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Conceptual Design of 17 DOF Dexterous Robotic Hand for grasping and Manipulation Task

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Abstract: The interest in robotics technology in India is increasing exponentially day by day. There are various studies going around the world in the field of robotics that will make the way of human life more comfortable. This paper presents a new conceptual design and analysis of a17 Degree of Freedom anthropomorphic robotic hand. The robotic hand is designed based on the experimental records accumulated from human subjects. In this study, the finite element analysis (FEA) method is used to assess the robot structure based on the robot design and materials used for robot components. The Deformation and stress testing are carried out using Solidworks software. It has been observed that the FEA result successfully achieved critical points marked for the degree of distortion and stress, respectively. It provides critical data on components of the robot hand that are vulnerable to damage under higher force applications. As a result, this might be applied to refine the design and ensure the compatibility of the robot hand in real-world applications.

Keywords: Anthropomorphic, Robot hand, Finite element analysis (FEA).

1. Introduction

Robotics research is becoming one of the world's leading technologies to replicate human behaviour and ensure smooth as well as tedious tasks accomplishment with great accuracy. They have many roles to play and are used in a wide scope of routes in the current society. Humans are the most intelligent creatures in the world, yet their physical capabilities are limited. As a result, robots are designed to complete activities that are physically impossible for humans to accomplish. For difficult, risky, repetitive, and tedious work, robots take the benefit of surpassing human restrictions. With the number of qualified laborers in the assembly industries reducing, an ideal robot with durability, adaptability, and intelligence is expected to assist in improving product production and quality. The human hand is one of the widespread devices in nature. There is no big surprise that analysts are anxious to apply the upsides of the most current transformative plans to foster the age of mechanical hand applications. The lesser degrees of opportunity and the involvement of the control framework represent the accessible business mechanical hands. With the fast-paced advancements in technology, robotics has proved to be applicable in many areas. The robot hand is designed to carry out any preferred project, such as welding, gripping, spinning, etc., relying on the application. Robotic Hands are frequently predicted to comprehend a huge variety of gadgets of various geometries and mechanics (e.g., profile, friction, softness, etc.) or manage gear in lots of special ways (e.g., twisting, pushing, wrenching, tearing, etc.).

The idea of a robot hand is not new, many are created for the purpose of the study. DLR Hand 2 [1-2], and improved kind of the first DLR Hand that has the form and dimensions of a human hand, was developed by researchers at the German Aerospace Center (DLR). It also has a reversible palm and five articulated fingers, all of which are driven via a set of powerful muscles capable of holding up to 30 N on the fingertip. Hassan and Karam developed a 4 DOF upper extremity rehabilitation robot for the rehabilitation of stroke survivors [2-4]. While developing robots, it's critical to make sure that the robot structure can resist the conditions for which the hand is intended. The outcome of a structural study of a robot design below a given level of stress can be used as a guide for additional design modifications or the selection of a robot's appropriate application. One of the procedures that can be employed is finite element analysis (FEA). Ohol et al [3] used a shape optimization method and FEA to develop a multi-fingered robotic gripper as an example of an FEA study on robot hand design. The research resulted in a considerable reduction in the robot's weight. The Fuzzy Type 1 Force Position Controller is designed to control 4DOF Rehabilitation Robots with disabilities [4]. Syed et al. introduced the flexible motion state sensor for applications with high repeatability, accuracy, and reliability in 2012 [5-7]. In 2014, Ali et al. proposed a system to control the capture of multiple fingers by focusing on the joint and the fingertip [6-9]. The rehabilitation robot was then utilised to increase the robot's nonlinear motion accuracy, and the two fuzzy kinds were employed to control the position of the servo motor. [7]. Hoare et al. developed the therapy robot, simple and low cost for stroke patients [8]. A fuzzy type 1 force position controller was established to control a 4-DOF rehabilitation robot for the disabled [9]. Olevi and Abdulmajid showed a human robot that senses movement was created using a 3D printer and a flex sensor installed on a smart glove [10-14]. The mechanical design of the robot fingers plays a very important role in its operation. Lotti and Vassura described a robotic finger made up of rigid links joined by a hip joint that is powered by a hip joint [11-13]. The functions a unique anthropomorphic robotic hand layout that makes use of a tendon pulley mechanism wherein all fingers are managed with the aid of a single actuator. This solution suggestively decreases cost and management complexity. However, to use 1 degree of freedom with a single push of a button for fingers, the delivery system must be designed very carefully, which is necessary for them to ensure an adequate rate of movement between the phalanges of the fingers. Finger movement is controlled by a set of pulleys located in the palm of your hand [12]. With their ability to accomplish and manipulate desired activities, these hands are meant to perform tasks by grasping a range of bodies. [13-17]. The aim is to design a hand that replicates a human hand with all functions along with aesthetics, overall performance, and versatility. Therefore, this paper attempts to investigate the finger behaviour of an anthropomorphic robotic hand. Each finger is separately actuated here to reduce friction losses and boost mechanical efficacy.

This paper presents to design and development of a 17DOF anthropomorphic servo-motor actuated robotic hand similar to the human hand. Its goal is to give hand functions that are similar to those of a human hand, such as gesturing and grasping objects. Finite Element Analysis (FEA) is conducted on the proposed model to give a brief view of boundary conditions such as stresses and distortion of material caused due to various loads acting on the hand and to evaluate the structural integrity of the design. Section 2 described the workflow of the proposed model. Section 3 shows the design consideration of the proposed model. Section 4 proposed the design of a human robotic hand using solid works software. Section 5 shows the design mechanism and Section 6 states the Finite element analysis (FEA) to identify how much load or pressure can a particular object hold by dividing the body or object into a number of nodes and elements of the proposed model. Section 7 shows the result & discussion and finally, in section 8, the paper's conclusion and future work are discussed.

2. Proposed Methodology

A robotic hand is capable to perform various tasks in the modern world. It can make human life more comfortable and efficient. The robotic hand design is considered from the human hand to make it more applicable to humans. The dimensions are taken by dimensioning the average of human hands. A virtual robotic hand is designed using Solid Works software in which 2D and 3D models are made. The design consideration is taken care of like grasping, manipulation, workspace, actuation, and sensing while designing the 17DOF Anthropomorphic Robotic Hand. After the designing to check the strength of the hand the material selection is done. For checking the integrity of the design and the structure Finite Element Analysis (FEA) is performed. The material selected is PLA (polylactic acid) as it is biodegradable, inexpensive, and easy to print. Then the FEA analysis is performed on the different parts of the proposed design to check its stability under different physical conditions. When the result of FEA is satisfactory then only further processes can be performed. Finite Element Analysis (FEA) is the usage of calculations, models, and simulations to expect and recognize how an object might behave beneath diverse bodily situations[18-22]. In the future work, the orientation and the position of the fingertips and fingertip trajectory by kinematic analysis can be performed on the designed robotic hand and the fingertip trajectories are plotted on a graph from the extracted coordinates, and on the graph of fingertip trajectories, the workspace of the model can be found. As shown below Fig. 1 suggests the flowchart containing all the steps for building the proposed work as discussed above.

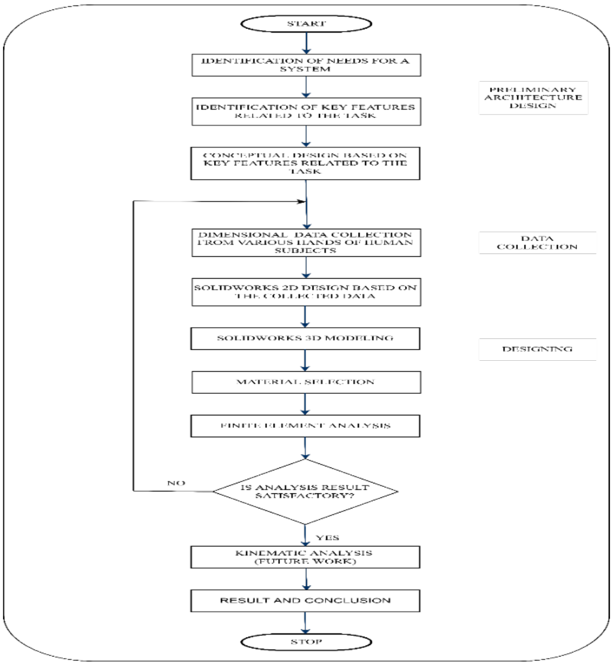

Fig. 1: Flowchart of Proposed Work.

3. Design consideration of the robotic hand

The purpose of the design considerations is to emphasize the significance of incorporating internationally accessible design concepts and standards into buildings and facilities. Recognize and examine the design flaw. In all expected and worst-case scenarios, designs must work properly. Determine the load conditions: Structures will be stressed, stretched, or displaced depending on the load circumstances. The authors explore how to improve the gripping capabilities of a low-cost, easy-to-use multi-finger robotic hand by addressing design concerns. The robotic hand with multiple fingers is meant to do a variety of jobs to save time & expense in the following ways:

1. MANIPULATION in robotic hand refers to the manners in which robots' interface with the objects around them i.e., getting a handle on an item, picking a book, pushing a door. All these activities expect the hand to grasp and control the movement of their phalanges and joints in the secure way. The most effective way to get a handle on an item can be easily chosen for example get a book from the shelve or to pick an object and choose how to explore their hand around the work space.
2. WORK SPACE of a robot is defined as the space in which the robot works. It does not matter where they are working however each and every industrial robot has its own work space area. The knowledge of work space of robotic hand is crucial in order to plan grasping and manipulation. Static and Dynamic equilibrium workspace are some of the types of robotic workspace.
3. ACTUATION devices are the parts of the robot that make it move. They are utilized to produce motion in robots and are the muscles of robots. Most popular actuators are electric engines, servos motors and stepper motors. In this model we are using servo motors as an Actuator. The mechanical finger is actuated by tendons. The tendon is just a flexure wire which will retract the motion of the hand. Robotic hands worked with under actuated systems have less actuators than degree of freedom. Tendons used in mechanical components are divided into two types: passive tendons and active tendons. A passive tendon isn't associated with an actuator, but instead a flexible component.
4. SENSING Sensor in robots allow robots to interact with object in flexible ways. The sensor converts stimuli such as motion, light into an electrical signal. Other type of sensors used in robotic hand are sound sensors, proximity sensors, motion sensor, and pressure sensor. In view of its open-source nature, Arduino has turned into the worldwide choice for sensors using robots. Some of the Sensors are the Flex motion sensor and microphone sensor which can be applied in this model to replicate the human motion.
5. GRASPING is defined as taking hold of an object firmly which include both from fingers and thumb. The analysis of the least contact forces that will ensure the stability of the grasping and the motion's feasibility is a significant challenge in operating a multi-fingered robotic hand gripping an object. Concerning, fundamental scientific ideas including power grasping and precision grasping are clarified. Power grasping is done by inner phalanges and precision grasping is done by the fingertips of the hand.

4. Modeling of the Proposed Robotic Hand

The human hand has about 40 muscle tissues that offer 23 degrees of freedom within the hand and wrist. Taking the experimental information of each finger and trying to replicate the human hand design and its consideration. Where the index finger, middle finger & thumb have 3 DOF, and ring & pinky finger have 4 DOF, the total degree of freedom is 17 DOF. Experimental data is collected for10 different human right hands. The length and radius of each finger and thumb are recorded for all the 10 human subjects and thereafter the dimensions of the proposed hand is taken in accordance to human hand by taking the average length of each finger and thumb. The human hand is replicated to design the 2D and 3D drawing in solid works as Fig. 2 and 4 shows 2D drawing and Fig. 3 and 5 shows 3D drawing of the finger and thumb. The Index finger is the first finger of a human hand. This finger is mostly used among other fingers for performing various tasks. The length and radius of the index finger will be 98.34 mm & 3.72 mm. The middle finger is the second finger of the human hand which is used for better functioning of any task done by the human hand. The length and radius of the middle finger will be 105.07 mm & 4.22 mm. The ring finger is the third finger of the human hand, it provides extra support to the human hand for various tasks. The length and radius of the ring finger will be 97.42 mm & 4.00 mm. The Pinky finger is the last finger of the human hand. It is the smallest in length among other fingers. The length and radius of the middle finger will be 79.94 mm & 3.61 mm. The thumb is the most crucial portion. of the hand without which the tasks are done by a human hand will become very difficult the length and radius of the middle finger will be 68.24 mm & 3.72 mm as shown in Table 1.

Table 1. Dimensions of Fingers & Thumb

Element	Length(mm)	Radius(mm)
Index Finger	98.34mm	3.72mm
Middle Finger	105.07mm	4.22mm
Ring Finger	97.42mm	4.00mm
Pinky Finger	79.94mm	3.61mm
Thumb	68.24mm	3.72mm

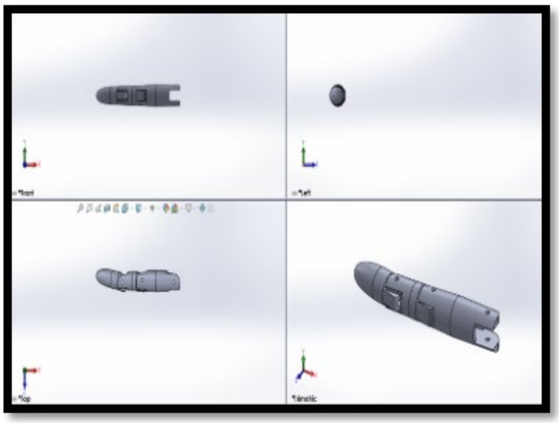

Fig. 2: 2D Design of finger

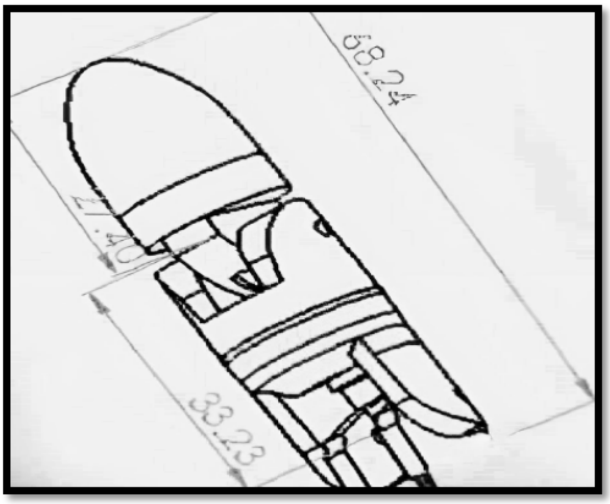

Fig. 3: 3D Positioning of fingers (front, left, top & trimetric view)

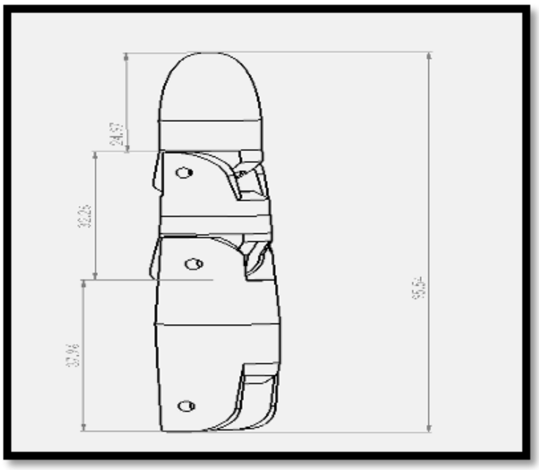

Fig 4: 2D Design of thumb

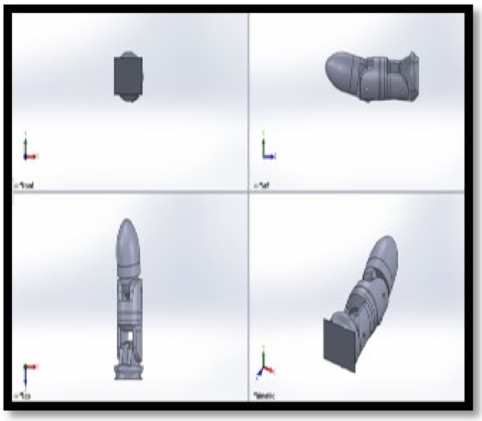

Fig 5: 3D Positioning Of thumb (front, left, top & trimetric view)

A phalanx is termed after its accompanying finger and whether it is proximal, middle, or distal. Proximal phalanges are those closest to the palm/base of the hand or foot. Knuckles are the prominent, knobby ends of the phalanges in the hand. The thumb lacks a distal phalanx. The bones at the tips of the fingers are known as the distal phalanges. Three phalanges are available on each finger. An average of 10 human finger and thumb including the three phalanges that is proximal, middle and distal is taken as shown in Table 2 to replicate the human finger and thumb motion to design the 2D and 3D structure model of the assembly of the multi finger robotic hand with all the components attached to it as shown in Fig. 6 and 7.

The Phalanges of the Hand are a group of small bones that make up the hand's fingers. Each hand contains 4 fingers and an opposing thumb, with three phalanges proximal, middle, and distal to each of the four fingers, whereas the firm has just two (proximal and distal).

Proximal: The initial bone of each finger can be located in the proximal phalanx. When measuring from the hand to the tip of the finger, the proximal phalanx is the longest of the three bones in each finger.

Middle: The middle phalanx is the center or second of the three bones of each finger, from the hand to the tips of the fingers. The phalanges at the base and at the end of the finger are connected by an intermediate phalanx known as the middle phalange.

Distal: The distal phalanx is the third of each finger's three bones, counting from the hand to the tip. The distal phalanx and the middle phalanx are connected by a single joint.

Table 2: Phalanges Data Collection of fingers & thumb.

Elements	**Proximal (mm)**	**Middle (mm)**	**Distal (mm)**
Index Finger	24.42mm	29.81mm	37.39mm
Middle Finger	26.13mm	34.38mm	40.24mm
Ring Finger	37.44mm	31.65mm	24.92mm

Pinky Finger	31.67mm	26.31mm	21.23mm
Thumb	27.40mm	----	33.23mm

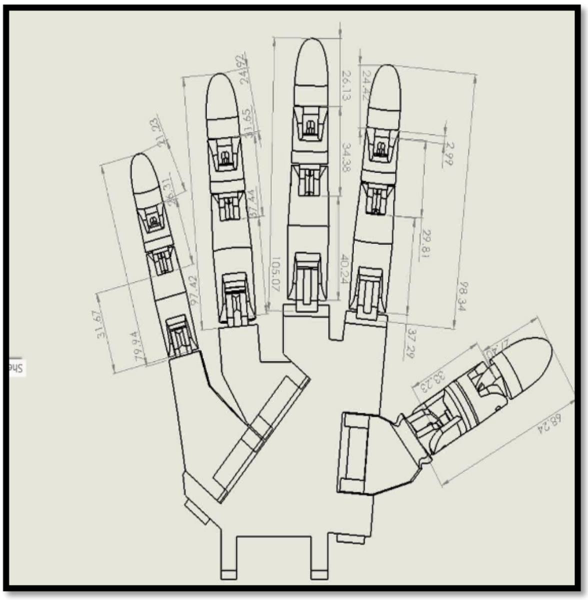

Fig. 6: Two-dimensional drawing of the anthropomorphic robotic hand.

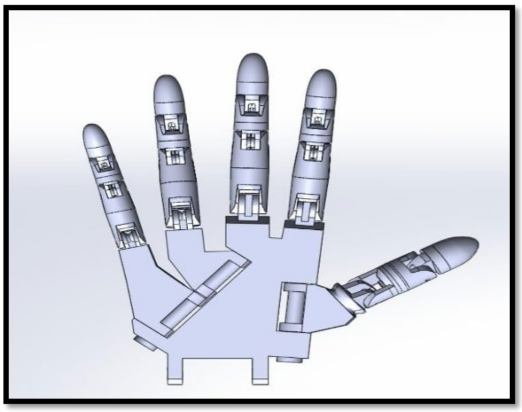

Fig. 7: Three-dimensional Assembly of the anthropomorphic robotic hand.

5. Design Mechanism

A robotic hand is capable to perform various tasks in the modern world. It can make human life more comfortable and efficient. The robotic hand design is considered from the human hand to make it more applicable to humans. The dimensions which is taken by dimensioning the average of human hands. A virtual robotic hand is designed using Solid Works software in which 2D and 3D models are made. After the designing to check the strength of the hand the material selection is done. For checking the integrity of the design and the structure Finite Element Analysis (FEA) is performed. When the result of FEA is satisfactory then only further processes can be performed. Finite Element Analysis (FEA) is the usage of calculations, design, and simulations to expect and recognize how an object might perform beneath diverse bodily situations. Afterward to find the orientation and the position of the fingertips and fingertip trajectory Kinematic Analysis is performed on the designed robotic hand. Through kinematic Analysis the coordinates are extracted from the result, the fingertip trajectories are plotted on a graph from the extracted coordinates, and on the graph of fingertip trajectories, the workspace of the model is found. This proposed robotic hand consists of 4 fingers, a thumb, and a palm, all designed using SOLIDWORKS. The Index finger, Middle, and Thumb have 3 Degree of Freedom (DOF) while Ring and Pinky finger has 4 DOF. The Palm is the base origin of the robotic hand which is in centre and connects all fingers and thumb. Fishing wire is connected to each finger at every joint to give the linear motion i.e., Expansion and Contraction of the fingers and the thumb. The fishing braid 200LB is used because it is long as it can pull and is thin enough to let the finger curl. Each finger has separate pair of wires which is connected further to the servomotors which give the motor-driven motion to the fingers. An external power supply is added because even if these servos are small, they draw too much current which might reboot your board. By connecting these servomotors at the base of the palm the hand is saved from vibrations caused due to servomotors. Servomotors are used to drive the finger of the hand and will give more stability to the system as compared to the pulley-driven system. As shown in Fig. 8 of the proposed mechanism which will help in the flexion and extension motion of the proposed multi-finger robotic hand.

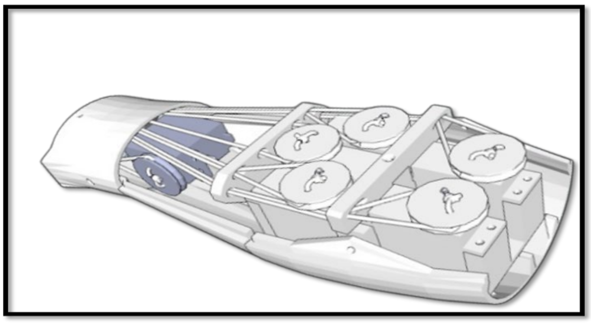

Fig. 8: Mechanism for the proposed robotic hand

6. Finite Element Analysis (FEA) of the Robotic Hand

FEA employs the finite element method (FEM), a numerical methodology that divides an object's structure into many sections, or elements, and then joins the elements at the node. finite element analysis is the use of calculations, models, and simulations to predict and understand how objects react in different physical situations (FEA). Engineers use FEA to uncover flaws in their design prototypes. Finite element analysis necessitates the production of a mesh, which is made up of millions of minuscule components that together determine the geometry of a building. Calculations must be performed on each individual component; the aggregate of these individual responses yields the overall result for the entire structure. Designers who use finite element analysis should be aware of the inherent errors that can occur in the process, such as the finite element method's simplification of geometry and the use of basic integration techniques. During the design process, you can use finite element analysis to optimize all components while reducing the number of prototypes and physical experiences created. In the product development cycle, virtual testing and design optimization are becoming more widespread, with the objective of enhancing product quality and lowering the time to market.

6.1 Structural Analysis

Structural analysis approaches come in a variety of forms. One of them is the strength analysis of materials, commonly known as the classical method. Often used for areas with simple shapes and loads. Many robotic designs, on the other hand, include complex forms of robot elements, demanding time-consuming and difficult computations based mostly on assumptions. As a result, the finite element technique (also known as finite element analysis) was created as a numerical method. FEA creates a grid called mesh by connecting selected finite points called nodes. Analyzing a large building, on the other hand, may be difficult.

6.2 Strength of Material

When a body is subjected to a certain level of external force, it will naturally deform. Due to the cohesion between the molecules, the body, on the other hand, tends to resist deformation. This resistance is known as material strength, and it can be classified as stress or strain [15, 23-26]. Distortion happens as a result of work-transferred force or energy-transferred temperature changes. It's called a strain, and It is defined as the change in body dimension divided by the initial measurement. Tensile, compressive, volumetric, and shear stresses are among the several forms of strain.

Meanwhile, stress, on the other hand, is defined as a body's resistance to deformation per unit area and is measured in the same way as pressure. Since it fluctuates in path and surface area, stress is a significantly more difficult variable than pressure. The stress mathematical formula is

$$\sigma = \frac{P}{A} \tag{1}$$

where stress, external force or load, and cross-sectional area are denoted by, P, and A, respectively.

The Von-Mises stress notion is developed from distortion energy failure theory and is employed in this investigation. According to the theory, mechanical component failure is anticipated to arise after the distortion energy in the real instance exceeds a certain threshold. In a basic uniaxial stress test, is equivalent to or greater than the distortion energy [16].

Performed FEA analysis on different parts of the multi-Finger robotic hand. FEA analysis performed on the finger is shown below. The material selected is PLA (polylactic acid) as it is biodegradable, inexpensive, and easy to print. Strain Analysis is done on the basis of ESTRN criteria as shown in Fig. 9. Stress analysis is done on the basis of von mises criteria as shown in Fig. 10. The area of maximum strain and deformation in the middle phalanges and tip of the finger. Below is the heat map of the analysis done with the force of 1000 N and the deformation on the scale is 3.69038. We can see that a little to negligible displacement is caused due to the applicate of stress on the parts of the robotic hand as shown in Fig. 11.

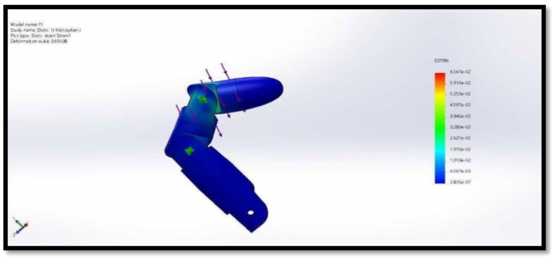

Fig. 9: Strain Analysis Finger

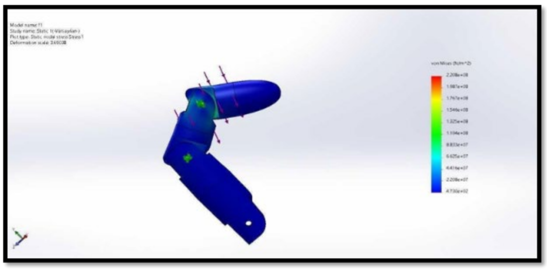

Fig. 10: Stress Analysis Finger

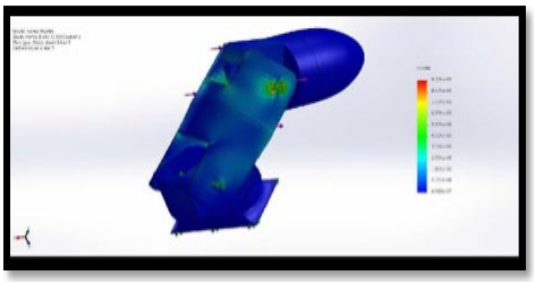

Fig.11: Displacement Analysis on Finger

FEA analysis performed on the thumb is shown below. The material selected is PLA (polylactic acid) as it is biodegradable, inexpensive, and has a yield tensile strength of 35.9MPa. Strain Analysis is done on the basis of ESTRN criteria as shown in Fig. 12. Stress analysis is done on the basis of von mises criteria as shown in Fig. 13. The area of maximum strain and deformation is between the proximal phalange and distal phalange pin joint. Below is the heat map of the analysis done with the force of 1000 N and the deformation on the scale is 1. We can see that a little to negligible displacement is caused due to the applicate of stress on the parts of the robotic hand as shown in Fig. 14.

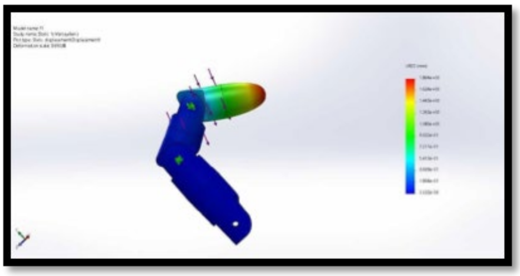

Fig. 12: Strain Analysis Thumb

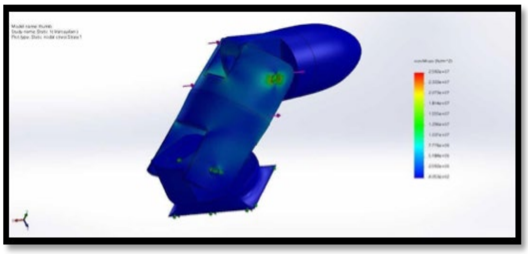

Fig. 13: Stress Analysis Thumb

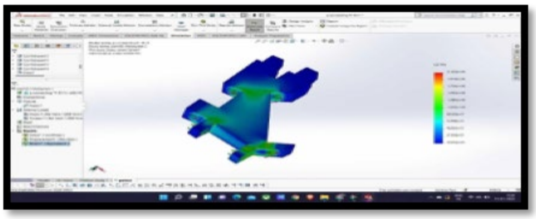

Fig. 14: Displacement Analysis on Thumb

Performed FEA analysis on different parts of the multi-Finger robotic hand. FEA analysis performed on the palm is shown below to get the design stability so it can bear force up to 1000 N without showing deformation therefore, the material selected is PLA (polylactic acid) as it is biodegradable and has an ultimate tensile strength of 26.4MPa. Strain Analysis is done on the basis of ESTRN criteria as shown in Fig. 15. The area of maximum strain and deformation is at the joints of the palm while applying 1000 N force. Stress analysis is done on the basis of von mises criteria as shown in Fig.16. Below is the heat map of the analysis done with the force of 1000 N and the deformation on the scale is 0.0365731. We can see that a little to negligible displacement is caused due to the applicate of stress on the parts of the robotic hand as shown in Fig. 17.

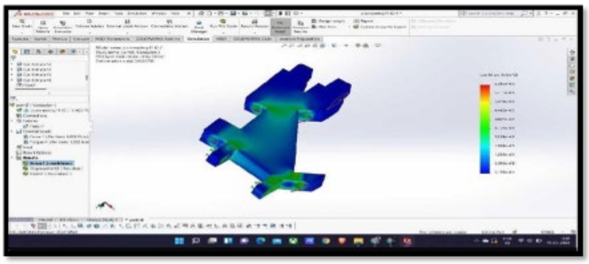

Fig. 15: Strain Analysis on Palm

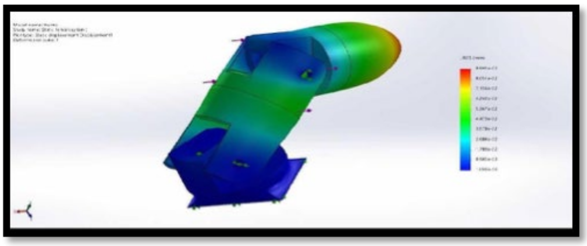

Fig. 16: Stress Analysis on Palm

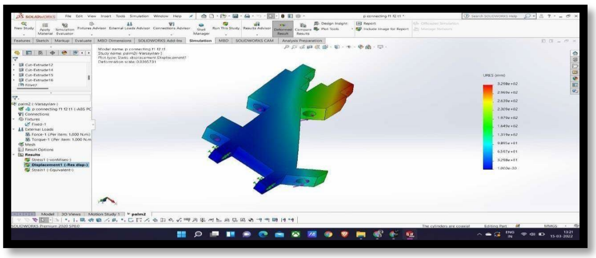

Fig. 17: Displacement Analysis on Palm

7. Results & Discussion

The FEA of the robot hand, which was initially designed in SolidWorks, was effectively executed using SolidWorks. Based on the simulation's deformation and stress findings, it is possible to derive that using the selected PLA material. The material selected is PLA (polylactic acid) as it is biodegradable, inexpensive, and easy to print. The mechanical properties of the selected material have a tensile modulus of 2300MPa, ultimate tensile strength of 26.4MPA, a Yield Tensile Strength of 35.9MPa and Poisson’s ratio is 0.35. Using various material and options for thickness a parametric study was done, Thickness From 2.5mm to 4mm were considered. A combination of PLA material and 3mm thickness was found optimal with the observed results. The study provides a work frame for FEA analysis using optimized meshing control and develops a procedure to evaluate the design of the anthropomorphic robot hand structure without additional substantial change. As shown in the following figures, the degree of deformation is indicated by red, yellow, green, and blue colors in reducing order from highest to lowest. The deformation results demonstrate that the impacts of 1000 N forces in various orders were felt on broader areas spanning from the force contact point to both finger links. Meanwhile, most of the minor strain values at equal forces in different directions were found to be below the tensile strength of the material, indicating that the material must be able to withstand the pressure without collapse. The study develops a design and inter validates the design using FEA analysis, which may be used to evaluate the structural integrity of the design. These conclusions can be utilized as a guide for choosing how the robot hand should be employed in future projects. Furthermore, When the robot is required to bear a heavier weight, it can be utilized to improve the robot design by reinforcing the previously stated damaged locations.

8. Conclusion and future work

This study aims to offer a in depth view of the current scenario of the robotics industry especially the mechatronically controlled multi-finger robotic hand domain of the vast field by the means of a literature review, Then the process to provide a systematic road map or procedure for designing and analyzing a multi-finger robotic hand for any specific operation is done. In this present study, the aim of the design was to create a robust and agile system that can operate in retrieval and reconnaissance field conditions. The study develops a design and then later validates the design by the use of FEA analysis that can be used to evaluate the structural integrity of the design. The study also provides a work frame for FEA analysis using optimise meshing control and develops a procedure to evaluate the design of a multi-finger robotic hand. The results of the finite element analysis with a mesh size of 0.01 are quite satisfactory, with a detailed inspection of maximum deformation, maximum stress, and maximum strain. In future work, the attempt to minimize the weight of the structure while also limiting structural deformations to increase stiffness can be worked on and the structure design can be improved and analysis can be done on various materials for improving structure integrity for making the design with least expense and least intricacy with most extreme effectiveness.

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