Robo Support : Exoskeleton For Knee And Ankle

A project report submitted in partial
fulfilment of the requirements for the degree
of

Bachelor of Engineering
In
Artificial Intelligence and Data Science

by

Rhea Bhalekar (9355)
Jacob Mire (9386)

Under the guidance of
Prof. Swati Ringe

DEPARTMENT OF ARTIFICIAL INTELLIGENCE AND DATA SCIENCE
Fr. Conceicao Rodrigues College of Engineering, Bandra (W), Mumbai - 400050
University of
Mumbai
(2023-24)

This work is dedicated to my family.

I am very thankful for their motivation and support.

Internal Approval Sheet

CERTIFICATE

This is to certify that the project entitled **"Robo Support : Exoskeleton For Knee And Ankle"** is a bonafide work of **Rhea Bhalekar (9355) and Jacob Mire (9386)** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of Bachelor in **Artificial Intelligence and Data Science.**

Prof. Swati Ringe
Supervisor/Guide

Dr. Jagruti Save
Head of Department

Dr. Surendra Singh Rathod
Principal

Approval Sheet

Project Report Approval

This project report entitled **Robo Support : Exoskeleton For Knee And Ankle** by Rhea Bhalekar and Jacob Mire is approved for the degree of Bachelor of Engineering in Artificial Intelligence and Data Science.

Examiner 1. ——————————

Examiner 2. ——————————

Date:

Place

Declaration

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Rhea Bhalekar (9355) ________________

Jacob Mire (9386) ________________

Date:

Abstract

One of the most common types of disabilities in the post pelvic region of the human body is primarily concerned with the knee and the foot. Since the area around the knee is a complex fusion of many tendons, ligaments , bones and muscles it is most prone to ailments and stress. In addition to that another such joint is the ankle joint which performs complex motion in the 3D axis.

Hence we focus on one of the most important issues which are:

1) Knee hyperextension and flexion : A very common problem faced by individuals due to excessive load on the calf muscles which causes the knee to either sink behind or propel outwards deviating from the original 180 degrees, causing degradation and further pain
2) Foot drop : A condition faced primarily by stroke patients where the human concerned is not able to have control over the angular movement of the ankle while walking. This leads to the limping and difficulty in walking

Our solution aims to address these issues by creating a cost effective and compact system which is easy to use and provides the user an opportunity to lead a near normal life, unlike existing systems which are massive and limit the movement and cause inconvenience.

Acknowledgments

We have great pleasure in presenting the report on **"Robo Support : Exoskeleton For Knee And Ankle"**. I take this opportunity to express my sincere thanks towards the guide Prof. Swati Ringe, C.R.C.E, Bandra (W), Mumbai, for providing the technical guidelines, and the suggestions regarding the line of this work. We enjoyed discussing the work progress with him during our visits to the department.

We thank Dr. Jagruti Save, Head of Artificial Intelligence and Data Science department, Principal and the management of C.R.C.E., Mumbai for encouragement and providing necessary infrastructure for pursuing the project.

We also thank all non-teaching staff for their valuable support, to complete our project.

Rhea Bhalekar (9355)
Jacob Mire (9386)

Date:

Contents

Abstract **iv**

List of Figures **ix**

List of Tables **x**

1 Introduction **1**

1.1 Motivation.. 1

1.2 Objectives... 1

2 Literature Review **2**

2.1 Literature Review……………………………………………………………..2

3 Problem Statement **11**

3.1 Drawbacks of Existing System...11

3.2 Solution To Above Problems..12

4 Project Description **13**

4.1 Overview of the project.. 13

4.2 Module Description.. 13

4.2.1 Hyperextension …... 13

4.2.2 Foot Drop.. 27

4.2.3 Block Diagram.. 31

4.2.4 Flowchart.. 31

4.3 Terrain detection using CNN..32

4.3.1 Datasets..32

4.3.2 Convolutional Neural Networks...33

4.3.3 Layers in our model...34

4.3.4 Classes in the dataset.. 36

4.3.5 Server...40

4.4 Bill of Materials...42

5 Implementation Details 44

5.1 Methodology.....44

5.1.1 Mechanical Structure..... 44

5.1.2 Interfacing Azure with Arduino and Esp32 CAM..... 46

5.1.3 CNN Model.....48

6 Conclusion and Future Enhancement 49

6.1 Conclusion.....49

6.2 Future Enhancement.....50

References 52

List of Figures

4.1 Shape Memory of Nitinol……………………………………………….…..14

4.2 Nylon 6,6 Twisted Coiled Polymer………………………………………17

4.3 Electromagnetic Tooth Clutch……………………………………………18

4.4 2D Drawing ………...……………………………………………….21

4.5 3D Drawing……………………………………………………….…...21

4.6 Total deformation of the shaft under load…………………………………..23

4.7 Equivalent Elastic Strain on the shaft under load……………..…………….23

4.8 Equivalent Stress on the shaft under load…………….……………………24

4.9 Total deformation of the spring Plate under load….…………………………24

4.10 Equivalent Elastic Strain on the spring plate under load……………………25

4.11 Equivalent Stress on the spring plate under load……………………………25

4.12 Total deformation of Brace under load………………………….……….26

4.13 Equivalent Elastic Strain on the brace under load…………….…….………26

4.14 Equivalent Stress on the brace under load……………………….………….26

4.15 2D Drawing………………………………………………………...……28

4.16 3D Drawing …………………………………………...……...………29

4.17 Heel Strike and ankle during mid air………………………...…………...30

4.18 Block diagram…………………………………………………...……….31

4.19 Flowchart for Ankle Mechanism…………………………………….……...31

4.20 Flowchart for Knee Mechanism……………………………….…………....32

4.21 Layers in the CNN………………………………………..…….……...36

4.22 Classes in the Road type dataset……………………………….……………37

4.23 KITTI CaRiNA and RTK dataset…………………………………………...38

4.24 Classes for road quality ……………………………………………………….38

4.25 Parameters learnt in CNN……………………………………………………..39

4.26 Azure Server Image ………………………………………...………....41

5.1 CAD Model for Ankle Mechanism……………………...………………….44

5.2 Prototype for Ankle Mechanism……………………..…………………..45

5.3 CAD Model and Prototype for knee Mechanism……………...……………45

5.4 Azure Code ……………………………………………...…………………47

5.5 Accuracy of training and testing ……………………...…………………48

5.6 Prediction made based on CNN Model……………………..………………48

6.1 AutoEncoder Results……………………………………………..……….51

List of Tables

2.1 Literature Review……………………………………………………………….2

4.1 Bill of Materials…………………………………………………………………...37

Chapter 1

Introduction

1.1 Motivation

At present, there are a large number of people in India who suffer various movement dysfunctions at different levels caused by stroke, spinal cord injury, and ageing. It causes a dual physical and mental impact on patients themselves and brings a heavy medical burden to society and family. The exoskeleton systems were identified as wearable man–machine devices made through anthropomorphic design, providing active assistance to the users according to their motion intention. Thus, to support the physically impaired members of the country who aren't blessed with a wealthy background, we intend to create a cheap and lightweight system to support their knee joints.

1.2 Objectives

- To design and manufacture an exoskeletal structure which can support the knee joints.
- To use multiple sensors and a microprocessor to read and analyse the strength and condition of the knee joint.
- Use of sensors to take electrical impulse as an input and analyse the condition
- To write an algorithm to automate the process of taking steps.

Chapter 2

Literature Review

2.1 Literature Review:

Table 2.1 Literature Review

Title of Paper	Publication and Year	Summary
Design and Experimental Verification of Hip Exoskeleton With Balance Capacities for Walking Assistance	T. Zhang, M. Tran and H. Huang, "Design and Experimental Verification of Hip Exoskeleton With Balance Capacities for Walking Assistance," in IEEE/ASME Transactions on Mechatronics, vol. 23, no. 1, pp. 274-285, Feb. 2018, doi:	This paper presents an innovative design and construction of a hip exoskeleton. The exoskeleton features powered joints for Hip Flexion/Extension (HFE) and Hip Abduction/Adduction (HAA) to support walking and maintain balance during walking. Each actuation unit employs a modular and compact Series Elastic Actuator (SEA) with a high torque-to-weight ratio, making the exoskeleton passively compliant. An online balance controller, based on the concept of Extrapolated Center of Motion (XCoM), is used to ensure gait stability in the coupled human-exoskeleton system.

	10.1109/TMECH.2018.2790358.	The hip exoskeleton provides assistance by applying a compliant guiding force to the leg that requires assistance during balance control, utilising an adaptive admittance control strategy. Experimental verification results demonstrate the promising potential of the proposed hip exoskeleton as a tool for aiding walking and balance. It's important to note that, in the current implementation of the hip exoskeleton prototype and balance control system, stable walking without the need for crutches has only been achieved for healthy individuals.
A Practical and Adaptive Method to Achieve EMG-based Torque Estimation for A Robotic Exoskeleton	K. Gui, H. Liu and D. Zhang, "A Practical and Adaptive Method to Achieve EMG-Based Torque Estimation for a Robotic Exoskeleton," in IEEE/ASME Transactions on Mechatronics, vol. 24, no. 2, pp. 483-494, April 2019, doi: 10.1109/TMECH.2019.2893055.	This paper introduces a practical and adaptable EMG-based estimator for the purpose of controlling the compliance of exoskeletons. It's important to note that this article has been accepted for publication in a forthcoming issue of this journal but has not yet undergone complete editing. The estimator has been integrated into the extended Slotine-Li scheme. Through a two-step learning approach, this novel estimator can acquire and update the EMG-torque model without the need for calibration or recalibration. The performance of this estimator was assessed through simulations and real-world experiments. It is worth mentioning that this estimator is not operable during the stance phase due to the presence of unknown Ground Reaction Forces

		(GRFs), which represents a limitation in the current study.
Retraining of Human Gait - Are Lightweight Cable-driven Leg Exoskeleton Designs Effective?	X. Jin, A. Prado and S. K. Agrawal, "Retraining of Human Gait - Are Lightweight Cable-Driven Leg Exoskeleton Designs Effective?," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 26, no. 4, pp. 847-855, April 2018, doi: 10.1109/TNSRE.2018.2815656.	This paper introduces an innovative exoskeleton model referred to as C-ALEX. The research demonstrates that, following a 40-minute training session, healthy participants can adopt a new gait pattern facilitated by C-ALEX. Notably, individuals can maintain this newly acquired walking style even after removing the C-ALEX exoskeleton. The training outcomes achieved with C-ALEX are on par with those of rigid-link exoskeletons, while the C-ALEX design offers advantages in terms of compactness and reduced weight. These findings suggest that C-ALEX holds significant promise as a candidate for robot-assisted gait training in stroke patients, with future clinical studies planned to investigate its suitability further.
Performance Evaluation of Lower Limb Exoskeletons: A Systematic Review	D. Pinto-Fernandez et al., "Performance Evaluation of Lower Limb Exoskeletons: A Systematic Review," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 28,	This review highlights a significant and exponential increase in the number of papers dedicated to the evaluation of robot-assisted locomotion, signalling a growing interest within the scientific community in assessing exoskeleton performance. The review also notes a substantial diversity in the variables and experimental setups proposed. While this lack of uniformity makes direct comparisons across different exoskeletons challenging, it also represents a

	no. 7, pp. 1573-1583, July 2020, doi: 10.1109/TNSRE.2020.2989481.	valuable collection of methods and tools that can serve as a solid foundation for establishing a benchmarking methodology. The majority of the reviewed papers primarily focused on walking on flat ground or treadmills, underscoring the prevailing emphasis on fundamental locomotion skills within the exoskeleton community. However, other motor skills, such as standing, balance, and walking on irregular terrain or when subjected to pushes, turns, or lateral steps, are gaining increasing attention but have not reached the same level of development. The review also discusses the importance of testing these functions to demonstrate readiness for real-world environments. Among the performance indicators (PIs) considered, kinematic/kinetic metrics and straightforward indicators based on distance and time were popular, especially in the evaluation of straight walking. Still, the use of human-robot interaction indicators was limited in assessing other motor skills. The review suggests that a more comprehensive application of these metrics would be beneficial for comparing exoskeletons across various motor skills, with specific attention to aspects related to symmetry, coordination, versatility, ergonomics, comfort, and stability against external disturbances.

		Finally, safety is emphasised as a primary requirement for any assistive, rehabilitation, or augmentation device, and the review suggests that it should be rigorously considered when evaluating exoskeleton prototypes. The findings of this review can serve as a starting point for the development of a unified and standardised benchmarking framework, encouraging the wearable robotics community to demonstrate the practical suitability of their robots for real market needs.

A Review on the Rehabilitation Exoskeletons for the Lower Limbs of the Elderly and the Disabled	T. Wang et al., “A Review on the Rehabilitation Exoskeletons for the Lower Limbs of the Elderly and the Disabled,” Electronics, vol. 11, no. 3, p. 388, Jan. 2022, doi: 10.3390/electronics11030388.	Nations worldwide have made significant strides in exoskeleton technology for medical rehabilitation. Emerging prototypes and commercial products offer innovative solutions to aid the rehabilitation of the elderly and disabled. However, the integration of exoskeletons into the broader social rehabilitation service system presents notable challenges. The following points were highlighted in the paper: 1. Compatibility between exoskeletons and the human body remains a critical issue. Systems with more active degrees of freedom, while providing flexibility, can become complex, affecting overall performance. Common ergonomic factors include relative positioning, interface adaptability, and misalignment of joint rotation centres during movement. These issues impact human-machine interaction and disrupt ergonomics. Novel designs inspired by unpowered exoskeletons aim to enhance comfort and ensure safe, ergonomic interfaces for lower limb exoskeletons. 2. Sensor-based motion feedback is fundamental for exoskeleton control and rehabilitation, employing joint angles and interaction torque. However, precise recognition and prediction of human movement intentions are challenging. Robust communication channels and data fusion

		algorithms are needed for accurate motion mode recognition. 3. Achieving lightweight, high power-to-weight ratios in driving units is challenging, as existing actuators often result in bulky structures. Innovative actuation forms and optimization methods are necessary, focusing on permanent magnet servo motors and precise control strategies. 4. Coordinating system motion control with human motion is complex, requiring dynamic control and optimization methods. Overcoming these challenges is essential for the widespread application of exoskeletons in assisting the elderly and disabled.
Human-in-the-loop layered architecture for control of a wearable ankle–foot robot	Martinez-Hernandez, Uriel & Firouzy, Sina & Mehryar, Pouyan & Meng, Lin & Childs, Craig & Buis, Arjan & Dehghani-Sanij, Abbas. (2023). Human-in-the-loop layered architecture for control of a wearable ankle-foot robot.	This study introduced a human-in-the-loop layered architecture for the control of a wearable ankle-foot robot. The architecture, consisting of high-, mid-, and low-level layers, intricately interconnected and synchronized, enabled the wearable robot to gather data from sensors attached to the human body, make precise decisions, configure control parameters, and effectively control the robot's actions, ensuring reliable interaction and assistance to the human foot during walking.

	Robotics and Autonomous Systems. 161. 104353. 10.1016/j.robot.2022.104353.	The wearable robot used to validate this layered architecture was developed using 3D printing technology and a novel actuation system. The architecture's accuracy and precise control ensured the safe and dependable performance of the wearable robot during interaction with the human body. To validate the system, a series of experiments was conducted, both in simulation and real-time environments, focusing on the recognition accuracy of walking events and the control and response of the wearable robot while assisting the human foot. These experiments collectively demonstrated the suitability of the proposed human-in-the-loop layered architecture for creating intelligent wearable robots capable of safe interaction and assistance to the human body.
Rapid, Reliable Shape Setting of Superelastic Nitinol for Prototyping Robots	H. B. Gilbert and R. J. Webster, "Rapid, Reliable Shape Setting of Superelastic Nitinol for Prototyping Robots," in IEEE Robotics and Automation Letters, vol. 1, no. 1, pp. 98-105, Jan. 2016, doi: 10.1109/LRA.2015.2507706.	In summary, the paper introduces a comprehensive system for achieving closed-loop, high-temperature resistance heating of Nitinol, accompanied by design guidelines for compatible fixtures. The system demonstrates expedited and dependable outcomes, making it an invaluable resource for laboratory prototyping with low production volumes. Particularly relevant to concentric tube robots, this system ensures precision in fabrication, aligning with emerging numerical optimal design methodologies for diverse surgical applications. The paper

		anticipates its applicability to extend to medical device prototyping laboratories and robotics research facilities seeking to shape-set superelastic Nitinol for a wide spectrum of contemporary and prospective applications, thereby advancing the field of smart materials and medical robotics.
Design of a Clutch–Spring Knee Exoskeleton for Running	Grant Elliott Biomechatronics Group, Department of Electrical Engineering and Computer Science, Andrew Marecki Department of Mechanical Engineering, Hugh Herr [DOI: 10.1115/1.4027841]	The document details the design and validation of a clutch-spring knee exoskeleton for running. It describes a complex control strategy, including a state machine and solenoid latency compensation, to mimic natural knee behaviour during the gait cycle. Through experimental testing and finite element analysis, the exoskeleton exhibits exceptional holding torque while maintaining a low mass. The control strategy demonstrates reliability in steady-state running but faces challenges during speed transitions. Suggestions for improvement include adapting parameters to varying speeds and incorporating additional gait states for robustness. The study contributes to understanding the biomechanics of human running and advances in wearable exoskeleton technology

Chapter 3

Problem Statement

3.1 Drawbacks of Existing Systems

The project which is Exoskeleton for Knee and Ankle is based upon an idea, that a power source such as electrical, pneumatic, hydraulic, etc. can be used to help disabled people suffering from Hyperextension and Hyperflexion to walk properly.

To overcome the problems some systems have developed such as Robin, CUHK-EXO, Kinesis,etc. But they have following drawbacks :

- These models are rigid and do not allow many free movements.
- They are very expensive and cannot be afforded by the common folk.
- These products mainly use a pneumatic pressure as a power source which makes the whole model heavy.
- These products usually have a manually operated mode selection system, for various actions performed by the patient.

3.2 Solution To Above Problems

In this project, we have tried to solve the above drawbacks and provide maximum comfort to the patient while walking. Our design involves making the use of an electromagnetic tooth clutch paired with a rotary encoder to actively track the movement of the knee to prevent over-extension of the knee and thus prevent hyperextension in the knee.

For overcoming the foot drop, a medium torque and low RPM motor is preferred and bevel gears are used to transmit the actuation in an efficient manner. The motor chosen is lightweight and the brace designed will help the patient to freely move and do their regular activities.

To control the mechanisms mentioned above, ie.: the electric impulse required to control the nitinol material in the mechanism, as well as controlling the medium torque and low RPM motor as required, to counter the hyperextension caused in the legs of patients, an integrated system of sensors as well as Artificial Intelligence is required. Thus, our model will incorporate an artificially intelligent system, with the help of sensors to gather various inputs about the movement of the foot. This data will be used to gather information about the walking pattern of the patient, and can be used to make the process more comfortable and easier for the patient. At the same time, we will be incorporating a camera system, wherein various information about the terrain will be collected. This information in the form of a video feed, will be processed with the help of a neural network, to determine the condition of the terrain, as well as types of objects around, to identify it.

Chapter 4

Project Description

4.1 Overview of the project

The project consists of 2 major modules: the Hyperextension for the knee and the foot drop mechanism for the foot. Both the mechanisms work together to provide support to the disabled person.

4.2 Module Description

The mechanisms are mainly divided into two parts, as it would help us to focus on each problem separately and gain deep knowledge of it. The two parts are as follows:

4.2.1 Hyperextension

Hyperextension is a common type of problem mainly faced by the athletes and old people because of which, many exoskeletons are developed and are available in the market. But not all the people can afford them and hence they have to undergo a surgery. So, our aim is to help these people to perform their daily activities comfortably at an affordable price. To solve the problem of hyperextension we have researched on:

1. Nitinol which is made up of elements like Nickel and Titanium
2. A twisted Coil Polymer like Nylon 66 monofilament (loosely written as nylon 6-6, nylon 6/6, nylon 6,6, or nylon 6:6) is a type of nylon polyamide .

The Solution to the Above problem is design of knee brace using Electromagnetic Tooth Clutch for passive braking to the hyperextension motion.

4.2.1.1 Nitinol

Nitinol is a shape memory alloy which possesses unique properties that can be used in various useful applications such as in aerospace, construction and medical industries. Recently, NASA has developed an indestructible wheel from Nitinol which can be used to drive a rover on the surface of mars which is a rough and uneven terrain. But, putting aside the high end applications of this phenomenal material we are going to use it to help people suffering from disability.

There are numerous properties of nitinol that are extensively used in medical, aerospace, construction, etc. types of industries. But, in this research we are mainly going to use two fundamental properties of Nitinol which are the Shape memory effect and Pseudoelasticity.

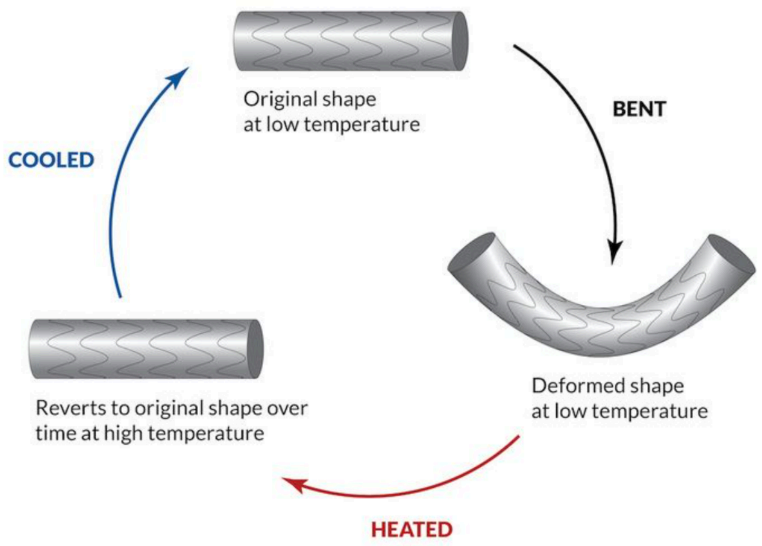


Fig 4.1 Shape Memory of Nitinol

- *Shape Memory Effect (SME):*

SME is a unique effect in which a material restores its shape, after being deformed plastically, when heated above its transformation temperature.

- *Pseudoelasticity:*

Pseudoelasticity or Superelasticity is a property of SMA's in which they regain their original shape when an external load is removed.
These properties can be specifically obtained and manipulated by just changing the composition of Nitinol and Titanium. For example, when the percentage of titanium is increased in the alloy, it results in higher transformation temperature which is a prominent SME. Likewise, if the Ni amount is in higher content the transformation temperature is lowered and the pseudoelastic properties of the obtained alloy is bestowed.

- *Inside chemistry of Nitinol:*

Nitinol undergoes a transformation which is a derivative of reversible solid state phase transformation called Martensitic Transformation which requires about 10,000-20,000 psi of mechanical stress between two martensite crystals.
By researching about the two states of the material we have found that, at high temperatures nitinol behaves as a simple cubic structure known as Austenite and at relatively low temperatures it seems more likely as a monoclinic crystal structure referred to as Martensite. There are four transition temperatures associated with the austenite-to-martensite and martensite-to-austenite transformations. Starting from full austenite, martensite begins to form as the alloy is cooled to the so-called martensite start temperature, or Ms, and the temperature at which the transformation is complete is called the martensite finish temperature, or Mf. When the alloy is fully martensite and is subjected to heating, austenite starts to form at the austenite start temperature.
As, and finishes at the austenite finish temperature, Af. The cooling/heating cycle shows

thermal hysteresis. The hysteresis width depends on the precise nitinol composition and processing. Its typical value is a temperature range spanning about 20–50 K (20–50 °C) but it can be reduced or amplified by alloying and processing.
On Further Research, Due to following Disadvantages of both types of Nitinol The materials were not Used In the design of Proposed System.

- High initial cost
- Hysteresis : Nitinol remains in its austenitic state even after the temperature has dropped well below the transition temperature.

4.2.1.2 Nylon 66

Nylon-6,6 is a type of polyamide and is made of two monomers each containing 6 carbon atoms, Hexamethylenediamine ,and adipic acid. A twisted Coil Polymer like Nylon 66 monofilament (loosely written as nylon 6-6, nylon 6/6, nylon 6,6, or nylon 6:6) is a type of nylon polyamide that when heated contracts and relaxes when cooled. In order to attain this property of negative thermal expansion the nylon filament needed to be coiled and annealed at 180 degrees celsius. For the contraction and relaxation of the nylon muscle Joule heating using nichrome wire was intended. However , upon practical trial the contraction produced could not pick the intended weight. Hence the idea was not implemented.
Disadvantage:

- Response time is slow.
- Requires high heat to activate its properties.

Fig 4.2 Nylon 6,6 Twisted Coil Polymer

4.2.1.3 Electromagnetic Tooth Clutch

Electromagnetic Tooth clutch is a motion transmission component which uses magnetic effect of electric current for actuation and transfers torque mechanically. It is mainly used in devices where accuracy is a priority such as printing presses, etc.

Parts:

- Stator : It is an outer housing made up of Mild Steel(MS) which provides a space for coil which is made up of copper. The coil is tightly winded and fitted inside the stator.
- Rotor : It is used to transmit torque, mechanically by using the magnetic effect.
- Copper Coil : Used as an electromagnet and is situated inside a stator.
- Washer : It is a part on which the rotor slides for completing circuit with the stator.
- Spring Bolts : These types of bolts are used to attach a rotor with a washer and it also helps the rotor to move back to its original position when the voltage is not applied.

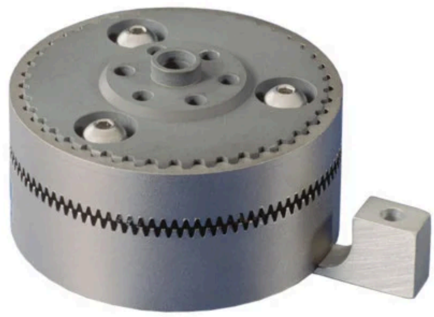


Fig 4.3 Electromagnetic Tooth Clutch

Working Principle:
When a potential difference or voltage is applied to the copper coil situated inside the stator of the electromagnetic clutch a magnetic field is generated with lines parallel to the surface of the stator. These magnetic field lines attract the rotor which is connected to the washer through the spring bolts. The rotor slides on the surface of the washer and completes the circuit by attaching to the stator. There is no backlash while transmitting the torque and hence electromagnetic clutches are used where accuracy and precision is a priority.

4.2.1.4 Mechanism

By rigorous testing of all the materials mentioned above and also by comparing their advantages and disadvantages we had decided to use an electromagnetic clutch for our mechanism. The detailed explanation of the of the mechanism used to overcome hyperextension in knee is as follows,

Components:

- Brace : It is a supporting structure as well as consists of the essential components required for the mechanism. The brace is divided into two parts which are, the stationary and dynamic parts, connected to the upper and lower limb respectively.

- Velcros : Used to hold the brace in the desired place on the surface of the leg.
- Electromagnetic Clutch : It is an essential component of the mechanism which is used to connect the upper and lower limb whenever required.
- Compression spring : It is used to correct the hyperextension and provides a cushioning effort to the knee when the mechanism is activated.
- Shaft : A 10 mm stainless steel shaft is used as a support of the clutch and spring and also connects the two parts of the brace.
- Lip ball bearing : They are the types of ball bearings which consist of a lip for holding the outer surface of the workpiece. In this mechanism, lip ball bearings are used as a load bearer in which a shaft is placed.
- Ball bearing : Used to support the Shaft.
- Key : It is used to hold the stator in the desired place.
- Aluminium plates and hollow sections : They are used as a support where the brace seems to be weak and is prone to failure.
- Rotary Encoder : It is used to send the signals which helps the patient to change the angle as per the patient's requirement.
- Spring plate 1 : It is manufactured using the FDM process and is made up of PLA material. It consists of half part of the compression spring holding in a slot and is attached to the shaft through coupling.
- Spring plate 2 : It is manufactured using the FDM process and is made up of PLA material. It consists of half part of the compression spring holding in a slot and is attached to the stationary part of the brace through fasteners.

Working :

- Initially, a patient should wear the brace comfortably and make sure that the velcros are stuck firmly and the brace is stationary.
- When a patient is walking and reaches the mid-stance phase of the gait cycle the whole weight of the body is concentrated on the affected leg and hence it is moved at

an angle more than 180 degrees.

- When an affected leg is in mid-stance phase, the rotary encoder sends a signal to the electromagnetic clutch when the knee reaches at the desired angle and it is activated. The angle at which the signal has to be sent can be decided by the patient as he has the control of the rotary encoder through the circuit.
- As the signal is received by the circuit of the electromagnetic clutch from the rotary encoder, a potential difference is applied to the copper coil in the stator and a magnetic flux is generated due to the electric current flowing through the loops.
- This magnetic flux results in formation of the magnetic lines of field with direction parallel to the surface of the stator and since the rotor is made up of mild steel which is a ferromagnetic material it gets attracted to the stator and passive braking can be seen due to the higher torque of the clutch.
- As the rotor and stator are engaged the dynamic part of the brace can rotate with respect to the stationary part.
- There are two phases for working of our mechanism which are Engagement and Disengagement of the electromagnetic clutch.
- In the disengagement phase, the dynamic part of the brace can move freely and the spring plate 1 which is attached to the shaft and spring plate 2 attached to the dynamic part of the brace holding the compression spring also rotate along it.
- This phase is activated if the knee is not hyperextended or the person is not walking.
- In the engagement phase, the rotor attached to the stationary part of the brace through washer via spring bolts slides 0.4 mm forward and attaches to the stator and since the washer is fixed to the stationary part of the brace the stator stops rotating and the dynamic part stops immediately which creates jerk and is harmful for the patient.
- To avoid the jerk from the engagement of the electromagnetic clutch, the two spring plates, namely spring plate 1 and spring plate 2 provides a cushioning effect.
- The compression spring is fitted tightly between the two spring plates with each spring plate 1 and 2 sharing 40% and 60% part of the spring respectively. At the time of

engagement phase the spring plate 1 connected to the stationary part of the brace stops immediately but the spring plate 2 attached to the dynamic part of the brace now can rotate freely and the spring between both the plates compresses and since the stiffness of the spring is more than the torque applied by the hyperextended knee the spring gain its original shape keeping the knee in the desired angle thus providing a cushioning effect to the knee.

- Hence, hyperextension of the knee is avoided as well as the jerk is reduced by this kind of mechanism.

4.2.1.4 Design of Model

- 2D Model:

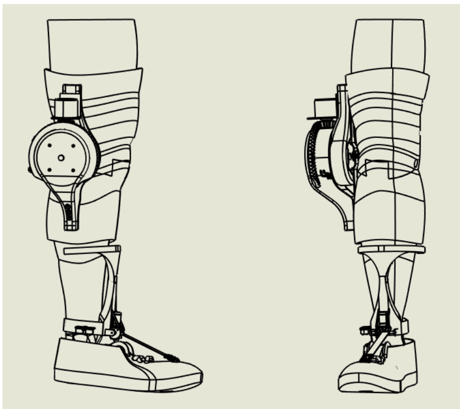


Fig 4.4 2D Drawing

- 3D model:

Fig 4.5 3D Drawing

- Dimensions:

  a. Length of Brace : 27.3cm
  b. Width of Brace : 13.8cm
  c. Thickness of Brace : 8.4cm
  d. Total Clutch diameter : 82cm
  e. Shaft diameter : 1cm
  f. Compression Spring dimensions :
     - Outer Diameter : 15.24mm
     - Inner Diameter : 9mm
     - Wire Diameter : 3.18mm
     - Spring Rate (1) : 408.61N/mm
     - Free Length : 12.7mm

4.2.1.5 Design of Model

An analysis was performed on the parts of certain parts of the brace using Ansys 2024 R1 (student version) software which experiences large stresses under a given load.

They are as follows :

1) <u>Analysis of Shaft</u>

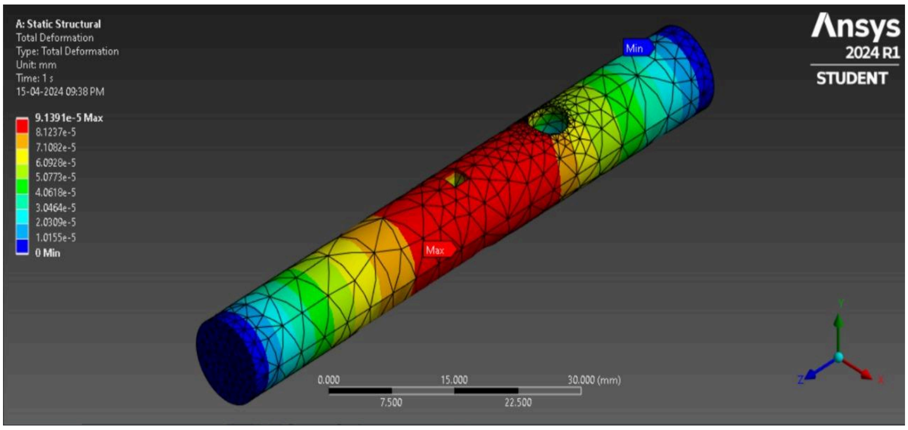


Fig 4.6 Total deformation of the shaft under load

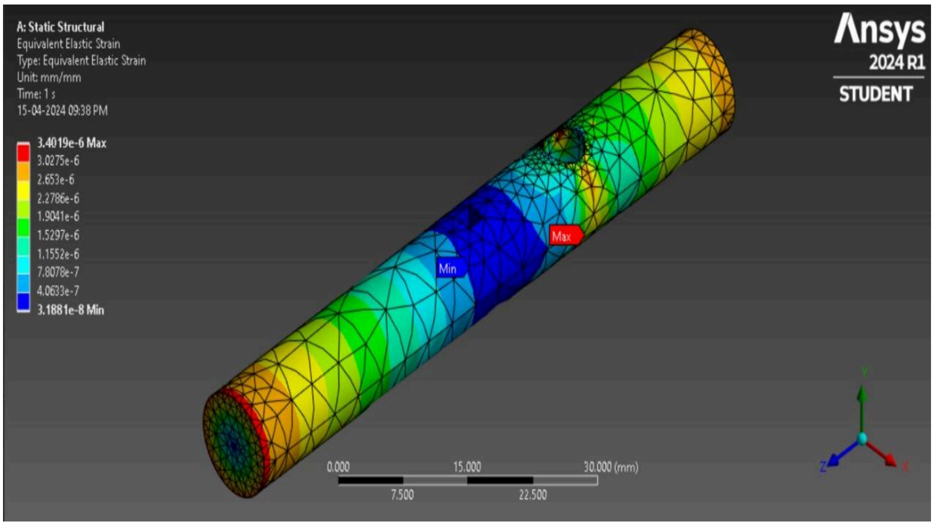


Fig 4.7 Equivalent Elastic Strain on the shaft under load

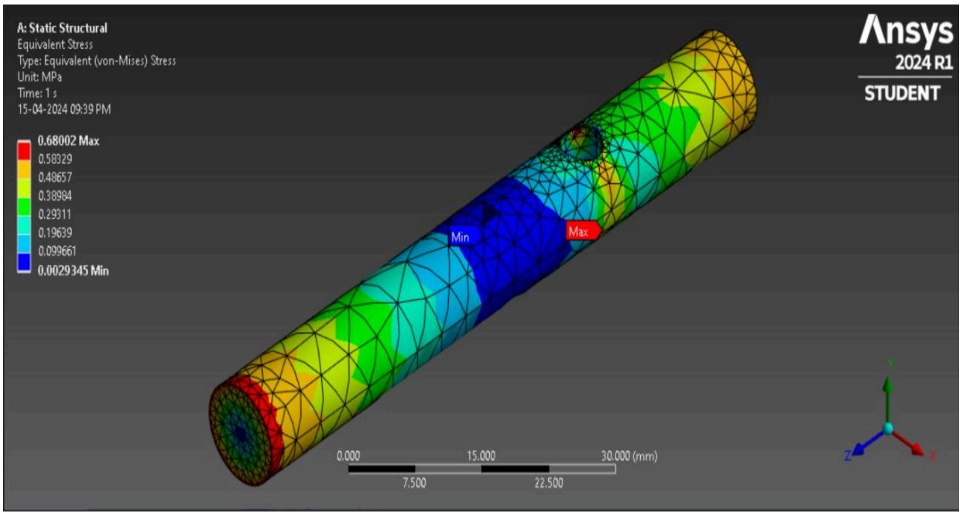


Fig 4.8 Equivalent Stress on the shaft under load

A static structural analysis including total deformation, equivalent elastic strain and equivalent stress is performed on a 10mm Stainless steel shaft. The maximum and minimum point of impact can be seen in the image. Since the total deformation, equivalent strain and equivalent stress is very small the component is safe.

2) <u>Analysis of Spring Plate</u>

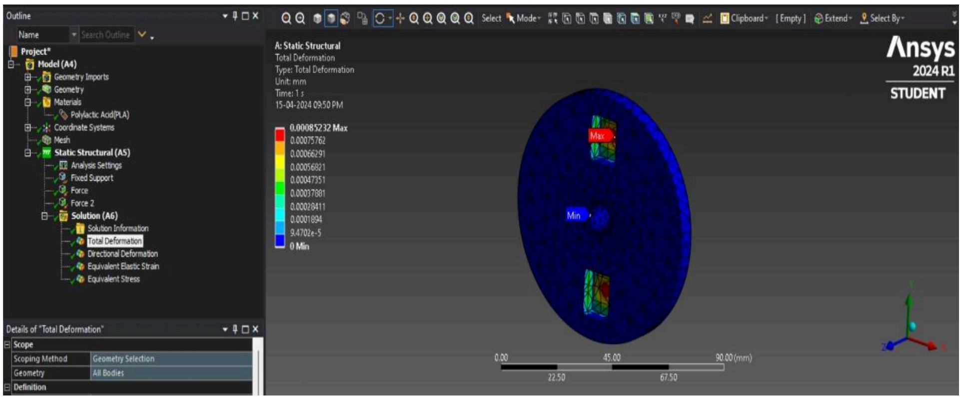


Fig 4.9 Total deformation of the spring Plate under load

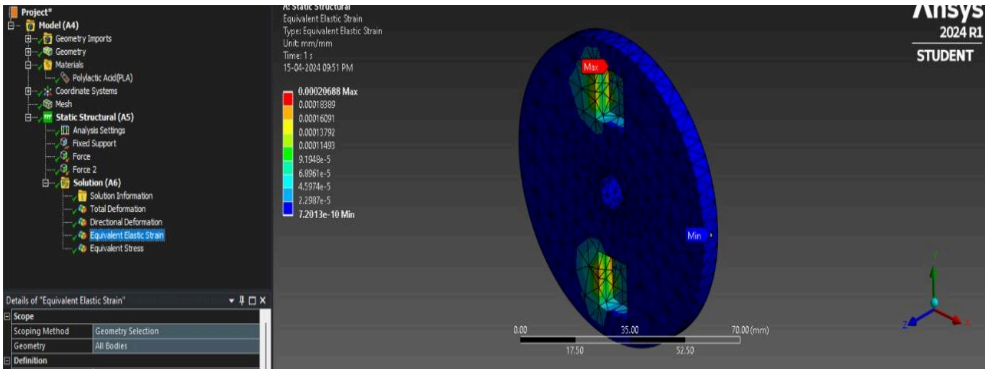


Fig 4.10 Equivalent Elastic Strain on the spring plate under load

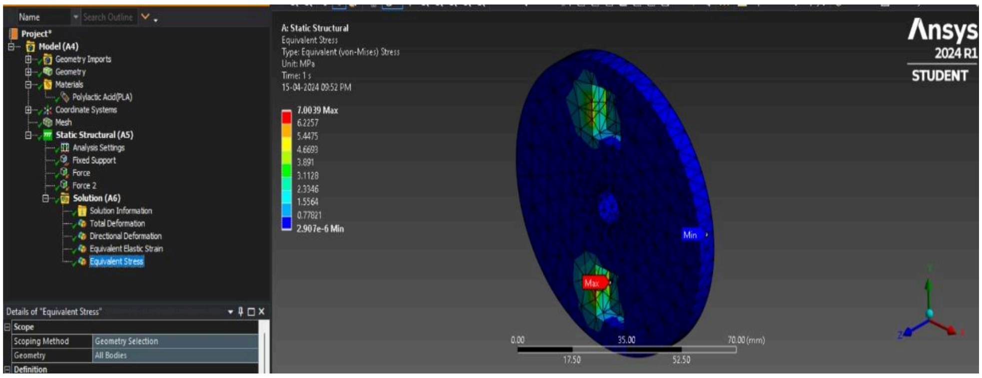


Fig 4.11 Equivalent Stress on the spring plate under load

A static structural analysis including total deformation, equivalent elastic strain and equivalent stress is performed on a Spring Plate. The maximum and minimum point of impact can be seen in the image. Since the total deformation, equivalent strain and equivalent stress is very small the component is safe.

3) <u>Analysis of Dynamic part of brace</u>

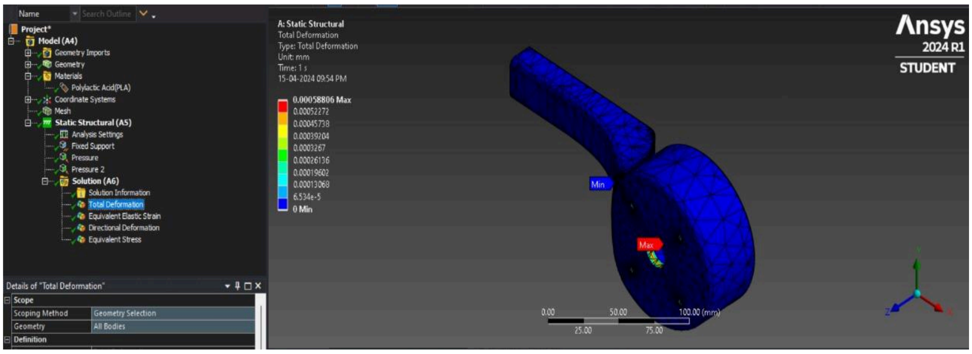


Fig 4.12 Total deformation of Brace under load

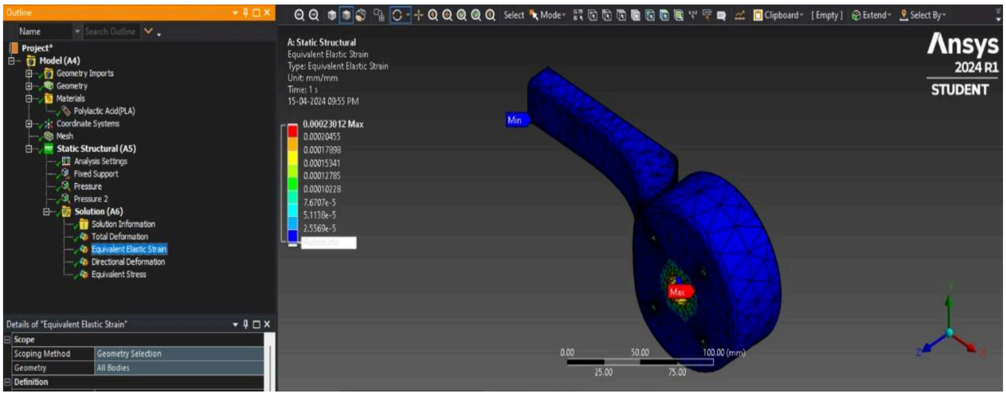


Fig 4.13 Equivalent Elastic Strain on the brace under load

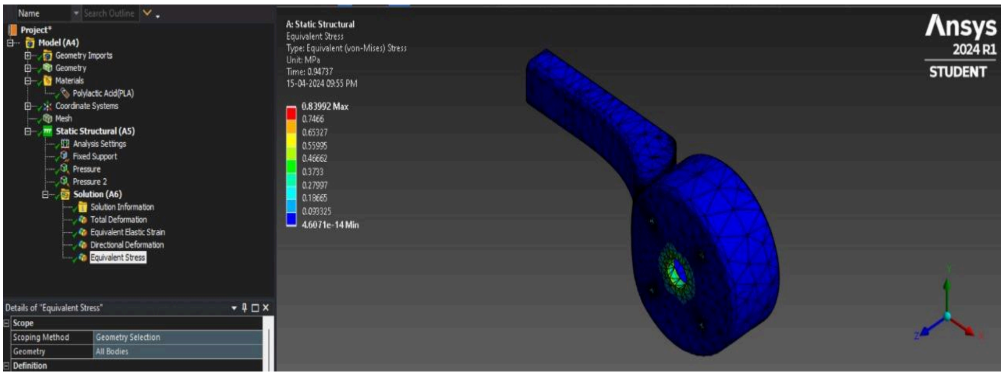


Fig 4.14 Equivalent Stress on the brace under load

A static structural analysis including total deformation, equivalent elastic strain and equivalent stress is performed on a Dynamic part of the brace. The maximum and minimum point of impact can be seen in the image. Since the total deformation, equivalent strain and equivalent stress is very small the component is safe.

4.2.1.6 Electronics Used

The actuation for Knee hyperextension is carried out using a relay model powered by an Arduino uno . The Arduino uno is the master node which controls the clutch and foot drop and simultaneously receives data from the esp32 cam. The relay works as a switch in order to energise and de energise the coil in the clutch..

4.2.2 Foot Drop

This is a detailed explanation of the mechanism used to overcome the foot drop problem. The aim of designing this mechanism is that the patient should be comfortable while walking and must be able to live a normal life.

Components:

- Bevel Gears : Use to transmit the power in a perpendicular direction.
- Medium Torque and Low rpm motor : Actuating Unit.
- Custom Brace : Works as a skeleton and storage space for the model.
- A buckle : A junction between the strap and the shoe of an affected foot.
- Strap/Ropes : Use to connect the foot to the Rod.
- SS Rod : Helps to maintain a circular motion which results in power transfer.
- Ball Bearings : Used to support and ensure the smooth motion of the rod.

Working of our system is as follows:

- We have designed a custom Brace which will be compact and lightweight in design.

- A high torque and low RPM motor will be attached to the Brace which is used as an actuator for the mechanism.
- One Bevel gear is attached to the motor with the help of an Allen bolt and another Bevel gear will be attached using a SS Rod with the Brace.
- The Rod will be able to rotate freely with the use of ball bearings inserted in the extension of the Brace.
- When the Motor is actuated the meshed Bevel Gears starts to rotate and this actuation is passed on to the SS Rod.
- As the Rod rotates a strap/rope attached with it is winded and the Buckle attached to the shoe will experience a force against Gravity and hence the foot will be lifted.

4.2.2.1 Design of Model

- <u>2D Model:</u>

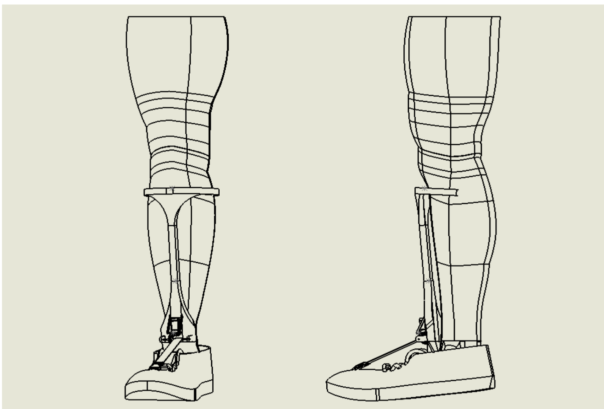


Fig 4.15 2D Drawing

- <u>3D model:</u>

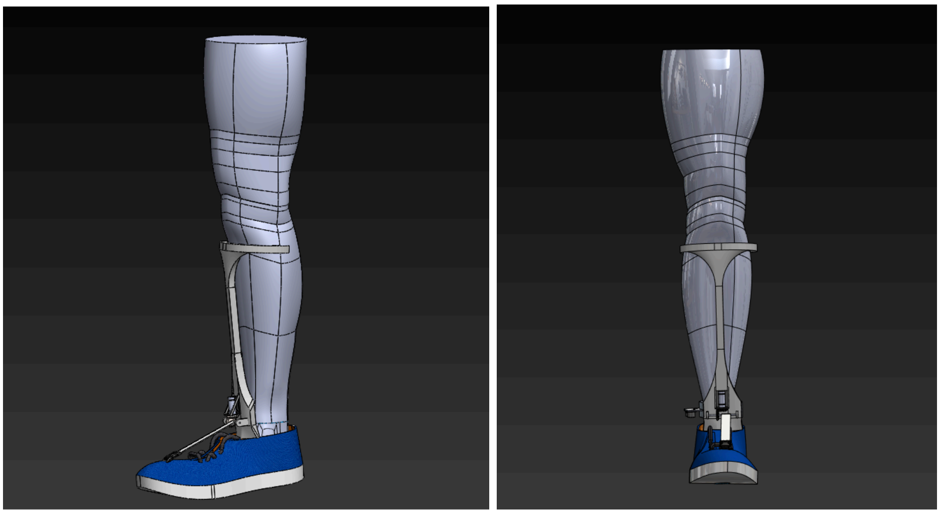


Fig 4.16 3D Drawing

- <u>Dimensions:</u>

  a. Length of Brace : 33cm
  b. Width of Brace : 40cm
  c. Thickness of Brace : 3cm
  d. Height of the lower limb selected : 40cm
  e. Width of the lower limb selected : 33cm
  f. Shoe size : UK 8
  g. Length of the foot : 24cm
  h. Length of straps : 20cm
  i. Outer Diameter : 32 mm
  j. Number of Teeth : 16
  k. Gear Module : 2.1
  l. Inner Bore : 6mm

4.2.2.2 *Electronics Used*

The actuation in the foot drop mechanism is carried out using a mid torque motor and the angular rotation and speed is controlled using a rotary encoder. An ultrasonic sensor is attached facing downwards to measure the distance of the foot from the ground.

While walking the ankle is at different positions from the ground during the gait cycle.

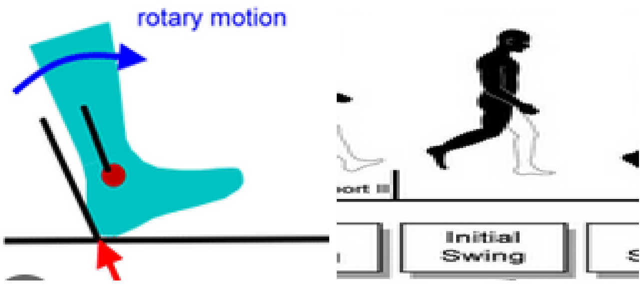


Fig 4.17 Heel strike and ankle during mid air

The above movement which is known as heel strike is the first contact of the foot with the ground. Foot drop patients face a difficulty in maintaining the angle of the foot.

In order to solve this the ultrasonic sensors activate the motor to actuate the foot at a particular angle in the mid air step prior to the heel strike. When the heel strikes the ground the ultrasonic sensors record the reading and actuate the motor to move the heel downwards. The rotary encoders help to obtain the required angle for the ankle. This angle is different for different individuals and has to be found experimentally.

The esp32 cam which is mounted over quadriceps takes real time input from the surroundings. It takes a photo of the terrain every 10 seconds and sends it over to the cloud instance. The CNN model deployed there carries out the classification task and forwards the result to the main Arduino Uno. The Arduino Uno then controls the foot drop mechanism with respect to the terrain of the surroundings like slope and roughness.

4.2.3 Block Diagram

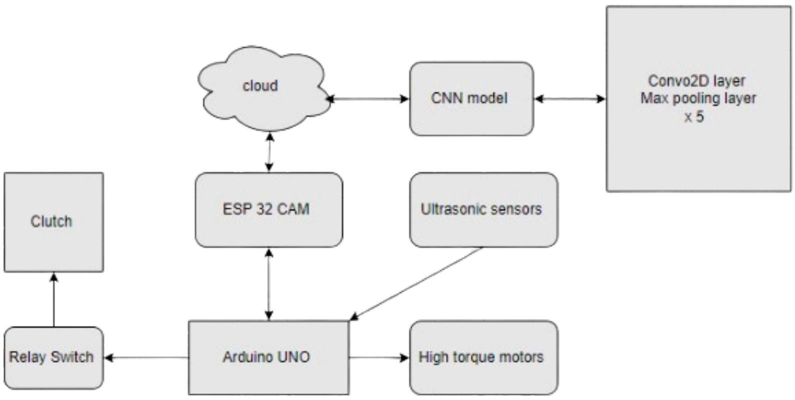


Fig 4.18 Block Diagram

4.2.4 Flowchart

For Ankle Mechanism:

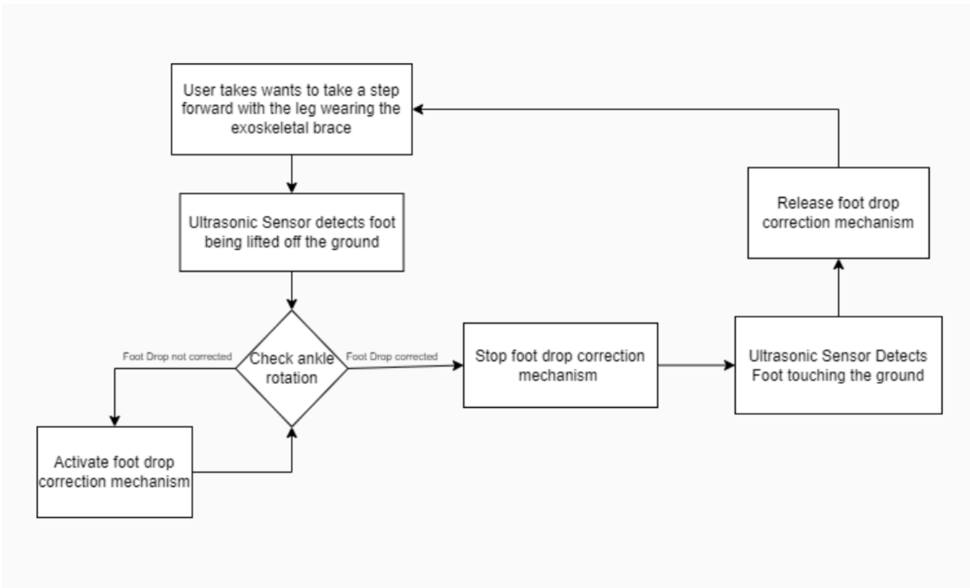


Fig 4.19 Flowchart for Ankle Mechanism

For Knee Hyperextension:

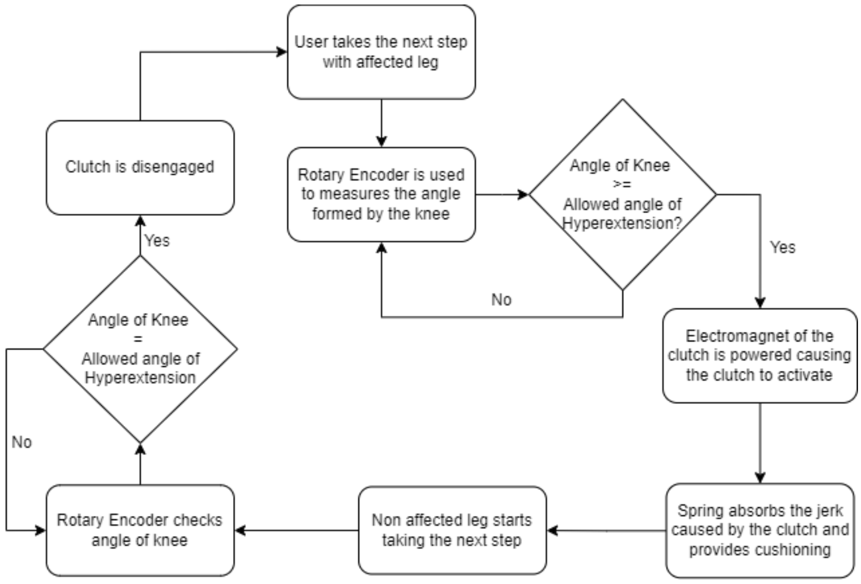


Fig 4.20 Flowchart for Knee Mechanism

4.3 Terrain Detection Using CNN

4.3.1 Dataset

The Dataset is a collection of various images in 3 datasets:

1. RTK dataset - The Road Traversing Knowledge (RTK) dataset is a specialised dataset used in the field of road infrastructure analysis and navigation. Unlike traditional RTK datasets used in GPS applications, the RTK dataset with context Road Traversing Knowledge (RTK) includes detailed information about road characteristics, such as road width, surface type, lane markings.
2. KITTI dataset - The Karlsruhe Institute of Technology and the Toyota Technological

Institute (KITTI) dataset is a widely used benchmark dataset for evaluating computer vision algorithms, particularly those related to surface types. The dataset was created by recording data from a variety of sensors mounted on a car driving around the city of Karlsruhe, Germany.

3. CaRINA dataset - The road surface type subset in the CaRINA dataset includes recordings of vehicles driving on different road surfaces, such as asphalt, concrete, gravel, and dirt roads. This collection includes photos of roads with various surfaces.

4.3.2 Convolutional Neural Network:

Neural Networks are composed of node layers, containing an input layer, one or more hidden layers, and an output layer. Each node connects to another and has an associated weight and threshold. If the output of any individual node is above the specified threshold value, that node is activated, sending data to the next layer of the network. Otherwise, no data is passed along to the next layer of the network.

In a regular **Neural Network** there are three types of layers:

- **Input Layers:** It's the layer in which we give input to our model. The number of neurons in this layer is equal to the total number of features in our data.
- **Hidden Layer:** The input from the Input layer is then fed into the hidden layer. There can be many hidden layers depending on our model and data size. The output from each layer is computed by matrix multiplication of the output of the previous layer with learnable weights of that layer and then by the addition of learnable biases followed by activation function which makes the network nonlinear.
- **Output Layer:** The output from the hidden layer is then fed into a logistic function like sigmoid or softmax which converts the output of each class into the probability score of each class.

Convolutional Neural Network (CNN) is a type of Deep Learning neural network architecture commonly used in Computer Vision. Computer vision is a field of Artificial Intelligence that makes it possible for a computer to comprehend and analyse an image or other visual data.

A CNN usually has multiple layers, with each able to learn and detect the different features present in an input image. A **kernel** which is a sort of a filter is applied over the set of input images to produce an output of features extracted which gets progressively more detailed and accurate after each layer.

In the initial layers, the filters usually start as simple features. At each successive layer, the filters progressively increase in complexity so as to check and identify the features that uniquely represent the set of input data objects. Thus, the output of each of the convolved images after each layer, becomes the input data for the next layer. In the last layer, which is a Fully Connected layer, the CNN is supposed to recognize the image or the object it represents. With each successive convolution, the input image goes through a set of kernels. As each filter activates certain features from the image, it does its work and passes on its output to the filter in the next layer. Each layer extracts different features and finally, all the image data progressing through the CNN's multiple layers allow it to identify the entire object.

We have decided to use a total of four CNN models. One model is solely to detect the road surface type. Depending on the output of this model, one of the other three models are selected, which will then predict the quality of the road to be “Bad”, “Good”, “Best”.

4.3.3 Layers in our model:

Our model architecture consists of several key components commonly found in convolutional neural networks (CNNs), particularly those designed for image classification tasks. Let's break down each layer:

- **Convolutional Layers (Conv2D):** Convolutional layers are the building blocks of CNNs and are responsible for extracting features from the input images. Each convolutional layer applies a set of learnable filters to the input image,which extracts important features by the convolutional operation. .During backpropagation,the kernel vector is adjusted to optimise the cost function . There are 3 Conv2D layers.

- **Fully connected layers :** Fully connected layers, also known as dense layers, are traditional neural network layers where each neuron is connected to every neuron in the previous layer. In our model, these layers take input from the convolutional layers in the form of a latent space matrix . They serve as a way to learn complex non-linear relationships in the data..
- **Softmax Layer:** The softmax layer is the output layer of the network and is used for multi-label classification tasks. It takes the output from the previous layer (usually logits or scores) and applies the softmax function, which normalises the values into a probability distribution over multiple classes. Each output node in the softmax layer represents the probability that the input belongs to a particular class. There is 1 softmax layer.

Overall, your model architecture follows a common pattern for image classification tasks, where convolutional layers are used for feature extraction, followed by fully connected layers for classification, and finally a softmax layer for generating class probabilities. Training such a model involves optimising the network's parameters (weights and biases) using a suitable optimization algorithm and a labelled dataset to minimise the classification error.

```
layer_conv1 = create_convolutional_layer(input=x,
               num_input_channels=num_channels,
               conv_filter_size=filter_size_conv1,
               num_filters=num_filters_conv1)
layer_conv2 = create_convolutional_layer(input=layer_conv1,
               num_input_channels=num_filters_conv1,
               conv_filter_size=filter_size_conv2,
               num_filters=num_filters_conv2)

layer_conv3= create_convolutional_layer(input=layer_conv2,
               num_input_channels=num_filters_conv2,
               conv_filter_size=filter_size_conv3,
               num_filters=num_filters_conv3)

layer_flat = create_flatten_layer(layer_conv3)

layer_fc1 = create_fc_layer(input=layer_flat,
                     num_inputs=layer_flat.get_shape()[1:4].num_elements(),
                     num_outputs=fc_layer_size,
                     use_relu=True)

layer_fc2 = create_fc_layer(input=layer_fc1,
                     num_inputs=fc_layer_size,
                     num_outputs=num_classes,
                     use_relu=False)

y_pred = tf.nn.softmax(layer_fc2,name='y_pred')
```

Fig 4.21 Layers in the CNN

4.3.4 Classes in the dataset:

4.3.4.1 Road Type Detection model:

- **Paved (Asphalt):**

  Paved asphalt roads are among the most common types of roads worldwide, known for their durability, smoothness, and relatively low cost. These roads are constructed using asphalt, a mixture of aggregates (such as sand, gravel, or crushed stone) and asphalt binder, which is a sticky, black, and highly viscous liquid derived from petroleum.

- **Paved (Concrete):**

  Paved concrete roads are a common type of road construction known for their strength, durability, and long lifespan. These roads are made using a mixture of cement, water, and aggregates (such as sand, gravel, or crushed stone), which is poured and then cured to form a solid surface.

- **Unpaved:**

  Unpaved roads, also known as dirt roads, gravel roads, or unsealed roads, are roads that are not covered with a hard, paved surface like asphalt or concrete. Instead, they are typically made from natural materials such as soil, gravel, or crushed stone.

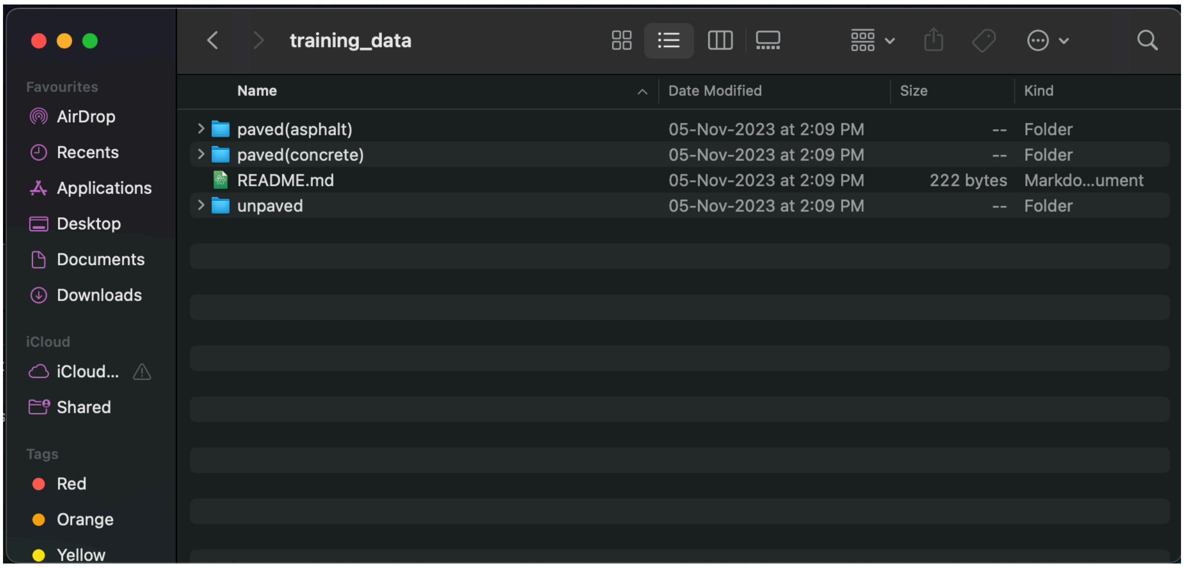


Fig 4.22 Classes in the Road Type Detection dataset

4.3.4.2 Road Quality Detection Model:

This model returns the quality of the road based on the type of the road detected by the previous model. The specific model returns the quality of the road in terms of percentage, with 0 being the lowest and 100 being the highest.

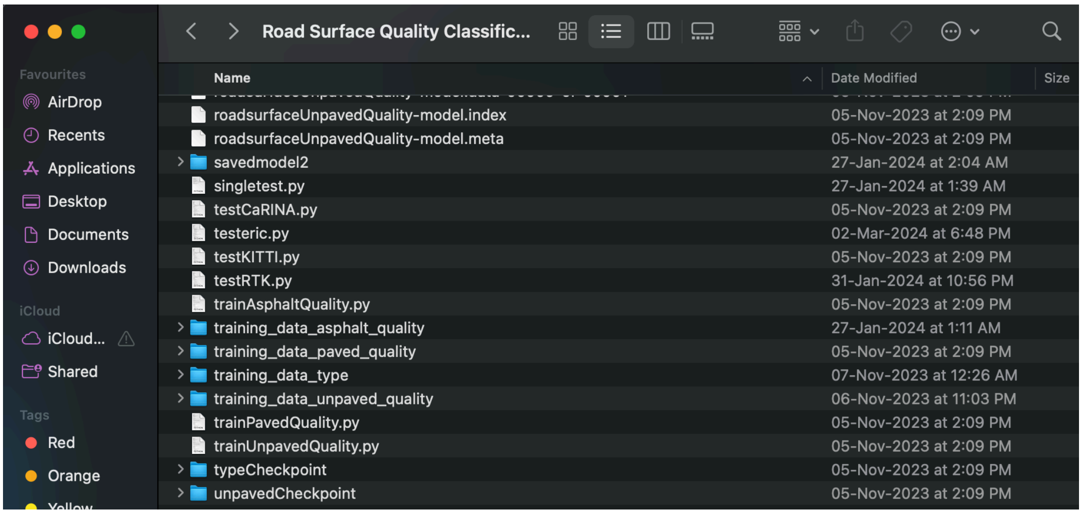


Fig 4.23 KITTI , CaRINA & RTK dataset

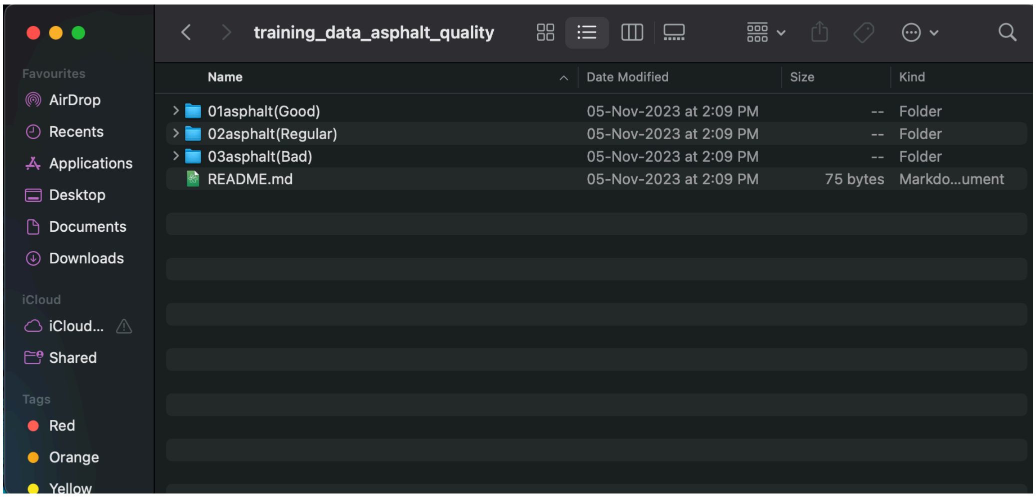


Fig 4.24 Classes for quality of road

We have made a terrain detection Convolutional Neural Network CNN to detect the condition of roads for the user to walk. The condition and type of the road is the primary factor in deciding the angle of the ankle and parameters of the sensors.

For the model, we made a custom dataset consisting of various images classified in 3 different classes Viz asphalt, muddy road and paved road. The CNN model will be deployed on raspberry pi to be accessed by the microcontroller to share images and obtain labelled data.

```
1]: model.summary()

Model: "sequential_4"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_11 (Conv2D)          (None, 126, 126, 32)      896

 max_pooling2d_8 (MaxPoolin  (None, 63, 63, 32)        0
 g2D)

 conv2d_12 (Conv2D)          (None, 61, 61, 64)        18496

 max_pooling2d_9 (MaxPoolin  (None, 30, 30, 64)        0
 g2D)

 conv2d_13 (Conv2D)          (None, 28, 28, 64)        36928

 flatten_4 (Flatten)         (None, 50176)             0

 dense_8 (Dense)             (None, 128)               6422656

 dense_9 (Dense)             (None, 2)                 258

=================================================================
Total params: 6479234 (24.72 MB)
Trainable params: 6479234 (24.72 MB)
```

Fig 4.25 Parameters learned in CNN

An ESP32 camera can be used to capture images and then send them to a server for real-time detection using various machine learning or computer vision algorithms. Here's a general overview of how this process works:

- **Capture Images:** The ESP32 camera captures images using its camera module. The camera module can be configured to capture images at regular intervals or in response to specific triggers.
- **Encode Images:** The captured images are then encoded into a suitable format for transmission over the network. Common formats for images include JPEG or PNG.
- **Send Images to Server:** The ESP32 connects to a server over a network (e.g., Wi-Fi) and sends the encoded images to the server. This can be done using HTTP or MQTT protocols, among others.
- **Server-Side Processing:** On the server side, the received images are decoded and processed using real-time detection algorithms. This could involve object detection, facial recognition, or any other computer vision task.
- **Response:** Based on the results of the detection algorithms, the server can send back instructions or data to the ESP32. For example, if a specific object is detected, the

server might instruct the ESP32 to take a certain action.

- **Feedback Loop:** The ESP32 can continuously capture and send images to the server, creating a feedback loop where real-time detection and actions can be performed based on the analysis of each image.

4.3.5 Server:

In this setup, the Azure Remote Desktop is acting as a host for an Ubuntu system, which serves as the environment for running your image classification model. The model likely utilises TensorFlow, to classify images sent from the ESP32. Here is how the process works:

- **Azure Remote Desktop Setup:** The Azure Remote Desktop is configured to run an Ubuntu operating system, providing a virtual environment for hosting your model. This setup allows you to access and manage the Ubuntu system remotely from any device with an internet connection.
- **Image Classification Model:** The Ubuntu system hosts the image classification model, which has been trained to recognize specific objects, scenes, or patterns in images. The model is likely implemented using a deep learning framework and has been trained on a dataset to learn the patterns associated with different classes.
- **ESP32 Image Transmission:** The ESP32 captures images using its camera module and sends them to the Azure Remote Desktop for classification. This communication is likely done over a network connection, such as Wi-Fi, using the HTTP protocol.
- **Image Classification:** Upon receiving an image, the Ubuntu system processes it using the image classification model. The model analyzes the image and produces a prediction, indicating the class or category that the image belongs to.
- **Feedback to ESP32:** The classification result is then sent back to the ESP32, which can use this information to take further action based on the classification result. For example, if the image is classified as containing a specific object, the ESP32 could trigger a corresponding action or response.

Overall, this setup allows for remote image classification using a model hosted on an Ubuntu system running on Azure Remote Desktop. It demonstrates the integration of edge devices (ESP32) with cloud-based resources for performing complex AI tasks such as image classification.

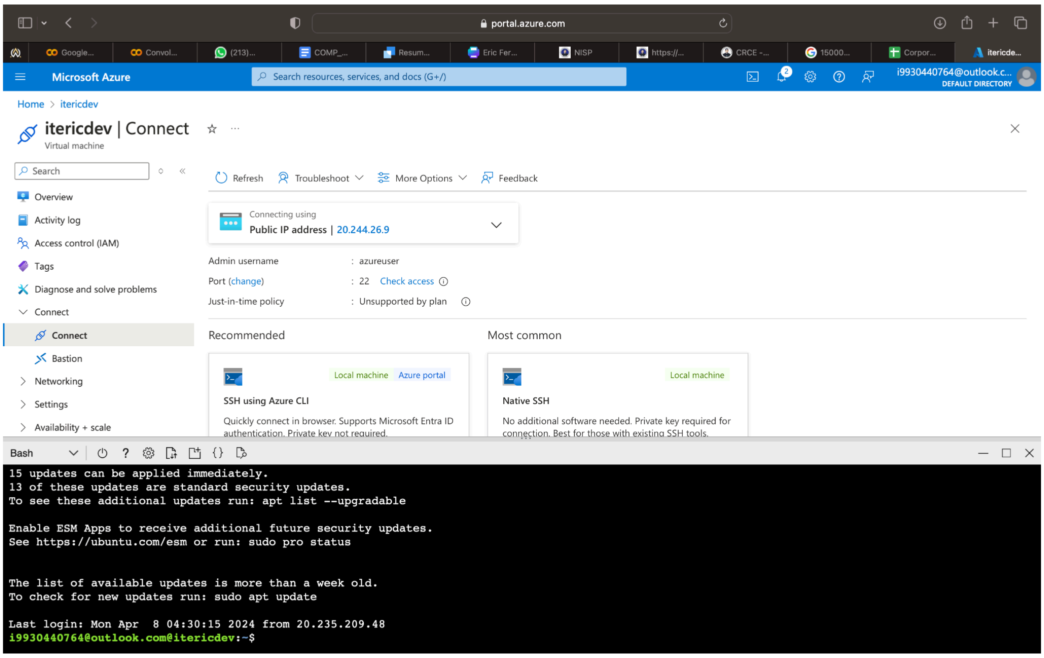


Fig 4.26 Azure Web Server

4.4 Bill of Materials

Table 4.1 Bill of Materials

Sr.No	Components	Material	Quantity	Price (Rs)
1.	ESP32-CAM	-	1	618
2.	Ultrasonic Sensors	-	1	86
3.	Cytron MD10C Motor Driver	-	1	1109
4.	Arduino Nano	-	1	264
5.	Electromagnetic Tooth Clutch	Mild Steel	1	7080
6.	Strap	Nylon	1	100
7.	Bevel gears	Nylon	2	750
8.	High Torque motor	-	1	1079
9.	8mm SS Shaft	Stainless Steel	1	100
10.	Ball bearings	Stainless Steel	3	225
11.	Fabrication cost	PLA, Aluminium	-	10000
12.	Rotary Encoder	-	1	1689
13.	Compression Spring	Spring Steel	2	150
14.	LiPo Batteries	-	1	6399
15.	10mm SS shaft	Stainless steel	-	150

16.	4mm Aluminium Plate	Aluminium 1060	1	70
17.	Lip Bearing	Stainless Steel	1	50
18.	Nuts, bolts, key and threaded rod	Stainless Steel	-	453
19.	Single Channel Relay	-	1	96
20.	Cloth brace	-	1	1270
	Total	-	-	**31,738**

Chapter 5

Implementation Details

5.1 Methodology

5.1.1 Mechanical Structure

5.1.1.1 Ankle Mechanism

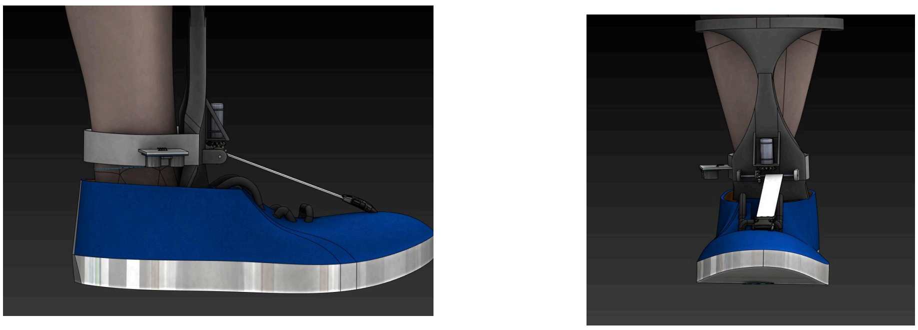


Fig 5.1 CAD model for Ankle Mechanism

Fig 5.2 Prototype for Ankle Mechanism

The mechanism controls the angular motion of the foot by pulling the ankle with the help of a nylon based fabric strip. The entire angular actuation is controlled using 2 bevel gears powered by a motor. The motor used is a medium torque motor which ensures efficient picking of the foot and maintaining the angle.

5.1.1.2 Knee Mechanism

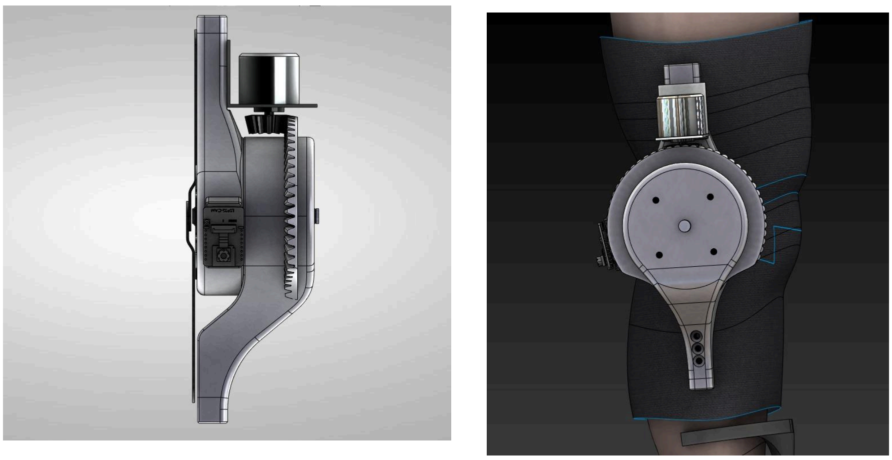
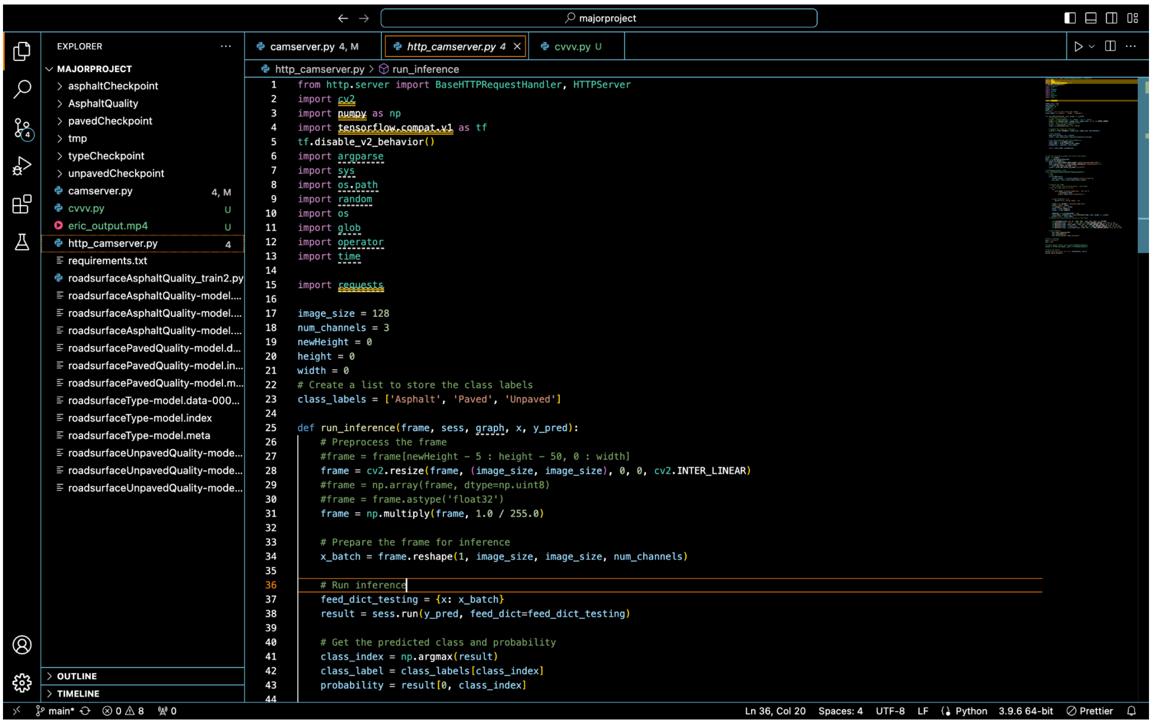


Fig 5.3 CAD model for Knee Mechanism

The above mechanism controls the excess motion of the knee in backward direction caused by hyperextension . The Above System uses a Electromagnetic tooth clutch to provide the braking force to restrict the excess Motion caused in the knee and is integrated with a clutch plate spring to provide a damping force to sudden jerky motion of clutch plate . The entire system is activated only when the knee moves beyond a certain parameter by using a rotary encoder as the feedback to the system.

5.1.2 Interfacing Azure with Arduino Uno and Esp32 Cam



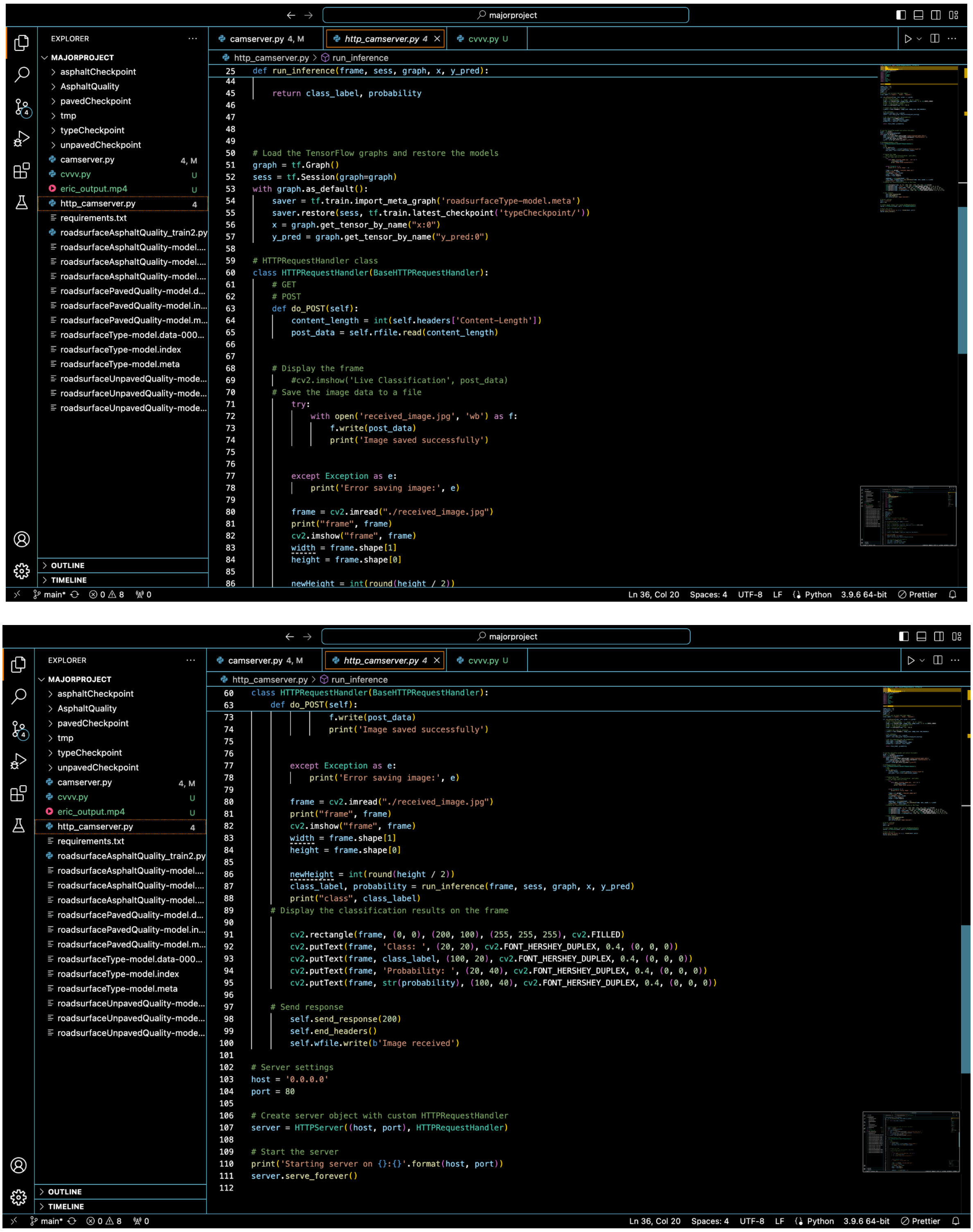
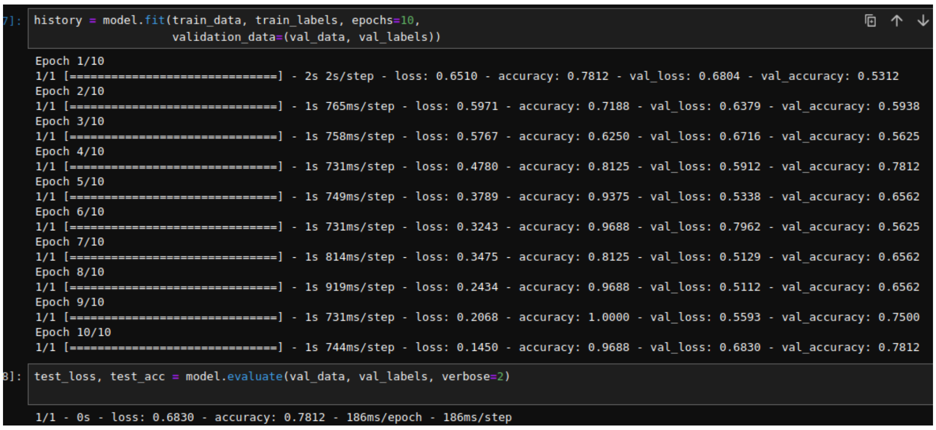


Fig 5.4 Azure Code

5.1.3 CNN Model

We have deployed a CNN model for determining the terrain of the road in front of the user which will distinguish between muddy road and smooth paved surfaces. Based on the output the microcontroller will adjust the speed and angular rotation of the mechanism to suit the particular terrain.

Made using Tensorflow 2.0 , it has a **training accuracy of 96.8 %** and a **testing accuracy of 78.12 %**, conversion in tensorflow lite and deployment over raspberry pi while integration with sensors and a wifi based microcontroller is yet to be done.



```
history = model.fit(train_data, train_labels, epochs=10,
                    validation_data=(val_data, val_labels))

Epoch 1/10
1/1 [==============================] - 2s 2s/step - loss: 0.6510 - accuracy: 0.7812 - val_loss: 0.6804 - val_accuracy: 0.5312
Epoch 2/10
1/1 [==============================] - 1s 765ms/step - loss: 0.5971 - accuracy: 0.7188 - val_loss: 0.6379 - val_accuracy: 0.5938
Epoch 3/10
1/1 [==============================] - 1s 758ms/step - loss: 0.5767 - accuracy: 0.6250 - val_loss: 0.6716 - val_accuracy: 0.5625
Epoch 4/10
1/1 [==============================] - 1s 731ms/step - loss: 0.4780 - accuracy: 0.8125 - val_loss: 0.5912 - val_accuracy: 0.7812
Epoch 5/10
1/1 [==============================] - 1s 749ms/step - loss: 0.3789 - accuracy: 0.9375 - val_loss: 0.5338 - val_accuracy: 0.6562
Epoch 6/10
1/1 [==============================] - 1s 731ms/step - loss: 0.3243 - accuracy: 0.9688 - val_loss: 0.7962 - val_accuracy: 0.5625
Epoch 7/10
1/1 [==============================] - 1s 814ms/step - loss: 0.3475 - accuracy: 0.8125 - val_loss: 0.5129 - val_accuracy: 0.6562
Epoch 8/10
1/1 [==============================] - 1s 919ms/step - loss: 0.2434 - accuracy: 0.9688 - val_loss: 0.5112 - val_accuracy: 0.6562
Epoch 9/10
1/1 [==============================] - 1s 731ms/step - loss: 0.2068 - accuracy: 1.0000 - val_loss: 0.5593 - val_accuracy: 0.7500
Epoch 10/10
1/1 [==============================] - 1s 744ms/step - loss: 0.1450 - accuracy: 0.9688 - val_loss: 0.6830 - val_accuracy: 0.7812

test_loss, test_acc = model.evaluate(val_data, val_labels, verbose=2)

1/1 - 0s - loss: 0.6830 - accuracy: 0.7812 - 186ms/epoch - 186ms/step
```

Fig 5.5 Accuracy on training and testing

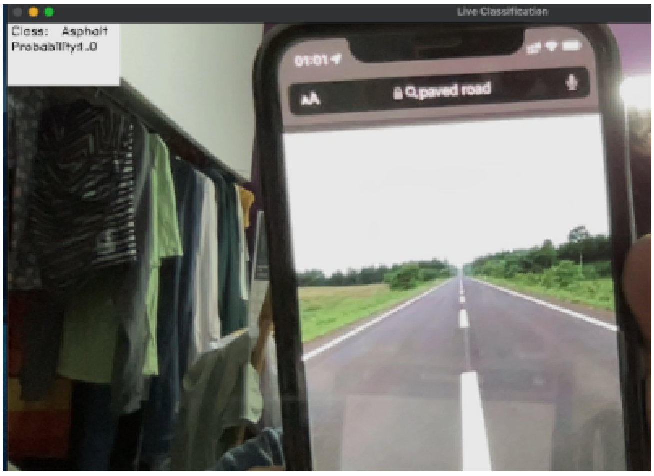


Fig 5.6 Prediction made based on CNN Model

Chapter 6

Conclusion And Future Enhancements

6.1 Conclusion

After thorough analysis of the given problem statement, i.e to assist the patient in walking in the correct and natural way, maintaining the most optimal posture and correct alignment of the knee, we developed a cost efficient and a robust mechanism to allow a smooth walking experience to the patients.

Various prototypes were generated, each representing a unique solution hypothesis. These prototypes allowed us to explore diverse approaches and possibilities. After extensive testing and evaluation, we selected the most optimal approach based on effectiveness, cost-efficiency, and durability.

Individual components of the selected approach underwent rigorous testing to ensure their reliability and functionality. Feedback from patients and healthcare experts played a pivotal role in shaping the final solution.

Their insights were actively incorporated into the development process. We continuously monitored and analysed results to assess the impact of the mechanism on walking gait, posture, and knee alignment. Our commitment to continuous improvement led to iterative refinements, ensuring that the solution met evolving user needs and expectations.

6.2 Future Enhancements

For further improvement in our model we will be integrating MPU which is a latest type of Micro Electromechanical Sensors (MEMS) for doing various tasks such as Climbing stairs, running and squatting. Further we can also incorporate features like monocular depth estimation in the image processing module using AdaBins.
The main aim of making this project is to make it cost friendly for the common folk who are suffering from the conditions and help them to live a happy and normal life.
We are also trying to make use of various dimensional reduction techniques to apply on the images from the ESP32 side, so that the latency to send the images is lower. The images are compressed, but the important features of the images are conserved so that we can reconstruct the image. One of the techniques we have used for this project is an AutoEncoder neural network. An AutoEncoder was trained on the 2014 MS COCO dataset. The AutoEncoder consists of an encoder, which takes in an input image of shape 128 x 128 and compresses it to a one dimensional vector of 128 bytes. The decoder on the server side then takes this one dimensional vector as an input, and attempts to reconstruct the image that was fed in.

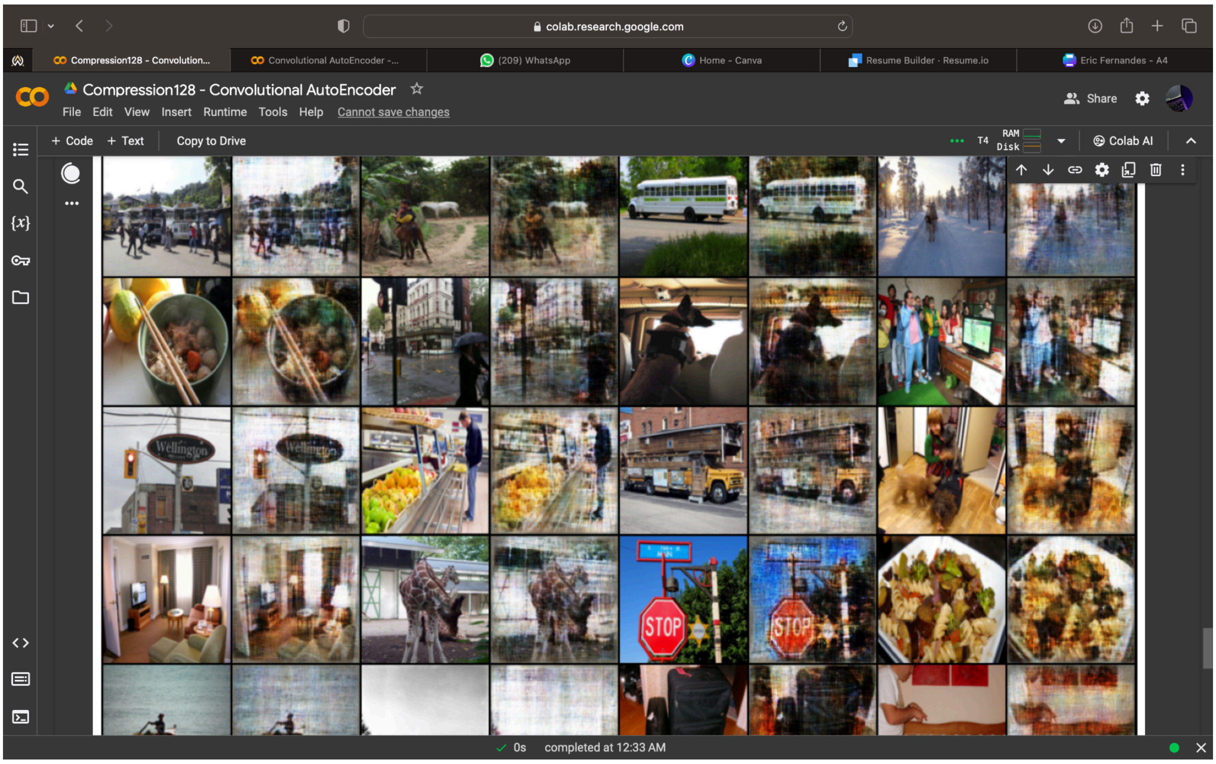


Fig 6.1: AutoEncoder Result

Chapter 7

References

[1] H. B. Gilbert and R. J. Webster, "Rapid, Reliable Shape Setting of Superelastic Nitinol for Prototyping Robots," in IEEE Robotics and Automation Letters, vol. 1, no. 1, pp. 98-105, Jan. 2016, doi: 10.1109/LRA.2015.2507706.

[2] T. Zhang, M. Tran and H. Huang, "Design and Experimental Verification of Hip Exoskeleton With Balance Capacities for Walking Assistance," in IEEE/ASME Transactions on Mechatronics, vol. 23, no. 1, pp. 274-285, Feb. 2018, doi: 10.1109/TMECH.2018.2790358.

[3] K. Gui, H. Liu and D. Zhang, "A Practical and Adaptive Method to Achieve EMG-Based Torque Estimation for a Robotic Exoskeleton," in IEEE/ASME Transactions on Mechatronics, vol. 24, no. 2, pp. 483-494, April 2019, doi: 10.1109/TMECH.2019.2893055.

[4] X. Jin, A. Prado and S. K. Agrawal, "Retraining of Human Gait - Are Lightweight Cable-Driven Leg Exoskeleton Designs Effective?," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 26, no. 4,

pp. 847-855, April 2018, doi: 10.1109/TNSRE.2018.2815656.

[5] D. Pinto-Fernandez et al., "Performance Evaluation of Lower Limb Exoskeletons: A Systematic Review," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 28, no. 7, pp. 1573-1583, July 2020, doi: 10.1109/TNSRE.2020.2989481.

[6] Sawicki, Gregory & Beck, Owen & Kang, Inseung & Young, Aaron. (2020). The exoskeleton expansion: Improving walking and running economy. Journal of NeuroEngineering and Rehabilitation. 17. 10.1186/s12984-020-00663-9.

[7] Al-Rahmani, Nour & Mohan, Dhanya & Awad, Mohammad & Wasti, Sabahat & Hussain, Irfan & Khalaf, Kinda. (2022). Lower-Limb Robotic Assistance Devices for Drop Foot: A Review. IEEE Access. 10. 1-1. 10.1109/ACCESS.2022.3174686.

[8] Uriel Martinez-Hernandez, Sina Firouzy, Pouyan Mehryar, Lin Meng, Craig Childs, Arjan Buis, Abbas A. Dehghani-Sanij,Human-in-the-loop layered architecture for control of a wearable ankle–foot robot,Robotics and Autonomous Systems,Volume 161,2023,104353,ISSN 0921-8890,

[9] Yeung, Ling-Fung & Lau, Cathy & Lai, Charles & Soo, Yannie & Chan, Man-Lok & Tong, Raymond Kai-Yu. (2021). Effects of wearable ankle robotics for stair and over-ground training on sub-acute stroke: a randomized controlled trial. Journal of NeuroEngineering and Rehabilitation. 18. 10.1186/s12984-021-00814-6.

[10] Awad, Louis & Kudzia, Pawel & Arumukhom Revi, Dheepak & Ellis, Terry & Walsh, Conor. (2020). Walking Faster and Farther With a Soft Robotic Exosuit:

Implications for Post-Stroke Gait Assistance and Rehabilitation. IEEE Open Journal of Engineering in Medicine and Biology. PP. 1-1. 10.1109/OJEMB.2020.2984429. Chellal AA, Lima J, Gonçalves J, et al. Robot-Assisted Rehabilitation Architecture Supported by a Distributed Data Acquisition System. Sensors (Basel). 022;22(23):9532. Published 2022 Dec 6. doi:10.3390/s22239532

PAPER NAME

BE_Project_Report.pdf

AUTHOR

Rhea Bhalekar, Jacob Mire

WORD COUNT

6395 Words

CHARACTER COUNT

31510 Characters

PAGE COUNT

42 Pages

FILE SIZE

10.3MB

SUBMISSION DATE

May 2, 2024 4:49 PM GMT+5:30

REPORT DATE

May 2, 2024 4:50 PM GMT+5:30

16% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

- 13% Internet database
- 8% Publications database
- Crossref database
- Crossref Posted Content database
- 12% Submitted Works database

16% Overall Similarity

Top sources found in the following databases:

- 13% Internet database
- 8% Publications database
- Crossref database
- Crossref Posted Content database
- 12% Submitted Works database

TOP SOURCES

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

1	techtarget.com Internet	2%
2	alchetron.com Internet	2%
3	ijirset.com Internet	1%
4	Younes Ledmaoui, Adila El Maghraoui, Mohamed El Aroussi, Rachid Sa... Crossref	1%
5	mdpi.com Internet	1%
6	github.com Internet	1%
7	University of Exeter on 2019-08-22 Submitted works	<1%
8	ezyxpo.com Internet	<1%

9 **coursehero.com** — Internet — <1%

10 **sciendo.com** — Internet — <1%

11 **geeksforgeeks.org** — Internet — <1%

12 **americaspg.com** — Internet — <1%

13 **Solihull College, West Midlands on 2018-12-17** — Submitted works — <1%

14 **University of Glasgow on 2021-08-19** — Submitted works — <1%

15 **kelloggsresearchlabs.com** — Internet — <1%

16 **Nottingham Trent University on 2023-02-19** — Submitted works — <1%

17 **University College London on 2012-09-03** — Submitted works — <1%

18 **Dingnan Zhang, Tao Peng, Ruixu Liu, Danhuai Zhao, Kai Sun, John Loo...** — Crossref — <1%

19 **The University of Manchester on 2019-05-13** — Submitted works — <1%

20 **ineltek.ru** — Internet — <1%

21	koreascience.or.kr Internet	<1%
22	Liverpool John Moores University on 2023-03-05 Submitted works	<1%
23	es.scribd.com Internet	<1%
24	University of Reading on 2019-04-29 Submitted works	<1%
25	University of Wales Institute, Cardiff on 2023-09-04 Submitted works	<1%
26	journal.lembagakita.org Internet	<1%
27	slideshare.net Internet	<1%
28	C. Subharaj, K. Logesh, S. Joe Patrick Gnanaraj, M. Appadurai, P. Maria... Crossref	<1%
29	Daniele Roberto Giacobbe, Cristina Marelli, Sabrina Guastavino, Sara M... Crossref	<1%
30	Energy Storage Compression and Switching, 1976. Crossref	<1%
31	Nottingham Trent University on 2024-04-18 Submitted works	<1%
32	University of East London on 2013-01-03 Submitted works	<1%

33	Blackpool and The Fylde College, Lancashire on 2024-03-26 Submitted works	<1%
34	University of Greenwich on 2024-04-28 Submitted works	<1%