Development and evaluation of robotic exoskeleton arm for enhanced human load carrying efficiency

Muhammad Aiman Mohd Azam[1], Khalil Azha Mohd Annuar[1], Mohd Razali Mohamad Sapiee[1], Sanjoy Kumar Debnath[2]
[1]Department of Electrical Engineering Technology, Faculty of Technology and Electrical Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia
[2]Department of Computer Science and Engineering, Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, India

Article Info

Article history:

Received Aug 6, 2024
Revised Oct 31, 2024
Accepted Nov 12, 2024

Keywords:

Arduino microcontroller
Electromyography sensor
Exoskeleton arm
Load carrying assistance
Robotic rehabilitation

ABSTRACT

In recent years, there has been a significant amount of research dedicated to the development of robotic exoskeleton systems. These technologies have been widely explored for their potential in virtual reality, human power enhancement, robotic rehabilitation, human power assist, and haptic interface applications. This research focuses on creating an exoskeleton arm that can assist individuals in carrying heavy objects. The exoskeleton arm is initially designed using Fusion 360, with the identification and calculation of important components such as the exoskeleton structure, motors serving as joints, an electromyography (EMG) sensor, and an Arduino UNO microcontroller. The research involves various aspects of mechanical design, electronic components, and programming. The effectiveness of the developed exoskeleton arm is then tested through experiments involving several individuals lifting a 2.5 kg and 5.0 kg load. The results of the experiments demonstrate that the force generated by the muscles is reduced when using the exoskeleton arm, compared to using a supporting system. Individuals' performance dropped by 36.06% to 50.44% when using an exoskeleton to lift 2.5 kg. This emphasises its effect on muscle activation and efficiency following physical activity. A 10.14% to 23.25% decline in a 5.0 kg lift shows nuanced impacts, emphasising the need for personalised modifications.

Corresponding Author:

Khalil Azha Mohd Annuar
Department of Electrical Engineering Technology, Faculty of Technology and Electrical Engineering
Universiti Teknikal Malaysia Melaka
Durian Tunggal, Melaka, Malaysia
Email: khalilazha@utem.edu.my

1. INTRODUCTION

Exoskeleton arm designs have developed as a promising technology with the potential to improve human capabilities in a variety of disciplines, including healthcare and rehabilitation [1]-[3], as well as industrial uses [4]-[6]. These devices are designed to improve the strength, endurance, and precision of human arms, allowing people to perform physically demanding activities more efficiently or supporting those with limited mobility in recovering their independence. Despite their intriguing potential, contemporary exoskeleton arm designs have a number of challenges and limitations that prevent widespread adoption and optimal performance [7], [8].

The development of arm exoskeleton has been primarily aimed at reducing the mechanical load on the shoulder and redistributing the weight of the arms. The novel technology exhibits potential in mitigating musculoskeletal disorders (MSDs) that frequently emanate from muscular exhaustion and repetitive strain. Arm exoskeleton endeavours to reduce the prevalence of work-related injuries and improve occupational health by offering external support and assistance to address the risk factors associated with MSDs [9]. MSDs are a prevalent source of pain and discomfort among individuals in the workforce, impacting various components of the musculoskeletal system such as muscles, bones, spinal discs, tendons, joints, ligaments, cartilage, nerves, and blood vessels [10]. MSDs are highly prevalent among healthcare professionals, with reported rates exceeding 80% among physiotherapists, masseurs, nurses, midwives, dentists, and surgeons, thereby indicating a significant risk for this population [11].

Electromyography (EMG) is a sensor that detects muscle action and the passage of nerve fibres within them. EMG is used in clinical settings to identify damaged muscles and nerves [12], explore the underlying causes of muscular dysfunction [13], monitor the healing process after motor nerve injuries [14], and watch nerve regeneration [15]. EMG data is also used to improve the content of muscle training workout apps that are offered to customers. This information can be used to calculate the muscle quality index (MQI), which provides information about muscle functionality and performance. The electrical potential generated by muscle cells in response to electrical or neurological stimulus is detected by EMG. These signals can be used to investigate the biomechanics of human body movement, detect medical anomalies, quantify muscle activation levels, and examine recruitment order. Furthermore, EMG signals can be used to detect a variety of medical anomalies. The amplitude of the EMG potential can vary greatly, ranging from 50 V to 30 mV, depending on factors such as the specific muscle being studied and the conditions present during the observation [16].

EMG sensors has been established in gauging muscle activation levels and approximating joint angles, thereby furnishing crucial feedback for regulating exoskeleton apparatus [17]. The research utilised a personalised calibration methodology to discern the user's intention to either lift or release a load while operating an upper-limb exoskeleton. The process of calibration entailed the utilisation of a cost-effective EMG sensor bracelet, which was strategically positioned around the user's arm. The EMG sensor bracelet facilitated the recognition and analysis of the user's intended movements and actions by detecting the electrical signals produced by the muscles. The amalgamation of individualised calibration methodologies with inexpensive EMG sensors presents a hopeful strategy for attaining improved regulation and efficacy in exoskeleton frameworks [18].

Arm exoskeletons have exhibited their effectiveness in reducing the mechanical burden placed on the shoulder while performing tasks that require overhead work. Arm exoskeletons have been designed with innovative features and functionality that effectively reduce the burden on the shoulder joint by providing external support and assistance. The decrease in mechanical burden holds noteworthy importance in occupational environments where there is a prevalence of overhead work. This decrease aids in the mitigation of MSDs that are linked to extended and repetitive overhead motions. The implementation of arm exoskeletons in such settings exhibits significant potential for augmenting occupational well-being and mitigating the prevalence of work-related harm [19]. There are many other research on the design of exoskeleton arm robot [20]-[23].

This research aims to develop an exoskeleton arm that produces assistive force for use in rehabilitation and to aid users with daily activities such as lifting heavy objects. The power assist exoskeleton proposed in this work is controlled by EMG inputs from the muscles. The study's participants will receive instructions to perform a lifting task with a standardised 2.5 kg and 5 kg load while utilising the exoskeleton arm. The measurement of the force exerted by the participants' muscles during the task will be conducted through the utilisation of force sensors that have been integrated into the exoskeleton arm.

2. METHOD

The system's electronic components begin by using sensors, notably EMG sensors, to gather data from the muscles while performing item transportation duties. These sensors capture data continually and send it to an Arduino UNO microcontroller for processing. To transform sensor readings into the appropriate unit, the microcontroller uses an algorithm or formula within the Arduino integrated development environment (IDE). After processing the data, the microcontroller communicates with a power window motor, which creates the required torque. This torque helps humans to carry the weight of the task with ease. Block diagram of the system is shown at Figure 1.

The mechanical design of an arm exoskeleton is crucial for ensuring user support, mobility, and functionality. When designing an arm exoskeleton, there are several important factors to consider. To begin, the exoskeleton should be ergonomically built to properly suit the user's arm and minimise discomfort and fatigue during operation. It should consider the arm's natural structure and range of motion, allowing for smooth and natural movements while reducing strain on joints and muscles.

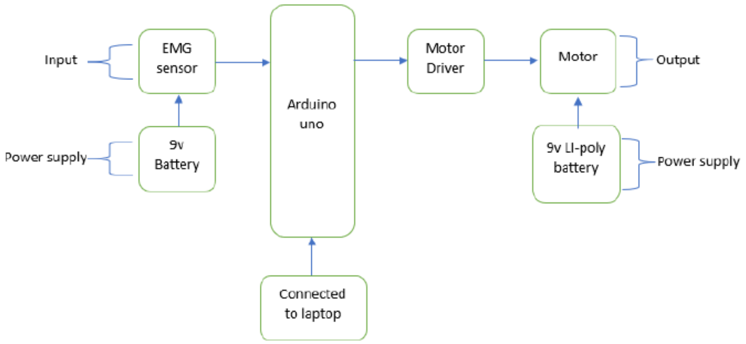
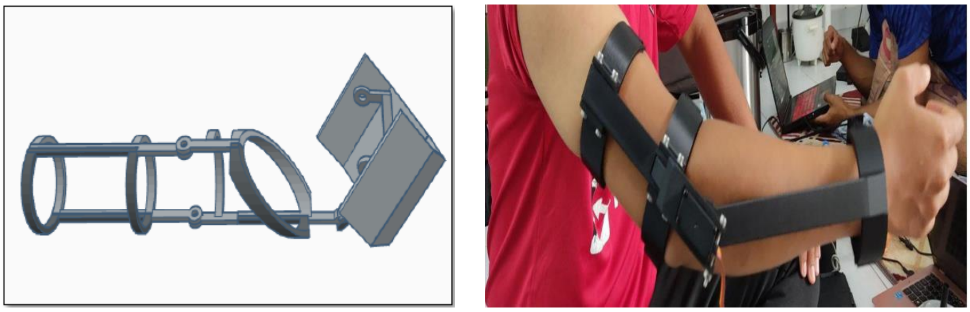


Figure 1. Block diagram of the system

Another important factor is the use of lightweight and long-lasting materials. Carbon fibre, aluminium alloys, and composites can give strength without adding extra weight, making the exoskeleton more comfortable to wear and minimising user fatigue [24]. The joint mechanics of the exoskeleton should closely mirror natural arm movement. To allow flexion, extension, and rotation at the elbow, wrist, and other important joints, hinges, linkages, or rotational devices can be used. This enables for a wide range of motion while still maintaining stability and control. The exoskeleton's functionality is dependent on actuation and power transfer technologies. Actuators can be electric motors, pneumatic or hydraulic systems, or a combination of these. The mechanical design should enable precise and responsive control of the exoskeleton's movements by ensuring efficient power transmission from the actuators to the joints.

It is critical to include sensors and feedback systems so that the exoskeleton can deliver real-time input and adapt its movements accordingly [25], [26]. Position sensors, force sensors, and EMG sensors can be utilised to detect muscle activity and collect reliable data for control and feedback. The placement and integration of these sensors should be considered in the mechanical design. The design of an arm exoskeleton must prioritise safety. Limit switches, mechanical stops, and torque control systems can help to avoid excessive joint motions, protect the user from overexertion, and keep the exoskeleton operating within safe boundaries.

According to Figure 2, it present two subfigure that depicts the design and implementation of the arm exoskeleton. Figure 2(a) shows the 3D design of the arm model using Autocad software. It is based on the structure of a human arm, with variable diameter rings. Two supports have been carefully placed to assist easier object carrying. To achieve force balance, each ring is securely linked to the framework. This intelligent design not only mimics the natural shape of a human arm, but also provides item handling functionality. The adaptability of varied diameters and the installation of supports improve both the structural integrity and functional efficiency of our arm-inspired design. Figure 2(b) presents the actual hardware of the exoskeleton during testing, demonstarting how the design transletes into physical prototype for assisting in lifting tasks.



(a) (b)

Figure 2. Arm exoskeleton design of (a) 3D design and (b) actual hardware

Make a connection circuit like the one are shown as Figure 3. There are two power supplies or batteries to generate +Vs and -Vs. Connect the negative side of the first battery to the positive side of the second battery first. As a result, an electric ground is formed for power delivery. As a result, the first battery's positive end is +Vs and the second battery's negative end is -Vs. After doing the connection, attach surface EMG sensor to the user.

In this procedure, a user wears an arm exoskeleton and connects a surface EMG sensor to assess muscle activation. Initially, the user lifts a burden, and the sensor detects muscle signals. If the sensor is having difficulty capturing signals, the electrode placements are modified to provide precise readings. Once successful muscle readings are acquired, the exoskeleton commences a lifting sequence for 10 seconds, supporting the user in carrying the burden. After this time, the exoskeleton returns to its previous place. Figure 4 shows a flowchart as outlines a simple yet effective approach for ensuring that the exoskeleton responds to the user's muscular action, giving support for the given duration, and then returning to a resting state, thereby improving the overall usability of the arm exoskeleton.

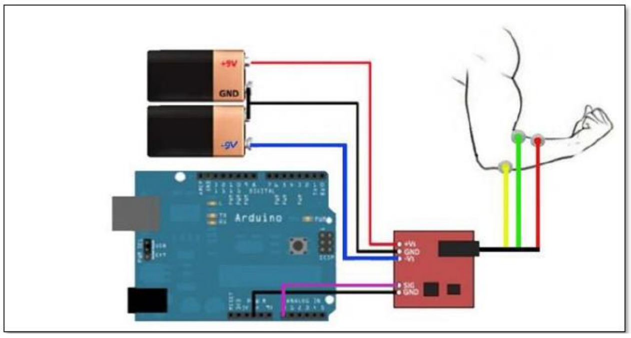


Figure 3. Connection circuit and attach to user arm

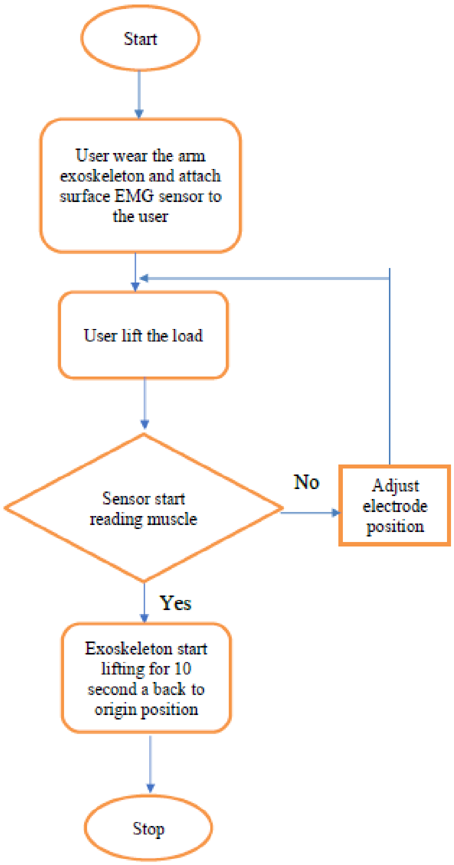


Figure 4. Connection circuit and attach to user arm

3. RESULTS AND DISCUSSION

In this section, the research's outcomes with a focus on hardware implementation. It provides insights into the concrete outputs and practical applications achieved through the creation and integration of physical components. The emphasis on hardware implementation emphasises the hands-on and practical components of the project's execution.

The exoskeleton research employs ion and lithium polymer batteries to power its circuit, with ion batteries specifically fueling the EMG sensor. This sensor detects subtle electrical signals from muscles, providing input to the servo motor for controlled movement. The Arduino UNO, highlighted in a previous chapter, assumes a pivotal role in system control and design. Its integration ensures efficient coordination of the electronics, facilitating seamless communication between the EMG sensor and servo motor. Overall, this combination of components empowers the exoskeleton to interpret muscle signals and execute precise movements, enhancing its functionality and user interface in a compact and energy-efficient manner. Figure 5 shows the schematic diagram the component.

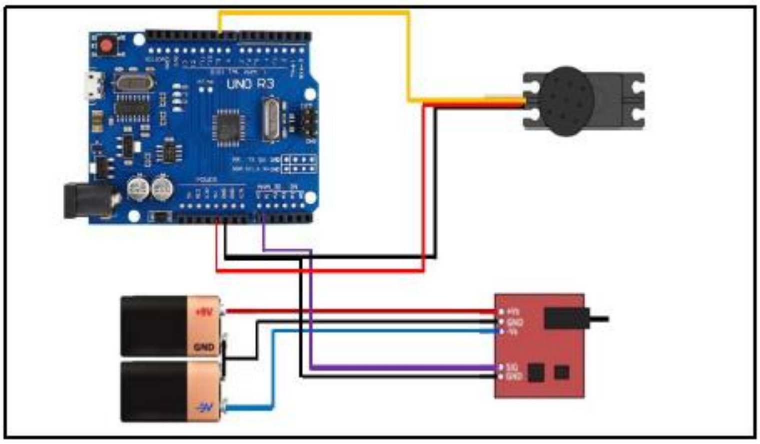
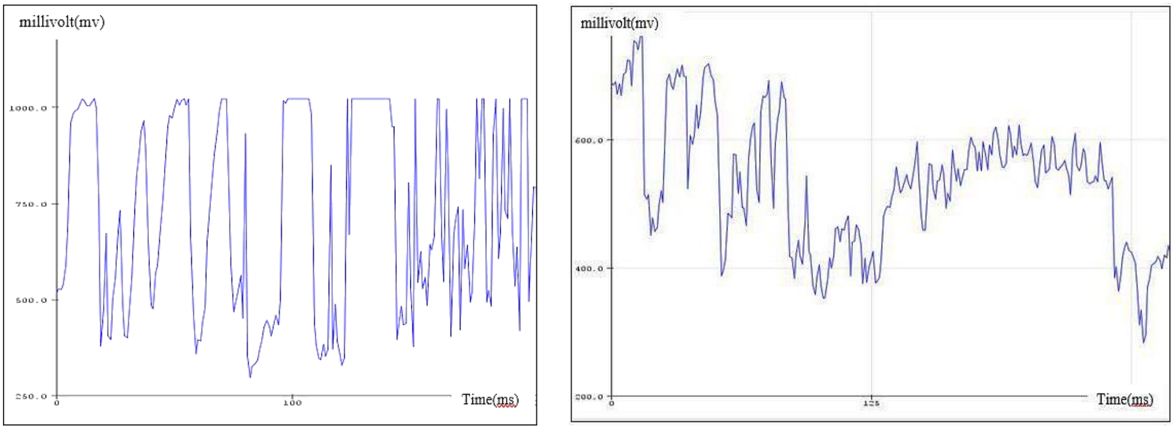


Figure 5. Schematic diagram

In Figure 6, the diagram depicts the movement of the exoskeleton before and after lifting items. The motor adjusts its angle in response to inputs from the signal from EMG sensor. The exoskeleton system is activated when signals from the EMG sensor are detected. To confirm the project's goal of making heavy item lifting easier, five people carried 2.5 kg and 5.0 kg weights for 10 seconds each. The EMG sensor output represents the electrical impulses created by the muscle, with higher signals indicating more energy generation. This data collecting technique evaluates the performance of the exoskeleton, offering information regarding its usefulness in assisting load jobs. Figure 6(a) illistrates the EMG sensor reading before using the exoskeleton, where higher peaks indicates greater muscle activation and energy expenditure during manual load lifting. While Figure 6(b) shows the EMG sensor reading after using the exoskeleton arm, where lower peak reflect educed muscle strain and energy exertion, demonstrating the effectiveness of the exoskeleton in assisting with heavy lifting tasks. These figures provide a direct comparison, showing the impact of the exoskeleton on muscle workload during load-handling tasks.

In the evaluation of the performance of the exoskeleton system, the selected participants demonstrate consistent efficacy. Subjects were chosen based on specific criteria, including gender, frequency of exercise per week, and history of arm injuries, to ensure a diverse range of physical activity habits and arm-related factors. Despite individual differences, the steady drop in data output demonstrates the exoskeleton's usefulness in handling large things, which aligns with research objectives. Table 1 provide a summary important information such as their gender, weekly exercise frequency, and arm injury history, providing insight into their physical activity habits and arm-related factors.

This compelling evidence highlights the system's concrete influence in enhancing human strength, showcasing its potential applicability in tasks requiring the lifting or carrying of substantial loads. Table 2 show the first attemt of the exoskeleton system performance with the 5 different people. This consistent effectiveness spans participants with diverse backgrounds.



(a) (b)

Figure 6. Serial plotter reading load (a) before using exoskeleton and (b) after using exoskeleton

Table 1. The performance of power and speed

No	Person	Gender	Frequency of exercise per week (days)	History of arm injuries
1	Person 1	Male	1-3	No
2	Person 2	Male	5-7	No
3	Person 3	Male	6-7	No
4	Person 4	Male	5-7	No
5	Person 5	Male	1-2	Yes

Table 2. System performance for using 2.5 kg in 10 second

No	Person	Average reading lift without using exoskeleton (mV)	Average reading lift using exoskeleton (mV)	Percentage performance (%)
1	Person 1	853.27	507.65	40.51
2	Person 2	651.91	416.79	36.07
3	Person 3	743.97	398.72	46.41
4	Person 4	645.41	402.5	37.64
5	Person 5	856.35	477.25	44.27

Figure 7 illustrates the comparative performance of an exoskeleton arm in lifting two different weights: 2.5 kg and 5 kg. There are two attempt each and lasting around 10 seconds. The charts present the average voltage readings (in mV) both with and without the use of the exoskeleton across five individuals. Then the corresponding percentage performance improvements from this two different method (with and without exoskeleton).

In both scenarios, the use of the exoskeleton results in a noticeable reduction in the voltage readings, indicating reduced muscle exertion. In the first attempt with a 2.5 kg weight (Figure 7(a)), the average voltage reading without exoskeleton are higher accross all participants. The percentage performance improvement ranges from approximately 36.07% to 46.41%, with the highest improvement seen in person 3. The second attempt as Figure 7(b) shows similar trend, with percentage performance improvements between 22.46% to 27.76%.

In the case of the 5 kg lift as Figures 7(c) and 7(d), the percentage performance improvement varies from about 22.46% to 27.76% in the first attempt and 18.67% to 24.75% in the second attempts. The lesser degree of improvement in the second attempt compared to the first attempt for both weights may suggest muscle fatigue or adaptation over consecutive lifts. The efficacy of the exoskeleton in reducing muscle strain during heavier lifting tasks highlights its potential in industrial and rehabilitation applications, where reducing the risk of musculoskeletal injuries is critical. These finding emphasize the exoskeleton's efficacy in reducing muscle strain during lifting tasks, with more pronounced effects observed in lighter lifting tasks. Additionally, the variations in performance improvement between the first and second attempts and between different weights underscore the importance of personalized exoskeleton adjustments and the consideration of user-specific factors such as strength, fatigue levels, and the nature of the task being performed.

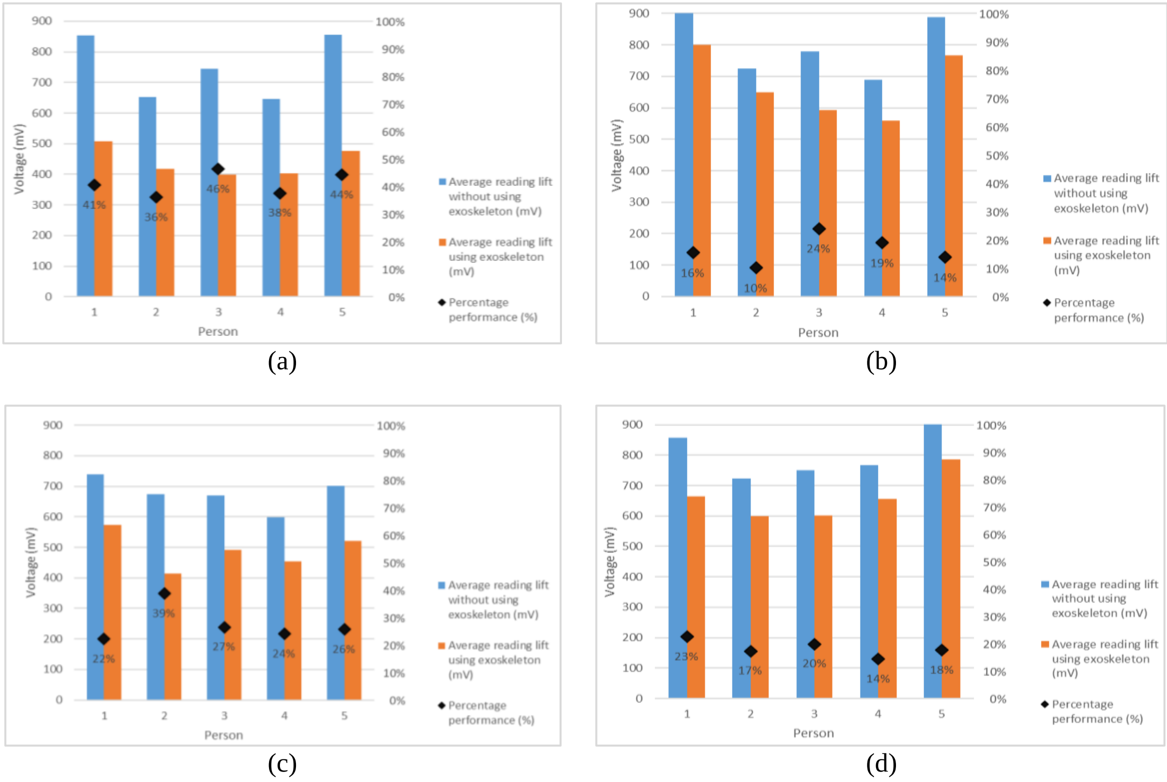


Figure 7. System performance comparison between without and using exoskeleton arm for (a) first attempt 2.5 kg weight, (b) second attempt 2.5 kg weight, (c) first attempt 5 kg weight, and (d) second attempt 5 kg weight

4. CONCLUSION

In conclusion, the research achieved its objectives by designing and building a surface EMG sensor-based exoskeleton arm. The created robotic arm interprets muscle impulses recorded by EMG sensors on the skin, opening up new possibilities for those with motor disabilities. This technology advancement has the potential to significantly improve such people's daily lives by giving them greater mobility and autonomy. Experiments with persons lifting 2.5 kg and 5.0 kg loads were used to evaluate the efficacy of the constructed exoskeleton arm. When compared to a supporting system, the exoskeleton arm produced less muscle force. During the use of the exoskeleton for a 2.5 kg lift, performance deterioration ranged from 36.06% to 50.44%, highlighting its influence on post-physical activity muscle activation and efficiency. A nuanced influence, as seen by a 10.14% to 23.25% drop during a 5.0 kg lift, highlights the importance of personalised adaptations. Notably, the exoskeleton arm, particularly in assisting weightlifting exercises, demonstrates its practical value, as demonstrated by thorough testing. The project's overall performance represents a significant step forward in the field of assistive robotics, leading to an enhanced quality of life and increased functioning for users with motor problems. Exploration of gesture recognition skills for intuitive control might also be explored as future work for the arm exoskeleton. The findings suggest potential applications in fields such as healthcare, where exoskeletons could aid in rehabilitation, and in industrial settings, where they could enhance worker safety and efficiency. Future work could focus on integrating gesture recognition for more intuitive control, further enhancing the system's usability and adaptability. To fully leverage the potential of exoskeletons in both rehabilitation and industrial applications, future research should focus on refining the customization of exoskeletons to individual user needs, ensuring that the device can be tailored for both physical and cognitive demands. In addition, collaborating with healthcare professionals and industrial safety experts during the development phase will help ensure that the technology is both effective and user-friendly across diverse environments.

ACKNOWLEDGEMENTS

The authors would like to thank for the support given to this research by Ministry of Higher Education Malaysia and Universiti Teknikal Malaysia Melaka (UTeM) for support this paper.

REFERENCES

[1] Y.-K. Ou, Y.-L. Wang, H.-C. Chang, and C.-C. Chen, "Design and development of a wearable exoskeleton system for stroke rehabilitation," *Healthcare*, vol. 8, no. 1, 2020, doi: 10.3390/healthcare8010018.

[2] Y. Liu, X. Li, A. Zhu, Z. Zheng, and H. Zhu, "Design and evaluation of a surface electromyography-controlled lightweight upper arm exoskeleton rehabilitation robot," *International Journal of Advanced Robotic Systems*, vol. 18, no. 3, 2021, doi: 10.1177/17298814211003461.

[3] G. Akgun, A. E. Cetin, and E. Kaplanoglu, "Exoskeleton design and adaptive compliance control for hand rehabilitation," *Transactions of the Institute of Measurement and Control*, vol. 42, no. 3, pp. 493-502, 2020, doi: 10.1177/0142331219874976.

[4] S. Coruk, M. C. Yildirim, A. T. Kansizoglu, O. Dalgic, and B. Ugurlu, "Design and development of a powered upper limb exoskeleton with high payload capacity for industrial operations," In *2020 IEEE International Conference on Human-Machine Systems (ICHMS)*, IEEE, pp. 1-4, 2020, doi: 10.1109/ICHMS49158.2020.9209374.

[5] S. Spada, L. Ghibaudo, S. Gilotta, L. Gastaldi, and M. P. Cavatorta, "Analysis of exoskeleton introduction in industrial reality: main issues and EAWS risk assessment," in *Advances in Physical Ergonomics and Human Factors: Proceedings of the AHFE 2017 International Conference on Physical Ergonomics and Human Factors*, pp. 236-244, 2018, doi: 10.1007/978-3-319-60825-9_26.

[6] J. Wesslén, "Exoskeleton exploration: research, development, and applicability of industrial exoskeletons in the automotive industry," Independent Thesis Advanced level (degree of Master), Jönköping University, School of Engineering, JTH, Industrial Engineering and Management, 2018.

[7] M. R. Islam, B. Brahmi, T. Ahmed, M. Assad-Uz-Zaman, and M. H. Rahman, "Exoskeletons in upper limb rehabilitation: a review to find key challenges to improve functionality," *Control Theory in Biomedical Engineering*, pp. 235-265, 2020, doi: 10.1016/B978-0-12-821350-6.00009-3.

[8] B. Chen *et al*., "Recent developments and challenges of lower extremity exoskeletons," *Journal of orthopaedic translation*, vol. 5, pp. 26-37, 2016, doi: 10.1016/j.jot.2015.09.007.

[9] M. Musso, A. S. Oliveira, and S. Bai, "Influence of an upper limb exoskeleton on muscle activity during various construction and manufacturing tasks," *Applied Ergonomics*, vol. 114, 2024, doi: 10.1016/j.apergo.2023.104158.

[10] B. Arnoux, A. Farr, V. Boccara, and N. Vignais, "Evaluation of a passive upper limb exoskeleton in healthcare workers during a surgical instrument cleaning task," *International Journal of Environmental Research and Public Health*, vol. 20, no. 4, 2023, doi: 10.3390/ijerph20043153.

[11] J. Jacquier-Bret and P. Gorce, "Prevalence of body area work-related musculoskeletal disorders among healthcare professionals: a systematic review," *International journal of environmental research and public health*, vol 20, no. 1, 2023, doi: 10.3390/ijerph20010841.

[12] W. Tang *et al*., "Quantitative assessment of traumatic upper-limb peripheral nerve injuries using surface electromyography," *Frontiers in Bioengineering and Biotechnology*, vol. 8, 2020, doi: 10.3389/fbioe.2020.00795.

[13] L. Szyszka-Sommerfeld, M. Lipski, and K. Woźniak, "Surface electromyography as a method for diagnosing muscle function in patients with congenital maxillofacial abnormalities," *Journal of Healthcare Engineering*, no. 1, 2020, doi: 10.1155/2020/8846920.

[14] L. R. Robinson, "Traumatic injury to peripheral nerves," *Muscle & Nerve*, vol. 66, no. 6, pp. 661-670, 2022, doi: 10.1002/mus.27706.

[15] A. Virkhare, S. Lakshmanan, O. Bhutia, A. Roychoudhury, N. Mehta, and S. Pandey, "Does evoked electromyography detect the injured facial nerve recovery earlier than clinical assessments?" *Journal of Oral and Maxillofacial Surgery*, vol. 80, no. 5, pp. 814-821, 2022, doi: 10.1016/j.joms.2021.12.010.

[16] E. Vavrinský *et al*., "Design of EMG wireless sensor system," in *2011 International Conference on Applied Electronics*, 2011, pp. 1-4.

[17] S. Wei and Z. Wu. "The application of wearable sensors and machine learning algorithms in rehabilitation training: a systematic review," *Sensors*, vol. 23, no. 18, 2023, doi: 10.3390/s23187667.

[18] B. Treussart, F. Geffard, N. Vignais, and F. Marin, "Controlling an exoskeleton with EMG signal to assist load carrying: a personalized calibration," in *2019 International Conference on Mechatronics, Robotics and Systems Engineering (MoRSE)*, 2019, pp. 246-252, doi: 10.1109/MoRSE48060.2019.8998701.

[19] P. T. Ziarati, T. Xia, S. Kudernatsch, and D. Peterson, "Experimental assessment of effectiveness of arm-supporting exoskeleton for overhead work," in *Proceedings of the 7th International Digital Human Modeling Symposium*, vol. 7, no. 1, 2022, doi: 10.17077/dhm.31770.

[20] F. Balser, R. Desai, A. Ekizoglou and S. Bai, "A novel passive shoulder exoskeleton designed with variable stiffness mechanism," *IEEE Robotics and Automation Letters*, vol. 7, no. 2, pp. 2748-2754, Apr. 2022, doi: 10.1109/LRA.2022.3144529.

[21] A. Zeiaee, R. S. Zarrin, A. Eib, R. Langari, and R. Tafreshi, "CLEVERarm: a lightweight and compact exoskeleton for upper-limb rehabilitation," *IEEE Robotics and Automation Letters*, vol. 7, no. 2, pp. 1880-1887, Apr. 2022, doi: 10.1109/LRA.2021.3138326.

[22] Z. Du *et al*., "Mechanical design and preliminary performance evaluation of a passive arm-support exoskeleton," in *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Las Vegas, NV, USA, 2020, pp. 3371-3376, doi: 10.1109/IROS45743.2020.9341290.

[23] N. Dunkelberger, J. Berning, K. J. Dix, S. A. Ramirez and M. K. O'Malley, "Design, characterization, and dynamic simulation of the MAHI open exoskeleton upper limb robot," *IEEE/ASME Transactions on Mechatronics*, vol. 27, no. 4, pp. 1829-1836, Aug. 2022, doi: 10.1109/TMECH.2022.3175507.

[24] Z. Zhang *et al.*, "Lightweight structural biomaterials with excellent mechanical performance: a review," *Biomimetics*, vol. 8, no. 2, 2023, doi: 10.3390/biomimetics8020153.

[25] M. Tiboni, A. Borboni, F. Vérité, C. Bregoli, and C. Amici, "Sensors and actuation technologies in exoskeletons: a review," *Sensors*, vol. 22, no. 3, 2022, doi: 10.3390/s22030884.

[26] Z. Song and S. Guo, "Development of a real-time upper limb's motion tracking exoskeleton device for active rehabilitation using an inertia sensor," *2011 9th World Congress on Intelligent Control and Automation*, Taipei, Taiwan, 2011, pp. 1206-1211, doi: 10.1109/WCICA.2011.5970708.

BIOGRAPHIES OF AUTHORS

Muhammad Aiman Mohd Azam received his bachelor of electrical engineering technology (industrial automation and robotics) (Hons) from Universiti Teknikal Malaysia Melaka (UTeM) in 2024. He previously completed a diploma in mechatronics engineering at Politeknik Ibrahim Sultan in 2020. He has a keen interest in the fields of automation and manufacturing. He can be contacted at email: aaiman.5767@gmail.com.

Khalil Azha Mohd Annuar received his bachelor of engineering (electrical - electronics) from Universiti Teknologi Malaysia (UTM), in 2006, and master of engineering (electrical - mechatronics and automatic control) also from UTM, in 2014. Currently, he is a Lecturer at Universiti Teknikal Malaysia Melaka (UTeM) and his interests are in energy harvesting, embedded system, internet of things, and control system. He can be contacted at email: khalilazha@utem.edu.my.

Mohd Razali Mohamad Sapiee received his B.Eng. degree in mechatronics from Universiti of Leeds, UK in 1997, and M.Eng. degree in electrical (mechatronics and automatic control) from Universiti Teknologi Malaysia (UTM), in 2009. Currently, he is Senior Lecturer at Universiti Teknikal Malaysia Melaka (UTeM) and his interests are in mechatronics, embedded system, and control system. He can be contacted at email: mohd.razali@utem.edu.my.

Dr. Sanjoy Kumar Debnath is an Assistant Professor at Chitkara University, Punjab, India. He holds a Ph.D. in electrical engineering from Universiti Tun Hussein Onn Malaysia (UTHM) and M.Eng. in electrical-mechatronics and automatic control engineering from Universiti Teknologi Malaysia (UTM). He completed his B.Eng. in electrical and computer engineering from Presidency University, Bangladesh. He is a Graduate Engineer with the Board of Engineers Malaysia (BEM), a member of IEEE, IEM, and IET UK. His research interests include artificial intelligence, smart systems, modern control, and the internet of things. He can be contacted at email: sanjoy.kumar@chitkara.edu.my.