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Quantitative Analysis of Ankle Spasticity Through Electromyography Signal

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***Abstract*—This study presents a more accurate evaluation method for assessing ankle spasticity compared to conventional goniometric techniques by utilizing measurements obtained from Inertial Measurement Units (IMU) and surface electromyography (sEMG) devices. Integrating IMU and EMG sensors provides substantial benefits for accurately determining the range of motion (ROM) associated with spasticity during targeted movements. In this study, the proposed method provides precise measurement and an objective evaluation of onset time detection of antagonistic muscle co-contraction, and accordingly the ROM of the actuated joint. Moreover, the implementation of cost-effective wearable sensors enables the monitoring of muscle spasticity in clinical environments and can be particularly valuable in regions with limited access to experienced therapists, providing a more efficient approach to tracking spasticity levels.**

Keywords— Ankle rehabilitation, objective assessment, spasticity, motor disorder

I. Introduction

Spasticity is a motor disorder that develops due to damage to the central nervous system (CNS) and is commonly observed in neurological conditions such as cerebral palsy, multiple sclerosis, and stroke (1). This condition, referred to as an upper motor neuron lesion, results in an abnormal increase in muscle tone, velocity-dependent muscle contractions, and involuntary reflex activities. Spasticity can cause significant problems in daily activities, particularly in walking and balance (2). Ankle spasticity is a common example of this motor disorder, significantly restricting patients' mobility, increasing the risk of falls, and slowing down walking speed (3).

The assessment of spasticity is a challenging process in clinical practice. Standard methods largely rely on subjective evaluations, which can affect the reliability and repeatability of the results (4). For example, measurement tools such as the Ashworth and Modified Ashworth Scales define spasticity as a velocity-dependent increase in muscle tone and are widely used by clinicians. However, these methods have significant limitations, such as the inability to distinguish between muscle stiffness and passive resistance (5).

The MAS is a tool used to evaluate muscle tone and spasticity by measuring the resistance encountered during the passive movement of a muscle group (5). Co-contraction, on the other hand, is characterized by the simultaneous activation of antagonist and agonist muscle groups, resulting in the concurrent contraction of muscles during a given movement (6). The relationship between co-contraction and the Modified Ashworth Scale typically emerges in the context of assessing spastic muscle tone. Spasticity tends to be more pronounced in situations where co-contraction is excessive, as the simultaneous and discordant activation of muscles increases resistance to movement (7). Consequently, MAS scores may be higher in such cases, as the clinician perceives the muscles to be stiffer and more resistant to movement.

Today, new technologies are being developed to assess spasticity more objectively and reliably. IMUs and sEMG devices stand out as key instruments within these advanced technologies. IMUs accurately measure body movements and positions, and IMU sensors capture the dynamic characteristics of movements with high levels of spasticity by recording joint angular velocities and accelerations (4,8). sEMG, on the other hand, records muscle activity and provides crucial information in the process of assessing spasticity (4).

The combined use of these technologies allows for the differentiation of the neural and mechanical components of spasticity, enabling a more precise measurement of the spasticity level (4). In a study conducted by Alibiglou et al., the correlation between Ashworth scale results and sEMG parameters was examined, and it was concluded that sEMG provides a more objective and sensitive assessment of spasticity compared to clinical scales (5). Synchronizing EMG with IMU data facilitates a clearer understanding of the relationships between muscle activity and joint movements (10). In a study conducted by McGibbon et al., a group assessed using the Modified Ashworth Scale was compared with another group evaluated using IMU and EMG. The study concluded that IMU and sEMG detected spasticity more precisely and provided more consistent results compared to the MAS (4). The combination of IMU and EMG offers significant advantages not only in clinical assessments but also in monitoring spasticity during rehabilitation processes. In a study conducted by Lopez-Meyer et al., the use of EMG

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and IMU sensors together was investigated for the automatic detection of temporal gait parameters in individuals who had experienced post-ischemic stroke. The results demonstrated that this combination provides high accuracy in the assessment of spasticity and other gait disorders (9). The proper use of IMU and sEMG analyses in clinical practice plays a valuable role in improving the treatment of spasticity. By enhancing the objectivity of spasticity assessment, these technologies allow treatment decisions to be grounded in objective scientific data. Furthermore, their use in rehabilitation processes is beneficial for monitoring treatment effectiveness and adjusting treatment plans as needed (11).

In this study, our goal is to investigate the objective assessment of ankle spasticity through IMU and sEMG and to examine the integration of these methods into clinical practice. In light of the current literature, the effectiveness and reliability of these technologies in spasticity assessment will be discussed, and practical recommendations will be provided for clinicians and researchers.

II. Materials and Methods

Establishing a safe range of motion (ROM) is essential in ankle rehabilitation, as exceeding this range can lead to pain or discomfort due to muscle spasticity. This discomfort is often associated with the co-contraction of antagonistic muscles in the lower leg, which acts as a physiological signal of the body's response to potentially harmful joint angles. By detecting co-contraction events and recording the corresponding foot angle, the safe ROM can be measured, which varies among patients based on their individual spasticity levels. To validate this approach, we developed a device, as shown in Figure 2, that incorporates IMU and EMG sensors designed to collect synchronized data on foot angular position and activation of antagonistic muscles.

A. Device description

The device incorporates an inertial measurement unit (MPU6050) to capture angular position and angular velocity data, along with biosignalsplux EMG sensors to monitor the activity of antagonistic muscles (tibialis anterior and gastrosoleus). The EMG sensor data is transmitted to MATLAB using the Lab Streaming Layer communication protocol at an acquisition frequency of 2000 Hz. Simultaneously, the MPU6050 sensor is connected to an Arduino for raw data pre-processing, with the processed data then transmitted to MATLAB via serial communication at a frequency of 10 Hz. The data is subsequently saved in MATLAB in a time-synchronized format, where every 200 data points from the EMG sensor are matched with one data point from the MPU6050 sensor, as illustrated in Fig. 1.

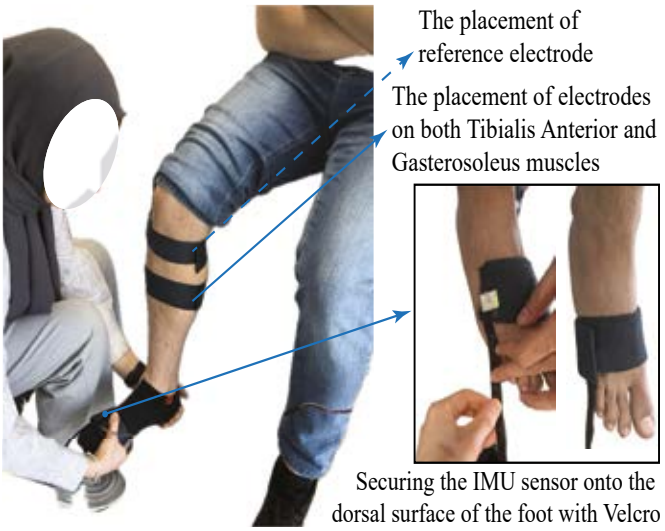

Fig. 2. Detection of RoM as a means of sEMG data from Tibialis Anterior and Gastrosoleus muscles in conjunction with IMU sensor

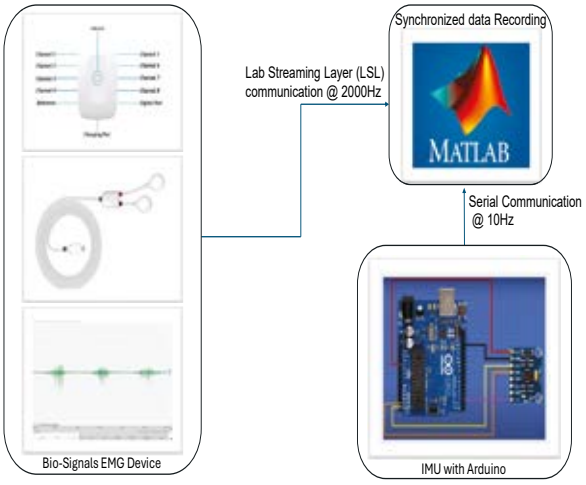

Fig. 1. Synchronized data collection of IMU and EMG sensors in MATLAB

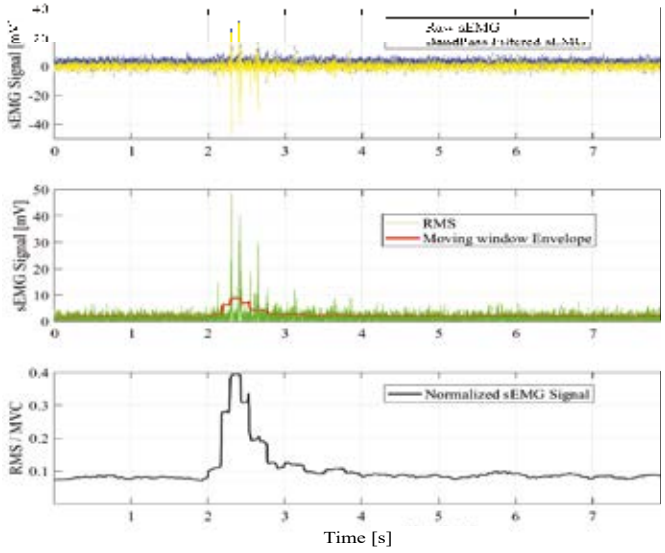

Fig. 3. sEMG signal conditioning of Gastrosoleus muscle (a) Raw sEMG data and filtered data (b) RMS sEMG signal and Envelope data (c) Normalized sEMG signal

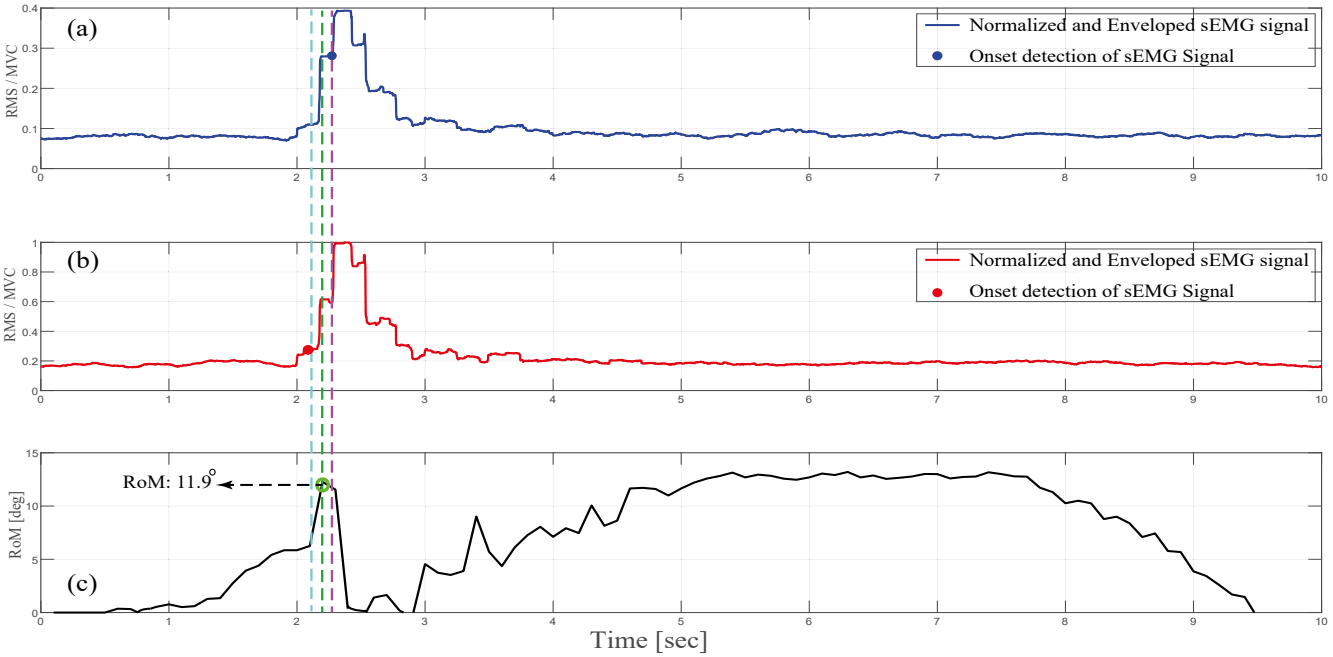

Fig. 4. Detection of ROM of ankle dorsiflexion through IMU sensor and sEMG device (a) Onset detection of Tibialis Muscle contraction (b) Onset detection of Gastrosoleus Muscle contraction (c) Angular position (RoM) of dorsiflexion measured by IMU sensor

B. Experimental Procedure

Prior to the commencement of the experiment, the healthy volunteers in all experimental evaluations presented in this study signed informed consent forms approved by the IRB of Istanbul Medipol University. During the experiment, participants were positioned in a prolonged seated posture with support placed under their knees. The normal range of motion (ROM) for ankle dorsiflexion (DF) and plantarflexion (PF) was measured using a traditional goniometer (Baseline Goniometer). It is important to note that the goniometer employed was not highly precise, as it measured in increments of 5 degrees. The participant's DF value was recorded at 15 degrees, and the PF value at 55 degrees. Subsequently, participants were adjusted to a seated position. IMU and sEMG electrodes were affixed to predetermined reference points. The reference point for the IMU was located at the inferior border of the 5th metatarsal bone, while the reference points for the sEMG were the motor points of the gastrosoleus (GS) and tibialis anterior (TA) muscles. Initially, the physiotherapist measured the passive DF-PF ROM and recorded the sEMG data. Following this, the participant's active DF-PF ROM was assessed, and corresponding sEMG recordings were obtained. Finally, participants were instructed to perform a sudden co-contraction during active ROM to simulate ankle spasticity. The experimental procedure is illustrated in Fig.2.

C. Data Collection and processing

Simultaneous recordings of IMU signals and EMG signals from the tibialis anterior and gastrosoleus muscles were obtained at frequencies of 10 Hz and 2000 Hz, respectively. The IMU data was smoothed using a three-sample moving average window filter to reduce noise and refine the data. The raw surface EMG signals were subjected to a band-pass filter between 10-450 Hz to remove noise and movement artifacts, allowing for the extraction of meaningful data, as shown in Fig.3-a. The RMS of the filtered sEMG data was then calculated to assess the signal's power, and a 500-sample moving average envelope detector was applied to create a continuous representation of the signal, as illustrated in Fig.3-b. This envelope data was further normalized by dividing it by the maximum sEMG signal recorded during the activity, resulting in a smooth and continuous normalized sEMG signal, as depicted in Fig.3-c. Finally, a threshold-based onset detection algorithm was implemented to accurately detect muscle activation.

III. Results

Figures 4-a and 4-b display the enveloped and filtered EMG data for the tibialis anterior and gastrosoleus muscles, with the onset events identified by small circles (detected using a threshold-based onset detection algorithm). Figure 4-c shows the corresponding angular position data recorded from the IMU sensor. The data reveals that co-contraction of these antagonistic muscles occurs after 2 seconds. The light green and magenta lines in Figure 4 indicate the activation onset of the tibialis anterior and gastrosoleus muscles, respectively. A slight delay of 200 milliseconds is observed between the activation of these two muscles, which can be considered as nearly simultaneous co-contraction. The co-contraction event is represented by a green line, marking the midpoint between the onset times of both muscles. The foot's angular position at this co-contraction event is identified as the safe range of motion (ROM), measured at 11.9 degrees in this test, providing

an essential metric for customizing rehabilitation exercises to prevent pain and ensure patient safety.

IV. Conclusion

This study explores the application of Inertial Measurement Unit (IMU) and Electromyography (EMG) technologies for the objective assessment of ankle spasticity. The advantages of IMU and EMG in spasticity evaluation stem from their ability to provide more accurate and consistent measurements of spasticity-related parameters. IMU sensors offer precise tracking of angular movement and velocity in body segments, making them ideal for objectively assessing movement limitations and range of motion (ROM) associated with spasticity. EMG, on the other hand, records muscle activity in real-time, serving as a crucial tool for quantifying the levels of involuntary muscle contractions.

Portable IMU sensors have enabled the precise measurement of joint and muscle movements. Compared to camera-based motion capture systems, these sensors are more practical and user-friendly. When combined with EMG, they allow for the detailed analysis of muscle activation and movement during rehabilitation exercises. For example, a study demonstrated that IMU and EMG sensors reliably measure spasticity and can be effectively integrated into daily clinical practice (11,12). In a systematic review conducted by Guo et al., the broad applications of technologies such as IMU and EMG for measuring muscle tone and spasticity are emphasized. These technologies are often integrated with other sensors to capture the dynamics of muscle contractions and joint stiffness. EMG plays a crucial role in recording involuntary muscle contractions, thereby offering a more comprehensive understanding of spastic responses. This combination of technologies allows for more precise assessment and monitoring of spasticity, enhancing both clinical diagnostics and treatment outcomes (13). In another study, the use of IMU sensors in children with cerebral palsy was examined. This structured system measures joint angles and velocity during movement, providing valuable insights into the spasticity levels of lower extremity joints, such as the knee and ankle. The integration of these sensors enables a more detailed and objective evaluation of motor function, particularly in assessing spasticity in the affected joints, which can lead to improved clinical decision-making and treatment strategies for cerebral palsy patients (14). Our findings suggest that IMU and EMG technologies hold significant potential in the assessment of spasticity. However, further research is necessary to test the effectiveness and reliability of these technologies in larger patient populations and across various levels of spasticity. Additionally, studies should be conducted to evaluate the impact of these technologies on other neurological disorders. Such research could pave the way for the broader and more effective use of IMU and EMG in clinical practice. In conclusion, these technologies have the potential to make spasticity treatment more scientific and personalized, thereby improving the quality of life for patients. Future randomized controlled trials and advancements in technology should contribute to further progress in this field.

V. References

1. A. W. Dromerick, "Clinical features of spasticity and principles of treatment," *in Clinical Evaluation and Management of Spasticity*, D. A. Gelber and D. R. Jeffry, Eds. Totowa, NJ: Humana Press, 2002, pp. 13–26.

2. G. Sheean, "The pathophysiology of spasticity," *Eur. J. Neurol.*, vol. 9, no. 1, pp. 3-9, 2002, discussion 53–61.

3. L. R. Logan, "Rehabilitation techniques to maximize spasticity management," *Top. Stroke Rehabil.*, vol. 18, no. 3, pp. 203–211, 2011.

4. C. A. McGibbon, A. Sexton, M. Jones, and C. O'Connell, "Elbow spasticity during passive stretch-reflex: clinical evaluation using a wearable sensor system," *J. Neuroeng. Rehabil.*, vol. 10, no. 1, p. 61, Jun. 2013.

5. L. Alibiglou, W. Z. Rymer, R. L. Harvey, and M. M. Mirbagheri, "The relation between Ashworth scores and neuromechanical measurements of spasticity following stroke," *J. Neuroeng. Rehabil.*, vol. 5, p. 18, Jul. 2008.

6. Y. Iwamoto, M. Takahashi, and K. Shinkoda, "Differences of muscle co-contraction of the ankle joint between young and elderly adults during dynamic postural control at different speeds," *J. Physiol. Anthropol.*, vol. 36, no. 1, p. 32, Aug. 2017.

7. M. Vinti, F. Costantino, N. Bayle, D. M. Simpson, D. J. Weisz, and J. M. Gracies, "Spastic cocontraction in hemiparesis: effects of botulinum toxin," *Muscle Nerve*, vol. 46, no. 6, pp. 926-31, Dec. 2012.

8. R. Caldas, M. Mundt, W. Potthast, F. B. de Lima Neto, and B. Markert, "A systematic review of gait analysis methods based on inertial sensors and adaptive algorithms," *Gait Posture*, vol. 57, pp. 204-210, 2017.

9. P. Lopez-Meyer, G. D. Fulk, and E. S. Sazonov, "Automatic detection of temporal gait parameters in poststroke individuals," *IEEE Trans. Inf. Technol. Biomed.*, vol. 15, no. 4, pp. 594-601, 2011.

10. M. Banky, G. Williams, R. Davey, and O. Tirosh, "Inertia sensors for measuring spasticity of the ankle plantarflexors using the Modified Tardieu Scale-A proof of concept study," *Sensors (Basel)*, vol. 22, no. 14, p. 5151, Jul. 2022.

11. Y. Cha and A. Arami, "Quantitative modeling of spasticity for clinical assessment, treatment and rehabilitation," *Sensors (Basel)*, vol. 20, no. 18, p. 5046, Sep. 2020.

12. Mokri, C., Bamdad, M., and Abolghasemi, V., "Muscle Force Estimation From Lower Limb EMG Signals Using Novel Optimized Machine Learning Techniques," *Medical & Biological Engineering & Computing*, vol. 60, no. 3, pp. 683-699, Mar. 2022.

13. X. Guo, R. Wallace, Y. Tan, D. Oetomo, M. Klaic, and V. Crocher, "Technology-assisted assessment of spasticity: a systematic review," *J. Neuroeng. Rehabil.*, vol. 19, no. 1, pp. 138, Dec. 2022.

14. S. Choi, Y. B. Shin, S. Y. Kim, and J. Kim, "A novel sensor-based assessment of lower limb spasticity in children with cerebral palsy," *J. Neuroeng. Rehabil.*, vol. 15, no. 1, pp. 45, Jun. 2018.