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Integrated Measurement System of Postural Angle and Electromyography Signal for Manual Materials Handling Assessment

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Abstract: Improper design of manual materials handling (MMH) tasks at workplace can cause musculoskeletal disorders such as muscle strain to industrial workers. To avoid these disorders, ergonomists and engineers require an integrated measurement system which allows them to study the interaction of body posture and muscle effort during performing MMH tasks. However, far too little attention has been paid to develop an integrated measurement system of body posture and muscle activity for assessing MMH tasks. The aim of this study was to develop and test a prototype of integrated system for measuring postural angles and electromyography (EMG) signals of a worker who doing MMH tasks. The Microsoft Visual Studio software, a 3D camera (Microsoft Kinect), Advancer Technologies muscle sensors and a microcontroller (NI DAQ USB-6000) were applied to develop the integrated postural angle and EMG signal measurement system. Additionally, a graphical user interface was created in the system to enable users to perform body posture and muscle effort assessment simultaneously. Based on the testing results, this study concluded that the patterns of EMG signals are depending on the postural angles which consistent with the findings of established works. Further study is required to enhance the validity, reliability and usability of the prototype so that it may facilitate ergonomists and engineers to assess work posture and muscle activity during MMH task.

Keywords: Work posture, muscle activity, ergonomics assessment, integrated system, manual lifting

1. Introduction

Manual materials handling (MMH) is a task of holding and transferring goods by physical efforts such as lifting, pushing and pulling. MMH is one of common activities in many industrial sectors especially in small scaled manufacturing and construction industries. During MMH tasks (e.g. lifting), activation of the back muscles is regularly accompanied by contraction of the abdominal muscles to enhance stability of the torso [1]. When the MMH tasks involved heavy loads and performed in strenuous postures such as bending or twisting, the level of muscle contraction

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and spinal compression increases considerably. Working in bending or twisting postures with a heavy load is a significant risk factor for developing back pain [2]. In occupational ergonomics, electromyography (EMG) is a widely applied method to acquire EMG signals from the skeletal muscles [3-6]. The EMG signals manifest the contraction of skeletal muscles due to posture, work, movement and gait [7-8]. A previous study proved that increase in muscle contraction will increase the EMG amplitude [9]. Hence, effort or exertion of skeletal muscle caused by MMH tasks can be analyzed from EMG signals. Improper techniques in performing MMH tasks can lead to awkward posture, muscle's sprain and strain among industrial workers [10]. An integrated measurement system of postural angle and EMG signals allows ergonomics practitioners and engineers to understand the interaction of work posture and muscle effort in MMH tasks. For instance, if a worker is bending downward his back 90-degree to lift a sheet metal, an ergonomics practitioner can analyse the effort or exertion of related muscles during this bending posture through an integrated measurement system. The advantage is that the ergonomics practitioners could design safe MMH tasks by referring to information on postural angle and muscle effort generated by the integrated measurement system. An example of integrated measurement system was developed by Hermanns [11] to analyze work posture and exposure of whole-body vibration at workplace.

Based on the literature, numerous studies have developed the work posture and muscle activity measurement systems, as presented in Table 1. However, to the best of the authors' knowledge, none of these systems is integrated, consequently do not allow the ergonomists and engineers to execute a simultaneous assessment of work posture and muscle activity, even though interaction between these two factors is significant in MMH tasks. Due to unavailability of an integrated measurement system, interaction of work posture and muscle activity in MMH task is difficult to examine comprehensively. As a consequence, ergonomics practitioners and engineers might not be able to design the MMH tasks ergonomically, in which can lead to awkward posture and muscle's sprain to workers.

Table 1 - Work posture and EMG systems developed by previous studies

Study	Aim of study	Measurement system developed
Haggag [12]	Investigate Microsoft Kinect for real time rapid upper limb assessment (RULA) to aid in ergonomic analysis.	Work posture
Carvajal [13]	Assess work posture of workers at packaging area in food industry.	Work posture
Plantard [14]	Validate the occlusion-resistant Kinect skeleton data correction through 2 experts.	Work posture
Manghisi [15]	Develop a fast, semi-automatic, and low-cost tool, based on the Kinect v2.	Work posture
Nahavandi [16]	Propose a method to automate the assessment process using depth imaging sensors such as Kinect and a random decision forest.	Work posture
Jiang [17]	Develop a posture load risk recognition method to evaluate the body RULA level.	Work posture
Toro [18]	Design a low cost EMG system for assessing muscle fatigue.	EMG
Brunelli [19]	Develop low cost EMG device for prosthesis control.	EMG
Fang [20]	Construct multi-channel EMG acquisition system with a novel electrodes using improved bipolar montage.	EMG
Poo [21]	Develop a low cost EMG signal acquisition system with two-channel input.	EMG
Aktan [22]	Fabricate an EMG system using Arduino microcontrollers and two nRF24L01 wireless communication modules.	EMG

In recognition the above-mentioned issue, the aim of this study was to develop a prototype of integrated measurement system for simultaneously assessing postural angles and EMG signals while performing MMH tasks. The developed system utilises a low cost 3D camera (Microsoft Kinect^{TM} sensor) and EMG hardware to record and save work postural angles and EMG signals. Ergonomics practitioners or engineers can utilize this system to investigate mismatches between worker and MMH tasks; and consequently provide effective design solutions to avoid strenuous posture and muscle strain. Hence, better compatibility of task and human maybe achieved resulting in workers' efficiency, productivity and occupational health improvement.

2. Methodology

This study consists of three stages. The first stage was development of postural assessment system while the second stage created the EMG signals acquisition system. In the final stage, both the postural assessment system and the EMG signals acquisition system were integrated using a graphical user interface (GUI). Additionally, the integrated measurement system was tested using a simulated case study of MMH task.

2.1 Development and validation of postural angle measurement system

A 3D sensor (Microsoft Kinect^{TM}) and Microsoft Visual Studio were used to develop the postural assessment system. The Kinect Software Development Kit (SDK) was installed as a platform to allow communication between the Microsoft Visual Studio and the Microsoft Kinect^{TM} sensor, and to visualize the image of posture and joints traced by a form of a skeleton. This study utilized the Microsoft.Kinect and System.Windows.Media.Media3D namespaces to access the 3D vectors of the joints. A calibration was performed to define the angle between the joints and the Kinects' x, y and z axes for various motions. The postural assessment system operates by recording the user's profile. This allows the user to measure the flexion/extension, lateral flexion, and abduction/adduction of upper arm, elbow, trunk, and neck. A detail explanation on the development and validation of the postural assessment system is available in the earlier publication of this research [23].

2.2 Development and validation of EMG signals acquisition system

The EMG signals acquisition system consists of a National Instruments USB 6000 data acquisition (NI DAQ USB-6000) - as the microcontroller, four EMG electrodes/ amplifiers, one Lithium-ion polymer (LiPO) battery - as the power supply, a voltage checker and two 9V relays. Its casing was designed using computer aided design (CAD) and fabricated by the Stratasys Mojo 3D printer machine (USA). Fig. 1 shows the basic circuit connection (left) and the complete internal construction (right) of EMG signals acquisition system.

The NI DAQ USB-6000 acts as the interface between the computer and EMG signals acquired from the muscles. It serves a function to digitize the incoming analogue signals of EMG to enable computer to interpret the data. This microcontroller is connected to EMG electrodes/ amplifiers. Four EMG amplifiers produced by Advancer Technologies Muscle Sensor v3 were applied to acquire and rectify the EMG signals. The EMG signals acquisition system performs three processes: amplification, rectification and smoothing. Since the EMG raw signals are too small, the amplifier will amplify them. Then the raw signals of the EMG will be rectified. In the smoothing stage, the noise from the EMG raw signals will be filtered by one capacitor (1 μF) and a resistor (80.6 kΩ) to yield smoothed EMG signals. This configuration filters the noise using active low pass filter. The active low pass filter is one of signal filtering techniques applied to impede the frequency in EMG raw signals above the selected cut-off frequency (the stop band), but this filter allows the frequency below the chosen cut-off frequency (the pass band) to pass with minimum distortion [24]. To ensure the quality of the EMG signals, the averaged baseline noise was maintained less than 5 μV when the muscle is relaxed [25].

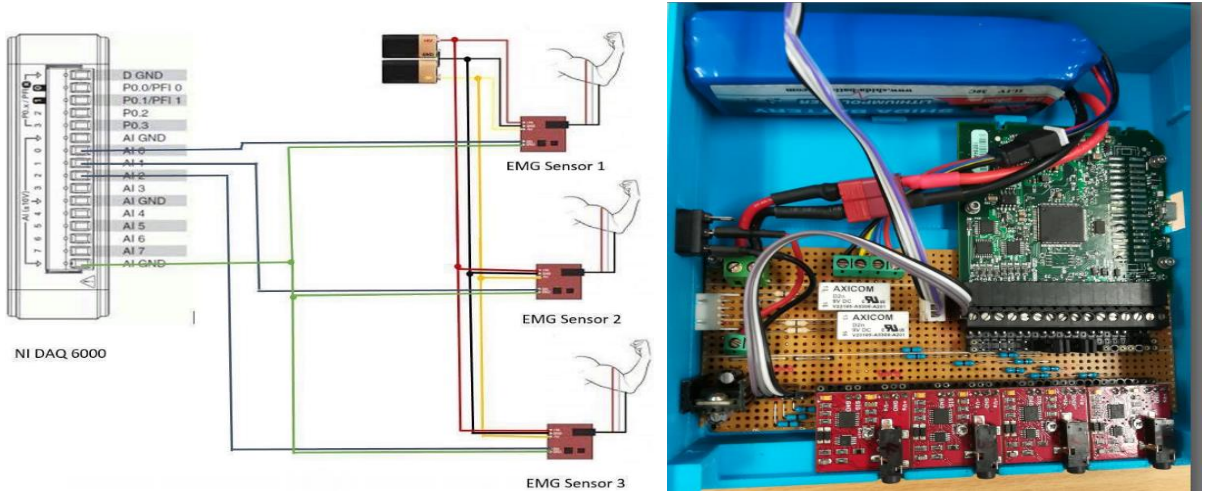
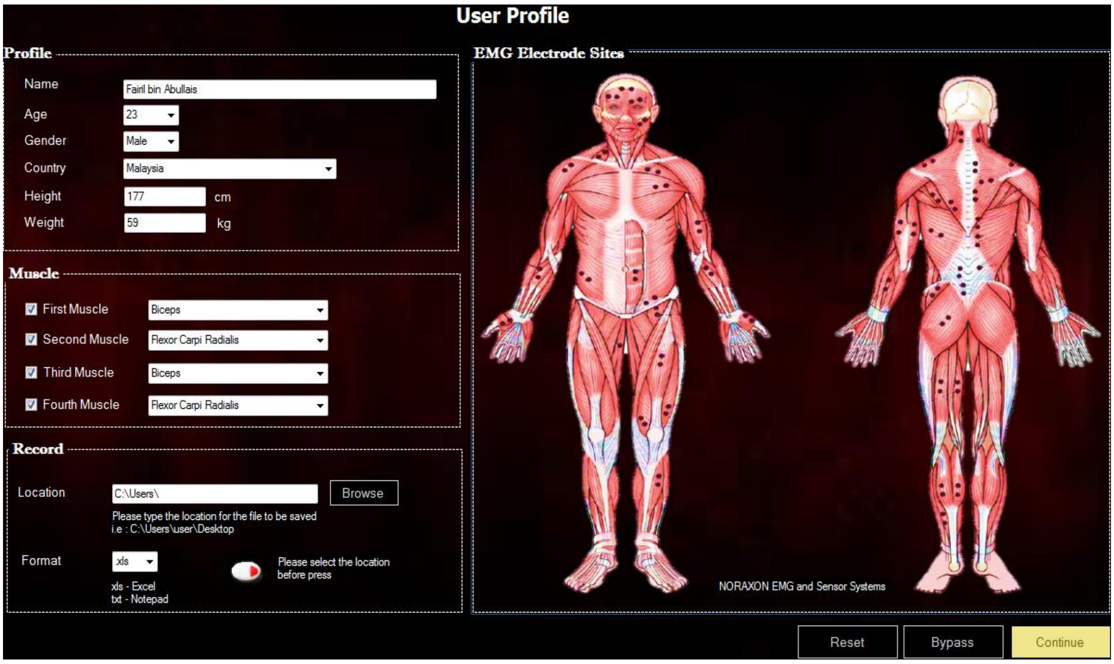


Fig. 1 - Basic circuit diagram (left) and internal construction of system (right)

Two Graphical User Interfaces (GUIs) were created to ease communication between the users and the EMG system. The first GUI (Fig. 2) records information on subject profile (e.g. name, age, gender, country, body weight and height). It also provides a list of muscles to be studied (with assistance of EMG electrode placement sites and diagrams of anterior and posterior of human anatomy), record and save data, navigate location of data saving and decide file format (e.g. MS Excel or pdf). Once these information have been entered in the first GUI, the user then clicks the 'Continue' button to proceed to second GUI (Fig. 3). In the second GUI, the user has to press 'ON' button to start data recording. At the moment, the NI DAQ USB 6000 will convert analogue signal to digital signal for displaying the raw EMG signals.

After the EMG raw signals have been detected, the amplifier will rectify them to be rectified EMG signals. The purpose of rectification is to transform the negative amplitudes of raw signals (data less than baseline ‘zero’) to positive amplitudes (all EMG data will be above baseline ‘zero’). This setting allows the users to read the signals easily. Additionally, this study applied Microsoft Visual Studio to calculate the maximum voluntary contraction (MVC) of voltage and current during amplifying and rectifying process.

An initial validation of the EMG signals acquisition system was executed by using a battery to test the input and output signals. The EMG system should display volt value if the battery is connected to the circuit and no volt value displayed when the battery is removed. Further validation was performed using a voltmeter and two 9V batteries to examine functionality and sensitivity of all four muscle electrodes/ amplifiers. These two testing are shown in Fig. 4.



User Profile

Profile

Name: Fairil bin Abullais
Age: 23
Gender: Male
Country: Malaysia
Height: 177 cm
Weight: 59 kg

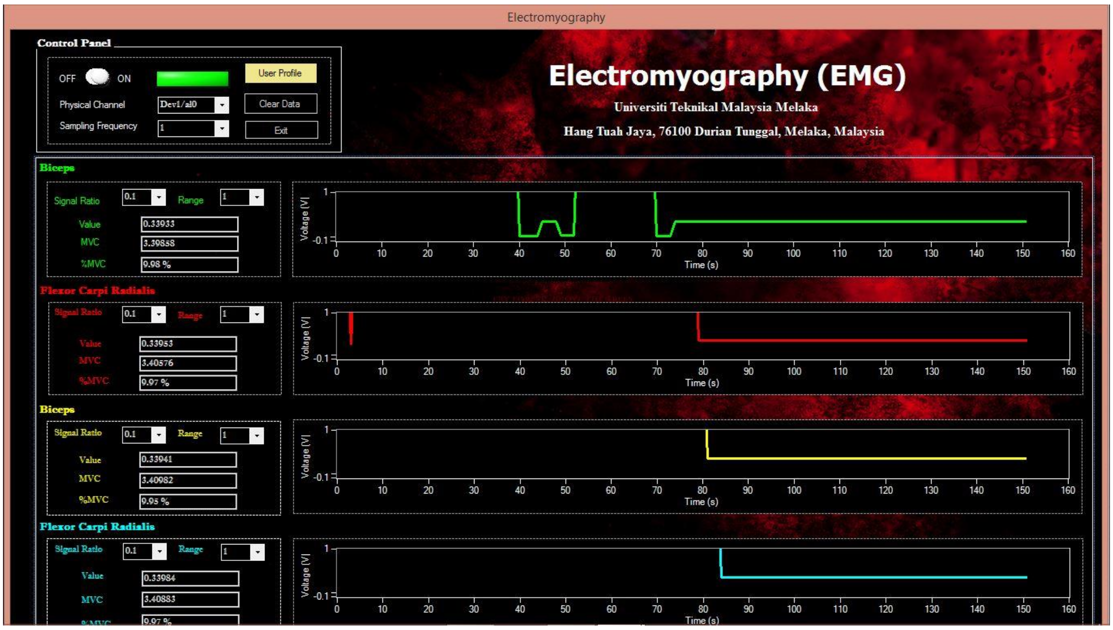
Muscle

☑ First Muscle: Biceps
☑ Second Muscle: Flexor Carpi Radialis
☑ Third Muscle: Biceps
☑ Fourth Muscle: Flexor Carpi Radialis

Record

Location: C:\Users\
Please type the location for the file to be saved
i.e : C:\Users\user\Desktop
Format: xls
xls - Excel
txt - Notepad
Please select the location before press

Fig. 2 - First GUI: Individual particulars, muscle measured, record and EMG electrode



Electromyography (EMG)
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

Control Panel

OFF ● ON
Physical Channel: Dev1/ai0
Sampling Frequency: 1

Biceps

Signal Ratio: 0.1 Range: 1
Value: 0.33933
MVC: 3.39858
%MVC: 9.98 %

Flexor Carpi Radialis

Signal Ratio: 0.1 Range: 1
Value: 0.33953
MVC: 3.40576
%MVC: 9.97 %

Biceps

Signal Ratio: 0.1 Range: 1
Value: 0.33941
MVC: 3.40982
%MVC: 9.95 %

Flexor Carpi Radialis

Signal Ratio: 0.1 Range: 1
Value: 0.33984
MVC: 3.40883
%MVC: 9.97 %

Fig. 3 - Second GUI: Control panel and graph of EMG signals

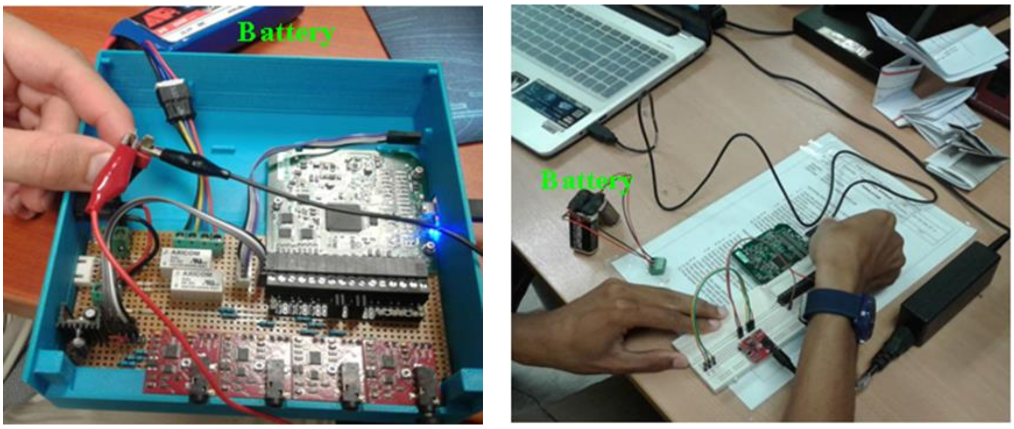


Fig. 4 - Testing of output EMG signals (left) and functionality and sensitivity (right)

Final stage of validation was a comparison of EMG signals (microvolt) generated by all four electrodes/ amplifiers of EMG system developed by this study and four EMG electrodes/ amplifiers of a commercial EMG system (Noraxon EMG, USA) – as the reference system. Three volunteers were assigned to perform a simple load lifting experiment as shown in Fig. 5. Two loads (5 kg and 10 kg) were lifted by subjects for both EMG systems. Also, the experiment procedures and electrodes placement were standardised based on The European Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) [26]. A ratio of microvolt values between lifting load of 10 kg and 5 kg was calculated for each EMG system. Then, the ratio from both EMG systems was compared by calculating the percentage difference. To get the percentage difference, the microvolt ratio of EMG system developed by this study minus the microvolt ratio of commercial EMG system, and divided by the average of these 2 ratios. Then multiply the result by 100 to yield a final value in percent, as simplified by this formula:

$$\frac{|V_1 - V_2|}{\frac{(V_1+V_2)}{2}} \times 100 \tag{1}$$

Whereby:
V1 = Microvolt ratio of EMG system developed by this study
V2 = Microvolt ratio of commercial EMG system (Noraxon EMG, USA)

This study paid a high attention to minimize the noise level in the EMG signals for aiming a percentage difference below than 5 percent [27]. This is important to ensure the accuracy of EMG data produced by the developed system. To achieve this target, the researchers made three efforts. The first effort was related to the software such as enhancement on the algorithm and program codes for better noise filtration. The second effort was given to the hardware – securing the electrode cables with a minimal tension. This is important to minimize artifacts due to cable movement and to avoid the electrodes detach from skin during the experiment. In this study, the researchers utilized a regular tape to secure the electrode cables. The third effort concentrated on the measurement procedures. This includes skin preparation and attachment of the electrodes. The quality of EMG signals mainly depends on a proper skin preparation. The purposes of skin preparation are to stable the electrodes attachment and allow a low skin impedance. This study applied the following skin preparation steps before attaching the electrodes:

i. Removing the hair – the hair was shaved with a disposable razor. This is needed to ensure the area where the electrodes would be attached must be cleaned and free from hairs.
ii. Cleaning of the skin – the skin was cleaned and dried by using alcohol and a soft textile towel.

To confirm the skin was prepared properly, it receives a light red color indicating a good skin impedance state [25]. Furthermore, this study attached the electrodes to the skin with the guidance of The European Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) [26].

Fig. 5 - Comparing EMG system prototype developed by this study (left) and Noraxon EMG, USA (right)

2.3 Integrating the postural assessment system and EMG signals acquisition system

This study created a GUI shown in Fig. 6. This GUI allows a user to perform measurement of postural angle and EMG signals simultaneously. As an alternative, the user can also execute individual measurement (measuring postural angle and EMG signals separately). Additionally, this GUI helps the user to visualize the data produced from the measurement. Fig. 7 shows the prototype of integrated system (left) with GUIs for postural angle and EMG signals measurement (right).

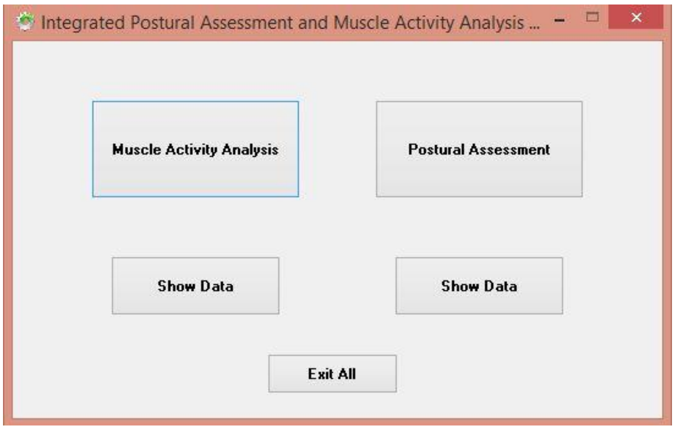
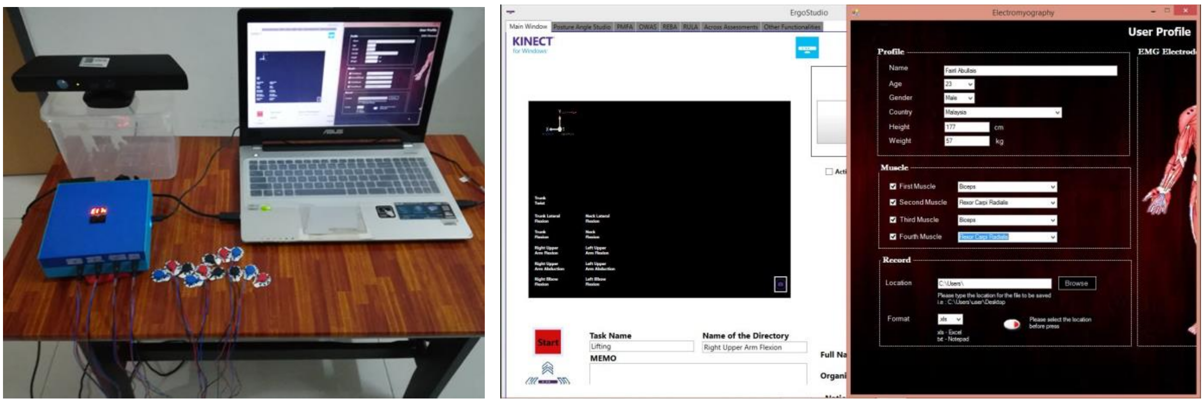


Fig. 6 - GUI for postural angle and EMG signals measurements



Task Name: Lifting
Name of the Directory: Right Upper Arm Flexion
MEMO

Age: 23
Gender: Male
Country: Malaysia
Height: 177 cm
Weight: 57 kg

☑ First Muscle: Biceps
☑ Second Muscle: Flexor Carpi Radialis
☑ Third Muscle: Biceps
☑ Fourth Muscle: Flexor Carpi Radialis

Location: C:\Users\
Please type the location for the file to be saved i.e : C:\Users\user\Desktop
Format: xls
xls - Excel
txt - Notepad
Please select the location before press

Fig. 7 - Prototype of integrated system (left). View of postural angle and muscle activity interfaces (right)

2.4 Testing of the Integrated System

The purposes of the testing were to visualize the data of postural angles and EMG signals, and to understand the interaction of these two variables. To do that, a case study of MMH task was simulated in the Ergonomics Laboratory of Universiti Teknikal Malaysia Melaka (UTeM). There were 26 male undergraduate university students participated as subjects in testing the prototype of integrated measurement system. Majority subjects were right-handed. The subjects were given a consent form to record their readiness to participate in the testing. Testing procedures and EMG electrodes placement were referred to European Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles

(SENIAM) [26]. The EMG signals were measured from four muscles, right and left biceps and right and left brachioradialis. A 3D sensor (Microsoft Kinect^{TM}) was positioned 2.3 - 3.5 meters away from the subjects to record and measure their postural angles.

In the simulated case study, the subjects were required to lift a load of 5 kg in a plastic crate. As shown in Fig. 8, the sequence of lifting process was: 1. Hold and lift the plastic crate from the floor (Activity A); 2. Stand up, hold and carry the plastic crate (Activity B); 3. Put the plastic crate onto a table (Activity C). The distance from the start point to the destination was 3 meters. The subjects performed this lifting process in one cycle with a duration less than 2 minutes. Before doing the experiment, all subjects were provided with a consent form. The consent form consists of research information and experiment procedures so that they can make a firm decision to participate in the study. The subjects were asked to sign the form and informed taking part in this experiment is voluntary basis – they can leave the experiment at any time without prejudice. A few trials were given to the subjects prior to actual testing to familiarize themselves with the experiment procedures. Each subject took around 20-30 minutes for the experiment preparation and execution. At the end of testing session, all subjects were given a reward to appreciate their participation. The experiment procedures were reviewed and approved by the Research Ethics Committee of Universiti Teknikal Malaysia Melaka (Reference no.: UTeM,11.02/500-25/1/4(21)). Data of postural angles and EMG signals generated from the experiment were compiled continuously to represent continuous activities of the simulated MMH task.

Fig. 8 - Lifting process of a 5 kg load

3. Results

Table 2 tabulates data of postural angles (deg.) and EMG signals (µV) of biceps (upper arm) and brachioradialis (forearm) from all subjects. These data represent the postures and muscle activity of subjects while performing a simulated case study of MMH task (holding, lifting and carrying of 5 kg load) as mentioned in 2.2. In general, the integrated measurement system developed by this study was capable to measure and generate data of postural angles and EMG signals. Specifically, Table 2 presents the maximum postural angles (deg.) between both left and right forearms and upper arms, and the maximum values of EMG signals (µV) measured in the left and right biceps and brachioradialis muscles. The biceps lie on the front of the upper arm between the shoulder and the elbow and the brachioradialis is located in the forearm. The EMG signals represent electrical voltage (measured in microvolts, µV) generated in the muscles during their contraction [28]. Higher EMG signals indicate greater muscle contraction, and hence larger force generated by the muscle. Additionally, muscle contraction varies among individuals [29], and this was proved by the current study whereby the magnitude of EMG signals is differ among the subjects (Table 2). One of direct factors influencing the EMG signals is intrinsic or inherent individual factors [28]. These factors include joint angle, number of active motor units, blood flow, muscle cross-sectional area, muscle fiber composition, muscle fiber diameter, depth and location of active muscle fibers and amount of tissue between muscle surface and EMG electrodes [28]. Furthermore, this study observed that majority subjects exerted higher contraction in the left biceps and left brachioradialis muscles than the right muscles (Table 2). This indicates the subjects paid greater effort on the left upper and lower arms to grip, lift and carry the load. The higher EMG values for the left muscles compared to the right in the present study reveal the right-handed subjects tend to exert more forces in left hand muscles, in line with the findings of previous study [30].

Line charts in Fig. 9 to Fig. 12 illustrates the interaction between the postural angles and the EMG signals when the subjects performed the simulated case study of MMH task. The EMG signals (µV) and postural angles (°) are plotted in horizontal (x) axis and vertical (y) axis respectively. Based on the charts, this study observed that the EMG signals in right biceps showed a marginally increase when the postural angle increase. However, the left biceps illustrated an opposite trend. Meanwhile the right brachioradialis muscle showed increment of EMG signals when the postural angles decrease. In contrast, the left brachioradialis muscle indicated the EMG signals increase when the postural angles increase.

Statistical analysis associated with Pearson correlation coefficient (Pearson's r) revealed that there is a low coefficient of correlation between the postural angles (deg.) and EMG signals (μV), as shown in Table 3. Generally, this indicates the correlation is exist but weak. In other words, the magnitude of EMG signals generated from the muscles were not change significantly regardless the increment of upper arm and forearm angles. This is due to handling the 5 kg load was not forceful enough to contract the muscles. The correlation coefficients of right upper arm, right forearm and left forearm show a positive correlation. This means, as the postural angles of these parts increase, the EMG signals are also rise. However, the correlation coefficient of left upper arm indicates negative correlation, which means there is a steady decrement of EMG signals as the postural angles of this part increase.

Table 2 - Postural angle (deg.) and EMG signals (μV) of biceps (upper arm) and brachioradialis (forearm)

	Right upper arm		***Right forearm***		***Left upper arm***		***Left forearm***	
Subject	Postural angles (deg.)	EMG signals (μV)	Postural angles (deg.)	EMG signals (μV)	Postural angles (deg.)	EMG signals (μV)	Postural angles (deg.)	EMG signals (μV)
1	23.192	2070	33.460	1550	15.783	2750	34.990	1330
2	27.819	600	34.684	1470	40.318	790	56.858	400
3	31.907	390	34.298	1420	33.043	1680	35.083	2390
4	35.166	770	23.406	780	35.456	860	20.374	550
5	24.164	940	21.742	390	25.696	970	5.770	1140
6	21.157	1070	44.798	2060	21.528	1940	33.509	1940
7	17.986	660	47.019	320	27.121	1230	47.935	1080
8	29.872	1910	19.742	3420	31.339	400	16.188	630
9	21.073	600	23.884	700	20.692	790	23.257	360
10	17.241	220	55.133	80	18.803	600	43.759	270
11	34.276	420	41.447	410	41.323	500	33.843	840
12	28.058	1250	33.517	910	27.455	980	31.851	860
13	17.861	1560	51.917	2600	20.757	1310	45.734	1470
14	25.424	1460	44.145	140	35.610	2460	35.920	750
15	20.684	3210	70.624	2510	23.589	2250	69.292	2900
16	25.329	1200	27.696	930	24.407	1890	22.846	1120
17	13.634	1930	51.915	110	13.736	1620	42.610	890
18	19.061	500	63.466	500	22.520	760	59.871	430
19	26.765	820	58.040	760	32.158	1360	51.873	1280
20	26.951	1120	58.238	910	15.655	1180	55.089	980
21	36.602	2000	62.100	820	18.002	1980	65.246	2500
22	33.193	1780	56.821	700	29.245	2180	61.421	1160
23	41.234	2300	81.534	920	34.021	2780	71.291	1220
24	23.811	1020	51.642	670	14.330	1610	44.186	990
25	27.318	760	47.067	1180	24.849	2060	41.312	2070
26	22.681	1900	51.485	920	21.664	3220	56.606	1350

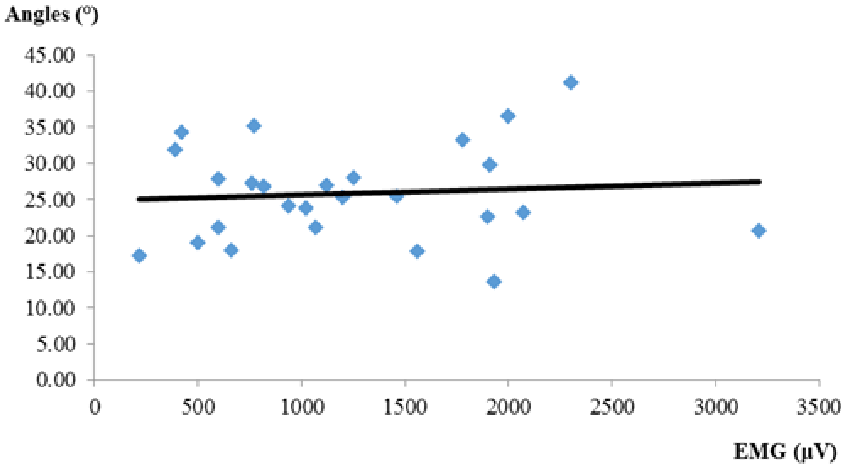


Fig. 9 - Interaction between postural angles and EMG signals in right biceps

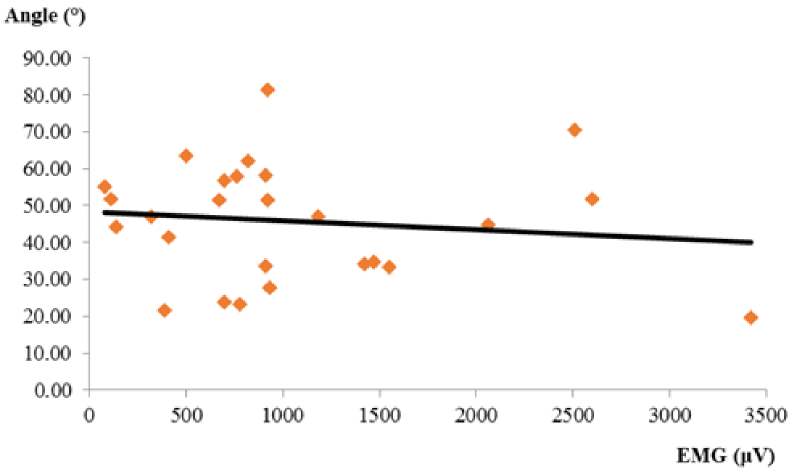


Fig. 10 - Interaction between postural angles and EMG signals in right brachioradialis

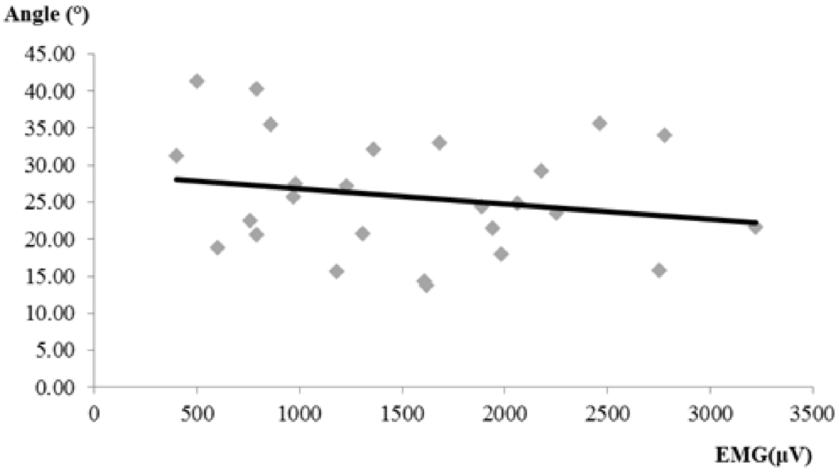


Fig. 11 - Interaction between postural angles and EMG signals in left biceps

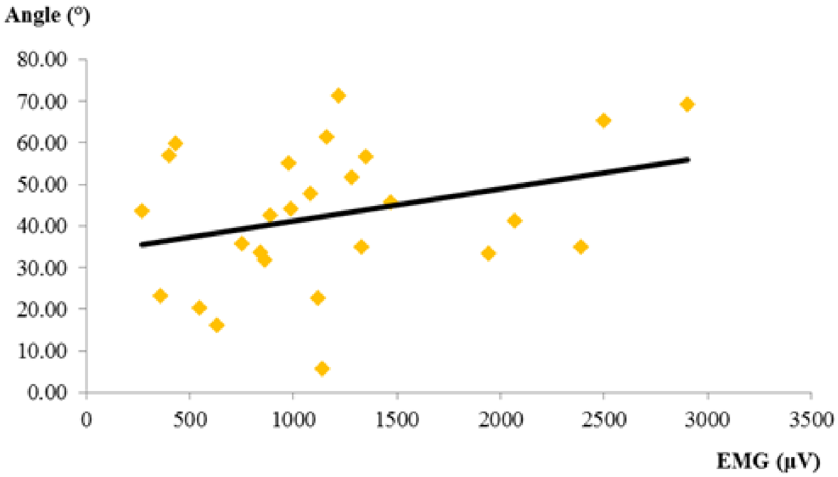


Fig. 12 - Interaction between postural angles and EMG signals in left brachioradialis

Table 3 - Correlation coefficient between postural angles (deg.) and EMG signals (µV)

	Pearson's *r*
Right upper arm	0.081797
Right forearm	0.097957
Left upper arm	-0.20288
Left forearm	0.313814

4. Discussion

Based on the aforementioned results, this study observed that the patterns of EMG signals are depending on hand postural angles when subjects performing a simulated case study of MMH task (holding, lifting and carrying of 5 kg load). Findings presented in this study showed a good agreement with the previous studies which reported the hand postural angles are important factors for the hand muscles contraction. Lee [31] identified that the hand posture has a great influence on the forearm muscle activities when lifting cylindrical and rectangular objects. Amar and company [32] in their study revealed that the postural angles determined muscle activities in one-handed lifting of 1, 1.5, 2, 2.5, and 3 kg loads. Lee [33] found that the hand postures resulted in significant differences of EMG activity of serratus anterior muscle during push-up plus exercise. Roman and Bartuzi [34] concluded that wrist posture influenced EMG signals of extensor digitorum communis and flexor carpi ulnaris muscles. Cudlip [35] detected that wrist posture affected over two thirds of muscle contraction levels. The back muscle activities increased as the upper trunk and pelvic angles exceeded 0° [36]. Shair [37] identified an interaction (but not significant) between trunk postural angle and EMG activity of erector spinae muscle during squat core-lifting task. One explanation on this postural angle and EMG signal interaction is that muscle shortening (concentric contractions) due to changes in postural angle stimulates the EMG signal and its amplitude [34].

Another plausible explanation for the interaction between the postural angle and EMG signal might be due to the different effects of gravity or mechanical load in different body postures. The above explanation was supported by a study conducted by Edmondston [38] whereby the authors identified that neck flexion increased mechanical load and extensor muscle activity compared to other neck positions. The above theory and explanation regarding the relationship between the postural angles and EMG activity had been applied by several researchers to develop an effective postural assessment tool. For example, Hignett and McAtamney [39] had developed Rapid Entre Body Assessment (REBA) to evaluate work postures due to postural angle, load and coupling. The postural scores of REBA were given based on the angle measured from the neutral position (0 degree), in which the scores will be higher when the postural angle deviates from the neutral position [39]. However, the above mentioned observational tools had its own limitation in terms of precision and clarity as they were developed based on semi-quantitative method. Therefore, it is necessary to develop an integrated measurement system that allows simultaneous quantification and accurate readings of postural angles and EMG signals.

The application of integrated measurement system developed by this study is to assist ergonomics practitioners and engineers to objectively measure postural angles and muscle exertion during MMH task. They can analyze the postural angles and EMG signals to justify risk level of work posture and muscle exertion. For example, if the torso in forward bending, 0°–20° is considered low risk, however, 20°–60° and greater than 60° are defined as medium and high risks respectively [40]. Meanwhile, based on EMG signals, ergonomics practitioners and engineers may determine the onset of muscle fatigue when holding load greater than 15% of maximum voluntary contraction (MVC) [41]. Additionally, they can utilize this integrated measurement system to analyze the interaction of work postures and muscles exertion so that MMH task can be designed ergonomically to avoid postural stress and muscle sprain.

With the advancement of digital technology and computational intelligence nowadays, many postural angle measurement system [42-44] and EMG signal acquisition system [45-47] were designed and built using a cost effective hardware. This study was also utilized a low cost 3D sensor for postural angle measurement and low cost EMG hardware (e.g. electrodes/ amplifiers and cables). However, dissimilar to the previous works, this study made an extra effort to develop and testing an integrated measurement system for measuring postural angles and EMG signals in MMH tasks. Advanced commercial human motion tracking and EMG signal acquisition systems available in the market might be provide an extensive feature and function for acquiring high quality postural angle and EMG data. The commercial ones employed multi high-speed and high-definition cameras, and state-of-the-art cables and amplifiers with adjustable gains which can offer highly accurate values; hence their performance is definitely higher than the low cost systems. For instance, EMG cable technology such as built-in miniaturized amplifier and PS/2 connector type play a significant role to avoid motion artefacts and noise during signals acquisition process. On the other hand, the advantages of low cost postural angle and EMG measurement systems are acceptable accuracy and inexpensive, thus making affordable to small-scale research laboratories and industry practitioners.

5. Conclusion

The contribution of this study was a prototype of an integrated measurement system for measuring postural angles and EMG signals. The application of this integrated measurement system is to provide a simultaneous assessment of work posture and muscle activity for ergonomics practitioners and engineers aiming to design a safe MMH task in industry workplaces. The system was developed using a cost effective hardware. Based on laboratory testing of manual lifting task, this study found that the developed system was able to generate postural angles which correlate to the patterns of EMG signals. Interestingly, this finding showed a good agreement with the established studies. Further study is required to enhance the reliability and usability of the system so that it may facilitate ergonomics practitioners and engineers to assess work posture and muscle effort in MMH task.

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