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MOTORIZED HOSE ROLLING TOOL FOR FIREFIGHTER: DESIGN AND FABRICATION PROCESS

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ABSTRACT

This paper addresses the critical problem of low back pain (LBP) among firefighters, particularly during hose rolling operations. The main objective is to lower the average probability of LBP risks by introducing a motorized hose roller for such activities. The development of this tool is guided by prior studies which included a survey. The design and fabrication processes of the motorized hose roller involved assessing existing patents for novelty, employing Solid Work software for design, using a morphological chart for concept selection, and finalizing fabrication through metal casting and wiring. Based on the experiment that had been conducted, the conventional hose rolling methods recorded an average LBP risk probabilities of 58.22%, while the motorized hose rolling tool method significantly reduced these risks to 17.44%, representing a 40.78% reduction of LBP risks. These findings highlight the effectiveness of motorized hose rolling tool and its potential as a safer alternative to existing methods, offering vital insights for improving occupational health and safety in hose rolling operation. This research further explores the design and fabrication of motorized tools, emphasizing their potential to alleviate the physical loads encountered by firefighters.

Keywords: Engineering technology, ergonomics, firefighter, hose roller, low back disorders.

INTRODUCTION

The conventional method of rolling fire hoses is associated with physical strain and safety hazards, necessitating improvement in hose rolling equipment. Gentzler et al. (2010) indicating these concerns, while Katsavouni et al. (2014) proposed ergonomically designed tools to alleviate physical exertion, enhance operational efficiency, and prolong hose lifespan. Recognizing the significance of these factors in firefighter safety and efficiency, this research shifts focus to the development of specialized hose rolling tools. Conducted at Universiti Tun Hussein Onn Malaysia (UTHM), Pagoh, in collaboration with firefighters, this paper aims to address practical implications by experimenting with ergonomic designs, material selection, and operational methods. By bridging critical gaps identified by Fiodorenko-Dumas et al. (2018), the research delves into fatigue analysis of firefighter body posture during hose rolling operations, particularly focusing on the risks of LBP.

A patent search reveals the lack of motorized hose roller tools tailored specifically for firefighting needs. Thus, this study investigates LBP risks associated with conventional, mechanical, and motorized hose rolling methods. Employing industrial lumbar motion monitors (iLMM) and Ballet software, the research analyses firefighters' body posture to assess LBP risks across different rolling techniques. The introduction of motorized hose rolling tools holds promise in improving firefighters' well-being and operational efficiency. By enhancing body posture and reducing LBP risks, these tools not only benefit firefighters' long-term health but also minimize fire hose maintenance costs. The reduction of friction between hoses and ground surfaces could extend hose lifespan, thereby lowering replacement expenses. In summary, this paper aims to investigate the risks of LBP associated with various rolling methods and to propose a design and development of motorized hose rolling tools. Through actionable insights derived from practical experimentation and academic research, the study seeks to make tangible improvements in firefighter safety, well-being, and operational effectiveness.

LITERATURE REVIEW

This section aims to provide an overview of earlier research and improvements in the design of ergonomic hose rolling tools, with a focus on fabricating a high efficiency tool in terms of operational method and reducing the LBP risks. This section also discusses the design and fabrication processes of the motorized hose roller tool.

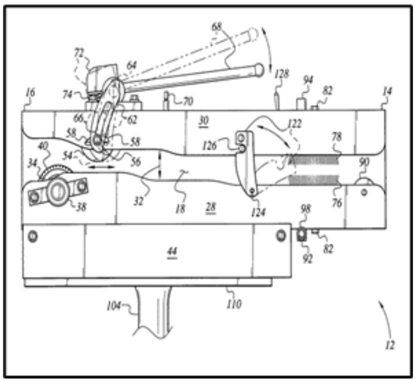
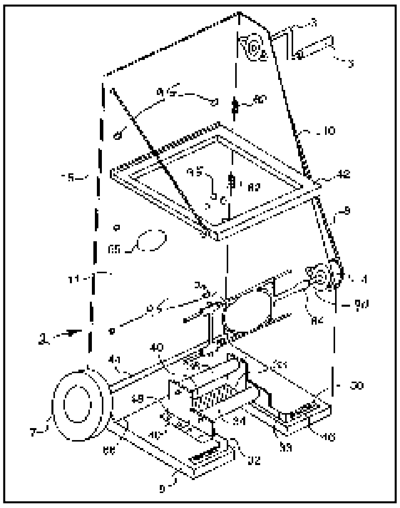
Current Design and Patent

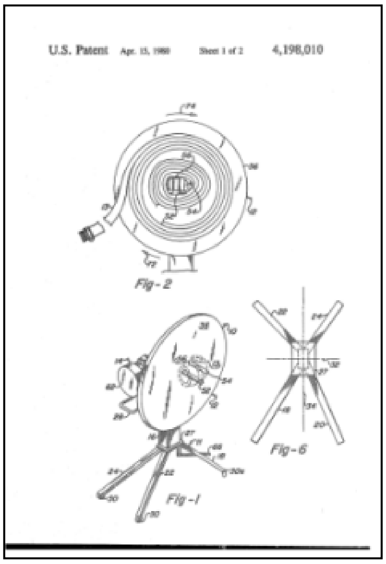
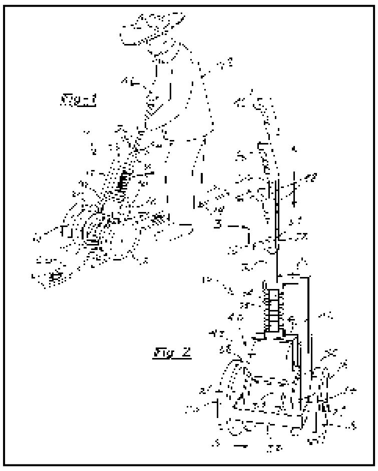
Examining existing designs within the industry is essential as they serve as wellsprings of ideas and information for product innovation. According to Cross et al. (2021), assessing products developed by other designers can illuminate prevailing issues and weaknesses, thereby enabling enhancements. Creative designers encounter roadblocks when seeking solutions to problems. However, by reviewing prior designs, a plethora of improvement ideas can be garnered for new designs (Cross, et al., 2021). Information concerning the diversity of previous designs or devices is advantageous during the design concept production stage. Various sources of design information are available in the market, including patents, reference books, magazines, journals, and user guides as stated by Haik, et al. (2015).

Patents are exclusive copyrights granted by law to designers, enabling them to sell and utilize their inventions for a period between 15 to 17 years from the date the invention has been created and approved. Patent reviews for this paper are as outlined in Table 1, which tabulates Figure 1 through Figure 4. Every patentable invention must be new, original, and possess commercial value. Hitchcock et al. (2022) posited that new and original inventions that have not yet been approved for patents but have been accepted as copyright are still given a certificate of innovation use for five years after the date of approval. For patent designers, this information serves as the source of their ideas. The study conducted by Kasim, et al. (2000) examines legally protected inventions that cannot be replicated, elucidates the process of patenting inventions without duplication, and identifies products produced competing institutions.

Table 1

Patented Hose Rolling Tolls

Authors	Tools	Component
Best (2003)	**Figure 1** *Fire hose retrieval winch patents.* 	• Motorized drive • Pressure roller • Adjustment handle • Opposes link • Brushes • Nozzles
Mosher (2004)	**Figure 2** *Portable winding and reeling apparatus patents.* 	• Frame • Rollers • Hose guide • Squeegee • Modular core • Wheels • Hand crank • Motor • Gears

Knapp (1978)	**Figure 3** *Hose winding apparatus patents.* 	• Winding disc • Electrical drive • Motor • Mobile base • Offset leg • Support plate • Offset guide
Peek (2001)	**Figure 4** *Wheeled squeegee for fire hose patents* . 	• Handle • Frame • Wheels • Roller • Squeegee blade. • Coil spring

This research focuses on developing an ergonomic, durable, and efficient motorized hose roller for firefighters, crafted from ductile high-strength aluminium. This study is continuity from earlier research, notably “Ergonomic and Workplace Improvement: A Case Study of Firemen at Pagoh” by Alias et al. (2020), and insights from “Design of an Ergonomic Portable Fire Hose Roller: A Simulation Study” by Isamudin et al. (2021). Ansys Software was utilized to analyse material performance, ensuring that the tool meets the rigorous demands of firefighting environments.

Low Back Pain (LBP) Risks

The five primary risk factors for lower back pain (LBP) include maximum moment, average twisting velocity, lift rate, maximum sagittal flexion, and maximum lateral velocity. As Fiodorenko-Dumas et al. (2018) point out, lifting is a frequent activity that occurs in a variety of industries and is a primary contributor to LBP. According to Kim et al. (2021), lifting-rate activities are common in professions such as emergency medical services and rescue operations, potentially contributing to the increased incidence of low back pain among firefighters. The relationship between LBP risks and spine twisting has been identified in a variety of job sectors. According to research by Al Amer et al. (2020), back twisting and other work-related activities are major contributors to the notably high incidence of LBP among healthcare professionals in Saudi Arabia. Research by Halonen et al. (2019) found that the main factor associated with risks of LBP is working in twisted positions.

Sagittal flexion, which divides the body into left and right halves, is the forward bending of the spine in the sagittal plane. According to Zawadka et al. (2018), the risk of low back pain may be significantly correlated with the forward movement of the hips and lower back. Hira et al. (2021) discovered that an elevated sagittal spine misalignment, particularly a greater sagittal vertical axis (SVA), was associated with higher rates of low back pain and poorer physical performance. The term “lateral flexion” describes the spine’s sideways bending, either to the left or to the right of the body. According to Edwards et al. (2020), this movement mostly occurs in the cervical and lumbar areas, enabling the torso to bend sideways while keeping alignment. According to research by Sadler et al. (2017), there is a greater chance of developing low back discomfort if you have lower lumbar lordosis, lower hamstring flexibility, and lower range of lateral flexion.

METHODOLOGY

A three-dimensional (3D) model of the tools can be created using SolidWorks software according to Pei et al. (2014), which helps to visualize the final product before it is fabricated. The drawing process of the hose roller tool using SolidWorks software began with parts and components. As indicated by Mazani et al. (2019) the SolidWorks software can specify design in terms of parts, assembly, and exploded view of a design.

The fabrication process involved assembly of the components, the attachment of fasteners or supplementary components, and the addition of any requisite electrical connections or wiring for the motor in the case of a motorized hose roller. This helps to understand the relationship between parts, and aids in the assembly process. The flowchart of the methodology is as shown in Figure 5.

For the morphological chart, three concepts for motorized hose rolling tools are proposed in Table 2, each addressing different design considerations. The first concept, represented by the blue line arrow, employs screw threads and rubber tyre wheels for surface friction. Its round-shaped body frame houses a large diameter closed fire hose hook, operated by a chain and pulley system connected to a DC motor. Consumers control this concept with a wired remote control. The second concept, denoted by the red line arrow, also uses screw-type threads and PU tyre wheels for enhanced grip. Its square-shaped frame features a steel fire hose hook with a guide ring, operated similarly to the first concept with a wired remote control. Lastly, the third concept, marked by the green line arrow, utilizes bolt and nut threads, PU tyre wheels, and a chain and pulley system, with the addition of wireless remote control for consumer convenience. Its square-shaped frame houses a small diameter steel fire hose hook for compactness and neat hose rolling.

Figure 5

Methodology flowchart

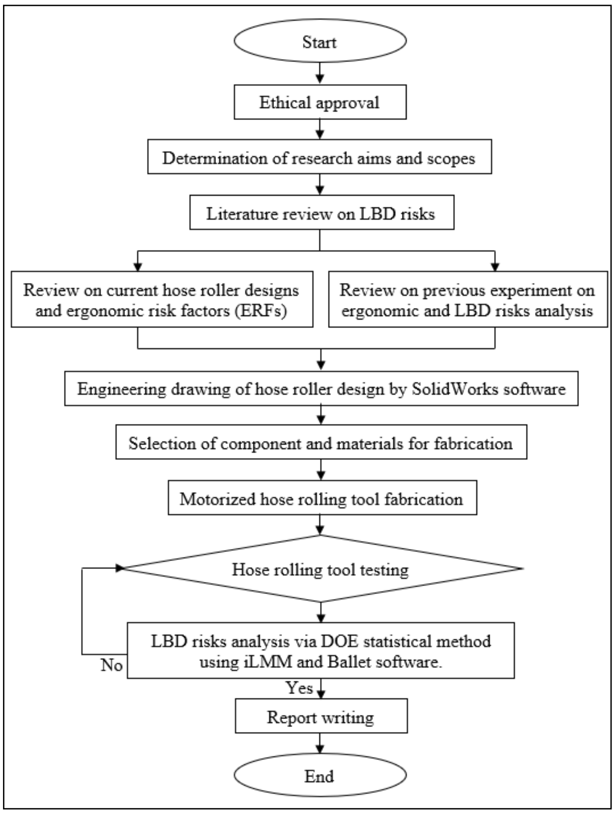


Table 2

Motorized hose rolling tool morphological chart.

No.	Concept 1	Concept 2	Concept 3	Concept 4
1	Rivet 	Screw 	Bolt and nut 	Weld 
2	PU tyre 	PU tyre with coupling	Rubber tyre 	N/A
3	Belt and pulley 	Chain and pulley 	Spur gears 	N/A
4	Cylindrical body frame 	Two sided body 	Square body frame 	Square body frame with brush and motor support 
5	Stainless steel hook 	Steel hook and guide ring 	Stainless steel loosed hook 	Small diameter steel hook 

6	Handle control 	Wired remote control 	Wireless remote control 	N/A
7	Fuel	Electric current	Men power	Battery

The manufacturing process primarily relies on metal fabrication since most components and apparatus of the duct roller are made of steel. Metal fabrication involves casting or forming a raw or semi-finished metal work piece, encompassing shaping, bending, and cutting. While welding is the most common metal fabrication technique, fitting and shaping methods are preferred over welding for the hose roller. This preference arises because welding can create a permanent connection, leading to difficulties in the maintenance process of the hose roller. The outer and inner systems of the hose roller were designed based on the embodiment of previous patents and designs.

The casing of the hose roller was fabricated using fitting and shaping methods. The aluminium sheet is shaped in accordance with the design sketched earlier in this research. A hollow steel frame measuring 20 mm width and 20 mm height was cut and shaped before it was welded, as depicted in Figure 6(a) below, according to the dimensions provided in the drawing. Pillow block bearings were mounted on the frame as shown in Figure 6(b) to provide support and stability to the shaft, allowing it to rotate smoothly.

Figure 6

Fabrication of (a) body frame and (b) installation of roller bearing.

(a)

(b)

Accurate alignment prevents issues such as friction, misalignment, or uneven rotation, ensuring the efficiency and durability of the motorized hose roller. By marking the shaft, it could help guide the path for the subsequent installation of wheels, sprockets, and chains. Attention to detail during the early stages of fabrication sets the foundation for the proper alignment and function of the motorized hose roller. This emphasizes the importance of precise alignment in achieving optimal performance.

The electrical parts of the motorized hose rolling tool include components such as a rechargeable battery, digital voltmeter, safety switch, speed controller, remote control, and a high torque DC gear motor. In the fabrication process, the circuit diagram for a motorized hose rolling tool visually represents the electrical system that controls the tool's functioning. The electrical circuit demonstrated in Figure 7 illustrates the relationships and roles of important parts involved in managing the motor that powers the hose roller.

Figure 7

Electrical system of motorized hose roller tool.

The digital voltmeter was integrated to provide current monitoring of battery voltage, offering users an indication of power status. An important component enabling regulated power distribution and emergency stop is the safety switch. To enhance adaptability, the speed controller enabled fabricators to adjust the rotational speed of the high-torque DC gear motor in accordance with specific specifications. The motorized hose roller tool could be operated wirelessly and regulated by a remote and motor speed controller, which provides an additional level of convenience. Each component was connected to one another component to ensure that the transmitted signals guaranteed accurate control, security, and effective function as depicted in Figure 8. The installation of electrical components in the motorized hose roller tool is also demonstrated in Figure 8.

Figure 8

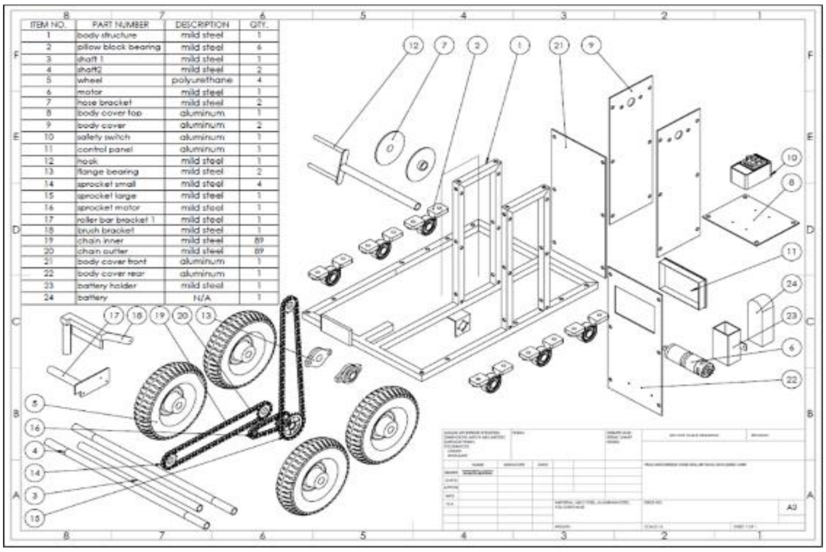
Installation of electrical components.

RESULT AND DISCUSSION

The motorized hose roller tool was sketched using the SolidWorks software. It consisted of body, frame, hook, chain, pulley, wheels, bearings, and DC motor. The body formed the main structure of the tool, housing various components and providing support. The frame added stability and rigidity to the tool structure. Similar to the mechanical hose roller, the hook secured the hose in place during storage or transport. The chain was used to transfer rotational motion from the motor to the drum, facilitating the rolling or unrolling of the hose. The pulley, connected to the drum, assisted the transferring of the rotational motion from the chain to the drum. Wheels were attached to the base of the tool, allowing for easy movement and transportation. Bearings were incorporated to enable seamless rotation between the drum, pulley, and wheels, reducing friction and ensuring efficient operation. The DC motor served as the power source for the tool, providing the rotational force required to roll or unroll the hose. Figure 9 presents detailed engineering drawings of the exploded view of motorized hose roller tool.

Figure 9

Motorized hose rolling tool exploded view



The fabrication of this research which involves efficient improvements is based on previous studies, proposed designs, and a testing process. The dimensions of the fabricated hose rolling tool indicate significant modifications from the previous design. The testing approach employed in this research resulted in improvements. The dimensions of the hose rolling tools have been increased to improve the performance of the hose rolling tool during LBD risks analysis. Furthermore, this function operates as an approach of achieving balance for the movement of the hose rolling tools. The newly developed motorized hose rolling tool designed using insights from previous models and patents was successfully tested and validated in a practical setting. The fabricated motorized hose rolling tool are as shown in Figure 10.

Figure 10

Fabricated motorized hose rolling tool.

The tool is powered by a DC motor, controlled remotely for ease of use and capable of multi-directional movement, adding to its operational flexibility. Safety measures are a standout aspect with a main power switch, a digital control board displaying speed and movement, and a battery indicator for monitoring power usage. The tool's effectiveness was put to the test at a local fire station, where firefighters provided first-hand feedback on its performance. Their experience confirmed the tool's practicality and safety in real-life fire scenarios, underlining its potential as an asset in firefighting equipment. This testing phase not only proved the tool's capabilities but also offered insights for future enhancements.

Moreover, data comparison was an approach used to evaluate the efficiency of each hose rolling method in reducing the LBD risk among firefighters. The data of conventional, mechanical, and motorized hose roller methods were collected and analysed using the Ballet Software. The most efficient hose rolling method in reducing the LBD risk was determine and data comparison of the LBD risk analysis is as depicted in Table 3.

Table 3

LBD risk analysis results

No.	**Method**	**Fire hose conditions**			**Total average probability of LBD risks**
		Dry (%)	Wet (%)	Dirty (%)	
1	Conventional Hose Rolling	59	59	54	58.22 %
2		59	59	57	
3		59	59	59	
4	Mechanical Hose Rolling Tool	39	34	27	34.33 %
5		48	28	32	
6		37	38	26	
7	Motorized Hose Rolling Tool	20	28	9	17.44 %
8		10	27	17	
9		11	24	11	

Data comparison was made using the Ballet software. The total average probability of LBD risk for each hose rolling method was calculated by adding the probabilities for all three conditions (total of dry, wet, and dirty) and divided by the number of conditions (3). Equation (1) shows the calculation for 10-m hose length for conventional hose rolling.

$$59\% \text{ (Dry)} + 59\% \text{ (Wet)} + 54\% \text{ (Dirty)} = 172\%$$
$$172\% \div 3 = 57.33\% \tag{1}$$

The overall average probability of LBD risk for the three methods was also calculated by adding the average probability values for each hose length and divided by the number of hose lengths. The calculation for conventional hose rolling method is as expressed in Equation (2).

$$57.33\%\text{(10-meter)} + 58.33\%\text{(20-meter)} + 59\%\text{(30-meter)} = 174.66\%.$$
$$174.66\% \div 3 = 58.22\% \tag{2}$$

Based on the results obtained, the experimental subject is more likely to face greater LBD risk through the conventional method compared to the other two hose rolling methods, with an average probability of LBD risk of 58.22%. On the other hand, the mechanical hose roller tool method recorded a total of 34.33% LBD risk, categorizing it as a hazardous hose rolling method. The method poses hazard to the user if the average probability of LBD risk exceeds half of the LBD risk scale, which is 30%. The motorized hose roller tool successfully completed all nine experimental trials, exhibiting the lowest average probability of LBD risk of 17.44%, making the motorized hose roller tool the most efficient method in reducing 40.78% of LBD risk among firefighters.

CONCLUSION

The potential of the motorized hose rolling tool to improve firefighter safety and well-being during hose rolling operations is highlighted, especially in relation to the risks of lower back pain (LBP). The research objectives focused on designing both conventional and motorized hose roller tools tailored to firefighters' needs, emphasized innovation, user-friendliness, and effectiveness. Fabrication using lightweight and durable materials, such as aluminium, further aligned with the goal of providing easy-to-handle tools. The analysis of LBD risks using methods such as Design of Experiments (DOE) and integrating industrial lumbar motion monitoring (iLMM) provided insights into optimizing hose rolling activities and understanding the impact of the hose roller tool on firefighters' lower backs. This ensured that the tools were ergonomically designed to minimize injury risks effectively.

The research's significance lies in its potential to revolutionize firefighting tools through ergonomic design principles and thorough LBD risk analysis. The outcomes not only benefit firefighters directly but also contribute valuable insights to the fields of manufacturing, product development, and occupational safety. A hose roller tool that is both dependable and efficient has the potential to significantly enhance the safety and efficiency of firefighting operations, thereby contributing significantly to the well-being of those who are committed to the protection of communities.

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REFERENCES

Al Amer H. S. (2020). Low back pain prevalence and risk factors among health workers in Saudi Arabia: A systematic review and meta-analysis. *Journal of Occupational Health*, 62 (1):e12155. https://doi.org/10.1002/1348-9585.12155

Best, G. R. (2003, July 15). *US7448110B2 - Fire hose retrieval winch – Google Patents*. Retrieved April 3, 2023, from: https://patents.google.com/patent/US7448110?oq=fire+hose+winder

Cross, N. (2021). *Engineering design methods: strategies for product design*. John Wiley & Sons. Retrieved January 18, 2023, from: ISBN: 978-1-119-72437-7

Edward N., Dickin, C., & Wang, H. (2020). Low back pain and golf: A review of biomechanical risk factors. *Sports Medicine and Health Science*, 2(1), 10-18. https://doi.org/10.1016/j.smhs.2020.03.002

Fiodorenko-Dumas, Ż., Kurkowska, A., & Paprocka-Borowicz, M. (2018). Spine pain in the firefighter profession. *Medycyna Pracy*, 69(4), 365-373. htpps://doi.org/10.13075/mp.5893.00679

Gentzler, M., & Stader, S. (2010). Posture stress on firefighters and emergency medical technicians (EMTs) associated with repetitive reaching, bending, lifting, and pulling tasks. *Work (Reading, Mass.)*, 37(3), 227–239. https://doi.org/10.3233/WOR-2010-1075.

Haik, Y., Sivaloganathan, S., & Shahin, T. M. (2015). *Engineering design process*. Cengage Learning. Retrieved March 4.

Halonen, J. I., Rahman, S., Linda L. Hanson, M., & Lallukka, T. (2019). Risk and prognostic factors of low back pain: Repeated population-based cohort study in Sweden. *Spine*, 44(17), 1248-1255. https://doi.org/10.1097/BRS.0000000000003052

Hitchcock, D. (2022). *Patent Searching Made Easy: How to do Patent Searches Online and in The Library*. Nolo. Retrieved May 15.

Hira, K., , Nagata, K.,, Hashizume, H., et al. (2021). Relationship of sagittal spinal alignment with low back pain and physical performance in the general population. *Scientific Reports*, 11(1), 20604. https://doi.org/10.1038/s41598-021-00116-w

Isamudin A. (2021). Design of an ergonomic portable 2021. hose roller: A simulation study. Universiti Tun Hussein Onn Malaysia. Retrieved April 2nd, 2021.

Kasim (2000). Proses dan Kaedah Reka Bentuk (1st ed., Vol. 2). Universiti Teknologi Mara.

Katsavouni, F., Bebetsos, E., Antoniou, P., Malliou, P., & Beneka, A. (2014). Work-related risk factors for low back pain in firefighters: Is exercise helpful?. *Sport Sciences for Health*, 10, 17-22.

Knapp, O. J. (1978). US4198010A - Hose winding apparatus - Google Patents. Retrieved April 3, 2023, from: https://patents.google.com/patent/US4198010?oq=fire+hose+roller

Magdalena, Z., Skublewska-Paszkowska, M., Gawda, P., et al. (2018). What factors can affect lumbopelvic flexion-extension motion in the sagittal plane: A literature review. *Human Movement Science*, 58 (2018), 205-218. https://doi.org/10.1016/j.humov.2018.02.008

Mahmood, S., Nasir, S.H., Mamat, N., Abdul Rahman, I. & Azis, N.A. (2022). Ergonomics and manual handling workplace improvement: A case study of firefighter at Pagoh. In Hassan, M.H.A., et al. *Human-centred technology for a better tomorrow*. *Lecture Notes in*

Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-16-4115-2_46

Mazani, N., Sapuan, S. M., Sanyang, M. L., Atiqah, A., & Ilyas, R. A. (2019). Design and fabrication of a shoe shelf from kenaf fibre reinforced unsaturated polyester composites. In *Lignocellulose for Future Bioeconomy* (pp. 315-332). Elsevier. Retrieved March, 5, 2023, from: https://doi.org/10.1016/B978-0-12-816354-2.00017-7 .

Min Gi K., & Yeon-Soon, A. (2021). Associations between lower back pain and job types in South Korean male firefighters. *International Journal of Occupational Safety and Ergonomics,* 27(2), 570-577. https://doi.org/10.1080/10803548.2019.1608061

Mosher, J. L. (2004, September 10). US8360353B2 - Portable winding and reeling apparatus - Google Patents. Retrieved April 6, 2023, from: https://patents.google.com/patent/US8360353?oq=fie+hose+roller

Peek, D. (2001, June 8). US20020185017A1 - Wheeled squeegee for fire hose Google Patents. Retrieved April 5, 2023, from: https://patents.google.com/patent/US20020185017?oq=fire+hose+roller

Pei, S., Cui, F., & Chu, F. (2014, June). *Application of SolidWorks in mechanical design and drafting courses.* In 3rd International Conference on Science and Social Research (ICSSR 2014) (pp. 90-93). Atlantis Press. Retrieved March, 11, 2023 from https://doi.org/10.2991/icssr-14.2014.22.

Sadler, Sean G., Martin J. Spink, Alan Ho, Xanne Janse De Jonge, & Vivienne H. Chuter. Restriction in lateral bending range of motion, lumbar lordosis, and hamstring flexibility predicts the development of low back pain: a systematic review of prospective cohort studies. *BMC Musculoskeletal Disorders,* 18 (2017): 1-15. https://doi.org/10.1186/s12891-017-1534-0