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AW-ELM-based Crouch Gait Recognition after ischemic stroke

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AW-ELM-based Crouch Gait Recognition after ischemic stroke *

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***Abstract*— Crouch Gait (CG) can be observed in the hemiplegia persons after ischemic stroke. Walking with Crouch Gait (CG) shown a large gaits disorder. This paper explores the use of adaptive wavelet extreme learning machine (AW-ELM) to classifying different gait conditions for hemiplegia and healthy subjects. Three participants having a Crouch Gait** problem with **categories of Mild, Moderate, and Severe gait conditions, also, one Healthy person are used their data in this work. The recognition system extracting number of time and frequency domain features for dimensionality reduction. While for the classification stage, the common Extreme Learning Machine (ELM) classifiers are used. AW-ELM achieved maximum testing accuracy up to 91.149 % and with using majority vote post-processing the accuracy achieves 91.547 %.**

I. INTRODUCTION

Ischemic stroke can be diagnosed by supposed a mechanism of the central brain injury also, the type and location of the vascular harm. This injury causes problems in limbs movement muscles and nerves like Crouch Gait (CG) [1]. CG patient has flexed position of hip and knee during the stance phase. Many problems in step gait will occur after stroke depending on which part of the body will be defects or injuries either joints like crouched gait or muscles like steppage gait. Patients walk scuffing their toes, to avoiding the scuffing, sometimes they raise their thigh to lift their foot which causing abnormal gait called ''steppage gait'' from lost dorsiflexion. They might swing out their leg widely to preventing unsafe of lifting the thigh[2].

Crouch gait is a movement pattern at individuals with cerebral palsy; it is categorized as an excessive flexion of the hip, knee, and ankle at stance phase of gait. Individual muscles are playing a main role to improve crouch gait [3]. Gait analysis has been applied by using different categories of motion sensors and systems, such as the accelerometer, gyroscope, magneto-resistive sensors, flexible goniometer, and an electromagnetic tracking system (ETS), sensing fabric, a force sensor, and sensors for electromyography (EMG). Constructed on these sensors, numerous gait analysis applications could be used a single form or a collective sensor system of multiple forms of sensors [4].

Surface electromyography (sEMG) is muscle signal that acquired from the skin surface. The effect leg muscles are Rectus Femoris (RF), Gastrocnemius (GAS) and Tibialis Anterior (TA) muscles produced a greater forward acceleration of mass center through crouch gait than unimpaired gait. On the other hand, Lateral Hamstring (LH) produced a greater backward acceleration of mass center [5, 6]. Several studies indicated that gastrocnemius (GAS) and soleus muscles supported the body weight and forward at late stance [7].

Many machine learning methodologies have been used to classify different gait conditions. This paper proposes a new myoelectric pattern recognition using adaptive wavelet extreme learning machine (AW-ELM) [8]. AW-ELM is an ELM that employs wavelet in its activation function. However, the shape of the wavelet is adjusted according to the input characteristic. On the other hands, ELM [9] is a learning structure for single layer feed forward networks (SLFNs). Although the network parameters are modified in classical SLFNs learning algorithms, most of these parameters are logically determine in ELM. Wavelet Extreme Learning Machine (W-ELM) is an exceptional method from extreme learning machine that the wavelet is an activation function for it[10]. To develop both the testing data and accuracy and post-processing accuracy, this paper proposes a new recognition system to detect three cases of Crouch Gait event depending on three types of stroke patients using four channels on each leg. This work used Adaptive Wavelet Extreme Learning Machine (AW-ELM), Wavelet Extreme Learning Machine (W-ELM) and common ELMs algorithms to classify the healthy and 3 type of Crouch Gait conditions for patients.

II. METHODOLOGY

A. *Proposed Method*

The proposed recognition system contains several stages. First, the sEMG device acquired EMG signals data. The filtering and windowing were utilized to collected data. Extracting features applied using time and frequency domains feature extraction methods. Seven sets of time domain features and one set of frequency domain were utilized to reduce a big repetitively data. The features set were classified by applying an AW-ELM, W-ELM, and common ELMs types and then refined them by using majority vote. CG gait conditions recognition system block diagram is described in fig.1.

B. *Participants*

The data in this work were provided by Open Sim software and available at www.simtk.org. The data had been

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collected from four subjects. Three of them had a single-limb stance CG problem with three individuals' conditions: mild, moderate, and severe CG cases. The fourth one is a healthy person. Table 1 describes the details of subject's characteristics for patients, healthy gait walking and simulation ID labels for one gait cycle.

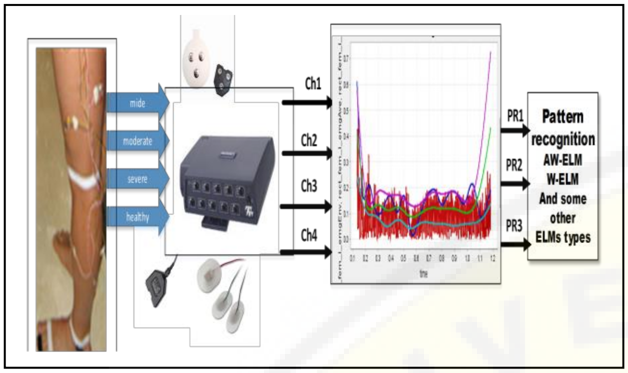

Fig.1. CG gait conditions recognition system block diagram.

The acquired EMG signals were amplified with a gain of 1000 and sampled at 1080 Hz. Appling a band-pass filter with frequency range between 20 and 400 Hz [3]. The EMG signals were sampled–down to 1000Hz to minimize the data size.

TABLE I. SUBJECT CHARACTERISTIC FOR SICK AND HEALTHY GAIT WALKING AND SIMULATION ID LABELS

Simulation ID, for sick & healthy subjects	Age (Years)	Height (cm)	Weight (kg)	Min KFA* (deg)	Speed (m/s)*
MI01	9.4	131.0	28.2	15.5	0.94
MO04	11.0	143.0	28.7	32.6	1.2
SE05	16.3	160.0	50.8	86.0	0.7
GIL01(health)	10.2	0.77	41.1		1.01

*m/s units for speeds and non-dimensional & *KFA = Knee Flexion Angle

C. *Time Domain Feature Extraction*

Feature extraction addresses the problem of finding the most compacted and instructive sets of features that can accurately describe the EMG signal in a shortened symbol. According to Khushaba et al. [11] appropriate feature set in EMG-based control should have a feature space maximum class separating. Besides, it should be strong in a noisy environment as possible, and should have a related low computation complexity.

Sixth features of time domain have been considered in this work. Mean Absolute Value (MAV) that can be measured by moving an average of full-wave rectified the EMG signal. Or it can be calculated by taken the average absolute value of the sEMG (aka myoelectric) signal. It is a simple method to detect the muscle contraction levels and it is a common feature using in a myoelectric control application. It is defined as shown in equation (1):

$$\mathrm{MAV} = \frac{1}{N}\sum_{n=1}^{N} |X_n| \qquad (1)$$

Where N represents the length of signal and X_n denotes the sEMG segment of this signal.

Mean Absolute Value Slope (MAVSLP) is an improved version of MAV. The modifications between the MAVs of adjacent segments are determined. Equation (2) can be defined it as:

$$\mathrm{MAVSLP}_i = \mathrm{MAV}_{i+1} - \mathrm{MAV}_i \qquad (2)$$

Root Mean Square (RMS) is a format of amplitude modulated the Gaussian random procedure that it's RMS is linked to the constant force with non-fatiguing contraction. It is related to the standard deviation. Equation (3) expresses it as:

$$\mathrm{RMS} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} x_n^2} \qquad (3)$$

Waveform length (WL): It is the accumulative length of the waveform with time division. WL relates to the waveform amplitude, time and frequency. Equation (4) clears it as:

$$\mathrm{WL} = \sum_{n=1}^{N-1} |X_{n+1} - x_n| \qquad (4)$$

Zero crossing (ZC): It is the number of times that the amplitude value of sEMG signal crossing the zero of the y-axis. In EMG feature, the threshold condition is applied to refrain from the background noise. This feature offers a nearest estimation of frequency domain properties. Equation (5) formulates it as:

$$\mathrm{ZC} = \sum_{n=1}^{N-1} \left[\mathrm{sgn}(x_n \times x_{n+1}) \bigcap |x_n - x_{n+1}| \geq \mathrm{threshold}\right] \qquad (5)$$

Where: $\mathrm{sgn}(x) = \begin{cases} 1, & \text{if } x \geq \text{threshold} \\ 0, & \text{otherwise} \end{cases}$

Slope Sign Change (SSC) is comparable to ZC. It denotes the frequency information of the sEMG signal. The changing of number among a positive and negative slope between three serial segments are executed with the threshold function to avoid the interference in the sEMG signal. The scheming is defined as[12]:

$$\mathrm{SSC} = \sum_{n=2}^{N-1} \left[f[(x_n - x_{n-1}) \times (x_n - x_{n+1})]\right] \qquad (6)$$

$$f(x) = \begin{cases} 1, & \text{if } x \geq \text{threshold} \\ 0, & \text{otherwise} \end{cases}$$

D. Frequency Domain Feature Extraction

Autoregressive Coefficients (AR) is a model describes each sample of the sEMG signal as a linear combination of earlier samples with a white noise error term. AR coefficients used as features in EMG pattern recognition. It is formed in equation (7):

$$X_n = -\sum_{i=1}^{p} a_i X_{n-1} + W_n \qquad (7)$$

Where X_n is a sample of the model signal, a_i is AR coefficients, W_n is white noise or error sequence, and p is the order of AR model.

Fig. 2, 3, and 4 are described the signals from four channel EMG located on the four Rec_Femor, Lat_Ham, Ant_Tibi and Gastascinumina muscles for each Mild, Moderate, and Severe patients. The Open Sim simulation software was used to plot and simulate the movement of the body.

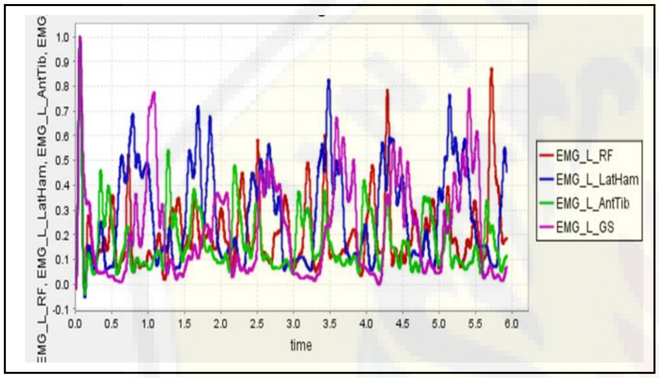

Fig.2. The Mild patient sEMG signal for rec_femor,lat_ham, Ant_tibi and Gas muscles using OSim plot

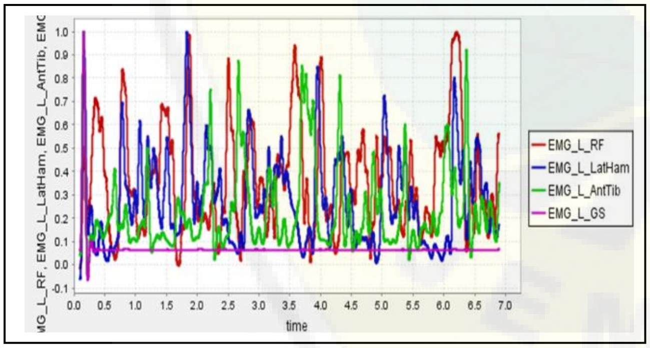

Fig. 3. The Moderate patient sEMG signal for rec_femor,lat_ham, Ant_tibi and Gas muscles using OSim plot .

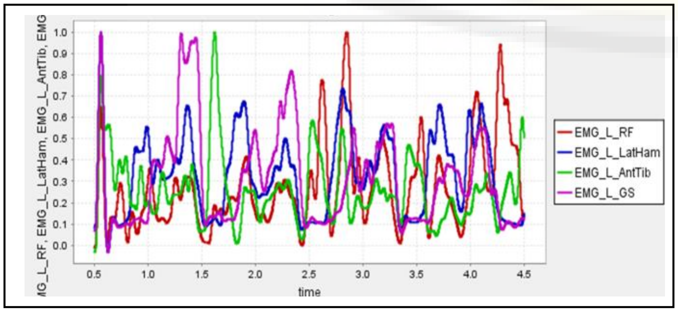

Fig. 4.The Severe patient sEMG signal for rec_femor,lat_ham, Ant_tibi and Gas muscles using OSim plot

E. Adaptive Wavelet Extreme Learning Machine (AW-ELM)

Adaptive wavelet extreme learning machine (AW-ELM) is a new version of ELM and wavelet neural network (WNN) that proposed in our work in [8]. According to WNN structure, this new system applied a wavelet function as an activation function in the hidden node. Nevertheless, the activation functions are not stable but they attuned as regards to the altering in the input [8, 13]. The output function of AW-ELM for generalizing SLFNs at one output node case is described in equation (8):-

$$f_i^k(x) = \sum_{j=1}^{M} V_{it}\psi_{ajbj}(W_j, C_j, X_k) = \sum_{j=1}^{M} V_{ij}\psi_{ajbj}\left(P_j(X_k)\right) \qquad (8)$$

Where $\beta = [\beta_1, ..., \beta_L]^T$ is the vector of the output weight between hidden layer of L nodes and the output node, $h(x) = [h_1(x), …., h_L(x)]$ is the output vector of the hidden layer and T is the target. Figure (6) shows the steps required to prepare the data set for training the ELM.

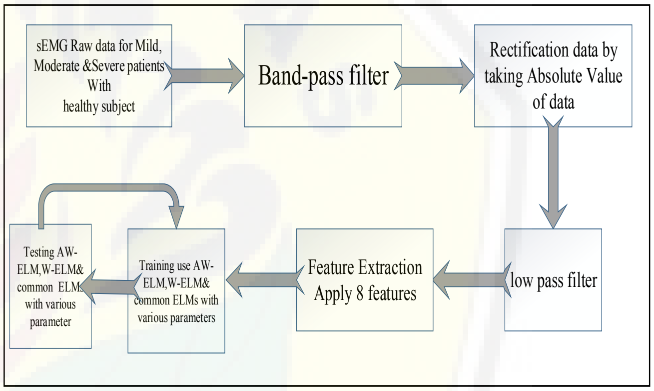

Fig.5. Flow chart for step sequence recognition

III. EXPERIMENTAL RESULTS

In this experiment, we applied a 200ms window length along with a 25 increment to the signal to compatible with real-time application.

Table 2 shows the classification results of seven classifiers to recognize four classes as defined in part (*B*). The Number of hidden nodes in common ELMs was varied from 50 up to 500. Table 3 described the accuracy majority vote to refine classification results with other cases of ELMs.

To simulate the collected sEMG signal data, OpenSim software operated to create a different dynamic movement for each case of patients: Mild, Moderate, and Severe.

The length of each arrow in figure (7) shows the different magnitude of Ground Reaction force (GRF) in Mild, Moderate, and severe patient cases. Therefore, we can investigate that the Mild patient has a value of GRF smaller than Moderate, while Severe has the maximum GRF than the two of Mild and Moderate.

In additional to the Majority vote matrix, the diagonal of Majority matrix is presented in fig.7. It can be seen on average values that the system was able to recognize the different cases of patients or healthy subject in accuracy 91.54%.

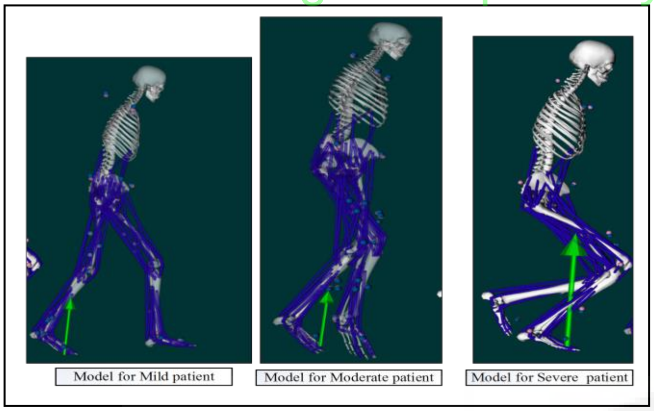

Fig.6. Simulink using Open-Sim for the Mild, Moderate, and Severe gait event patient

TABLE II. THE AVERAGE CLASSIFICATION TESTING ACCURACY OF AW-ELM ACROSS FOUR SUBJECTS USING TEN-FOLD CROSS VALIDATION COMPARED WITH W-ELM , SIG-ELM & ALL ELMS TYPES.

Testing Accuracy (%)							
Hidden Node	***W-ELM***	***AW-ELM***	***Sig-ELM***	***Sine-ELM***	***Rad-ELM***	***Hard-ELM***	***Tri-ELM***
50	75.0209	**90.1567**	87.2668	87.8621	85.8728	89.0528	84.8671
75	83.8836	90.2523	87.8651	88.1595	84.8743	89.1551	87.3612
100	87.1656	89.7523	87.8679	87.9553	85.9862	89.4490	88.8639
150	88.0688	89.8532	88.3634	88.1602	87.3598	89.4509	89.1482
200	89.7473	90.2499	89.4576	89.5578	89.7607	90.1518	89.9459
300	89.9551	90.3548	89.9497	89.7545	90.2529	90.7517	90.4529
500	90.5511	**91.1493**	90.4531	90.2505	90.1560	91.0484	90.8520

TABLE III. TABLE AVERAGE CLASSIFICATION MAJORITY ACCURACY OF AW-ELM ACROSS FOUR SUBJECTS USING TEN-FOLD CROSS VALIDATION COMPARED WITH W-ELM , SIG-ELM & ALL ELMS TYPES.

Accuracy Majority Voting (%)							
Hidden Node	***W-ELM***	***AW-ELM***	***Sig-ELM***	***Sine-ELM***	***Rad-ELM***	***Hard-ELM***	***Tri-ELM***
50	91.3509	**91.3591**	90.9482	91.1483	91.3481	91.3480	91.3511
75	91.2481	91.4498	91.3507	91.4449	91.4455	91.2492	91.3483
100	91.2489	91.4424	91.0502	90.9473	91.4401	91.2451	91.3472
150	91.4412	91.4474	91.2455	91.4311	91.3452	91.3490	90.9484
200	91.3477	91.5450	91.1528	91.4519	91.3460	90.9508	91.3460
300	91.2472	91.3455	91.2469	91.3446	91.2490	91.1498	90.9490
500	91.4410	**91.5472**	91.4512	91.0475	91.0501	91.3484	91.4510

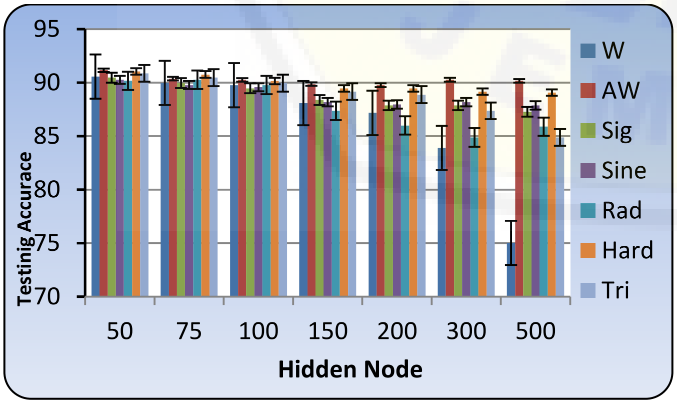

Fig.7.The diagonal of Majority Vote Accuracy

IV. CONCLUSION

The objective of previews classification is to recognize four classes of the Crouch Gait and healthy gait. The statistical analyses of classes Mild (M), Moderate (O), Severe (S) and Healthy (H) were performed to substantiate the result. In this paper, the performance of the proposing AW-ELM is comparing to a wavelet extreme learning machine (W-ELM), Sigmoid (Sig-ELM), Sine (Sine-ELM), Radial basis (Rad-ELM), Hard lime (Hard-ELM) and Triangular Extreme Learning Machine (Tri-ELM). All classifiers classified four muscle movements using surface EMG signal from four channel electrodes. The ten-fold cross validation is applied to validate the classification results. The results indicate that the average testing accuracy with AW-ELM was higher than standard W-ELM and all other cases of ELMs. The same performance for AW-ELM when using Accuracy Majority Vote to refine classification results with other cases of ELMs, but it gives better results than using testing accuracy.

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