Design and Finite Element Analysis of Prosthetic Hand Controlled by Wireless Gestures for Differently-abled People

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Abstract. This paper focuses on the design and finite element analysis of the prosthetic hand for differently-able people. The prosthetic hand consists of two sections: one is the transmitting section and another one is the receiving section. The transmitting section consists of a glove embedded with a series of flex sensors connected with a microcontroller and a wi-fi module. The flex sensors are fixed along with each finger which captures and converts the motion of the fingers into analog signals and is transmitted to the receiving section through the wi-fi module. The receiving section consists of the prosthetic hand in which each finger is actuated by the servo motors. The transmitted signals are received by the wi-fi module in the receiver section through the microcontroller and are converted into digital signals. The fingers of the prosthetic hand are actuated by the servo motors corresponding to the received digital signals. The methodology involved in this research is the designing, meshing, and analyzing of a prosthetic hand using the PTC Creo software and then assembling electronic components. The analysis of the prosthetic hand involves the analysis of equivalent stress and total deformation at various regions of the prosthetic hand by selecting steel as a material to fabricate.

1. Introduction
Robotics is a multidisciplinary field that is a combination of mechanical, computer science, electrical and electronics fields. Nowadays, robots have replaced many works which involve more human effort and it also improves our lifestyle. The word ‘Prosthetics’ refers to the artificial system which is similar to that of the human body part \cite{1}. In recent years, the robotics field makes many changes in the prosthetics area. The hand, one of the most important and complex parts of our human body can be replicated as a prosthetic hand by using the robotic systems. Several kinds of research have been carried to day-to-day to develop an effective prosthetic hand. Our research aims to design a prosthetic hand which is affordable to all customers by using easily available electronics components \cite{1}. The prosthetic hand is designed and then it is meshed and analyzed by using PTC Creo software to find the stress, strain, and total deformation at various regions of the prosthetic hand. Not only for differently-abled persons, but the enlarged model of this design can also be used in industries to handle heavy, harmful, and high-temperature objects. The prosthetic hand may help the differently-abled people to do their day-to-day activities like taking, holding, etc., and helps them live a normal life like other people.
2. Literature review

There are many types of research have been carried out on the prosthetic arm around the world till now. The prosthetic hand and arm design researches emerged in the late 1980s. In 1986, S. Jacobsen et al. of Utah university and MIT [2] have developed a simple prosthetic hand consists of three fingers and one thumb and it was used to observe the mobility of machines for construction purposes. Robert Vinet et al. [9] designed a multifunctional prosthetic hand by using the four-bar mechanism for the individual fingers in 1995. They analyzed the angle of flexion for relative motions of the hand and analyzed the mechanism. Hun-Pang Huang and Chun-Ying [8] Chiang used a digital signal processor (DSP) to analyze the EMG signals for distinguishing the pattern recognition from the hand motions in 2000 and it provided a correct value of about 87.5% for the hand motions. In early 2002, M. C. Carrozza et al. [5] have developed a novel prosthetic hand based on bio-mechatronics design. The proposed hand is designed to have enhanced grasping capabilities by involving various mechanisms, actuators, sensors, and embedded systems while maintaining approximately the same dimension and weight.

In 2005, Stefan Schulz et al. [4] designed a hand having 15 degrees of freedom controlled by small flexible fluid actuators. The fluid actuators are placed within the hand and it can handle different objects reliably and naturally. Achintya Das et al. [10] designed a prosthetic hand by using micromotors and Programmable Interface Controller (PIC) in 2010 which enables them to do appropriate linear movements and they used Lagrangian function of the motion of the finger to study their model. Also, Arindam Chatterjee et al. [7] developed a new type of prosthetic hand in 2010 which was controlled wirelessly by using a remote control system. The remote control consists of four switches for doing four different operations by applying different grip forces. In 2017, Punit Kumar Rohilla et al. [3] conducted an experimental analysis of the prosthetic hand by using different materials by using ANSYS. They concluded that Nylon 6 has a suitable material for manufacturing the prototype of the prosthetic hand. Moin Uddin Atique [6] designed a cost-effective myoelectric prosthetic hand in 2018 for wrist amputees instead of manipulating all the fingers which is complex and expensive. The microcontroller interface detects the EMG signals and it converts into motion by using several DC gear motors.

3. Design of prosthetic hand

The prosthetic hand has been designed similar to the actual human hand dimensions. The 3D model of the prosthetic hand has been created with PTC Creo. The designed model has 14 degrees of freedom, that is, every 4 fingers will have 3 degrees of freedom and the thumb will have 2 degrees of freedom. The sections of the fingers are connected by a pin rotary joint and the finger sections are also designed accordingly to avoid unusual finger movements. The sections of the finger are connected to the servo motor through a nylon wire rope. The front and rear side of the designed prosthetic hand is shown in figure 1 and figure 2.

![Image](image_url)

**Figure 1.** The front side of the Prosthetic hand
4. Analysis of prosthetic hand

The above designed prosthetic hand has been done finite element analysis by using the PTC Creo software. The static stress analysis has been done to the individual fingers and the palm section of the prosthetic hand. Static analysis is defined as the analysis of stresses, strains, deformations, and the forces acting in the components due to the applied loads without including the inertia and damping effects. The prosthetic hand is analyzed for the equivalent stress (von-misses stress) and total deformation. The analysis has been done by selecting the material as steel and the results of the analysis are tabulated below. A load of 30 N is applied to the prosthetic hand and the resultant stress and deformation at various points are analyzed.
Figure 3 shows the equivalent stress analysis or von Mises stress analysis of the palm section of the prosthetic hand and figure 4 shows the total deformation analysis of the palm section. Figure 5 and figure 6 show the equivalent stress analysis and deformation analysis of the individual finger. As all the fingers design are the same, the above-analyzed result will apply to all the fingers.

5. Results of Analysis
From the above analysis of the prosthetic hand, it is found that the maximum equivalent stress of 0.8938 Mpa is acting on the palm section. The equivalent stress is maximum at the joints which connect the fingers with the palm. The deformation of about 6.453×10^{-4} mm occurs on the palm section at the joint which connects the thumb with the palm section. In the fingers, the maximum equivalent stress of about 0.205 Mpa is acting on the fingers, and the maximum deformation of about 0.023 mm acts on the edges of the fingers. From the analysis, the design is safe to handle the loads which are handled by the human hands. The below table 1 compares the analysis results of the prosthetic hand at various sections.

| S.no. | Parameter                                      | Value         |
|-------|-----------------------------------------------|---------------|
| 1.    | Maximum equivalent stress at the palm section | 0.8938 Mpa    |
| 2.    | Maximum deformation at the palm section       | 6.453×10^{-4} mm |
| 3.    | Maximum equivalent stress at the individual fingers | 0.205 Mpa    |
| 4.    | Maximum deformation at the individual fingers | 0.023 mm      |

6. Circuit Connection
The prosthetic hand consists of two sections: one is the transmitting section and another one is the receiving section. In the transmitting section, a series of five flex sensors embedded in each finger of the glove is connected to the microcontroller and a wi-fi transmitter is also connected to the microcontroller. In the receiving section, the prosthetic hand which is designed previously is connected to five servo motors to actuate the five fingers by using the nylon braid wires. The servo motors are connected to the microcontroller in which the battery and wi-fi receiver is also connected. Figure 7 and figure 8 shows the circuit connection of the transmitting and receiving section respectively.

![Figure 7. Circuit of Transmitting section](image-url)
7. Working Procedure and Result

The person has to wear gloves in one hand and the prosthetic hand should be inserted into another hand. When the person moves the fingers of the hand in which the transmitter section attached, the flex sensor bends which generates an analog signal and it is transmitted to the receiver section through the microcontroller and wi-fi transmitter module. The analog signals are received by the wi-fi receiver module and it is processed and converted into digital signals by the microcontroller. The digital signals are used to actuate the servo motors which are attached to the prosthetic hand by using nylon braid wires. Thus, the gestures of one hand are converted into the prosthetic hand movement by using the flex sensors, servo motors, microcontroller, and wi-fi module. The flow chart of the working procedure is shown in figure 9.
8. **Conclusion**

This research work is about the design and finite element analysis of prosthetic hand controlled by wireless gestures for differently-abled people. This work clearly explains the key concepts which are involved in the conversion of hand gestures in one hand into the movements of prosthetic hand by using flex sensors, servo motors, microcontroller, and wi-fi module. From the analysis, the equivalent stress and total deformation of the prosthetic hand have been calculated and it is also found that steel is suitable to fabricate the prosthetic hand. The prosthetic hand is designed for differently-abled persons to do their daily activities. Not only for differently-abled persons, but it can also be used to handle harmful, hazardous objects in industries.

9. **References**

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