equipment in question, it is an extremely important variable. It can be determined by using a specific transducer, gyroscope, or it can be determined by using the goneometer and a time basis Calota *et al.* (2008).

In this approach, it is considered the angular rate sensor ARS-15 MHD, for the ATASENSERS, with a resolution of 570º/s.

4.5. Actuator

In order to allow the limb movement at constant speed, a motor will be coupled to the structure. It allows, thus, the study of spasticity at a constant speed, imposed by the engine (Figure 4).

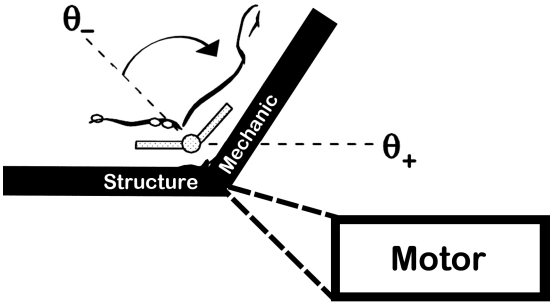

Figure 4. Motor for constant velocity limb movement.

4.6. Signal conditioning

Figure 5 shows the schematic for the signal conditioning system.

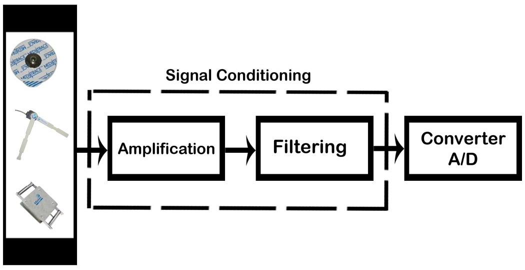

Figure 5. Conditioning system.

For the correct acquisition of the EMG signal, there is a need to use a bandpass filter [10, 500 Hz] (Delsys, 2003).

The amplification is the most important task and it is responsible for providing the best signal quality. The instrumentation amplifier must have a number of features namely:

- High common mode rejection (CMRR);
- High input impedance;
- Low noise;
- Gain selectable;
- Frequency operation [20, 500 Hz].

The amplifier of Analog Devices AD620 (AD620, 2004), or another of the same family, will be appropriate:

- CMRR (> 90dB)
- Input Impedance (10 MOhm)
- Low noise (<5 microvolts RMS)
- Gain selectable (350 to 3000)
- Frequency [10, 490 Hz]

4.7. Data acquisition system

Table 3 summarizes the type and the range of the data acquisition input signals regarding the selected variables for the spasticity device.

Table 3. Data input signal

	EMG	**Force**	**Angle**	**Velocity**
Frequency	10-500 Hz	-	-	20Hz-2kHz
Signal	Analog.	Analog.	Analog.	Analog.

The sampling rate of the signal, according to Nyquist's theorem (Delsys, 2003), must be at least twice the higher signal frequency. Thus, the sampling rate of the proposed spasticity device must be at least 4 kHz. Due to its specifications (sampling rate 250 KHz, analogue inputs/outputs), high-quality ratio functionality/price and possibility to expand, the NI USB-6211 board from National Instruments was chosen (National Instruments, 2010). It has also USB interface that gives portability to the system, a requisite of the device.

The user interface to be developed includes system monitoring, data acquisition, processing and saving on a database for further analysis as well as the actuation on the force element.

LabView Software, Laboratory Virtual Instrument Engineering Workbench, from National Instrument enables the development of graphical interfaces and the development of Virtual Instruments (VI's) specific to each application. This software is user-friendly and suitable for this kind of applications and will allow, very easily, improving or changing the application developed for this controller, and for other kind of applications, if necessary.

5. OBTAINED ASSISTED SYSTEM

As it is an ongoing work, the assisted system is, currently, being tested, successfully, in clinical environment and the first results showed that the system is reliable and well adapted to Spasticity quantification.

The Instrumentation Setup is presented in Figure 6. It is composed by all the described components, above, and also by a laptop in order to store, and treat, all acquired information.

Figure 6. Instrumentation Setup.

After receiving all necessary information, and needed time to reflect on their participation in the study, it was obtained the informed consent of each patient.

Each patient was evaluated in three evaluation sessions, separated from two to five days, between consecutive sessions. It was defined the initial position of the elbow joint, in each evaluation, the position corresponding to the maximum allowable bending the arm and forearm, with no contact between segments. The goneometer was attached to the patient member to be assessed, with its axis of rotation aligned with the axis of rotation of the elbow joint. A goneometer arm was aligned with the patient's forearm while the other goneometer arm was aligned with the patient's arm. Then, the surface EMG electrodes were placed in correspondence with the motor point of the muscle. The figure 2 illustrates the instrumentation setup, in the left elbow.

After being checked all initial conditions, it was started the process of recording the EMG signals and angular displacements, by starting stretching the muscles. The forearm was extended, by the evaluator, at different velocities, from its initial position to the maximum extent allowed in each patient. At each evaluation, were promoted about ten stretches at “low velocity”, about ten stretches at “moderate velocity” and about ten stretches at “high velocity”. Concerning the velocities it was considered: “low velocity” with velocity comprised between 2º/second and 150º/second; “moderate velocity” with velocity comprised between 151º/second and 300º/second; and “high velocity” with velocity higher than 300º/second.

The time instant at which a SR occured was defined as corresponding to the time instant in which it is verified a sustained increase of the EMG activity, two standard deviations (SDs) above the average of the signal that is observed without movement of the patient’s arm. This systematic analysis allowed determining, accurately, the corresponding values of angle and angular velocity. The DSRT was defined considering both: the angle of the joint and the value of the angular velocity. For each evaluation, DSRT were presented in a graph in two dimensions, considering: angular velocity (vertical axis) versus joint angle (horizontal axis). Tonic stretch Reflex Threshold (TSRT) was estimated by calculating a linear regression through the DSRT.

Figure 7 illustrates an example of TSRT estimation, considering a studied patient. It can be observed the distribution of 28 DSRTs presented as small circles that allowed the calculation of the regression line, following the methodology presented before.

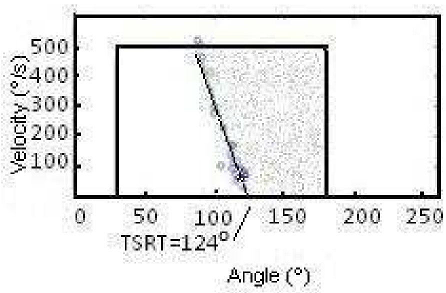

Figure 7. Regression line calculation trough DSRTs, in order to obtain TSRT value.

It can be stated that the regression line intersects the axis corresponding at the angular displacement at the value 124º, clearly inside of the range of movements of the joint.

The detailed presentation and discussion of results is presented in other publication of the same team that deals with this project, Ferreira *et al.* (2011).

6. CONCLUSIONS

This paper presents the study and design of a controller for spasticity quantification, to be used in joint of ankle, elbow and knees. This approach is based on Lance´s work that states the velocity dependence increase in the tonic stretch reflexes.

The components of this assisted systm were chosen taking into account the system variables and the corresponding measurement range. In particular, the electromyography signal has a measuring range of 20-500 Hz; the angle, 180º; the force is 100 kgf; and the angular velocity, 500º/s.

The data acquisition system, board and software, selected are from National Instrument due to its functionalities. The USB interface of the board enables system portability, an important requirement of the proposed device.

The first results obtained and discussed, in detail at Ferreira *et al.* (2011), allow us concluding that the developed assisted system is reliable and well adapted to Spasticity quantification.

7. ACKNOWLEDGEMENTS

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