DESIGN AND FABRICATION OF

EXO-SKELETON ARM FOR BIO MEDICAL USE

PROJECT REPORT

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

Bachelor of Technology

in

Mechanical Engineering

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2023-24

<u>CERTIFICATE</u>

This is to certify that the project report entitled **Design & Fabrication of Exo-skeleton Arm for Bio Medical Use** submitted by **Daksh Sharma, Navneet Kumar** and **Mayank Awasthi** to the Zakir Hussain College of Engineering and Technology, Aligarh Muslim University in partial fulfillment for the award of the degree of B. Tech in Mechanical Engineering is a bona fide record of project work carried out by them under my supervision. The contents of this report, in full or in parts, have not been submitted to any other Institution or University for the award of any degree or diploma.

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DECLARATION

I declare that this project report titled **DESIGN AND FABRICATION OF EXOSKELETON ARM FOR BIO MEDICAL USE** submitted in partial fulfillment of the degree of **B. Tech in Mechanical Engineering** is a record of original work carried out by me under the supervision of **Prof. Arshad Hussain Khan** and has not formed the basis for the award of any other degree or diploma, in this or any other Institution or University. In keeping with ethical practice in reporting scientific information, due acknowledgements have been made wherever findings others have been cited.

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ACKNOWLEDGEMENT

We extend our heartfelt gratitude to Professor Arshad Hussain Khan for his unwavering guidance and invaluable contributions during our final year B-Tech project. Under his mentorship, we embarked on an exhilarating journey focused on designing and fabricating an exoskeleton arm—an endeavor that challenged our engineering skills and ignited our passion. Professor Khan's profound knowledge and enthusiasm for the subject left an indelible mark on our project. His perceptive recommendations, constructive criticism, and extensive experience were instrumental in steering us toward success. Beyond the technical aspects, his commitment to fostering a positive learning environment inspired us to strive for excellence and surpass our intellectual limits.

Throughout the project, Professor Khan demonstrated a rare blend of patience, encouragement, and attention to detail. His ability to simplify complex concepts, solve intricate problems, and provide timely feedback was invaluable. Moreover, his mentorship extended beyond the project itself, emphasizing professional growth, accountability, and unwavering dedication to our work. We are immensely grateful for the opportunities he provided us to apply theoretical knowledge in real-world scenarios. His guidance not only enhanced our technical proficiency but also instilled the confidence and resilience needed to tackle practical engineering challenges.

ABSTRACT

Our project focuses on the design and fabrication of an advanced upper body exoskeleton. Seamlessly integrating biomechanics and engineering, this cutting-edge system addresses critical challenges in rehabilitation, therapeutic applications, and physically demanding occupations.

The exoskeleton meticulously replicates natural limb movements, ensuring a comfortable fit and ease of use. By bridging the gap between biomechanics and technology, it promises seamless integration with the user's body. Unlike its bulky predecessors, our exoskeleton stands out as an ergonomic, cost-effective solution. Activated by motion sensors, it caters to a wide range of users, from clinical settings to home-based rehabilitation.

Onboard sensors provide real-time data on muscle contraction intensity, facilitating precise movements and gradual improvement over time. This benefit extends to patients with conditions like cerebral palsy, myopathy, and muscular dystrophy. Beyond clinical applications, our exoskeleton significantly reduces the risk of injuries resulting from heavy lifting in physically demanding occupations and search and rescue operations—an issue affecting thousands of workers annually.

Specifically targeting the arm, our exoskeleton enhances users' ability to lift additional weight during daily activities. This addresses a wide range of needs that were previously challenging for individuals. Moreover, the outlined development process emphasizes augmenting the load-lifting capacity of the human arm, with potential applications spanning defense, physiotherapy, and manufacturing.

In essence, our exoskeleton arm represents a pioneering advancement—one poised to make a substantial difference in the lives of individuals across diverse domains. Beyond physical strength, it embodies hope, progress, and the relentless pursuit of enhancing human mobility and well-being.

Keywords : **Exoskeleton, Hydraulic, Pneumatic, Electric, Arm, Design**

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1. INTRODUCTION

In recent years, the development of wearable external skeletal systems—commonly known as exoskeletons, has captured the imagination of researchers, engineers, and healthcare professionals alike [1]. These remarkable technologies hold the promise of revolutionizing various fields, from medical rehabilitation to industrial augmentation [2], by strengthening human capabilities and enhancing overall quality of life [3].

Our project focuses on a specific frontier within this domain and aims to assist individuals with limited arm mobility, empowering them to regain independence and participate more fully in daily activities. Whether aiding stroke survivors on their path to recovery, supporting people with disabilities, or safeguarding workers against occupational hazards, exoskeleton arms embody a convergence of engineering prowess and compassion.

In this report, we delve into the intricate blend of mechanical and electronic considerations that underpin the creation of our exoskeleton arm. We explore design principles, control mechanisms, materials selection, and various manufacturing processes—all crucial components that shape the exoskeleton's functionality and user experience. Moreover, we address critical aspects such as user adaptability, ergonomics, and the integration of emerging technologies to ensure that our exoskeleton arm aligns with the evolving needs and expectations of its users.

Beyond technological innovation, our project represents a compassionate endeavor—one that seeks to enhance mobility, improve lives, and bridge the gap between human potential and physical limitations. As we embark on this journey, we invite you to explore the intricacies of our exoskeleton arm and witness the transformative impact it can have on individuals across diverse domains.

Fig. 1 Basic design of Exo-skeleton Arm

(Source : Medium - https://medium.com/@debashree.dey/empowering-lives-the-role-of-exoskeletons-in-rehabilitation-46d4da12ab73)

2. LITERATURE REVIEW

The realm of exoskeleton arm technologies has witnessed remarkable progress, driven by the collective efforts of researchers and engineers. These innovations aim to enhance human capabilities across daily tasks, rehabilitation [4,5], and industrial contexts [2]. In this literature review, we explore key contributions that have shaped the landscape of exoskeleton arms, transcending mere mechanics to empower individuals and redefine possibilities.

Lomonova et al [6]: Actuation Principles and Applications: Lomonova and colleagues conducted an insightful analysis of actuation principles within arm support systems. Their work categorizes these systems based on user environments—ambulatory, rehabilitation, and industrial. By shedding light on diverse applications and actuation technologies (including electromechanical, pneumatic, hydraulic actuators, and semi-active dampers), Lomonova's research provides a foundational understanding for subsequent advancements.

Panich et al [7]: Kinematic Exoskeletons for Strength Augmentation: Panich's team delved into the development of a kinematic exoskeleton suit for human arms using MATLAB simulation. This innovative design, characterized by one link length, three link twists, two link offsets, and three joint angles, aims to augment human strength. Notably, its potential industrial applications—such as moving or lifting loads in otherwise inaccessible areas—underscore the versatility of exoskeleton technology.

Sheeba P. S et al [7]: Pneumatic Air Muscles for Enhanced Upper Body Motion: Sheeba P. S and collaborators contributed significantly by harnessing pneumatic air muscles (PAMs) to enhance natural upper body motion. Their powered exoskeleton, driven by PAMs, amplifies muscular movement, enabling individuals to perform tasks beyond their physical limitations. The deliberate choice of power assist over costlier power amplification devices, coupled with the integration of EMG electrodes, reflects a commitment to affordability and accessibility.

Nicholas Yagn [8]: Milestone in Walking, Jumping, and Running Assistance: Nicholas Yagn's invention marked a pivotal milestone—the development of the first exoskeleton structure specifically designed to assist walking, jumping, and running. By utilizing compressed gas bags as both a power source and a power amplification device, Yagn's innovation improved mobility and reduced strain during physical activities. This breakthrough underscores the transformative potential of exoskeletons in enhancing human mobility.

General Electric's Hardiman: A Leap in Exoskeleton Capabilities: The collaboration between General Electric and the United States Military yielded the powerful exosuit known as Hardiman. With the ability to lift 110kg and reduce effort by a factor of 10, Hardiman represented a substantial leap in exoskeleton capabilities. However, its complexity—due to the multi-jointed system—highlighted the delicate balance required in designing exoskeletons that amplify strength while maintaining user-friendly controls and power requirements.

Rhyan Andrad et al: Stand-Alone Exoskeleton Controller: Rhyan Andrad and colleagues introduced a stand-alone, portable, programmable exoskeleton controller for a robotic arm. This innovation prioritized independence from computers, portability, and user-friendliness. While addressing key objectives, the project acknowledged limitations related to high-accuracy movement translations and response speed. Nevertheless, it exemplifies the ongoing quest for practical, accessible exoskeleton solutions.

In Conclusion—A Dynamic Landscape: The literature paints a dynamic picture of exoskeleton arm technologies—spanning diverse actuation principles, designs, and applications. From foundational work to advanced capabilities, each contribution propels the field forward. As researchers continue to innovate and address challenges, the future promises even more sophisticated and accessible exoskeleton arm technologies, bridging the gap between human potential and physical limitations.

2.1 TYPES OF ACTIVELY USED EXOSKELETON ARMS

Hydraulic, pneumatic, and electronic actuated exoskeleton arms are all types of wearable robotic systems designed to assist or enhance the capabilities of the wearer's arm. Here's a comparison of these three types:

2.1.1 Hydraulically Actuated Exoskeleton Arm

- Power Source: Typically powered by hydraulic fluid under pressure.
- Strength and Force: Offers high strength and force capabilities, making it suitable for heavy lifting tasks.
- Flexibility: Can provide precise control and a wide range of motion.
- Weight: Usually heavier due to the hydraulic components and fluid reservoir.
- Complexity: More complex to maintain and may require a hydraulic pump.
- Applications: Often used in industrial settings for tasks involving heavy loads.

Fig. 2 Hydraulically actuated Exoskeleton Arm (Source – https://www.Medium.com/)

2.1.2 Pneumatically Actuated Exoskeleton Arm

- Power Source: Utilizes compressed air as a power source.
- Strength and Force: Offers moderate strength and force capabilities.
- Flexibility: Provides good control and flexibility.
- Weight: Typically, lighter than hydraulic systems.
- Complexity: Simpler in design compared to hydraulic systems.
- Applications: Commonly used in applications where weight and mobility are important, such as rehabilitation and some industrial tasks.

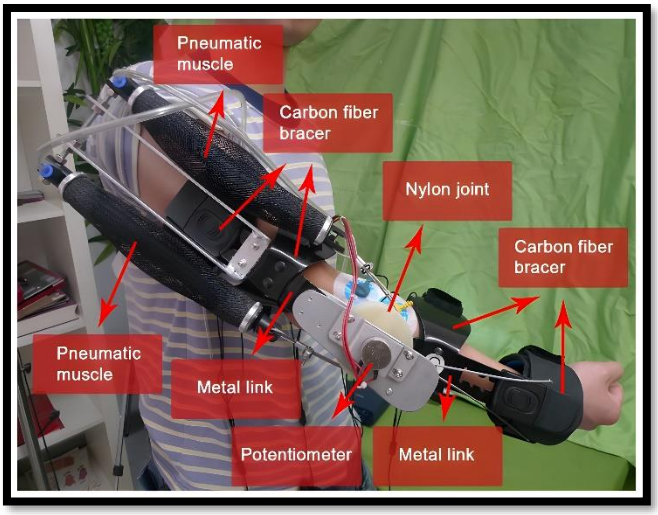


Fig. 3 Pneumatically actuated Exoskeleton Arm

(Source : Research Gate - https://www.researchgate.net/figure/The-overview-of-the-upper-limb-power-assist-exoskeleton_fig1_261608823)

2.1.3 Electrically Actuated Exoskeleton Arm

- Power Source: Relies on electric motors and batteries.
- Strength and Force: Generally, offers lower strength compared to hydraulic and pneumatic systems.

- Flexibility: Can provide precise control and agility, often with programmable movements.
- Weight: Typically, lighter than both hydraulic and pneumatic systems.
- Complexity: Easier to maintain and control, with the potential for more advanced features.
- Applications: Often used in a wide range of settings, including medical rehabilitation, assistive devices, and military applications.

Fig. 4 Electrically actuated Exoskeleton Arm

(Source : Research Gate - https://www.researchgate.net/figure/The-soft-exosuit-for-assistance-of-the-elbow-joint-Pressure-distribution-measures-were_fig1_328277415)

The choice between these types of exoskeleton arms depends on the specific application requirements, including the need for strength, mobility, weight, and complexity. Hydraulic systems excel in heavy-duty tasks, while electronic systems are versatile and adaptable for various purposes. Pneumatic systems offer a balance between strength and mobility.

3. RESEARCH GAPS

Research on exoskeleton arms has made significant progress, but there are still several gaps in our understanding and development of this technology. Some of the major research gaps include –

3.1 USER INTERFACE AND CONTROL

This includes scope of improving the control mechanism of exoskeleton arms and real time feedback systems in order to improve the controllability and ease of use of the arm.

3.2 ERGONOMICS AND COMFORT

This includes the scope of improvement in the field of longtime wearability and comfort provided to the user/wearer on the basis of their respective human anatomy and shapes.

3.3 CUSTOMIZATION AND ADAPTABILITY

Improvements are possible in the design in order to make the same exoskeleton wearable to a wider section of society irrespective of their age and body ergonomics.

3.4 COST REDUCTION

Making exoskeleton technology more affordable so as to expand its use in society.

3.5 CONFINED MEDICAL APPLICATIONS

The need of exploration of additional medical applications beyond rehabilitation, such as assistive devices for people with disabilities or elderly individuals.

4. PROBLEM DESCRIPTION

Exoskeleton arms have emerged as a promising technology within the field of biomedical engineering, offering transformative potential in addressing a wide spectrum of challenges related to human mobility, rehabilitation, and healthcare. In this problem description, we delve into the critical issues and hurdles associated with the development and practical implementation of exoskeleton arms for biomedical purposes.

4.1 Enhancing Arm Mobility:

- Limited arm mobility due to injuries, neurological conditions, or disabilities significantly impacts individual's quality of life [10]. Our mission is to design exoskeleton arms that effectively assist users in regaining function, restoring independence, and enhancing their daily lives.
- Additionally, stroke rehabilitation remains critical. Exoskeleton arms developed specifically for stroke patients play a crucial role in aiding their journey toward regaining motor control, strength, and coordination.

4.2 Industrial Augmentation:

- Beyond healthcare, exoskeleton arms find applications in industrial settings by enhancing strength [2]. Their ability to lift additional weight can safeguard workers against occupational hazards.
- Balancing strength augmentation with user-friendly interfaces is essential for successful adoption.

4.3 Ergonomic Design and User Comfort:

- Ensuring that exoskeleton arms are comfortable for extended wear is pivotal for their adoption in the medical field.
- Lightweight, ergonomic systems that minimize user discomfort and fatigue are critical design considerations.

4.4 Cost and Accessibility:

- The cost of exoskeleton arms designed for medical use can be prohibitive, limiting their availability to a broader population.
- Developing cost-effective solutions that remain accessible to patients, clinics, and healthcare facilities is an urgent priority.

4.5 Customization and Adaptability:

- Users' needs and physical conditions vary significantly. Therefore, creating adaptable exoskeleton arm designs is essential.
- Customization—such as adjusting to different arm sizes and accommodating varying levels of impairment—poses a complex yet crucial challenge.

4.6 Integration with Healthcare Systems:

- Exoskeleton arms used for medical purposes must seamlessly integrate with existing healthcare systems. This integration enables therapists and clinicians to monitor patient progress and tailor treatment plans effectively.
- Data sharing, real-time monitoring, and connectivity are vital components.

4.7 User Training and Acceptance:

- Successful adoption of exoskeleton arms in healthcare hinges on user training and acceptance.
- Designing intuitive control mechanisms and providing adequate training and support for both users and caregivers are key challenges.

4.8 Energy Efficiency and Battery Life:

- Exoskeleton arms must strike a delicate balance between energy efficiency and performance. Sufficient battery life is crucial to accommodate rehabilitation sessions or daily use.
- Optimizing power consumption while maintaining functionality remains a technical hurdle.

In essence, our project aims to address these multifaceted challenges, pushing the boundaries of exoskeleton technology to enhance lives across diverse domains.

5. SOLUTION METHODOLOGY

As per the above discussed issues and research gaps included the following methodologies are adapted in order to provide a new and better design of exoskeleton arms –

5.1 USER-CENTRIC INTERFACE ENHANCEMENTS FOR EXOSKELETON

Prioritizing user comfort and seamless control through innovative interface enhancements. User-specific adaptation of exoskeleton arms can greatly enhance comfort, effectiveness, and overall user experience. The following modifications are being provided here in order to enhance the overall design –

- **Enhancing Exoskeleton Control Mechanism –** For user-friendly controllability, our project aims to improve the control mechanisms of the exoskeleton, ensuring ease of use and better acceptance by users.

- **Anthropometric Adjustments –** This involves altering the exoskeleton's dimensions to fit the user's body accurately. This includes adjustable shoulder belts and straps to accommodate variations in height, arm length, and body proportions.

- **Comfort and Longevity**: The exoskeleton is ergonomically designed for extended wear, providing comfort during prolonged use. It’s lightweight contribute to overall wearability, making it suitable for various activities and environments.

5.2 VERSATILITY BEYOND MEDICINE

While exoskeletons have medical applications [11], they’re not limited to healthcare settings. Our design allows them to assist with lifting additional weights in industries and households, enhancing productivity and reducing strain.

5.3 COST EFFECTIVENESS

By incorporating simpler design with minimized components, cost-effective actuators and sensor selection, resulting in an efficient and affordable solution.

6. MODELING

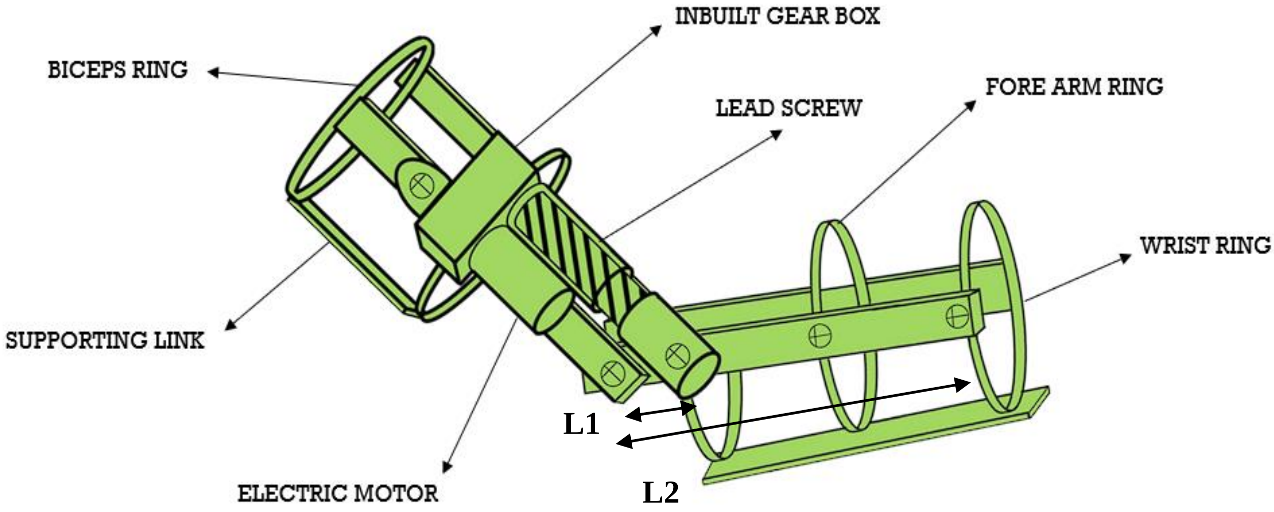


Fig. 5 Preliminary Exoskeleton Design

6.1 MATERIAL SELECTION:

When designing an exoskeleton arm, material selection becomes crucial. We must consider factors such as material availability, suitability for the arm's working conditions, cost, and relevant physical, chemical & mechanical properties. Additionally, the type of exoskeleton, factor of safety and lifting capacity also play a crucial role in material selection [12] . We should also understand how manufacturing processes and heat treatments impact material properties.

Reasons For Using **Mild Steel** (**EN24** or **AISI 4340** **): -**

- Mild Steel is readily accessible in the market.
- It is economical to use.
- Available in standardized dimensions.
- Easily machinable due to good mechanical properties.
- Maintains a moderate factor of safety, balancing material wastage and risk of failure.
- Exhibits high tensile strength.
- Has a low coefficient of thermal expansion

6.1.1 EN24 Composition: -

Table. 1 EN24 Composition (Source : SolidWorks)

The following table shows the chemical composition of EN24 steel:

Element	C	Si	Mn	P	S	Cr	Mo	Ni
Content (%)	0.36-0.44	0.10-0.35	0.45-0.70	0.035 Max	0.040 Max	1.00-1.40	0.20-0.35	1.30-1.70

6.1.2 EN24 Properties: -

Table. 2 EN24 Properties (Source : SolidWorks)

Property	Value	Units
Elastic Modulus	2.05e+11	N/m^2
Poisson's Ratio	0.285	N/A
Shear Modulus	8e+10	N/m^2
Mass Density	7850	kg/m^3
Tensile Strength	745000000	N/m^2
Compressive Strength		N/m^2
Yield Strength	470000000	N/m^2
Thermal Expansion Coefficient	1.23e-05	/K
Thermal Conductivity	44.5	W/(m·K)

Taking Factor of Safety = 3Bending Stress = Yield Stress / FOS

$\sigma_t = \sigma_b$ = 470 / 3 =156.6 N/mm^2

And Shear stress = 0.5 Bending stress

σ_s = 0.5 σ_b = 0.5 x 156.66 = 78.33 N/mm^2

6.2 DESIGN CALCULATIONS

The linear actuator we have purchase will be of capacity (F1) = 700 N

Distance of actuator from hinge point L1 = 185 mm

Distance of load from Hinge Point L2 = 350 mm

And Maximum Load Lifting Capacity of Exoskeleton = F2

Therefore, F1 x L1 = F2 x L2

700 x 185 = F2 x 350

F2 = 129500 / 350 = 370 N

But this is the maximum force which the linear actuator can lift but according to our design we will lift about 370 /3 = 123.34 N

In Kg, 125 /9.81 = 12.57 Kg

So, the weight that the exoskeleton can lift is approx.~ 12.5 Kg

Fig. 6 : MS Flats

(Source : IndiaMart - https://m.indiamart.com/proddetail/stainless-steel-strip-304-316-310-201-17922577997.html)

We are choosing M.S. Flats of having a width and thickness as 20 mm x 2.5 mm of the material EN24. As they have a low weight of about 0.470 kg/m and are readily available in the market and have a low cost as well.

Table. 3 EN24 Available MS Flats Sizes

Size (mm)	Weight (kg/ft)	Weight (Kg/mtr)
12 x 3	0.086	0.282
12 x 5	0.143	0.470
18 x 4	0.180	0.585
20 x 3	0.143	0.470
20 x 5	0.241	0.790

6.2.1 Design of Hook: -

The hook may fail under bending. It is made up of M.S. Flat of size 20 mm x 2.5 mm

Now the maximum force that the hook will lift = 123.34 N

Distance of load from topmost point hook = 80 mm

For Cantilever beam: M = F x L

So, M = 123.34 x 80 = 9867.2 N mm

Also, Section Modulus will be $Z = bh^2/6$

$Z = (1/6) \times 3 \times 20^2$

$Z = 166.67\ mm^3$

Now, Using Relation $\sigma_b = M / Z$

$\sigma_b = 9867.2 / 166.67 = 59.20\ N/mm^2$, It is under the safe limit.

6.2.2 Design of Transverse fillet Welded Joint: -

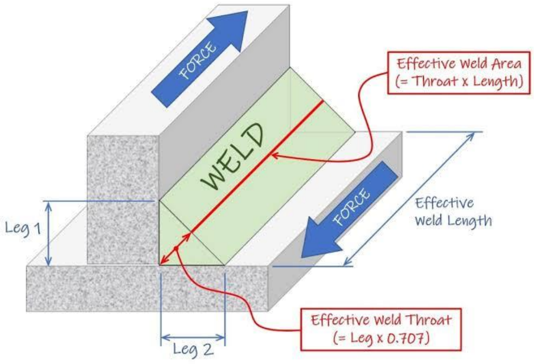


Fig. 7 : Effective Weld Area

(Source : LinkedIn -Welding of Welders https://www.linkedin.com/posts/welding-of-welders_how-to-determine-weld-size-activity-7192969953493368833-o4j3)

Leg Size = 2.5 mm

So, throat size = 0.707 x leg size = 0.707 x 2.5 = 1.7675 mm

Therefore, Area of weld (A_t) = 0.707 x throat size x L

A_t = 0.707 x 1.7675 x 20 = 25 mm^2

Also, maximum stress capacity of Fillet weld is σ_{wn} = 470/ sqrt (3) = 273 N/mm^2

And σ_{aw} = 0.6 σ_{wn} = 0.6 x 273 = 163.8 N/mm^2

Now the stress acting on the weld Area (σ) = Force / Area (At)

σ = 123.34 / 25 = 4.93 N/mm^2

The applied stress is much lesser than the maximum allowable stress for the fillet weld.

6.2.3 Design of Bolt: -

Bolt may fail under Shearing:

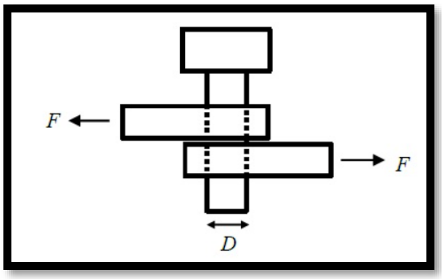


Fig. 8 : M6 Bolt

(Source : Pro-Bolt - https://www.pro-bolt.com/titanium-hex-head-m12-x-1-25mm-x-75mm/)

Chosen Bolt = M6

M6 Bolt diameter (d) = 6 mm

Force acting on bolt by linear actuator (P) = 700N

Also, $P = (\pi/4) \times (d^2) \times \sigma_s$

Where, σ_s is the shear stress acting on bolt

So, $\sigma_s = (700 \times 4) / (3.1415 \times 6^2) = 24.76$ N/mm^2

It is safe as it is much lesser than the Maximum allowable shear stress

7. MECHANICAL DESIGNING & VALIDATION

For an electrically actuated exoskeleton, the basic mechanical structure of the upper and lower arms usually consists of a combination of joints, actuators, sensors, and rigid structural elements. The classified outline of the same is as follows-

7.1 UPPER ARM COMPONENTS

7.1.1 SUPPORTING LINKS AND BICEP RINGS

An exoskeleton's upper arm supports links disperse mechanical loads and offer structural stability. Bicep rings improve overall biomechanical efficiency by ensuring optimal force transmission and enhancing joint alignment. When combined, they create a supportive and well-balanced framework that improves the exoskeleton's functionality and the arm movement user experience.

7.1.2 LINEAR ACTUATOR ASSEMBLY

Controlled joint movements are made easier by an exoskeleton's upper arm's linear actuator and lead screw assembly. It allows the exoskeleton’s joint angles to be precisely adjusted by converting rotational motion from an electric motor into linear motion. This assembly is essential for improving the user’s range of motion and supporting them when moving their arms.

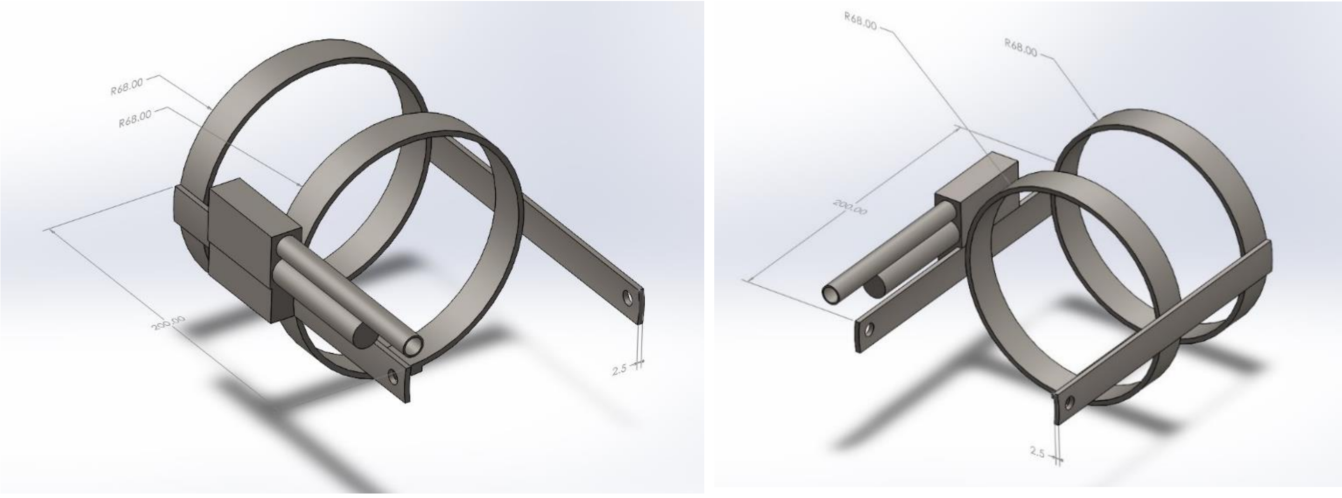


Fig. 9 Upper limb (bicep structure) of Exoskeleton (Source : SolidWorks)

7.2 LOWER ARM COMPONENTS

7.2.1 SUPPORTING LINKS (ALONG WITH HOOK)

An exoskeleton's lower arm supporting link is a vital structural component that improves stability and load-bearing ability. By ensuring appropriate force distribution, it reduces the strain on actuators and joints. The hook at the end also performs a practical function by offering a safe place for external tools or objects to be attached. This feature increases the exoskeleton's usefulness for tasks like object handling and tool manipulation by enabling users to carry out actions that ask for flexibility and precision.

7.2.2 FOREARM AND WRIST RINGS

An exoskeleton's lower arm's forearm and wrist rings give necessary structural support and enable precise control over elbow and wrist movements. It guarantees effective power and feedback transfer. Their lightweight, ergonomic structure is preserved while improving user mobility and functionality.

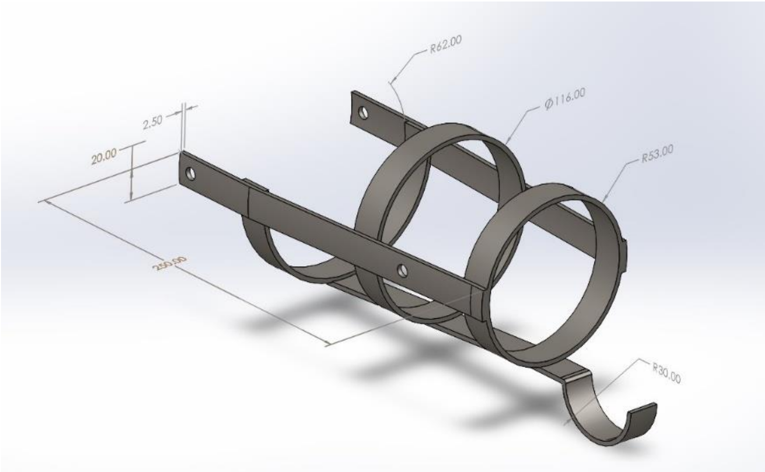


Fig. 10 Upper limb (forearm structure) of an Exoskeleton (Source : SolidWorks)

7.3 LEAD SCREW

A lead screw is an essential part that joins the upper and lower arms of an electrically operated exoskeleton arm. By acting as a link between these segments, the lead screw enables coordinated and managed movement. With the help of this threaded rod, the exoskeleton's joint angles can be precisely adjusted by converting the rotational motion generated by electric motors into linear motion. The lead screw causes corresponding linear motion when it rotates, which essentially extends or retracts the exoskeleton's arm segments. With the help of this mechanism, the exoskeleton can accurately replicate the motion of the human arm. The lead screw functions as a linkage and is essential to the smooth coordination of the movements of the upper and lower arms. It also enhances the exoskeleton arm's overall functionality, flexibility, and ergonomic design.

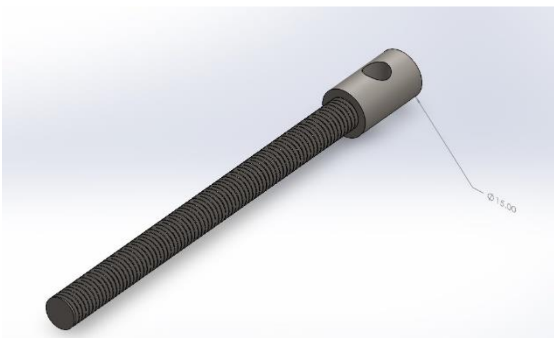


Fig. 11 Lead screw / Precise motion convertor (Source : SolidWorks)

The above components are solely responsible for the exoskeleton arm strength and lifting capability thus their dimensions need to be specified keeping in mind the factor of safety, mechanical strength and flexibility which is made sure through the following calculations.

7.4 TECHNICAL DRAWING :

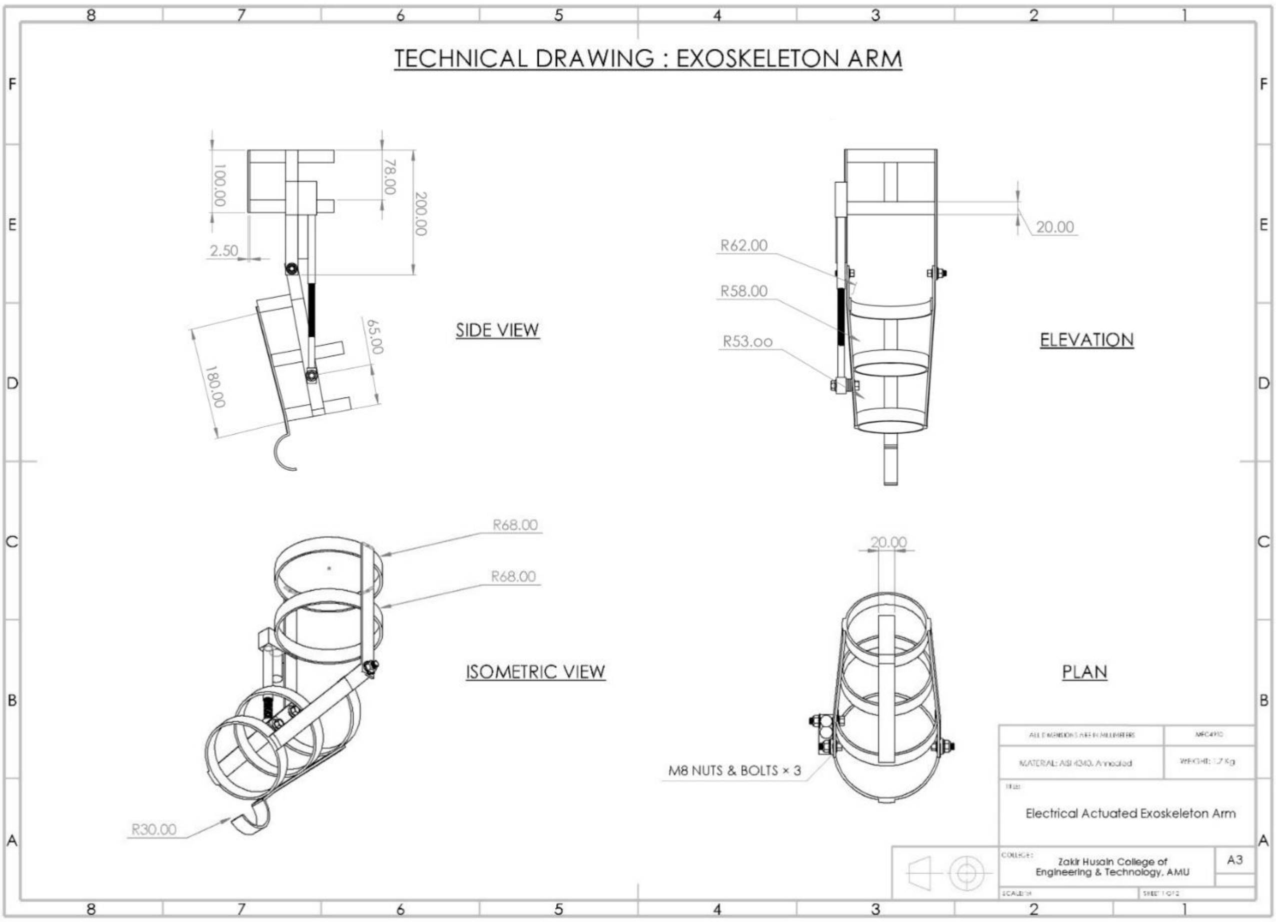


Fig. 12 : Technical Drawing (Source : SolidWorks)

This technical drawing sheet for the electrical actuated exoskeleton arm encompasses elevation, plan, side, and isometric views, all scaled at 1:4. The dimensions assigned to the drawings are derived systematically from values based on the average human upper limb size and cross-sectional dimensions, as per calculations. All dimension are in millimeters.

7.5 COMPONENTS ASSEMBLY

The SolidWorks 3D assembled model of the electrical actuated exoskeleton arm serves as a crucial representation of the theoretical design, providing a tangible insight into the physical realization of the project. The assembly process involved the strategic application of a range of mates, including concentric, tangent, coincident, and limit distance mates. The concentric mates ensure the alignment of cylindrical components, guaranteeing precise rotational symmetry. Tangent mates establish smooth surface transitions, enhancing the aesthetic and functional integration of components. Coincident mates facilitate the exact alignment of key points, contributing to the overall stability of the assembly. The incorporation of limit distance mates imparts specific spatial constraints, reflecting the biomechanical considerations integral to the exoskeleton arm's functionality. By leveraging these diverse mates, the assembled model achieves a cohesive and functional representation, mimicking the anticipated motions of a human upper limb. This meticulous assembly process aligns with industry standards, ensuring not only the visual accuracy of the model but also paving the way for a seamless transition from virtual design to physical implementation. Utilizing data from reputable sources on biomechanics and exoskeleton design further bolsters the model's authenticity, underscoring its potential for real-world application in enhancing human motor functions.

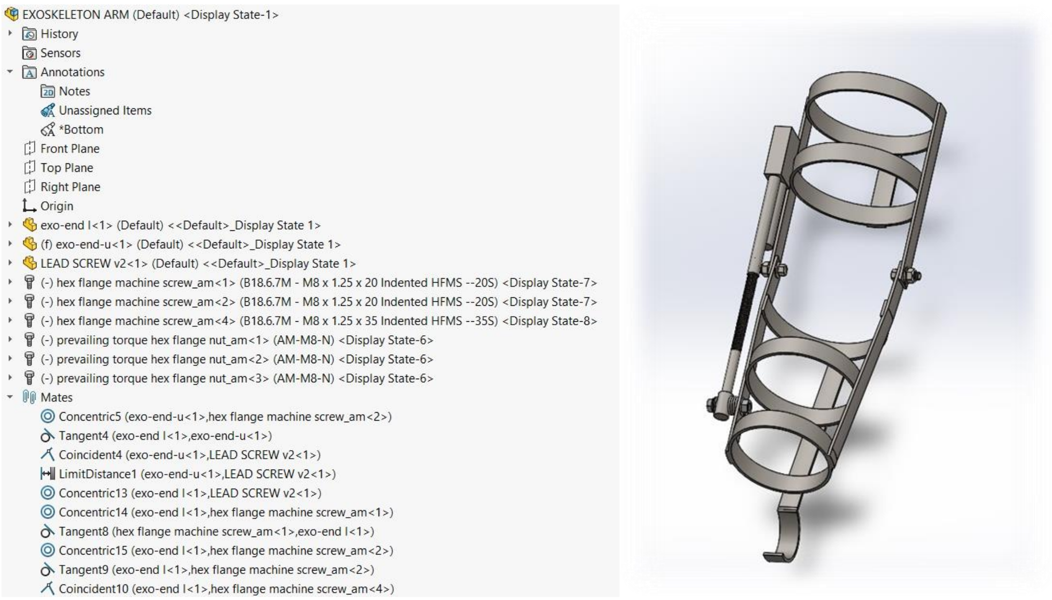


Fig. 13 : Design Tree & Mates (Source : SolidWorks)

7.6 STRUCTURAL VALIDATION THROUGH SOLIDWORKS STRESS SIMULATION

The integration of SolidWorks stress simulation images for the hook and bolts serves as a critical assessment of its structural reliability [3]. The initiation of the analysis involves the application of fixtures, establishing constraints for precise stress distribution evaluation. Subsequent application of loads and moments to key surfaces, considering factors of safety (FoS), simulating operational conditions realistically. This approach acknowledges the various forces and stresses the exoskeleton arm might encounter during use.

The incorporation of an appropriate mesh, a discretized representation of the model, facilitated the execution of the stress analysis study. The results obtained from the simulation, showcasing stress distributions across the components, closely align with the theoretically calculated values of stress. This congruence serves as a validation of the model's structural adequacy, reassuring that the hook and bolts can withstand operational loads without compromising safety. In support of these findings, established principles of finite element analysis (FEA) in structural simulations highlight the significance of accurate boundary conditions and mesh refinement for reliable outcomes. Verification against safety margins and industry standards assures end-users of the exoskeleton arm's suitability for its intended purpose.

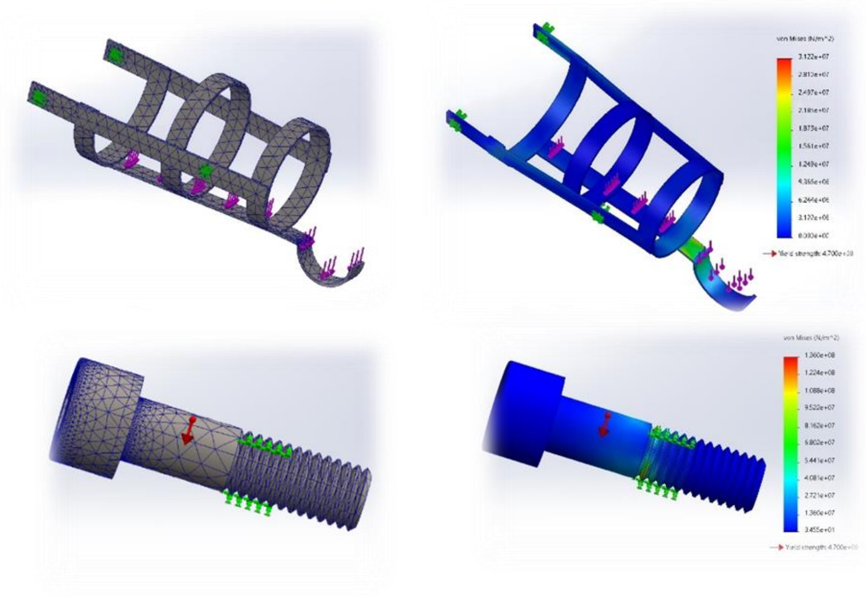


Fig. 14 Solidworks Stress Simulation (Source : SolidWorks)

8. ELECTRICAL PARTS OF THE EXOSKELETON ARM

8.1 ELECTRIC LINIEAR ACTUATOR MOTOR

This sophisticated electrical actuator system operates seamlessly in both forward and reverse directions. It offers additional functionalities crucial for industrial use. At the end of each movement, built-in switches act as safety guards, preventing the system from exceeding its limits and causing damage. Even during ongoing movements, this system ensures safety by avoiding accidental overextension. In case of a power failure, the system can switch to manual mode, allowing continued operation. Additionally, users can receive feedback on the precise position of the system. Whether in industrial setups or vehicles, this system easily integrates with various control systems, including computers or basic relay-based setups.

8.2 BATTERY

For this project, we will be utilizing a 12-volt, 7.5-ampere-hour lead-acid dry battery. The lead-acid battery, one of the earliest rechargeable battery technologies, may have lower energy-to-weight and energy-to-volume ratios, but it compensates with the ability to deliver substantial surge currents. This favorable power-to-weight ratio, coupled with cost-effectiveness, makes lead-acid batteries appealing for applications like motor vehicles, where the high current demands of automobile starter motors can be effectively met.

8.3 LIMIT SWITCH

This switch operates in a straightforward yet effective manner: when pressed, it breaks the circuit, interrupting the flow of current. Essentially, it acts as a safety mechanism, allowing us to stop the arm precisely at any required orientation. By opening the circuit, the limit switch ensures that the arm halts at the desired position, preventing overextension or unintended movement. This functionality is crucial for achieving precise control and safety during exoskeleton operation. Whether adjusting joint angles or maintaining stability, the limit switch plays a pivotal role in enhancing the arm’s functionality and usability.

8.4 ARDUINO UNO

The Arduino UNO, an open-source microcontroller board, centers around the Microchip ATmega328P microcontroller. This compact board boasts a collection of digital and analog input/output (I/O) pins, making it compatible with various expansion boards and other electronic circuits. With 14 digital pins and 6 analog pins, the Arduino UNO provides ample connectivity options. Programmed using the Arduino IDE (Integrated Development Environment) via a type B USB cable, it offers flexibility in development. Powering the Arduino UNO is equally adaptable—it can draw power from a USB cable or an external 9-volt battery, handling input voltages ranging from 7 to 20 volts. In brief, the Arduino UNO serves as a versatile platform for creating custom electronic projects, bridging the gap between hardware and software.

8.5 MUSCLE SENSORS (ELECTROMYOGRAPHY SENSORS)

The measurement of skeletal muscle activation through electric potential, a technique known as electromyography (EMG), provides valuable insights into muscle function. One fascinating application of EMG technology is in the field of Human-Computer Interface (HCI), where it plays a crucial role in creating seamless interactions between humans and machines [2]. Muscle BioAmp Candy is an affordable EMG sensor designed for precise muscle signal recording. Despite its compact size, it packs powerful capabilities. With an input voltage range of 3.3V to 30V, an impressive input impedance of 10^{11} Ω, and a fixed gain of x2420, it amplifies weak muscle signals effectively. The 72–720 Hz bandpass filter ensures optimal signal quality. We can connect it to any development board with an ADC (e.g., Arduino UNO, Nano, ESP32) or use a standalone ADC. Muscle BioAmp Candy finds applications in prosthetic hands, human augmentation, game controllers, rehabilitation, and medical diagnosis

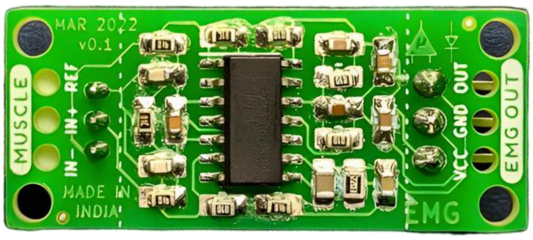


Fig. 15 Pin Layout

(Source : Upside-Down Labs - https://store.upsidedownlabs.tech/product/muscle-bioamp-candy/)

8.6 OPTO ISOLATED RELAY MODULE (2 Channel)

The Opto-Isolated Relay Module (2 Channel) is a versatile component designed for various applications. Operating at 5V, it interfaces well with common microcontrollers and digital systems. The term “opto-isolated” refers to its use of optocouplers (optoisolators), which provide electrical isolation between the input (control side) and the output (relay side). This isolation protects sensitive circuits from voltage spikes and noise. The module contains two separate relay channels, each capable of independently controlling a load. These high-current relays can handle up to 10A of current, whether switching AC (up to 250V) or DC (up to 30V). Their robustness ensures reliable performance, simplifies complex tasks and enhances efficiency.

9. FABRICATION AND WORKING

9.1 MECHANICAL STRUCTURE

- **Cutting and shaping:** The long EN24 (20mm×3mm) steel strips are measured and cut into suitable lengths as per the dimensions of the exoskeleton arm geometry with the help of an electric cutter machine (800watt, 10 mm disc). The sheets measured respectively to the circumference of the supporting rings are then bent with help of circular dies in order to attain circular shape.

- **Welding:** After successful acquisition of carefully measured steel parts, the linear strips and the circular rings (complete and partial) are clamped at the desired positions keeping the geometry upright. Electrode welding is performed to join these parts after setting the necessary voltage and current ratings.

- **Drilling:** Holes are drilled on the side supports of the upper bicep part and the lower wrist part respectively matched with the dimensions of linear actuator (to be fitted later). A knee and column type vertical drilling machine with an M5 drill bit is used to perform the above operation.

- **Grinding:** In order to obtain better user comfort and wearability, all the sharp and rough edges are grinded using the Bosch (M10,800watt, 100mm disc) grinder. This not only makes the exoskeleton more comfortable but also improves the surface finish, precise dimensional control and overall aesthetics of the arm.

Fig. 16 Fabrication Process (Source : Camera)

9.2 ELECTRONIC CIRCUIT ASSEMBLY AND WORKING

9.2.1 Assembly:

The synchronized arrangement of the earlier stated electric parts can be defined as follows –

- Beginning with the piezoelectric force detector band, the three wires (red, blue and green) are connected to their respective positions on the band. The combined wire is then connected with the BioAmp candy muscle sensor.
- The signals from the sensor are then transmitted to the Arduino board as follows- ‘VCC’ to ‘5V’, ‘GND’ to ‘GND’ and ‘OUT’ to ‘A0’.
- A separate power input from a 9V battery is fed to Arduino with the help of a connecting cable.

- The ‘2’ and ‘3’ ports of the digital outputs are then connected to ‘IN1’ and ‘IN2’ of the dual channel relay. ‘GND’ of relay is connected to ‘GND’ of digital output of Arduino. The leftover ‘VCC’ input of the dual channel relay is connected to the 5V power pin of Arduino.
- For the relay output to be considered, the ‘NC1’ is shorted to ‘NC2’ and ‘NO1’ is shorted to ‘NO2’. ‘NC1’ and ‘NO2’ are respectively connected to the positive (+ve) and negative (-ve) terminals of the ‘12V Battery’. ‘COM1’ and ‘COM2’ are connected to the ‘Linear Actuator’.

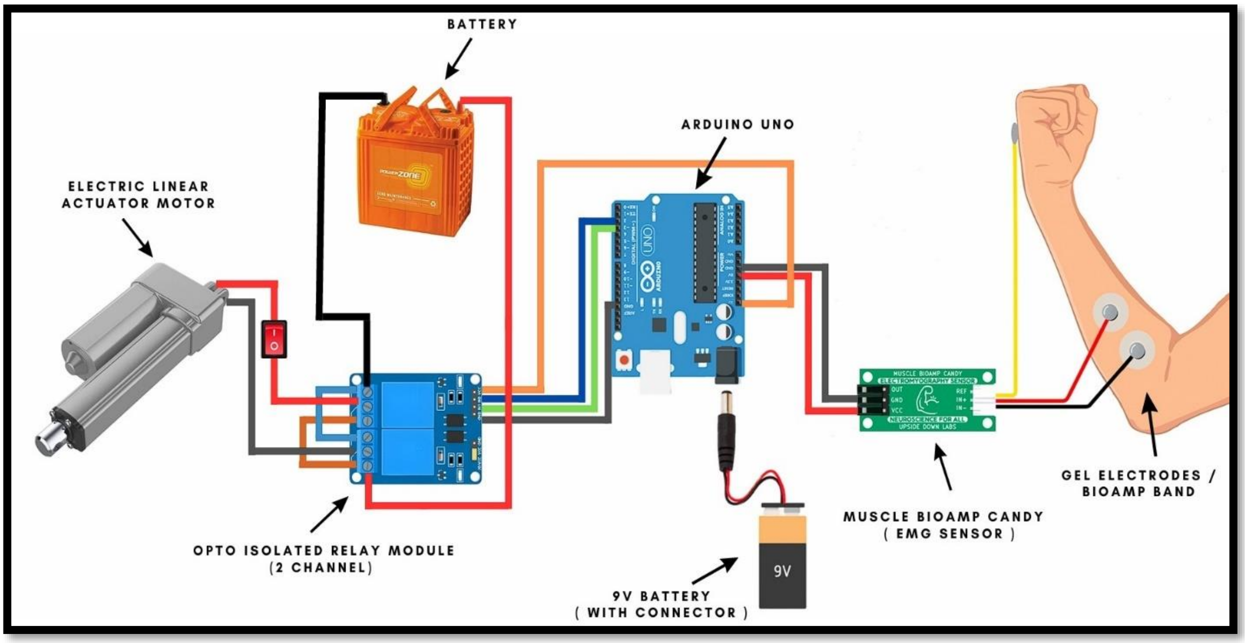


Fig. 17 Electrical circuit configuration

9.3 EXOSKELETON ARM CODE & CONTROL LOGIC EXPLANATION

9.3.1 Pin Definitions

- **INPUT_PIN (A0):** Analog pin connected to the EMG sensor.
- **relayUpPin (2):** Relay pin for moving the exoskeleton up.
- **relayDownPin (3):** Relay pin for moving the exoskeleton down.

9.3.2 Setup

- **Serial Communication:** Initialize serial communication at ‘115200’ baud rate for debugging and monitoring.
- **Pin Modes:** Configure ‘relayUpPin’ and ‘relayDownPin’ as output pins.

9.3.3 Loop

- **Timing Control:** Calculate the time elapsed since the last loop iteration to maintain a consistent sample rate.
- **Read Sensor Data:**
    - Read the analog value from the EMG sensor (‘INPUT_PIN’).
    - Apply a filter (‘EMGFilter’) to the sensor value to reduce noise and enhance signal quality.
    - Compute the envelope of the filtered signal using `getEnvelope` function to get a smooth signal amplitude.

9.3.4 Control Logic

- **Thresholds:** Define a threshold (‘20’) to detect significant muscle activity.
- **Activity Counters :**
    - Increment ‘up_counter’ if the envelope value exceeds the threshold.
    - Reset ‘up_counter’ and increment ‘down_counter’ if the envelope value is below the threshold.
- **Motor Control Based on Counters:**
    - Move Up: If ‘up_counter’ reaches a certain value (‘10’) and the arm is not already moving up, activate the relay to move the exoskeleton up and reset the ‘down_counter’.
    - Move Down: If ‘down_counter’ reaches a certain value (‘10’) and the arm is not already moving down, activate the relay to move the exoskeleton down and reset the ‘up_counter’.

9.3.5 Motor Control Functions:

- moveUp(): Activate the relay connected to 'relayUpPin' to move the exoskeleton up.
- moveDown(): Activate the relay connected to 'relayDownPin' to move the exoskeleton down.

9.3.6 Serial Output: Print the envelope value to the serial monitor for debugging and monitoring purposes.

9.3.7 Watchdog Timer: Reset the watchdog timer 'wdt_reset()' periodically to prevent the system from hanging.

9.4 CODE :

```
#include <avr/wdt.h>

#define SAMPLE_RATE 500
#define BAUD_RATE 115200
#define INPUT_PIN A0
#define BUFFER_SIZE 64

int circular_buffer[BUFFER_SIZE];
int data_index, sum;
bool arm_up = false;
bool arm_down = false;
int up_counter = 0;
int down_counter = 0;

void setup() {
    Serial.begin(BAUD_RATE);
    pinMode(2, OUTPUT); // Relay 1 control pin for upward movement
    pinMode(3, OUTPUT); // Relay 2 control pin for downward movement
}
```

```
void loop() {
    static unsigned long past = 0;
    unsigned long present = micros();
    unsigned long interval = present - past;
    past = present;

    static long timer = 0;
    timer -= interval;

    if (timer < 0) {
        timer += 1000000 / SAMPLE_RATE;
        int sensor_value = analogRead(INPUT_PIN);
        int signal = EMGFilter(sensor_value);
        int envelope = getEnvelope(abs(signal));
        Serial.println(envelope);

        if (envelope > 20) {
            up_counter++;
            down_counter = 0;
        } else {
            down_counter++;
            up_counter = 0;
        }

        if (up_counter >= 10 && !arm_up) {
            digitalWrite(2, HIGH); // Activate relay 1 for upward movement
            arm_up = true;
            arm_down = false;
        }

        if (down_counter >= 10 && !arm_down) {
            digitalWrite(3, HIGH); // Activate relay 2 for downward movement
            arm_down = true;
            arm_up = false;
        }

        if (arm_up && envelope < 20) {
            digitalWrite(2, LOW); // Deactivate relay 1
            arm_up = false;
            up_counter = 0;
        }
```

```
        if (arm_down && envelope > 20) {
            digitalWrite(3, LOW); // Deactivate relay 2
            arm_down = false;
            down_counter = 0;
        }

        wdt_reset(); // Reset watchdog timer to prevent Arduino from hanging
    }
}

int getEnvelope(int abs_emg) {
    sum -= circular_buffer[data_index];
    sum += abs_emg;
    circular_buffer[data_index] = abs_emg;
    data_index = (data_index + 1) % BUFFER_SIZE;
    return (sum / BUFFER_SIZE) * 2;
}

float EMGFilter(float input) {
    float output = input;

    // First stage of filtering
    static float z1_stage1, z2_stage1;
    float x_stage1 = output - 0.05159732 * z1_stage1 - 0.36347401 * z2_stage1;
    output = 0.01856301 * x_stage1 + 0.03712602 * z1_stage1 + 0.01856301 * z2_stage1;
    z2_stage1 = z1_stage1;
    z1_stage1 = x_stage1;

    // Second stage of filtering
    static float z1_stage2, z2_stage2;
    float x_stage2 = output - -0.53945795 * z1_stage2 - 0.39764934 * z2_stage2;
    output = 1.00000000 * x_stage2 + -2.00000000 * z1_stage2 + 1.00000000 * z2_stage2;
    z2_stage2 = z1_stage2;
    z1_stage2 = x_stage2;

    // Third stage of filtering
    static float z1_stage3, z2_stage3;
    float x_stage3 = output - 0.47319594 * z1_stage3 - 0.70744137 * z2_stage3;
    output = 1.00000000 * x_stage3 + 2.00000000 * z1_stage3 + 1.00000000 * z2_stage3;
    z2_stage3 = z1_stage3;
    z1_stage3 = x_stage3;
```

```
    // Fourth stage of filtering
    static float z1_stage4, z2_stage4;
    float x_stage4 = output - -1.00211112 * z1_stage4 - 0.74520226 * z2_stage4;
    output = 1.00000000 * x_stage4 + -2.00000000 * z1_stage4 + 1.00000000 * z2_stage4;
    z2_stage4 = z1_stage4;
    z1_stage4 = x_stage4;

    return output;
}
```

9.4.1 Logic Explaination :

- The code reads analog signals from the EMG sensor to measure muscle activity.
- Muscle activity is categorized into moderate and high levels based on defined thresholds.
- The exoskeleton movement is controlled by activating and deactivating relays connected to the electric linear actuator motor.
- The code is designed to respond to different levels of muscle activity, providing a basic form of human-machine interaction in the context of an exoskeleton.

9.5 INTEGRATION

For the harmonious working of the arm, the mechanical structure and the electronic circuit needs to be arranged in most efficient and ergonomic manner. This is achieved as follows-

- The piezoelectric force sensor band is freely suspended through the bicep rings of the exoskeleton so as to attain user flexibility.
- The linear actuator is mounted on the outer side supports, with one end on the upper bicep region and the other, screw (shaft) on the side supports of the wrist region.
- The remaining electrical components including 12V and 9V batteries, Arduino, BioAmp muscle sensor, dual channel relay and all their respective connecting wires are placed into a small sized backpack so as to improve the overall ergonomics, comfort and simplicity of the exoskeleton arm and its wearer.

9.6 WORKING

The following steps explains the working of the electric circuit –

- The red and black wires are placed to muscular parts of the body where major muscle movement is expected to occur, the remaining yellow wire is placed at a relatively stationary or steady non muscular part as reference signal.
- The signals are then transferred to BioAmp muscle sensor which feds the data to the Arduino as analogue input.
- The Arduino reads, processes and interprets the data from muscle sensor as per the fed computer program. The interpreted data is converted to digital outputs useful in activating different channels of the dual channel relay respectively.
- As per the input digital signal received by the dual channel relay keeps changing the polarity of the battery terminals, based on different channels activation. This leads to the linear actuator motor to move either in the 'clockwise' direction or 'counterclockwise' direction i.e. the 'IN' and 'OUTWARD' motion of the actuation screw or shaft respectively.
- Hence, the desired motion of the Exoskeleton Arm is obtained.

10.BILL OF MATERIALS:

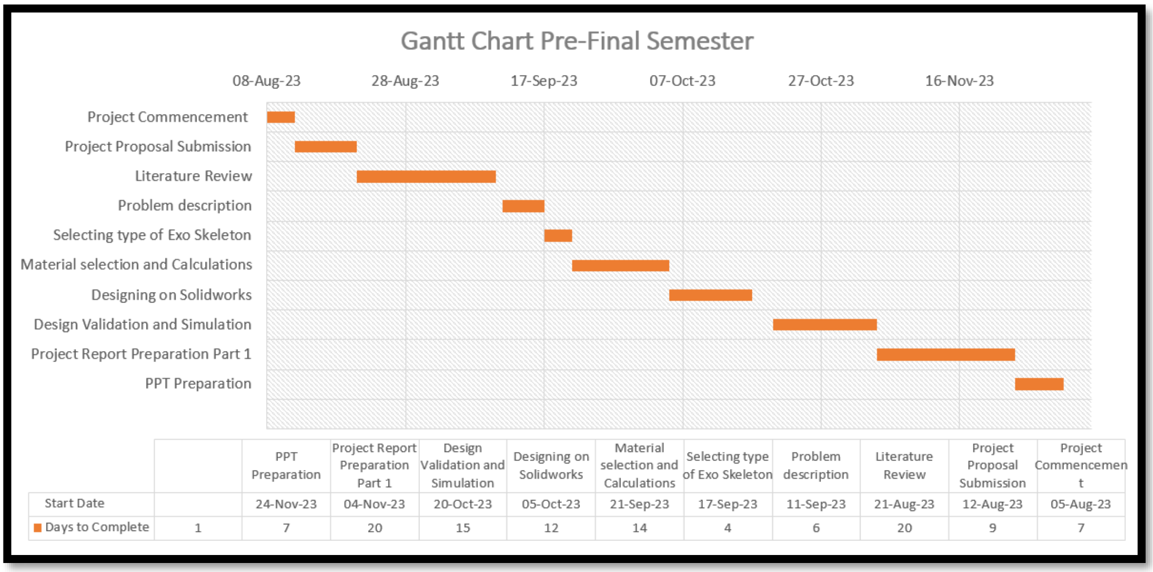
Table. 4 Bill of Materials

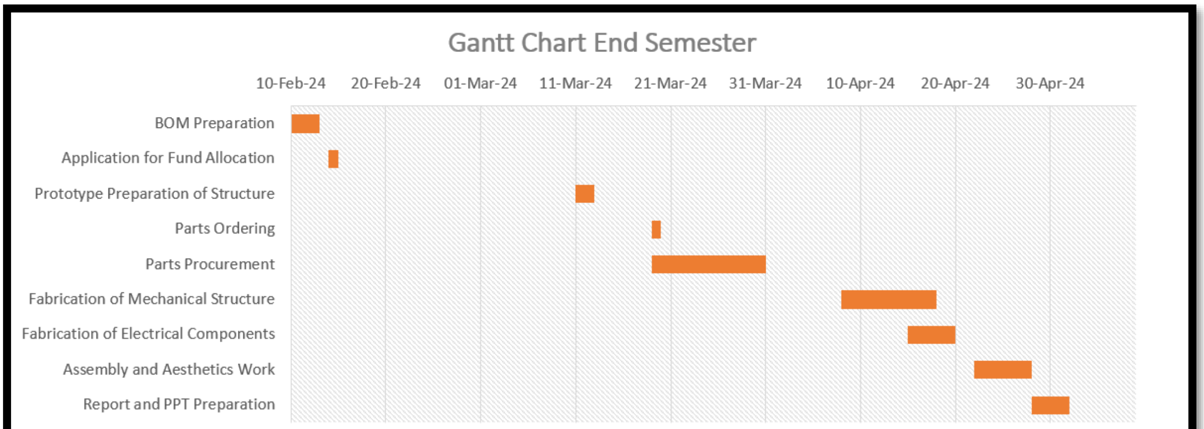
BOM Level	Part No.	Description	Unit Cost	Quantity	Cost
1	756	Annealed AISI 4340 Metal 20mm * 2.5 mm	₹ 80 / *meter*	3.25 meter	260
2	95	Linear Actuator Motor 12VDC Speed,100mm,15 mm/s, 700N	₹ 3480	1	3480

3	LB8579	Battery 12 Volt, Lead-Acid & Charger	₹ 1690	1	1690
4	342	Arduino Uno Kit	₹ *340*	1	340
5	PRS045	Electromyography Sensor Kit	₹ 1380	1	1380
6	MOD0065	Opto-Isolated Relay Module 2 Channel, 5V, 10A	₹ 90	1	90
7	812	9V Batteries & connector	₹ *40*	2	80
8	LB7474	Wires Cable Pack	₹ 100	1	100
9	NB8	Nut – Bolt Assembly M6	₹ 10	4	40
10	-	Manufacturing Cost	₹ *1600*	1	1600
11	-	Miscellaneous (Aesthetics)	₹ *350*	1	350
					₹ 9410

11.GANTT CHART

Table. 5 Gantt Chart





	Report and PPT Preparation	Assembly and Aesthetics Work	Fabrication of Electrical Components	Fabrication of Mechanical Structure	Parts Procurement	Parts Ordering	Prototype Preparation of Structure	Application for Fund Allocation	BOM Preparation
Start Date	28-Apr-24	22-Apr-24	15-Apr-24	08-Apr-24	19-Mar-24	19-Mar-24	11-Mar-24	14-Feb-24	10-Feb-24
Days to Complete	4	6	5	10	12	1	2	1	3

12.CONCLUSION

The integration of human and robot into a single system offers remarkable opportunities for a new generation of assistive technology. The designed exoskeleton arm has proven to be more effective than alternatives that are currently on the market in terms of affordability, weight reduction, user comfort, and controllability. A combination of creative design decisions, effective manufacturing techniques, and a user-centric mindset is responsible for this success. The project highlights the potential for exoskeleton technology advancements by emphasizing customization, affordability, and the overall user experience.

Fig. 18 Exoskeleton Arm : Fully Functional Model

To sum up, exoskeleton technology has a lot of potential to improve human capabilities, from industrial uses to rehabilitation. Future developments in exoskeleton technology are probably going to concentrate on enhancing control interfaces, increasing energy efficiency, and removing financial obstacles to mass adoption. There is still a lack of research on the long-term effects of exoskeleton use, how to optimize neurorehabilitation protocols, and how to investigate ethical issues. As progress is made, closing these gaps will be crucial to maximizing the potential of exoskeletons in various domains and guaranteeing their incorporation into industry and mainstream healthcare.

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