Development of an occupational upper-limb exoskeleton

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Contents

1 Aim

This project aims to develop an occupational upper-limb exoskeleton specifically targeting the elbow joint to assist workers in lifting heavy objects, focusing on mechatronic design, system characterisation and control, physical and sensor interface design, and user testing.

2 Objectives

1. To investigate the present state of art on upper limb exoskeletons and their possible impact on physical exposures and worker performance.
2. Develop a novel, wearable elbow exoskeleton that can assist workers in performing heavy lifting tasks and reduce the risk of work-related injuries.
3. Conduct physical testing of the exoskeleton on a mannequin designed to mimic the bio-mechanics of the human arm and evaluate its mechanical performance, including load-bearing capacity, range of motion, and ease of use.
4. Integrate a range of sensors, including EMG and IMU, to record and analyse data related to the user's muscle activity, joint angles, and other kinematic and kinetic parameters during exoskeleton use.
5. Conduct user testing with diverse individuals, including experienced and novice workers, to assess the exoskeleton's impact on lifting capacity, user comfort, and overall performance.

3 Motivation

This research aims to address the issue of occupational upper limb injuries, and the physical strain workers in various industries encounter. These injuries can result in long-term disability and decreased productivity, which has an economic and societal cost. Exoskeletons can help reduce such injuries by assisting workers in lifting hefty objects and decreasing physical strain, enhancing worker health and well-being, increasing productivity, and lowering economic costs.

3.1 Why this aim

The elbow joint is one of the most vulnerable locations of the upper limb. Injuries to this joint can result in long-term disability. The goal of designing an occupational upper-limb exoskeleton targeting the elbow joint is to protect this joint. We can help prevent injuries and promote worker health and well-being by focusing on this joint.

Musculoskeletal disorders (MSDs) are among the most frequent types of work-related accidents and illnesses, accounting for more than 35% of all work-related diseases globally [1]. In the United Kingdom, 469,000 occurrences of MSDs were reported in 2018/2019, costing employers an estimated £8.2 billion [2]. These conditions impact the musculoskeletal system, which includes the muscles, tendons, ligaments, nerves, and other soft tissues. MSDs can cause pain, discomfort, and disability, resulting in decreased productivity, increased absenteeism, and a lower quality of life for workers [3].

Upper limb MSDs are most common in professions that involve repetitive, intense, or uncomfortable movements, such as manufacturing, construction, and agriculture. These industries employ millions globally, putting them at risk for upper limb injuries [4]. A UK research, for example, discovered that upper limb MSDs had the highest incidence among construction workers, with 28% reporting symptoms [5].

Employers face high economic costs in addition to the human costs of workplace injuries and illnesses. Wounded or ill employees may require time off work to heal. This results in productivity loss, higher healthcare costs, and the need to acquire replacement workers or pay overtime to existing staff to maintain production levels [6].

In the United Kingdom, for instance, the estimated cost of a nonfatal work-related injury is £8,200, which includes lost productivity, healthcare expenditures, and legal fees. According to a study in the United States, the estimated price of a work-related MSD is $28,000 per case, including direct medical costs and indirect costs such as missed productivity and absenteeism [7]. These expenditures can be especially difficult for small and medium-sized businesses (SMEs) with limited finances to cover workplace accidents, and illnesses [8].

Upper limb injuries are a significant issue in many sectors, especially those that involve repetitive or severe actions [9]. These injuries can result in pain, discomfort, and impairment, reducing productivity and increasing absenteeism. Exoskeletons, wearable technology that can support movement and lessen the chance of damage, are one answer to this problem [10].

3.2 Why this application

This application is aimed towards manual labourers in various industries, including manufacturing, construction, and logistics. Because of the repetitive nature of their labour, these individuals are at a greater risk of upper limb injuries and physical strain. The exoskeleton can help workers lift big objects, decreasing physical strain and injury risk.

Occupational injuries and diseases are significant issues around the world. The International Labour Organization (ILO) estimates that roughly 2.78 million workers die each year due to industrial accidents or illnesses [11]. Furthermore, 374 million nonfatal workplace injuries and illnesses are reported yearly, resulting in significant human and economic losses. In the United Kingdom, 581,000 nonfatal workplace injuries in 2018/2019 cost businesses an estimated £15 billion [2].

In sectors like production and construction, exoskeletons lower the danger of damage [12]. Research conducted in Japan, for example, discovered that utilising an upper limb exoskeleton decreased muscular activity and tiredness during overhead labour, lowering the chance of injury [13]. Furthermore, exoskeletons can increase worker productivity while reducing the physical strain of manual work [14].

3.3 Why this challenge

Numerous research has shown that using OEs is beneficial. Using a passive back-support exoskeleton, for example, reduced spinal compression pressures by 10-40% during lifting duties, according to a study by de Looze et al [15][16]. Another study by Kim et al. [17] found that wearing an active shoulder-assist exoskeleton during overhead tasks reduced shoulder muscle activity by 20-50%.

Due to the complexity of the mechatronic design, the need for correct system characterisation and control, and the creation of physical and sensor interfaces that can offer accurate input to the user, the development of an occupational upper-limb exoskeleton provides a substantial challenge. Furthermore, the exoskeleton must be comfortable and unobtrusive so that personnel can efficiently complete their tasks.

3.4 Why is it new

Most contemporary exoskeletons are intended for the shoulder or hand, ignoring the critical significance of the elbow joint in lifting duties [17]. The elbow joint is essential to the upper limb because it provides stability and enables arm extension and flexion. The elbow joint is also in charge of managing the forearm's orientation during lifting duties, which is critical for maintaining good bio-mechanics and lowering the risk of injury [18]. As a result, an elbow exoskeleton is required to enhance the user's lifting ability and the ergonomics of manual lifting jobs.

The proposed project is novel in that it entails the creation of an occupational upper-limb exoskeleton with a focus on the elbow joint. Unlike past efforts to construct upper-limb exoskeletons, this research takes a different approach by focusing on a specific joint and addressing the accompanying problems.

3.5 Why me

Occupational injuries and illnesses are a significant problem worldwide, with musculoskeletal disorders being one of the most common types of work-related injuries. Upper limb injuries are especially common in sectors that require repetitive or severe actions, and they can have significant economic and human consequences. Exoskeletons may solve this problem because they can help with movement and lessen the danger of damage.

To effectively create an occupational upper-limb exoskeleton targeting the elbow joint, our team possesses the requisite skills in mechatronic design, system characterisation and control, physical and sensor interface design, and user testing. We are also dedicated to promoting employee health and well-being, and this project is consistent with our core values and mission.

4 Literature Review

4.1 Methodology:

A thorough search was undertaken for this literature review utilising several electronic databases, including PubMed, ScienceDirect, and IEEE Xplore. "Upper limb exoskeleton," "exoskeleton design," "exoskeleton technology," "exoskeleton applications," and "exoskeleton problems" were the search terms.

4.2 The inclusion criteria for the papers:

1. The text is in English.

2. From 2015 and 2023, it will be published.

3. Full-text papers are available.

4. Upper limb exoskeleton design and applications are the focus.

4.3 The exclusion criteria for the papers:

1. Publications focusing on wearable devices other than exoskeletons.

2. Articles focusing mainly on exoskeletons of the lower limbs.

3. Abstracts from conferences or articles that needed to be peer-reviewed.

4.4 Introduction:

Work-related musculoskeletal diseases (MSDs) are a significant problem in the workplace, affecting employees' health, productivity, and quality of life. MSDs accounted for 33% of all worker injury, and sickness cases in 2019 [12], according to the Bureau of Labor Statistics, with back, shoulder and elbow injuries being the most common. These injuries are major causes of repetitive or extended tasks involving lifting, carrying, pushing, or hauling big things. Exoskeletons are wearable devices that provide external mechanical support or power to augment or assist human mobility. In recent years, there has been a surge of interest in using exoskeletons for professional reasons, to reduce the physical burden on employees doing demanding tasks and eliminate MSDs [19].

Wearable devices that support and help the arm and hand during physical activities are upper limb exoskeletons. These gadgets can help people with upper limb limitations live better lives and help workers do physically demanding tasks. Exoskeleton development that is both practical and user-friendly necessitates thorough consideration of design concerns and challenges. This literature review provides an in-depth look at the present state of upper limb exoskeleton design and applications.

4.5 Analysis:

The papers chosen cover a wide range of subjects concerning upper limb exoskeletons. The papers' primary focus is on design considerations for upper limb exoskeletons. Gull et al. (2017) present a detailed upper limb exoskeleton design analysis, highlighting key design considerations and problems [20]. Rosales et al. (2019) present a detailed examination of an upper limb exoskeleton's mechanical design, and modelling [21]. In contrast, Altenburger et al. (2019) discuss the design of a passive, iso-elastic upper limb exoskeleton for gravity correction [22].

Evaluating upper limb exoskeletons in diverse applications is another main subject of the studies. Bosch et al. (2019) investigated the effects of a passive exoskeleton on muscle activity, discomfort, and endurance time during forward bending work [23]. In contrast, Desbrosses et al. (2019) investigated the influence of exoskeleton design and load on muscular adaptations and balanced regulation during overhead work [24].

Other studies also explore the difficulties of developing upper limb exoskeletons. McFarland and Fischer (2020) thoroughly examined the effects of active and passive upper limb exoskeletons on physical exposures [25]. Crea et al. (2021) outlined a strategy for the widespread adoption of occupational exoskeletons [26]. The authors cite problems such as the need for increased energy efficiency, more user-friendly control interfaces, and personalised designs that may meet the needs of individual users.

Despite the variety of themes covered by the selected publications, the conclusions share certain similarities. The papers emphasise the significance of user-centred design and the need for more collaboration among researchers, manufacturers, and end users. The authors also emphasise the importance of increased energy efficiency, compact designs, and user-friendly control interfaces.

There are, however, variations in the findings given in the chosen studies. Some studies, for example, concentrate on creating and modelling upper limb exoskeletons, while others concentrate on evaluating exoskeletons in diverse applications. Furthermore, some publications focus on the obstacles that exoskeleton development faces, while others give answers to these challenges.

Furthermore, passive exoskeletons have been demonstrated to improve endurance time by lowering muscular activity and pain during forward bending. These findings imply that passive exoskeletons can lower the incidence of musculoskeletal injuries in workers performing repetitive or physically demanding occupations.

On the other hand, active exoskeletons have been demonstrated to have mixed benefits in minimising physical exposure and boosting worker performance. According to one study, active exoskeletons did not lower muscular activity during overhead labour any more than passive exoskeletons did. Another study found that while active exoskeletons boosted endurance during repetitive lifting tasks, they also increased discomfort and restricted shoulder range of motion.

The literature review highlights the advantages and disadvantages of employing exoskeletons for occupational applications. While exoskeletons have demonstrated promise in lowering the physical load and preventing MSDs, various issues must be considered when creating exoskeletons, including exoskeleton design, load, customisation, and human factors. Additionally, exoskeleton standards and regulations are required to ensure their safety and efficacy in the workplace. The suggested elbow exoskeleton solves difficulties by emphasising mechatronic design, system characterization and control, physical and sensor interface design, and user testing. By incorporating a variety of sensors, the exoskeleton will enable the evaluation of user muscle movement, range of motion, and other kinematic data and kinetic variables during exoskeleton use, allowing the development of a customisable and ergonomic device that can seamlessly integrate into the user's work environment. Finally, the creation of an elbow exoskeleton has the potential to considerably reduce the incidence of work-related injuries, boost worker productivity, and improve workers' quality of life.

5 Impact Assessment

The development of an occupational upper-limb exoskeleton has the potential to influence workers and employers in various industries substantially. This impact assessment will examine the possible benefits of utilising an exoskeleton in the workplace, such as reduced work-related injuries and costs, increased productivity, and improved worker health and well-being. It will also investigate the potential drawbacks of exoskeleton adoption and provide solutions.

5.1 Social Impact

Creating an occupational upper-limb exoskeleton can have a significant social impact by enhancing the health and well-being of workers in various industries. It can potentially lessen upper limb injuries and tiredness associated with repetitive manual labour, leading to long-term disability and a lower quality of life. This project can also improve employees' working conditions, productivity, and job satisfaction by minimising physical strain and assisting workers in performing jobs more efficiently. This can eventually lead to improved social welfare for workers, and society [27].

5.2 Economic Impact

The planned project has a considerable economic impact [28]. Upper limb injuries and related musculoskeletal disorders (MSDs) are a primary cause of occupational absenteeism and decreased productivity. The exoskeleton can reduce the costs associated with lost productivity and medical bills by lowering the incidence of such injuries. Furthermore, installing exoskeletons can boost work speed and efficiency, resulting in higher output and profitability for businesses [29]. This can also lead to new work opportunities in developing, manufacturing and maintaining exoskeletons [30].

5.3 Legal Impact

Using exoskeletons in the workplace presents severe legal concerns that must be addressed. Regulations and standards must be devised to ensure that exoskeletons meet safety and performance requirements. Exoskeletons must also be appropriately incorporated into employers' occupational health and safety rules and procedures. Additionally, legal liability difficulties may arise in the event of an exoskeleton-related injury or accident. As a result, it is critical to creating regulatory frameworks that govern the research, manufacturing, and usage of exoskeletons in the workplace [31].

5.4 Ethical Impact

Exoskeleton development and application in the workplace create ethical concerns that must be addressed. Exoskeletons are equipped with sensors that capture data on workers' movements and actions, which raises privacy and data protection concerns. There are also issues about worker autonomy and the possibility of employers using exoskeletons to monitor and regulate workers' behaviour. As a result, it is critical to guarantee that exoskeletons are designed and executed ethically, with workers' autonomy, privacy, and rights respected [31].

5.5 Environmental Impact

The planned project has a low environmental impact. Developing industrial exoskeletons can reduce the carbon footprint of numerous sectors. It is critical to guarantee that exoskeleton manufacturing and disposal are environmentally friendly. Utilising environmentally friendly materials and recycling systems can reduce the project's environmental impact.

5.6 Analysis

Finally, the suggested project of constructing an occupational upper-limb exoskeleton has the potential to have substantial social, economic, legal, ethical, and environmental implications. It can improve workers' health and well-being, boost productivity, and create a safer and more efficient workplace. As a result, it is critical to ensure that exoskeleton development and implementation are done correctly and sustainably, considering numerous social, economic, legal, ethical, and environmental factors.

6 Risk Register

Risk	**Mitigation**	**Likelihood (A)**	**Impact (B)**	**Score (AxB)**
Injury to the user during testing	Provide proper training to users on using the exoskeleton and performing testing in a controlled environment with safety measures	1	3	3
Technical failure of the exoskeleton during testing	Conduct thorough testing of the exoskeleton before human testing, including stress tests and reliability tests, and have backup systems in place	2	3	6
Difficulty in controlling the exoskeleton	Develop and implementing robust control algorithms to ensure the exoskeleton responds accurately to user movements	2	2	4
Inadequate sensor data	Use multiple sensors to ensure accurate and reliable data collection and implement signal processing techniques to filter out noise	1	2	2
Inability to recruit enough participants for testing	Develop a recruitment strategy that includes multiple sources and incentives for participation	1	1	1

7 Timeline

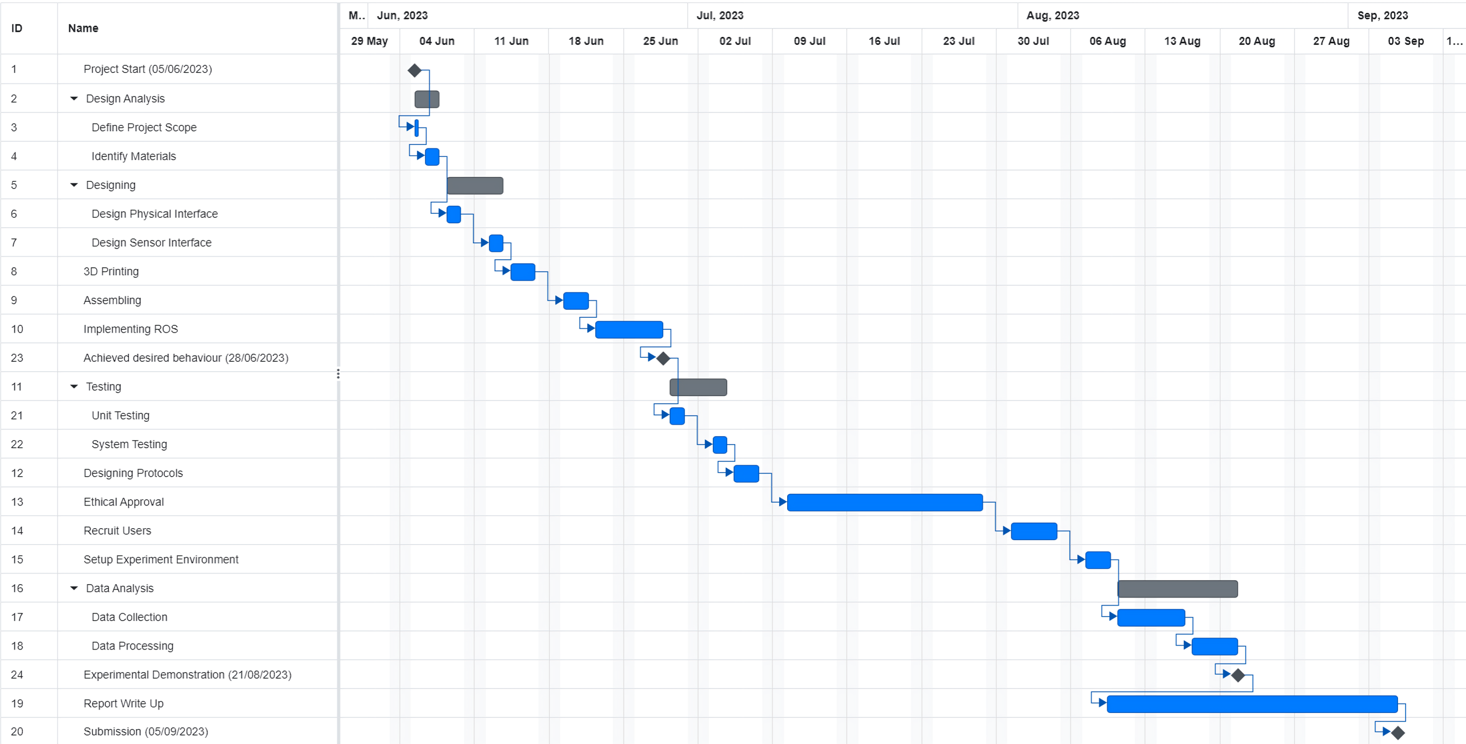

Figure 1: Gantt Chart for the Development of an Occupational Upper-Limb Exoskeleton Project (June 5, 2023 - September 5, 2023)

1. **Design Analysis:** This task entails examining the exoskeleton design's requirements and restrictions, finding relevant literature, and specifying design parameters.

2. **Designing:** Using computer-aided design (CAD) software, create a thorough design of the exoskeleton and its components.

3. **3D Printing:** This task entails utilising a 3D printer to create the exoskeleton components.

4. **Assembling:** Assembling the printed components, evaluating their fit and performance, and making any necessary revisions are all part of this activity.

5. **Implementing ROS:** This task entails programming the exoskeleton to communicate with the Robot Operating System (ROS) to control its movements and receive sensor data.

6. **Testing:** This exercise entails assessing the functionality of the exoskeleton, such as its ability to support lifting and its response to user input.

7. **Designing Protocols:** This activity entails creating experimental protocols for user testing, which includes deciding on relevant tasks, processes, and data-gathering methods.

8. **Ethical Approval:** This activity entails obtaining ethical approval for user studies.

9. **Recruit Users:** This activity entails identifying potential participants for user studies, confirming they fit the inclusion requirements, and gaining informed consent.

10. **Prepare for Experimentation:** This task entails setting up the experimental setup, which includes sensors, equipment, and data-gathering software.

11. **Data Analysis:** This activity examines the data acquired from user studies, including statistical analysis and result interpretation.

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