

DEGREE PROJECT

→ysIDEA→



TEJAS PATEL

2022

Institute of Design
Nirma University

Degree / Major Research Project

Design of SEA and PEA based robotic arm

Type of Project :

Industry Sponsored

Student: Tejas Patel

Roll No: 18bdi036

Programme: Industrial Design



DECLARATION BY THE CANDIDATE

Student: Tejas Patel

Roll no.: 18bdi036

Programme: Bachelors of Design (B. Des)

I solemnly declare that the project report DESIGN OF TABLETOP ROBOTIC MANIPULATOR is based on my own work carried out during the course of our study under the supervision of Haris P.M. I assert the statements made and conclusions drawn are an outcome of my research work. I further certify that

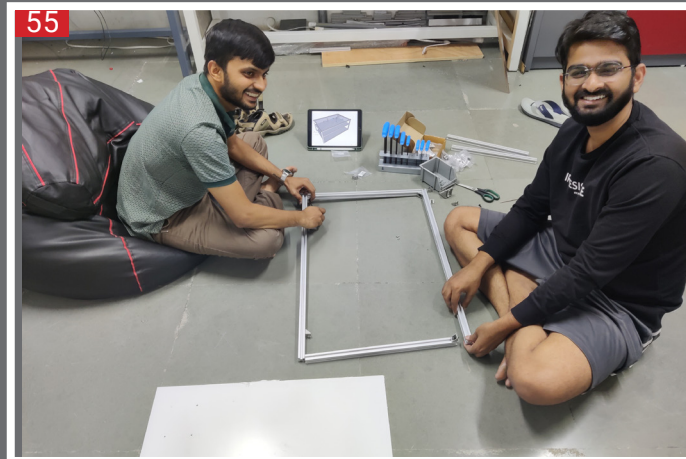
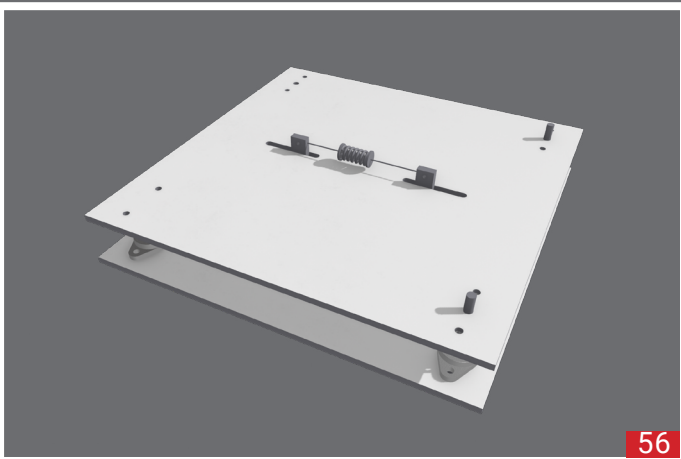
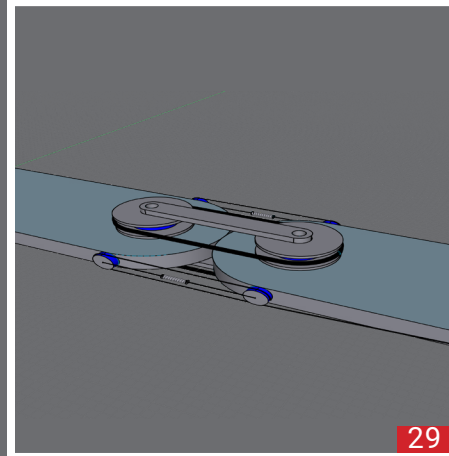
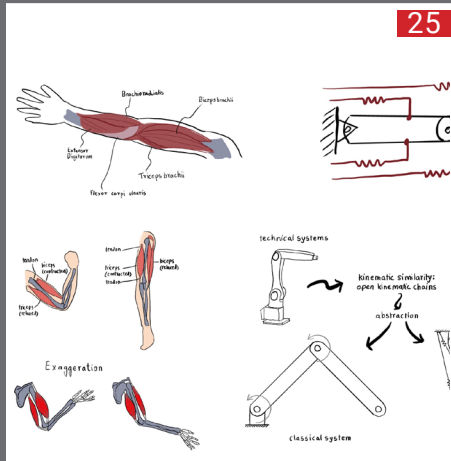
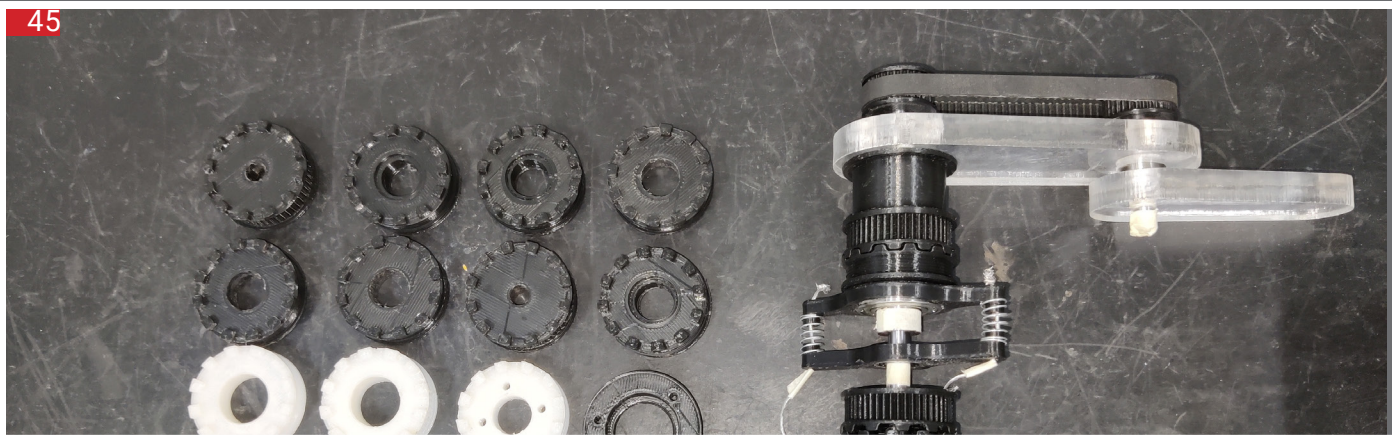
1. The work contained in the documentation is original and has been done by me under the general supervision of organisation sysIDEA Research Labs, IIT Gandhinagar.
2. The work has not been submitted to any other Institution for any other degree/diploma/certificate in this university or any other University of India or abroad.
3. We have followed the guidelines provided by the university in writing the report.
4. Whenever we have used materials (data, theoretical analysis, and text) from other sources, we have given due credit to them in the text of the report and given their details in the references.
5. I hereby grant the Department of Design, Nirma University the right to archive my Degree Project Documentation.

Student: TEJAS PATEL

SIGNATURE

Patel





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PREFACE

This document is a concise report of my four weeks internship, starting from January 17, 2022 and ending in JMay 17, 2022, that I underwent at sysIDEA Robotics Lab at IIT Gandhinagar. The objective of this Major research project was to ease students into the routine of a proper work environment as well as understand the functioning of the respective industry the work in. the document talks about the lab, my role as a designer and the projects worked on. It also speaks of the various learning experiences, and how I evolved as a designer throughout these eighteen weeks.



ABOUT ME

I am an Industrial Designer currently based in Ahmedabad, India. Studying at Institute of Design, Nirma University. I use cutting-edge 3d software like Solid Works, Rhino and Creo to create detailed models, product geometry and surface aesthetics. For me Design is a blend of mechanism, technology, sculpture, interaction and manufacturability. Rapid prototyping a product is critical to testing and understanding what's working and what needs further exploration. I use traditional techniques native to carpentry, metalworking and even sewing, alongside high-tech processes like CNC, machining,

developing composite materials and 3d printing.

Designing the product itself is obviously very important but there's another idea we call the product's Ecosystem, that's equally as important. It has more to do with the experience. It's also got a lot to do with owning it over a long period of time and even what it means for how you throw it away when you're done. Every step of that process is designed experience.

ABOUT INSTITUTE OF DESIGN

Department of Design commenced in 2017 with a vision of the management, to build a holistic campus of varied disciplines. The mandate was to expand the innovative science and logic-based disciplines to include creative, disruptive and non-linear thinking disciplines. Being the youngest department on the university campus, the vision is to offer inter-disciplinary orientation that is necessary for today's industry demands. The Department of Design is in its fourth year, having commenced its programme in 2017.

The department has helped us in exploring opportunities extensively and motivated us in finding our real passion. Inter-disciplinary and co learning has assisted in studying and exploring emerging areas. Being the first graduating batch of NU-DOD and me being the first student graduating, we have had the responsibility to set the benchmark for coming batches.

Department of Design offers two disciplines of learning- Industrial Design and Communication Design. The 4-year undergraduate programme begins with a common foundation year in Design. There is an intense 15 weeks of learning in each of the 7 semesters in studios, classrooms, workshops

and through field work. Learning through Internships and Apprenticeships happens during the 10 weeks' summer vacation period, each year. The 8th Semester is a 4-month Industry project, on the basis of which the final degree is granted.

The philosophy for both programmes is inclusive design with a focus on universal design. Students work closely with indigenous clusters in western India as well as other parts of the country, that they belong to. Being located in Ahmedabad – the design capital of the country, the programme draws from the expertise of multiple design practitioners and design academics residing in the city.

Renowned industrialist and philanthropist Dr Karsanbhai K Patel, the founder of the Nirma Group of Industries, established the Nirma Education and Research Foundation (NERF) in the year 1994 with a vision to promote higher education and provide excellent educational facilities to the youth in India. In 1995, Nirma Institute of Technology – affiliated to Gujarat University – was established by the NERF.

Acknowledgement

The success and final outcome of this project required a lot of guidance and assistance from many people and I am extremely privileged to have got this all along the completion of my project. All that I have done is only due to such supervision and assistance and I would not forget to thank them.

I respect and thank Prof. Harish PM, for providing me an opportunity to do the project work in SysIDEA robotics lab and giving me all support and guidance, which made me complete the project duly. I am extremely thankful to him for providing such a nice support and guidance, although he had busy schedule managing the academics affairs.

I would not forget to remember Barat, Shail and Sujay, of Research labs at IIT-gn for their

encouragement and more over for their timely support and guidance till the completion of our project work.

I heartily thank our internal project guide, Prof. Harish, Associate Professor, Mechanical Engineering for his guidance and suggestions during this project work.

I am thankful to and fortunate enough to get constant encouragement, support and guidance from all staffs of IIT Gandhinagar which helped me in successfully completing my project work.

About Lab and Team



Harish PM

Associate Professor

Everybody is capable of extraordinary things! As a roboticist, research, educator, teacher, and administrator I try to tap into this potential in all of us to try and push the boundaries of robotics and education.



haris_palanthandalam_
madapusi



Barat S

PhD Fellow

A curious child evolved, admiring the inspiring achievements of ISRO & DRDO in their fields. Robots caught my attention during childhood, which slowly flourished into passion by time. This inspiration to design the complex machines drove me to pursue Engineering.



baratsuresh2811



Shail Jadav

PhD Student

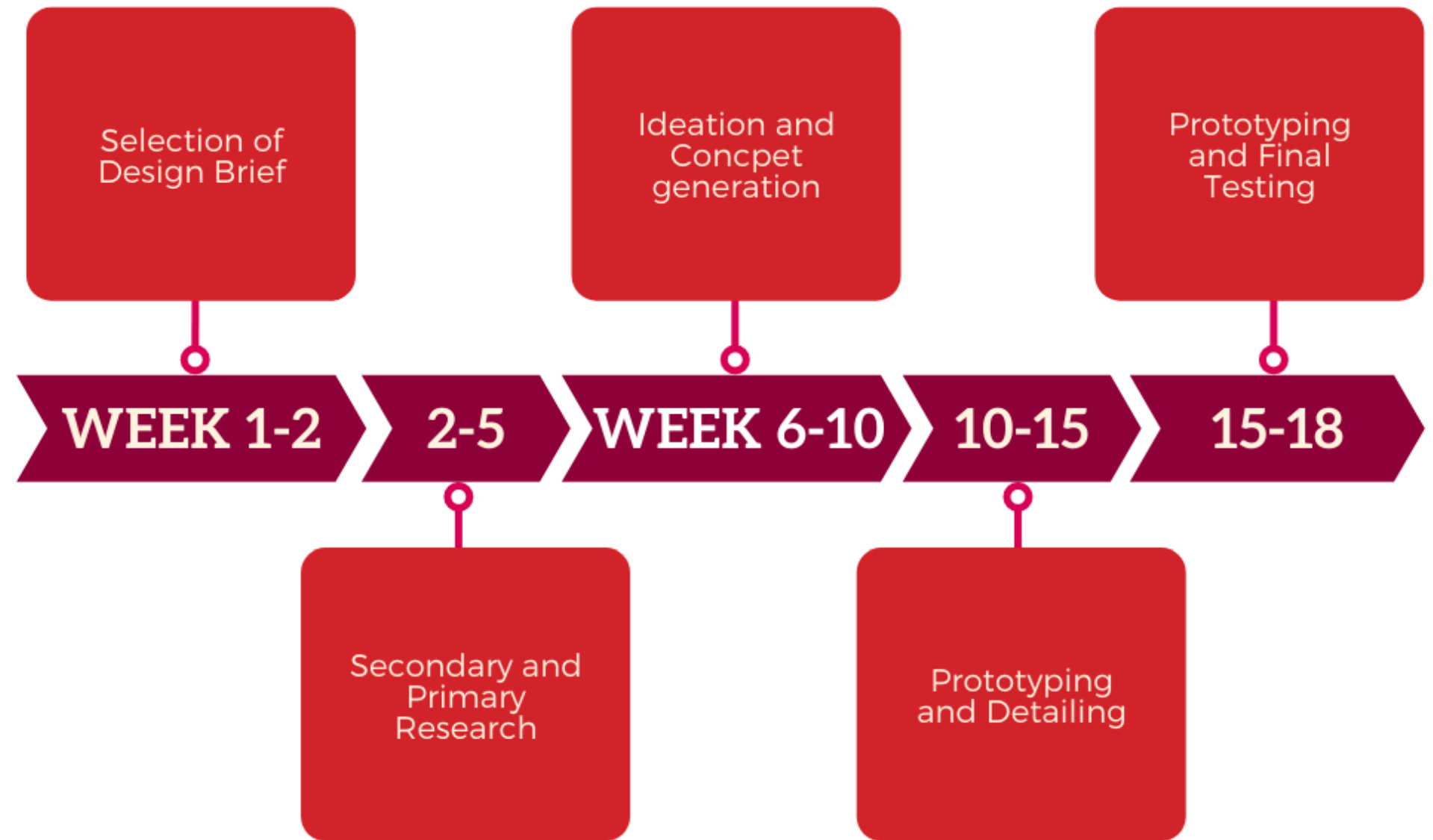
I'm from Ahmedabad, the city of foodies (and yes, I am a foodie). I am an upskill biomedical engineer with a BE from GEC Gandhinagar. Currently, as part of my doctoral studies, I am working on a gait trainer for stroke patients, and studying control aspects of the human upright posture



shail-jadav-248b66b4

SysIDEA Robotics Lab engages in a wide range of projects in robotics and allied areas that use basic engineering principles related to the dynamics, control theory, systems theory, and sometimes signal processing and data analysis. The projects often span the entire spectrum from mathematical theory, modelling, & analysis, computational simulations, table-top experiments & validations, and in some cases human subject studies. The lab thus has diverse interests and also attracts a diverse set of people from varying backgrounds and interests (including people who are passionate about experimental work, mathematical work, computational studies, specific applications, and making an impact on the field), and both discovery-driven and invention-driven projects are undertaken in the lab.

Time-line



A rough project timeline is shown here, which gives a pretty good understanding of what design process was followed in the project. Going from an idea in the head to execution and creating final prototype

Background

Robot scenario

When we think of robots, we might imagine sci-fi inspired, human-like automatons. While these types of machines are still mostly still fictional, there are many other types of robots operating in the world today. But what are robots? And how will they change the world?

Traditionally, the field of robotics centres on creating robots to perform simple or repetitive tasks at scale or to function in hazardous conditions where humans would otherwise be unable to work.

However, recent developments in machine learning and artificial intelligence means that we may see an increase in human-to-robot interactions in the future.

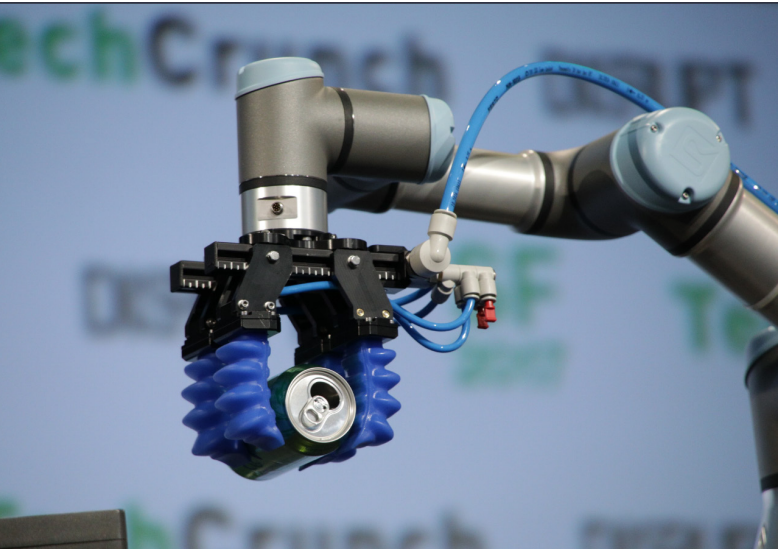
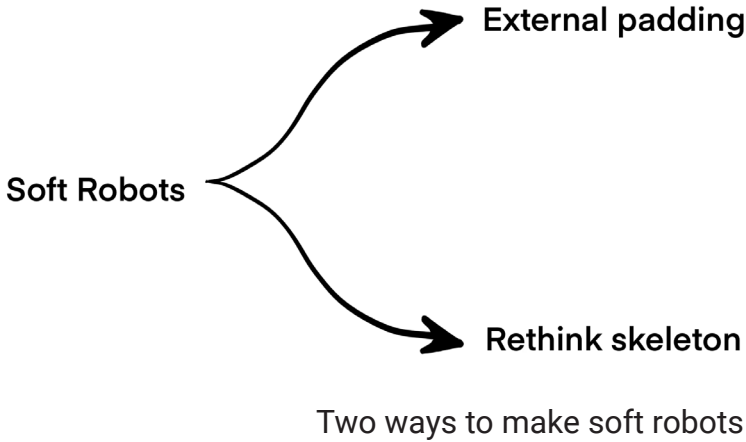
Introduction to Human-Robot interaction

Human-Robot Interaction (HRI) is a field of study dedicated to understanding, designing, and evaluating robotic systems for use by or with humans. Interaction, by definition, requires communication between robots and humans. Communication between a human and a robot may take several forms, but these forms are largely influenced by whether the human and the robot are in close proximity to each other or not.

Proximate interactions – The humans and the robots are co-located (for example, service robots may be in the same room as humans).

Social and Soft Robots

Social Robotics is the study of robots that are able to interact and communicate among themselves, with humans, and with the environment, within the social and cultural structure attached to its role. This covers a broad spectrum of topics related to the latest technologies, new research results and developments in the area of social robotics on all levels, from developments in core enabling technologies to system integration, aesthetic design, applications and social implications. It provides a platform for like-minded researchers to present their findings and latest developments in social robotics, covering relevant advances in engineering, computing, arts and social sciences.



Soft robotics is a subfield of robotics that concerns the design, control, and fabrication of robots composed of compliant materials, instead of rigid links. In contrast to rigid-bodied robots built from metals, ceramics and hard plastics, the compliance of soft robots can improve their safety when working in close contact with humans.

Problem Statement

Series Elastic Actuator

In contrast to the conventional actuation, which contains rigid gears that transmit the force/torque to the load which is proportional to the motor torque, which is also proportional to the current flowing through it.

Evidence from biomechanics research suggests that to replicate human-like control of a robot it is necessary to replicate tendon's series elasticity which allows muscle to act in an optimal range of its force-length and force-velocity curves to achieve work and power amplification.

There are lots of applications of SEA for quadruped robots, biped robot, dual arm robots and wearable robots, have demonstrated that SEA is the promising actuator system.

Introduction to Series Elastic Actuator (SEA)

SEA is basically the practice of utilizing elasticity in series with a prime mover, such as an electric motor or hydraulic cylinder, for actuation tasks. The term "series elastic actuator" commonly describes an integrated actuation unit that contains a spring whose deflection is measured for use in a closed loop force controller. However, generally the focus in the more general case of actuators is that they utilize one or more series elastic elements to intentionally improve the dynamic and control properties of the system. Further, the performance measure (and utility of the series compliance) will depend entirely on the specific task required of the actuation system.

Design Brief

Design and construction of a table-top robotic hardware setup that consists of a robotic manipulator (with atleast two degrees of freedom) that can be subjected to different force and environmental perturbations. The robot will be equipped with a learning control system that is expected to learn and adapt to the varying perturbations and the environmental conditions.

Design Process



Requirement Definition

- Design Research
- Competitive and adjacent landscape analysis
- Requirements and Architecture Development
- IP investigation



Concept

- Design Studies
- POC
- Concept Validation
- Usability testing
- Architecture and requirement refinement



Design

- Industrial Design Detailing
- Detailed electrical, Mechanical design
- Prototyping
- Subsystem Testing



Test and Validation

- Final Design to Prototype
- Design Detailing



Prototyping

- Test plan development and execution
- Design Refinements

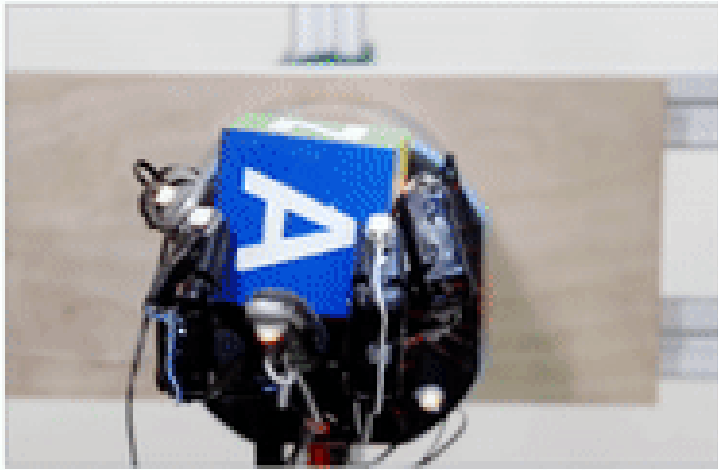


Manufacturing

- Manufacturing build test support
- Regulatory process completion

Design Research

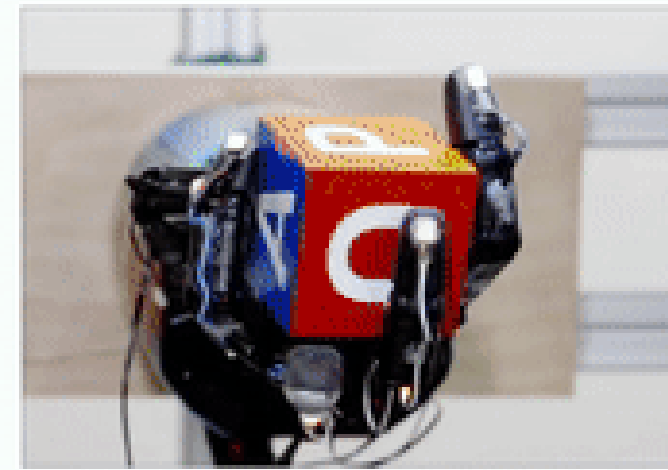
Design research has become more important in business, as industries move towards designing high-quality products. Design research is not about how a product looks (that's called product design). It is a research approach that uses curiosity to look at the client themselves and create a broad understanding of their perspectives.



FINGER PIVOTING



SLIDING



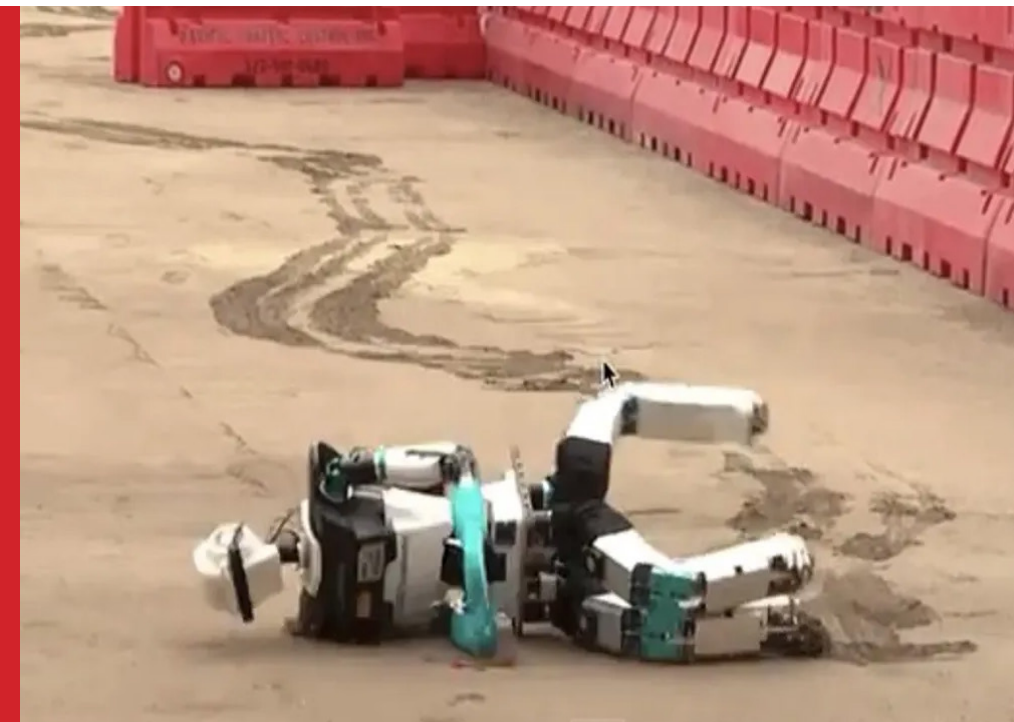
FINGER GAITING

The current state of dexterity in robots and its future

Robots can't orient a hand tool properly — say, lining up a Phillips head screwdriver with the grooves on a screw, or aiming a hammer at a nail. And they definitely can't use two hands together in detailed ways, like replacing the batteries in remote control.

To even come close to rivaling what our hands are easily capable of, robot hands need better agility, reliability and strength.

Dexterity in robotics is at a nascent stage but is expected to improve significantly



On dexterity and dexterous manipulation

Author- Raymond R. Ma;
Aaron M. Dollar
Year- 2016

Dexterity in general refers to the variety of tasks that the system can complete, and also how well it can perform those tasks, though the means by which that can be quantified is still open to interpretation. Though a standard industrial manipulator with a 6–7 degree of freedom arm and simple grasper has proven to have a great deal of utility, we have detailed many scenarios where a dexterous end effector is crucial to compensate for functional shortcomings or in the presence of obstacles.

Muscle Biomechanics

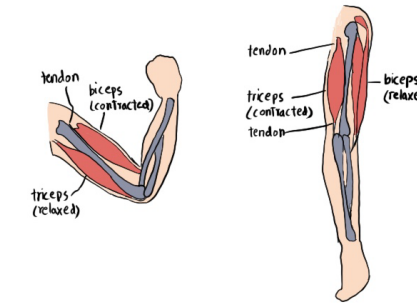
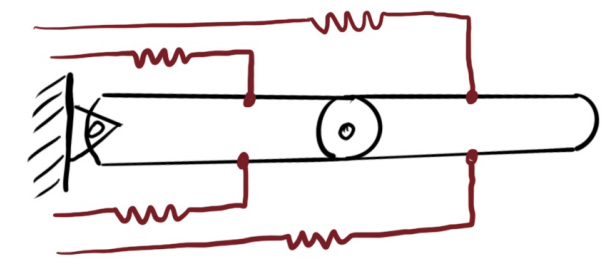
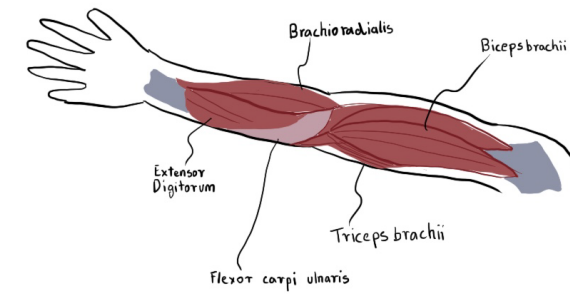
The skeletal muscles could be organized in two different components based on their function and architecture namely:

The Series Elastic Component (SEC)

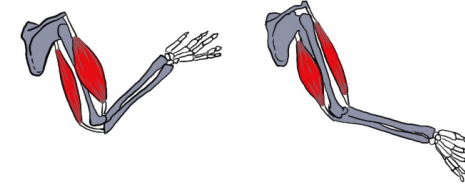
The Parallel Elastic Component

The series and parallel elastic component are defined in parallel relation to their arrangement with the contractile components, the later arranged in line with the contractile components. The parallel elastic component is suggested to consist

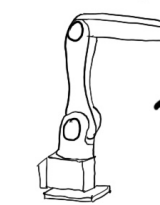
of the membranes surrounding the contractile components which includes the sarcolemma, sarcoplasmic reticulum, the perimysium and the epimysium, while the series elastic components reside in the tendons and aponeuroses.



Exaggeration



technical systems

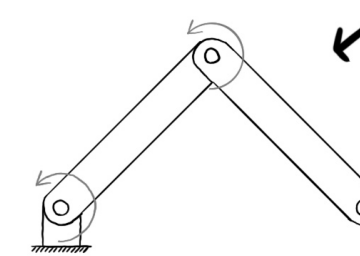


human extremities

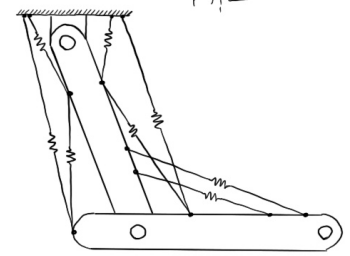


kinematic similarity: open kinematic chains

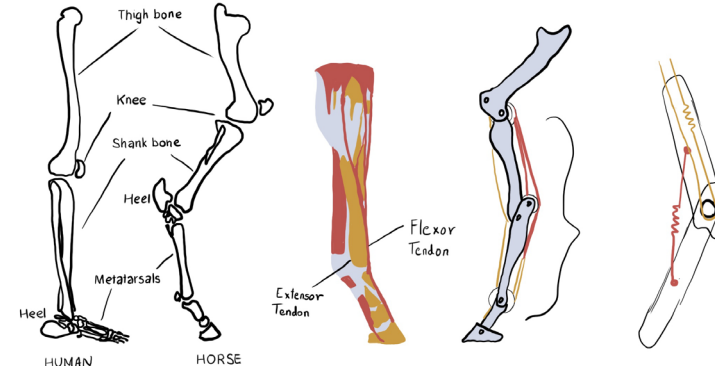
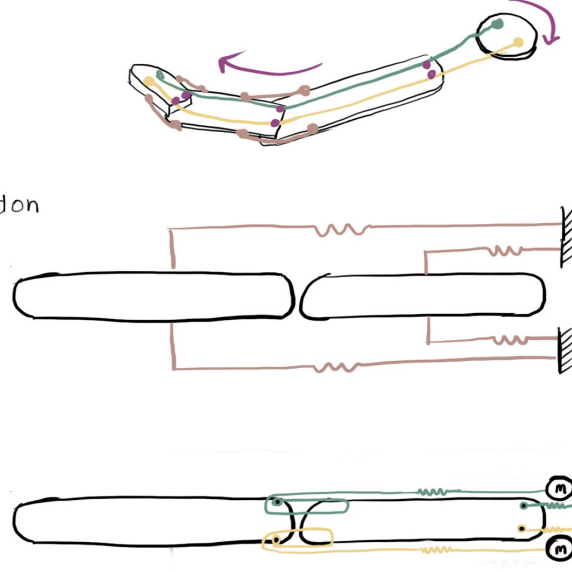
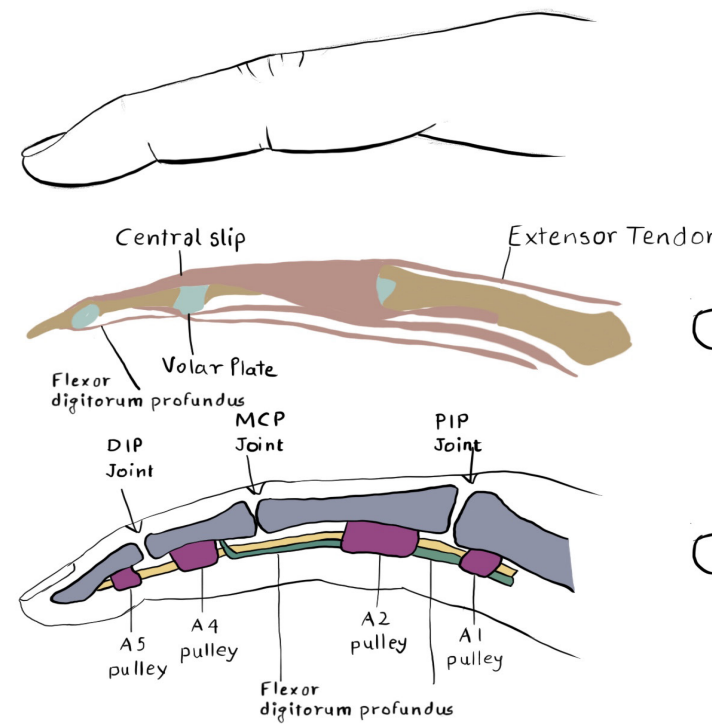
abstraction



classical system



bioinspired system



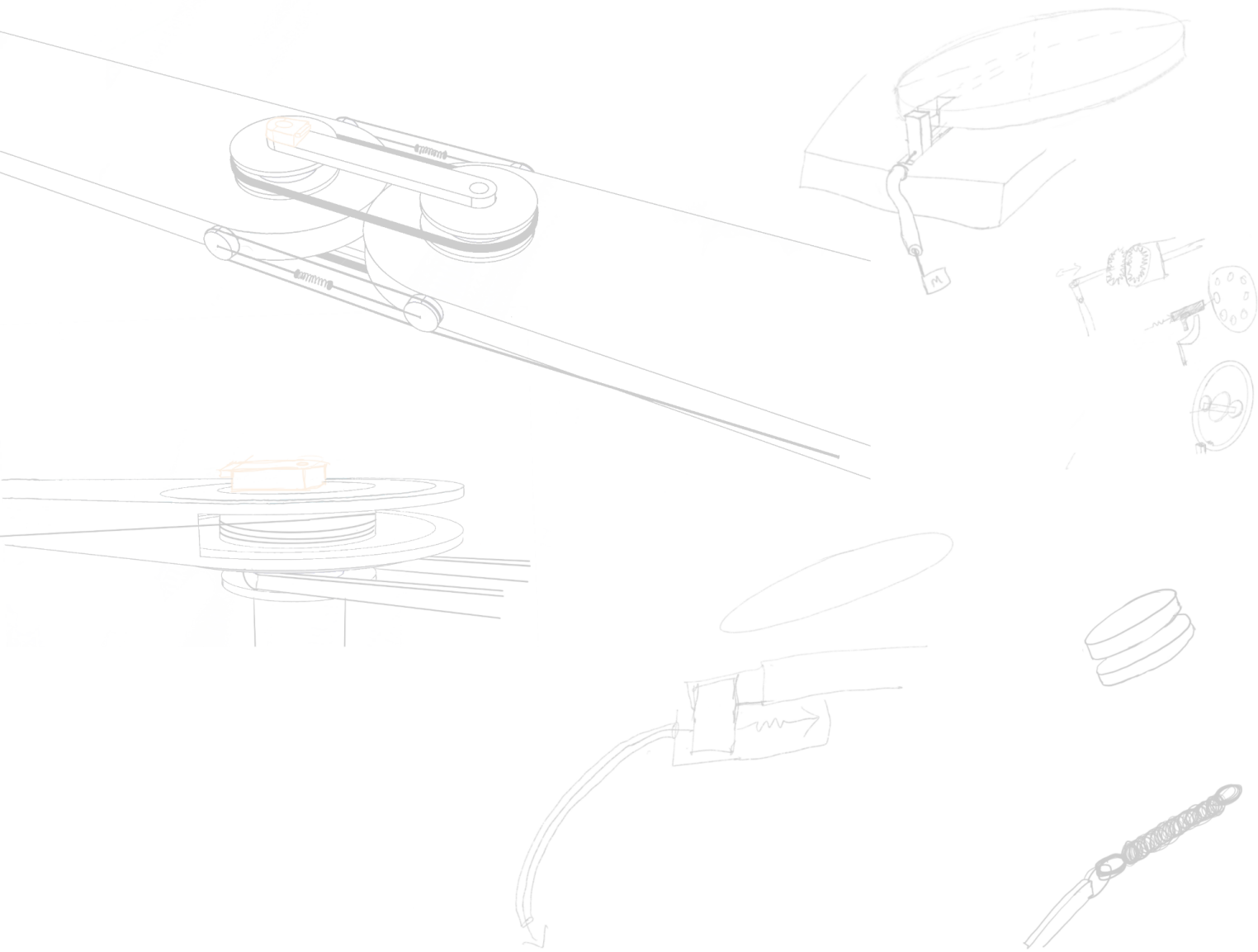
- Relation can be drawn between nature's best runner and human leg.
- Abstracting & simplifying structure, we can get an efficient leg for robot

Passive Compliance

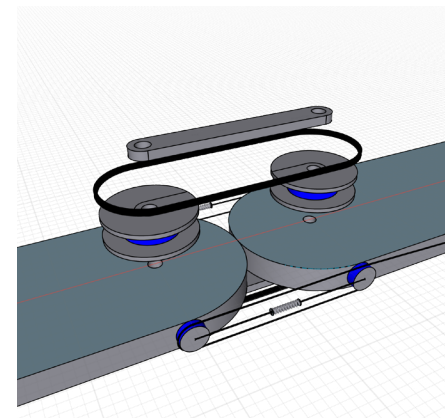
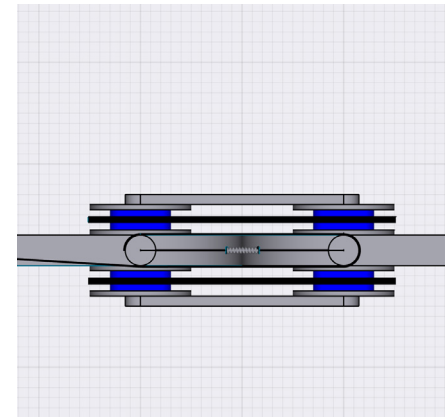
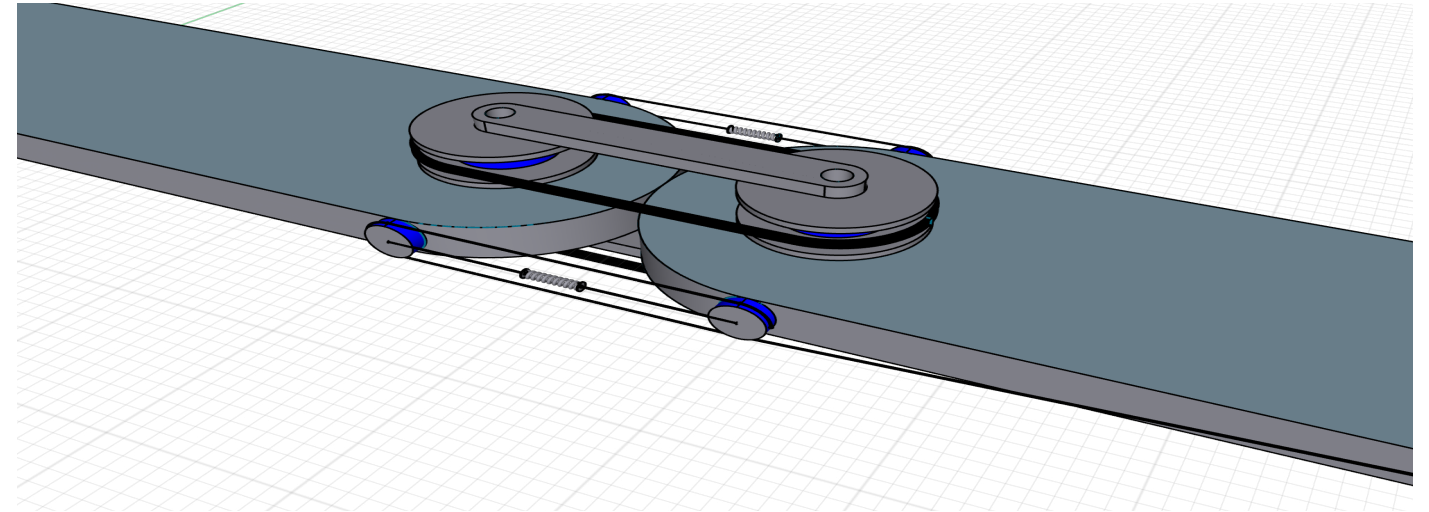
- *Predetermined, stays active in the background
- *Plays important role of providing safety
- *Inherent to structure of robot
- *Important when human-robot collaboration are intended

Ideations and Concepts

This stage in design process is about ideation sketches, Design studies, and concept validation.



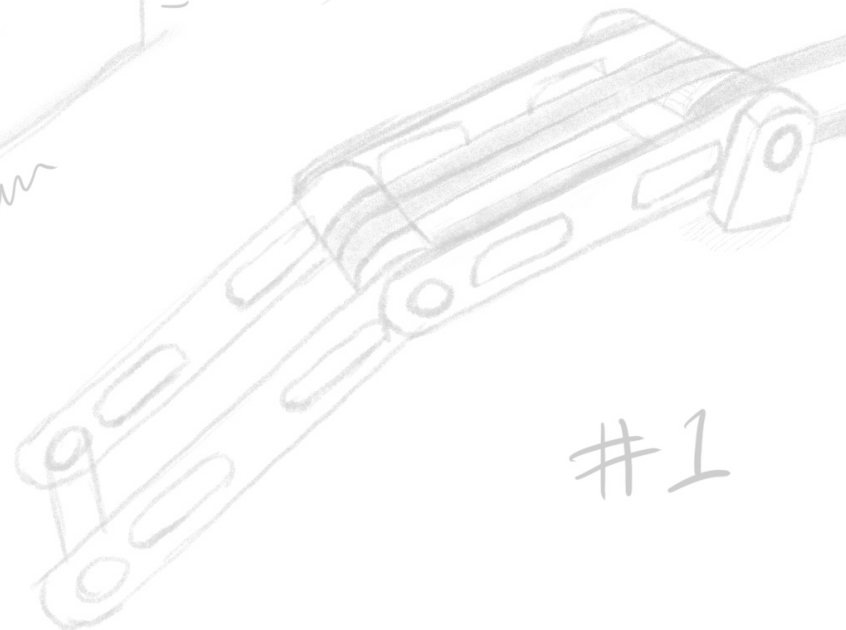
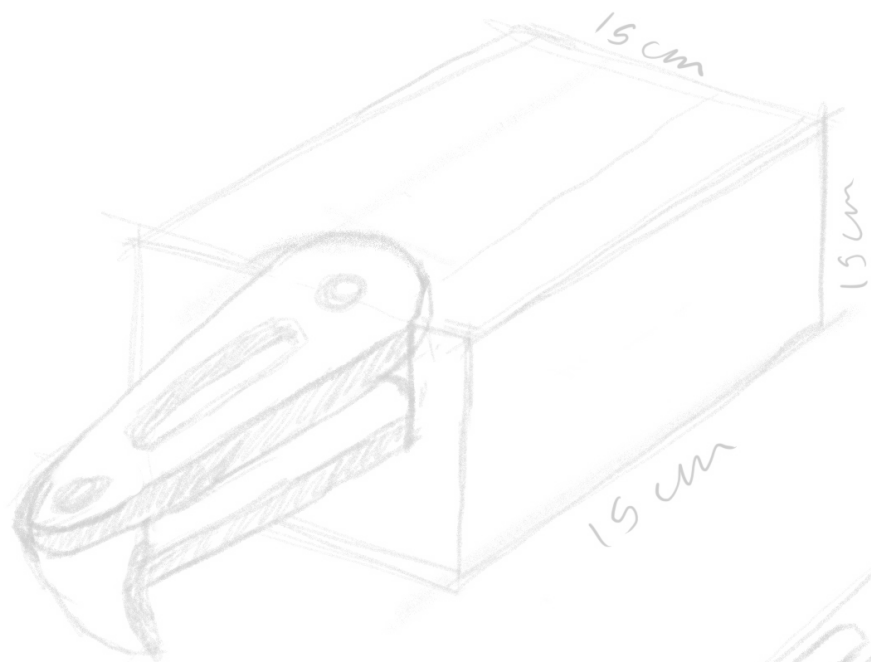
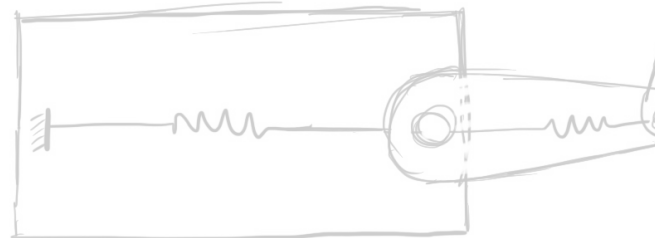
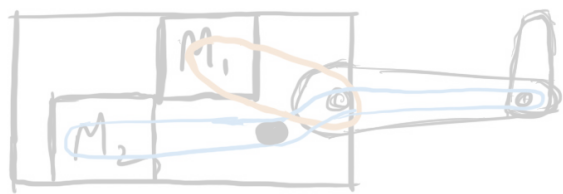
concept 1



Unique joint mechanism with rolling surfaces

This is a planar mechanism but it is highly unstable in the vertical direction of the link. Cable driven system allows high torque transfer from motor to the link.

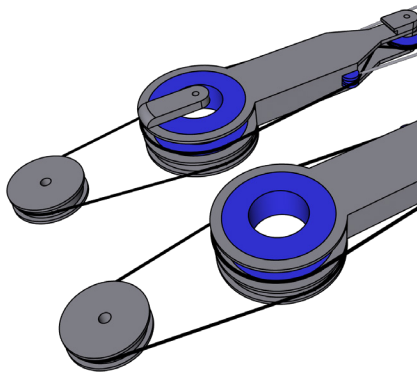
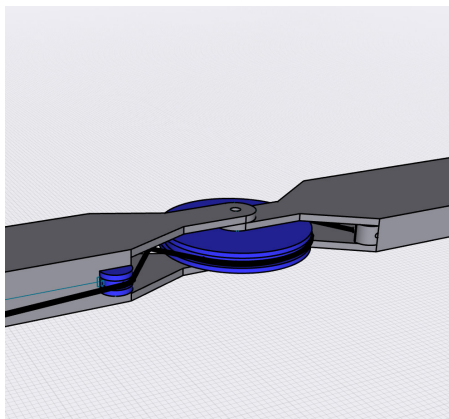
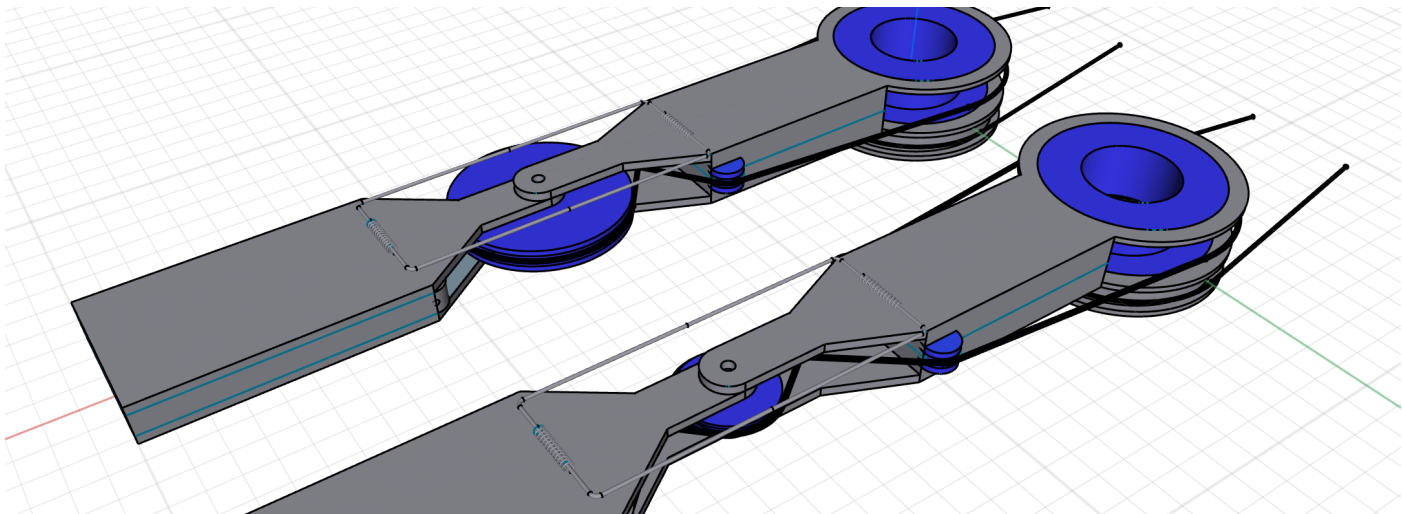
Some of the negative points of this design include: cables being exposed which can compromise safety, limited range of motion, cable slack on Parallel Elastic Element, and encoder positioning being complex.



#1

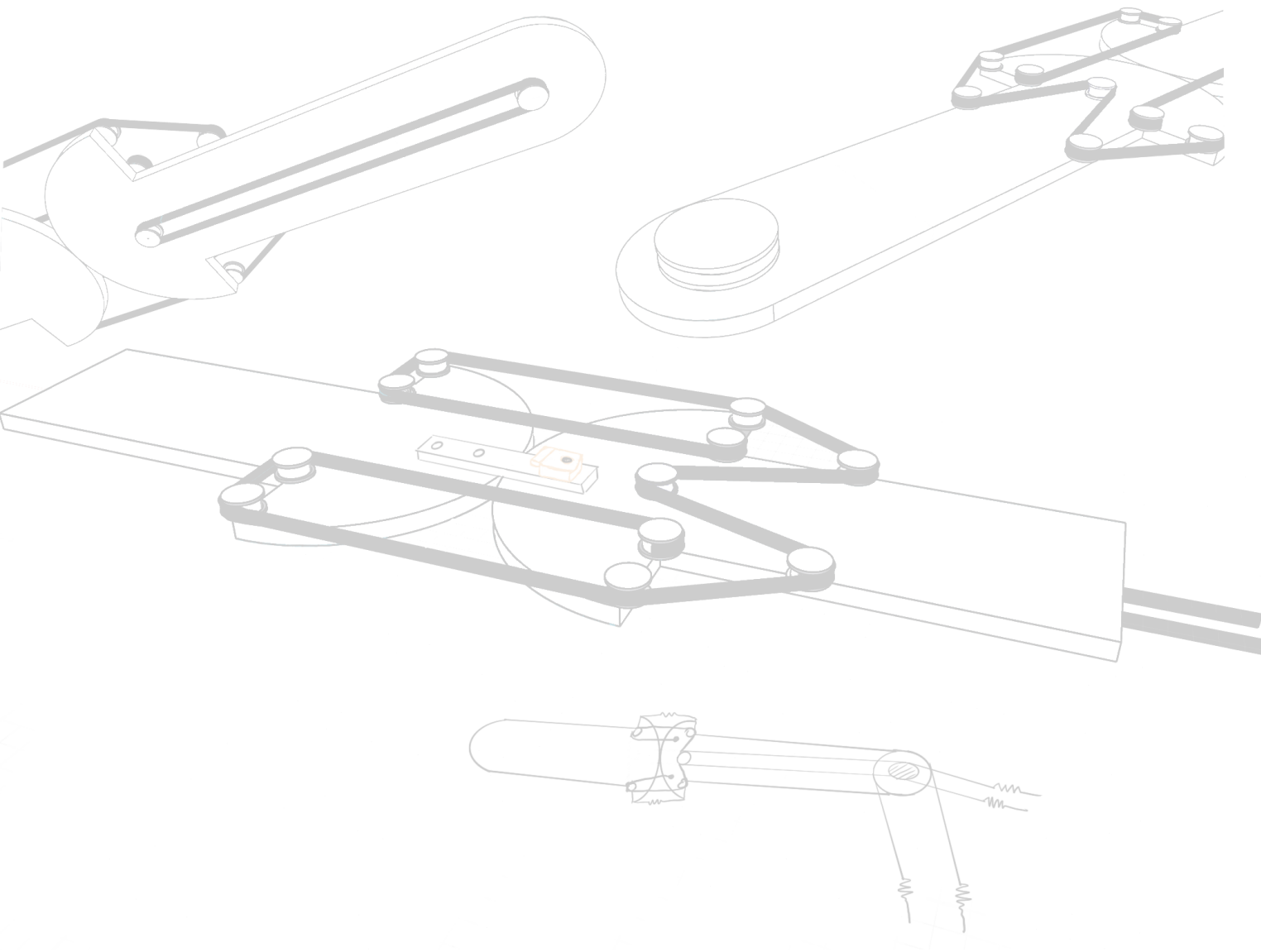
Aprox motor dim
12 cm
4.5 cm

concept 2

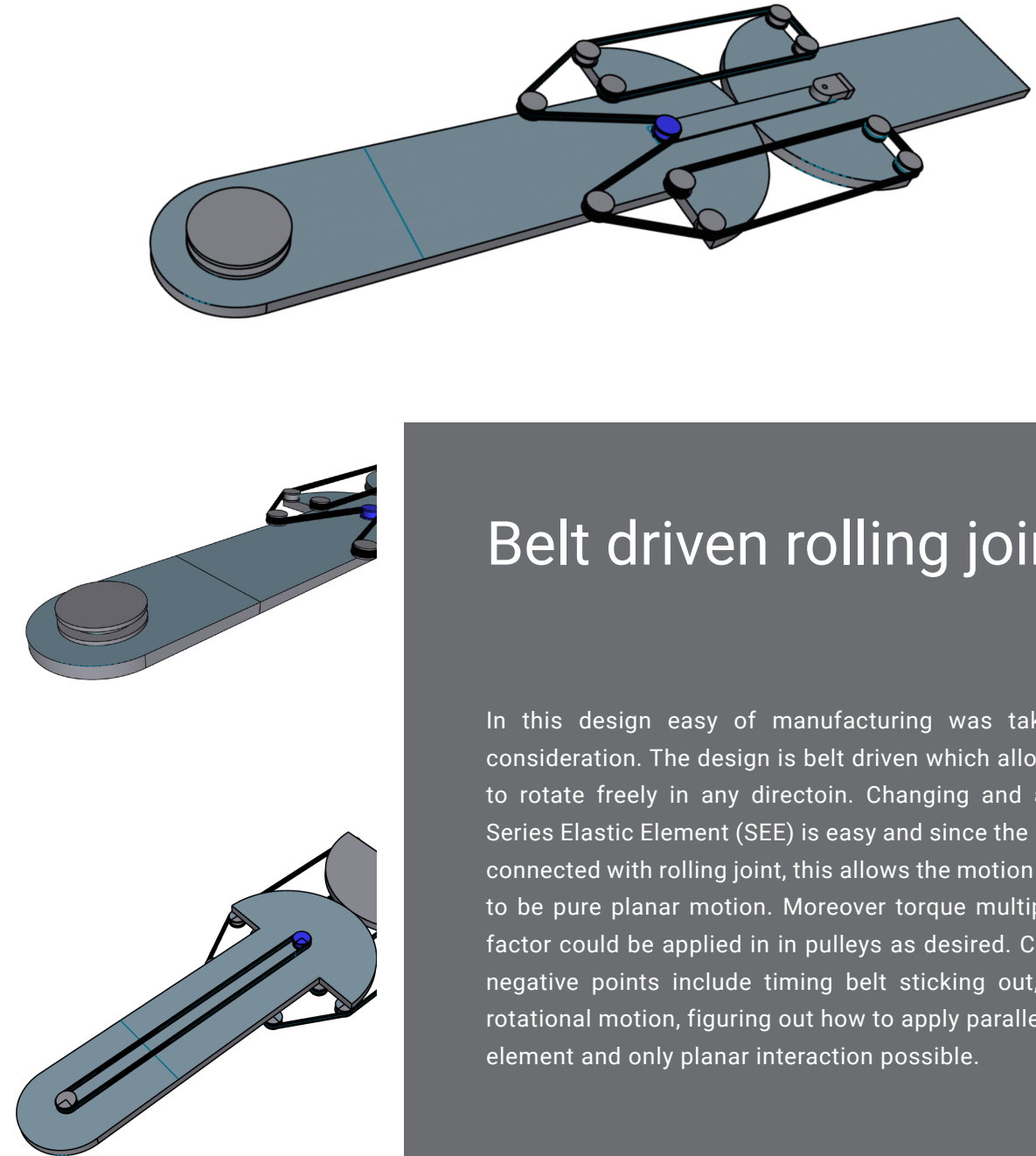


Concept using cables for high torque output

The design is cable driven which limits link's motion. Changing and applying Series Elastic Element (SEE) is a bit difficult and take more steps. The motion of robot is pure planar motion. Moreover torque multiplication factor could be applied in in pulleys as desired. Some of the arguments against this design are as follows: Placement of parallel elastic element is complex and has a high probably of salacking. Motion of link two is limited to less than 360 degrees. Manufacturing would require complex machining of metal and it is hard to accommodate series elastic element as well.

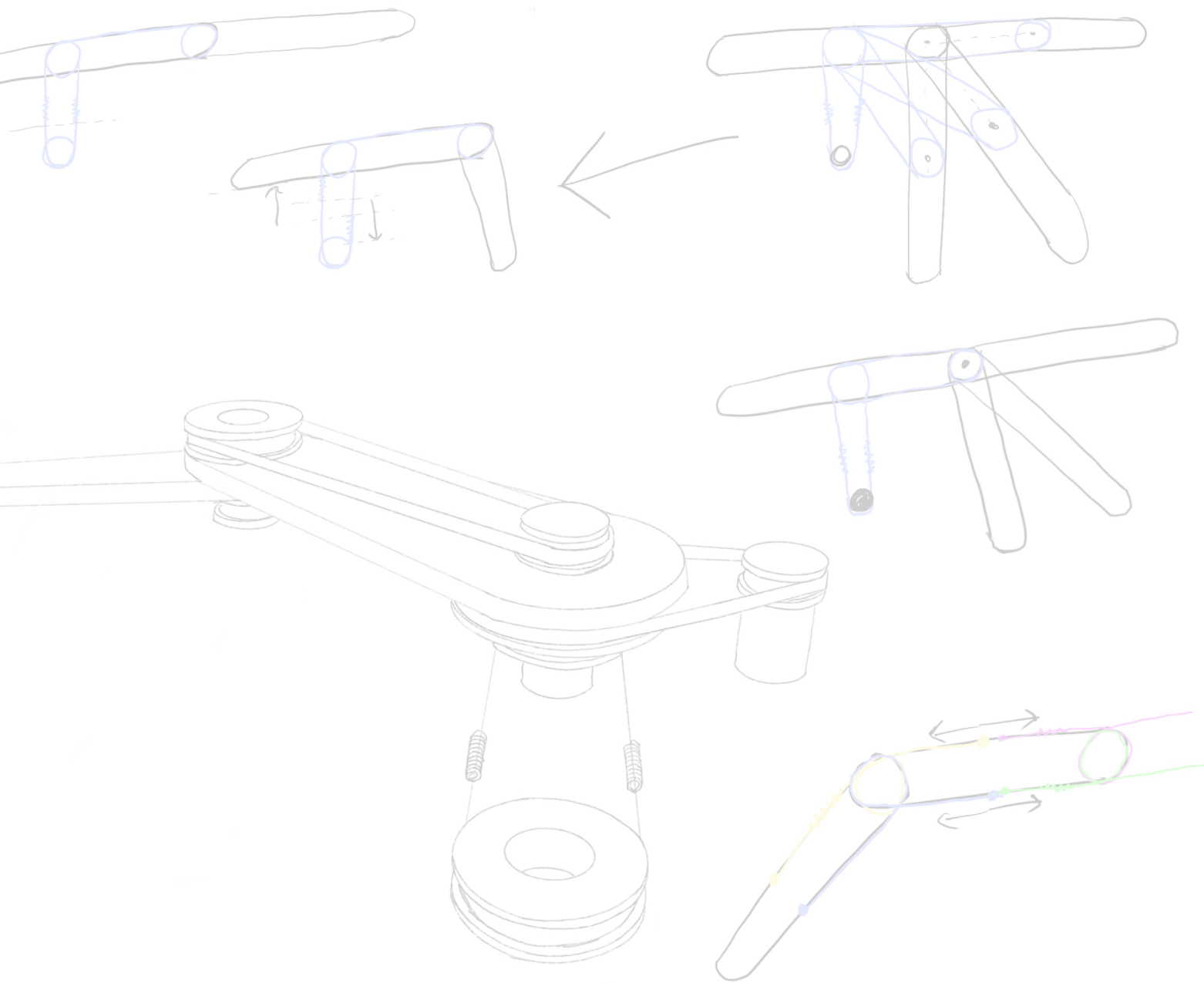


concept 3

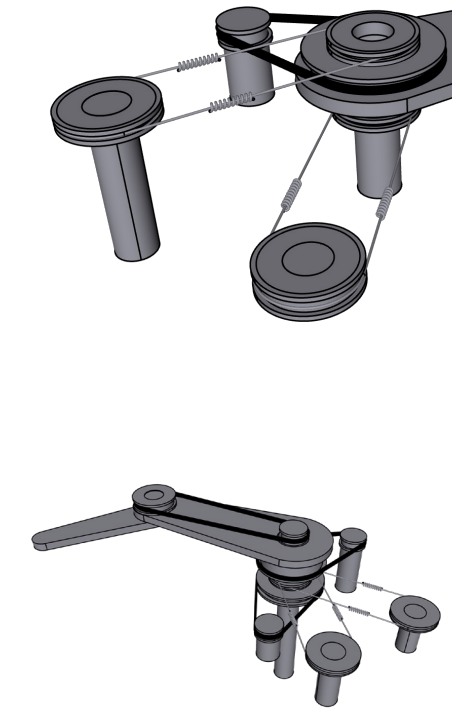
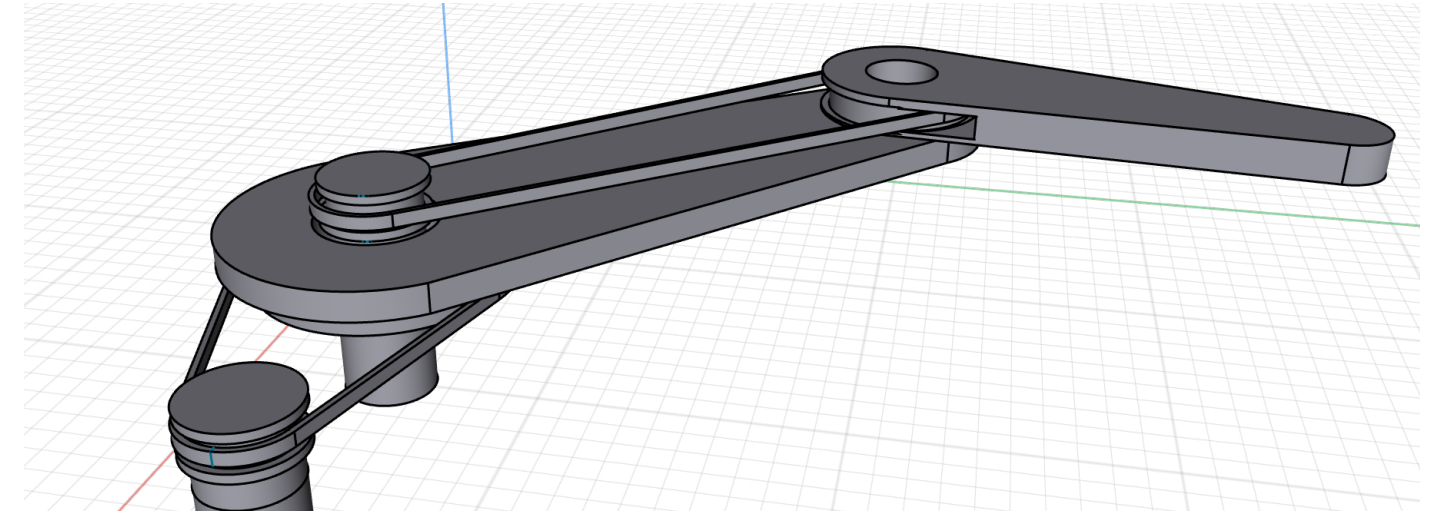


Belt driven rolling joint

In this design easy of manufacturing was taken into consideration. The design is belt driven which allows links to rotate freely in any direction. Changing and applying Series Elastic Element (SEE) is easy and since the links are connected with rolling joint, this allows the motion of robot to be pure planar motion. Moreover torque multiplication factor could be applied in pulleys as desired. Couple of negative points include timing belt sticking out, limited rotational motion, figuring out how to apply parallel elastic element and only planar interaction possible.



concept 4

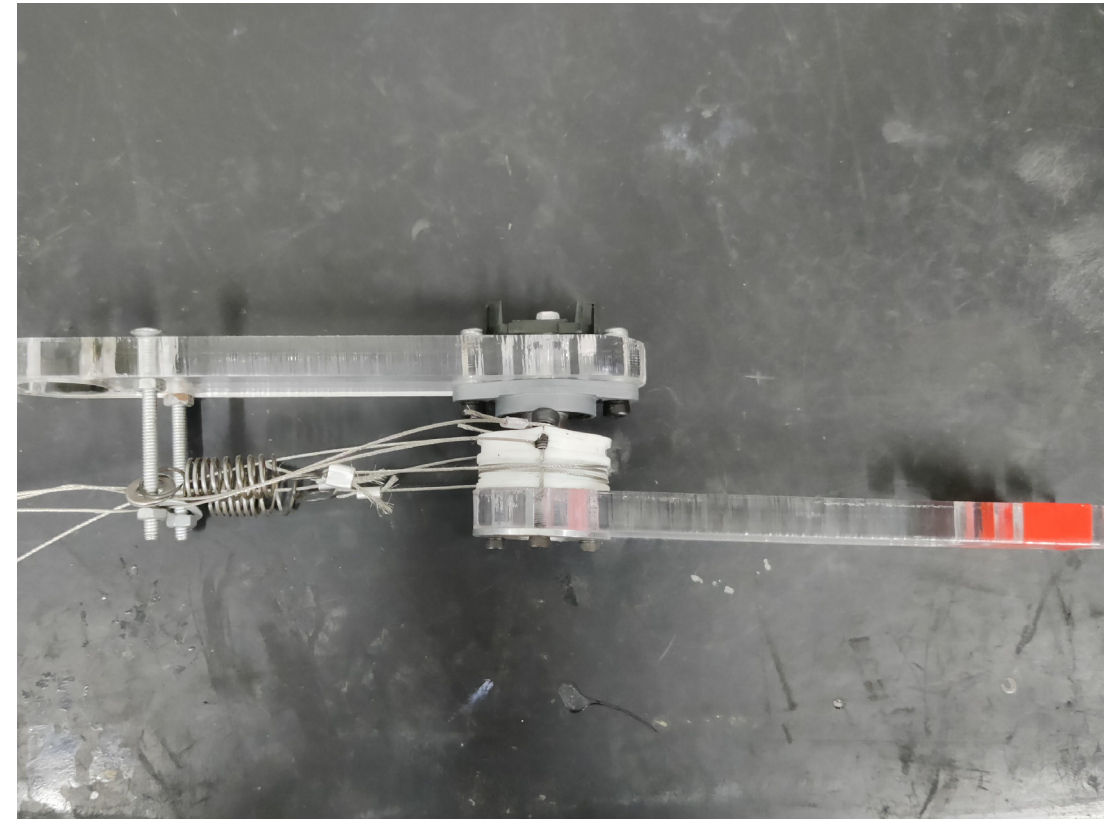


Remotly driven links

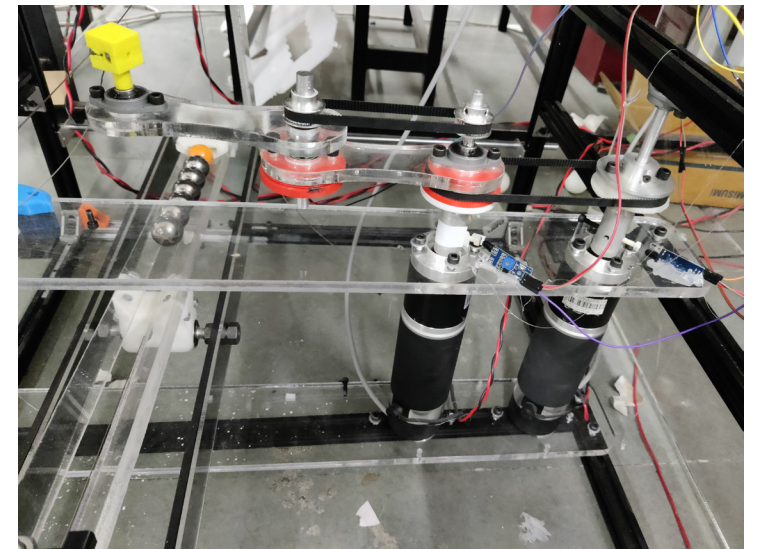
In this design I have tried and succeded to to drive link connecting second arm via link connecting the first arm, allowing it to be driven remotly. This allows the robotic arm to have less inertia while in motion. As a result, this not only allows robot to operate at higher speed but also helps reduce load on motor allowing it to use less energy.

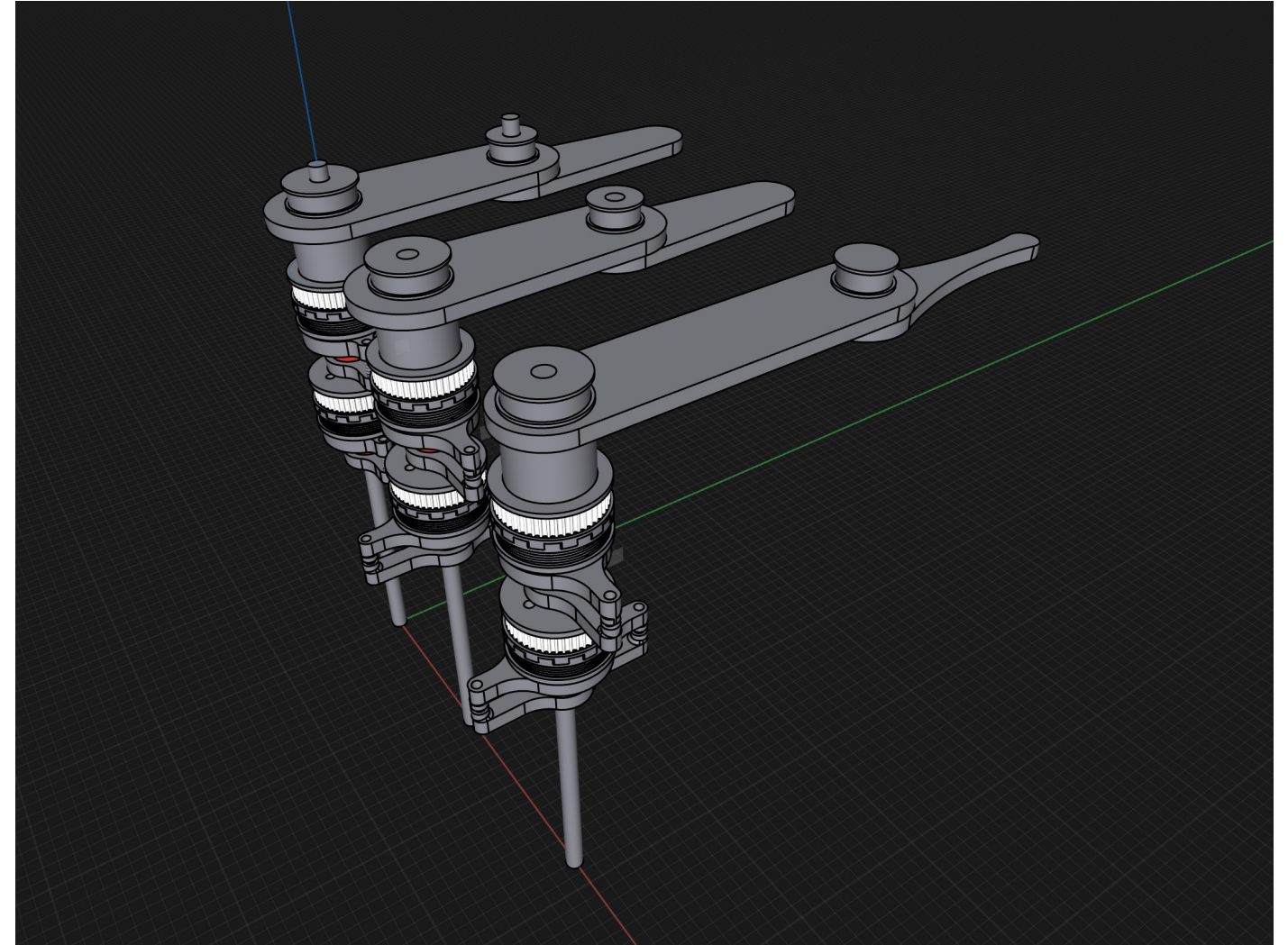
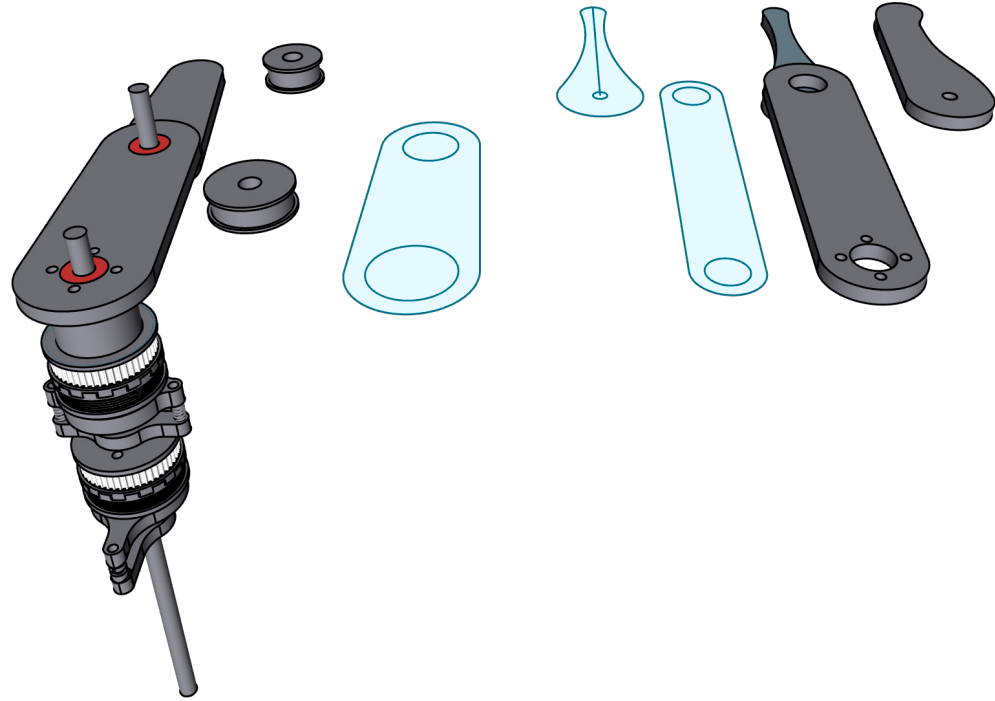
Prototyping

This stage in design process is about Industrial Design Detailing, Detailed electrical and mechanical Designs, Prototyping and subsystem testing



Exploration (material, mechanism and setup)





Initial Ideas  Refined models



Tool

Exploded view of tool that is used to run simulations and measure forces acting at tip of robotic arm

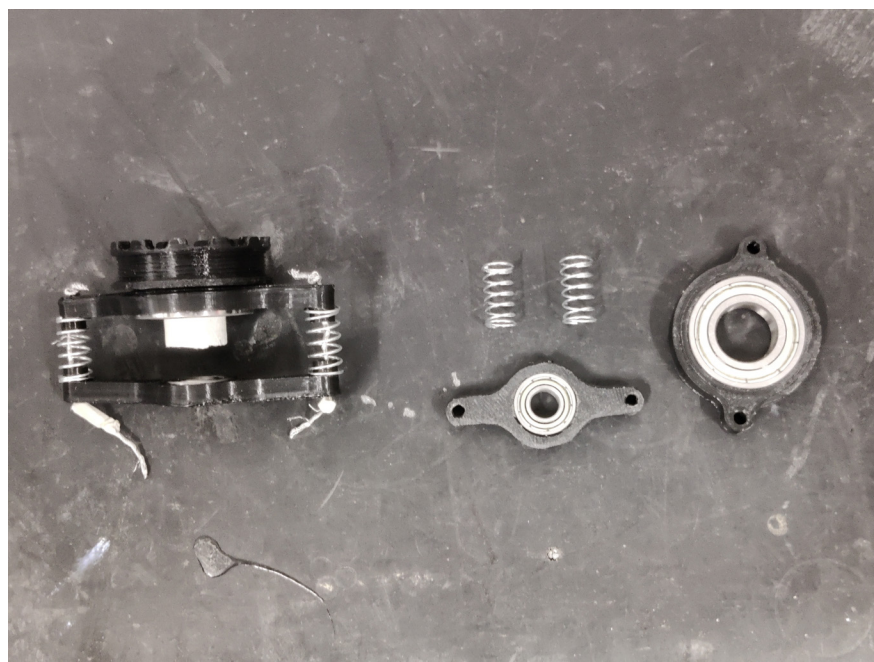
Subsystem testing

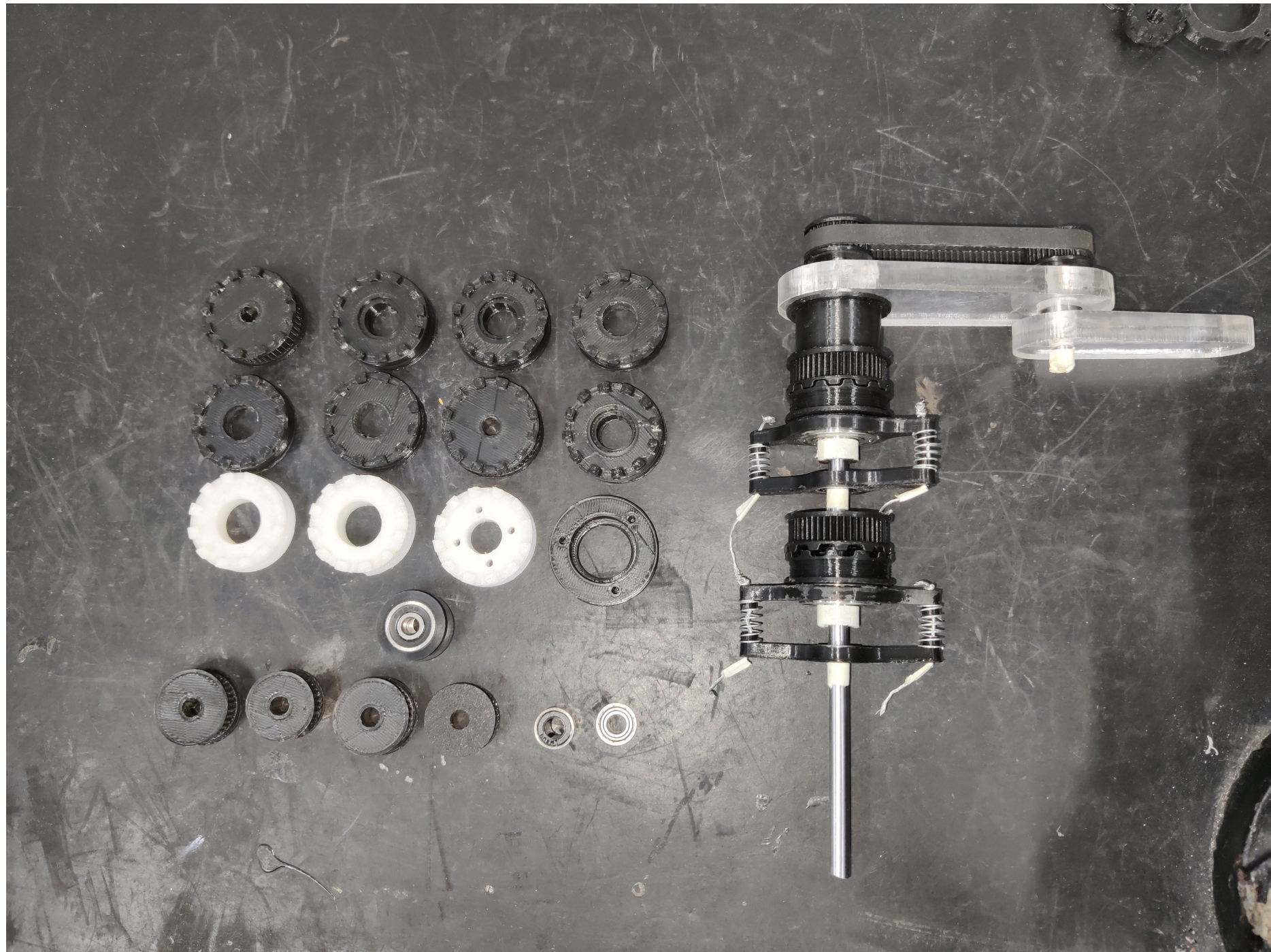
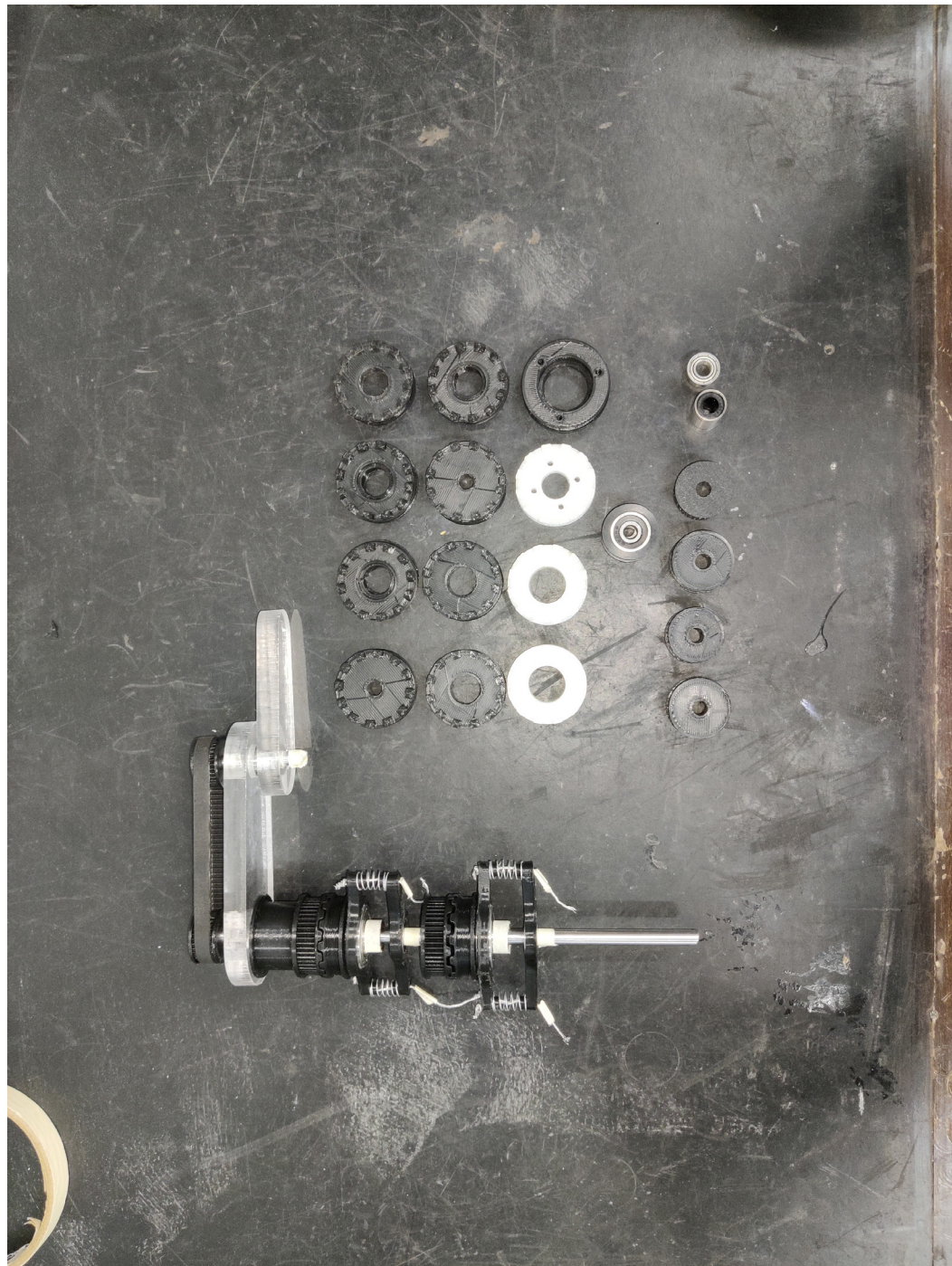
Testing of shaft thru which all power is transmitted and where the magic happens

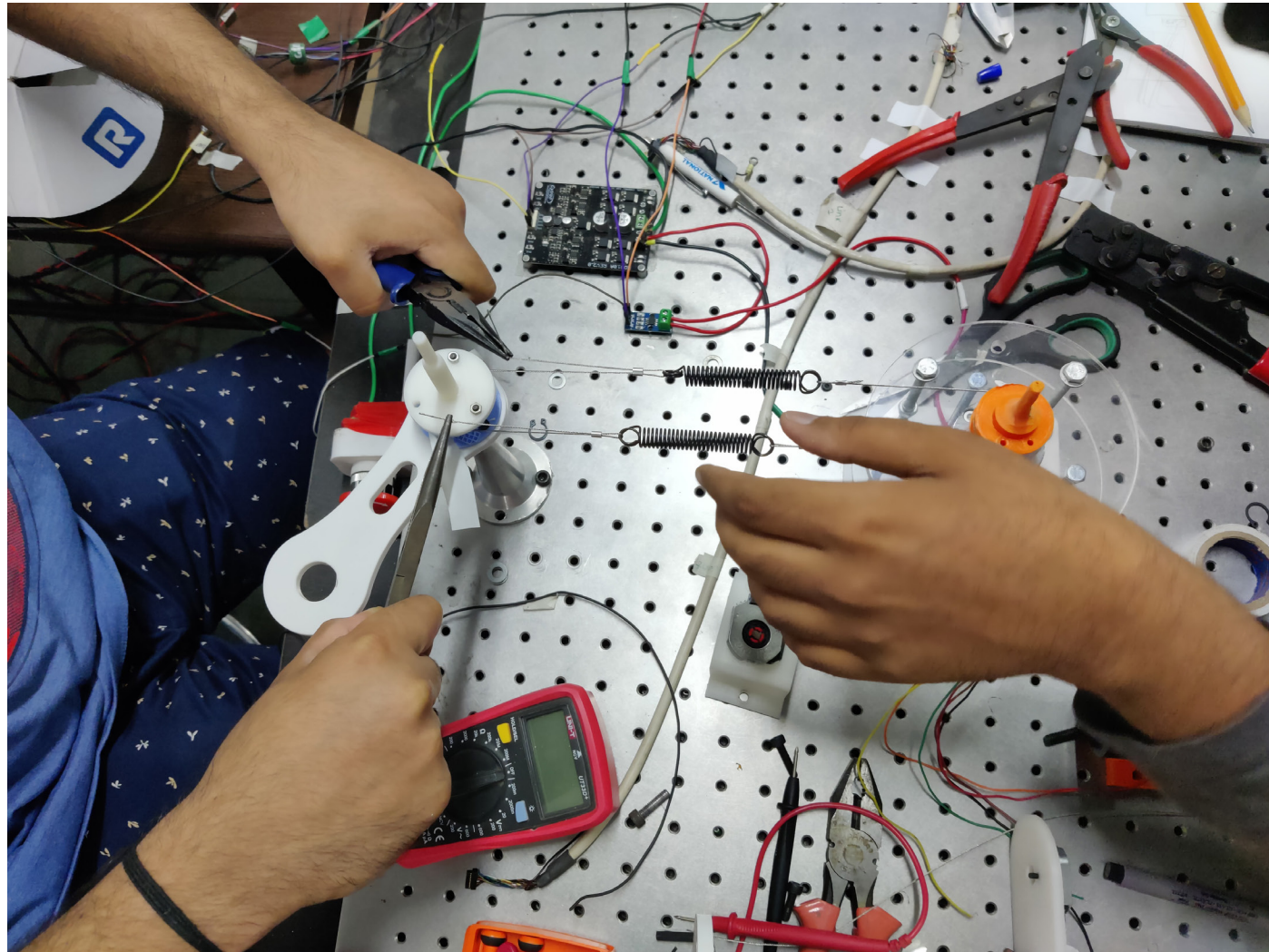


Clutching Mechanism

Unique Clutching mechanism was developed to engage and disengage PEE in addition to SEA.

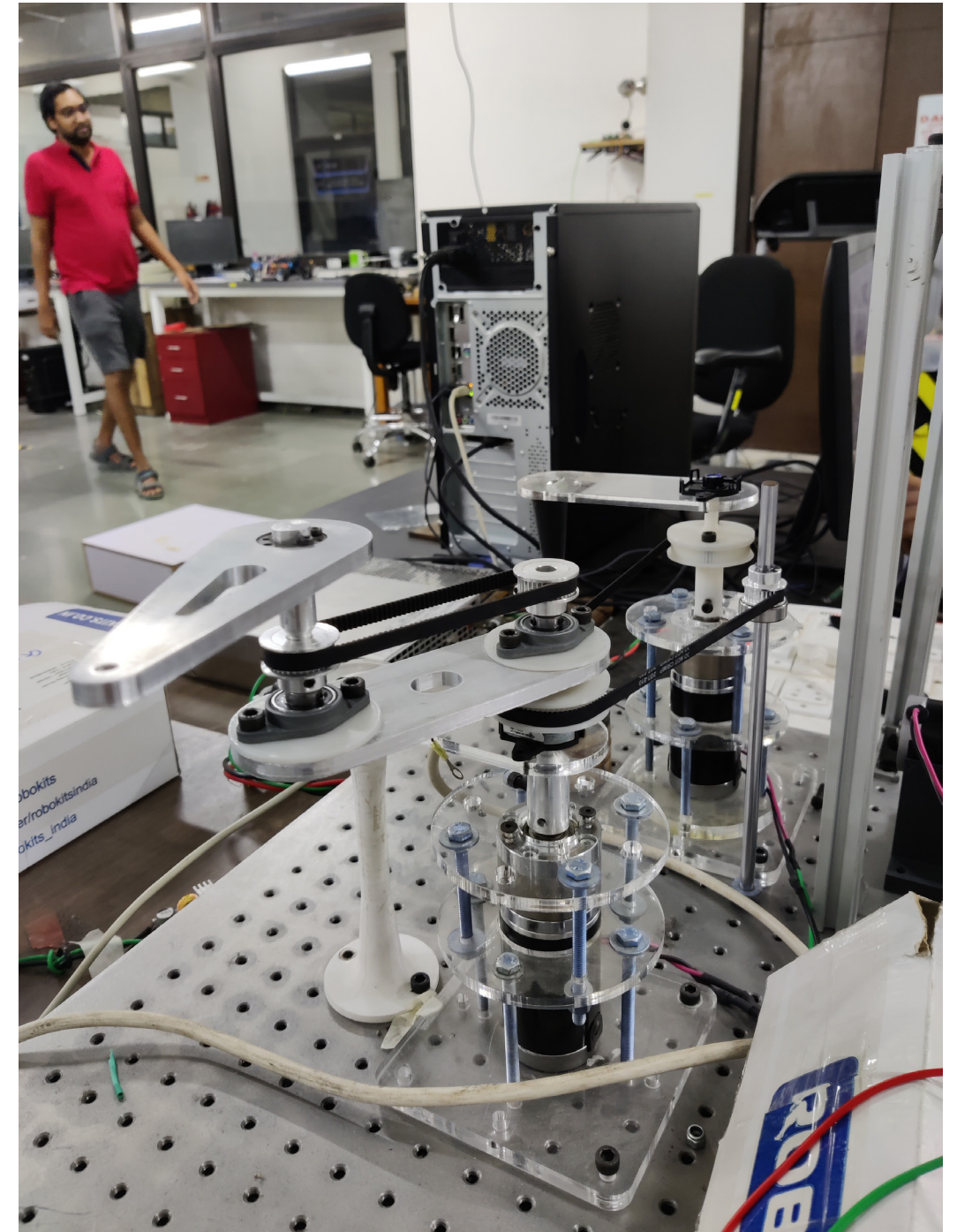


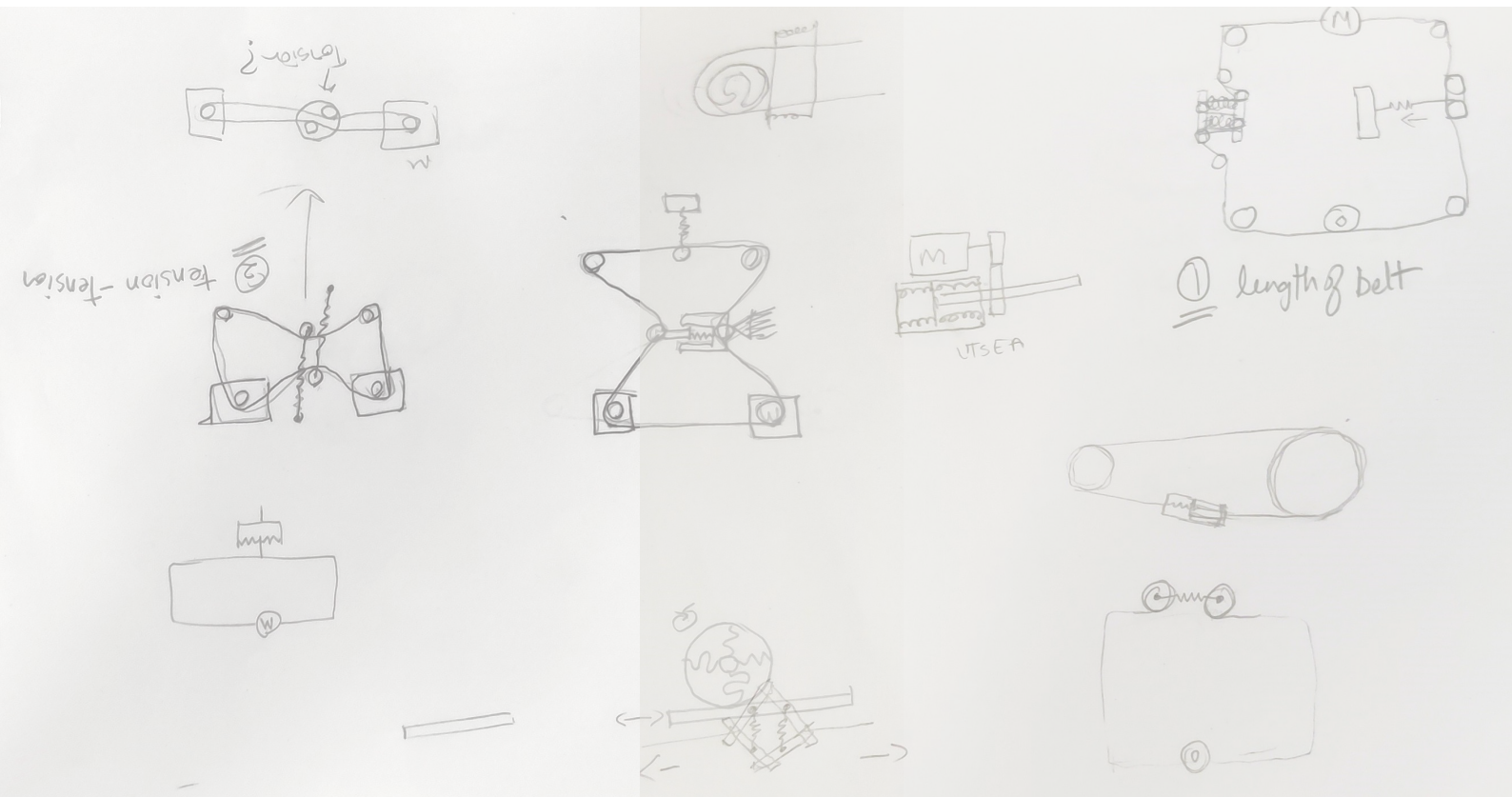




Testing of controls and mechanisms of the robotic setup. It is done on the optical breadboard so it can be quickly assembled and disassembled, which is a requirement in the testing phase of the design process

T E S T I N G

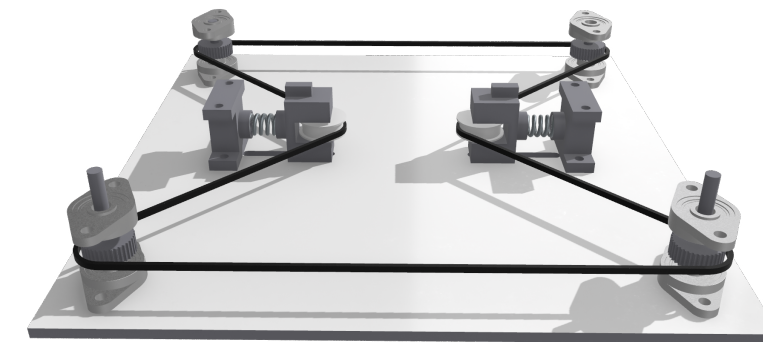




In general, actuators are built to be as stiff as possible to increase the bandwidth. When a robot works in a structured environment, its automation is easier than in a non-structured environment in which case its modeling is quite difficult and presents a high computational effort. To overcome this difficulty, series elastic actuator (SEA) has been applied in compliant robotic grasping. Unlike rigid actuators, a SEA contains an elastic element in series with the mechanical energy source. Such an elastic element gives SEAs tolerance to impact loads, low mechanical output impedance, passive mechanical energy storage, and increased peak power output. The spring has to be able to support the loads, but it cannot be too stiff; otherwise, system impedance will be high.

Overview: Physics are the Bottleneck

Actuator Dynamics limit possible behaviors. Actuators are not ideal force, torque or motion sources. They are complex systems that have intrinsic dynamics, and these dynamics must be considered during design of the mechanism and controller. We will use electric motors for most examples in this paper, as they are most common in robotic systems; and electric motors, with a transmission, all have reflected inertia, which is the effect of accelerating actuator components to high speeds through a transmission. This reflected inertia combined with torque limits on the motor will limit the possible acceleration of the actuator. For geared electric motors, the reflected inertia can be sizeable, sometimes comparable to the inertia of the entire robot mass.

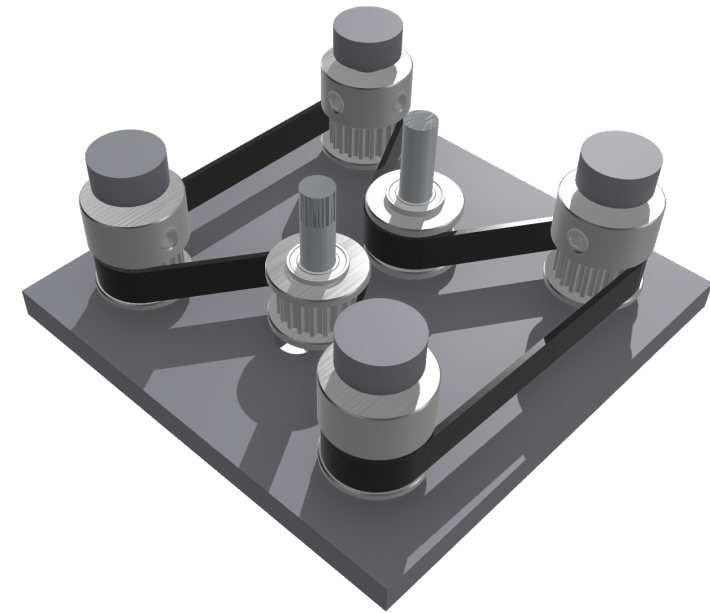
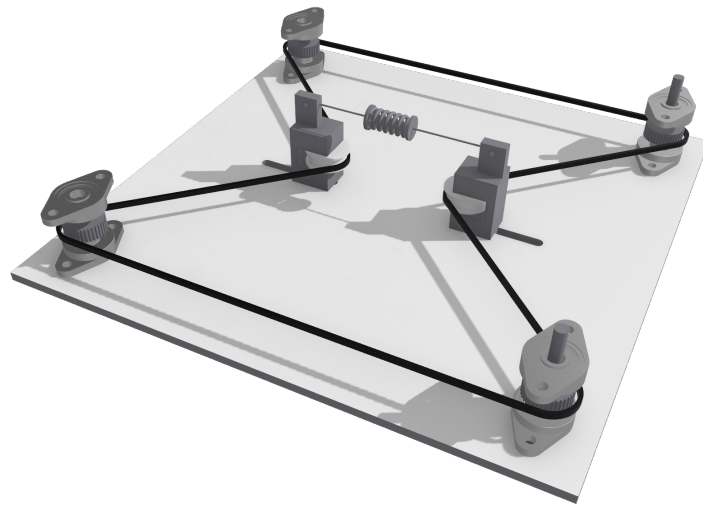
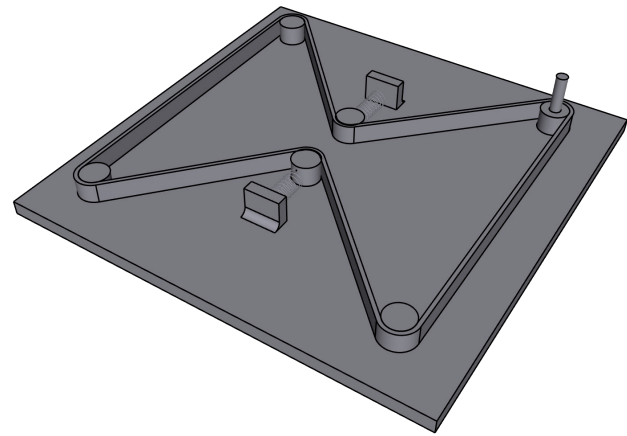


Design of Series Elastic Actuator

In the design of a series elastic actuator, many design choices are engineering trade-offs, helping some tasks while limiting others. Actuator series elasticity is particularly useful for physical interaction with uncertainty. In robot arms, for example, adding tuned and sensed physical compliance can improve their ability to behave stably when compliance is an important behavioral trait. In assistive prosthetics, careful control of applied forces is important for user comfort. Implementing force control is dramatically improved by using series elasticity to sense forces through deflections and to moderate force error from environmental interaction.

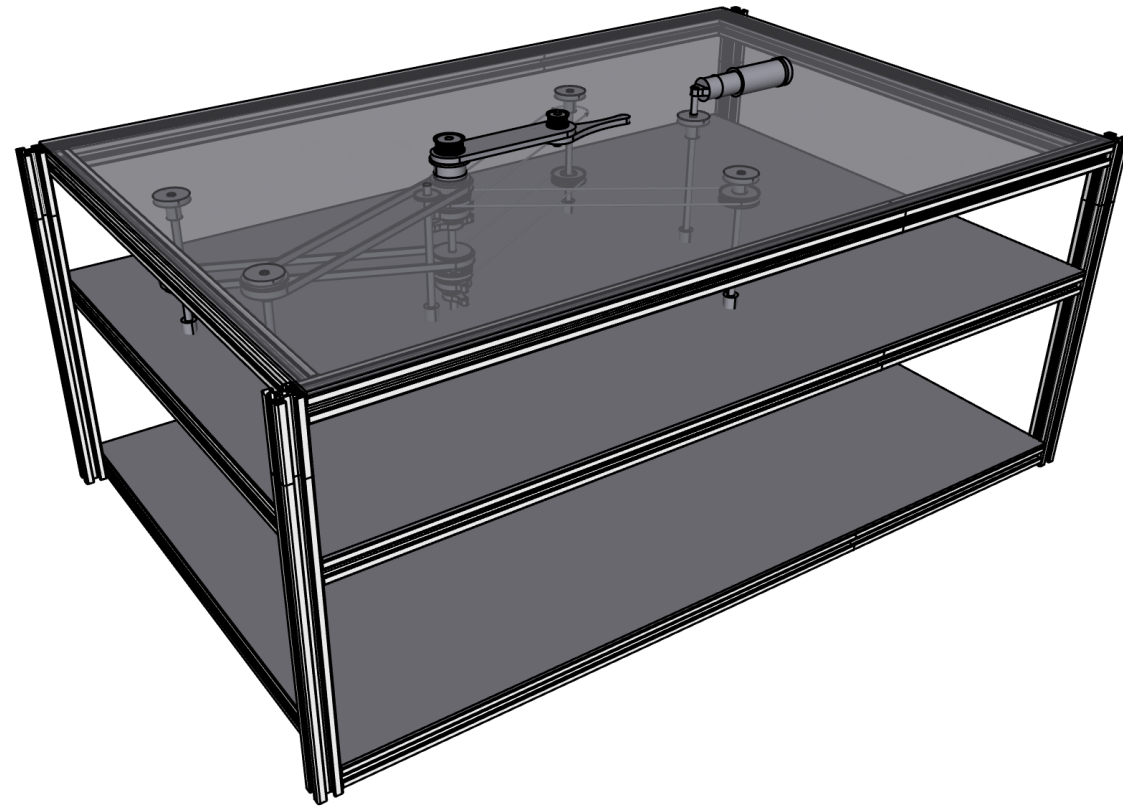
Evolution of design

Lo-Fi Cad Model → Detailed Cad Model → Scaled down and fir to constraints

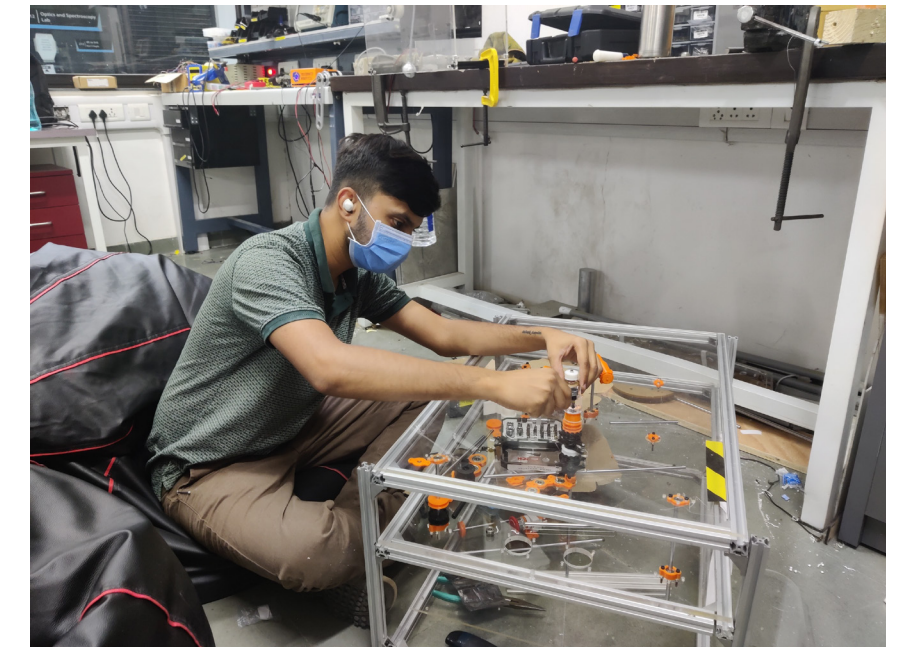


Final Prototype and Models

This stage in design process is about design of final prototype, design detailing, test plan development and execution, design refinement and manufacturing.



This design incorporates unique clutched elastic actuators (CEAs). Clutched elastic actuators use clutches to control the energy flow into springs. CEAs in exoskeletons, prostheses, legged robots and robotic arms have shown the ability to reduce the energy consumption and motor requirements such as peak torque and peak power. Because of those abilities, they are increasingly used in robotics. We categorize existing CEA designs, identify trends in those designs and provide a method to analyze their functionality. The main trend is that CEA designs are becoming more complex, meaning that the number of clutches and springs increases. Here we have tried to minimise number elastic components and packaged it in a different way which thinks of compactibility and safety in a new way.



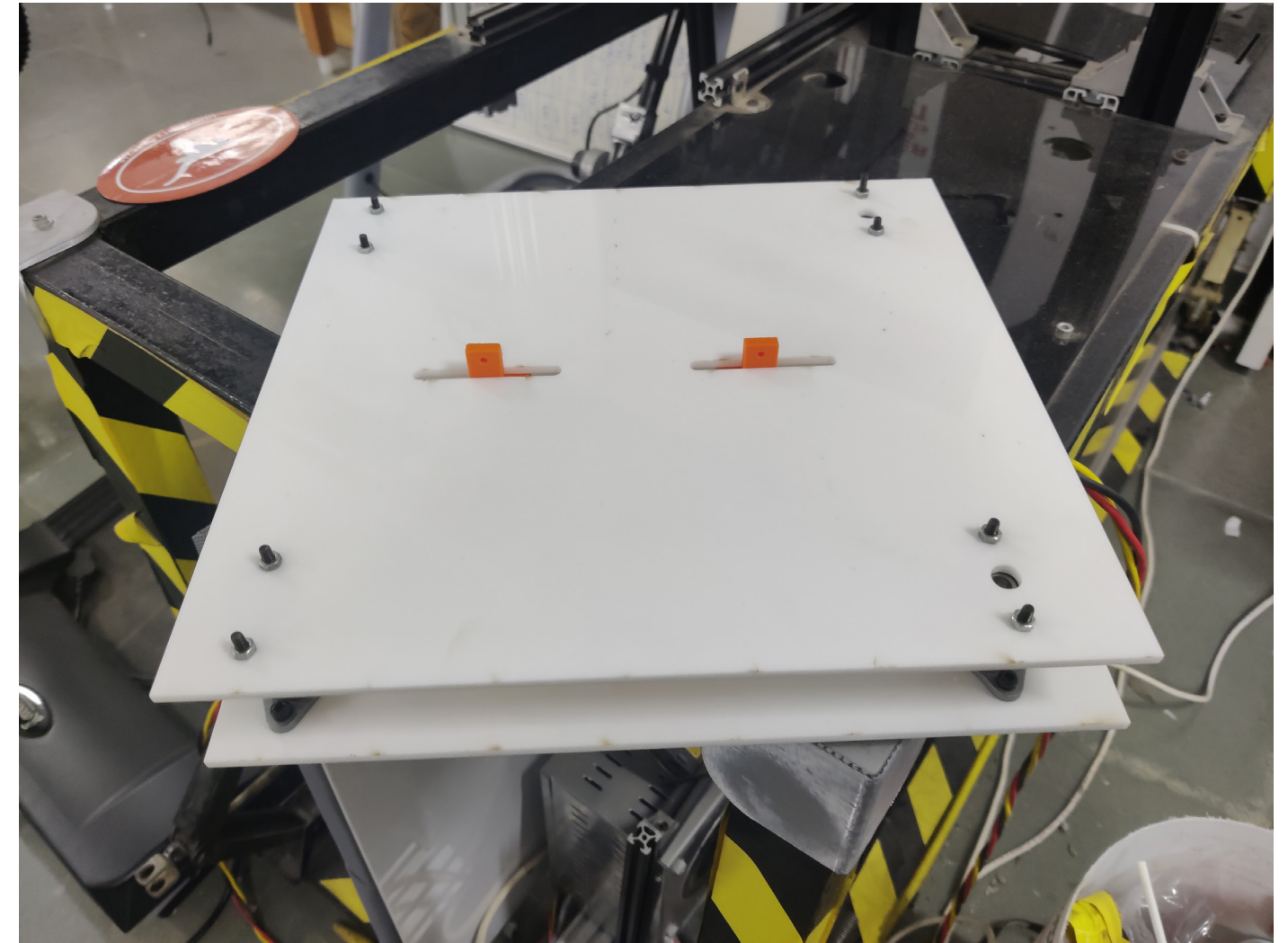
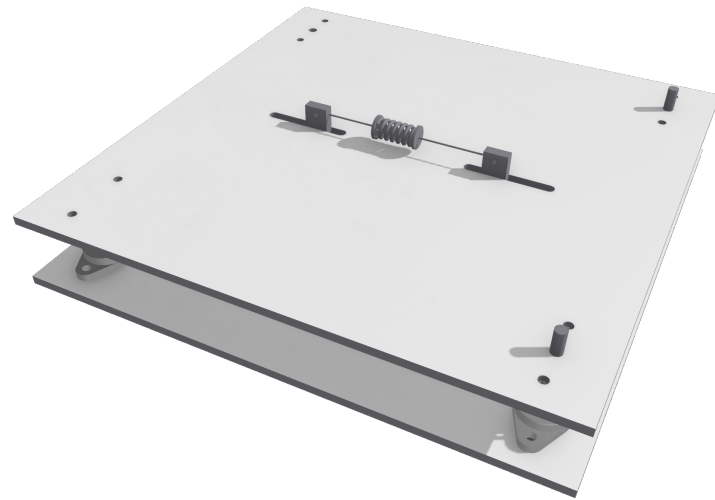
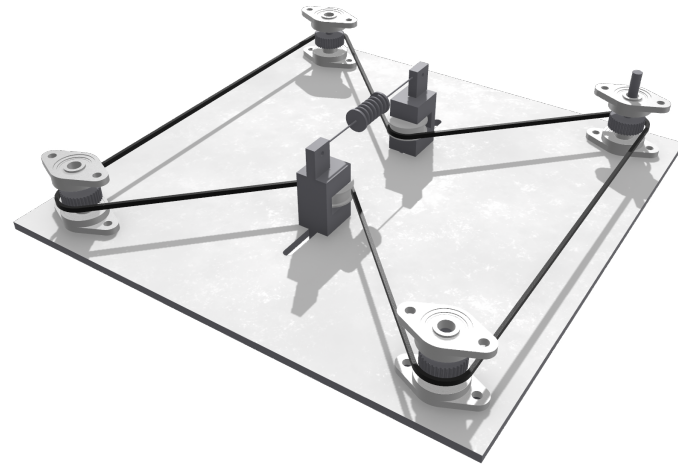
Three Layers of Design

First/ bottom consists of all electronic components, including a microcontroller enabled with reinforcement learning, power supply, motor, and killswitch.

Second layer consists of purely mechanical power transmission, including series elastic and parallel elastic actuators and clutching mechanism, and a divergent force field for the tool.

Third/ top layer is the only open layer, and it contains the robotic arm and tool to run simulations and perform tests on.

Series Elastic Actuator



Conclusion

Concluding the project, reflections and learnings have been articulated, along with the next steps for the project. A mention of bibliography has been given for reference.

Reflections & Learning

The past four years of my studies were put to the test while completing this project, hitting the trifecta of blood, sweat, and tears. Inspiring from the human body to studying a horse's leg and relating it to robotics was novel; it only increased my admiration for nature. It was also my first time staying away from home for an extended time which helped me grow as a person.

Conclusion

My degree project at sysIDEA Research Lab at IIT Gandhinagar was an exciting time for me. These 18 weeks were full of challenges and difficulties. Help from lab members and my project investigator Prof. Harish P.M. was exceptional, and it helped me and the project grow and take its final form. While working here, I developed a deeper understanding of robotics like never before. It was pretty challenging to combine the hardcore engineering and design field but fun nevertheless. My past learnings from the Institute of Design, Nirma University, helped me a lot in my degree project.

Bibliography & References

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