2021 43rd Annual International Conference of the
IEEE Engineering in Medicine & Biology Society (EMBC)
Oct 31 - Nov 4, 2021. Virtual Conference

Electromyography and Inertial Motion Sensors Based Wearable Data Acquisition System for Stroke Patients: A Pilot Study

Muhammad Ahmed Khan[1], Bayram Metin Bayram[2], Rig Das[1], *IEEE Member*, and Sadasivan Puthusserypady[3], *IEEE Senior Member*

Abstract— **Development of wearable data acquisition systems with applications to human-machine interaction (HMI) is of great interest to assist stroke patients or people with motor disabilities. This paper proposes a hybrid wireless data acquisition system, which combines surface electromyography (sEMG) and inertial measurement unit (IMU) sensors. It is designed to interface wrist extension with external devices, which allows the user to operate devices with hand orientations. A pilot study of the system performed on four healthy subjects has successfully produced two different control signals corresponding to wrist extensions. Preliminary results show a high correlation (0.42-0.75) between sEMG and IMU signals, thus proving the feasibility of such a system. Results also show that the developed system is robust as well as less susceptible to external interferences. The generated control signals can be used to perform real-time control of different devices in daily-life activities, such as turning ON/OFF of lights in a smart home, controlling an electric wheelchair, and other assistive devices. Such a system will help decrease the dependency of disabled people on their caretakers and empower them to perform their daily-life activities independently.**

I. Introduction

Stroke is one of the leading causes of chronic disability for people and has devastating socioeconomic impacts. Recent studies show that there are about 25.7 million stroke survivors worldwide, and individuals recovering from stroke often experience helplessness and social isolation, which is linked to their decreased ability to manage their daily activities and subsequently, increased depression [1]. Thus, stroke survivors mainly depend on others in their daily routines, making it necessary to design a compact, portable and easy-to-use system that can assist them to lead an independent life.

Approximately 65% of stroke patients suffer from hemiparesis, i.e., paralysis or muscular weakness on either side of their body [2]. Thus, the idea is to analyze their healthy hand movements and decode them to operate targeted devices (like smart home appliances, assistive devices, etc.). For such real-time human-machine interaction (HMI) applications, surface electromyography (sEMG) is widely being used. It is an electric signal produced from muscle movements that can be acquired by placing EMG electrodes on the skin surface [3]. Vasylkiv et al. [4] has used sEMG sensors that identified different hand gestures to control smart home lights. Similarly, in [5-7], sEMG signals are used to control rehabilitative devices. Besides, Yid et al. [8] and Song et al. [9] developed a system to maneuver an electric wheelchair prototype. This system uses the electric potential generated by finger movements [8] and squeezed fist [9]. However, there are several limitations of sEMG based systems, which need to be taken into consideration for future improvement. These systems are sensitive to electrode positioning and prone to sweat conditions and changes in skin impedance [10-11]. To acquire good quality sEMG signals, high-tension movements are required to achieve muscular contraction, causing the muscles fatigue and, thus, deteriorating the performance of the system [4]. Furthermore, there are also challenges related to sEMG signal processing that includes algorithm robustness, adjustment of signal variability, and artifact removal [12].

The aforementioned shortcomings can be overcome by developing a hybrid data acquisition system by combining sEMG and inertial measurement unit (IMU) motion sensors. IMU is a motion-tracking sensor that contains a gyroscope and accelerometer and can determine accurate hand movements. Previous research [13-15] has shown that the combination of sEMG and IMU sensors increases hand movements detection and hand gestures recognition accuracy. Zhang et al. [13] used five sEMG sensors and a 3-axis accelerometer to classify 72 Chinese sign language words. Georgi et al. [14] used 16 sEMG and an IMU sensor to identify 12 different hand gestures. Wolf et al. [15] developed a BioSleeve that contains eight sEMG and an IMU sensor, which is able to classify nine dynamic and 17 static gestures. These studies have shown the promising results; however, none of them is a wireless system and does not generate the control signals for HMI applications.

In this work, a pilot study is presented for developing a wearable and wireless data acquisition system for stroke patients. The system contains two sEMG (located on the forearm) and an IMU sensor (located near the wrist) and is easy to use on a daily basis. The system is able to detect different wrist extension angles and muscle potential generated by extensor carpi radialis muscles (primary muscle to perform wrist extension [16]). Based on the recorded data, it sets different threshold levels for sEMG potential, and on achieving the threshold, it generates the respective control signals to wirelessly operate the peripheral devices. Moreover, the integration of wrist extension and EMG signals increases the accuracy for generation of desired control signals.

Funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 713683 (COFUNDfellowsDTU)

[1]M. A. Khan (mahkh@dtu.dk) and R. Das (rigdas@dtu.dk) are Post-Doctoral Researchers at Health Tech. Department of Technical University of Denmark, 2800, Lyngby, Denmark

[2]B. M. Bayram is a Master's Student at Health Tech. Department of Technical University of Denmark, 2800, Lyngby, Denmark

[3]Sadasivan Puthusserypady (sapu@dtu.dk) is an Associate Professor at Health Tech. Department of Technical University of Denmark, 2800, Lyngby, Denmark

II. Materials And Methods

A. Hardware Development

A hybrid data acquisition system is developed that is capable of analyzing wrist extension and correlate it with the muscle activity produced by that movement. Based on the recorded parameters, the system can produce command signals to control the assistive/rehabilitation devices. During the system development, the following design requirements and specifications are considered:

- Should be compact, wearable, and portable,
- Should be wireless: The system should transmit recorded data using Bluetooth communication,
- Should be functional offline: The system has to be developed with consideration on the fact that the user cannot always depend on having access to a nearby computer with an internet connection,
- Able to monitor wrist extension angle via measuring wrist pitch orientation, and
- Able to measure the potential generated by the activity of extensor carpi radialis muscle, which plays a vital role in wrist extension movement [161].

The schematic representation and hardware prototype of the proposed wearable data acquisition system are shown in Fig. 1 and Fig. 2, respectively. The system mainly comprises sEMG sensor V3, IMU motion sensor, Arduino Nano, 5V power supply, DC/DC converter, and Bluetooth data transmission module.

sEMG sensor V3: It contains a rectification unit(converts acquired raw analog sEMG signal into a digital signal), followed by modules for smoothening and amplifying a digitized signal. It also contains electrodes that are positioned on the targeted muscle groups depending on the application.

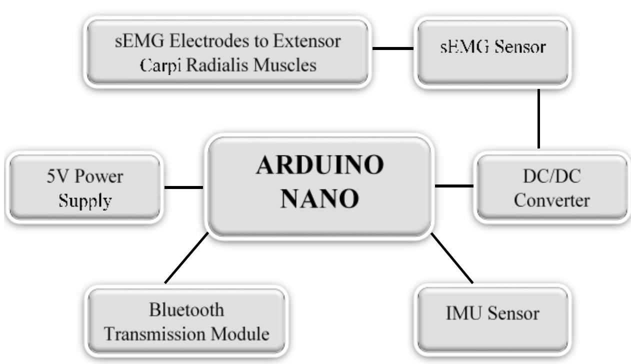

Figure 1. Schematic Representation of Portable Data Acquisition System

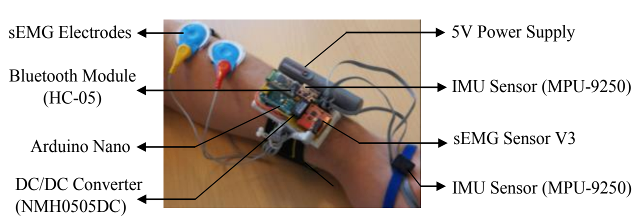

Figure 2. Hardware Prototype for Portable Data Acquisition System

IMU Motion Tracking Sensor (MPU-9250): The MPU-9250 from InvenSense is a 9-axis motion-tracking sensor containing a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer. In medical applications, it can be used to determine different body movements by analyzing roll, yaw, and pitch orientations with respect to a defined reference point.

Arduino Nano: This microcontroller unit is very small in size (18 x 45 mm) and can analyze both analog and digital signals. It is recognized as the 'Brain' of the system, as it controls the communication between interfacing components and capable of performing the computation needed for the execution of required action.

DC/DC Converter (NMH0505DC): These converters are ideally suited for converting DC voltage into dual regulated DC voltage, e.g., converting 5V DC input to ±5V output. Also, they contain galvanic isolation that reduces the circuit noise.

Bluetooth Data Transmission Module (HC-05): This module is designed for establishing wireless communication between master and slave devices. For instance, transmitting and receiving the task-specific commands between the microcontroller (master) and external devices (slaves), such as sensors, robotic orthosis, electronic wheelchair, etc.

In the developed system, Arduino Nano is interfaced with an sEMG sensor, IMU sensors, and Bluetooth transmission unit (Fig. 1). The Arduino is powered up by the 5V power bank, whereas the IMU sensor and Bluetooth module is directly driven by Arduino. sEMG sensor V3 is regulated by Arduino via NMH0505DC DC/DC converter, which converts 5V DC Arduino output to ±5V that is required by the sEMG sensor.

B. System Architecture

The system architecture is shown in Fig. 3, which represents the overall methodology, starting from wrist extension to controlling external devices. Firstly, the electrodes and sensors are positioned to the following allocated locations (Fig. 2): (i) The sEMG electrodes are positioned on extensor carpi radialis muscle to measure the muscle potential, (ii) One IMU sensor is placed on the opposite side of palm that measures the wrist extension angle with respect to forearm, and (iii) One IMU sensor is placed on the top of the device, which acts as reference sensor to measure the extension. After electrodes placement, the device is calibrated for each user. The calibration process is user-specific, and depending on their muscle activities, the two threshold levels (Th1 and Th2) of sEMG potentials are set. Once the calibration is done, the wrist extension action is performed. The pitch orientation of the wrist is detected, and the bipolar sEMG configuration applied on the extensor carpi radialis enables the simultaneous monitoring of the muscle activity. The acquired data from sensors is sent to the Arduino, which determines the correlation between IMU and sEMG signals. If the correlation coefficient is higher than 0.3, then the double-level threshold method is applied on sEMG signal [17]. The threshold method determines the control command (CC) generation based on muscle activation and deactivation state. If the sEMG potential amplitude is greater than Th1 baseline, the Arduino returns CC-1, and if greater than Th2, the Arduino returns CC-2 state. For instance, to control the ON/OFF functioning of smart home light, the Arduino

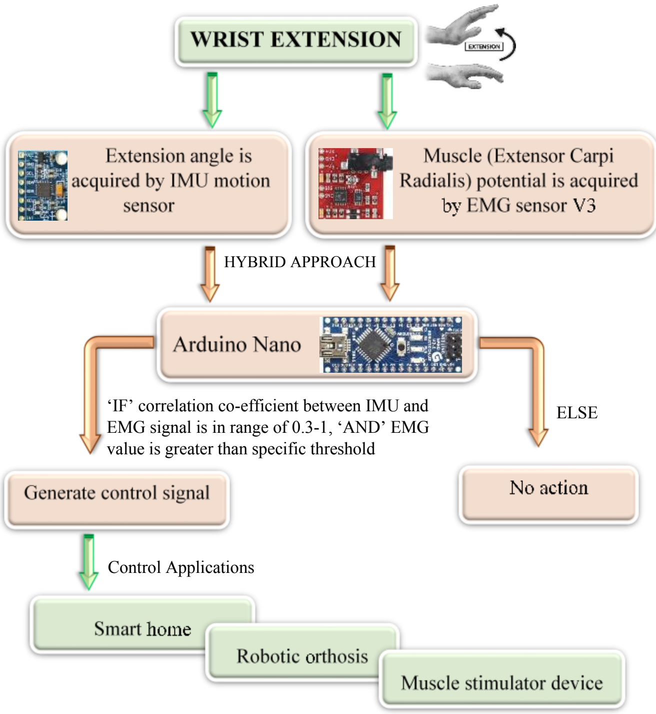

Figure 3. Methodology for Controlling External Devices via Hybrid Approach Based Portable Data Acquisition System

wirelessly sends the control commands based on the level of threshold. It turns ON the light on achieving Th1 and turns it OFF on attaining Th2. Additionally, the relative orientations of the wrist, the muscle activity, and control signal generation information are sent to a computer via Bluetooth, where the received data is recorded and visualized via the Matlab program.

III. EXPERIMENTAL RESULTS

A pilot testing of the developed system is performed on four healthy subjects (S1-S4), while wearing the device in the same configuration and with the arm placed on a table (Fig. 2). Initially, each user is asked to execute 15 lower angle extension and 15 higher angle extension movements for device calibration. Fig. 4 shows the boxplot representation of the wrist's pitch angle (IMU sensor output) and the extensor carpi radialis potential (sEMG sensor output) during the successive wrist extension cycles. Each boxplot contains four quadrants (Q1-Q4), in which Q1 and Q2 represent low angular pitch extensions and their corresponding muscle potentials, whereas, Q3 and Q4 represent high angular pitch extensions and their respective potentials. During calibration, the average muscle potential against low and high angle extensions are used to compute the sEMG Th1 and Th2, respectively (Fig. 4). Additionally, a strong correlation between the sEMG and IMU data, as indicated by the calculated correlation coefficients of 0.42-0.75 (Fig. 5), further validates the accomplishment of correct calibration

After calibration, each subject executes four wrist extension movements (Task1-Task4) and generates CC based on correlation values and achieved thresholds (Table I). First, the algorithm calculates the correlation between IMU and sEMG signal. If the correlation is less than 0.3, then no control

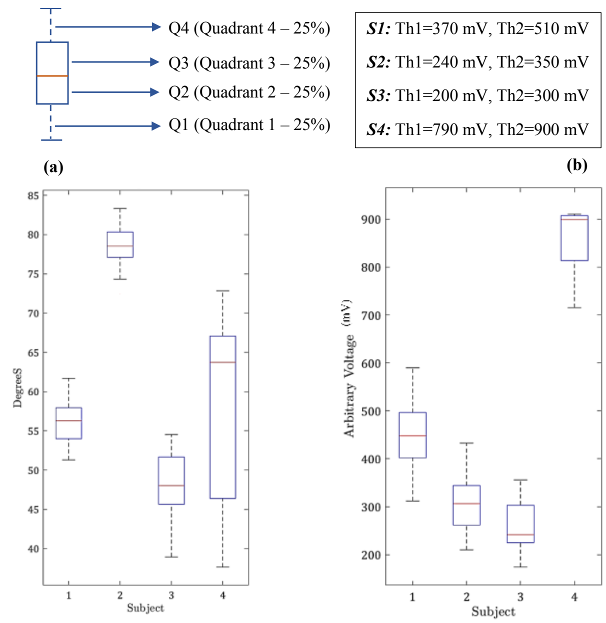

Figure 4. Boxplot Representations (a) Pitch Angle during the Wrist Extension (IMU Output). (b) Voltage Amplitude from the Extensor Carpi Radialis during the Wrist Extension (sEMG Output).

signal is generated. In case the coefficient is greater than 0.3, the sEMG voltage is analyzed. Based on the achieved Th1 or Th2, either of the two different Arduino digital output ports is set to 5V, which indicates the generation of control commands, CC-1 or CC-2. The external devices can be controlled by either connecting to the Arduino output digital port or interfacing wirelessly via Bluetooth communication. In Table I, for all four subjects, the correlation, wrist pitch orientation, muscle potential, and control command produced against the four different wrist extensions are reported. It is evident that each subject successfully generates the correct control signal related to specific threshold values for each wrist extension. The result also shows that all the users are able to achieve a correlation greater than 0.3, which confirms that all the acquired muscle potentials are generated due to wrist extension, and no external interference or artifact is included in the obtained signal. As the developed system is user-specific, each subject has its own voltage threshold against the wrist extension angle.

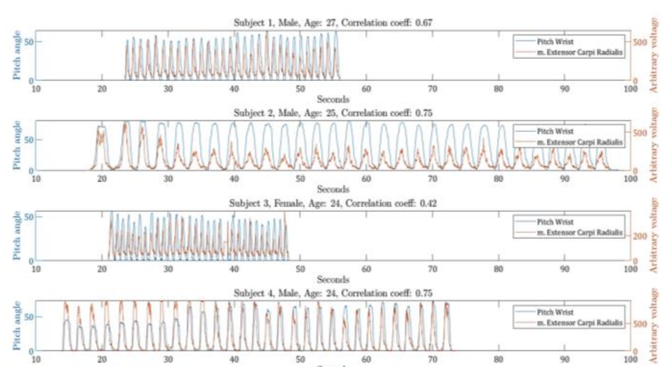

Figure 5. Wrist Pitch (Blue) and Extensor Carpi Radialis Activity (Red) during 30 Cycles of Wrist Extension in Four Healthy Subjects. Correlation Coefficient between the IMU and sEMG Signals are indicated in the Title for Each Subject.

TABLE I. PRELIMINARY RESULTS FOR PILOT TESTING OF THE PROPOSED PORTABLE DATA ACQUISITION

	(1) Correlation, (2) Pitch Angle, (3) sEMG Potential, (4) Comments (Th=Threshold Level, CC=Control Command)			
	Task 1	***Task 2***	***Task 3***	***Task 4***
S1	1) 0.6 2) 54º 3) 410 mV 4) Exceeds Th1 and generates CC-1	1) 0.55 2) 65º 3) 630 mV 4) Exceeds Th2 and generates CC-2	1) 0.7 2) 20º 3) 205 mV 4) Below threshold and no CC Generation	1) 0.6 2) 60º 3) 550 mV 4) Exceeds Th1 and generates CC-1
S2	1) 0.45 2) 42º 3) 170 mV 4) Below threshold and no CC Generation	1) 0.5 2) 77º 3) 270 mV 4) Exceeds Th1 and generates CC-1	1) 0.65 2) 81º 3) 360 mV 4) Exceeds Th2 and generates CC-2	1) 0.75 2) 60º 3) 550 mV 4) Exceeds Th1 and generates CC-1
S3	1) 0.8 2) 46º 3) 220 mV 4) Exceeds Th1 and generates CC-1	1) 0.75 2) 53º 3) 310 mV 4) Exceeds Th2 and generates CC-2	1) 0.85 2) 40º 3) 180 mV 4) Below threshold and no CC Generation	1) 0.7 2) 52º 3) 230 mV 4) Exceeds Th1 and generates CC-1
S4	1) 0.55 2) 47º 3) 820 mV 4) Exceeds Th1 and generates CC-1	1) 0.6 2) 35º 3) 710 mV 4) Below threshold and no CC Generation	1) 0.6 2) 65º 3) 880 mV 4) Exceeds Th1 and generates CC-1	1) 0.75 2) 85º 3) 920 mV 4) Exceeds Th2 and generates CC-2

IV. DISCUSSION AND FUTURE WORK

In the presented paper, a pilot study is performed to demonstrate the functionality and feasibility of using the hybrid approach (sEMG + IMU) to develop wireless wearable data acquisition system. The preliminary results are promising and show that the proposed portable system is able to detect the user's intention for producing control signals based on IMU and sEMG signals. The initial testing is performed on healthy subjects; however, the final objective is to test the system on stroke patients. This system will assist stroke patients in regaining their independence by controlling different devices in their surroundings. For instance, the stroke patient can turn ON/OFF the light or fans at their smart home by their non-paretic wrist movements. In addition, they can perform the rehabilitation exercises on their own by regulating the muscle stimulation device or robotic glove through the movement of their healthy limb. The current limitation of the system is its capability to work only for two degrees of freedom applications (like executing ON/OFF functions). In the future, the design will be enhanced by introducing multiple IMU sensors for monitoring the finger movements and develop a machine/deep learning algorithm for classification. Such advanced algorithms will extract different combinations of IMU and sEMG features to command the devices with higher degrees of freedom. For example, controlling the movement of an electric wheelchair in different directions. Currently, we are working on developing functional electrical stimulation (FES) device and robotic assistive unit for stroke patients that can be operated by using the developed wearable acquisition system. Furthermore, in the future, randomized controlled trials (RCTs) will be performed on stroke patients, where the proposed system's clinical performance will be compared with the 'Only EMG' based data acquisition system.

REFERENCES

[1] Johnson, Catherine Owens, et al. A Systematic Analysis for the Global Burden of Disease Study 2016." The Lancet Neurology, vol. 18, no. 5, May 2019, pp. 439–58. DOI: 10.1016/S1474-4422(19)30034-1.

[2] Go, Alan S., et al. "Heart Disease and Stroke Statistics—2013 Update: A Report From the American Heart Association." Circulation, vol. 127, no. 1, Jan. 2013. DOI: 10.1161/CIR.0b013e31828124ad.

[3] Armagan, Onur, et al. "Electromyographic Biofeedback in the Treatment of the Hemiplegic Hand: A Placebo-Controlled Study." American Journal of Physical Med. & Rehabilitation, vol. 82, no. 11, Nov. 2003, pp. 856–61. DOI: 10.1097/01.PHM.0000091984.72486.E0.

[4] Vasylkiv, Yurii, et al. "Smart home interactions for people with reduced hand mobility using subtle EMG-signal gestures." Studies in Health Technology and Informatics, vol. 257, 2019, pp. 436-443. DOI: 10.3233/978-1-61499-951-5-436

[5] Tong, L. H. et al. "Multi-channel sEMG time series analysis based human motion recognition method". Acta Autom. Sinica, vol. 5, no. 40, 2014, pp. 810-821. DOI: 10.3724/SP.J.1004.2014.00810

[6] Young, Aaron J., et al. "A Biomechanical Comparison of Proportional Electromyography Control to Biological Torque Control Using a Powered Hip Exoskeleton." Frontiers in Bioengg. and Biotechnology, vol. 5, June 2017, p. 37. DOI: 10.3389/fbioe.2017.00037.

[7] Durandau, Guillaume, et al. "Voluntary Control of Wearable Robotic Exoskeletons by Patients with Paresis via Neuromechanical Modeling." Journal of NeuroEngineering and Rehabilitation, vol. 16, no. 1, Dec. 2019, p. 91. DOI: 10.1186/s12984-019-0559-z.

[8] Yid, M. Syazwan Md, et al. Development of Wireless Arm Switch EMG Control System for Rehabilitation. 2019, p. 020118. DOI: 10.1063/1.5118126.

[9] Song, Min-Su, et al. "Wireless, Skin-Mountable EMG Sensor for Human–Machine Interface Application." Micromachines, vol. 10, no. 12, Dec. 2019, p. 879. DOI: 10.3390/mi10120879.

[10] Farina, Dario, et al. "The Extraction of Neural Information from the Surface EMG for the Control of Upper-Limb Prostheses: Emerging Avenues and Challenges." IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 22, no. 4, July 2014, pp. 797–809. DOI: 10.1109/TNSRE.2014.2305111.

[11] Young, A. J., et al. "Analysis of Using EMG and Mechanical Sensors to Enhance Intent Recognition in Powered Lower Limb Prostheses." Journal of Neural Engineering, vol. 11, no. 5, Oct. 2014, p. 056021. DOI: 10.1088/1741-2560/11/5/056021.

[12] Tariq, Madiha, et al. "EEG-Based BCI Control Schemes for Lower-Limb Assistive-Robots." Frontiers in Human Neuroscience, vol. 12, Aug. 2018, p. 312. DOI: 10.3389/fnhum.2018.00312.

[13] Xu Zhang, et al. "A Framework for Hand Gesture Recognition Based on Accelerometer and EMG Sensors." IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, vol. 41, no. 6, Nov. 2011, pp. 1064–76. DOI: 10.1109/TSMCA.2011.2116004.

[14] Georgi, Marcus, et al. "Recognizing Hand and Finger Gestures with IMU Based Motion and EMG Based Muscle Activity Sensing:" Proceedings of the International Conference on Bio-Inspired Systems and Signal Processing, SCITEPRESS - Science and and Technology Publications, 2015, pp. 99–108. DOI: 10.5220/0005276900990108.

[15] Wolf, M. T., et al. "Decoding Static and Dynamic Arm and Hand Gestures from the JPL BioSleeve" 2013 IEEE Aerospace Conference, IEEE, 2013, pp. 1–9. DOI: 10.1109/AERO.2013.6497171.

[16] Basmajian JV, de Luca CJ. "Muscles Alive: their functions revealed by electromyography". Postgrad Med J, vol. 39, no. 449, March 1963, DOI: 10.1002/ar.1091470317

[17] Laksono, Pringgo Widyo, et al. "Mapping Three Electromyography Signals Generated by Human Elbow and Shoulder Movements to Two Degree of Freedom Upper-Limb Robot Control." Robotics, vol. 9, no. 4, Oct. 2020, p. 83. DOI: 10.3390/robotics9040083.