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Impact of Robotic Exoskeleton Based on Electromyography for Rehabilitation of Post Stroke Patient

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Abstract. Ischemic stroke is one of the stroke types that commonly occur in people with stroke. This is usually followed by symptoms such as weakness or paralyzed limb. The purpose of this study is to train the stroke patient independently using a robotic exoskeleton based on electromyography (EMG) signal. This study was an experimental research with a compare one sample. The results of conventional exercise were used independently in addition to the robotic exoskeleton method for two weeks. Samples were taken based on the patient who MT-3 (Manual Scale Testing) measurement scale. The EMG signal was collected from biceps during the exercise. The EMG signal was extracted using root mean square (RMS) feature which represented the energy of the muscle. The EMG data were analyzed using single factor ANOVA to obtain a significant difference of RMS. Results indicated that there was no significant difference of RMS with a p-value of 0.85 (alpha= 0.05). The used of the robotic exoskeleton method for rehabilitation of stroke patient was not effective for a short time assessment but more preferred as an observation of the EMG activities during the exercise for the post-stroke patient

INTRODUCTION

Rehabilitation is a form of integrated therapy services which include a medical, psychosocial, educational, vocational approach involving physicians, neuroscientist, medical rehabilitation doctor, nurse, physiotherapist, occupational therapy, medical social worker, psychologists and clients as well as the role of the family to reach the most functional capabilities and prevents the attack [1]. A rehabilitation based on exoskeleton is a model of therapy that uses hardware and software, as a tool for rehabilitation of muscles in stroke patients. Currently, the number of stroke incidence in Indonesia continues to increase every year, the number of stroke sufferers increases from 8,3 % per 1000 population in 2007 to 12.1% in 2013 [2]. WHO estimates that the number of stroke patients in several European countries increases from 1.1 billion per year in 2000 to 1.5 billion per year in 2025. In Indonesia, according to the data released by Post-stroke Foundation Indonesia, it shows a steadily increasing trend year by year. In 1900 a study showed cases of post-stroke found that 3,98% of the entire population or estimated around 500.000 residents suffered from post-stroke attack and about 125.000 of them died or disabled for life. Then in 2000 the case of post-stroke apparently continued to surge, in 2004 research results in some hospital found that 23,636 patients were hospitalized because of post-stroke.

The results of the survey showed that the strokes also increased from 8.3 per 1000 population (2007) to 12,1 per 1000 population [2]. Stroke has become the main cause of death in nearly all hospitals in Indonesia, by 14.5% [2]. And in general, the incidence of strokes is preceded by hypertension. Hypertension is a risk factor that causes uncontrolled broken blood vessels which lead to the stroke and the prevalence of stroke among Indonesian of >18 years old is 25.8 %[2]

Karunesh developed an exoskeleton design for stroke rehabilitation [3]. The results showed that rehabilitation which used exoskeleton-based EMG are better than conventional rehabilitation. The healing factor is faster for 5%. Then Karunesh states that the use of a robotic exoskeleton for muscular rehabilitation also gives better results than the conventional In the conventional stroke therapy, the weaknesses are the service time in the institution and the

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willingness of patients to follow the therapy [4] A widely developed mature technology devices that can help stroke patients in restoring motor function or restore the muscle has been designed in EMG-signal based exoskeleton.

A mobilization is a form of early rehabilitation of specific disease conditions, in this case, the clients who have experienced stroke can avoid complications [1]. Early mobilization needs to be done to improve muscle tone, i.e. include an exercise Range of Motion (ROM) and awarding positions as rehabilitation and effective form of exercise is used to prevent disability in stroke patients. According to Kozier [5] Range of Motion (ROM) describes a systematic movement by showing each exercise 3x and a series of exercises 2x per day. Puspawati states that administering 2x of Range of Motion (ROM) exercise every day for ischemic stroke patients further increase muscle strength than 1x per day [1]. With a routine exercise, the patient will be able to improve their life quality. The research by Kwakkel, et al [6] showed that an increase in the intensity of the exercise especially if the duration is at least 16 hours in the first six months, it has a small influence but meaningful impact on the functional ability of stroke sufferers. Based on the research systematic review, the task-oriented exercise training have a small to moderate effect on the motor ability of the stroke sufferers, especially if it is done intensively and early [6][7]. Some previous studies have proposed exoskeleton based on EMG control with various methods [8] [9]. Kiguchi proposed a robotic exoskeleton to support an elderly and disable people for better live [10]. In the study he used a neuro-fuzzy controller based on EMG signal. In order to complete the previous studies in stroke rehabilitation, this study is to analyze the impact of the exercise of using exoskeleton unit in stroke patients by observing the RMS of the EMG signal.

MATERIALS AND METHODS

The EMG signal was collected on the biceps using disposable electrodes (Ag/AgCl). Five subjects who have a post-stroke were used in this study. In the data acquisition, the therapist instructed the subjects to move the elbow in the flexion and extension motion. The EMG signal was recorded using an internal analog to digital converter (ADC) of ARM microcontroller. Furthermore, the EMG signal was extracted using root mean square (RMS). In order to control the exoskeleton servo motor, the RMS feature was converted into a pulse width modulation (PWM) so that the position of the exoskeleton arm was in accordance with the position of the elbow joint of the subjects. A potentiometer was placed in the exoskeleton frame to measured the real position of the elbow joint angle. A computer unit was used in this data acquisition to observe the graph of the EMG signal and to control the exoskeleton. In this work, the Delphi programming was used to record the EMG data, features extraction process, and controlling the exoskeleton unit. The diagram block of this works is shown in Figure 1.

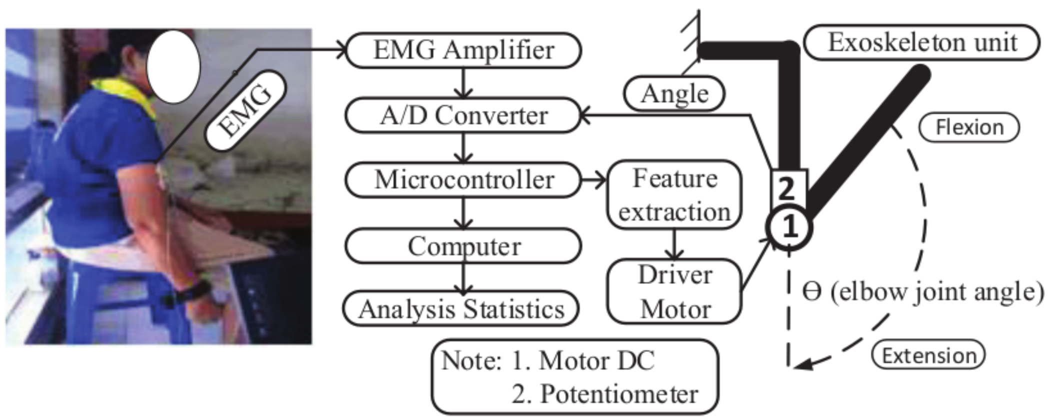

FIGURE 1. Diagram block of the proposed method.

Feature Extraction

Due to the EMG signal has a random and stochastic characteristic then the EMG signal needs to be extracted in order to obtain the feature. Time domain feature is widely used by previous studies to extract the EMG signal because of the computation cost is low. The root mean square (RMS) is one of many time domain features which was used by previous works to extract the EMG signal. The RMS feature is written as follows [11]:

$$RMS = \sqrt{\frac{1}{M}\sum_{i=1}^{M} x(i)^2} \quad (1)$$

where x(i) is the EMG sample, M is the number of sample in a segment, and RMS is the EMG features. Figure 2 shows the representation of the EMG signal and RMS features. Generally, in order to obtain a smooth estimation, a lowpass filter [11], as well as Kalman filter [12][13], is performed after feature extraction process.

In order to obtain the differences in the EMG activities between pre and post therapy, this research was conducted for two hours each day up to eight days. The subjects of the research were stroke patients at the Hospital in Surabaya city in the Rehabilitation Unit. The subjects are meet the succeeding requirement as follows: 1) ischemic stroke patient of over 6 months, 2) able to execute an order, 3) patients with muscle test condition within range of MT3 to MT5, and 4) the patients willing to follow the exercise during the research that is proven by letter of statement.

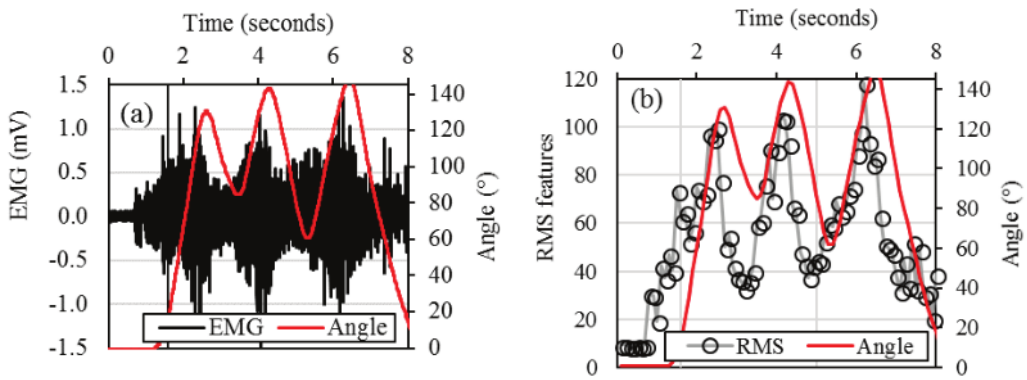

FIGURE 2. The representation of (a) EMG signal and (b) RMS features in accordance with elbow joint angle.

Statistical Analysis

The EMG signal was extracted using the RMS feature in order to observe the energy of the EMG signal. The RMS was calculated for each day with the total of rehabilitation is eight days. The statistical analysis of ANOVA was performed to find the significant difference of RMS among the days. A 95% confidence level was chosen in this analysis.

RESULTS AND DISCUSSION

Driving the Exoskeleton

The angle of the exoskeleton was depended on the position of the elbow joint. The EMG signal was directly influenced by the position of the elbow joint. Furthermore, after the feature extraction process, the EMG was converted into a PWM (*pulse width modulation*). Table 1 shows the PWM value in accordance with the elbow joint angle.

TABLE 1. Measurement of the angle based on PWM

No.	PWM (%)	Angle Position (°)
1	0	0
2	3%	45
3	5%	90
4	7.5%	135

The results show that the PWM linearly affected the position of the exoskeleton arm. This linear response will make easy in controlling the exoskeleton unit in accordance with the EMG signal. The standard parameter to control the servo motor is the frequency of the PWM is 50 Hz and the duty cycle ranged between 0% and 7.5%.

EMG Signal from Stroke Patient

The EMG signal which recorded form biceps muscle was measured during eight days. In the recording process, the subject performed a flexion and extension motion for five-movement (trial) for each day. The trial was beginning in the full extension position and was continued to full flexion and then return to extension position. Figure 3 shows that the EMG signal represents a different response in according to the position of the elbow joint angle. The black line shows the EMG signal and the red line shows the position of the elbow joint. In the lower elbow joint angle, the EMG signal shows less activities than the higher elbow joint angle. The figure 3 shows that the EMG signal is random in nature or characteristics. Figure 3 described the measured EMG in the day one which the EMG amplitude ranged between -1.5 and 1.5 mV and the elbow joint angle covers from 0 up to 160°. Nevertheless, in eight days measurement (Figure 4), the amplitude of the EMG signal increased and more noises in the EMG signal than the first day.

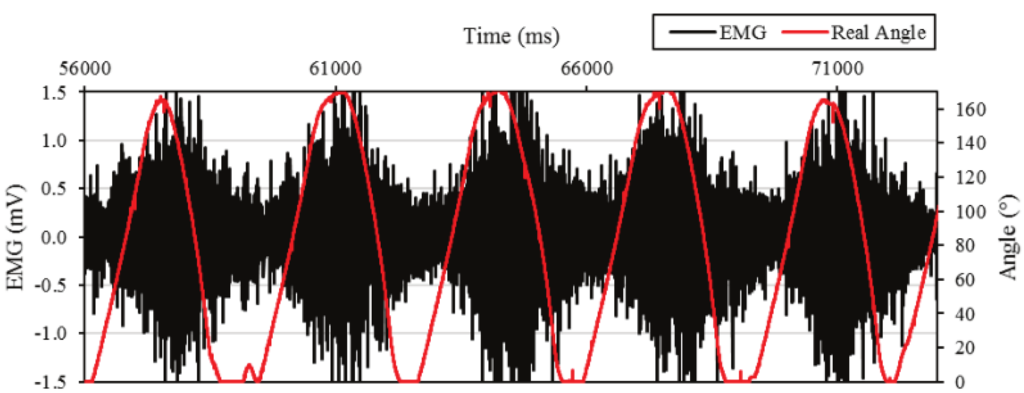

FIGURE 3. The sample of the EMG signal which was collected from bicep muscles.

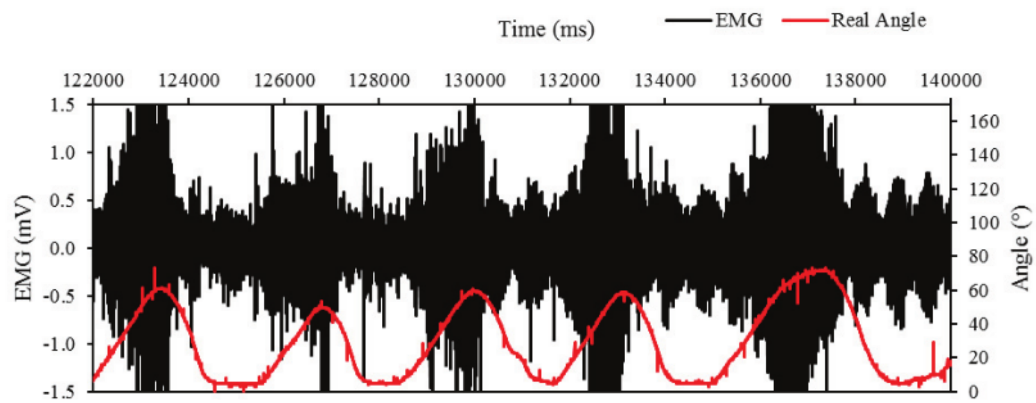

FIGURE 4. EMG signal which was measured on the 8th day.

The RMS Features of the EMG Signal

In order to obtain the information related to the elbow joint angle in motion, the EMG signal was extracted using root mean square (RMS) as shown in Eq. (1). The feature extraction process was conducted for each 100 ms of windows length. The result of features extraction process is shown in Figure 5.

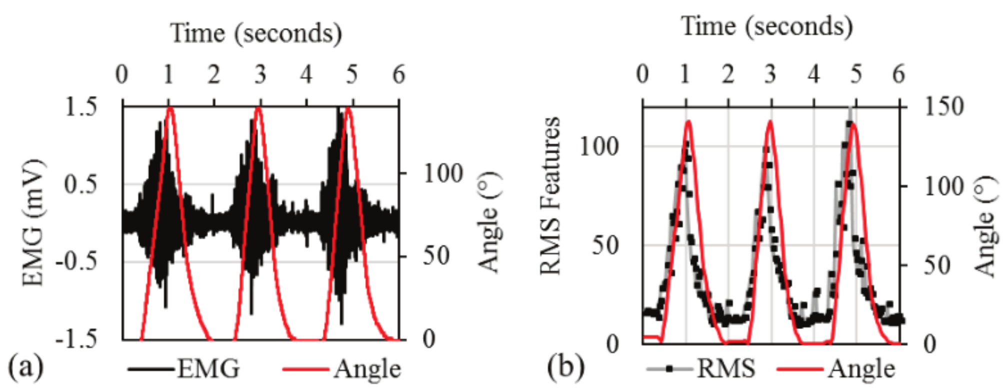

FIGURE 5. The (a) EMG signal and (b) result of RMS features.

The EMG signal was extracted for every 100 samples using RMS feature. In this study, the window length was recommended by a previous study [14]. The RMS mean was calculated based on eight cycles of flexion and extension for eight days. Figure 6 shows the comparison of RMS line among the days (day 1st up to day 8th).

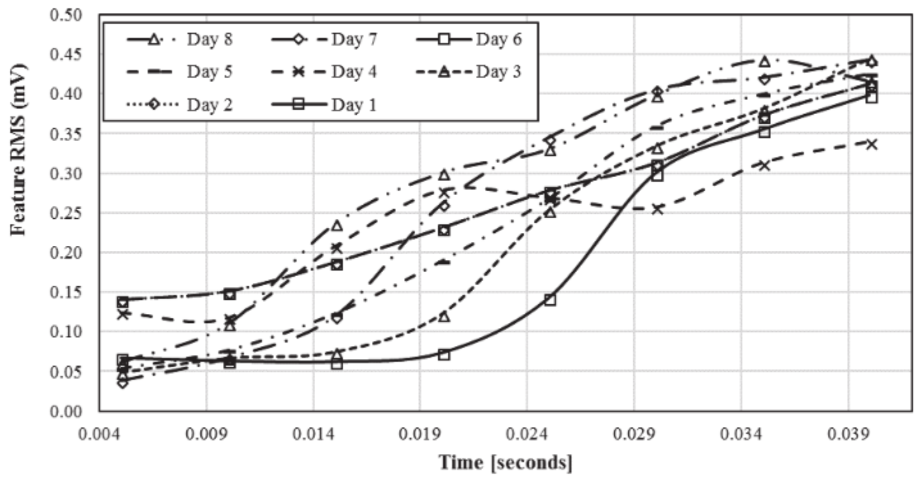

FIGURE 6. The Observation of the RMS value from the first to eight days.

Figure 6 shows that the RMS values indicated a different behavior for each day. In the first day, the graph of the RMS value tended to be the lowest RMS value. However, we can not find the difference of RMS lines among day 2nd, 3rd, 4th, 5th, and 6th. The RMS plot of the day 7th and day 8th almost coincide. The plotline was compared to the conventional method which is conducted using standard measurement with MMT of 3 to 4.

Statistical Analysis of Single Factor ANOVA

In order to obtain the significant difference of RMS among the days, the statistical analysis of ANOVA was performed. In this analysis, the differences of RMS between the first and eight days was performed with a confidence level of 95% (alpha = 0.05). Although there is a difference of RMS between the first and eight days as shown in Figure 7 however the statistical analysis shows that the RMS plot between the first and eight days is insignificant difference (p-value>0.05).

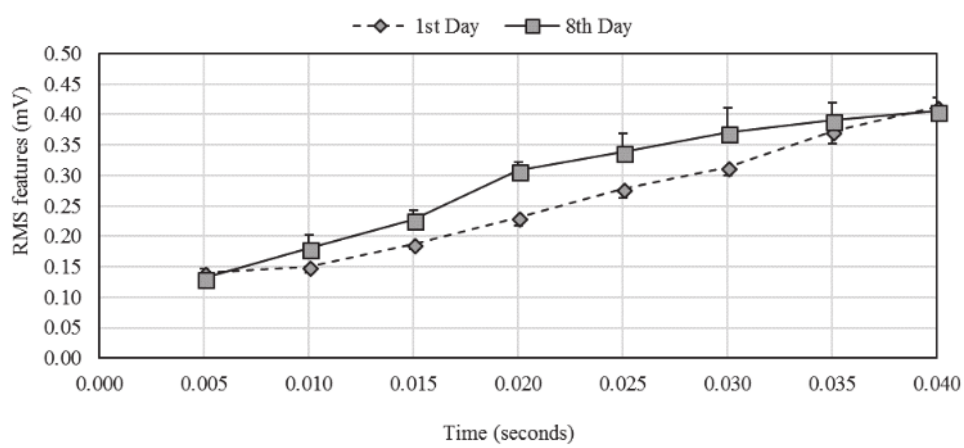

FIGURE 7. The comparison of the EMG energy in RMS value from first to eight days. (the solid line indicates the post-test measurement and the dashed line indicates the pre-test measurement)

Table 2 shows that the RMS mean between 1^{st} day and 8^{th} day indicated insignificant different with a p-value of 0.85, F-value of 0.0328, and F critical of 4.35. the insignificant of RMS between 1^{st} and 8^{th} day is caused that the observation duration for RMS measurement is to short (only in eight days). This is due to the limitation of the schedule in the research.

TABLE 2. The ANOVA test of RMS values between day 1^{st} and 8^{th}

DESCRIPTION					Alpha	0.05		
Groups	*Count*	*Sum*	*Mean*	*Variance*	*SS*	*Std Err*	*Lower*	*Upper*
1st Day	11	707.95	64.36	538.7427	5387.427	6.378295	50.14692	78.57037
8th Day	11	689.9629	62.7239	356.2754	3562.754	6.378295	48.51217	76.93563

ANOVA

Sources	*SS*	*Df*	*MS*	*F*	***P value***	*F crit*	*RMSSE*	*Omega Sq*
Between Groups	14.69809	1	14.69809	0.032844	**0.858011**	4.351244	0.054643	-0.04598
Within Groups	8950.181	20	447.509					
Total	8964.879	21	426.899					

CONCLUSION

The proposed of this study is to compare the RMS values among the days (day 1^{st} to day 8^{th}) while the subjects controlled the exoskeleton unit using the EMG signal. In order for the EMG able to control the exoskeleton unit, the EMG signal need to be extracted using RMS feature. Furthermore, the RMS values are converted into the PWM in order to control the servo motor of the exoskeleton. After 8^{th}-day measurement of the RMS values, the results showed that there is no significant difference of RMS between day 1^{st} and day 8^{th}. Further research should be conducted in long duration to obtain a significant difference in RMS values. In future work, number of DOF (degree of freedom) is suggested to be added.

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