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Dept of Mech. Engg.

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Final Presentation

Neurorehabilitation Of Wrist Using Manipulandum

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Overview of presentation

Introduction-MOTIVATION-1

- Approximately 780,000 people suffer from stroke in the US. Even though majority number of people survive, they do so with a permanent disability. Greater than 11 lakh adults reported restraints in their day to day activities caused due to stroke. 50% - 70% of stroke survivors get back their functionalities post stroke. Still 30% are disabled permanently, in which 20% require professional care for 3 months post stroke. The chances of stroke doubles after every decade after the age of 55 years, this group is specifically prone to suffer from cerebrovascular accident.
- The inability to achieve the natural strength may have additional effect on the subject , such as depression and anxiety.
- The current rehabilitation exercises are monotonous in nature, and doesn't check for the evaluation parameters Eg Frenkel Exercises
- There is no diagnostic tool to gauge the competency of the subject, failing to understand the improvement of the subject.

Summary of slide

The study of neurorehabilitation enables to evaluate and judge the subjects' base don certain parameters. The key to effective treatment of impairment is neuro rehabilitation, which enable the sensory part of the human body to attain the lost natural strength in an effective way.

Introduction- Motivation 2

- Being a self monitored device, the product is able to penetrate the market very easily without any sort of inaccessibility
- A continuous monitoring device for performance based evaluation based treatment is required, which the existing manipulandum failed to achieve.
- Wood-Dauphinee et al examined the performance of traditional care versus a disciplinary team in a randomized controlled trial for male and female patients and compared the performance measures, this was tested for motor performance and functional abilities. The total time spent on rehabilitation varies significantly between institutions, countries and units.
- It was found out that the estimated stroke cost around 3% of the total national health expenditure which is approximately $30 billion in the US.
- According to recent report by Transparency Market Research(TMR), the global neurorehabilitation devices market is estimated to expand at CAGR of 15.5% for the forecast period 2016-2019, and expected to reach a valuation of USD 3.2 billion, from estimation of USD 894.9 mn in 2015.

Summary of slide

The global scenario involves a great scope for research in the field of bio mechanics, for consistent development and adapting various technologies to overcome the patient inabilities. The manipulandum has a wide range of applications and its market is expected to reach $32billion by 2024

Literature Review - Review on Apparatus and Materials

- A multi DOF robot manipulandum out of 7000 aluminium series to make it light and portable. The grip was cylindrical in form and is fabricated from the same material . [1]
- A parallel wrist rehabilitation robot fabricated out of aluminium 6061-T6 series . The fatigue life was determined considering eight hours per day for five days of the week as the routine having semi annual maintenance. The design had modifications for measurement for different angles. The grip was slender cylindrical end effector. The system had a secondary system for measurement of the secondary movements of wrist.[2].
- A single degree of freedom manipulandum with six different types of grips. They are a combination of the finger spacing and the structure of the grip. The material here used was aluminium plate for all the mountings along with foam to overcome undue vibrations.[3].
- A single degree of freedom manipulandum was used to analyse the motor dysfunction in children. The grip was a rectangular bar which tend to make the patient finger an angle of 20 degree. The main frame was built out of aluminium billets with modular extensions, so as to enable required changes as per alteration in the age group. [4].

<u>Summary of slide</u>

A number of manipulandum was developed with aluminium along with foam with a cylinder form of grip. All the device was designed for semi annual maintenance with maximum of 8 hrs/day and five days a week.

Literature Review - Review on Apparatus and Material

- A gripper made of rapid proto typing, while the rest of the assembly out of aluminium. To reduce the complexity of wiring and routing within the grip, the rapid proto typing was adopted. [5].

  Summary of slide

  A manipulandum device was developed by rapid prototyping, having the form of a bottle enabling suitable interface for the subject. The material here used was acrylonitrile butadiene styrene.

Literature Review - Review on Experimental Studies

- With three minute warm up wrist exercise and is set for measurement. The test had 12 sets of reading of random motion of wrist. The individual is asked to relax their muscles from time to time .Range of motion was measured from the experiment performed. [6].
- A set of three to five exercises lasting fifteen minutes .Immediately followed by resting period of two minutes. The measurement included the three dimensional data captured by the infra red cameras. The physiological motion space was obtained from the acquired data.[7]
- Measuring the force and torque that is exerted on the grip of the robot using hybrid impedance control. The patient was guided to perform a series of exercise which includes passive, active, isotonic, isometric exercise. The parameters that were assessed were force , torque and range of motion. The torque on the couple arm was obtained in the entire process.[8]

Summary of slide

The measurement of evaluation parameters require the patient to loosen their muscles, so as to avoid any error in the measurement. The pre existing stress creates too much variation in the reading.

Literature Review - Review on Experimental Studies

- With the help of a single degree of freedom, measured force at various grip positions and angles. A compressive load cell was used to measure the force exerted on the grip and corresponding graph of force versus angle and force versus time is plotted.[9]
- The sensori-motor impairment, which was assesed by the accuracy of the reproducibility of a memorized angle, with the patient vision occluded. Reactive muscle response was checked for various perturbation in tasks that had to be executed. Mirror vision therapy was also used for illusionary sensory feedback. [10]
- Measuring the force on the manipulandum. It comprised of four sessions and each session had 80 trials respectively. The trial begins with fixation of the grip at hold position on the screen and then followed by the path traced on the computer. Each path being unique gives force a various positions. The pneumatic actuator assists the patient in achieving the required target.[11].

Summary of slide

The experimental studies for neurorehabilitation involves evaluation parameters such as force, torque and the range of motion of the wrist. The grip strength at various positions of the wrist angle is mapped at the respective positions.

Literature Review - Review on Sensors And Actuation

- A study comprising of two different manipulandum of which one is fixed and the other being able to float with the help of wood mountings. The displacement was measured with the help of a electro magnetic motion capture system, which was a non contact sensor and thus was more reliable.[15].
- The rehabilitation device was pneumatically actuated and provided controlled flexion and extension torques, while also monitoring actuator pressure and joint angles. The reading was made through commercially available sensors [16].
- The evaluation of chronic stroke patients with the help of a robot assisted manipulandum. The torque was measured using a torque sensor AKC-250A at every interval. The wrist angle signals were measured by the encoder in the motor and having a check on the forearm that is fixed on to the platform. [17].
- H shaped cable driven differential mechanism, thus giving direct transmission and ease of control. It led to a very responsive system with force transmission bandwidth greater than 10Hertz. [18].

Summary of slide

Multiple actuators starting from pneumatic, electronic were implemented, yet due ton repetitive usage the electronic actuators find its application more dominant. The sensory part of the manipulandum involving non contact sensor prove to ineffective as their awas measurement error or certain offset to be entered every time.

Literature Review - Review on Machine Learning Algorithms

- Examining the influence of disability of arm, shoulder and hand(DASH), range of motion, and anthropometric data on grip and pinch strength. They used multiple regression analysis for finding the association between the variables that could predict the grip strength. [12]
- The loss of motion range of the wrist and elbow to predict the impairment percentage for the upper extremity through statistical analysis softwares. High R-squared values indicated strong prediction capabilities, except for adduction and abduction of the shoulder, using just the range of motion as parameter.[13]
- Study involving nine parameters in 22 patients for their fine motor skills, and concluded that grip force scaling, speed of motion and motor coordination to be the differentiating factors between healthy and impaired individuals. They were able to successfully predict the results of the JTHFT test by their analysis.[14]

Summary of slide

Running a regression model verifies that motor skills were successfully predicted by physiological factors. Extension of the work lead to determining of the percentage impairment. Most important factors out of 9 factors were found to be grip strength, speed of motion and coordination.

Objectives

- A manipulandum is to be developed which consists of a grip that can swing about a motor axis. Using wrist flexion/extension, the patient range of motion is to be recorded using encoder readings.

- The grip also has to measure grip strength using a load cell so that patients can record their grip strengths at angles in steps throughout their range of motion.

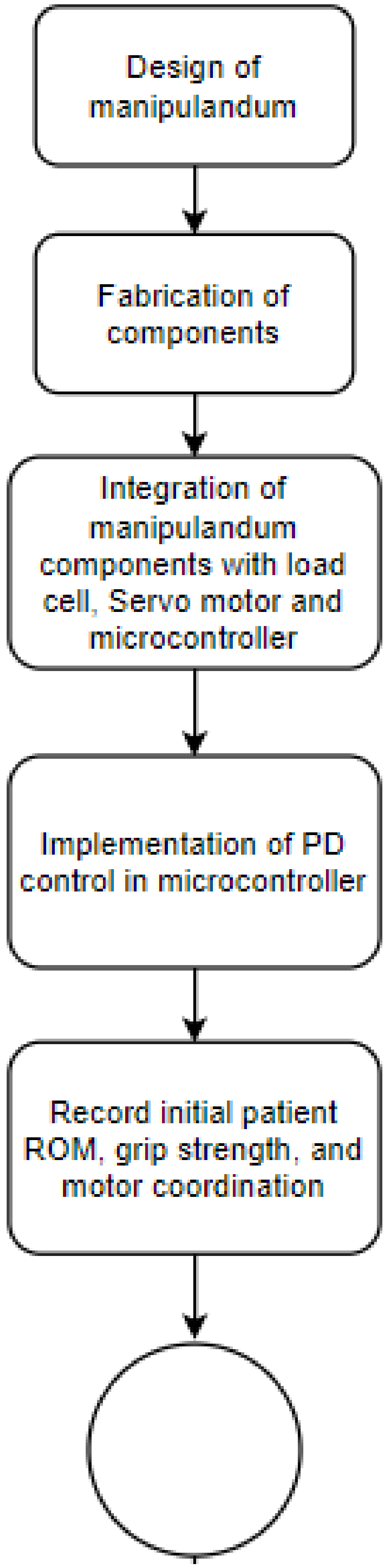
- Motor coordination is to be measured as the patient tries to coordinate wrist motion with a pre-programmed marker which moves randomly about the same axis as the grip.

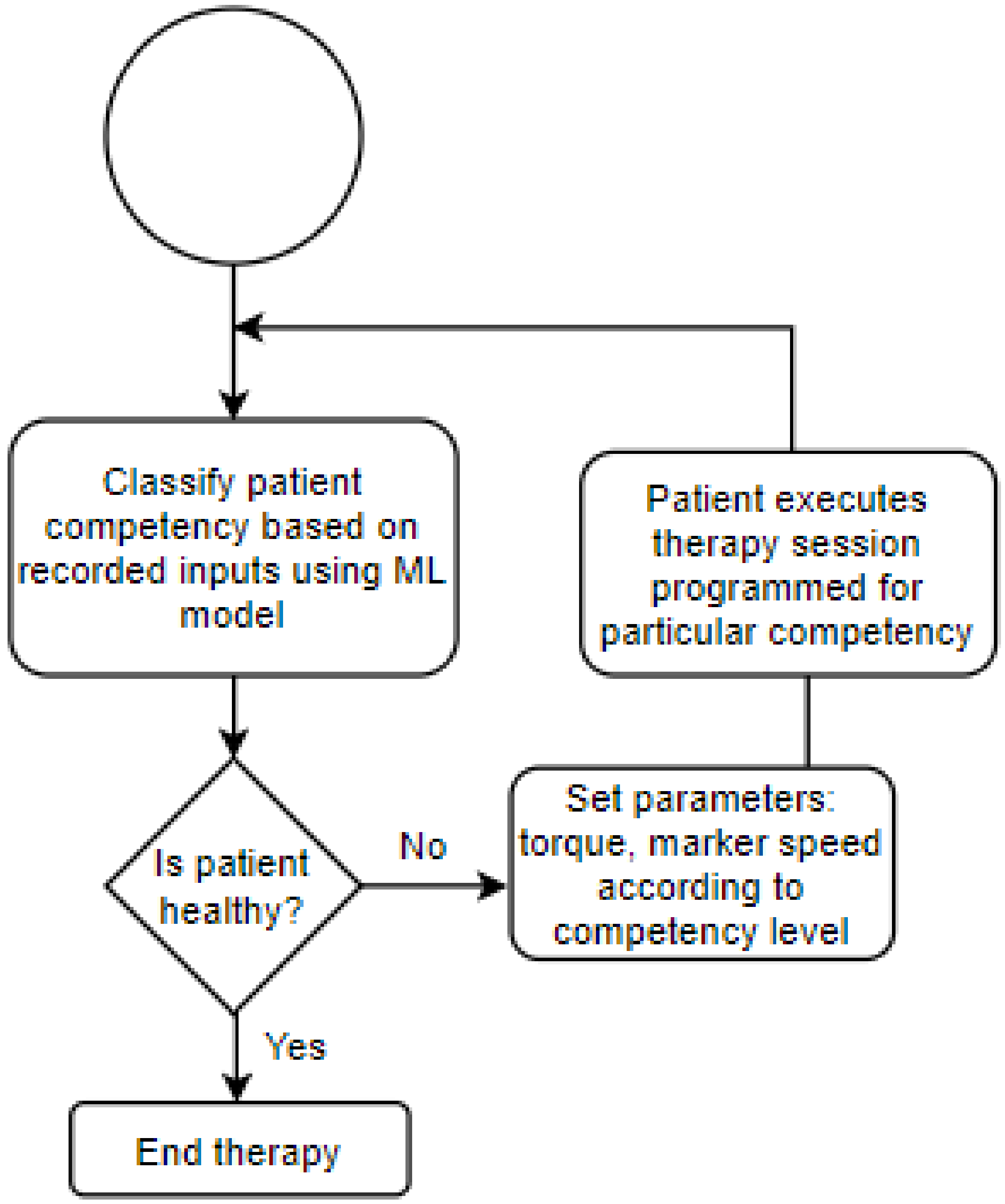
- A machine learning model has to be deployed and trained to classify the patients either as healthy or as impaired, in which case the degree of impairment is also determined.

- Suitable therapies are determined according to degree of impairment. These therapies have to differ from each other in terms of torque impedance of motor that has to be overcome in order to move the grip, or even the speed and randomness with which the marker which has to be followed, moves.

- Assist-as-needed control of servo motor also has to be programmed to implement passive motion in case of inability to move wrist.

Methodology

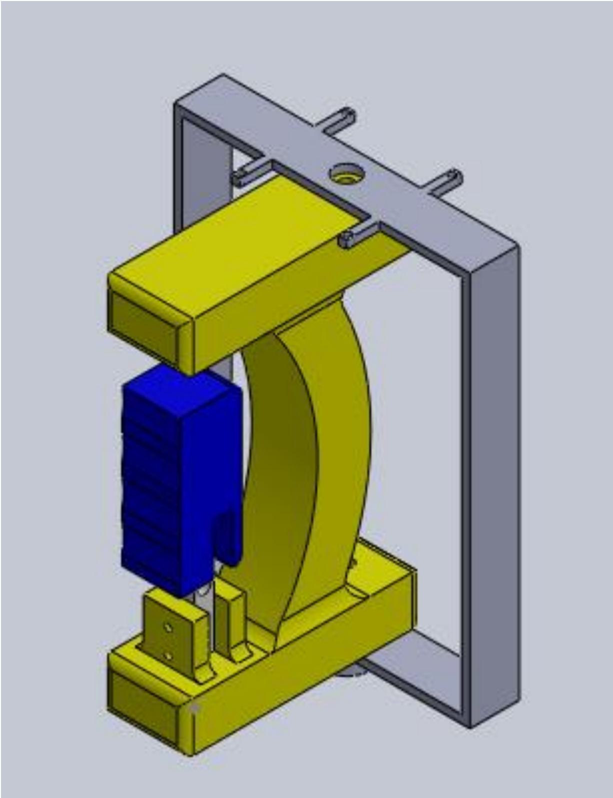


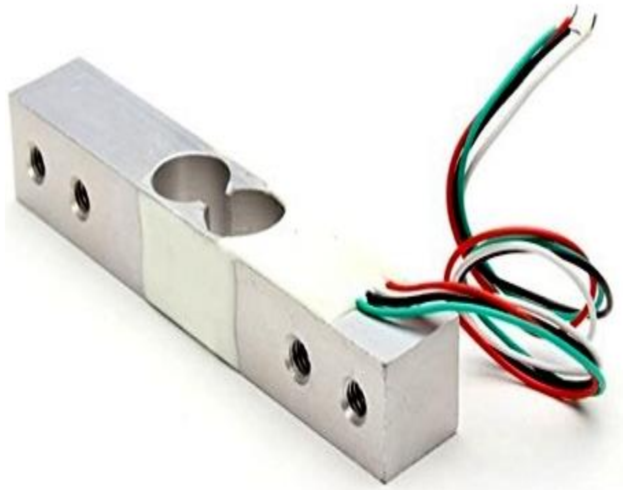


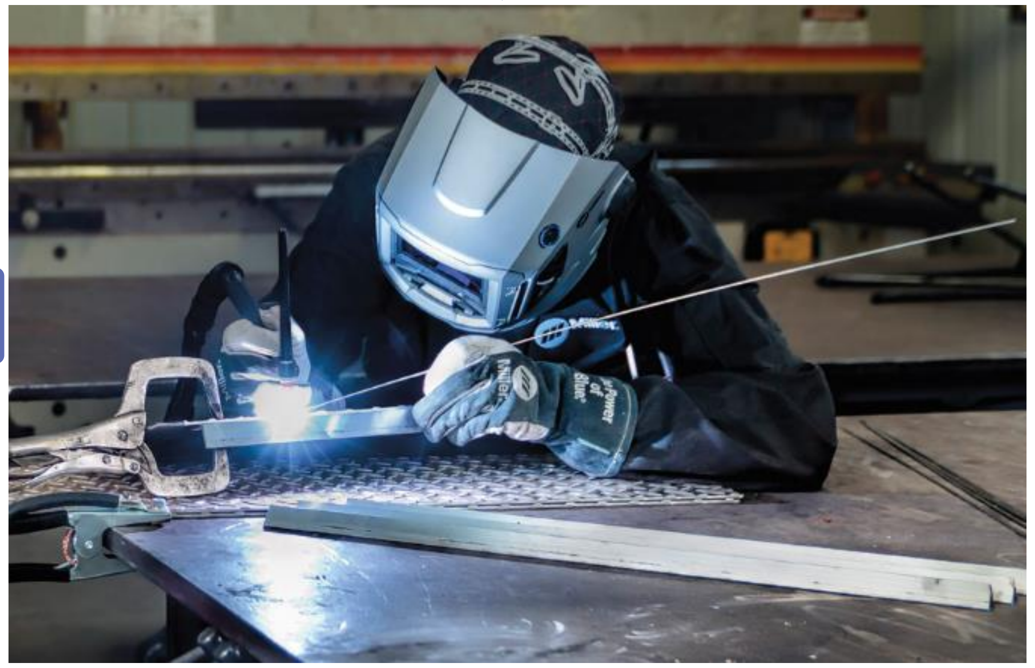
Methodology

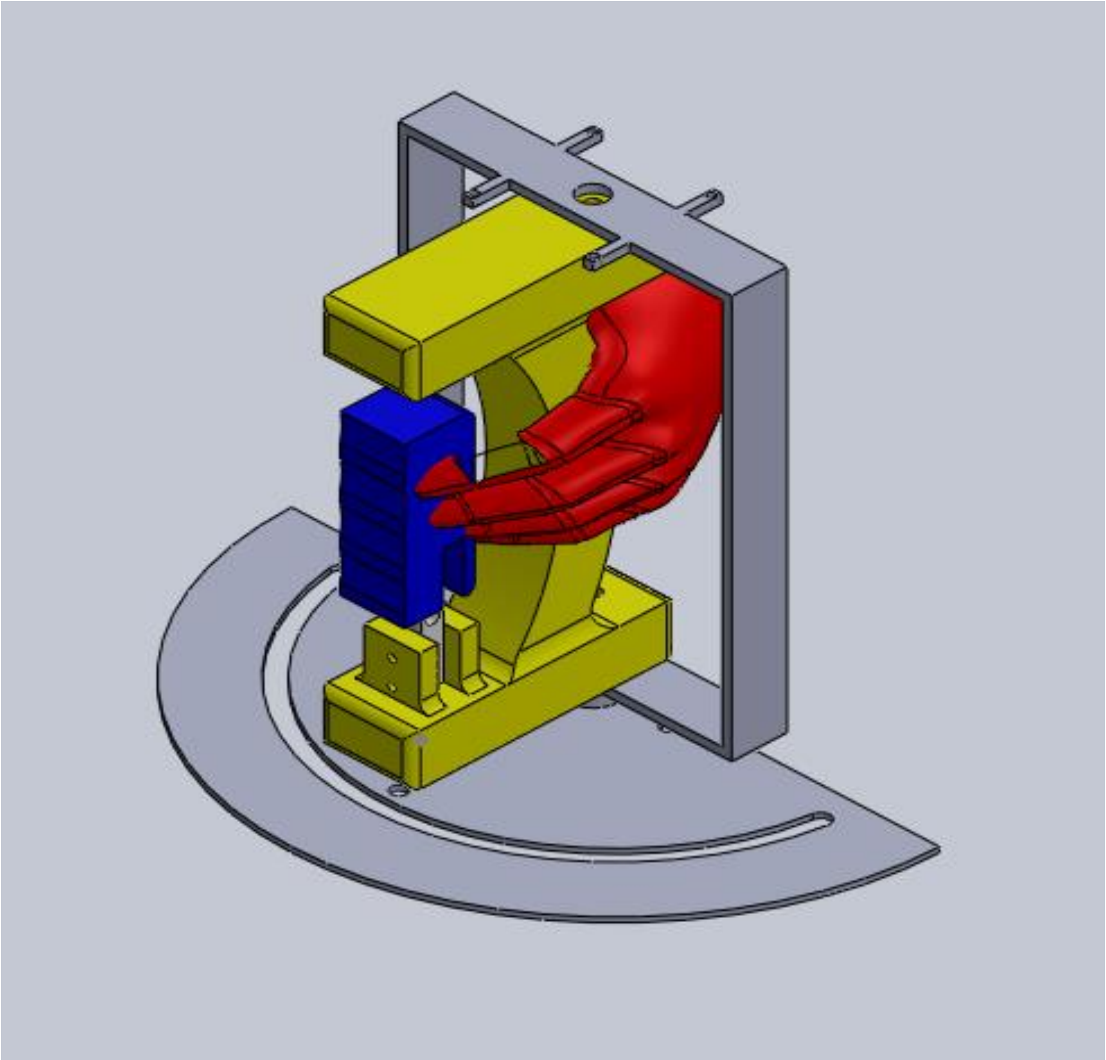
- A one DOF manipulandum is designed and developed for a specific age group.
- The manipulandum is then integrated with the sensor (strain gauge) and the actuator (Servo Motor) having the digital encoder.
- Further the system is integrated with machine learning algorithm and creating an interface between motor, actuator and the algorithm.
- The test subject is locked with his for arm at a the neutral position and checked for grip strength and range of motion at neutral position followed by various wrist angles.
- The data acquired is then used to determine the competency of the patient and suggest suitable therapeutic exercises.
- The subject is then exposed to continuous exercise evaluation of the manipulandum and is checked for the competency at regular intervals.
- The subject is either assisted or resisted based upon the competency passively.
- The process is carried out till the evaluation parameters are at par with the normal condition.

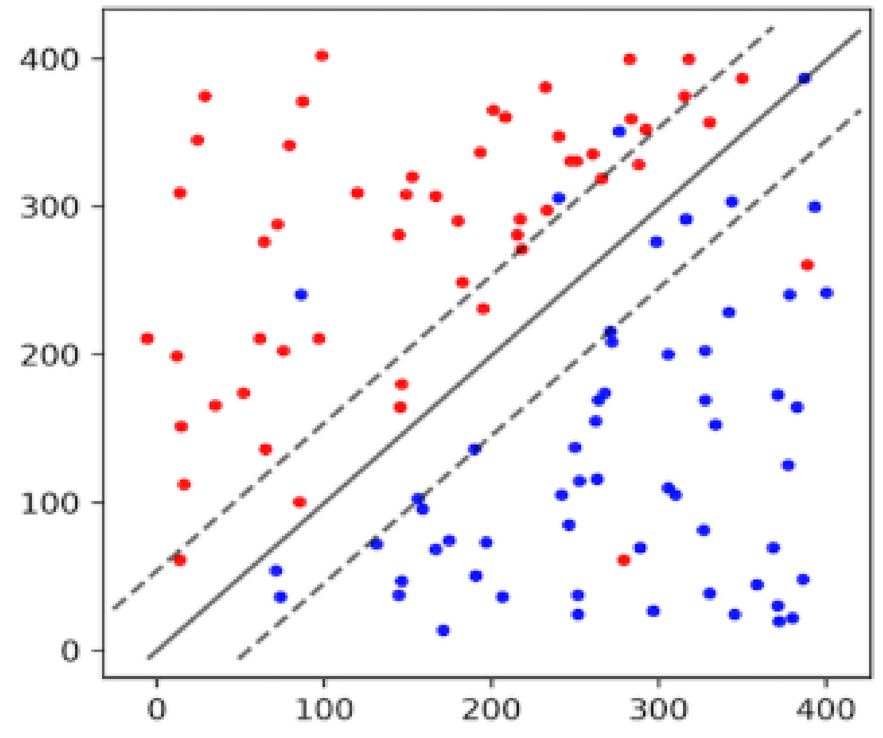
Work carried out





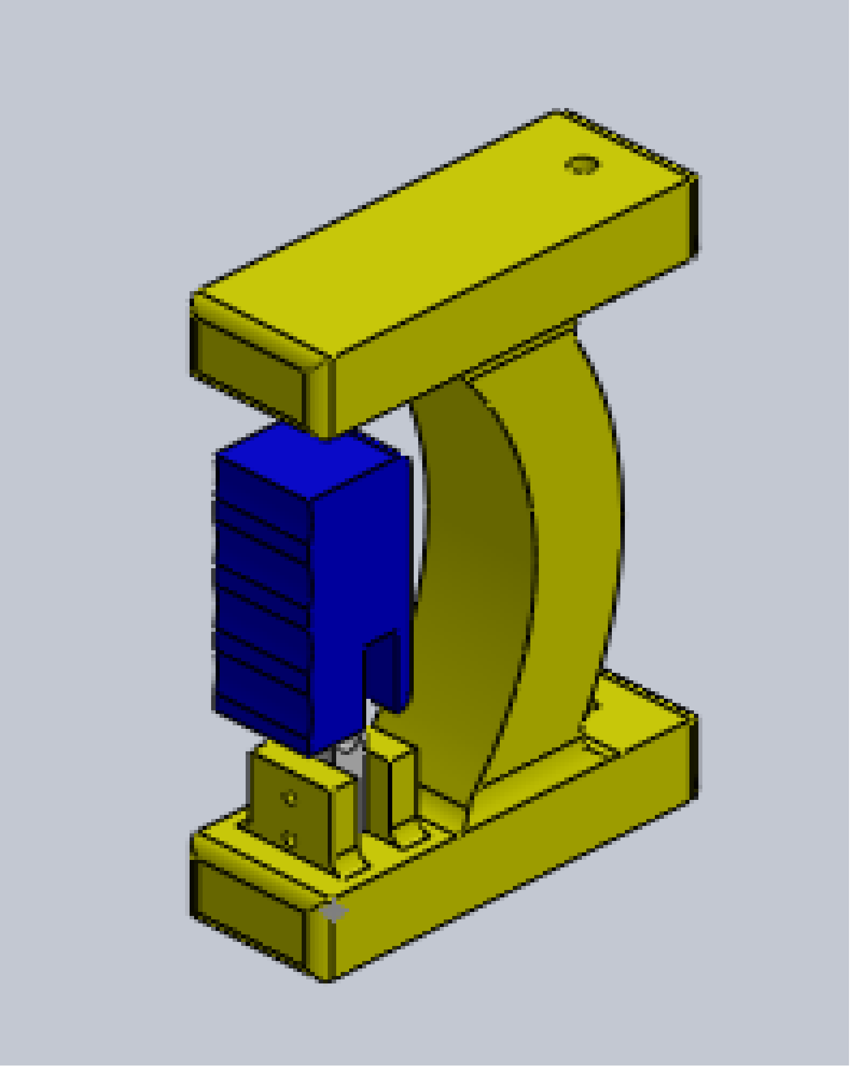


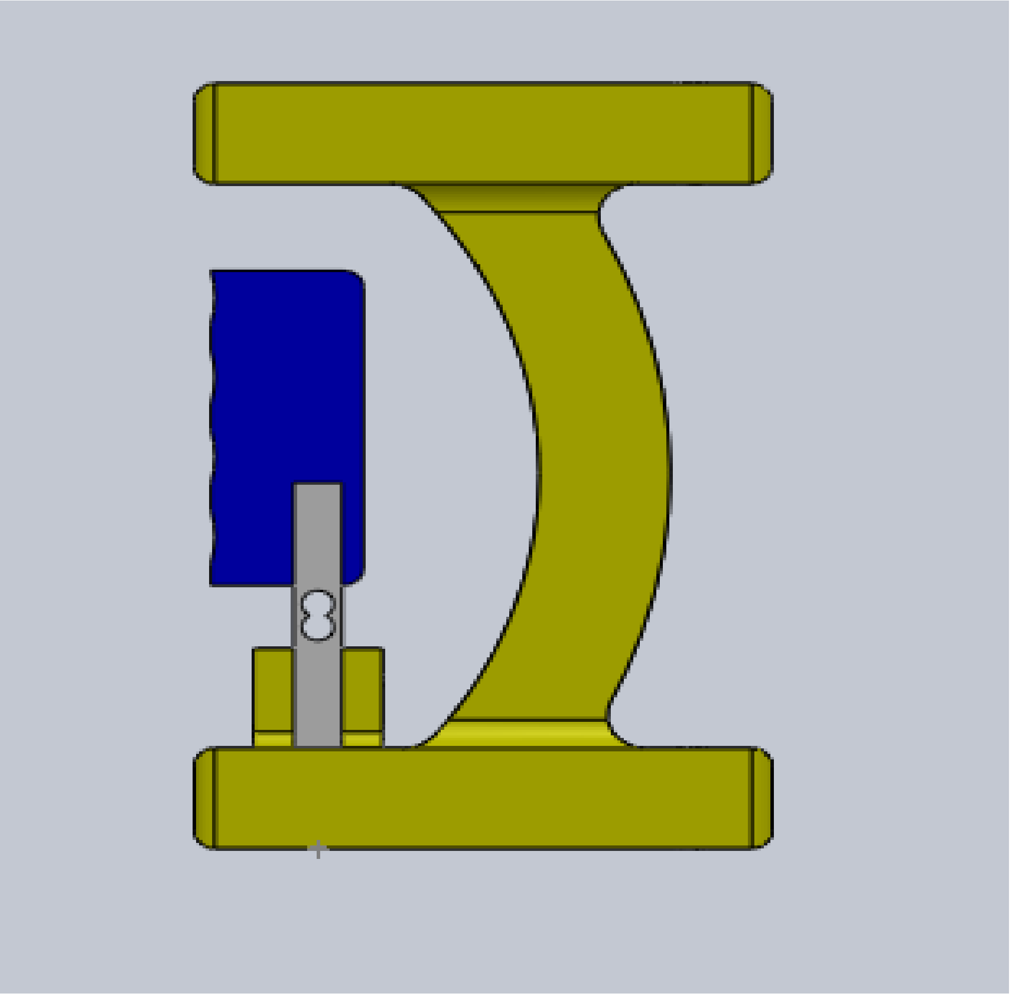




Detailed procedure of Methodology

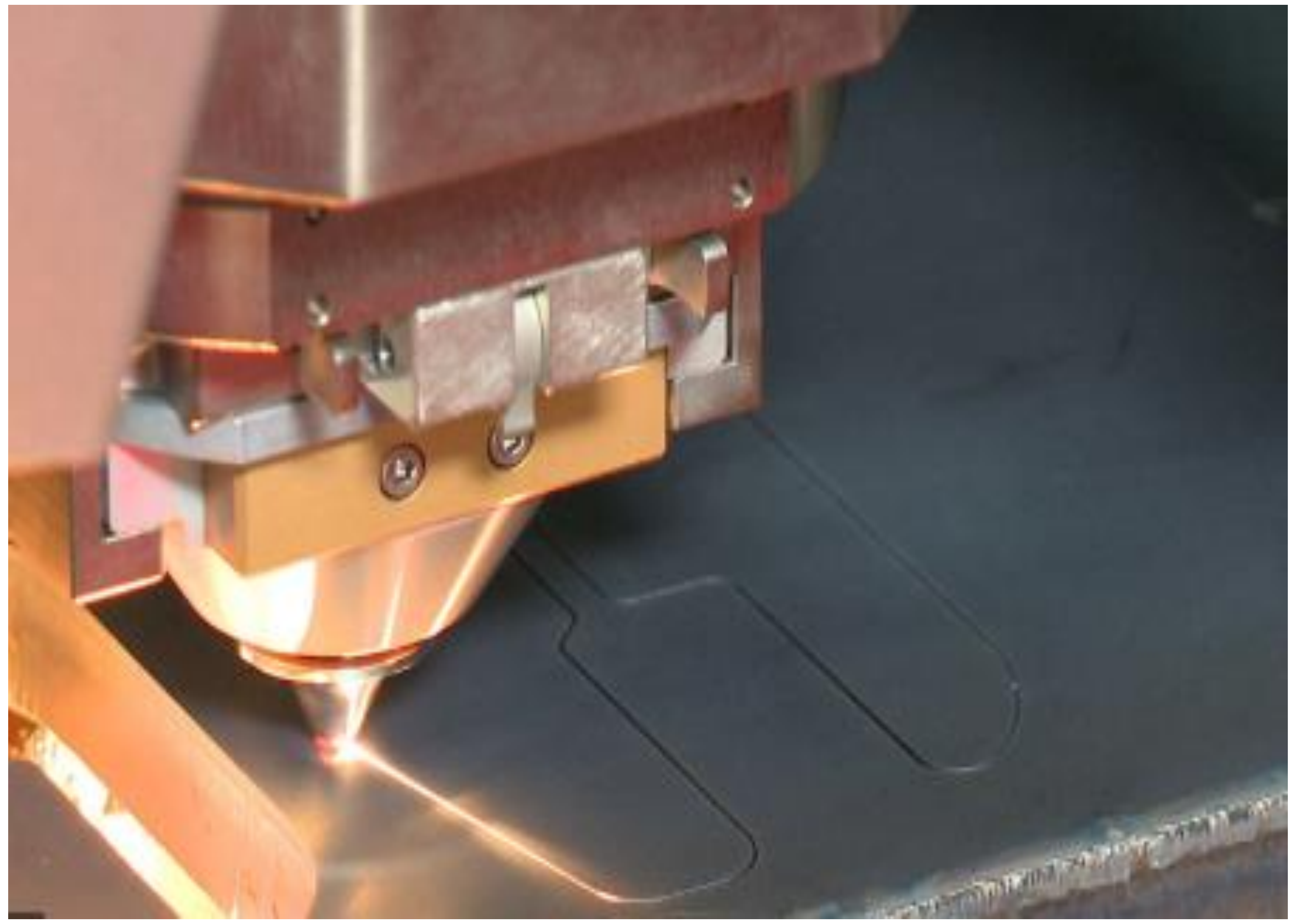
Methodology 1: Manipulandum Design Analysis

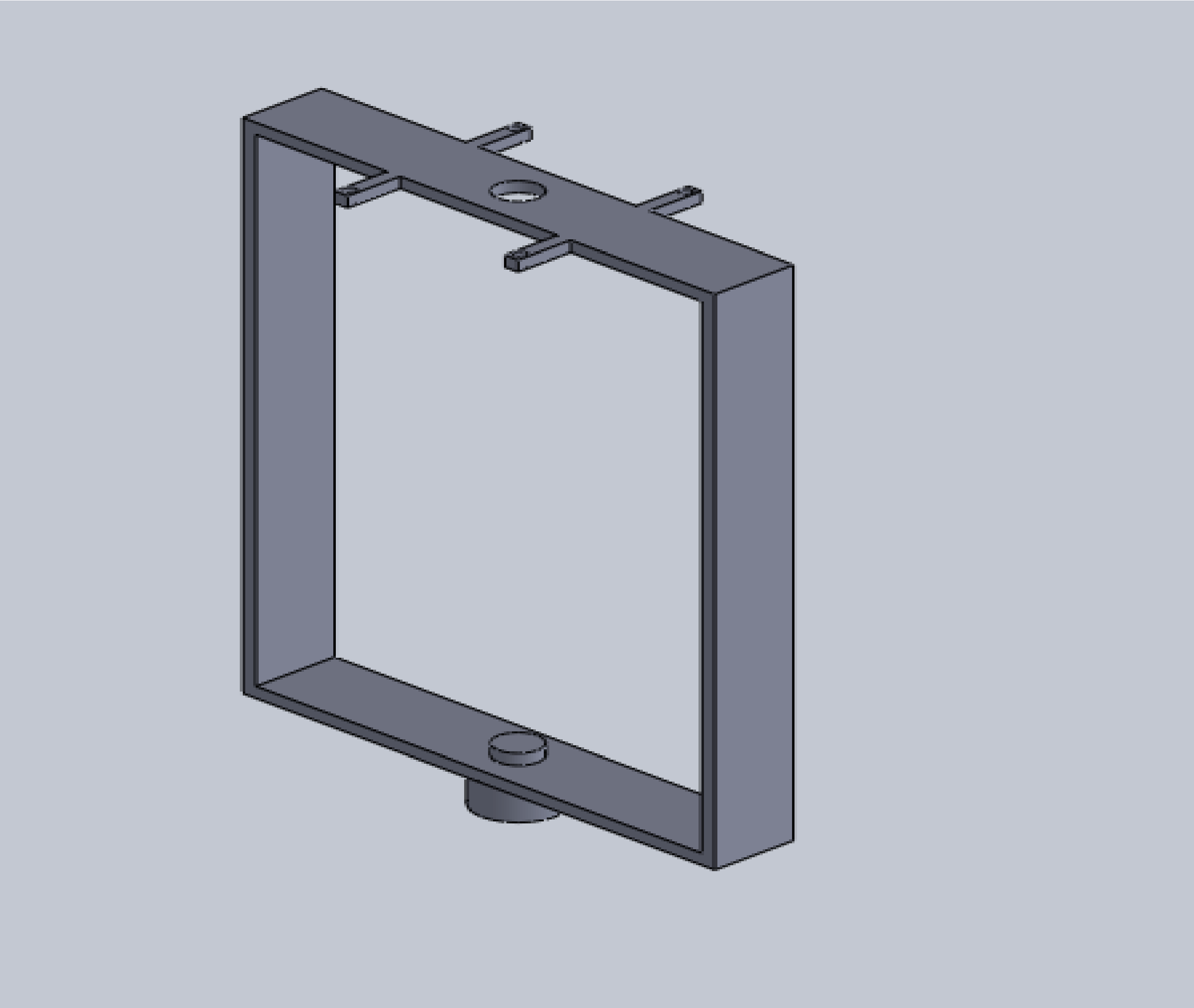




- The constraints to design the manipulndum were seeked from a physiotherapist for a specific age group of 20-50 years old.
- The manipulandum design is inspire by the current existing jamar dynamometers which gives it’s shape of a curved beam.
- The curved beam is designed for two different conditions. The loading conditions were known from the book of Bio mechanics of Kinesology the maximum torque about the pivot point is 8Nm and maximum load on to the grip is 300N.
- The manipulandum is similar to the compliant revolute joint with a curved rib connecting the ends.
- Analytical analysis of the design include the behaviour under load application and its kinematics.

Laser Cutting of Aluminium Plate





•The maximum thickness that is possible to machine in laser cutting is 6 mm, the constraint to have it within 4mm was preferable.

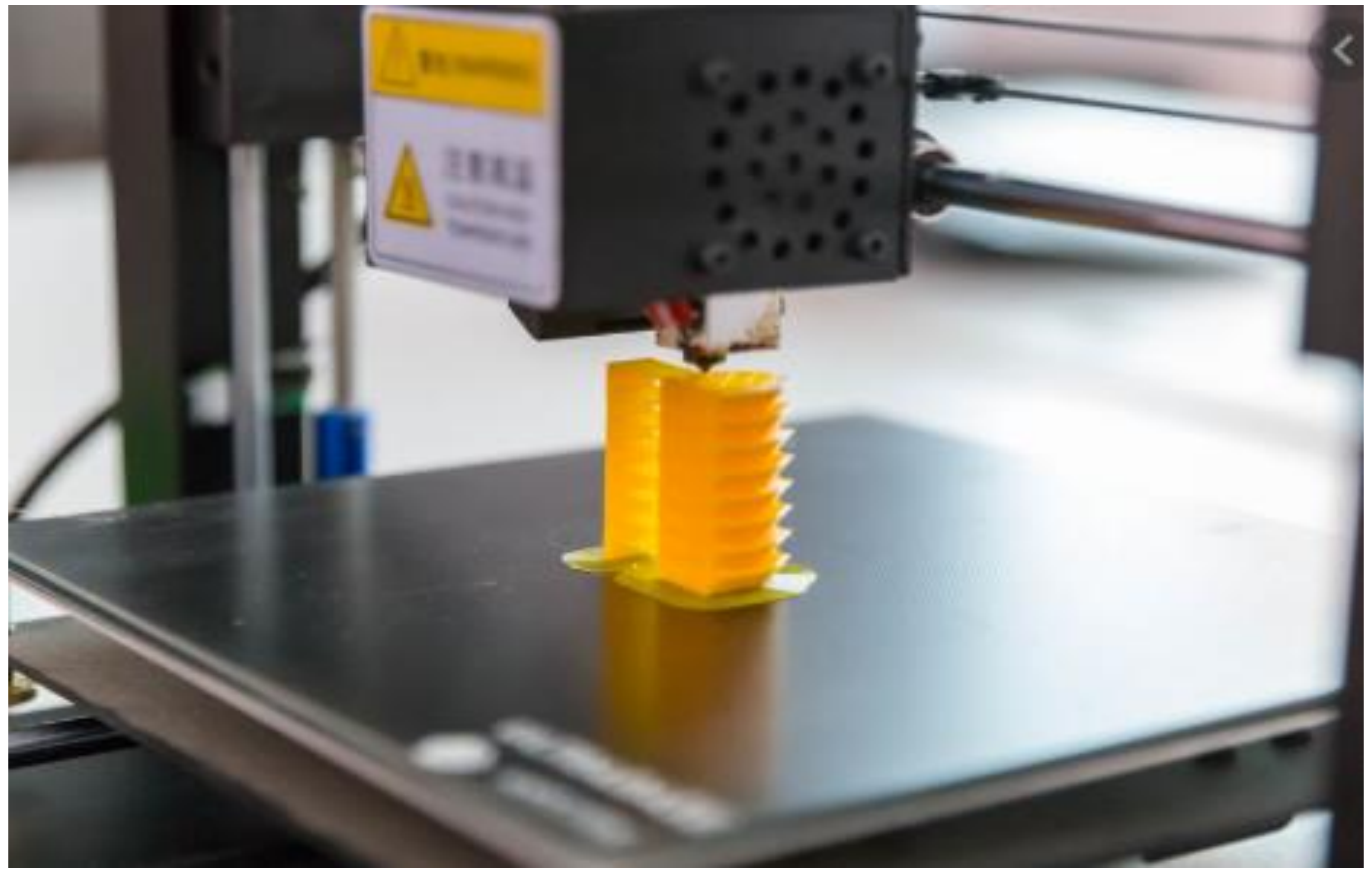
•The series of Aluminium that is used is 6063T6 due to its weldablitiy properties. As rest of the series did no have the required weldablilty .

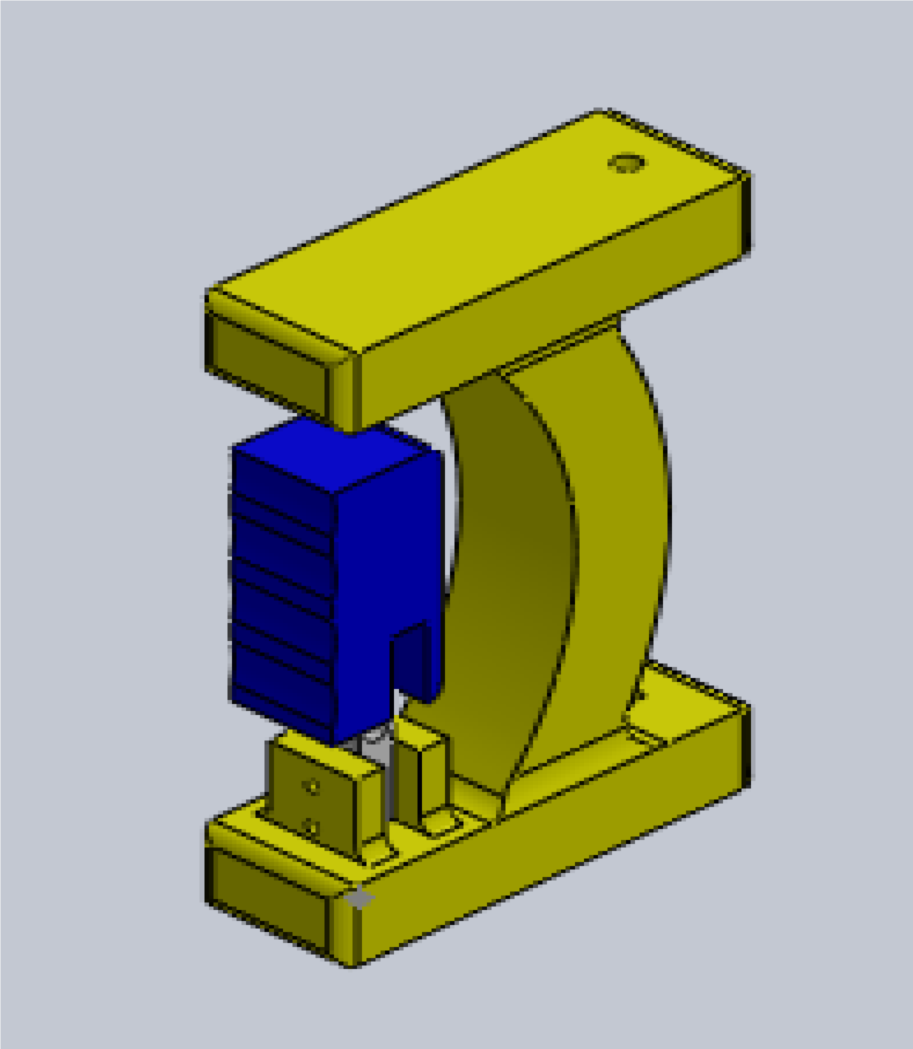
•The surface of the plates is cleaned to make it free from any dust particles so as to avoid the interference during machining.

•The laser cut plates are then to be welded with a professional TIG welder, as TIG welding accounts for the easy breaking of oxides generated in the process.

Design Procedure of Methodology

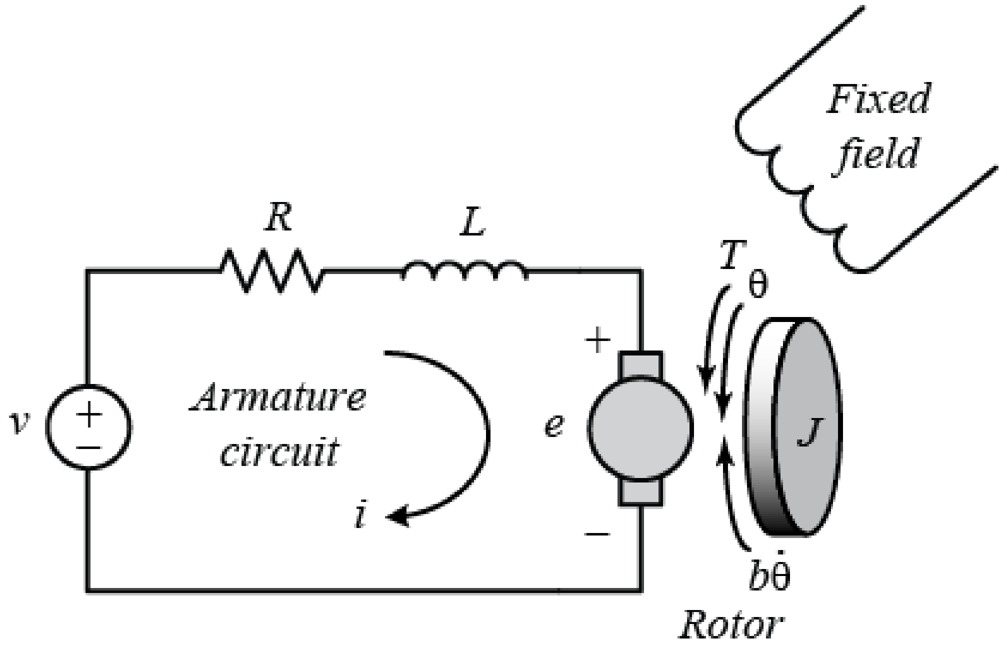
Rapid Prototyping of the hand grip





- The material for the grip is ABS- Acrylonitrile Butadiene Styrene, as the ultimate strength of it is arounf 40 Mpa which is well within our range.
- The material requires a pre heated substrate or bed making it easier to retrieve the model without any burrs.
- The total of working hours required to print is 19 hrs.
- Its resistant properties towards impact and heat makes it more feasible as there are a chances of heating at the junction joints due to continuous movement against the main frame.

Methodology 2: Motor Control and Load Cell Calibration



- (J) Moment of inertia of the rotor 2.2917E-5 kg.m^2
- (B) Motor viscous friction constant 1.5836E-5 N.m.s
- (Kb) Electromotive force constant 0.004831 V/rad/sec
- (Kt) Motor torque constant 0.004831 N-m/Amp
- (R) Electric resistance 0.0678 Ohm
- (L) Electric inductance 2.75E-6 H

$$T = K_t i$$

$$e = K_b \dot{\theta}$$

Based on Newton's 2nd law and Kirchhoff's voltage law.

$$J\ddot{\theta} + b\dot{\theta} = Ki$$

$$L\frac{di}{dt} + Ri = V - K\dot{\theta}$$

Applying the Laplace transform

$$s(Js + b)\Theta(s) = KI(s)$$

$$(Ls + R)I(s) = V(s) - Ks\Theta(s)$$

Transfer Function of the motor

$$\frac{\Theta(s)}{V(s)} = \frac{K}{s((Js + b)(Ls + R) + K^2)} \qquad [\frac{rad}{V}]$$

Methodology 2: Motor Control and Load Cell Calibration

Performance Data:

	No Load	Stall	Maximum Efficiency	Maximum Power
Current (A)	0.80	176.86	5.04	16.18
Efficiency (%)	-	-	62	39
Output Power (W)	-	-	37.47	79.00
Speed (rpm)	17034	-	14689	8517
Torque (mNm)	-	176.86	24.35	88.43

- Torque constant and electromotive force constant:

  $T = K_T\, i_a$ (K_t= Torque constant)

  $K_T = T/ i_a$

  $= 24.85/ 5.04$

  $= 0.004831$ Nm/A

  $K_b=K_T$ (K_b= Electromotive force constant)

- Moment of Inertia:

  $J = (mR^2)/2$

  $= ((109*10^{-3})8*(14.5*10^{-3})^2)/2$

  $= 2.2917*10^{-5}$ kgm^2

- Armature Resistance

  Output power (W)= η* input power

  O/P = η*I/P= η*VI (η=0.62)

  37.47=0.62*V*5.04

  V=12 V (applied voltage)

  Stall current (i_s) = 176.86 A = $V/R_T = 12/R_T$

  R_T = 0.0678 ohm

- Motor constant

  $K_m= K_T/ \sqrt{R_T} = 0.004831/\sqrt{0.0678}$

  K_m= 0.018472 N-m/√W

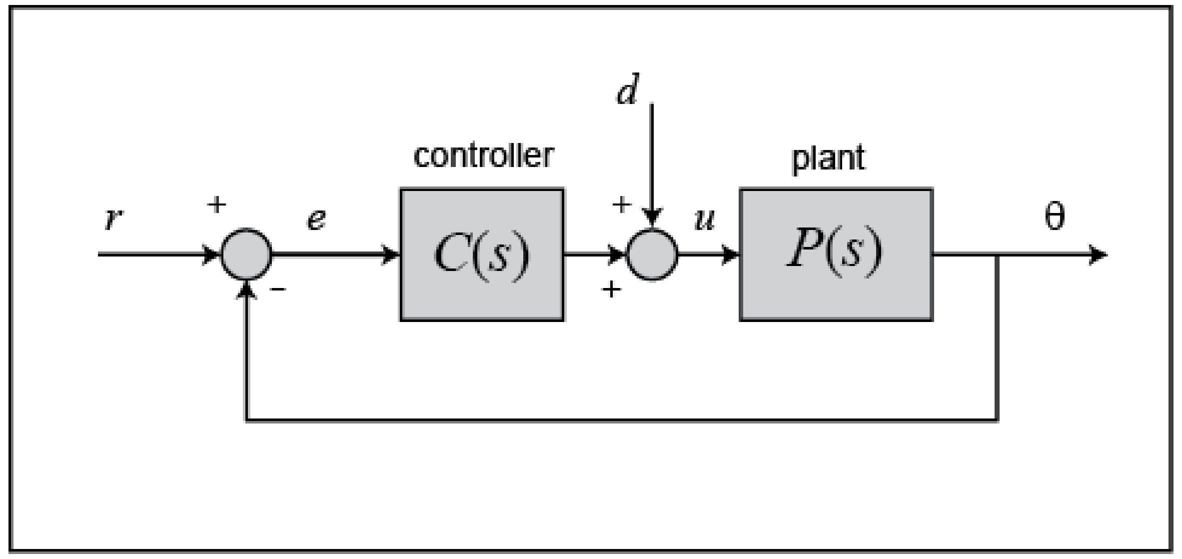
- Motor Viscous friction coefficient (B) = K_T*i /W

  W= 2ΠN/60

  B= (0.004831*5.04*60)/(2*Π*14689)

  B= $1.5836*10^{-5}$ N-m-s

Methodology 2: Motor Control and Load Cell Calibration

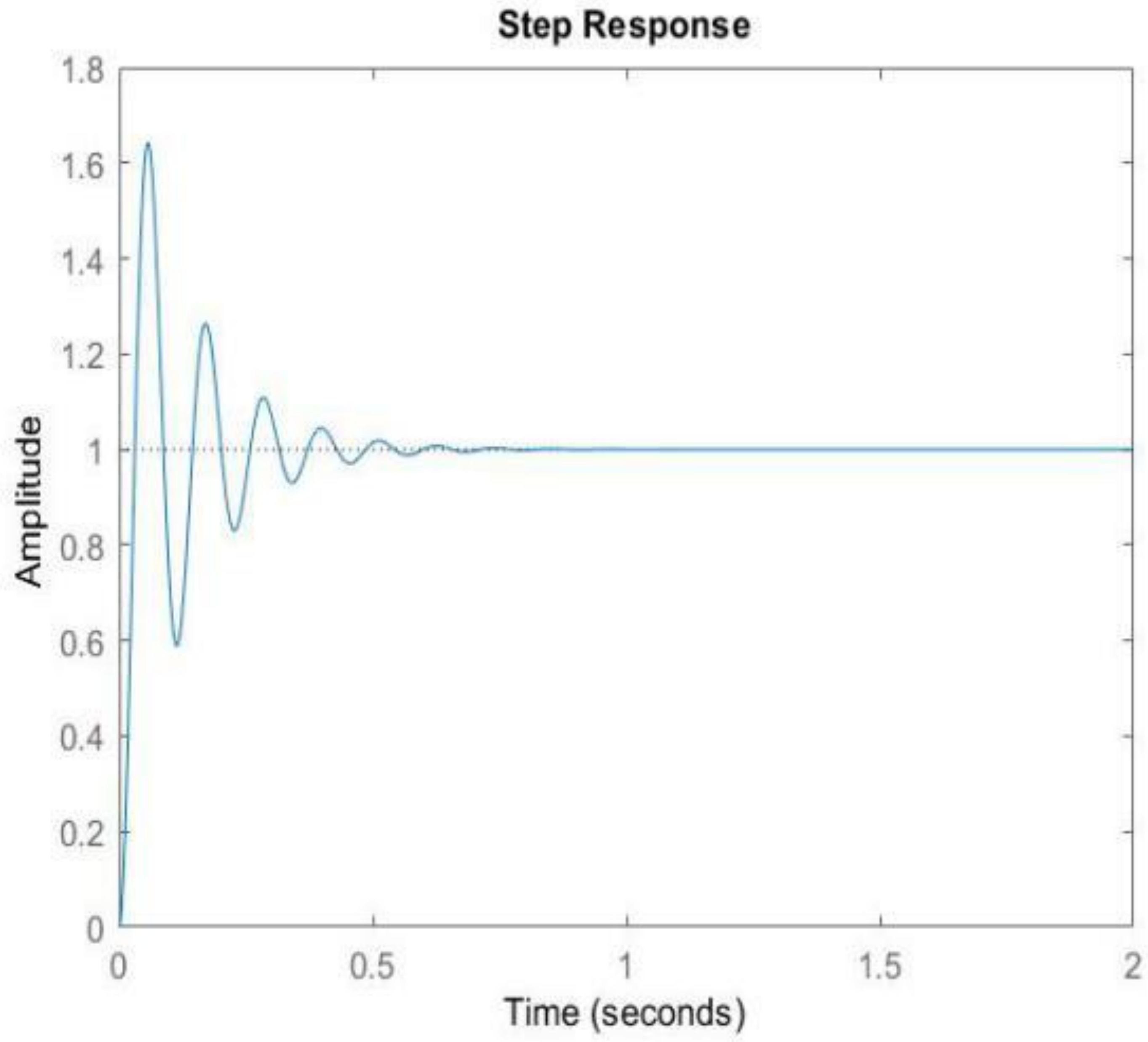


- Settling time less than 40 milliseconds
- Overshoot less than 16%
- No steady-state error
- No steady state error due to a disturbance

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_p \frac{de}{dt}$$

$$K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s}$$

```
P_motor =

                    0.004831
  ---------------------------------------------
  6.302e-11 s^3 + 1.554e-06 s^2 + 2.441e-05 s
```

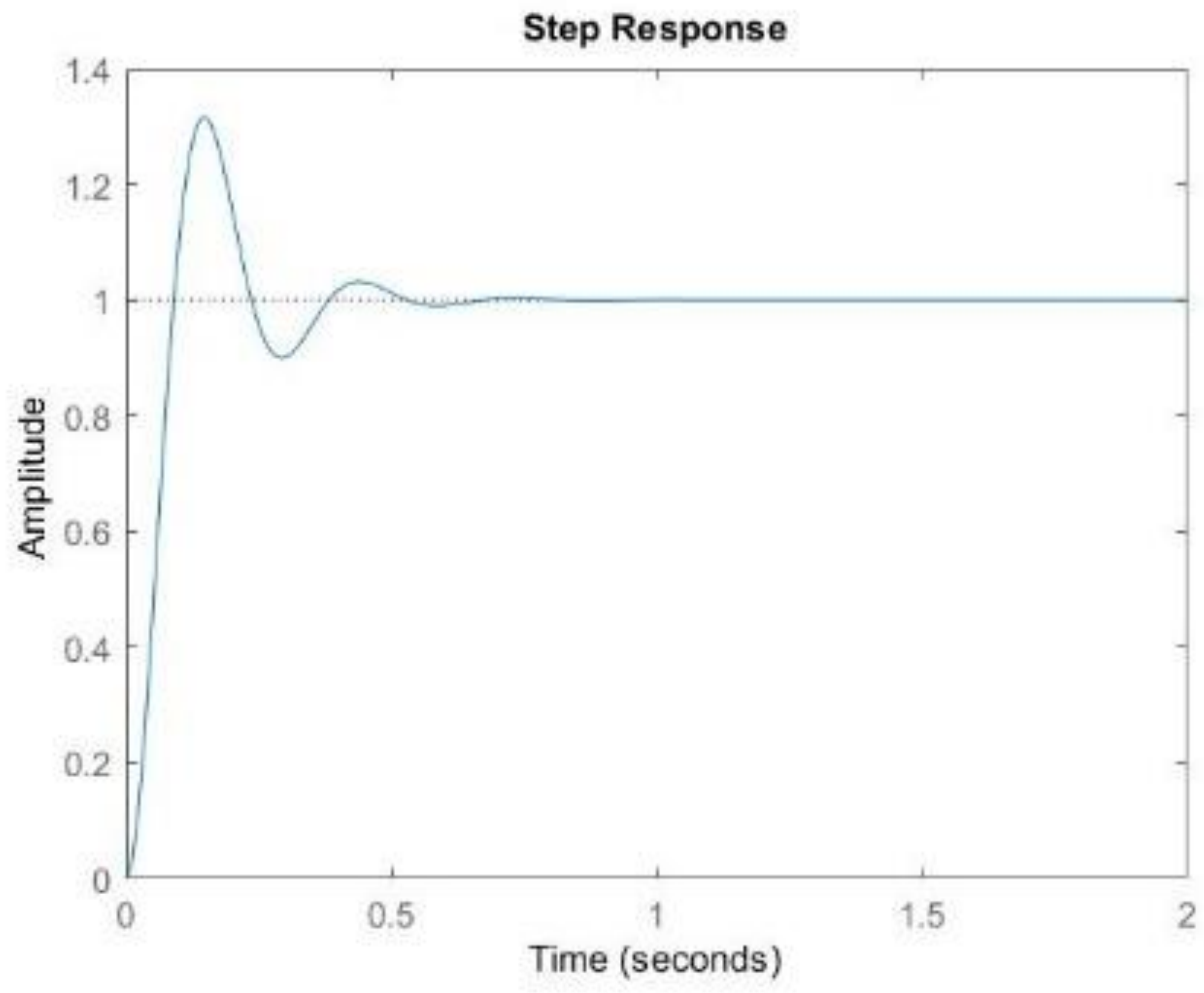


Closed loop response of the plant without the controller

Methodology 2: Motor Control and Load Cell Calibration

Proportional Control

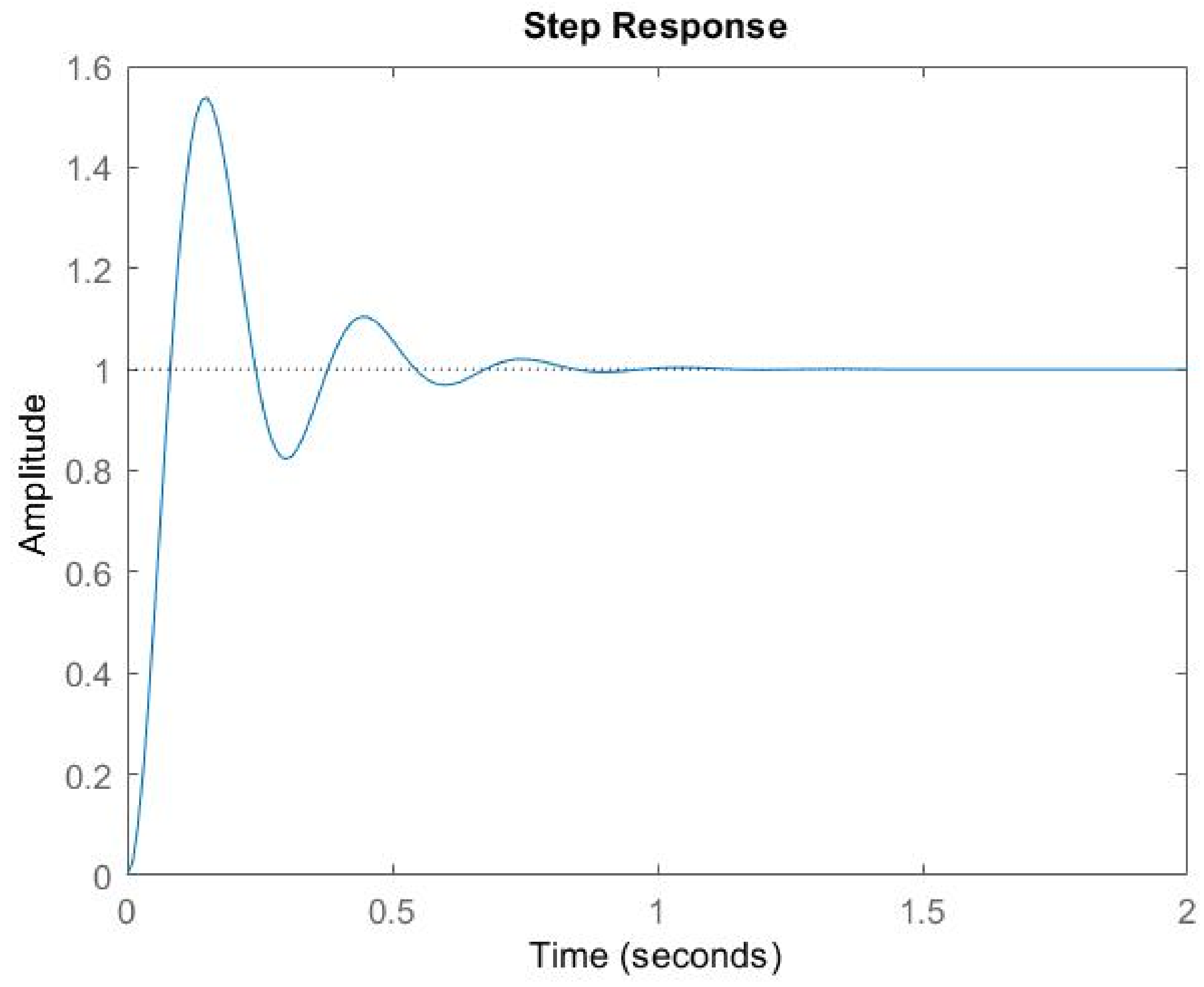
```
Kp = 0.168

T =                        0.0008121
  -------------------------------------------------------
  6.302e-11 s^3 + 1.554e-06 s^2 + 2.441e-05 s + 0.0008121
```



Step response of a closed loop transfer using a Proportional Controller

Proportional Integral Control

```
Kp = 0.168, Ki = 0.676

T =
                       0.0008121 s + 0.003266
  ----------------------------------------------------------------------
  6.302e-11 s^4 + 1.554e-06 s^3 + 2.441e-05 s^2 + 0.0008121 s + 0.003266
```



Step response of a closed loop transfer using a Proportional Integral Controller

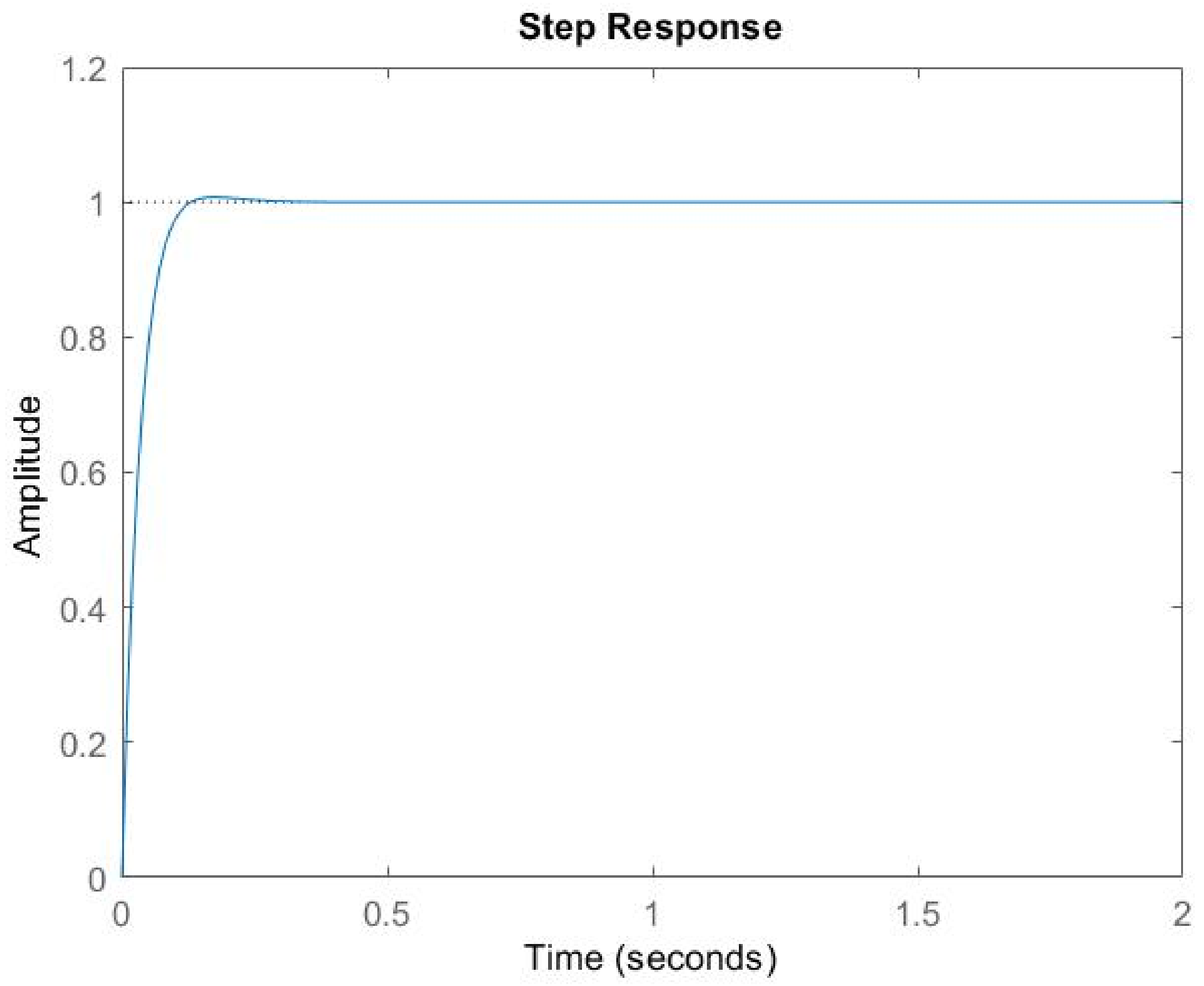
Methodology 2: Motor Control and Load Cell Calibration

Proportional Derivative Control

Kp = 0.168, Kd = 0.0093

T =

$$\frac{4.491e-05\ s + 0.0008121}{6.302e-11\ s^3 + 1.554e-06\ s^2 + 6.932e-05\ s + 0.0008121}$$



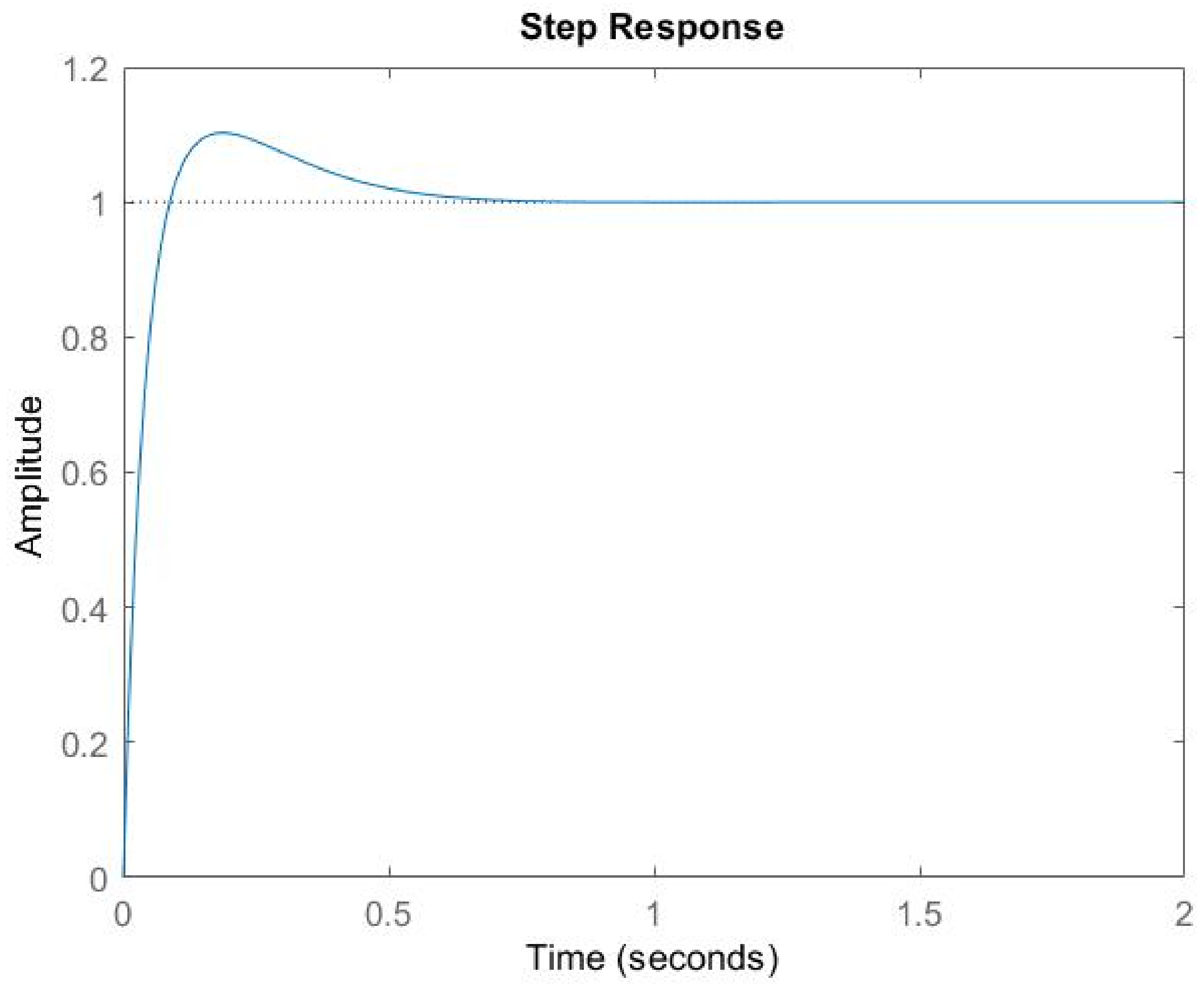
Step response of a closed loop transfer using a Proportional Derivative Controller

Proportional Integral Derivative Control

Kp = 0.168, Ki = 0.676, Kd = 0.0093

T =

$$\frac{4.491e-05\ s^2 + 0.0008121\ s + 0.003266}{6.302e-11\ s^4 + 1.554e-06\ s^3 + 6.932e-05\ s^2 + 0.0008121\ s + 0.003266}$$



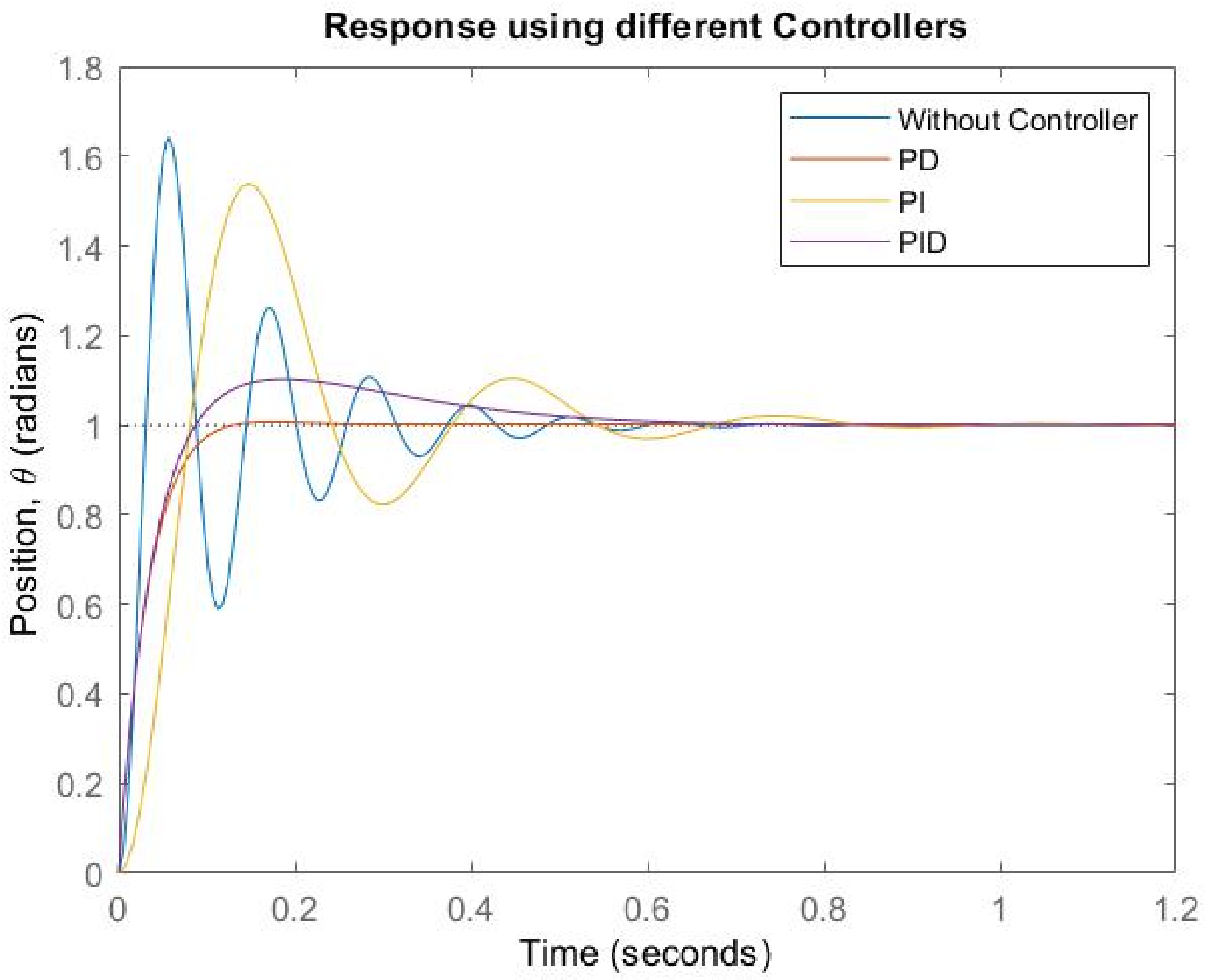
Step response of a closed loop transfer using a Proportional Integral Derivative Controller

Detailed procedure of Methodology

Methodology 2: Results

Controller Selection

Performance	Motor with unity feedback	Motor with PD controller	Motor with PID controller
Rise Time	0.0209	0.0668	0.0601
Settling Time	0.4699	0.1046	0.5023
Settling Min	0.589	0.9063	0.9132
Overshoot	64.1401	0.7472	10.2548
Undershoot	0	0	0
Peak	1.6414	1.0075	1.1025
Peak Time	0.0563	0.1732	0.1859

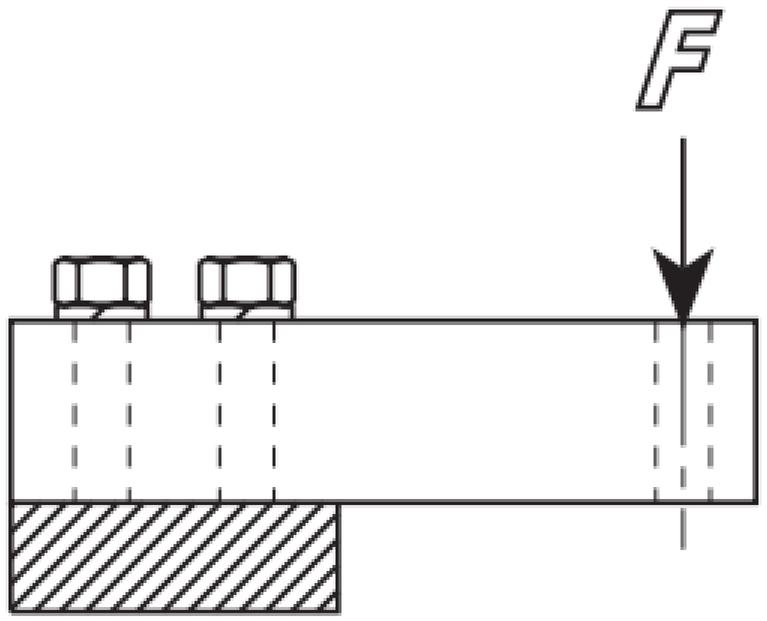


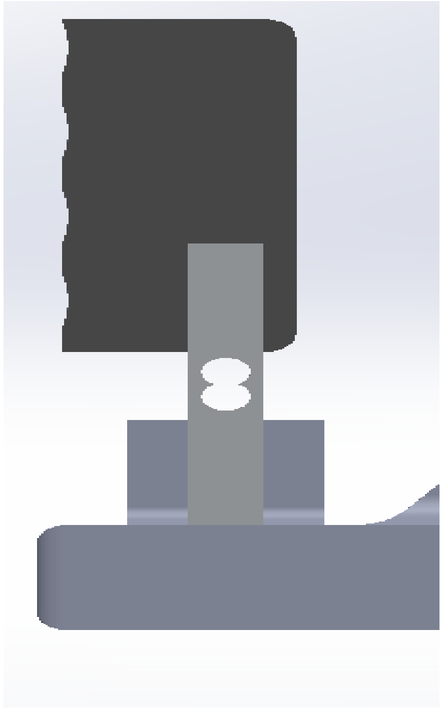
Response of closed loop transfer function without controller, PD, PI, PID

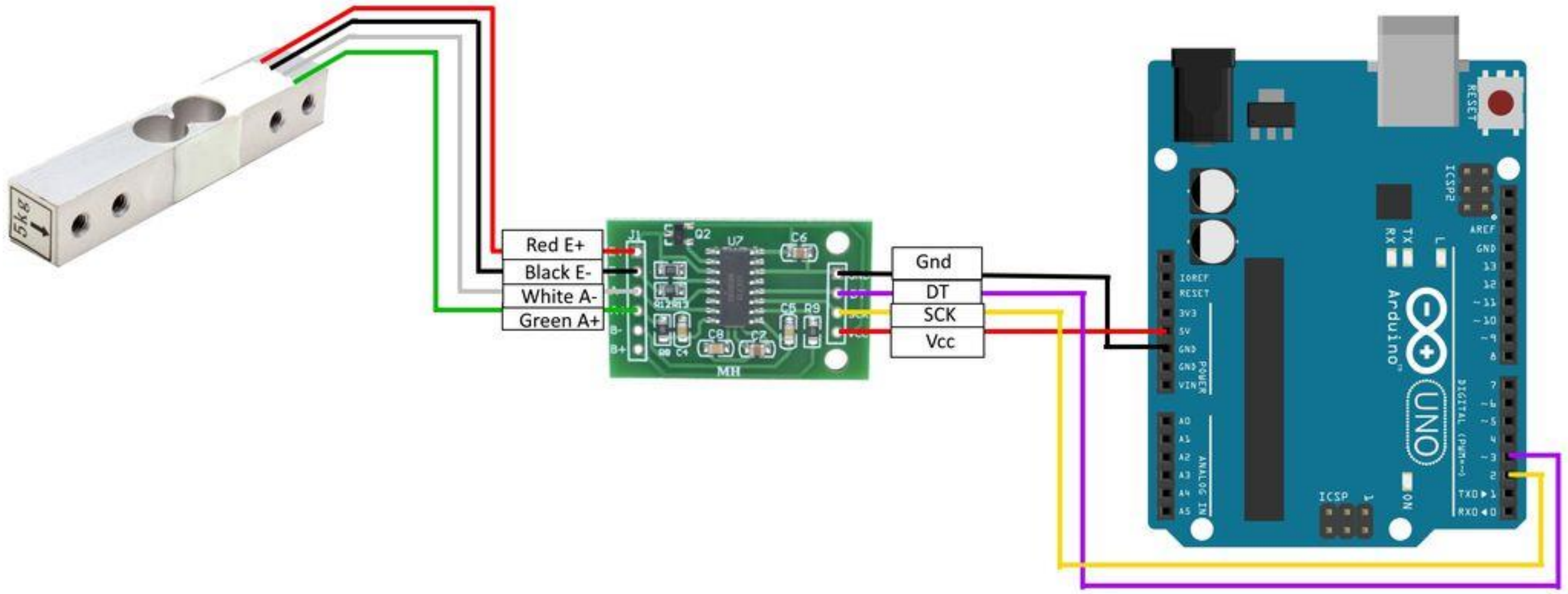
The response of the motor without any controller was ruled out because of very high overshoot characteristics leading to high inaccuracies for position control. The response of the closed loop transfer function with the PD controller gave the result of a slightly higher rise time compared to PID control, but all other parameters were better in the case of a PD controller than a PID controller; hence a PD controller was used for a position feedback control.

Detailed Procedure of Methodology

Methodology 2: Motor Control and Load Cell Calibration







The electrical resistance is changed as loads are applied on the load cell. However, for this change to be recorded, there is a requirement of amplification of this signal. For this purpose, an HX711 module is used. HX711 is a 24 bit analog-to-digital converter which amplifies the signal, which is sent to the microcontroller.

The interfacing with Arduino Uno with HX711 amplifier is shown in the figure. The HX711 module can be powered with a 2.7V - 5V source. Hence, the Arduino Uno can be used for this purpose and is used to obtain the grip strength values from the Communication with the HX711 module can be established with the help of a driver. It is installed in the system and added to the existing libraries.

Detailed Procedure of Methodology

Methodology 2: Motor Control and Load Cell Calibration

Calibration of the load cell is performed to scale the inputs to Arduino in terms of force (N). For this, we required a number of known weights which are used for adjusting the calibration factor.

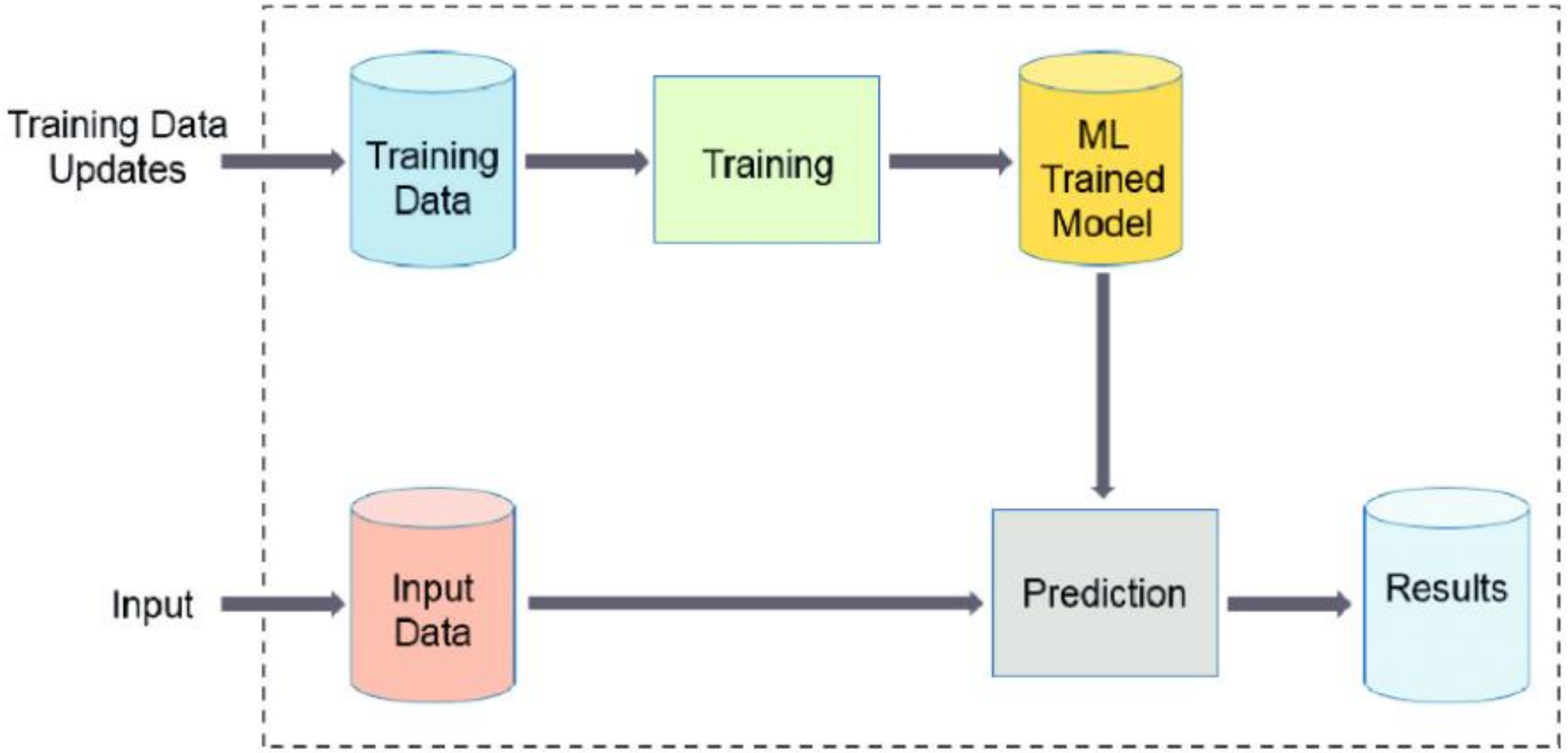
This is the calibration sketch. Used to determine calibration factor.

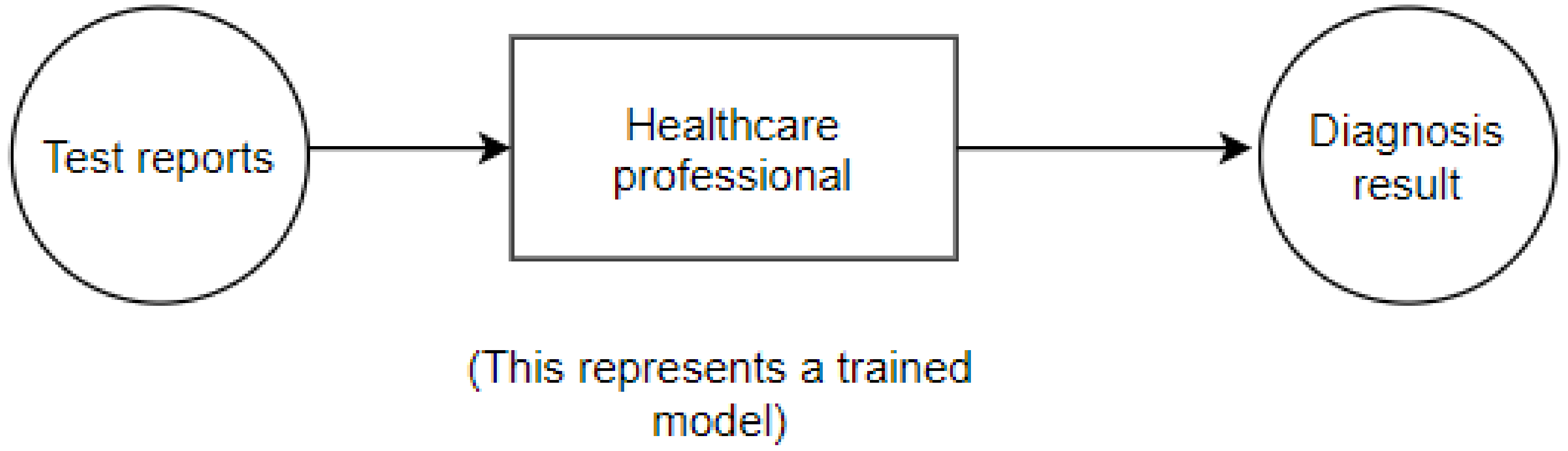
- Setup your scale and start the sketch WITHOUT a weight on the scale
- Once readings are displayed place the weight on the scale
- Press +/- or a/z to adjust the calibration factor until the output readings match the known weight
- Your calibration factor may be very positive or very negative. It all depends on the setup of your scale system and the direction the sensors deflect from zero state

```
#include "HX711.h"
#define LOADCELL_DOUT_PIN  3
#define LOADCELL_SCK_PIN  2
HX711 scale;
float calibration_factor = 100;
void setup() {
  Serial.begin(9600);
  Serial.println("HX711 calibration sketch");
  Serial.println("Remove all weight from scale");
  Serial.println("After readings begin, place known weight on scale");
  Serial.println("Press + or a to increase calibration factor");
  Serial.println("Press - or z to decrease calibration factor");
  scale.begin(LOADCELL_DOUT_PIN, LOADCELL_SCK_PIN);
  scale.set_scale();
  scale.tare();   //Reset the scale to 0
  long zero_factor = scale.read_average(); //Get a baseline reading
  Serial.print("Zero factor: "); //This can be used to remove the need to tare the scale.
Useful in permanent scale projects.
  Serial.println(zero_factor);
}
void loop() {
  scale.set_scale(calibration_factor); //Adjust to this calibration factor
  Serial.print("Reading: ");
  Serial.print(scale.get_units(), 1);
  Serial.print(" lbs");
  Serial.print(" calibration_factor: ");
  Serial.print(calibration_factor);
  Serial.println();
  if(Serial.available())
  {
    char temp = Serial.read();
    if(temp == '+' || temp == 'a')
      calibration_factor += 10;
    else if(temp == '-' || temp == 'z')
      calibration_factor -= 10;
  }
}
```

Methodology 3:Implementing Machine learning model

The general flow of a Machine Learning model is shown.





A medical diagnosis can be considered as a classification task. This is represented in the figure

The creation of model requires selection and training of appropriate model for the classification task. We have acquired set of 66 data-points consisting of six features each from both healthy and impaired individuals.

Methodology

Methodology 3:Implementing Machine learning model

Selection of parameters and collection of data

- Accurate diagnosis is subject to selection of collection of data set from both healthy and impaired individuals, comprising of parameters as mentioned below. The size of data set helps in developing a more robust model, and thus be more reliable.
- The grip force, motion speed, and motor coordination were the three major factors to help differentiate between healthy and impaired individuals.
- Flexion and extension, radial and ulnar deviation are motions of the wrist which is important in assessing motor control. Moreover, the ranges of these motion might vary when passively assisted.
- Side of dominant hand, gender and age also determine the strength of grip and motor skills. Thus these need to be measured as well.

Selection of learning method

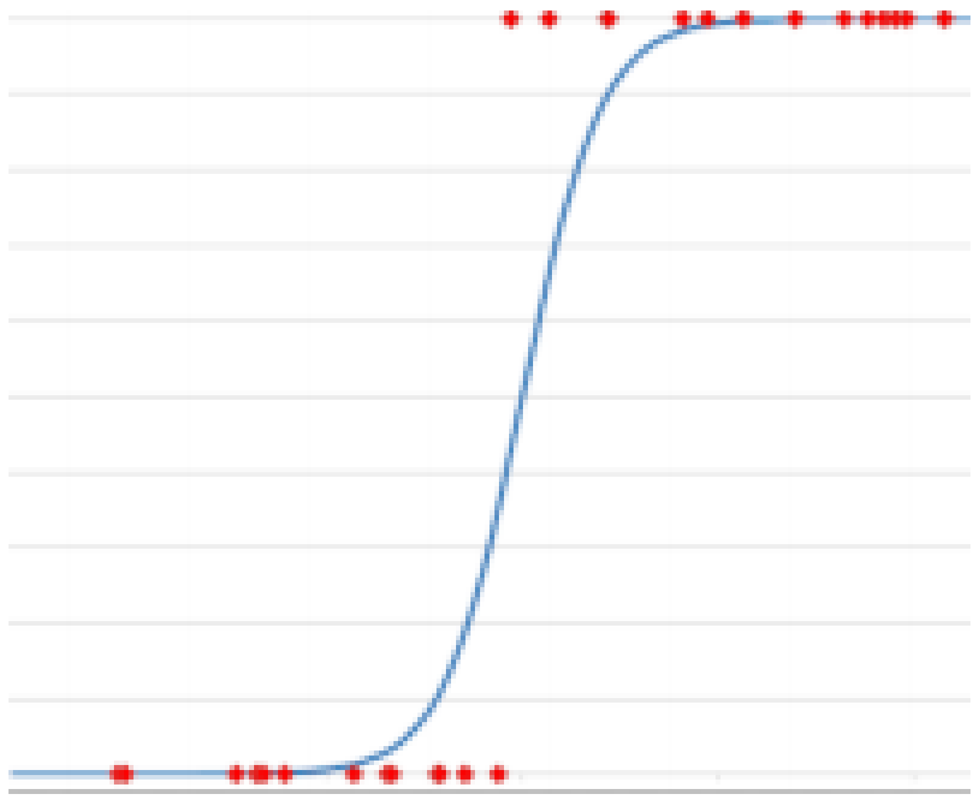
- The choice of learning method depends on the available input features. We have the following inputs:
  (i)Age(Continuous), (ii)Range of motion(Continuous),(iii)Dominant side (Categorical),(iv)Gender(Categorical)
  (v)Grip strength(Continu)
- Classification task can be modelled by a number of algorithms:
  (i) Logistic regression (ii) k-nearest neighbours (iii) Decision tree (iv) Support Vector Machines

Methodology

Methodology 3:Implementing Machine learning model

Selection of learning method

- Algorithms selection has been done keeping in mind the size of data set available.
  We had 66 input-output data available for the classification task of diagnosis,each having six set of features.
- Greater number of features may lead to overfitting, where the model just memorizes the input samples.
- Such cases lead to generalization error.
- The logistic regression is a simple model which does not take many assumptions (bias). It has given reasonable accuracy. In this model, a linearity is assumed in input data. This model is less likely to overfit in lesser dimensions. The model is easier to train and implement. The interpretability of the model is high. Moreover, the model enables online input of data, that is, data can be readily added later on, unlike other models such as SVM and Decision trees. There are models which have given better accuracy, like decision trees and KNN. However, they have their own limitations.
- It gives a probabilistic output of the data lying in either of the classes.



Methodology 3:Implementing Machine learning model

The model is parameterized using the following function:

$$h_\theta(x) = g(\theta^T x)$$

where $z = \theta^T x$

and uses the logistic function to generate the output

$$\phi(z) = \frac{1}{1+e^{-z}}$$

The evaluation of the model parameter θ is often done by solving an optimization problem.
The cost of a logistic regression model is given by:

$z = \theta^T x$

$$J(\theta) = -\frac{1}{m}\sum_{i=1}^{m}[y^{(i)}\log(h_\theta(x^{(i)})) + (1-y^{(i)})\log(1-h_\theta(x^{(i)}))]$$

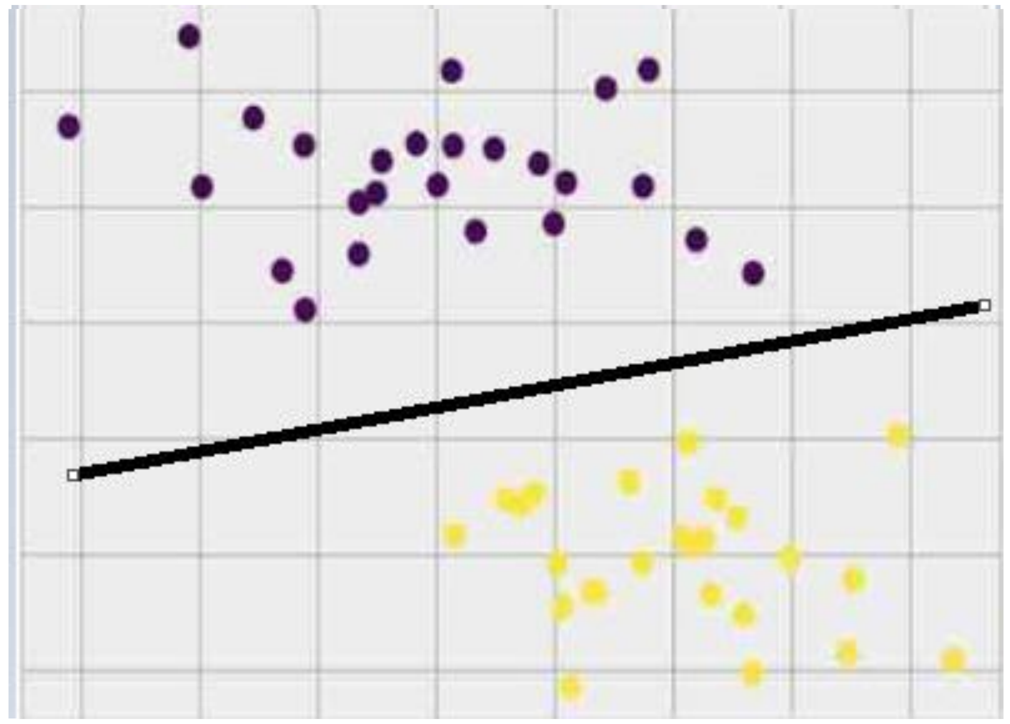
where y(i)’s represents actual output of training set, and x(i)’s the training input.

Methodology 3:Implementing Machine learning model

Optimization was done using a gradient descent algorithm. Minimizing the cost function gives:

Iterate until convergence

$$\{ \quad \theta_j = \theta_j - \alpha(h_\theta(x) - y)\, x \quad \}$$



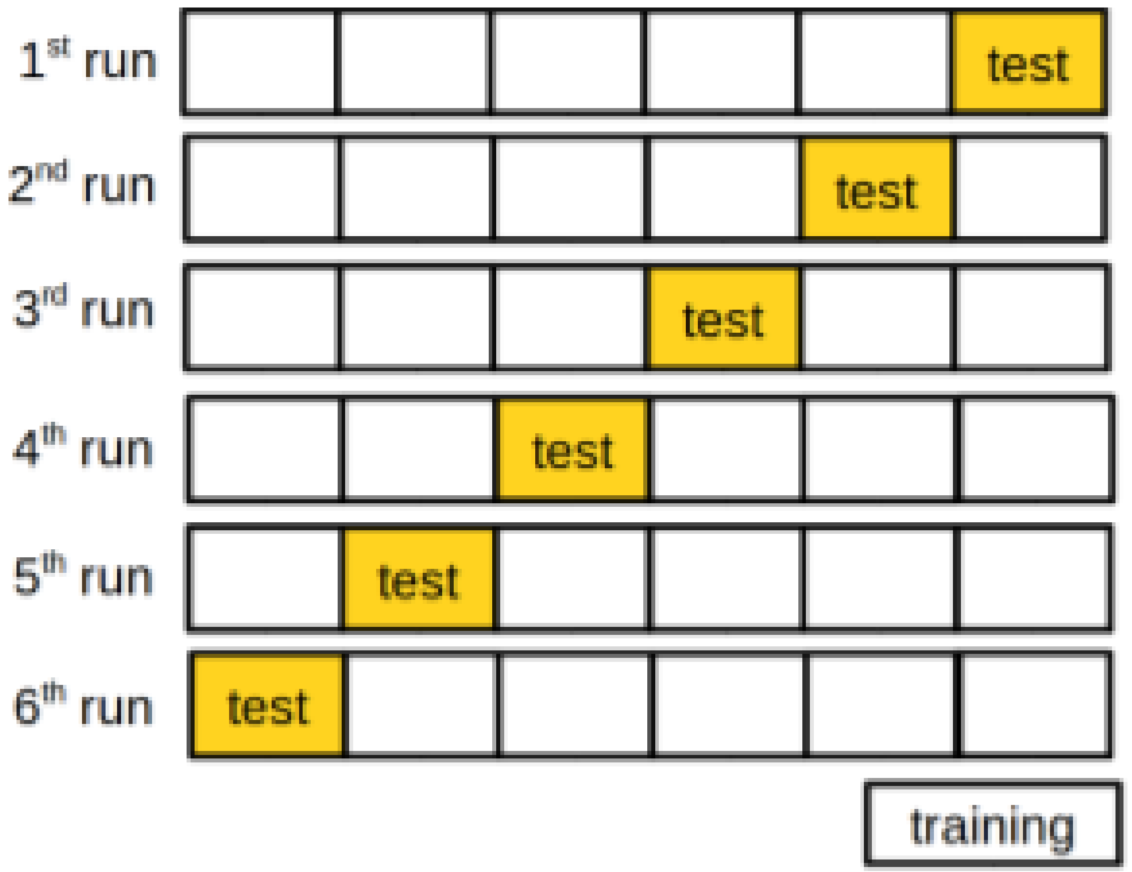
Snippet of code in MATLAB is shown:

```
input_raw=readtable('covergred_data_physiotherapist.csv');
input_final=table2array(input_raw);
output_raw=readtable('physio_output_final.csv');
output_final=table2array(output_raw);
m=length(input_final);
x_train=[ones(m,1),input_final(:,1:5)];
ytrain=output_final(:,2);
xtrain=zscore(x_train(:,1:end));% Normalizing the input features
using z-standardization
x_test=xtrain;
y_test=ytrain;

%Finding Cost of logistic function and applying gradient descent
iter=1000; % No. of iterations for weight updation

theta=zeros(size(xtrain,2),1); % Initializing all weights as zero
 alpha=0.1 % Learning rate
[J grad h th]=cost(theta,xtrain,ytrain,alpha,iter) % Cost of
logistic function
ypred=x_test*th; % prediction of target variables
% Sigmoid application followed by thresholding to 0.5
[hp]=sigmoid(ypred); % Hypothesis Function
ypred(hp>=0.5)=1;
ypred(hp<0.5)=0;
%%%cost function%%
function [J grad h th] = cost(theta, xtrain,ytrain,alpha,iter)
th=theta
m=size(xtrain,1);
for j=1:iter
h=sigmoid(xtrain*th);
J=-(1/m)*sum(ytrain.*log(h)+(1-ytrain).*log(1-h));
th=th+(alpha/length(xtrain))*xtrain'*(ytrain-h)
end
grad=zeros(size(theta,1),1);
for i=1:size(grad)
    grad(i)=(1/m)*sum((h-ytrain)'*xtrain(:,i));
end
end
```

Methodology

Methodology 3:Implementing Machine learning model

- The entire data set is not used for training. Instead a part of it is kept for testing the learned model and validating the model. This was done by simply dividing data set into training set and testing set into 70:30 ratio.
- However, this resulted in variation in the model accuracy. Thus, the problem can be solved using cross validation, in which the input data set is divided into ‘k’ equal folds, or parts, and the training is iteratively given to the model such with (k-1) folds and one is held back for testing, such that each fold has been used for testing once. The number of folds, k was chosen as 6.



Methodology

Methodology 3:Implementing Machine learning model

The 6-fold validation gave the output as:

```
1st fold:
predicted: [0. 1. 1. 0. 0. 1. 0. 0. 1. 1. 0.]
actual:    [1. 1. 1. 0. 0. 1. 0. 0. 1. 1. 0.]
Errors: 1
Accuracy: 90.9090909090909%

2nd fold:
predicted: [0. 1. 1. 0. 0. 1. 1. 0. 1. 0. 0.]
actual:    [0. 0. 0. 0. 1. 0. 1. 0. 1. 0. 0.]
Errors: 4
Accuracy: 63.63636363636363%

3rd fold:
predicted: [0. 0. 0. 0. 1. 0. 1. 0. 0. 1. 0.]
actual:    [0. 0. 0. 0. 1. 0. 1. 0. 0. 1. 0.]
Errors: 0
Accuracy: 100.0%

4th fold:
predicted: [0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 1.]
actual:    [0. 0. 0. 0. 0. 0. 1. 0. 0. 1. 1.]
Errors: 1
Accuracy: 90.9090909090909%

5th fold:
predicted: [0. 0. 1. 0. 0. 0. 1. 0. 0. 1. 1.]
actual:    [0. 0. 1. 0. 0. 0. 1. 0. 0. 1. 1.]
Errors: 0
Accuracy: 100.0%

6th fold:
predicted: [0. 1. 1. 1. 0. 0. 1. 1. 0. 1. 0.]
actual:    [1. 1. 1. 1. 0. 1. 1. 1. 0. 1. 0.]
Errors: 2
Accuracy: 81.81818181818181%
>>>
```

The confusion matrix of the output is as follows:

	Predicted 1	Predicted 0
Actual 1	22	5
Actual 0	3	36

Here, 1 denotes classification as disabled, and 0 denotes classification as healthy.

Methodology

Methodology 3:Implementing Machine learning model

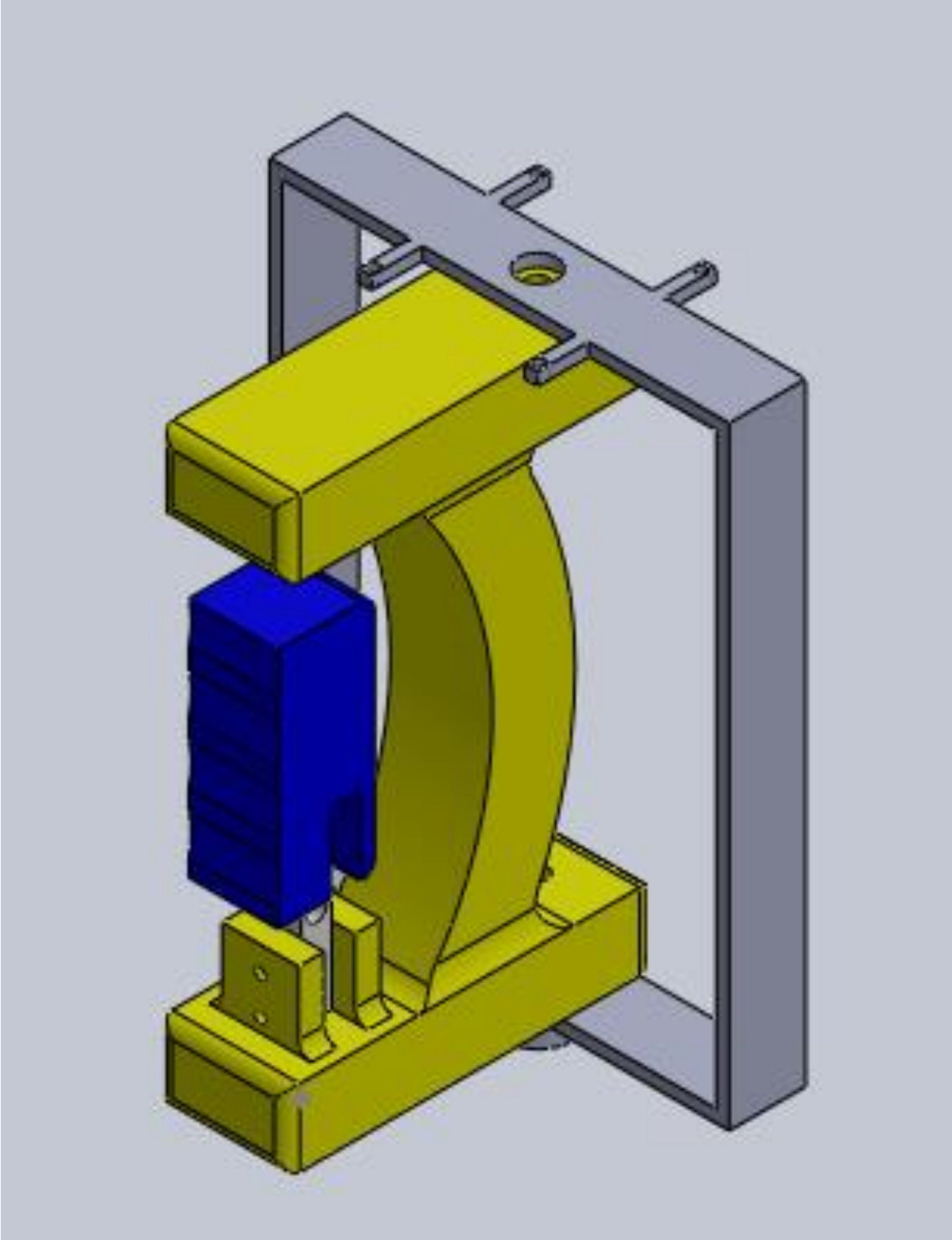
Sensitivity	0.8148	TPR = TP / (TP + FN)
Specificity	0.9231	SPC = TN / (FP + TN)
Precision	0.8800	PPV = TP / (TP + FP)
Negative Predictive Value	0.8780	NPV = TN / (TN + FN)
False Positive Rate	0.0769	FPR = FP / (FP + TN)
False Discovery Rate	0.1200	FDR = FP / (FP + TP)
False Negative Rate	0.1852	FNR = FN / (FN + TP)
Accuracy	0.8788	ACC = (TP + TN) / (P + N)

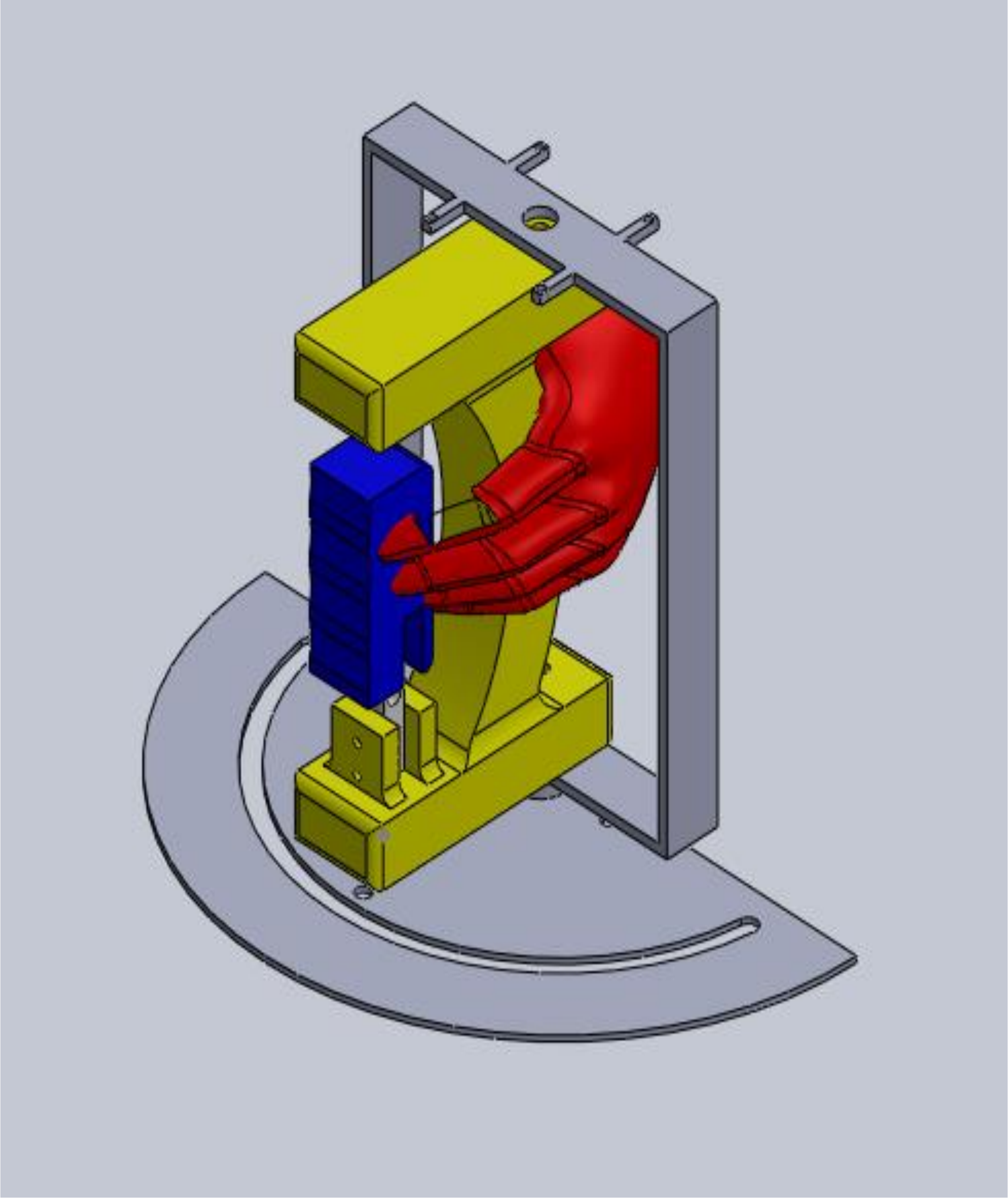
Evaluating a model based on accuracy (total correct predictions/no. of prediction) holds true if the number of samples in both classes are equal. However, this was not the case here as data of healthy individuals was more than that of impaired individuals. Hence, there are other metric used to study the performance.

- The model was able to correctly diagnose 81.48% of the patients who were actually impaired.
- It also showed a 92.31% rate of correctly diagnosing people as healthy, which meant an exceptionally low rate of misclassification as 'healthy' by the model.
- Moreover, it showed 88% surety in its prediction being true when an individual was classified as 'impaired'.

FEM Modelling

The manipulandum is modelled on Solidworks as four separate parts and then assembled. It is then saved as an STEP file.





FEM Modelling

The engineering data is opened and the required values are inserted as shown in the figure

Properties of Outline Row 3: ABS

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	1040	kg m^-3		
4	Isotropic Elasticity				
5	Derive from	Young's Modulus and Poi...			
6	Young's Modulus	2.39E+09	Pa		
7	Poisson's Ratio	0.399			
8	Bulk Modulus	3.9439E+09	Pa		
9	Shear Modulus	8.5418E+08	Pa		
10	Tensile Yield Strength	4.14E+07	Pa		
11	Compressive Yield Strength	6.5E+07	Pa		
12	Tensile Ultimate Strength	4.43E+07	Pa		
13	Compressive Ultimate Strength	6.5E+07	Pa		

Material data of Acrylonitrile Butadiene Styrene (ABS)

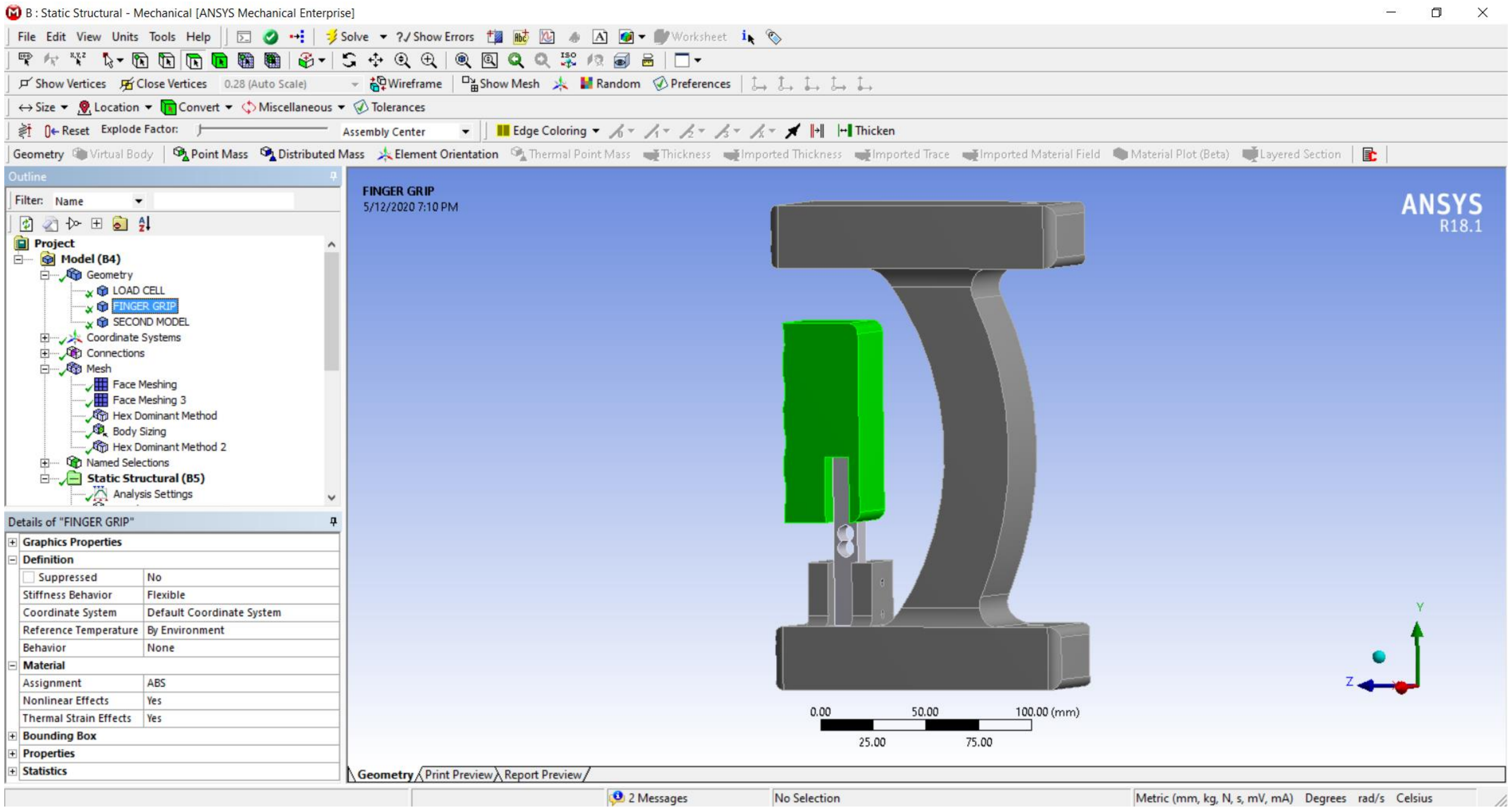
Properties of Outline Row 4: Al 7075-T6

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	2780	kg m^-3		
4	Isotropic Elasticity				
5	Derive from	Young's Modulus and Poi...			
6	Young's Modulus	7.17E+10	Pa		
7	Poisson's Ratio	0.33			
8	Bulk Modulus	7.0294E+10	Pa		
9	Shear Modulus	2.6955E+10	Pa		
10	Alternating Stress Mean Stress	Tabular			
11	Interpolation	Linear			
12	Scale	1			
13	Offset	0	Pa		
14	Strain-Life Parameters				
15	Display Curve Type	Strain-Life			
16	Strength Coefficient	8.27E+08	Pa		
17	Strength Exponent	0.11			
18	Ductility Coefficient	2.57			
19	Ductility Exponent	-0.987			
20	Cyclic Strength Coefficient	5.6E+08	Pa		
21	Cyclic Strain Hardening Exponent	0.19			
22	Tensile Yield Strength	5.03E+08	Pa		
23	Compressive Yield Strength	5.08E+08	Pa		
24	Tensile Ultimate Strength	5.72E+08	Pa		
25	Compressive Ultimate Strength	5.8E+08	Pa		

Material data of Aluminium 6061-T6

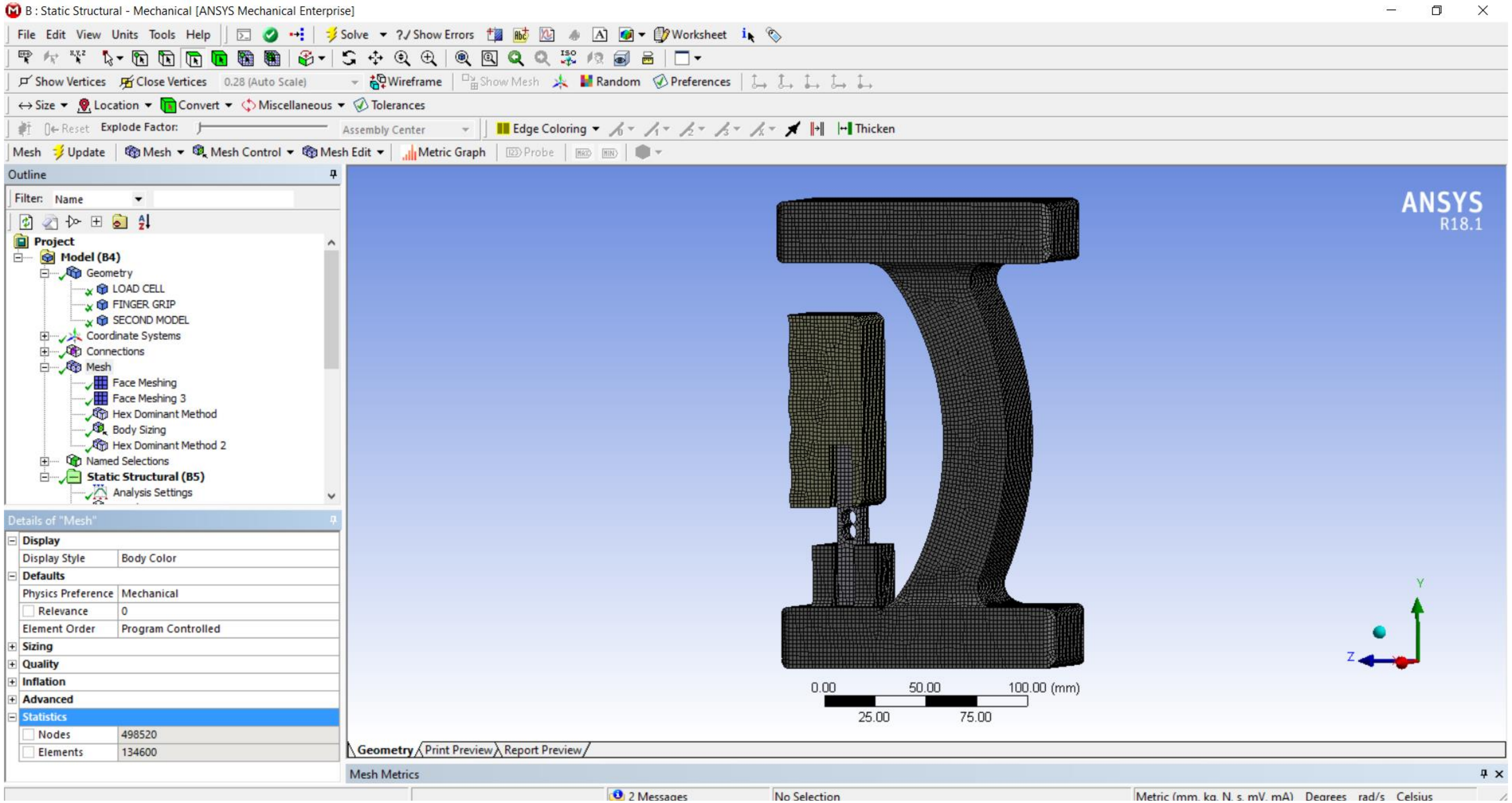
FEM Modelling

The setup option is selected to open the corresponding window. The materials are assigned to the structure, gripper and load cell using the geometry setting.



FEM Modelling

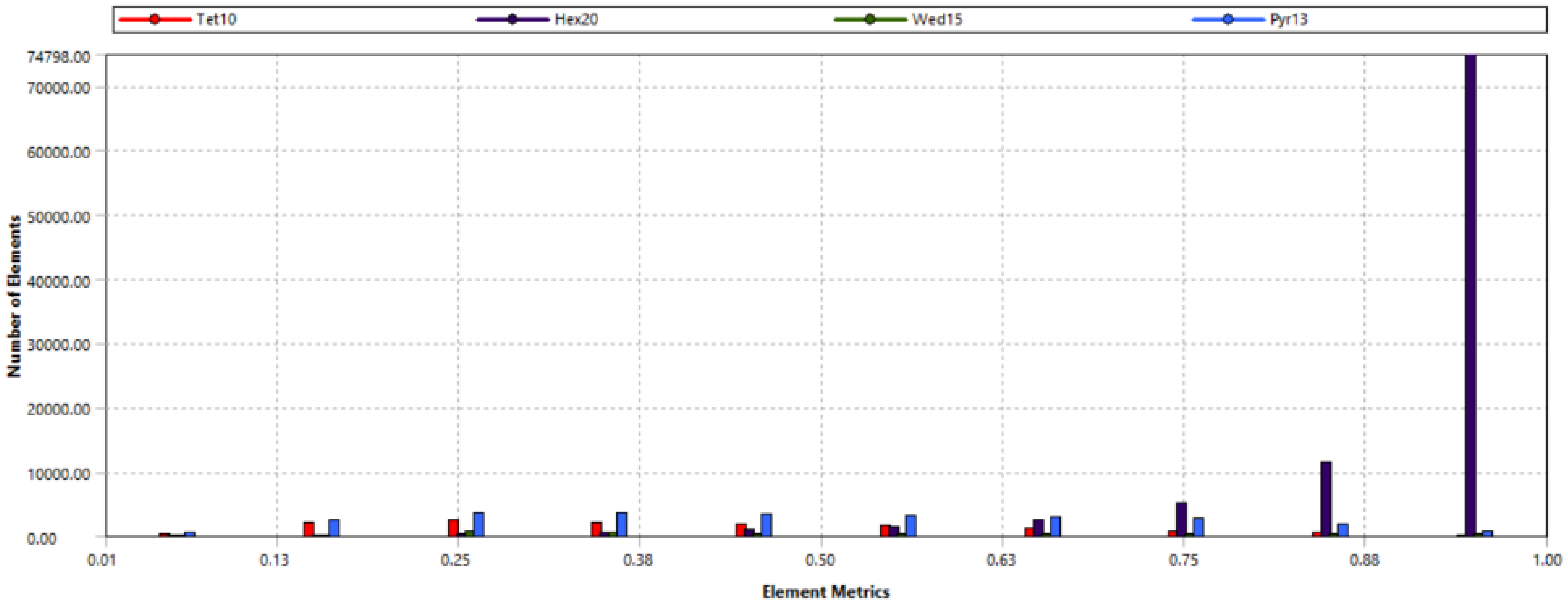
Hex-dominant meshing was done using an element size of 2mm



FEM Modelling

Under the Mesh Metrics, the average element quality is 0.799 (Desired value: 0.7 to 1)

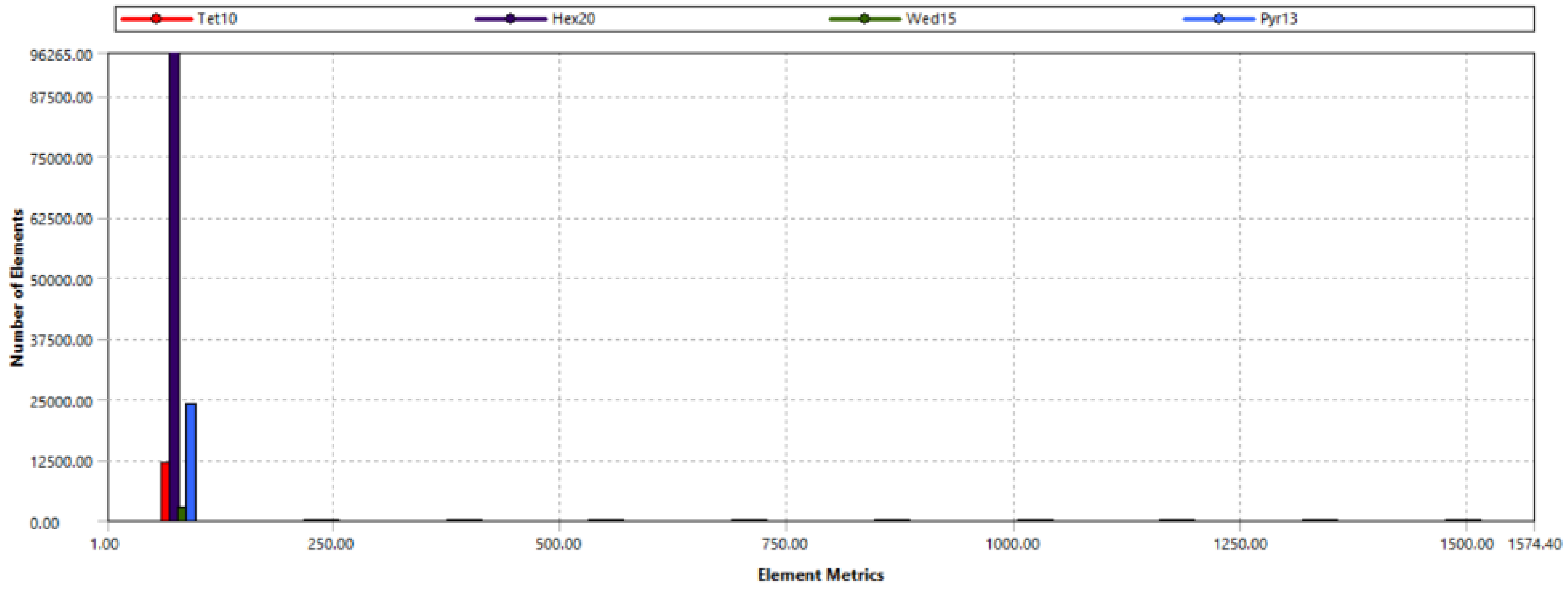
Mesh metric	Element Quality
Minimum	6.4938e-003
Maximum	1
Average	0.79942
Standard Deviation	0.26252



FEM Modelling

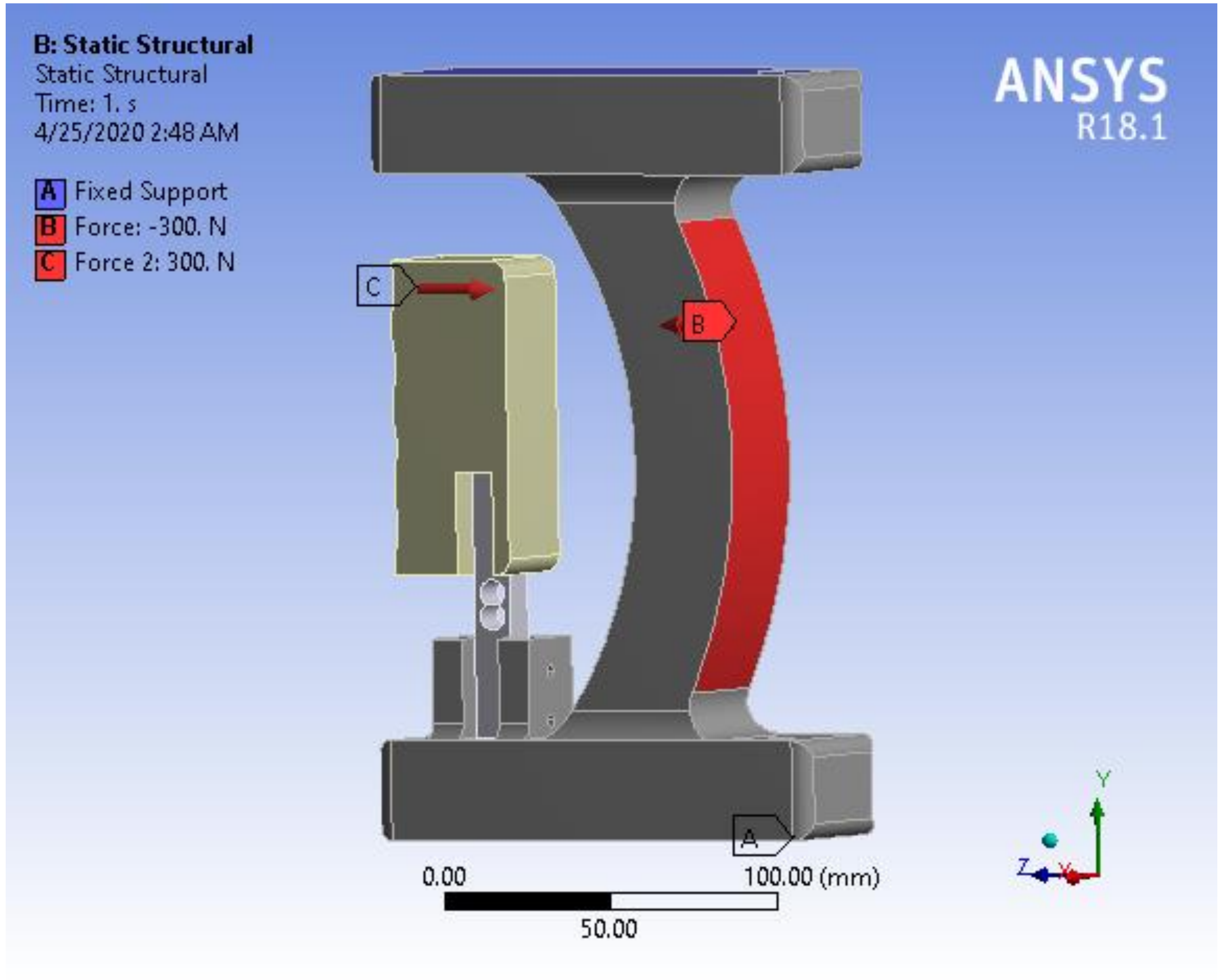
Under the Mesh Metrics, the average element quality is 2.894 (Desired value: less than 5)

Mesh metric	Aspect Ratio
Minimum	1.0003
Maximum	1574.4
Average	2.894
Standard Deviation	8.7517



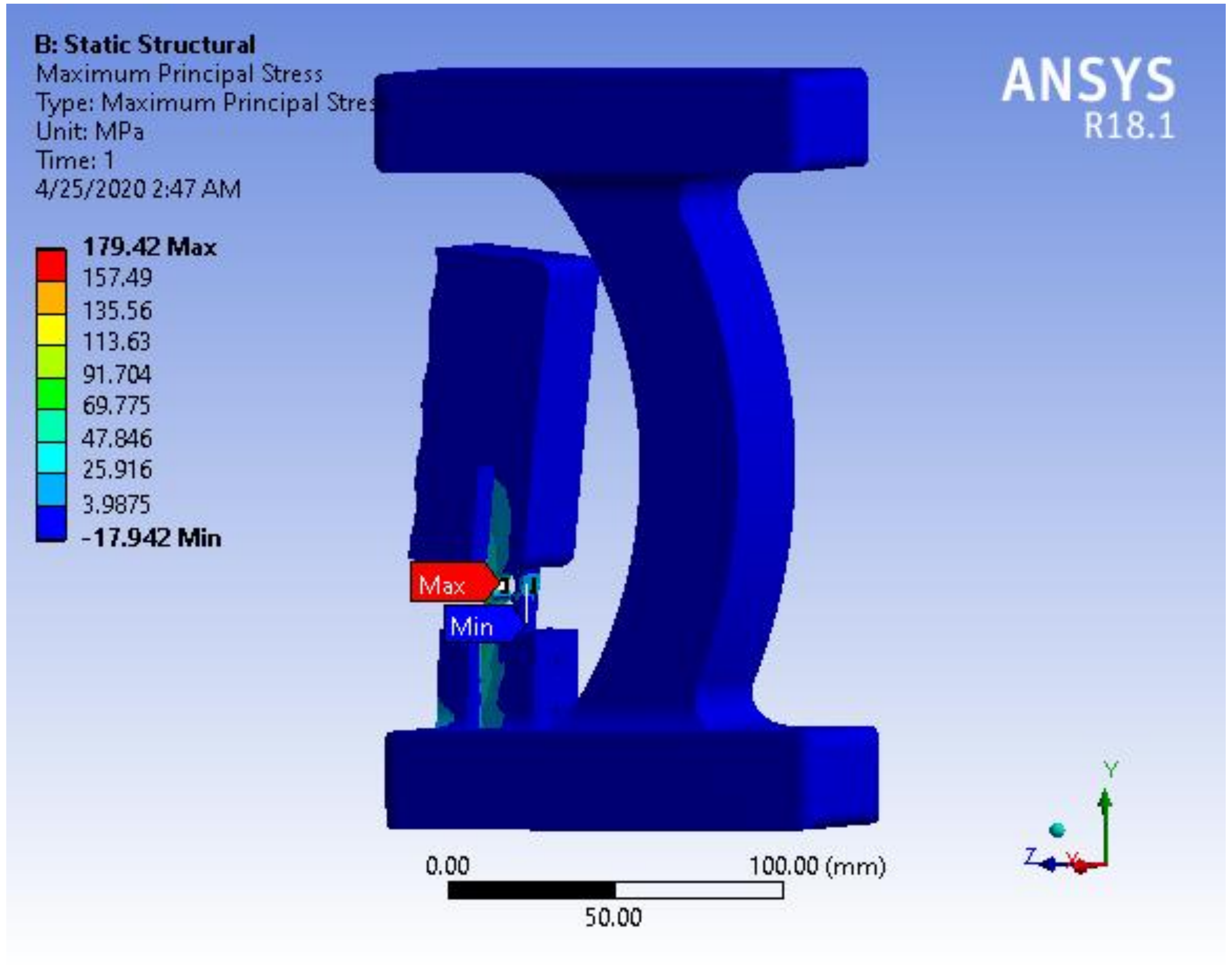
FEM Modelling

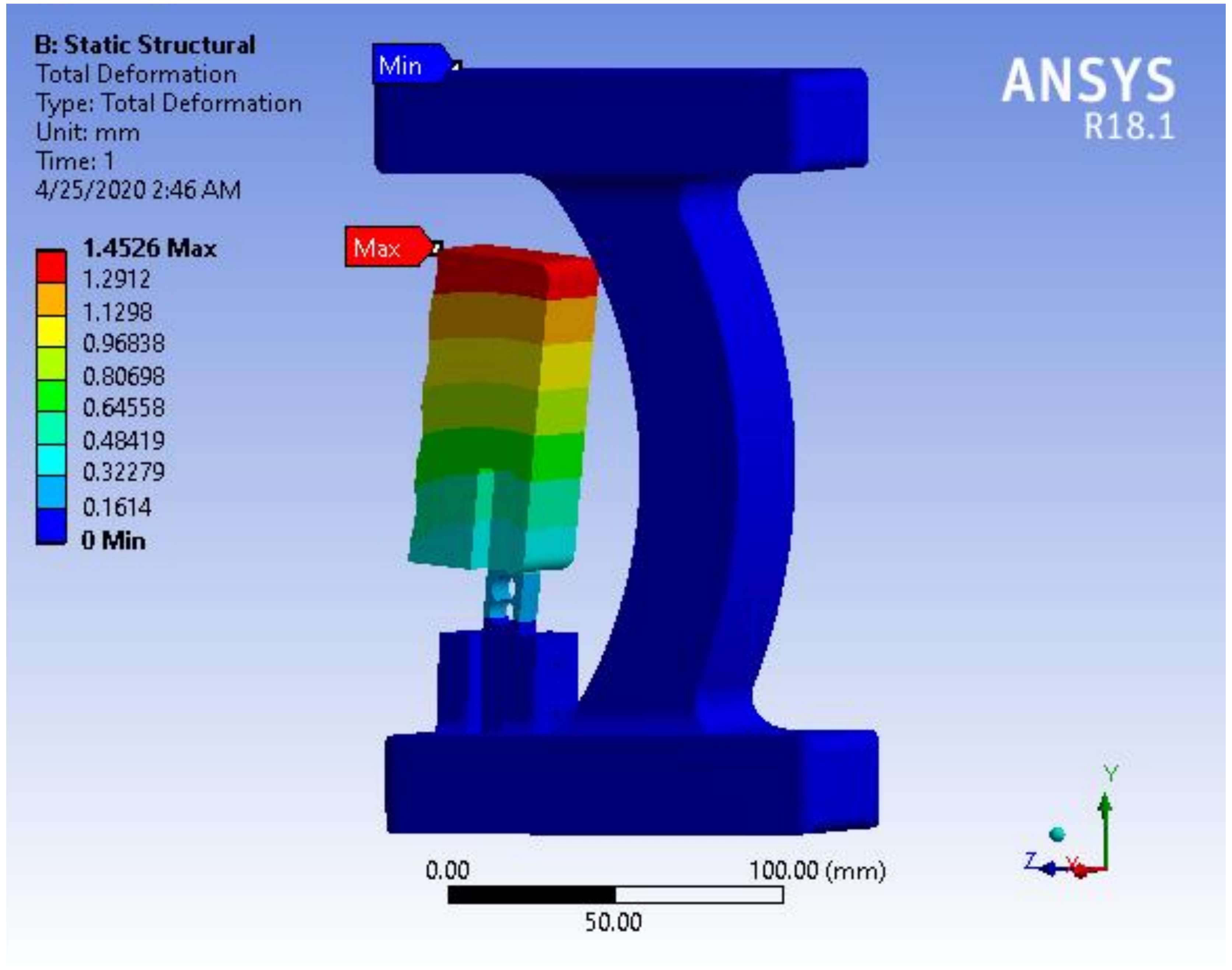
The loading condition was such that 300N was applied on the grip and an equal and opposite reaction was applied on the support structure by fixing the ends of the supporting structure.



FEM Modelling

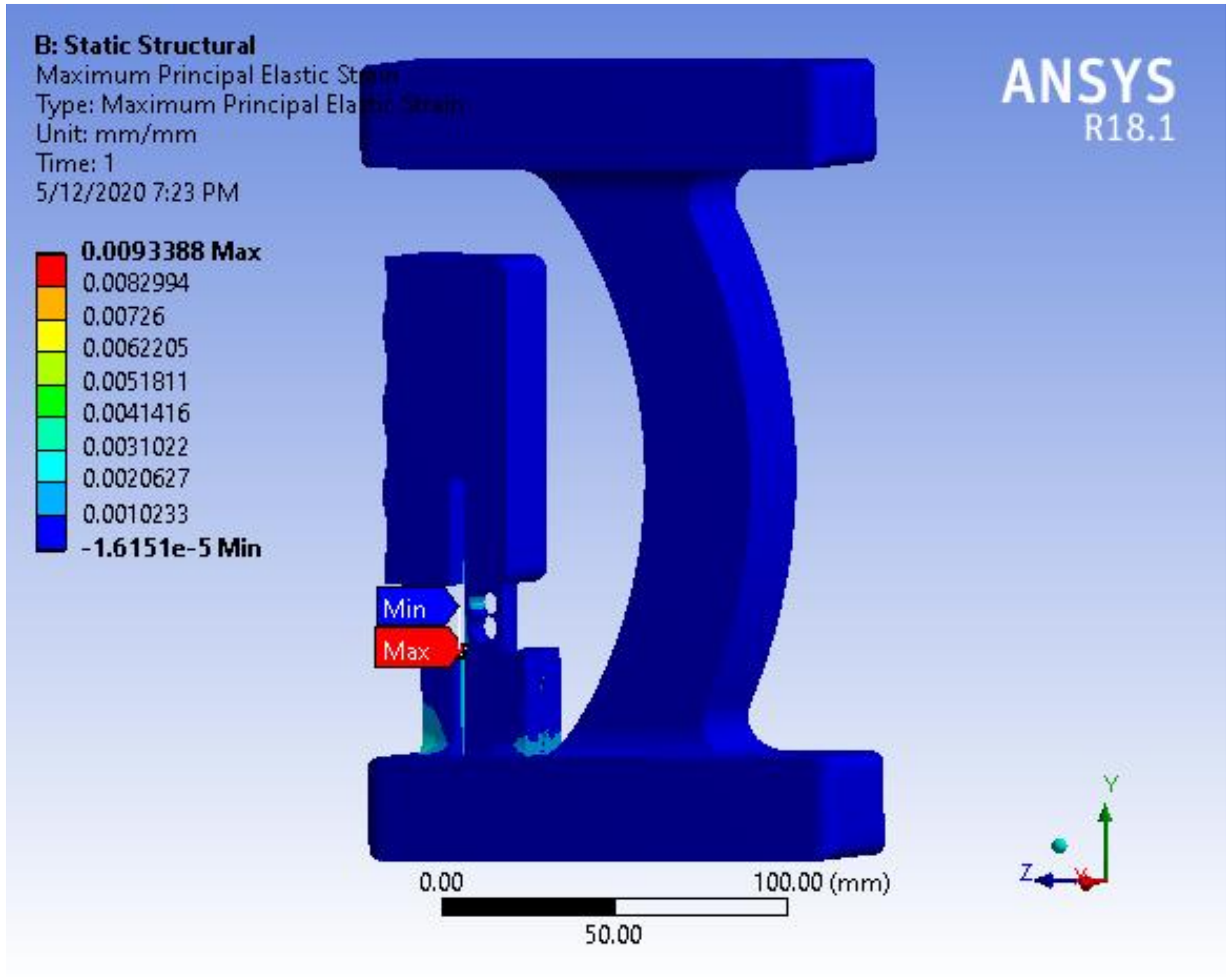
Finally, we solve and obtain the maximum principal stress of 179MPa and the total deformation of 1.452mm

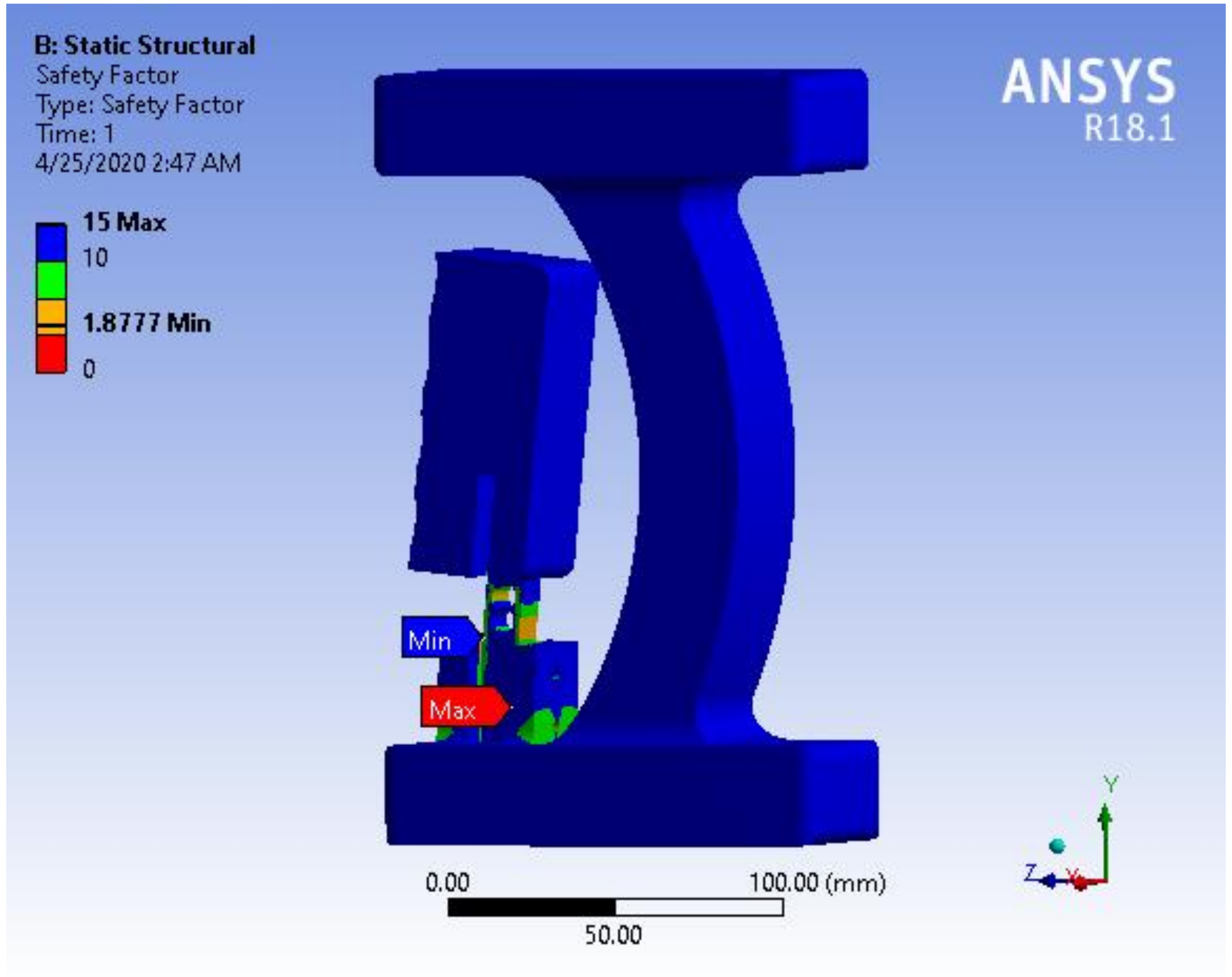




FEM Modelling

Finally, we solve and obtain the maximum principal elastic strain of 0.0093mm/mm and the Factor of Safety of 1.87





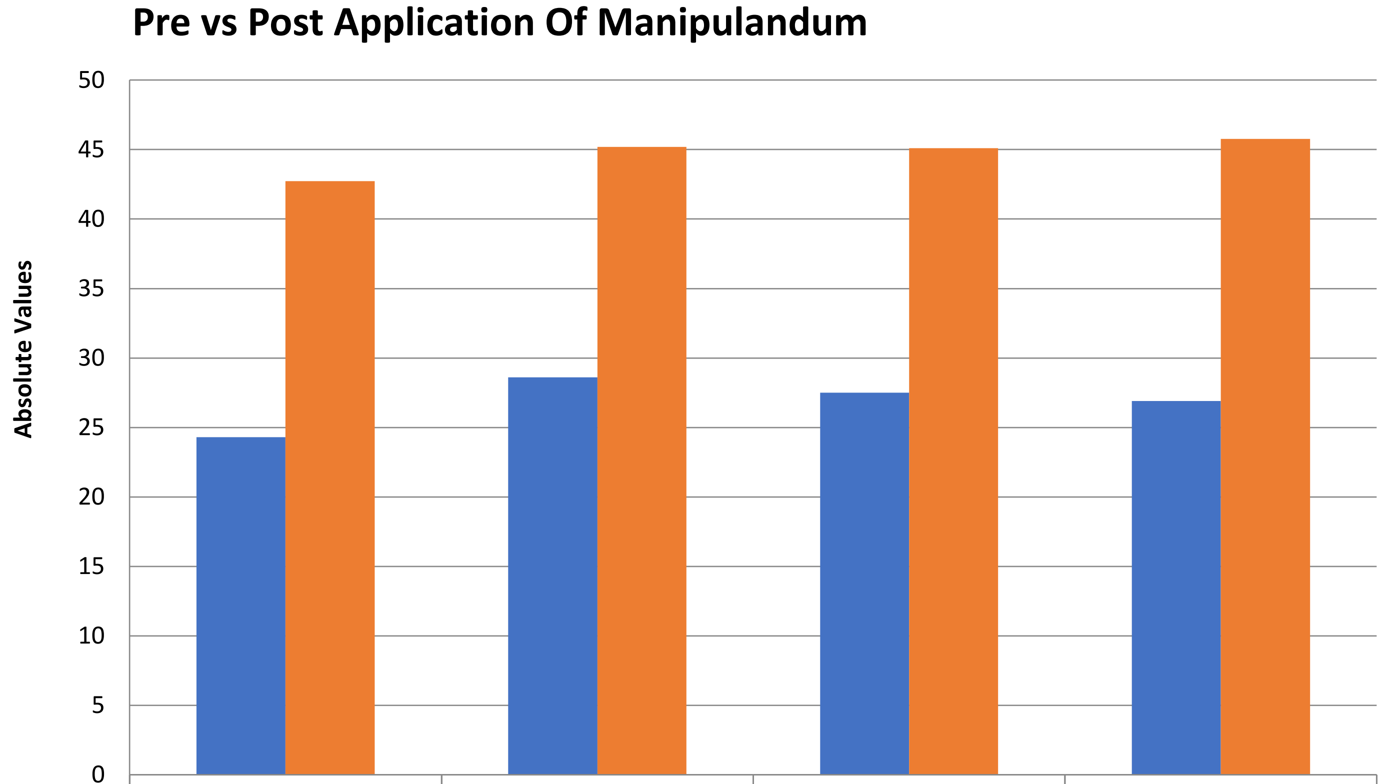
Results & Discussion

	Affected Arm		Unaffected Arm	
	Pre Application	Post Application	Pre Application	Post Application
Grip Strength (N)	24.3	28.6	27.5	26.9
ROM of Wrist Extension (deg)	42.74	45.2	45.1	45.78
ROM of Wrist Flexion (deg)	78.4	80.5	83.9	83.7
Precision (%)	88.3		87.5	

Grip Strength of Affected Arm and Unaffected arm of Pre and Post Rehabilitation

The above table is a simulation result of the subjects' both affected and unaffected arm. The comparative results give the improvement in figures after being subjected to manipulandum rehabilitation. A considerable improvement is to be seen in the affected arm. The range of motion for wrist extension post application has improved by 5%, meaning the manipulandum rehabilitation proves to be effective. The precision values suggest that the device was able to record the same value over five set of trials for a given specific position and corresponding such readings can be obtained over various wrist angle positions. The range of motion for wrist flexion has proven to be effective, as the changes in the affected arm is 2.1 degrees. The unaffected arm reading does not vary and is about the same value.

Results & Discussion



	Affected Arm		Unaffected Arm	
	Pre Application	Post Application	Pre Application	Post Application
Grip Strength	24.3	28.6	27.5	26.9
ROM Of Wrist Extension	42.74	45.2	45.1	45.78

Representation of grip strength and ROM of Pre vs Post Rehabilitation

Comparison of the result data simulated for rehabilitation. The evaluation parameters are grip strength and range of motion of wrist extension. The values are mean about various wrist positions, which imply the various angles of wrist. While there is hairline improvement in the unaffected arm, significant number improvement is for the unaffected arm.

Conclusion

- Findings of this pilot study proves that evaluation parameters such as grip strength and range of motion to be a rate dependant property as the it was observed that post application of the manipulandum therapy the grip strength was increased with decrease in the level of impairment making a better competency.
- The competency classification algorithm was successful in differentiation the test data from that of the healthy individuals.
- The PID motor control configuration was proved to be efficient in driving to the desired place with the adaptive torques of 6Nm, 8Nm and 10 Nm.
- The trials postulate that the device is capable of dual modalities which are therapeutic and assistive device.
- The therapeutic group had only the grip strength improving, while the assistive had both the evaluation parameters convincingly improved.
- Range of motion was slower to improve than the grip strength in the case of affected arm. The range of motion increased at the rate of 0.024deg/day, while the grip strength improved at a rate of .04387N/day.
- The results secured are beneficial in overcoming the demerits of the conventional therapy such as professional intervention, intensive treatment and lacking patients’ co-operation. Further it provides a new intuition to the method of rehabilitation technique, integrate error free computation with an unique way of interactive simulation.

Future Scope

- Extension of one DOF motion to multi DOF.
- To make an adaptable type of grips, widening to pinch, snap type of wrist grips.
- To target all age groups and inculcate forearm circumference as one of the evaluation parameters.
- To develop an adaptive interface between the subject and the manipulandum
- The number of subjects and the training groups selected were few in number and add to the demerit of the study. A larger study involving focus groups, enhanced target groups, varied cases of impairment are suggested to be undertaken.

Thank You