DEDICATIONS

With profound gratitude, I dedicate this research to my beloved parents, whose unwavering inspiration moral, spiritual, emotional, and financial support have been the compass guiding my academic journey. As Shakespeare said, "I can no other answer make but thanks, and thanks, and ever thanks."

Alhamdulillah and Allahu Akbar, their influence has been a source of strength and resilience, allowing me to persevere in my studies. To my cherished friends, whose camaraderie has added joy to this pursuit, I express heartfelt appreciation. As the Bard himself once said, "Those friends thou hast, and their adoption tried, grapple them to thy soul with hoops of steel."

ACKNOWLEDGEMENTS

The preparation of this report has been a collaborative effort, and I am deeply grateful for the invaluable contributions of numerous individuals who have played significant roles in shaping my understanding and thoughts. Throughout the course of my work, I have had the privilege of engaging with a diverse group of people, including researchers, academicians, and practitioners, whose insights have enriched this report.

I would gladly thank my Supervisor from Department of Electrical Engineering, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Dr Hyreil Anuar Bin Haji Kasdirin for help and guide me through my final year project with full flexibility responsive to answer all my question and helpful feedback.

Next, I would like to express my appreciation to my friends for being supportive and helpful for giving me a lot of ideas and useful tips to undergo my final year project. Finally, thank you to my parents for becoming my motivation and providing all my needs in my study for my bachelor's degree.

ABSTRACT

The research project aims to design an intelligent control system for upper limb exoskeletons, specifically targeting elbow impairments, with a focus on enhancing performance and functionality through smart control mechanisms. The current challenge lies in optimizing PID controller tuning methods for upper limb exoskeletons to improve performance, adaptability, and efficiency, addressing limitations in controlling complex dynamics. The scope includes designing and developing an exoskeleton elbow model for simulation, emphasizing the elbow joint's range of motion. The literature review highlights the importance of PID controllers, tuning methods, Particle Swarm Optimization, and the significance of the elbow joint in exoskeleton design. The methodology involves designing the exoskeleton elbow model using SolidWorks, simulation testing, and prototyping, with future work focusing on implementing intelligent controls, improving PID tuning techniques, and analyzing the impact on exoskeleton operation and user comfort, aiming to advance upper limb exoskeleton technology and rehabilitation through intelligent control applications.

ABSTRAK

Projek penyelidikan bertujuan untuk mereka bentuk sistem kawalan pintar untuk eksoskeleton anggota atas, dengan tumpuan khas kepada kecacatan siku, dengan fokus meningkatkan prestasi dan fungsi melalui mekanisme kawalan pintar. Cabaran semasa terletak pada pengoptimuman kaedah penyelarasan PID untuk eksoskeleton anggota atas bagi meningkatkan prestasi, kebolehgunaan, dan kecekapan, menangani kekangan dalam mengawal dinamik kompleks. Skop termasuk mereka bentuk dan membangunkan model siku eksoskeleton untuk simulasi, menekankan julat pergerakan sendi siku. Kajian literatur menyorot kepentingan pengawal PID, kaedah penyelarasan, Optimum Partikel Swarm, dan kepentingan sendi siku dalam reka bentuk eksoskeleton. Metodologi melibatkan mereka bentuk model siku eksoskeleton menggunakan SolidWorks, ujian simulasi, dan prototaip, dengan kerja masa depan memberi tumpuan kepada pelaksanaan kawalan pintar, meningkatkan teknik penyelarasan PID, dan menganalisis impak terhadap operasi eksoskeleton dan keselesaan pengguna, bertujuan untuk memajukan teknologi eksoskeleton anggota atas dan rehabilitasi melalui aplikasi kawalan pintar.

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LIST OF SYMBOLS AND ABBREVIATIONS

PID	-	Proportional-Integral-Derivative
PSO	-	Particle Swarm Optimization
DOF	-	Degree of Freedom
CAD	-	Computer-Aided Design
Kp	-	Proportional gain
Ki	-	Integral Gain
Kd	-	Derivative Gain
xml	-	eXtensible Markup Language

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CHAPTER 1

INTRODUCTION

1.1 Background

Upper limb exoskeletons have been proposed as promising interventions in rehabilitative and assistive settings, providing support and benefits to people with upper limb impairment. Adding intelligent control systems to these exoskeletons has taken it one step further, allowing the devices to make decisions without human input and to adapt to the user as they deviate from preprogrammed movements.

For this "Intelligent Control for Application of Upper Limb Exoskeleton" research project, it is intended to introduce a high-level control for a subject-specific elbow exoskeleton. In this work, a simulation-based modeling of an exoskeleton elbow has been proposed to investigate the upper limb control mechanism and improve its performance by smart control.

A comparison of PID controller tuning methods (conventional PID tuning and Particle Swarm Optimization (PSO) controller tuning) is one of the crucial parts in this project. This study is a comparative analysis in nature to enhance the effectiveness of the control system, by studying various tuning strategies and applying intelligent techniques.

By exploring and applying the optimal technique for control (PSO algorithm for PID tuning) this work aims to add to literature of upper limb exoskeleton technology and rehabilitation. This study is anticipated to shed new light on the contribution of intelligent control to improve the performance and functionality of elbow-reaching compliant upper limb exoskeletons for the individuals with elbow impairments.

This project does not only focus on the solution of the problem of movement of elbow, but it is a progress towards the creation of intelligent and adaptable assistance and aids for the rehabilitation of the upper limb. When used properly, resulting from the integration of the developed control approaches, the quality of life and independence of people with upper limb impairments are improved far beyond its current capacity.

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1.2 Motivation

In this work, the reason for this performance improvements comes from the PID controller parameters tuning for the upper limb exoskeleton, the motivation for which is studied in upper limb exoskeleton, are improving the performance and user experience of the robotic device. While conventional PID controllers have been broadly employed in exoskeleton platforms, owing to these controllers being explicit, simple and their well-established theoretical background, the success of PID controllers significantly depends on Kp, Ki and Kd such that the PID satisfies the required closed-loop performance. The proposed optimization algorithm for PID parameters adjustment like Particle Swarm Optimization (PSO) is used to find the optimal parameters that can optimize the performance of tracking accuracy, energy consumption, robustness, and user tolerance in control of the exoskeleton elbow joint step by step. The reason to choose PSO algorithm here is that it is simple, suitable for continuous optimization problems and has been successfully applied in the field of robotics, which means it can be used to optimize the parameters of PID controller of the upper limb exoskeleton.

1.3 Problem Statement

PID Controller Tuning Methods for Upper Limb Exoskeletons Optimization - An Ongoing Assistive Technology & Rehabilitation Engineering Challenge Traditional PID tuning methods have been widely used for controller design, while more advanced optimization algorithms could potentially be applied to further improve the respective performances, adaptability, and efficiency of control mechanisms in upper limb exoskeletons. Several previous research studies have highlighted the intrinsic drawbacks of standard PID tuning techniques when it comes to designing for a high-performance human neuromuscular system, especially in terms of controlling the complex dynamics of upper limb movements and under certain diseases or injuries.

The need to develop PID controller tuning strategies to be properly tuned per subject to control the higher demand on the performance of the upper limb exoskeleton technology entails bolstering the optimal performance of exoskeleton and controlling the essential properties of the subject with upper limb defect. The optimal parameters of the PID controller used for assistive controller proposed in this study could be fully optimized to be more adaptable, to respond more quickly and to be more precise with Particle Swarm Optimization (PSO) algorithm by researching the state-of-the-art optimization algorithms as the first research of assistive technology application for exoskeleton in upper limb rehabilitation.

Given the current challenges and opportunities that exist in the field of assistive technology for upper limb rehabilitation, it is critical to investigate novel solutions which can incorporate intelligent control methodologies and advanced optimization methods. These features combined with integration of sophisticated control strategies and rigorously optimized, promise to substantially improve rehabilitation or assistance provided by the upper limb exoskeleton to upper limb impaired individuals [1].

1.4 Research Objective

All The study's aims concentrated on numerous objects related to the design and development of intelligent control for the application of upper limb exoskeletons:

i. To design an exoskeleton elbow model for the simulation of upper limb control mechanism.

ii. To develop intelligence control mechanism for the application of upper limb exoskeleton.

iii. To analyze the performance and functionality of intelligent control for the application of upper limb exoskeleton.

1.5 Scope of Research

The scope of this research focused on several points that are related to design and development of intelligent control for the application of upper limb exoskeletons, these points are summarized as follows:

i. All research and development will be performed and analyzed and will be focused on elbow impairment.

ii. The software that will be used in the research is Simulink and MATLAB R2023b.

iii. Upper limb will be focused on simulated elbow model which will be designed by SolidWorks 2023.

iv. The research will focus on the elbow joint's range of motion, specifically targeting elbow flexion and elbow extension.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

Literature review looks at upper limb exoskeletons, their role in assisting individuals with physical disabilities, and the necessity of smart control strategies. This covers the role of PID controllers in providing stability and smoothness to exoskeleton control and goes further to stress the importance of tuning methods. It also goes into Particle Swarm Optimization (PSO) for PID tuning, showing that it produces great results at optimization. It also mentions the key role of the elbow joint in exoskeleton design, presenting studies on lightweight exoskeletons, passive force control, and exoskeletons with minimalistic joint design principles for elbow rehabilitation.

2.2 Overview of upper limb exoskeletons

Upper limb exoskeletons are a promising technology that can fulfill several applications in rehabilitation, assistive, and industrial domains. These are wearable robotic redirections created to increase the abilities of the human upper limb, strength, endurance, and accuracy [2]. Advances in actuators, sensors, and control systems have all contributed to the evolution of the technology which allows for greater performance and functionality.

Design Considerations The design of upper limb exoskeletons includes selecting suitable components for integration. Actuators (like electric motors, hydraulic or pneumatic systems) oversee that force which moves the exoskeleton [3]. The brakes for the motors must provide the same function of avoiding any room for excessive force in that for the joints, and sensors (such as torque, position, force and movement sensors for each joint of the exoskeleton) give the electronic control with the necessary feedback to monitoring and correcting the exoskeleton operation [4].

Intelligent Control Systems The formation of intelligent control systems is the critical part of any upper limb exoskeleton. These advanced control algorithms using machine learning approaches can improve the response, the safety, and the ease of use of the exoskeleton [5]. These control systems are capable of learning users' movement patterns, environmental conditions, and task requirements, resulting in more intuitive control of the exosuit from a human-machine interaction perspective [6].

Applications in Rehabilitation and Assistive Sectors Rehabilitation and assistive sectors are where upper limb exoskeletons have found wide applications. In the situation of rehabilitation, these devices can help a patient to recover motor functions of the upper limb in case of an impairment, e.g., due to stroke, spinal cord injury; or another neurological condition [7]. The exoskeleton enables selective and regulated movements of limbs, which may allow muscle groups to be retrained and functional capabilities to be recovered [8]. Furthermore, in the assistive field, an upper limb exoskeleton can improve the daily living experience of people with non-normal conditions, allowing them to perform tasks more easily and independently [9].

Industrial Sector The use of exoskeleton limbs in the industry has been understood back early years. These include devices that can help with the strength and endurance of workers in tasks requiring elevated levels of exertion involving heavy lifting, repetitive motions, or sustained manual labor [6]. Upper limb exoskeletons reduce the workload of the worker's upper body, e.g., shoulders and arms, resulting in several benefits including increased productivity, reduced fatigue, and risk of musculoskeletal disorders.

Conclusions this review shows that advances in wearable upper limb exoskeletons have opened a broad space of opportunities in the domains of rehabilitation, assistance, and industrial applications. Essential elements like actuators, sensors and control systems help to improve its functionality for performance. Additional integration of intelligent control systems can improve how the user and the exoskeleton interact making the experience more natural and intuitive.

2.3 PID Controllers and Tuning Methods in Exoskeleton

In the context of exoskeleton control, PID (Proportional-Integral-Derivative) controllers are key to the control of a process variable to minimize error in the stability, accuracy and smoothness of motion. These combine three control actions, proportional, integral and derivative, to improve the system performance. The proportional term is based on current errors, the integral term on errors accumulated over time, and the derivative term on errors expected in the future as per the error rate. The PID tuning methods are applicable in exoskeleton control as well[10].

The PID controller is defined by the transfer function:

$C(s) = Kp + Kis + Kd{\cdot}s \longrightarrow 1$

where Kp, Ki, and Kd are the proportional, integral, and derivative gains, respectively.

PID controllers are extensively employed in a variety of control systems, such as automotive, aerospace, industrial, and robotics. PID controllers are utilized in robotics to regulate joint movements, maintain stability, and control trajectory tracking. To enhance the accuracy of tracking and attain precise position control, a PID controller was incorporated into a robotic arm [11].

It is imperative to adjust the yields of the PID controller to guarantee the control system's optimal performance. Various conventional adjustment methods, including the Ziegler-Nichols, Cohen-Coon, and Tyreus-Luyben methods, have been proposed. Ziegler and Nichols introduced a widely used tuning method that is based on the system's step response and is used to ascertain the critical gain and oscillation period. The initial estimates for the PID gains are provided by the method, and they can be further refined through manual calibration or optimization algorithms[12].

The tuning of PID controllers is essential in the context of exoskeleton control to improve the user's stability, convenience, and safety during movement. The responsiveness of the exoskeleton can be enhanced, tracking errors can be reduced, and energy consumption can be minimized by finely tuning PID gains. The PID gains of an upper-limb exoskeleton were optimized using a modified Ziegler-Nichols tuning procedure. The findings indicated that the motion accuracy was enhanced, and the excess was reduced during dynamic tasks[13].

The design and control of exoskeleton systems are significantly influenced by PID controllers and tuning methodologies. Researchers and engineers can create sophisticated exoskeleton control strategies that optimize user experience and performance by comprehending the fundamentals of PID controllers and employing efficient tuning techniques.

2.4 Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a powerful stochastic optimization algorithm motivated by the social behavior of birds and fish. This includes the movement of particles in the search field, updating the positions in accordance with experience and swarming best positions.

Proportional-Integral-Derivative (PID) controllers are usually tuned with PSO for best tracking performance. Results of experiments show that PSO can get good solution for PID optimization and demonstrate the efficiency of presented algorithm for different applications like robotics and industrial processes. Investigated an adaptive PSO algorithm for real-time PID controller tuning, leading to increased control performance [14].

In their work Clerc and Kennedy underscored the significance of parameter selection in the design of PSO Algorithm for PID controller tuning [15]. This agent helps to set population size and acceleration coefficients which make PSO slightly faster. The previous discussion indicates that PSO as an optimization algorithm can be considered as a powerful application of PID controller tuning and yields promising results for the improvement of control system performance.

2.5 Elbow Model

Recently, development of exoskeletons has become an active area of research and innovation, and a significant number of upper-limb exoskeleton research works have been conducted for various purposes including rehabilitation, industrial needs, and military operations, etc. The elbow joint is one of the most significant elements of the upper-limb exoskeleton due to the fundamental impact it has on the overall functioning and performance of the device [16], [17].

There are a variety of types of research related to elbow exoskeleton design and development. For assistive and rehabilitation purposes, presented a lightweight, low-cost elbow exoskeleton paying special attention to ergonomics and user comfort during the development. Similarly, [18]. This Section (Revolutionizing Robotics) is used with permission from Patrick Aubin et al., who showed an interesting case study in developing a human-robot interaction platform of an elbow exoskeleton with advanced control algorithms and sensors to highlight a natural and intuitive interaction force control with the robot [19].

In the example of 1 DOF elbow exoskeleton design, the work by Banala et al. gives good info. This study is on a one degree-of-freedom exoskeleton assisting elbow rehabilitation, showing that a one degree-of-freedom simplified design could still provide effective assistance and comfort to the elbow movement of the user. Furthermore, a study of the design of a variable stiffness exoskeleton for the upper extremity by Ergin and Patoglu has some important takeaways in the sense of actuation and control mechanisms for elbow exoskeleton [20], [21].

The design and development process are important in exoskeletons and so the use of computer-aided design (CAD) software like SolidWorks is critical. Subsequently researchers have used SolidWorks to build a 3D model of the Exoskeleton systems and goodness of design and simulated the performance of their exoskeleton system [22], [23].

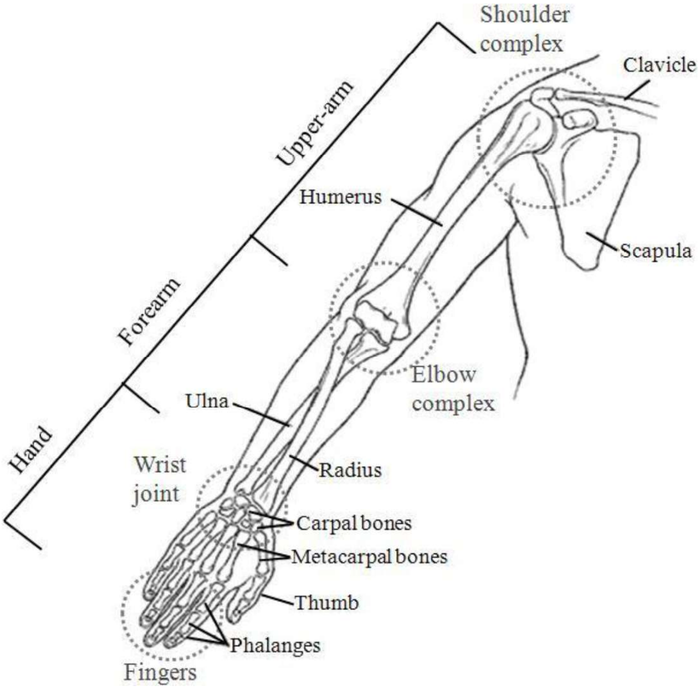

Figure 2.1 Segment of Upper Limb[23]

Figure 2.1 above describes the gallery Human skeleton anatomy, the diagram shows the human skeleton from front. It illustrates the shoulder complex with the clavicle and scapula, upper arm with humerus, elbow joint for arm movement, forearm with radius and ulna, and wrist joint for manipulation of hand orientation. It also depicts the bones of the hand (carpal bones in the wrist, metacarpals in the palm, and phalanges in the fingers) showing how the thumb has a separate range of mobility [23].

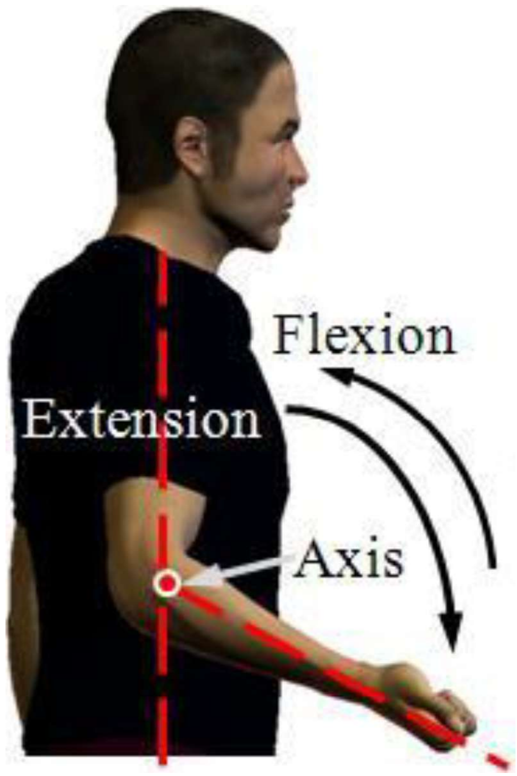

Figure 2.2 Human Upper Limb Motion (Elbow)[23]

An image showing in figure 2.2 a person in lateral view flexion and extension of the elbow joint This shows a person standing sideways with an arm bent at the elbow, demonstrating the movement in relation to the pivot point, labelled as "Axis" at the elbow joint. A red dashed line represents extension, running from the shoulder along the extended arm (up and down), curved arrows are labeled "Flexion" show bending motion of forearm towards upper arm in essence, this diagram can depict the anatomical concepts of elbow joint flexion and extension by illustrating the actual movements[23].

In sum, the literature presented above gives a sound basis for creating 1 DOF elbow exoskeleton on SolidWorks. The insights and design concepts that have been presented should inform our own design process by enabling us to develop an exoskeleton that is ergonomic, intuitive, and can better assist and guide the user movement of the elbow.

2.6 Summary

The literature review discusses the importance of upper limb exoskeletons in rehabilitation, assistive, and industrial sectors. It highlights the role of PID controllers, tuning methods, and Particle Swarm Optimization (PSO) in ensuring stability and smooth motion. The review also highlights the pivotal role of the elbow joint in exoskeleton design, focusing on ergonomics, user comfort, and natural interaction force control. The use of computer-aided design software like SolidWorks is highlighted for 3D modeling of exoskeleton systems. The review provides a comprehensive overview of upper limb exoskeletons, emphasizing the role of PID controllers, tuning methods, intelligent control systems, and the significance of the elbow joint in exoskeleton design.

CHAPTER 3

METHODOLOGY

3.1 Background

The method to realize Objective 1 is presented to design the exoskeleton elbow model, from initially drafting the design using SolidWorks to iterations refining it with biomechanics and user needs and finalizing the validation with simulations and finally prototyping. Objectives 2 and 3 from this work, regarding the design of an intelligent control application and the performance and functionality analysis, respectively, are expected to extend into next semester. This continuation will contain the steps to move forward with a PID controller, comparison for different tuning, simulation testing, and Performance evaluation based on set of metrics argued. Moving on to Objectives 2 and 3 in the next semester aims to improve the project results in the context of the project aims and specs.

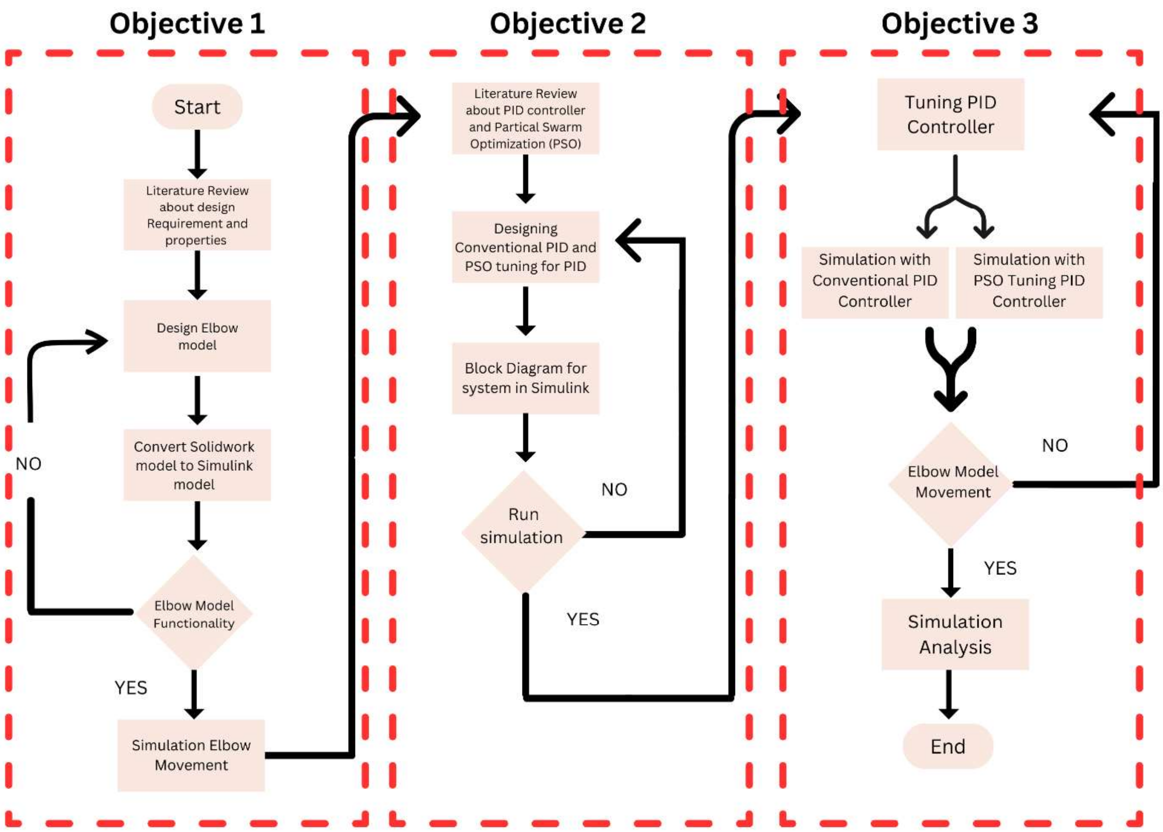

Figure 3.1 Flowchart of the research to achieve all required objectives

Design of Objective 1 in figure 3.1, by developing an exoskeleton elbow model that should first be designed in detail 3D using the SolidWorks tools, focusing on anthropometrical ergonomics and biomechanics. Afterwards, the model will enter a refinement phase where feedback from biomechanical experts and end-users will be implemented to refine functionality and comfort. The design will next be validated through simulation testing with software such as MATLAB/Simulink to protect for structural integrity and motion dynamics, then prototyping and testing will be performed on the physical design to vet out functionality and ease of use. It is very important to document the design steps and the improvements made and back hence by validation results and user feedback to sign that the final model of exoskeleton elbow is effective in meeting the objectives of the project and to meet the user requirements.

3.2 Design an exoskeleton elbow model for the simulation of upper limb control mechanism.

3.2.1 Task 1: Identify the design requirement for hand exoskeleton

To establish the design constraints for the 1-DOF elbow exoskeleton, details about the motion range must be determined. The design constraints are its passive assistance/resistance to flexion/extension elbow joint movements in a defined range of motion. The exoskeleton must fit the natural biomechanics of the elbow joint as it combines smooth and controlled movement with support and stability. One other aspect that verifies a proper system-coupling is the range of motion of the exoskeleton considering physiological limits at the elbow joint. Further the mechanical design and the actuation system of the exoskeleton should be tuned to aid the assistance or resistance requirements at the range of motion with a given bandwidth, to improve functionality and thus user acceptability.

3.2.2 Task 2: Designing Upper Arm, Forearm and Elbow Joint Connector

The exoskeleton elbow model, designed using SolidWorks, simulates upper limb control mechanisms. The upper arm, forearm, and elbow joint connector are designed for flexibility, durability, and ease of integration. These components enhance the biomechanical compatibility and usability of the exoskeleton system, providing a seamless upper limb control simulation experience.

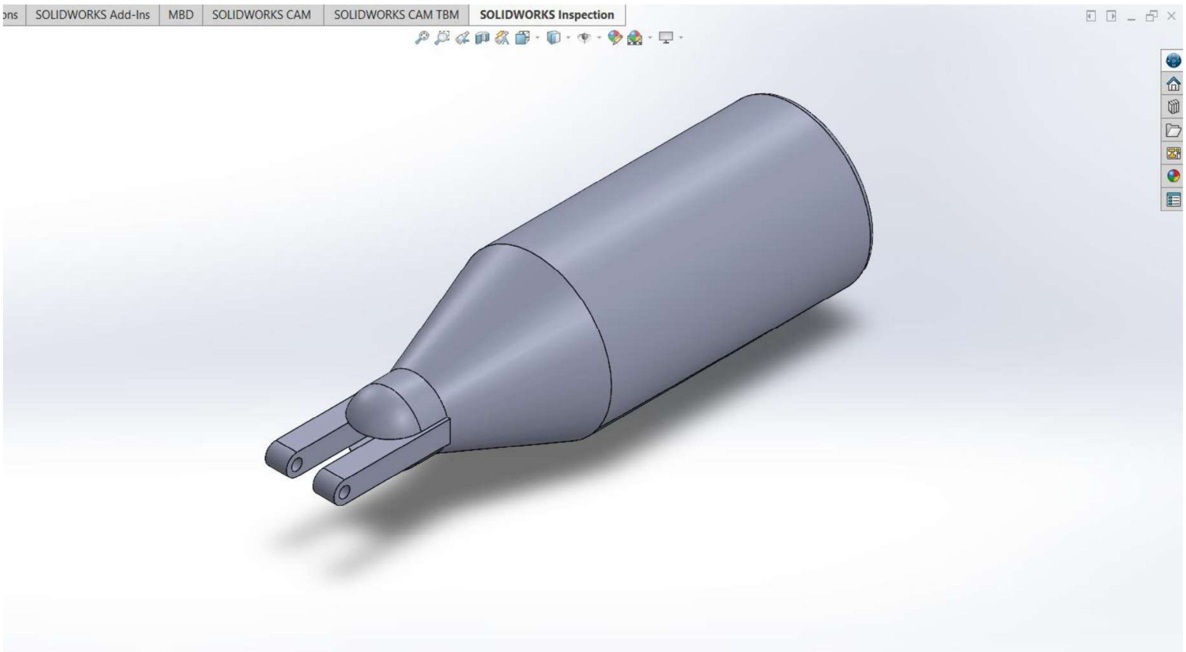

Figure 3.2 Upper Arm Design

Figure 3.2 is on shape design of the upper arm part, detailed in SolidWorks, with a lead out into the wrist flexors, a large-scale cylinder-shaped thing that tapers to one end. The main body was a straight sleek cylinder, granting a simple and long-life strong termination, tailored to fit the arm folds. This design has two holes in its circle-shaped part, which is probably how the exoskeleton is chained together, and it also has a pair of parallel, forked pins on the pointed end, which should be for the joint of the elbow and forearm of the exoskeleton. These extensions also allow it to move rotationally while keeping connections in place, guaranteeing its functionality and its flexibility. The exoskeleton prioritizes good design, with both durability and willingness to be replaced by other components that might be more efficient in certain situations.

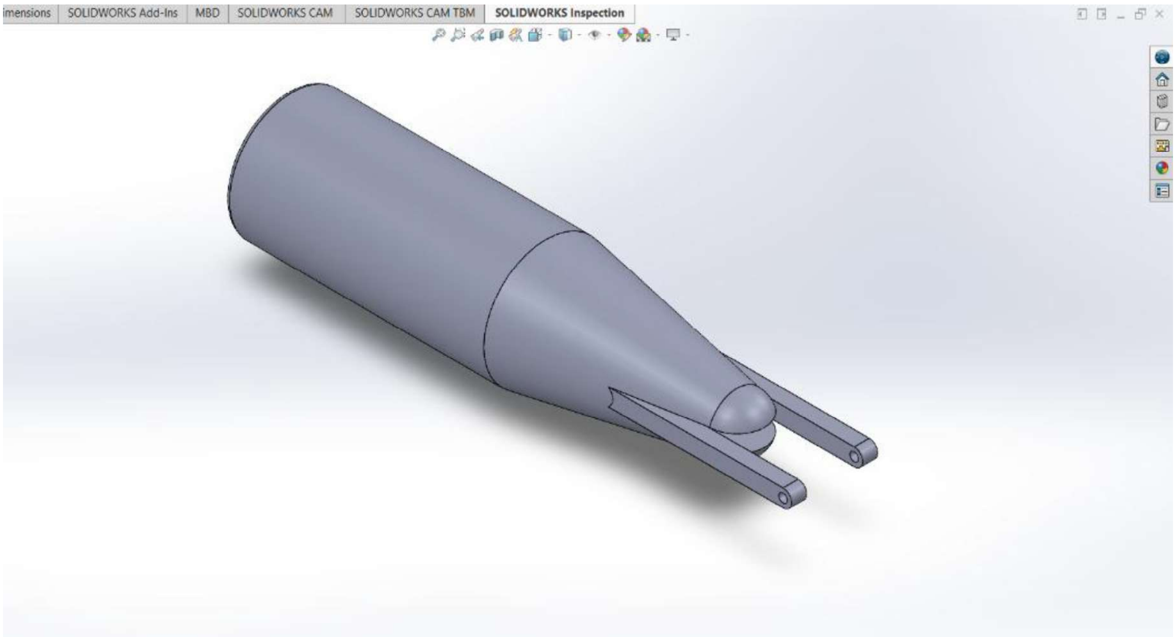

Figure 3.3 Forearm Design

This design in figure 3.3, created using SolidWorks, consists of a smooth, slightly cylindrical form that narrows at the end of the forearm part of an exoskeleton. The main body of the component is in the form of a long, smooth cylinder that reinforces the forearm support and adds an ergonomic design. At one of the tapered ends, the design features a pair of parallel, fork-like appendages with holes presumably for connecting this segment to other parts of the exoskeleton, for instance, the elbow. These ensure rig and flexibility while the exoskeleton is operating by facilitating movement rotations and securing connections. The general theme is maintaining a structure that is robust and can accommodate other components efficiently while providing the user with the experience that is expected from an exoskeleton.

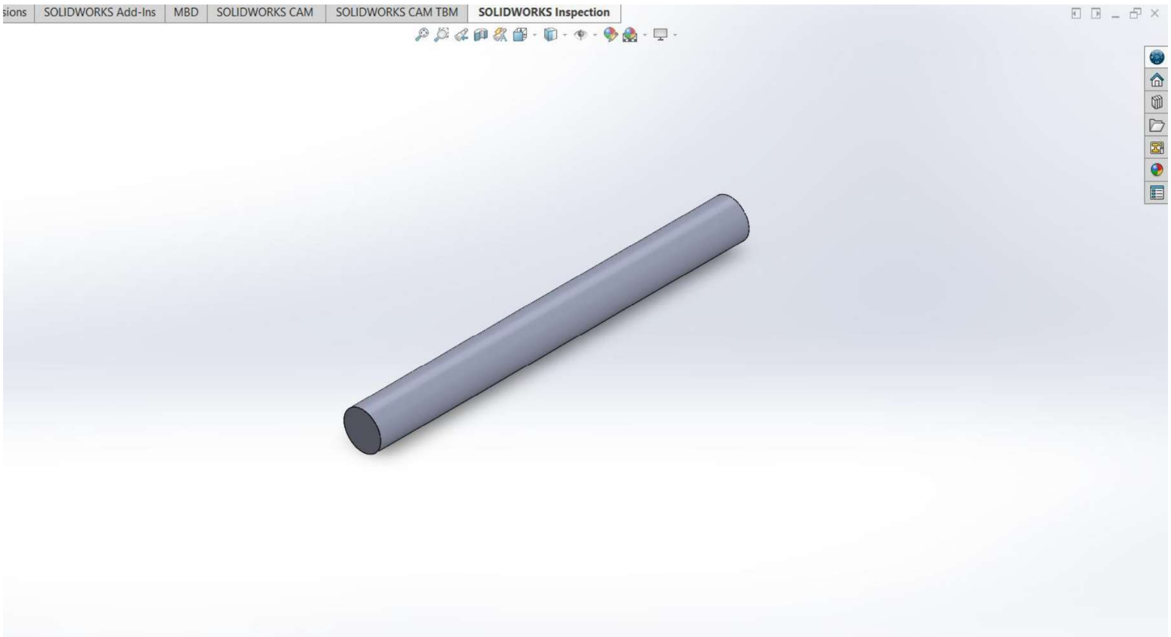

Figure 3.4 Elbow Joint Connector Design

Since it is a simple, cylindrical rod, the elbow joint connector of the exoskeleton model designed in SolidWorks in Figure 3.4. The connector is a filiform cylinder, whose diameter remains unchanged over its entire length. This design would indicate the connector is designed to join the upper arm and the forearm components of the exoskeleton at a pivotal axis or linkage. To rotate or swivel smoothly where the upper arm and the forearm meet, the cylinder was a nice smooth shape. Its design is quite simple, for good reason, the joint connection it represents must be functionally reliable, easy to integrate, and capable of supporting the wide range of motion the human elbow achieves.

3.2.3 Task 3: Elbow Model Assembly

The project aims to design an exoskeleton elbow model for simulating upper limb control mechanisms. It involves assembling three components in SolidWorks, aligning, mating, and testing for movement. The model is exported to MATLAB/Simulink, ensuring smooth interaction and optimizing task performance.

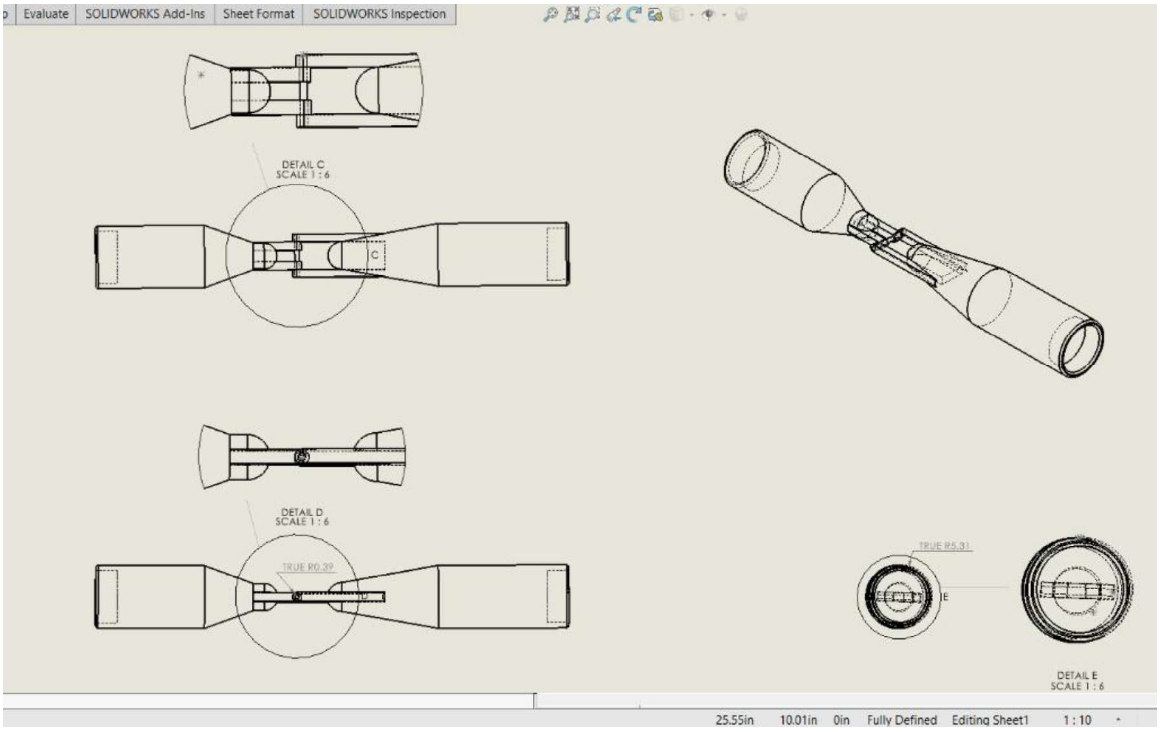

Figure 3.5 Full Assembly Drawing of Elbow Model

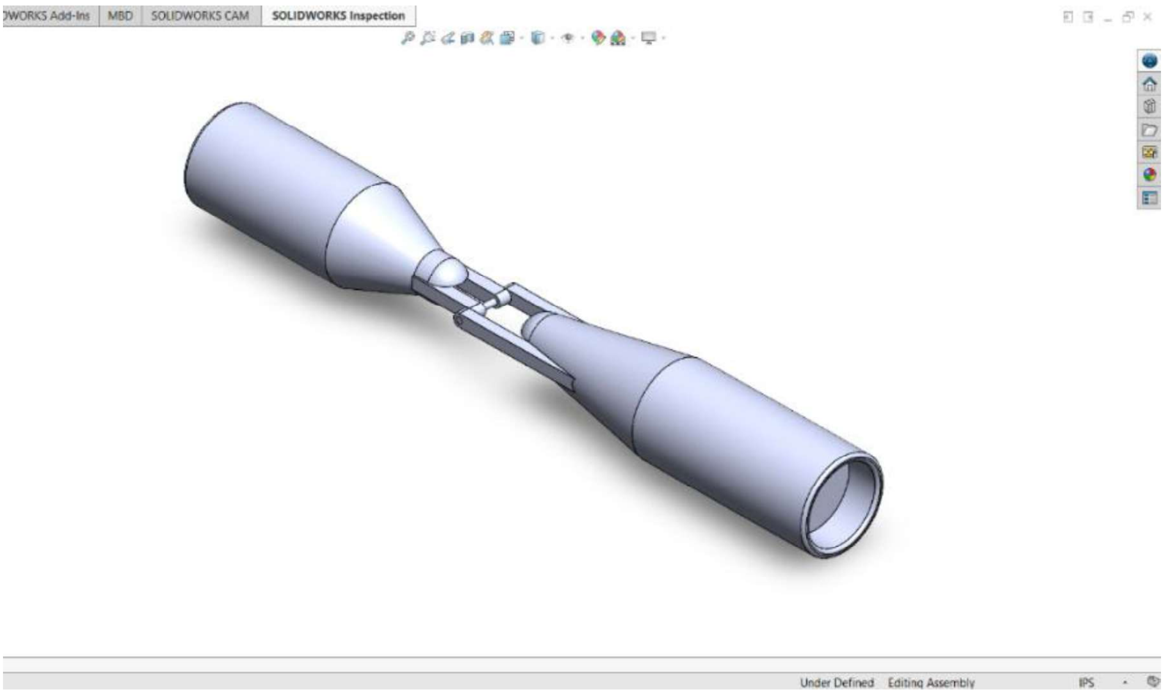

Figure 3.6 Full Assembly Elbow Model Design

Figure above is for the SolidWorks elbow model assembly, the three components are upper arm part, the forearm part, and the elbow joint connector, respectively its parts, the upper arm and forearm, are cylindrical in shape which then tapers to each end in which connects to the elbow joint. With the elbow joint connector cylindrical bar connecting the upper arm and forearm parts-the elbow joint can rotate, allowing the elbow to flex and extend naturally. Put the components into the slots, align the upper arm to the forearm in position, put an elbow joint connector inserted in place and assembled between the two, mate those together, line all up and give it a test, see if it moves properly and then save the file.

3.2.4 Task 4: Converting the Model from SolidWork to MATLAB/Simulink

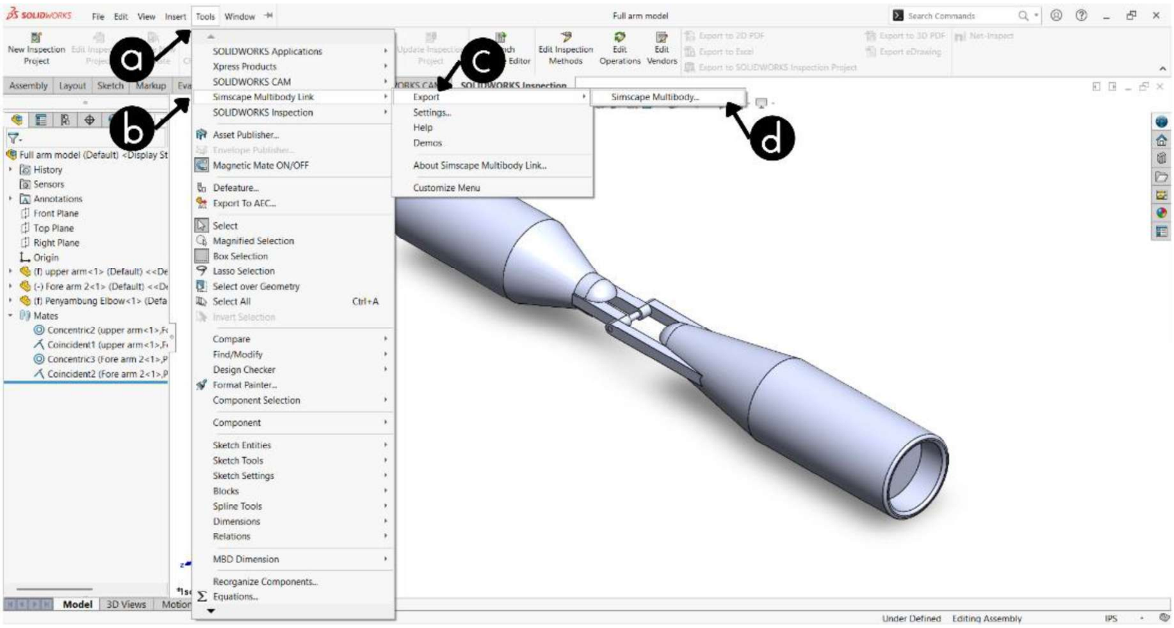

Figure 3.7 Exporting SolidWorks as .xml file

Figure 3.7 is to export the model from SolidWorks to MATLAB Simulink, the model needs to be converted to xml file which we need export by using Multibody features in SolidWorks.

Procedure based on Figure 3.7:

Table 3.1 Procedure exporting SolidWorks as xml file

Step	Procedure
a	Go to tool tabs
b	Choose Simscape Multibody Link
c	Click export
d	Choose Simscape Multibody

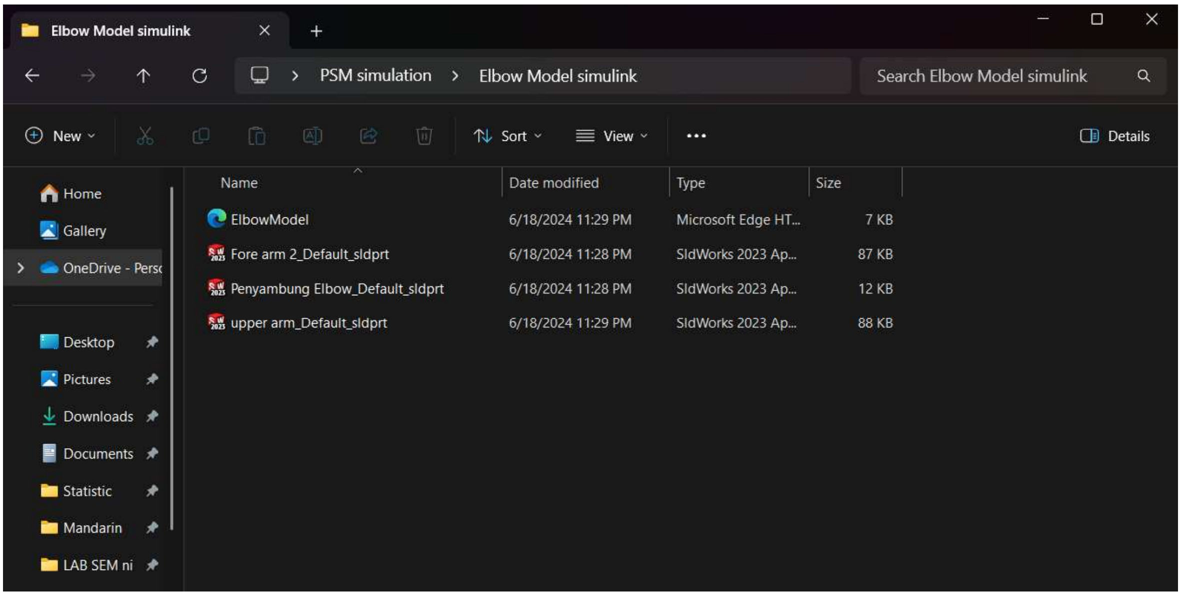

Figure 3.8 Save the xml File

After exporting the Elbow Model from SolidWorks, save the xml file to the new folder, all SolidWorks file that have been assembly will be saved the same folder as xml file in figure 3.8.

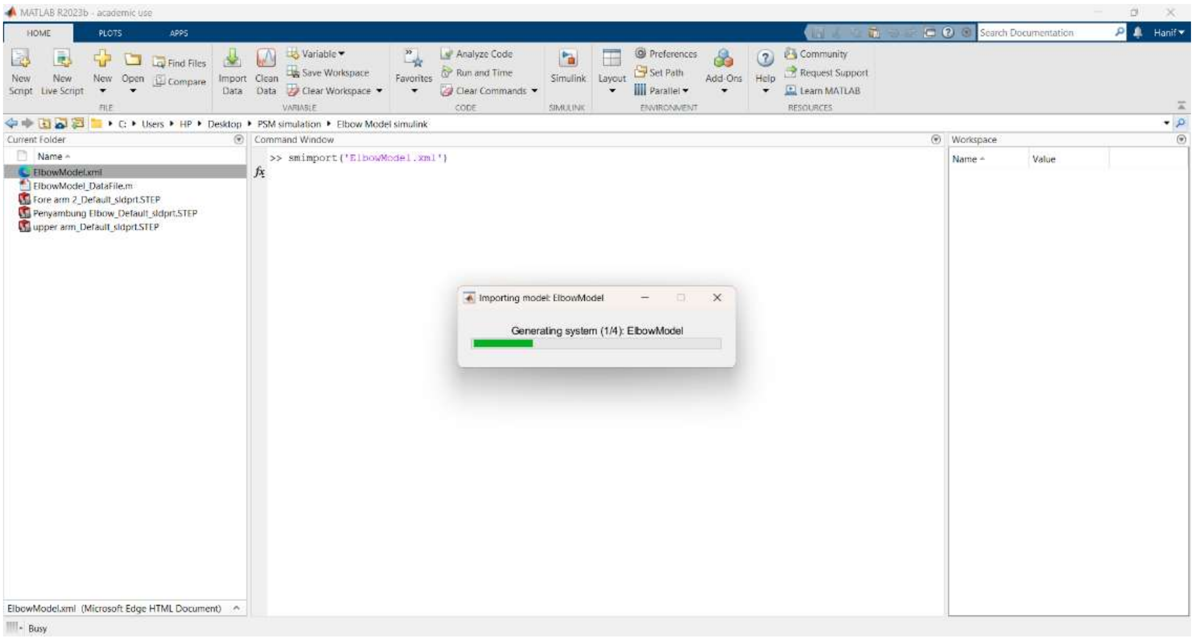

Figure 3.9 Model Building from MATLAB

Open the MATLAB and type at command window smimport('fille_name.xml') and press enter, it will be generated to the Simulink Model, that show in figure 3.9.

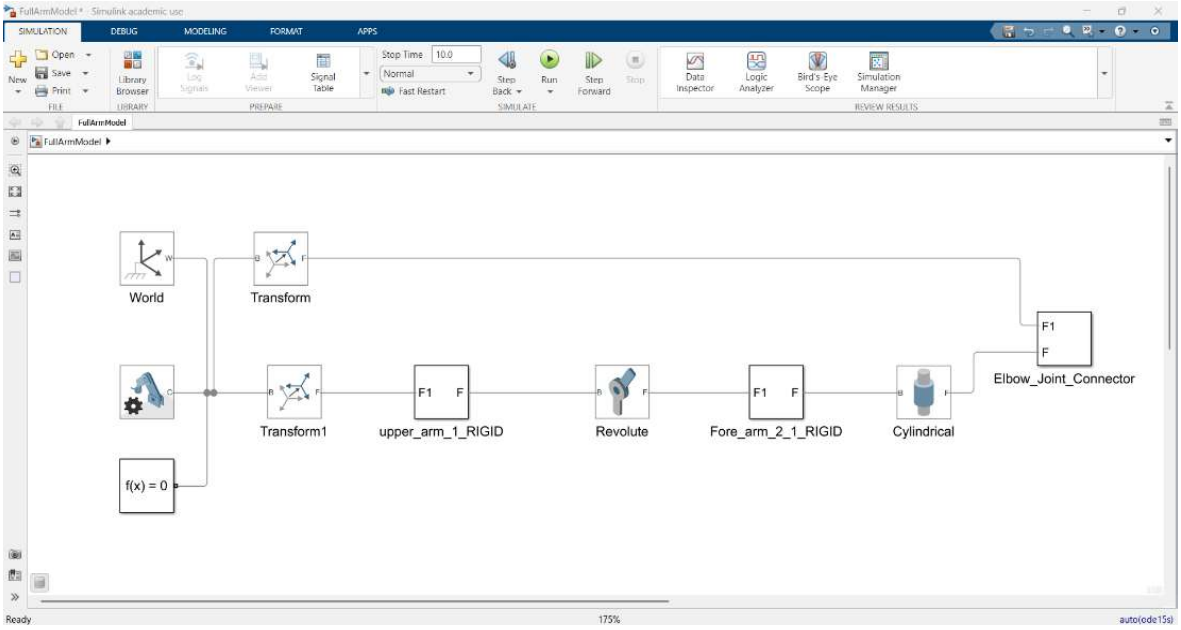

Figure 3.10 Simulink Model of Elbow Model

Figure 3.10 shows Simulink model of the elbow assembly is created by calling MATLAB commands to the xml file, this demonstrates the structure and interaction of the upper arm, forearm and elbow joint connector components. The model consists of Transform blocks to arrange the entities, Rigid Transform blocks to rigid body transformation, and a Revolute Joint block for elbow joint rotational movement.

To summarize, the exoskeleton elbow model design methodology emphasized verification of upper limb control mechanism through identification and response to major design problems. This consisted of tasks such as identification of design constraints for the elbow exoskeleton, SolidWorks design and improvement of the upper arm, forearm, and elbow joint connector parts, assembly of the elbow model to demonstrate functionality, and implementation of the model into simulation software to allow for realistic movement. With considerations in quality of movement, kinematic adaptation, and task performance optimization, the method presented allows the design of an exoskeleton free-arm model provided the exoskeleton elbow model designed takes comfortable, supportive, and seamless interaction with upper arm, forearm, and elbow joint attachment components.

3.3 Summary

The final year project aims to design an exoskeleton elbow model and implement intelligent control applications for upper limb control mechanisms. The project involves initial design using SolidWorks, iteration based on biomechanics and user feedback, simulation testing, and prototyping. The next semester will focus on implementing a PID controller, comparing tuning methods, conducting simulation testing, and evaluating performance metrics. The methodology includes identifying design requirements, designing upper arm, forearm, and elbow joint connectors, converting the model to MATLAB/Simulink, and building a Simulink model.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Background

Figures 4.1 and 4.2 illustrate the development from its very beginning structural model to the full physical model simulation of the elbow in Simulink. On the low-level, Fig. 4.1 introduces the fundamental cylinder parts, which build the basis for further development and simulation, whereas Fig. 4.2 shows the completely simulated exemplarily elbow model about the style of a human elbow and hence is essential to understand its mechanical behavior and control requirements within the exoskeleton system. These simulations provide visual explanations of how the elbow works and stress the importance of control for effective operation in practice. Moreover, no active control was enabled in the elbow model of Figure 4.3. The free and random joint movement of the simulated human elbow joint showed the necessity of having a controlling element in the system to organize the movement of the exoskeleton joint for more accurate and personalized control of the device during operation in real-life situations.

4.2 Simulation from Simulink Model of Elbow Model

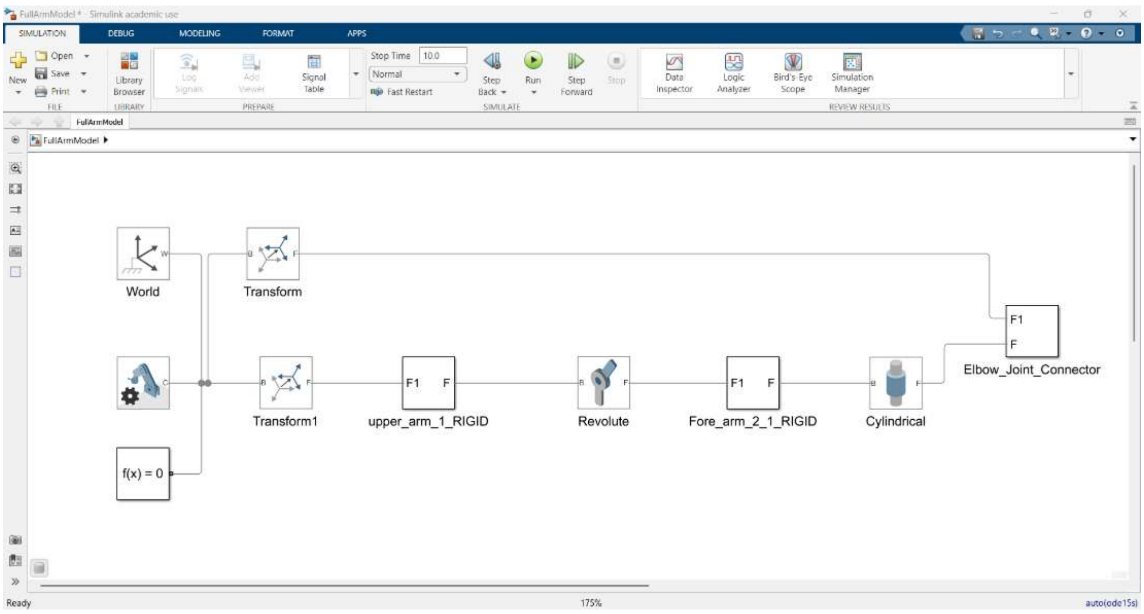

Figure 4.1 Simulink Model of Elbow Model

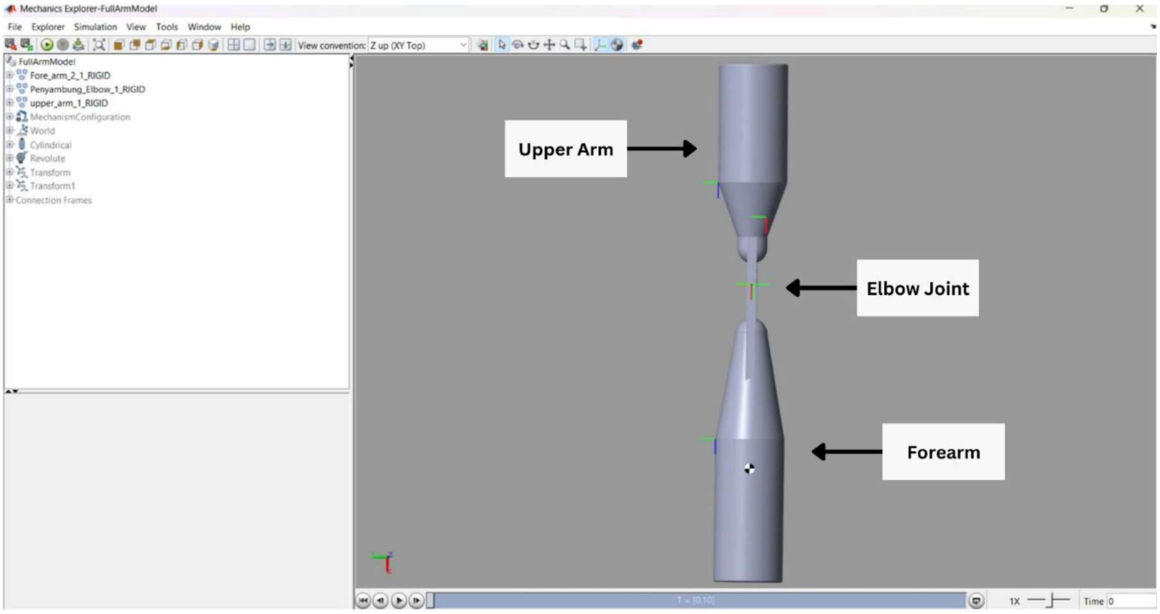

Figure 4.2 Simulated Elbow Model

Figure 4.1 demonstrates the initial structural configuration of the elbow model in Simulink containing a simple cylindrical component to form the basis for the elbow assembly model development and simulation. By contrast, Figure 4.2 shows the elbow model with the full physics simulation applied. The resemblance of this a representation of a human elbow makes this complete model useful in understanding the mechanical behavior as well as the control needs of the joint when it is assimilated into an exoskeleton system. These simulation results illustrate the operation of the elbow in simplified visual form and the need for accurate control mechanisms to finely tune its operation in actual applications.

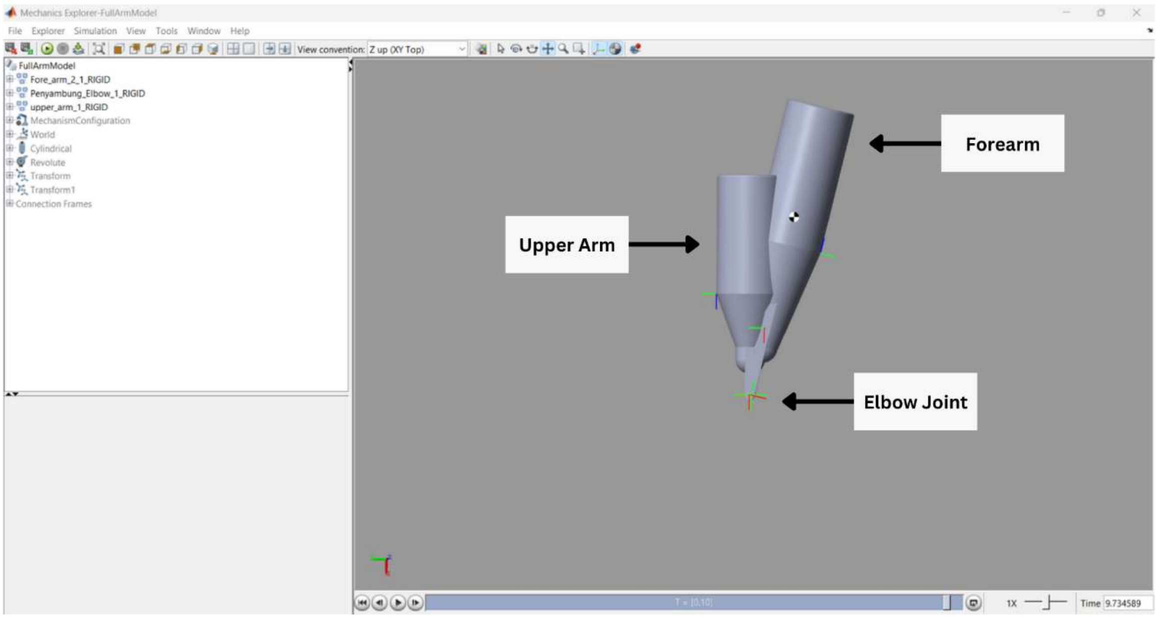

Figure 4.3 Simulated Elbow Model Without Controller

Figure 4.3 is the same simulated elbow model in which there is no active control, but all the components move freely without any constraint suited low level operation. In this case the elbow joint will move freely and as much as allowed by the physiological empty space available for a natural, unrestricted movement pattern. The joint is behaving too poorly, such that, without a controller and with little else to do, it swings back and forth carelessly, fully flexing and extending, a lack of external factors influencing its behavior, it has been left to do as it will. This capability to freely move is an inherent mechanical property of the elbow assembly, and functions as a constant to understand system behavior in a passive mode. It underlines the need to introduce a mechanism to control and coordinate joint movement, making accurate and individualized operation of the exoskeleton in realistic settings possible.

4.3 Summary

For now, the final year project aims to design an exoskeleton elbow model. The project involves initial design using SolidWorks, iteration based on biomechanics and user feedback, simulation testing, and prototyping. The next semester will focus on implementing a PID controller, comparing tuning methods, conducting simulation testing, and evaluating performance metrics. The methodology includes identifying design requirements, designing upper arm, forearm, and elbow joint connectors, converting the model to MATLAB/Simulink, and building a Simulink model.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Finally, the research project on "Intelligent Control for Upper Limb Exoskeletons" has worked on the design of a subject-specific elbow exoskeleton. This study has contributed to the comparison of conventional PID tuning methods and PSO controller tuning to better the operation of the upper limb control mechanism. The study aimed to be a contribution to the progress and application of the technology, upper limb exoskeleton, for rehabilitation through simulation and modeling. Results allude to the significance of intelligent control for enhanced application and performance of compliant upper limb exoskeletons for people with elbow impairment.

5.2 Future Works

Future works will investigate in more detail and implement intelligent controls for upper limb exoskeletons in the research project. This involves improving PID tuning techniques using optimization algorithms such as PSO to improve control system performance. Furthermore, the impact of more intelligent control on the exoskeleton operation and comfort for people with upper limb impairments will be analyzed using this study. Future research should continue real-time testing and improvement of the control strategies to maximize the performance of the exoskeleton technology. By incorporating these developments, we want to push the frontiers of upper limb exoskeleton technology and rehabilitation through intelligent control applications.

REFERENCES

[1] A. Sheta, M. Braik, D. R. Maddi, A. Mahdy, S. Aljahdali, and H. Turabieh, "Optimization of pid controller to stabilize quadcopter movements using meta-heuristic search algorithms," *Applied Sciences (Switzerland)*, vol. 11, no. 14, Jul. 2021, doi: 10.3390/app11146492.

[2] K. Anam and A. A. Al-Jumaily, "Active exoskeleton control systems: State of the art," in *Procedia Engineering*, Elsevier Ltd, 2012, pp. 988–994. doi: 10.1016/j.proeng.2012.07.273.

[3] R. A. R. C. Gopura, K. Kiguchi, and D. S. V Bandara, "A Brief Review on Upper Extremity Robotic Exoskeleton Systems."

[4] Robotics Society of Japan. and Institute of Electrical and Electronics Engineers., *IROS 2009 : October 11-15, 2009, St. Louis, USA : the 2009 IEEE/RSJ International Conference on Robots and Intelligent Systems.* IEEE, 2009.

[5] M. A. Vélez-guerrero, M. Callejas-cuervo, and S. Mazzoleni, "Artificial intelligence-based wearable robotic exoskeletons for upper limb rehabilitation: A review," *Sensors*, vol. 21, no. 6. MDPI AG, pp. 1–30, Mar. 02, 2021. doi: 10.3390/s21062146.

[6] Y. Ding, M. Kim, S. Kuindersma, † Conor, and J. Walsh, "Human-in-the-loop optimization of hip assistance with a soft exosuit during walking," 2018. [Online]. Available: http://robotics.sciencemag.org/

[7] T. Proietti, V. Crocher, A. Roby-Brami, and N. Jarrasse, "Upper-limb robotic exoskeletons for neurorehabilitation: A review on control strategies," *IEEE Reviews in Biomedical Engineering*, vol. 9. Institute of Electrical and Electronics Engineers, pp. 4–14, 2016. doi: 10.1109/RBME.2016.2552201.

[8] P. Maciejasz, J. Eschweiler, K. Gerlach-Hahn, A. Jansen-Troy, and S. Leonhardt, "JNER JOURNAL OF NEUROENGINEERING AND REHABILITATION REVIEW Open Access A survey on robotic devices for upper limb rehabilitation," 2014. [Online]. Available: http://www.jneuroengrehab.com/content/11/1/3

[9] T. Bützer, O. Lambercy, J. Arata, and R. Gassert, "Fully Wearable Actuated Soft Exoskeleton for Grasping Assistance in Everyday Activities," *Soft Robot*, vol. 8, no. 2, pp. 128–143, Apr. 2021, doi: 10.1089/soro.2019.0135.

[10] "PID Controllers_Theory, Design, and Tuning".

[11] M. Mistry, P. Mohajerian, and S. Schaal, "An Exoskeleton Robot for Human Arm Movement Study *."

[12] "Optimum Settings for Automatic Controllers".

[13] F. Hassan, A. C. Zolotas, and T. Smith, "Optimized Ziegler-Nichols based PID control design for tilt suspensions," *Journal of Engineering Science and Technology Review*, vol. 10, no. 5, pp. 17–24, 2017, doi: 10.25103/jestr.105.02.

[14] Y. Shi and R. Eberhart, "A Modified Particle Swarm Optimizer."

[15] M. Clerc and J. Kennedy, "The Particle Swarm-Explosion, Stability, and Convergence in a Multidimensional Complex Space," 2002.

[16] S. K. Banala, S. H. Kim, S. K. Agrawal, and J. P. Scholz, "Robot assisted gait training with active leg exoskeleton (ALEX)," in *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, Feb. 2009, pp. 2–8. doi: 10.1109/TNSRE.2008.2008280.

[17] Institute of Electrical and Electronics Engineers., *ICRA 2012 : 2012 IEEE International Conference on Robotics and Automation : St. Paul, Minnesota, USA, May 14-18, 2012.* [IEEE], 2012.

[18] S. Hussain, P. K. Jamwal, M. H. Ghayesh, and S. Q. Xie, "Assist-as-needed control of an intrinsically compliant robotic gait training orthosis," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 2, pp. 1675–1685, Feb. 2017, doi: 10.1109/TIE.2016.2580123.

[19] A. Otten, C. Voort, A. Stienen, R. Aarts, E. Van Asseldonk, and H. Van Der Kooij, "LIMPACT:A Hydraulically Powered Self-Aligning Upper Limb Exoskeleton," *IEEE/ASME Transactions on Mechatronics*, vol. 20, no. 5, pp. 2285–2298, Oct. 2015, doi: 10.1109/TMECH.2014.2375272.

[20] "Wearable Robots."

[21] IEEE Robotics and Automation Society., *2005 IEEE International Conference on Robotics and Automation (ICRA) : Barcelona, Spain : 18-22 April, 2005.* IEEE, 2005.

[22] F. Giovacchini *et al.*, "A light-weight active orthosis for hip movement assistance," in *Robotics and Autonomous Systems*, Elsevier B.V., Nov. 2015, pp. 123–134. doi: 10.1016/j.robot.2014.08.015.

[23] "Mechanical designs of active upper-limb exoskeleton robots_State-of-the-art and design difficulties".

APPENDICES

APPENDIX A GANTT CHART OF PROJECT