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Modelling and Finite Element Based Analysis of a Five Fingered Underactuated Robotic Hand

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Abstract: Imparting the dexterity and autonomous competence to a robotic system is a significant burden in humanoid robotics, especially in the fields of industrial manufacturing, prosthetics, orthopedic rehabilitation, etc. Operating a humanoid hand requires a very innovative actuator and transmission system. The under-actuated concepts are proving to be a possible means of achieving extremely dexterous robotic hands without the need for diverse mechanical design. The main characteristics of an under-actuated robotic hand are that fewer actuators are required to operate it than the degrees of freedom. The under-actuated equivalent hand is significantly less expensive than the fully-actuated equivalent hand and remarkably reduces the complexity of the control system. The existing work dealt with the modeling and finite element-based analysis of an anthropomorphic underactuated robotic hand using five fingers including the thumb and palm with dexterity and with a total of twenty-one degrees of freedom.

Keywords: Anthropomorphic, Dexterous, Grasping, Underactuation

I. INTRODUCTION

The human hand is the most sophisticated and diverse outer end of the human body and is a result of innovation dating back thousands of years [1].The human hand is used in performing a wide ranges of work. Referring to the human hand the robotic hands are designed to perform a wide ranges of work in varied field where human hand has its limitations. In the process of designing a robotic hand fully actuated as well as underactuation concept can be implemented. [2]. Objects of any shape and size can be vigorously adjusted by the human hand. It is a great challenge for the designer to construct the robotic hand with fewer actuators while maintaining the same degrees of freedom for dexterous gripping. It will be very difficult to implement the robot in unstructured conditions since it is not known what kind of object it will hold in shape and size. The fully actuated hand can be implemented to solve the above problems, but the cost factor is high and the weight will be heavier compared to the under-actuated hand using a smaller number of actuators[3]. The process of under-actuation in the robotic hand significantly reduces complexity. Technological development in sensing and other related fields insists that designers implement under-actuation techniques in the robotic hand, which prove to be more effective in terms of proper grasping, a better index of dexterity, and easier to expose control compared to a fully-actuated hand[4]. The actuation processes required for proper grasping and anthropomorphism have been discussed for better function. It has been studied to achieve proper grasping and dexterity operations with the fewest number of degrees of freedom for the rigid robotic hand with no sliding and rolling contact pairs[5]. A tendon driven hand with three finger having active and passive tendons has been designed that focuses upon the control mechanism of the hand. Mathematical modelling and kinematic Analysis of a tendon driven robotic hand is proposed [6].One of the mechanisms involves the same tendon and actuator actions of human muscle and the other mechanism involves two-pulley systems that allow to detect the non-linear change of the lever arm according to changes in the joint angle[7]. The design of a tendon-driven finger for a five-fingered robotic hand has been proposed and its analysis has been presented that include mechanisms that replicate the features of the human finger[8].A five-finger multi-sensor based bio-prosthetic hand has been designed as HIT/DLR hand which is based on the under-actuation mechanism[9]. The detailed concept of the Design of an anthropomorphic robotic hand with the combined effect of the tendon as well as linkage driven has been studied[10]. Modelling and Finite Element Based Analysis of Grasping of a Cuboidal Shaped Object by a Five Fingered Underactuated Robotic Hand is presented[11]A robotic hand with five fingers that are optimized kinematically has been discussed[12].The process of adaptive alliances for operation with a high degree of merging has been presented in UNIPI-hand[13]. Forward and reverse kinematic analysis of five-fingered robotic hands has been proposed, with research focusing first on grasping differently shaped objects and secondly on analyzing the movement of robotic fingers when grasping differently shaped objects[13]. An anthropomorphic hand in which tendons were used to drive the phalanges have been studied extensively where interaction with the object to be grasped[14].

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A robotic hand has been designed that involves two actuators and seventeen joints as a total for the hand which can be used to reshuffle synergies the first two postures of the hand[15]. Mathematical modelling and kinematic analysis of a tendon driven robotic hand are proposed where research has been carried out in modelling concept of under actuation[16].Finite element based analysis is presented[17].

Modelling and finite element based analysis of an anthropomorphic underactuated robotic hand is presented [18].An anthropomorphic Under actuated robotic hand with 5 fingers,15 degrees of freedom (DOF) and a single actuator has been discussed[19]. Finite element analysis of a three fingered robotic hand is presented [20].A hand with five fingers called the S-type kinematic humanoid hand has been proposed. This hand is capable of dexterous gripping, showing hand shapes and the master-slave system using the five-finger bilateral process technique. Considering the common coupling configuration for an underact to maximize grip and reduce contact forces for a variety of targets, dimensions and locations discussed without considering force capability[21]. Theoretical studies on the kinematic modeling of a multi-finger robot hand were presented. A dynamic gripping method was projected for an arbitrary polyhedral body using a hand-arm system with hemispherical fingertips and using a non-holonomic rolling constraint formulation between individual fingertips and the object's surface[22].Development of anthropomorphic robotic hand with underactuated mechanism is presented[23]. overview of finite element method is described [24].Even though numerous works were approved still some works that need to be highlighted. Keeping this the present work deals with the modelling of anthropomorphic underactuated robotic hands using modelling software and later on analysis has been carried out for grasping. The analysis, includes the deformation, stress and strain analysis. The proposed hand model has 15 joints, 21 DOF and 17 nos of actuators. The Distal Interphalangeal Joint ,Metatarsophalangeal joint and proximal interphalangeal joint of all the four fingers i.e. Index finger, Middle finger, Ring finger and little finger have been taken as underactuated in the present analysis.

II. MATERIAL AND METHOD

The material used for the analysis of the proposed hand model is, Aluminium Alloy, stainless steel and Carbon Fibre (395GPa). Carbon fiber is a material composed of thin, strong crystalline carbon filaments. Carbon fibers offer a variety of advantages including: high stiffness, high tensile strength, low weight-to-strength ratio, high temperature tolerance, low thermal expansion, high chemical resistance. Carbon fibers are made up of carbon atoms linked in a long chain. The fibers are extremely stiff, strong and light and are used in many processes to create excellent building materials. Carbon fiber material comes in a variety of raw building blocks including yarns, unidirectional, fabrics, braids and a few others, which in turn are used to make carbon fiber composite parts. The properties of the material are mentioned in the table.1.

Table 1: Properties of the Material

Mechanical properties	Aluminium Alloy	Stainless steel	Carbon Fiber (395 GPa)
density	2.77e-06Kg/mm3	7.75e-06 kg/mm³	1.8e-06 kg/mm³
Young’s modulus	71000 MPa	1.93e+05 MPa	3.95e+05 MPa
Poisson’s ratio	0.33	0.31	0.2
Shear modulus	26692MPa	73664MPa	8000MPa

III. MODEL OF THE PROPOSED ROBOTIC HAND

The projected robotic hand comprises of 4 fingers and a thumb. Each finger consists of three phalanges. Each finger consists of three joints i.e.PIP, DIP and MCP joints. The thumb consists of CMC.MCP and IP joints. The index finger has 4 degrees of freedom. The ring, middle and index fingers have 4 degrees of freedom each. The thumb comprises of 5 degrees of freedom. The schematic diagram of the hand model with all the phalanges, joints and degrees of freedom are presented in fig.1.

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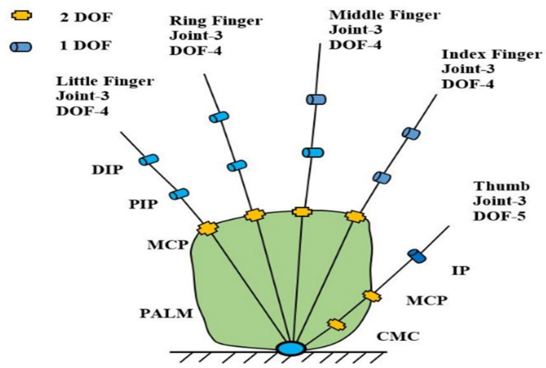

Fig. 1 Model of Robotic Hand with the Number of Joints and Degrees of Freedom

The dimension of all the phalanges of the proposed hand are stated in table 2.The proposed hand has a palm, a thumb and four fingers as similar to a human hand. The fingers are attached to the base of the palm. The fingers consist of three phalangs each. All the phalanges of a single finger are connected to each other by means of revolute joints. The model is built by considering the anthropomorphic data of the size of a normal male human being[25] mentioned

Table 2 Dimension of the Proposed Hand Model

Name of the finger	Dimension (length x width x thickness in mm)
Palm	80 x 42 x12
Thumb	29.23 x 12 x 9
Index Finger	17.945 x 8 x 5
Middle Finger	19.98 x 10 x 5
Ring Finger	19.8 x 10 x 5
Little Finger	17.21 x 7 x 4

The five fingered robotic hand is modelled by using the solid work platform. The model of the hand is shown in fig.2 where all the fingers are there with thumb and the palm..Fig.3 shows the guide ways and the path for the tendon and pulley arrangement. There are various methods are used to underactauate the fingers .The most used methods are tendon pulley arrangement, Linkage bar mechanism ,gear driven mechanism etc. From detailed study and analysis amongst the best methods, in this present work use of tendon pulley system to under-actuated the index finger, middle finger, ring finger and the little finger is attempted. Operation and movements of the digits of the thumb is done manually. The degrees of freedom and angle restrictions for motion have been emulated in the model of the hand to make it skill full.

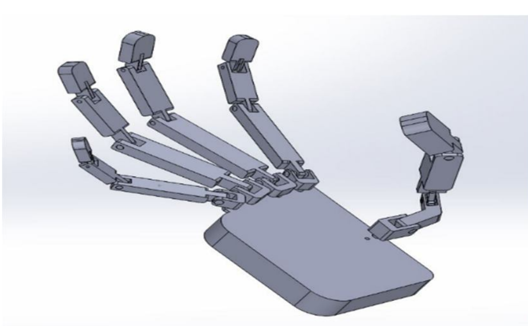

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Fig. 2 Model of the Robotic Hand

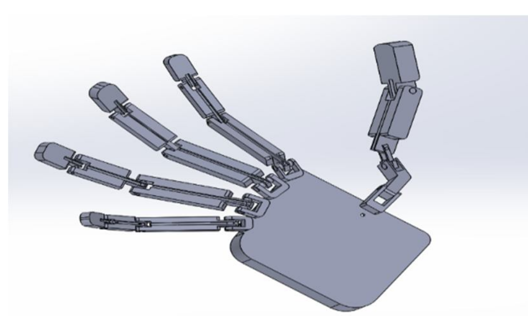

Fig. 3 Model of the Hand for Tendon Pulley Guide ways

The model of robotic hand is like a human hand and it consists of four fingers i.e. index finger, middle finger, ring finger and the little finger each having equal numbers of joints as in a human hand with a minor modification. The thumb comprises three joints i.e. CMC joint, MCP joint and IP joints and it has five numbers of degrees of freedom. Tendon pulley mechanism is one of the most commonly used mechanism in under actuation. The tendon pulley arrangement is shown in figure 4 and figure 5.where pulleys are present at the axis of the phalanges and are free to rotate about the axis.

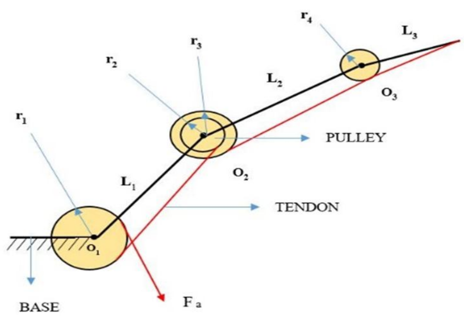

Fig. 4 Tendon Pulley Arrangement

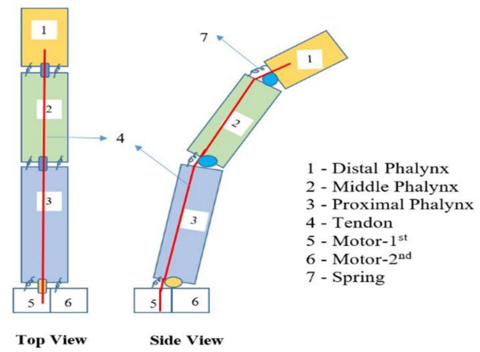

Fig. 5 Tendon Pulley Arrangement of a Single Finger

The axis shared by the pulleys and the equivalent phalanx joints is same. It is important to note that the pulleys are free to freely revolve about their axes without causing the phalanges to rotate as well. If this requirement is not happened, the finger won't be underactuated instead, the phalanges will move together and the finger will only have one degree of freedom.Refering to the figure as the tendon is pulled inward the pulleys rotate and the phalanges closes against the spring thus the springs get contracted and when the tendon releases the spring extends making the phalanges move outward.

IV. GRASPING

Grabbing and manipulating functions of the human hand are its foremost functions. The collection of techniques and actions that must be recognized in a robotic hand in order to hold an object in the hand is known as grasping. Finding a design for the dexterous robotic hand that can perform a strong hold is one of the difficulties. When using a power grip, the hand uses a power grip motion. The object is encased by the fingers and palm, which make several touches with it. The object is firmly grasped between the fingers and palm. The hand grips the object so firmly that there will not exist any relative motion between the hand and the object. In other words, the force applied by the hand on the object is so high that it resists all possible external force that may act on the object. In precision grasp the object is grasped by the finger tips only. There is neither more number of contact points at the fingers nor there is palm connection with the object. Though precision grasp has a high degree of manipulability, it does not have a large ability to resist loads. So the firm grasp is not achieved in this kind of grasp.

V. ANALYSIS OF THE HAND

The proposed hand is modelled in a solid work 2015 environment and the analysis is done on the Ansys-2021 platform. The material used for the analysis is aluminium alloy, stainless steel and carbon Fiber (395 GPa). The mesh is a triangular mesh. The analysis of the hand in Ansys work bench has 28145 nodes and the total number of elements is 10819. During the analysis, the palm is fixed. In the present work analysis is carried out in two categories. In the 1st category forces are applied on the surfaces of the phalanges of each finger perpendicularly. The magnitude of the forces increases from 10N to 50N gradually with an increase of 10N. In the 2nd category force acting on the phalanges are as follows: 50N force on the proximal phalanges of index, middle, ring finger.25N force on the proximal phalynx of the little finger,40N force on the middle phalanges of the index, middle and ring finger,20N force on the middle ring phalynx.5N force on the distal phalanges of four fingers and thumb.5 N force on the proximal phalynx thumb. Top face of the palm is fixed. Meshing of the proposed hand is presented in fig6. The direction of the applied force is on the plane surface of the phalanges and is perpendicular to the phalynx surface and is presented in figure 7.

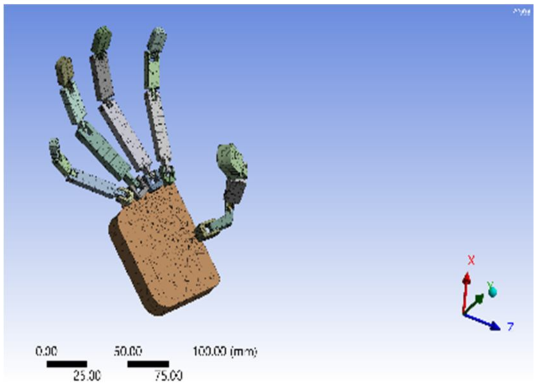

Fig. 6 Meshing of the Hand in Ansys Workbench

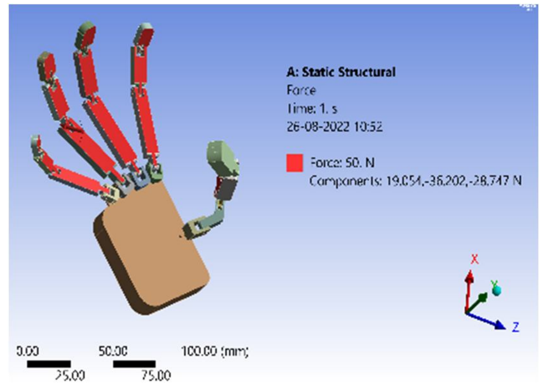

Fig. 7 Direction of Application of Force

The deformation of the total hand model at 50N force for Al Alloy is presented in figure 8. The blue colour indicates the minimum value and the red colour indicates the maximum value.

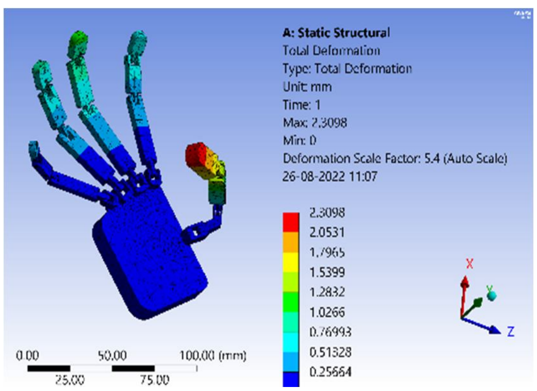

Fig. 8 Deformation of Hand at 50N Force for Al-Alloy

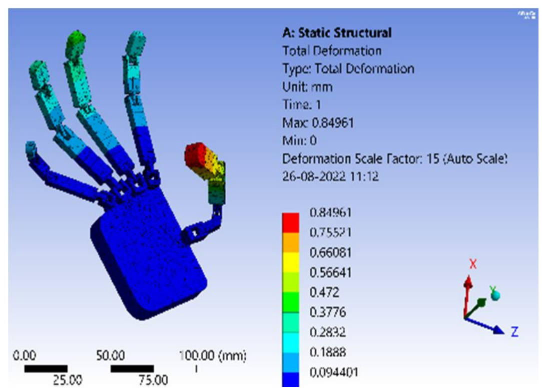

Fig. 9 Deformation of Hand at 50N Force for Stainless Steel

The deformation of the total hand model at 50N force for stainless steel is presented in figure. 9. Similarly the deformation of the modelled hand for Carbon Fibre-395GPa at 50N force is presented in figure10.

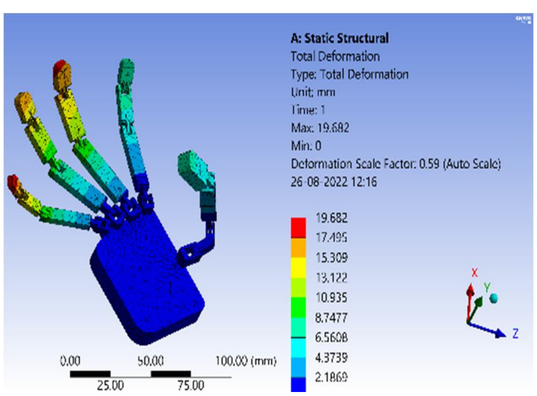

Fig. 10 Deformation of Hand at 50N Force for Carbon Fibre-395GPa

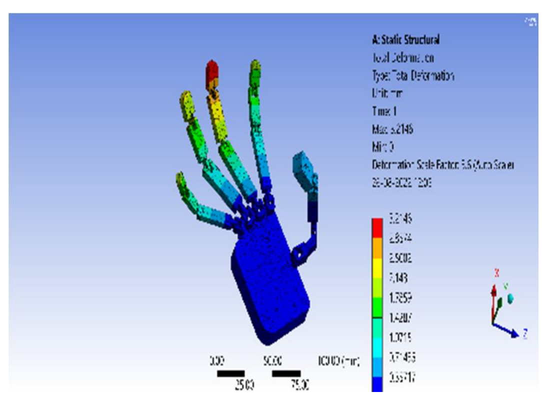

Fig. 11 Deformation of Hand at Variable Force for Al Alloy

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Figure 11 represents the deformation diagram of the modelled hand for Al Alloy at variable forces at the phalanges. Similarly the hand deformation for stainless steel material of the proposed hand due to variable force application is presented in figure 12. and for Carbon fibre-395GPa is presented in figure 13.

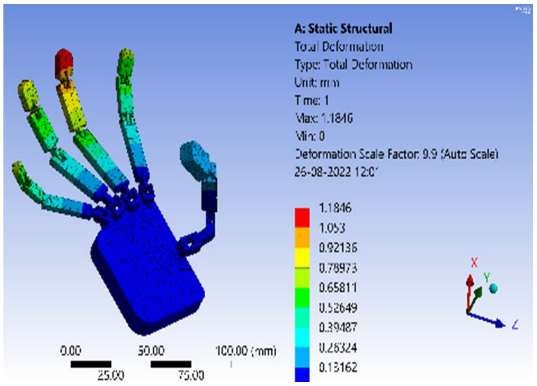

Fig. 12 Deformation of Hand at Variable Force for Stainless Steel

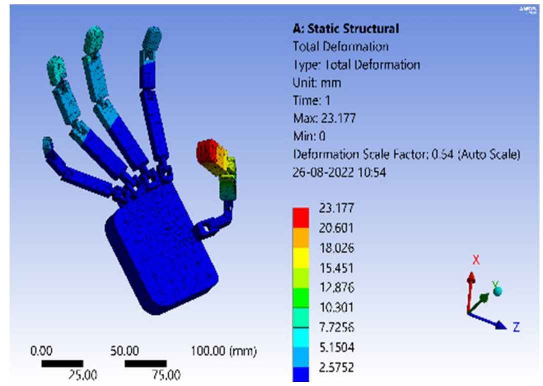

Fig. 13 Deformation of Hand at Variable Force for Carbon Fibre-395GPa

VI. RESULT AND DISCUSSION

The analysis of deformation, maximum principal stress and maximum principal elastic strain for the modelled hand for Aluminium Alloy is is presented in table 3. Where the maximum values obtained in the analysis is presented.

Table 3 Values of the Mechanical Properties for Aluminum Alloy

Force (N)	Deformation (mm)	Maxm. Principal stress(Mpa)	Maxm. principal strain (mm/mm)
10N	0.46196	63.184	8.93E-04
20N	0.92391	126.37	1.79E-03
30N	1.3859	189.55	2.68E-03
40N	1.8478	252.74	3.57E-03
50N	2.3098	315.92	4.46E-03

The values of the mechanical properties for the proposed hand model made up of stainless steel is presented in table 4.The various mechanical properties analysed are deformation, Maximum principal stress and maximum principal strain.

Table 4 Values Mechanical Properties for Stainless Steel

Force (N)	Deformation (mm)	Maxm. Principal stress(Mpa)	Maxm. principal strain (mm/mm)
10N	0.16992	63.265	3.29E-04
20N	0.33984	126.53	6.57E-04
30N	0.50977	189.79	9.86E-04
40N	0.67969	253.06	1.31E-03
50N	0.84961	316.32	1.64E-03

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The values of the mechanical properties for the proposed hand model made up of Carbon fibre-395GPa is presented in table 5.All the mechanical parameters are analysed and the values are presented for 10N to 50N force with an interval of 10N .

Table 5 Values Mechanical Properties for Carbon Fiber -395GPa

Force (N)	Deformation (mm)	Maxm. Principal stress(Mpa)	Maxm. principal strain (mm/mm)
10N	4.6353	279.56	1.04E-02
20N	9.2707	559.12	2.07E-02
30N	13.906	838.68	3.11E-02
40N	18.541	1118.2	4.14E-02
50N	23.177	1397.8	5.18E-02

The values of the mechanical properties for variable force application is presented in table 6 where three different material is chosen in Ansys platform. It is found from the data that the deflection is more for Carbon Fiber (395GPa) as compared to Al Alloy and stainless steel. All the other mechanical properties are mentioned in the table.

Table 6 Values of the Mechanical Properties at Variable Force

Material	Deformation (mm)	Maxm. Principal stress (Mpa)	Maxm. principal strain (mm/mm)
AL Alloy	3.2146	726.59	1.18E-02
Stainless steel	1.1846	713.4	4.24E-03
Carbon Fibre(395GPa)	19.682	3466.2	7.23E-02

eferring to the data obtained from the table 3, 4 and table5 the comparison statement of various mechanical parameters are drawn.

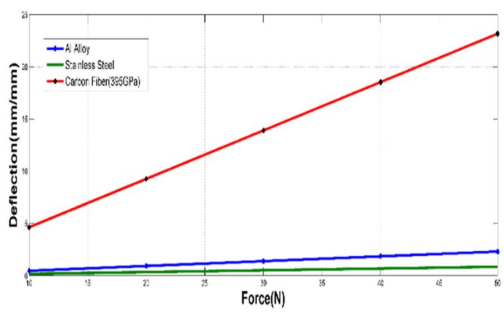

Fig. 14 Comparison Graph for Deformation

The comparison graph for the maximum principal stress is described in figure 15. It is found that as the value of the force increases the stress value also increases. The stress value for the Aluminum alloy and stainless steel are approximately same and are align in a single line. The slope of the stress value for carbon fiber 395 GPa is more as compared to the other two material which is indicated in red line.

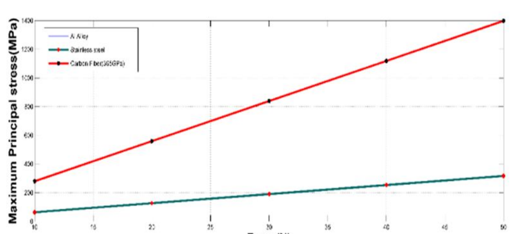

Fig. 15 Comparison Graph for Maximum Principal Stress

The comparison graph for the maximum principal strain value is described in figure 16. It is found that as the value of the force increases the strain value also increases.

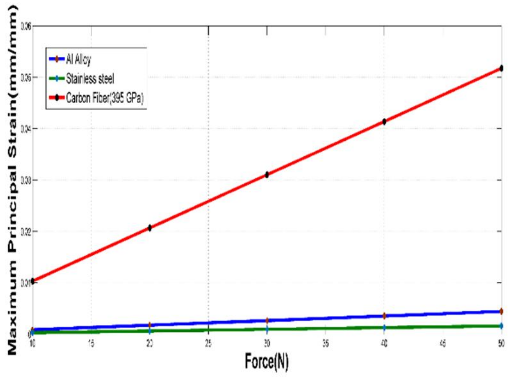

Fig. 16 Comparison Graph for Maximum Principal Strain

The strain value for the Aluminum alloy and stainless steel are nearly close to each other which are presented in green and blue line The slope of the strain value for carbon fiber 395 GPa is more as compared to the other two material which is indicated in red line.

VII. CONCLUSION

The present Project work deals with the modelling and analysis of a five fingered underactuated robotic hand. The proposed hand is driven by tendon and pulley which are present in each fingers. The modelling has been carried out in modelling software. For robotic hand and analysis is carried out in two categories .In first category values of the forces is constant for three materials and gradually varies and for second category the magnitude of the forces are different on the different phalanges of the hand. The material taken for the hand are Stainless steel, Al-Alloy and carbon fibre-. . The material is chosen individually for the palm and all the fingers. The analysis has been carried out for the proposed hand model for grasping. The deformation, Maximum principal stress and maximum principal strain for all the categories are analysed in the Ansys environment

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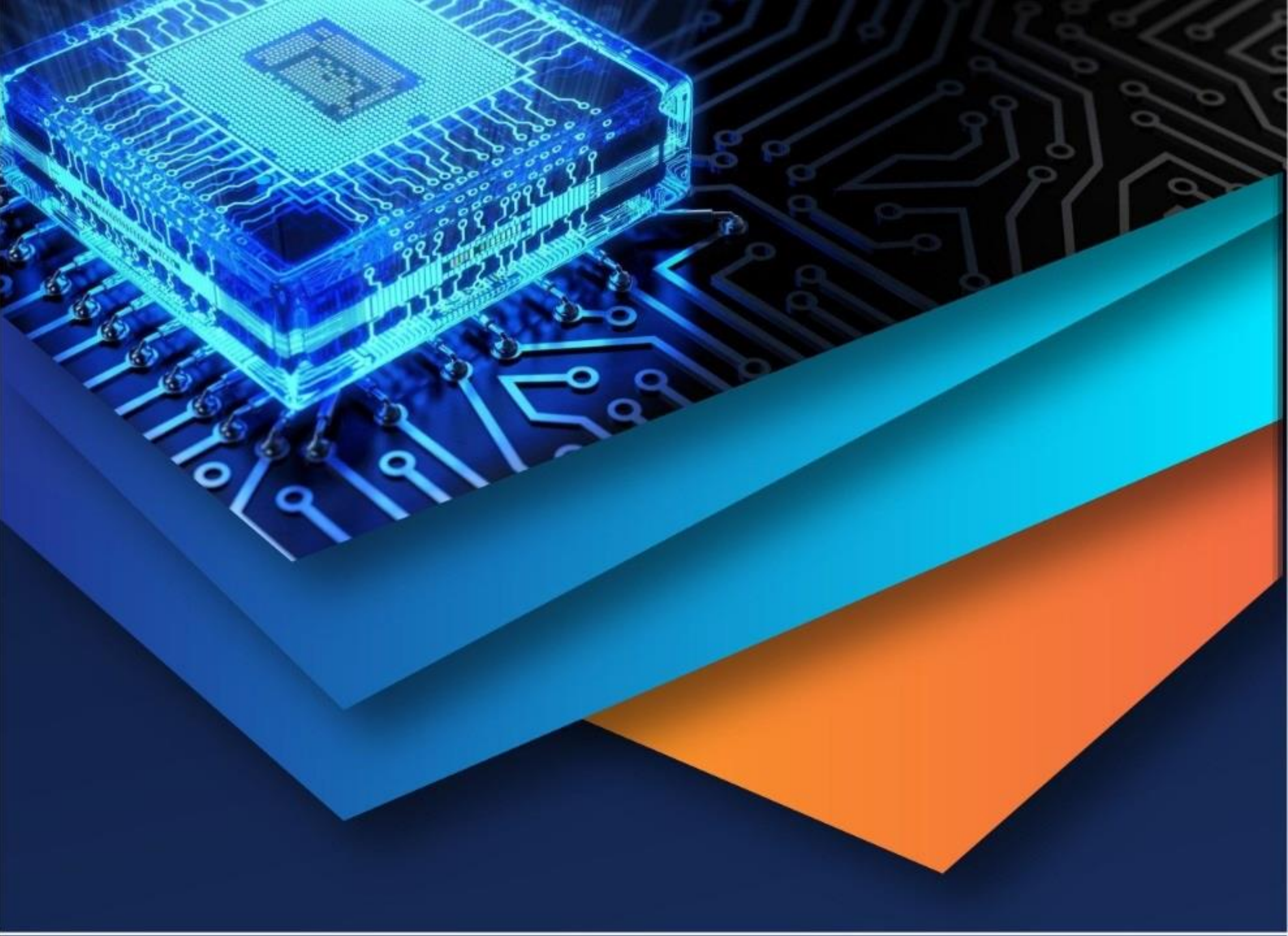

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