An Approach for Spasticity Quantification Based on the Stretch Reflex Threshold

João Ferreira; Paulo Rodrigues; Filomena Soares, *IEEE member*
Industrial Electronics Dept., ALGORITMI Research Centre
University of Minho
Guimarães, Portugal
fsoares@dei.uminho.pt

José Machado, *IEEE member*
Mechanical Engineering Dept., CT2M Research Centre
University of Minho
Guimarães, Portugal
jmachado@dem.uminho.pt

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 in the literature but there is still a need for measurement improvements. This paper presents the design of a mechatronic device for spasticity quantification, in joint of ankle, elbow and knees. This approach is based on the velocity dependent of the tonic stretch reflexes. The relevant variables, the measurement range and the adequate measurement systems are selected. The data acquisition system, board and software, are also defined. The designed system for quantifying spasticity was tested and validated in laboratory environment. Next step consists of system validation in clinical environment.**

Keywords: Spasticity Quantification, Electromyography, Mechatronic Device.

I. INTRODUCTION

Spasticity is a complex motor disorder due to a supra-spinal inhibition, resulting from a hyper-excitability of the stretch reflex (SR) [1]. Spasticity affects more than 12 million persons in the world [2], and is always seen in patient with upper motor neuron dysfunctions such as cerebral vascular accidents, spinal cord injuries, and multiple sclerosis. The mechanism of spasticity is commonly thought of as an exaggerated SR, which is a velocity-dependent increase in the resistance to the passive movement [3]. The SR Threshold is significantly reduced in spastic muscles, and this reduction is correlated to the increase in reflex joint torque [4]. Spasticity in conjugation with excessive muscle tone frequently interferes in the voluntary motor function, causing difficulties in daily activities [3]. 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 correct quantification of spasticity has been under an extensive study by the scientific community, but there is not yet available a well-accepted standard method for spasticity determination and quantification. The literature presents several methods for spasticity quantification: The Ashworth Scale (AS) and the Ashworth modified version (MAS); Isokinetic device with generator torque; Pendulum Test. None of them is fully accepted, duo to various reasons [2], [5], [6]. The AS and the MAS are the common scales in clinical quantifications of spasticity, despite experts 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 velocity, which is the feature that differentiates spasticity [5]. This scale has a low reproductive rate, a lack of validation in all muscle groups, usually affected by spasticity [1]. The approach of traditional measures is based on the phase and magnitude of the tonic SR and the resistance to passive stretch. Nevertheless, this measure is not correlated to the clinical impression of the spasticity degree, inability to differentiate the mechanical stiffness from the reflective stiffness and the implementation of the device is still complex; also, the measurement does not meet the criteria of the known theory. Hence, there is still a need for a device that meets these requirements [1], [5], [6].

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 [5], [6]. The work presented in [7] defined spasticity as: “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 SR; 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 SR; 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 [8]. This last statement is the key issue for spasticity quantification [2].

This paper presents the 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 SR, according to the criteria of spasticity definition proposed by Lance [7], to establish the relationship, for clinical evaluation, between all levels of spasticity.

The article is divided in four sections: section one introduces the spasticity concept and the problem formulation; section two presents the proposed approach used for spasticity quantification; section three discusses the obtained results and explains related ongoing works and, finally, section four resumes the conclusions.

II. PROPOSED APPROACH

The SR is an involuntary contraction elicited by a brief stimulus to muscle receptors. If the arm and muscle are immobilized the result will be a measurable change in the tension of the tendon [4].

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. It aims to develop a universal device that allows the evaluation for the joint of ankle, knees or elbow. On this approach the method is focused on the velocity dependent increasing in the Tonic SR, according to the criteria of standard definition of Spasticity, proposed by Lance [7]. This definition suggested that the Stretch Reflex Threshold (SRT) depends on the velocity of stretch.

It is determined the angle of biomechanics range and the angular velocity when an increase in electromyography activity occurs, 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 [9] and 120º for elbow [10]. These ranges should be considered to ensure the assessment of movement in the whole biomechanical range, recruited in daily life. The study proposed in [2], where are studied patients with stroke, there is detected an increase of activity of the EMG (electromyography) 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 SR, in muscle affected by spasticity.

To determine the SR Threshold we propose three measurements: EMG signal activity in the muscle; angular velocity of passive muscle stretch and the joint angle position. 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
angular velocity	500º/s

A. *Experimental setup*

The experimental set-up protocol (Figure 1) consists of the following steps.

The patient sits on a chair and the electromyography sensors are fixed on a motor point of a biceps brachial and the EMG signal at rest (tone) is recorded. To record the biomechanical angle, biomechanical range and compute the angular velocity a goneometer is fixed to the arm of the individual. The axis of rotation of the goneometer is placed in correspondence to the elbow joint. The arm of goneometer is aligned and fixed to the arm and forearm of the patients. The patient is placed in the ideal joint position. The initial angle position and biomechanical range of joint are recorded and constantly monitored, to ensure maximum repeatability and maximal Reflex response of the Biceps Brachial. In each stretch the initial angle joint is checked and only starts a new stretch if this condition is confirmed. The beginning of each stretch only occurs if the EMG signal, in the initial position, corresponds to the signal captured at rest, (the muscle tone).

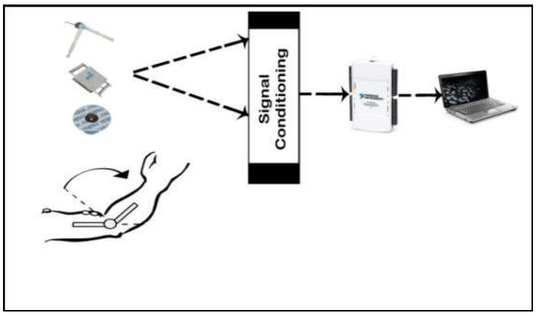

Fig. 1: Proposed system for spasticity quantification.

B. *Experimental procedure*

In order to determining the dynamic SRT (DSRT), the muscle is stretched manually at different velocities. DSRT is defined as the joint angle and the corresponding velocity value, when the EMG signal amplitude also increases with the velocity, above the threshold corresponding with the EMG signal amplitude at rest. The Tonic SRT (TSRT) represents a specific value of DSRT when velocity equals to zero (at rest). In this approach, the DSRT and the TSRT are expressed in velocity and angular coordinates values. The SRT can be expressed as a specific point in the range of joint angle. Thus the SRT can be related to the body frame of reference.

In Figure 2 the DSRT is plotted on a coordinate system, in two dimensions, angular velocity versus angle. Regression analyses can be used in order to compute TSRT value, by extrapolating the regression line through the points of DSRT.

When the regression line crosses the axes corresponding at velocity value equal to zero, it corresponds to the coordinate angle at rest (TSRT).

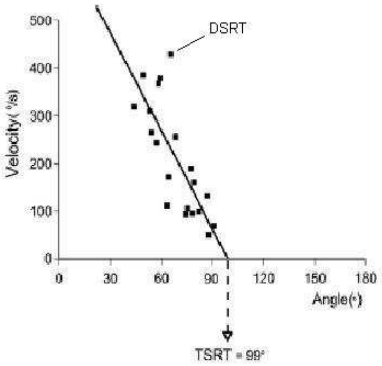

Fig: 2 Diagram Velocity (°/s) versus angle (°). Adapted from [3].

Figure 3 shows the relation between the range of regulation of TSRT and biomechanical range of the joint [1]. The grey areas to right of diagonal lines indicate the areas where spastic muscle is active [2], [11] Previous studies with animals and humans suggest that in healthy individuals the range of regulation λ (Figure 3) beyond biomechanical range of joint (θ-, θ+), where θ- is the start position of the passive stretch and θ+ is the end position of stretch. In sick individuals the range of regulation λ lies within the biomechanical range of joint.

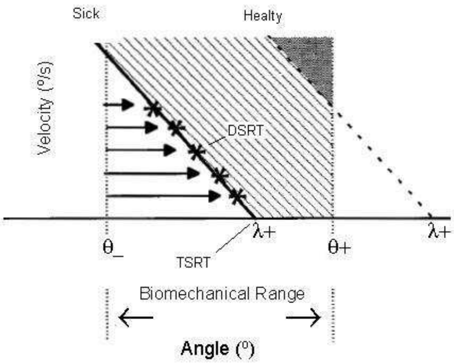

Fig: 3 Relation between range of regulation of STRT and biomechanical range of joint. Adapted from [11].

C. EMG Signal detection

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.

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 and they do not cause pain to the patient. The SENIAM [12] 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.

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.

The raw EMG signal is detected, amplified and sampled with an analog to digital converser (ADC), after filtering with an anti-aliasing filter. The detection algorithm is implemented in software in LabVIEW Software, Laboratory Virtual Instrument Engineering Workbench, from National Instrument so that the user can monitor the procedure and the results. The EMG signal increase detection is calculated by the method proposed in [13].

Precise detection of on-off timing of human skeletal muscle during movement, based on surface electromyography (sEMG), is an important issue in the analysis of the motor system. The results depend on the chaise of threshold. The goal is to perform signal estimation from noise contaminated EMG signal. The common method for resolving motor-related events from EMG signals consists of visual impression by trained observers. The “single-threshold method”, which compares the EMG signal with a fixed threshold, is generally unsatisfactory. Double threshold detection method proposed by [13] is better than single-threshold because it yields higher detection probability and higher sensitivity. Double-detection allows the user to adapt the link between false alarm and detection probability with a higher degree of freedom than the single-threshold [11], [14].

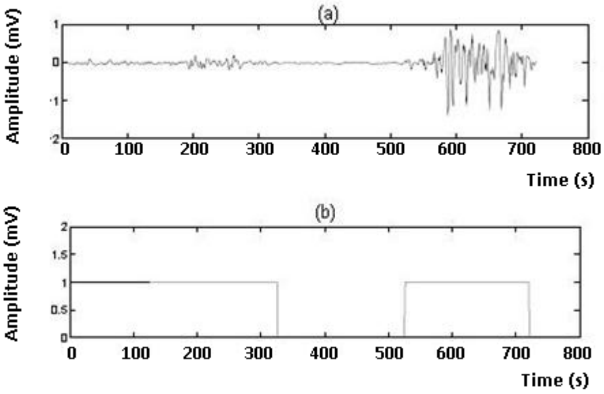

Fig.4. Detection results for Vastus Lateralis muscle group; (a) original raw EMG signal; (b) results of proposed method on-off detection [13]

III. Results and Discussion

A precise data acquisition related to the electrical signals, angular velocity, joint angle and electromyography signal activity in the muscle, can assure that the developed mechatronic device is working as expected and, also, that it allows quantifying spasticity according to the previous presented methods. Figures 5 and 6 show how successful was the data acquisition done with the developed device. Fig. 5 shows the acquisition related with joint angle and angular velocity and Fig. 6 shows the acquisition related to electromyography signal activity in the muscle. The tests were performed simulating a real exam with variable angular velocities, resulting in the EMG signal and angle for every instant of tests.

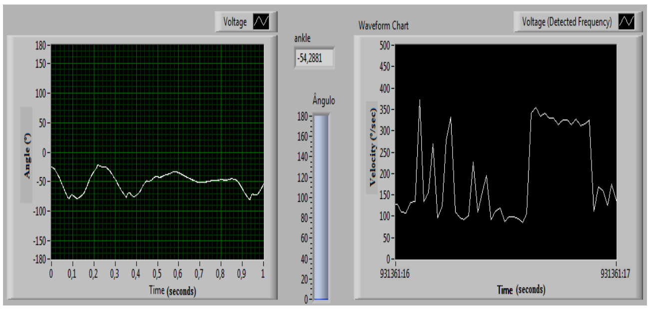

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Fig.5. Angle and velocity graphics

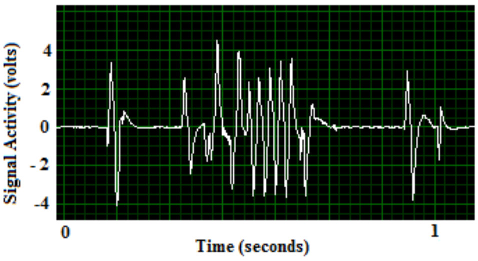

Fig.6. Original raw EMG signal

Concerning the developed system, presented in this paper, we can assure that it is able to solve the problem of spasticity quantification.

The most important tasks for this device are the correct data acquisition related to angular velocity, joint angle and electromyography signal activity in the muscle.

We are, still, developing work in two directions: the first one is related o the double threshold detection following the method proposed by [13]. In this case, we believe that it is a simple task of application of a known and published method. On the second direction of work, it is intended to apply the developed device to measure spasticity in clinic environment. We are waiting, only, formalization of informal consent, in order to start data acquisition in clinical environments.

IV. Conclusions and Future Work

This paper presents the study and design of a device for spasticity quantification, to be used in joint of ankle, elbow and knees. This approach is based on Lance´s work [7] that states the velocity dependence increase in the TSR. To determine the SRT, three measurements were proposed: EMG signal activity in the muscle; angular velocity of passive muscle stretch and the joint angle position.

The sensor devices 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; 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 system prototype was validated in laboratorial environment. Next step consists of the implementation, testing and validation of the proposed mechatronic device in clinical environment, by medical staff. For this task, we are waiting formalization of informal consent with a public Portuguese hospital and a private Portuguese clinic.

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