Human Factors and Ergonomics Journal 2018, Vol. 3 (2): 12 – 16

ORIGINAL ARTICLE

A PRELIMINARY INVESTIGATION ON THE USAGE OF AN EXOSKELETON SYSTEM FOR MANUAL HARVESTING OIL PALM TREES

Muhammad Fuad, MOHD[1], Hazreen H., HARITH[1*]

[1] *Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia.*
** corresponding author (email:hazreen@upm.edu.my)*

ABSTRACT

Agricultural activities in Malaysia is still laborious at large as numerous tasks are performed manually, including in the oil palm industry. The involvement of manual and energy-intensive activities for harvesting tasks in oil palm plantations partly limits its productivity. The manufacturing industry still involves manual tasks, however, exoskeleton systems are actively adopted to improve productivity and safety of operations involving human. Therefore, we postulate that they could also be applied in the agricultural industry. A challenge in adopting any commercially available exoskeleton system for harvesting oil palm trees is to match the system's feature and the requirements of the harvesting task. Since manual harvesting requires extensive upper limb motion, therefore this study investigates the feasibility of using a passive upper limb exoskeleton system for manual harvesting activity. Electromyography (EMG) signal of the anterior deltoid muscle located at the shoulder was compared when carrying 2 kg, 4 kg and 5 kg loads with and without an upper limb exoskeleton system. The test involved tugging motion and holding the weights at arm's length for 1 minute. EMG results indicate that the muscle activity was reduced when performing these exercises while donning the exoskeleton for all tested loads. Nonetheless, the exoskeleton design requires optimization to suit oil palm harvesting tasks so that the productivity and safety of manual oil palm harvesting activity can be enhanced.

Keywords: *Exoskeleton, Muscle activity, EMG, Fatigue, Oil palm, Manual harvesting, Biomechanics*

INTRODUCTION

The oil palm industry is one of the largest industries in Malaysia. Very simply, harvesting of the fresh fruit bunches (FFB) is performed in two stages; harvesting of the FFB from the tree, and evacuating the FFB onto a collector lorry (Ng *et al.*, 2013). The harvesting of FFB is typically performed using a long pole. The difficulty in handling the long pole increases with tree height due to the flexure of the pole. While automated harvesting machines could ease the harvesting process (Shokripour *et al.*, 2012; Baker *et al.*, 2015), manual harvesting is still the preferred method of harvesting due to ease of handling and easy access to challenging terrains, amongst other reasons.

Manual harvesting provides a wide range of manoeuvrability during harvesting. It enables workers to direct the pole to the desired position on the palm oil tree efficiently. This is important because the location of the FFB on the tree trunk and the arrangement of the fronds restricts direct access to the FFB. Unfortunately, since manual harvesting is laborious and requires eccentric posture, its productivity is limited by the physical fitness of the harvester. Fatigue is a major factor that reduces harvesting productivity and poses musculoskeletal problem risks on the harvesters (Ng *et al.*, 2014, 2015).

An exoskeleton is a wearable device that can augment human's physical performance or provide additional support to the human body (Herr, 2009; Butler, 2016). Several studies have demonstrated exoskeleton systems designed for specific tasks in specific environments, including rehabilitation (Mohammadi *et al.*, 2014), manufacturing (Garrec, 2010) and strength training (Wu and Chen, 2014). In the field of agriculture, for example, an exoskeleton has been reported to assist ambulation and posture in gardening (Toyama & Yamamoto, 2009). The study reported that the exoskeleton reduced physical exertion by more than 70% during use. However, no elaboration was provided regarding the productivity of the task.

A passive exoskeleton system is an unpowered exoskeleton system and provides support mechanically. An upper limb exoskeleton to assist performing overhead tasks was designed and build. It has arms support mechanism strapped around the biceps, providing lifting support to the shoulder joint. As the harvesting activity also requires repetitive extension of the arm while handling the pole and performing the cutting task, this passive system may be feasible to assist the activity. Given the tough nature of harvesting oil palm FFB using manual pole, this study aims to provide an initial study on the feasibility of using an upper limb exoskeleton to reduce the effect of fatigue during the activity, by analysing muscle activity.

METHODS

EMG measurement

For muscle activity detection, an EMG sensor circuit with AD8232 chip; common-mode rejection ratio: 80dB (dc to 60Hz), was used. This circuit board utilizes surface electrodes to detect electrical activity of the muscle below the attached skin. Custom length electrode leads were used to reduce interference. The sensor is connected to the 10 bit analogue to digital converter of an Arduino Uno microcontroller board, which reads and stores data onto a class 10 SD card. OriginPro software (version 2016) by OriginLabs ("OriginLab", 2016) was used for post-processing.

The EMG signal of the anterior deltoid muscle (onwards referred to as deltoid) was recorded, which functions to flex the arm (Hawkes *et al.*, 2012). The signal was stabilized for 10 seconds before starting the exercise. Disposable, self-adhesive pre-gelled Ag/AgCl electrodes with conducting area of 10 mm diameter were used. With an interelectrode distance of 20 mm, the electrodes were placed parallel to the muscle fibres and away from other muscle groups according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) standards (Stegeman & Hermens, 2007). Skin preparation was done using alcohol wipes to reduce electrode impedance with the skin. The EMG data was band-pass filtered and fully rectified in accordance with the international guidance; 10-500Hz for surface electrodes (Merletti & Torino, 1997) and denoised using wavelet transform, type DB6. The EMG averaged envelope was acquired using moving averaging window so that EMG levels can be compared.

The EMG signal is illustrated in waveform graph that represents muscle contraction. The peaks indicate muscle contraction in millivolts(mV). Additionally, higher peak indicates stronger muscle contraction, and thus greater force produced by the muscle. The high peak is produced by muscle fibres of the fast type, which has stronger contraction, but is susceptible to fatigue (Svebak *et al.*, 1993). A previous study (Komi & Viitasalo, 1977) showed that eccentric muscle contraction uses higher energy expenditure which causes muscle fatigue compared to concentric muscle contraction. In this study, the EMG waveform when wearing the exoskeleton was compared to pre-wearing the exoskeleton. A lower EMG peak would suggest that in a long-term activity, fatigue levels would be lower when using the exoskeleton compared to without the exoskeleton.

Subjects and experimental setup

Four (4) healthy male volunteers were recruited for the test. Informed consent was obtained from the participants to perform the assessment. Their physical characteristics are described in Table 1. Each subject performed two types of work tests, namely tugging and holding, 5 times within 5 days. Subjects rested in between assessments.

Table 1 Physical characteristics of the subjects with respect to age, height and weight

Subjects	Age	Height	Weight
L.S	22	175	55
L.C	23	176	80
A.A	22	165	75
M.F	28	177	85

The Functional Impairment Test-Hand, Neck, Shoulder and Arm (FIT-HaNSA) protocol was modified to assess the feasibility of using an upper limb exoskeleton for oil palm harvesting activities. Informed consent was obtained from the participant to perform the assessment. The FIT-HaNSA test as described by (MacDermid, 2007), involves three tasks. Task 1 requires lifting weights from the waist height to a shelf 25cm above it; Task 2 involves lowering weights from the eye level to a second shelf 25 cm below; Task 3 requires screwing and unscrewing bolts at an overhead position. Each task was performed until the objective was met or a maximum time of 5 minutes.

For this study, 2 kg, 4 kg and 5 kg weights were chosen to test the limit of assistance by the exoskeleton. Assuming harvesting a 10-meter oil palm trees requires a 3 m long and 10 kg harvesting pole equipped with a cutter, 5 kg weight was used to simulate the weight of the pole on each arm. The EMG signal at the deltoid muscle was recorded while each subject performed the modified versions of Task 1 and Task 3 of the FIT-HaNSA protocol. Task 1 simulates pole tugging motion during oil palm harvesting. It required the shoulder joint to be abducted 90 degrees perpendicular to the body, while the forearm was abducted 90 degrees perpendicular to the ground (Figure 1a). The subject moved the arm and forearm up and down 5 times while keeping the posture of the forearm stable. The subject completed five sets or until fatigue. The subject rested for five minutes before repeating the exercise using 2kg, 4kg, and 5kg weights.

Task 3 represents the endurance test for the purpose of simulating pole handling during harvesting. This exercise requires the subject to flex the arm forward 90 degrees perpendicular to the body (Figure 1b). The subject held the arm in such position for one minute or until tired. The subject rested for five minutes before repeating the exercise while holding 2kg, 4kg, and 5kg weights. The EMG signal was allowed to stabilize for ten seconds before starting the exercise. Both exercises were performed with and without donning the exoskeleton.

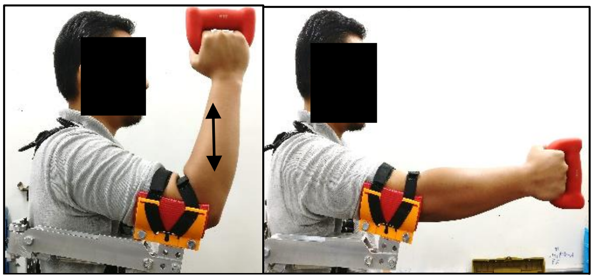

Figure 1 a) Tugging exercise to simulate motion during palm oil harvesting while wearing the exoskeleton. **b)** Endurance exercise simulating

RESULTS AND DISCUSSION

EMG analysis

The deltoid muscle functions to flex the arm. Therefore, the high peaks in the EMG signals indicate upward motion of the arm. Since the tugging exercise involves large motion, it can be clearly seen in Figure 2 that the high peaks correspond to lifting the arm. Comparing the recorded EMG signals when performing Task 1 with and without the exoskeleton, it was found that the peaks were lower with the exoskeleton than without the exoskeleton (Figure 2). This indicates lower muscle activation when wearing the exoskeleton.

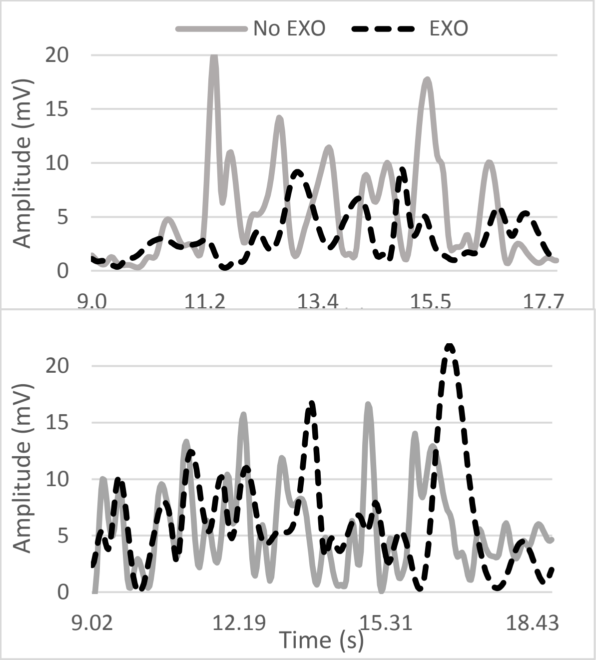

Figure 2 EMG measurements comparison during tugging exercise (Exercise 1). Higher amplitude represents greater muscle motor unit (MMU) activation, therefore higher contraction force by the muscle. a) Lower amplitude suggests reduced muscle forces needed to lift the same 2kg weight. b) Similar peaks during 5kg lifts indicate little to none reduction in muscle contraction with and without the exoskeleton.

Endurance analysis

Similarly, the EMG amplitude of the deltoid muscle shows noticeable differences between wearing and not wearing the exoskeleton when performing Task 3. In each weight set, the amplitude of the EMG signal when wearing the exoskeleton was lower than that without it. Lower peaks indicate low muscle activity, thus as described earlier, increasing the time to fatigue for the muscle. The amplitude difference between wearing and not wearing the exoskeleton was calculated for all subjects, for all test loads, represented in percentage. The average of the percentage is shown in Figure 3. Apparent EMG signal difference can be seen in Table 2, especially when comparing the EMG signals of 2 kg and 4 kg weights. However, the 5 kg EMG signal across all subjects shows smaller differences between wearing and not wearing the exoskeleton, which may suggest that the exoskeleton support was limited. Figure 3 shows each subject's average EMG levels in the 5kg exercise had a reduction of 47.5% compared to 53.3% from the 4kg exercise.

Table 2 Average EMG comparison when wearing and not wearing the exoskeleton

Subject	Load	Average EMG level (no exos)	Average EMG level (with exos)
A.A	2kg	0.083	0.05
	4kg	0.153	0.078
	5kg	0.16	0.09
L.C	2kg	0.074	0.043
	4kg	0.138	0.08
	5kg	0.174	0.119
L.S	2kg	0.165	0.065
	4kg	0.28	0.117
	5kg	0.345	0.126
M.F	2kg	0.071	0.037
	4kg	0.155	0.056
	5kg	0.189	0.092

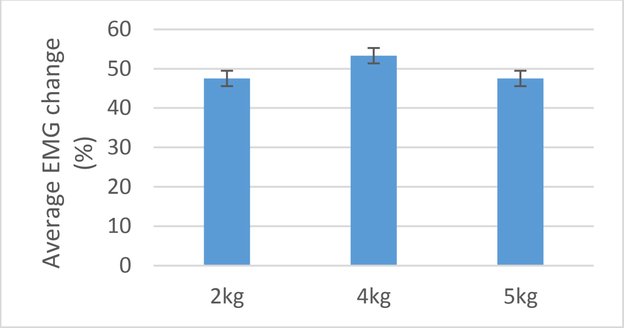

Figure 3 Chart of average EMG levels reduction in percentage between wearing and not wearing the exoskeleton. 5kg load shows smaller change compared to the 4kg load.

Task 3 allows the assessment of endurance while holding different weights. Subjects were able to hold the 2 kg weights for one minute while supported or unsupported by the exoskeleton. However, for the 4 kg and 5 kg loads, the subjects were able to hold the loads longer while assisted by the exoskeleton. As shown in Table 2, without exoskeleton assistance, the maximum holding time of subject L.C for 4 kg and 5 kg was 31 s and 19 s respectively. While using the exoskeleton, the maximum holding time was 41 s and 30 s. The ability for the subjects to hold the weights longer indicates lower muscle energy expenditure when using the exoskeleton, which in turn, would delay fatigue.

Table 3 Comparison of the average holding time for 2kg, 4kg and 5kg load when supported and unsupported by the exoskeleton with

Subject	2kg		4kg		5kg	
	No exos	With exos	No exos	With exos	No exos	With exos
L.S	60s	60s	22s	35s	15s	28s
L.C	60s	60s	31s	41s	19s	30s
A.A	60s	60s	15s	40s	14s	30s
M.F	60s	60s	21s	34s	16s	30s

Exoskeleton mobility in relation to the exercises

It was also observed that the subjects were able to perform the exercises without any restriction when testing was performed, which shows that the exoskeleton components did not interfere with the current exercises.

In addition, the arm support mechanism continuously provides lifting support to the shoulder joints. However, harvesting motion requires swift downward motion during cutting. In such situation, the mechanism would resist lowering of the arms.

CONCLUSION

The usage of a properly-designed upper limb exoskeleton system for harvesting oil palm trees can reduce the effect of fatigue. Such assistance is helpful in increasing the productivity of the harvesters. As shown in the results, the tested exoskeleton was able to reduce the peak muscle activity during the exercises that simulate palm oil harvesting activities. The subjects were able to hold the weights longer when assisted by the exoskeleton, as shown in the endurance test, suggesting that muscle fatigue could be delayed for the tested weights. Since the support provided by the exoskeleton helps in the reduction in muscle activity, it is useful to reduce the effect of fatigue when harvesting the oil palm trees manually. Nevertheless, in an effort to provide a biomechanically-functional exoskeleton that impacts positively on harvesters' productivity and safety, the exoskeleton design requires further improvements to suit the motions involved during manual oil palm harvesting activity.

ACKNOWLEDGEMENTS

This study was supported by Universiti Putra Malaysia (UPM) through the Geran Putra-IPM initiative (Project title: The Development of An Exoskeleton for Oil Palm Harvesting Activity) and Fundamental Research Grant Scheme (Project title: A Biomechanical-based Approach to Improve Energy Expenditure in Manual Oil Palm Harvesting Activity).

COMPETING INTERESTS

There is no conflict of interest.

REFERENCES

Baker, T., Chiros, C., Derius, M., Gates, S., Levin, T., & Smith, A. (2015). Final Report – Palm Harvester Project. Florida, USA.

Butler, T. R. (2016). Exoskeleton Technology Making Workers Safer and More Productive. Exoskeleton Technology: Making Workers Safer and More Productive, *Professional Safety*, September 2016, 32–36.

Garrec, P. (2010). Design of an anthropomorphic upper limb exoskeleton actuated by ball-screws and cables. *UPB Scientific Bulletin, Series D: Mechanical Engineering,* **72**(2), 23–34.

Hawkes, D. H., Alizadehkhaiyat, O., Fisher, A. C., Kemp, G. J., Roebuck, M. M., & Frostick, S. P. (2012). Normal shoulder muscular activation and co-ordination during a shoulder elevation task based on activities of daily living: An electromyographic study. *Journal of Orthopaedic Research*, **30**(1), 53-60.

Herr, H. (2009). Exoskeletons and orthoses: classification, design challenges and future directions. *Journal of NeuroEngineering and Rehabilitation*, **6**(1), 21.

Komi, P. V., & Viitasalo, J. T. (1977). Changes in Motor Unit Activity and Metabolism in Human Skeletal Muscle during and after Repeated Eccentric and Concentric Contractions. *Acta Physiologica Scandinavica*, **100**(2), 246–254. https://doi.org/10.1111/j.1748-1716.1977.tb05943.x

MacDermid, J. C. (2007). The Functional Impairment Test-Head, and Neck/Shoulder/Arm (FIT-HaNSA) Protocol, (April 2007), 1-6.

Merletti, A. R., & Torino, P. (1997). Standards for reporting EMG data. *Journal of Electromyography and Kinesiology*, **7**(2), I–II.

Mohammadi, E., Zohoor, H., & Khadem, S. M. (2014). Control system design of an active assistive exoskeletal robot for rehabilitation of elbow and wrist. *2014 2nd RSI/ISM International Conference on Robotics and Mechatronics*, ICRoM 2014, 834-839.

Ng, Y. G., Bahri, M. T. S., Syah, M. Y. I., Mori, I., & Hashim, Z. (2015). Ergonomics Observation : Harvesting Tasks at Oil Palm Plantation Ergonomics Observation : Harvesting Tasks at Oil Palm Plantation. *Journal of Occupational Health*, **55**(October 2015), 405–414.

Ng, Y. G., Tamrin, S. B. M., Yik, W. M., YusoffF, I. S. M., & Mori, I. (2014). The Prevalence of Musculoskeletal Disorder and Association with Productivity Loss: A Preliminary Study among Labour Intensive Manual Harvesting Activities in Oil Palm Plantation. *Industrial Health*, **52**(1), 78–85.

Ng, Y. G., Tamrin, S. B. M., Yusoff, I. S. M., Hashim, Z., Deros, B. M. D., Bakar, S. A., & How, V. (2015). Risk factors of musculoskeletal disorders among oil palm fruit harvesters during early harvesting stage. *Annals of Agricultural and Environmental Medicine*, **22**(2), 286–292.

OriginLab. (2016). Retrieved from https://www.originlab.com/index.aspx?go=Products/Origin/

Shokripour, H., Wan Ismail, W. I., Shokripour, R., & Moezkarimi, Z. (2012). Development of an automatic cutting system for harvesting oil palm fresh fruit bunch (FFB). *African Journal of Agricultural Research*, **7**(17), 2683-2688.

Stegeman, D., & Hermens, H. (2007). Standards for suface electromyography: *The European project Surface EMG for non-invasive assessment of muscles* (SENIAM), 1.

Svebak, S., Braathen, E. T., Sejersted, O. M., Bowim, B., Fauske, S., & Laberg, J. C. (1993). Electromyographic activation and proportion of fast versus slow twitch muscle fibers: A genetic disposition for psychogenic muscle tension? *International Journal of Psychophysiology*, **15**(1), 43–49.

Toyama, S., & Yamamoto, G. (2009). Development of wearable-agri-robot - Mechanism for agricultural work. *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2009*, 5801–5806.

Wu, T. -M., & Chen, D. -Z. (2014). Biomechanical study of upper-limb exoskeleton for resistance training with three-dimensional motion analysis system. *Journal of Rehabilitation Research and Development*, **51**(1), 111–126.