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# Biomimetic Approach for Design of Multifingered Robotic Gripper (MRG) & Its Analysis for Effective Dexterous Grasping

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**Abstract.** A human hand can handle various objects by fingers, with better adaptive capacity and precision. Although there have been an enormous number of studies on robot hands trying to reproduce such adaptive and handy operation, performance is still not as per the real world's expectations. The industrial developments for automated operations by using robots are undeniably expecting an independent grasping action, for all types of materials / object. Existing sensory feedback can help to work out some of the final required operating parameters, but still their performance limitations are non-reliable. Hence, sophisticated gripping, mimicking the human grasping action is a need of robot industries to make autonomous material handling. Biomimetic approach is adopted for the gripper design in this work because available literature review emphasizes that a stable grasp can only be achieved with multi-fingered grippers. This work provides information on design of Multifingered Robot Gripper (MRG) with biomimetic approach. Its kinematics design analysis, Finite element analysis of critical parts and mode shape analysis of complete gripper system offers confirmative results for its effective grasping. Thus presented MRG system developed by this study elaborates various aspects of design while developing the universal dexterous grasping system.

**Keywords:** Grasp, Multifingered Robot Gripper, Under actuated, Dexterous Grasping, Biomimetic Approach Introduction

## 1. Introduction

### 1.1. Multifingered Robot Gripper (MRG)

Industrial Robots are usually specified without grippers, the reason being that the grippers are peculiar to the task or application for which it is assigned.

Dexterous grasping is the specific task and it has been accepted and adopted by many researchers as a priority issue while designing the hands with available advanced sensors. The essential modifications related to the robotic grippers such as improved force sensing capacity and improved flexibilities at the gripping are to be implemented. The easy orientations for the perfect grasping with real time feedback are to be implanted.

The shortcomings of working style of the existing commercial / industrial robots can be well improved by mimicking the dexterity of the human hand along with better sensing capabilities. This paper focuses a light on the possible improvements in the gripping action for robot gripper by using anthropomorphic approach at design.

Manufacturing of multifingered robot gripper / robot arm has been started in the early stage of the robotics research and is still actively studied. Especially, manipulation using haptic sensation has been considered important for achieving human-like dexterity. The scope of this work is to design an anthropomorphic multifingered robot gripper which will pick up a load up to 1 kg.

The action in which a desired object is gripped by the fingers of a hand is called as a grasp. Grasps is categorized into three general groups. Those are precision grasps, power grasps and partial grasps. Precision grasps can grip an object with the fingertips, where as power grasps and partial grasps are involved in less delicate operations. Under-actuated robotic hands are the intermediate solution between robotic hands for multipurpose handling ( i.e. versatile, stable grasps, expensive, complex control, and many actuators) and simple robotic grippers for specific task ( i.e. simple control, few actuators, task specific, unstable grasps).

Material handling actions where arms & ammunition are produced / handled / assembled requires precision and there is a risk of life. Similarly, the material handling where skillful act is essential such as:

1）Semisolid material handling
2）Fragile material handling
3）Fruit with thin skin type items handling
4）Foam / spongy material handling
5）Objects with oily and smooth surface …....etc., biomimetic approach based designs are proved to be more helpful.

Even the trend of study in various areas like MRG, Prosthetic hands, grippers for dexterous material handling…etc. is found to be supported by such theories as per the literature survey made as given below.

## 1.2. Literature Review

Currently many researchers are actively working on this type of task which can offer universal gripping system with dexterous approach in the operations. The design concepts discussed while developing Gifu Hand, [1] narrates towards biomimetic approach. Issues related to the use of tendon / cables for gripping actions are discussed in this study. Also remedy is provided by using the linkages for mechanical grasping.

Another similar effort by making provision of multimodal sensors placed on / in a soft surface of the tip of the gripper finger.[2] They have proposed a design for tactile sensing to embed as many receptors as possible randomly in soft material so as to provide different kinds of sensing modalities. The fingertip has two layers of different hardness with two kinds of receptors randomly distributed i.e. strain gauges and PVDF films. Discrimination of hard surfaces are confirmed by this gripping system.

It is emphasized that an anthropomorphic term associated with grasping phenomenon is expected for the gripper with versatility and human like approach. In a study by J. L. Bank, [3] feedback about the content of its surroundings is suggested in order to exhibit flexibility for embedding adaptability in the system. To impart the qualities of human action to the robot which enable adaptability, the incorporation of active, multi-point sensation is experimented. Internally generated as well as externally imposed contact forces to the system are offering dynamic presentation of the gripper system.

A paper by G. S. Gupta et. al. provides the information on the design and development of a low-cost control rig to intuitively manipulate an anthropomorphic robotic arm using a bilateral master–slave control methodology.[4] It is a similar attempt for achieving biomimetic gripping action with real time sensory feedback based control action.

Further patterns of hand motion during grasping and the influence of sensory guidance is experimented by M. Santello et. al.[5] This widens the scope of biomimetic action analysis by experimenting for grasping with the conditions such as, the memory guided movements, virtual imagination and physical object handling, with the help of 15 DOF hand.

Biorobotics is another term which also reflects the similar logic for total robotic action with robot gripper as a subset. Associated parameters like Hand kinematics, Finger joint actuators, Drive chain components, Number and location of sensors are discussed with biomechanical design strategies by J N Marcincin et. al.[6]

For initial and final conditions of grasping, human unconsciously changes the grasp strategy according to the size of object even if they posses same geometry. It is termed as the grasp planning for the scale dependent grasp. The grasp patterns thus observed in human grasping are applied with couple of grasp procedures to multi-fingered robot hands by T. Shirai et. al.[7] . In this study a sliding based grip and a rolling based grip with four different patterns are suggested for multifingered Robot hand on the basis of study of human hand grasping.

A concept for integrating the control system of an anthropomorphic robot hand into the control system of an entire humanoid robot was presented by D. Osswald [8]. A grasp taxonomy was developed on the basis of the objects and actions in the intended environment that can be used to describe the grasp patterns required for robot gripping. The architectures of the overall control system and of the superior and local hand control system in particular is presented. This once again emphasizes the need of biomimetic design approach at the control as well.

It is interesting that A Dollar has worked out for the study of the effect of load carrying on the speed of locomotion in arthropods and a biomimetic arthropod robot. This type of biomimetic study from living animals and creatures is found equally helpful for understanding creativity of nature as per the need for the living being.[9] [10] This extensive review helps to get different view points of the researchers in the area of biomimetic studies. Further this motivates and guides for transforming the observations into the mechanisms or the working models.

Biomimetic approach at design becomes essential when the design of prosthetic hand for automatic functions is discussed. Control philosophy for a simulated prosthetic hand is detailed by T. Iberall et. al. [11]. Using one (Multifingered Robot Hand ) MRH as a prototype prosthetic hand in order to evaluate a system that translates task-level commands into motor commands is experimented by them in virtual environment.

Multifingered mechanical hands are attempts at approximating human hand functionality which is also highly developed discipline directly related to the designs of the sophisticated prosthetic hand. Oxford and Manus prostheses hand are compared by P. J. Kyberd and J. L. Pons [ 12] This paper focuses a light on the current trends in the research on the prosthesis and study of aspects related to mechanical design, sensors and manipulation schemes.

The recent trend as depicted in the various attempts as per the above mentioned studies clearly indicates that biomimetic approach is essential for improving the grasping modality of the robot gripper. Accordingly multifingered hand and gripper are designed and controlled successfully.

## 2. Biomimetic Design of MRG

With the use of intelligent mechanisms, an underactuated robot hand can be developed for multipurpose grasping. In an under actuated robotic hand, the number of actuators is less than the hand's degrees of freedom (DOFs). Passive elements are used to kinematically constrain the finger and ensure the shape adaptation of the finger to the object grasped.

The designed MRG has four fingers. First three fingers are in a line and fourth finger is mounted exactly opposite to the middle one of the three fingers. The first three fingers are equal in length while the fourth finger is shorter than other three. The fourth finger is referred as thumb (fig. 1).

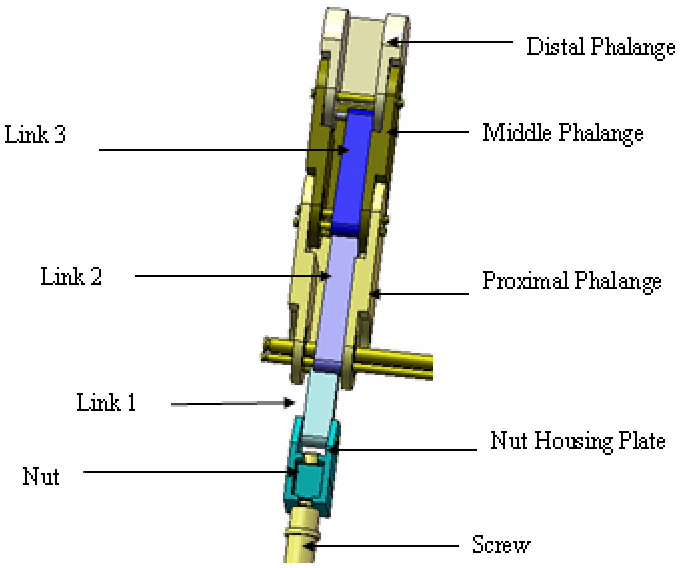



Figure 1. Details of Finger of MRG

Thus, the gripper has three fingers and one thumb. Even to adopt relative concern with biomimetic approach the proportion of 1:1.5 is referred for the MRG design with respect to actual average dimensions of human hand.

The mechanical intelligence embedded into the design of the hand allows the automatic shape adaptation of the fingers. The under actuated DOFs are, in this case, governed by mechanical limits.

Special control action or specific sensors are not required for desired finger movement.

MRG has four fingers, first three fingers are in a line and fourth finger is mounted exactly opposite to the middle one of the three fingers. The first three fingers are equal in length while the fourth finger i.e. thumb is shorter than other three. We shall refer to the fourth finger as thumb (fig. 2). Thus, the gripper has three fingers and one thumb.

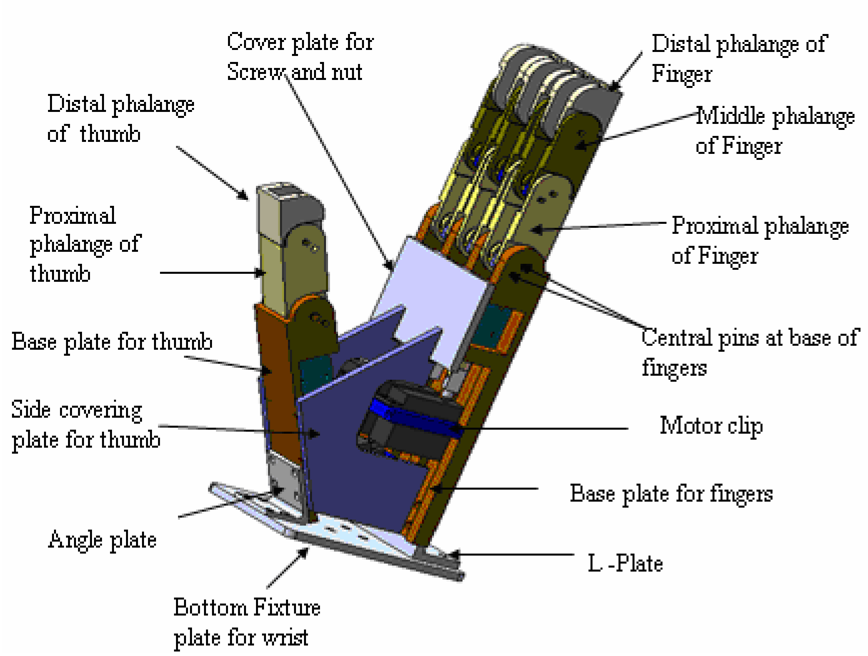



Figure 2.A 3-D view of solid model of MRG

Each finger has three degrees of freedom and one actuator (motor). Thumb has two degrees of freedom and one actuator. Thus, there are total 11 degrees of freedom and 4 actuators for the actuation mechanism.

The links provide the actuation to the successive joints. Therefore, separate actuation is not required at each joint.

The links move inside the grooves cut in the phalanges, thus providing limits to the motion of the gripper. This total mechanism is discussed as shown in fig. 2. Mechanical design process completed intone with the above discussions is further validated by kinematics of the MRG system as discussed below.

Table No. 1 Joint Parameters for Finger of MRG

| **Joint No.** | $a_{n-1}$ | $\alpha_{n-1}$ | $\theta_n$ | $d_n$ |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 1 | 15 | 0 | 0 | 0 |
| 2 | $l_1 = 15$ | 0 | 0 | 0 |
| 3 | $l_2 = 4.8$ | 0 | $50+\theta_3$ | 0 |
| 4 | 0 | 0 | -50 | 0 |
| 5 | $l_4 = 29.4$ | 0 | $\theta_5$ | 0 |
| 6 | $l_5 = 25.2$ | 0 | $\theta_6$ | 0 |
| 7 | 13 | 0 | 30 | 0 |

## 3. Kinematic Design

To understand the orientations, positioning and the performance at operational condition we need to know the information of the various parts in accessible format ( i.e. usable in programming )

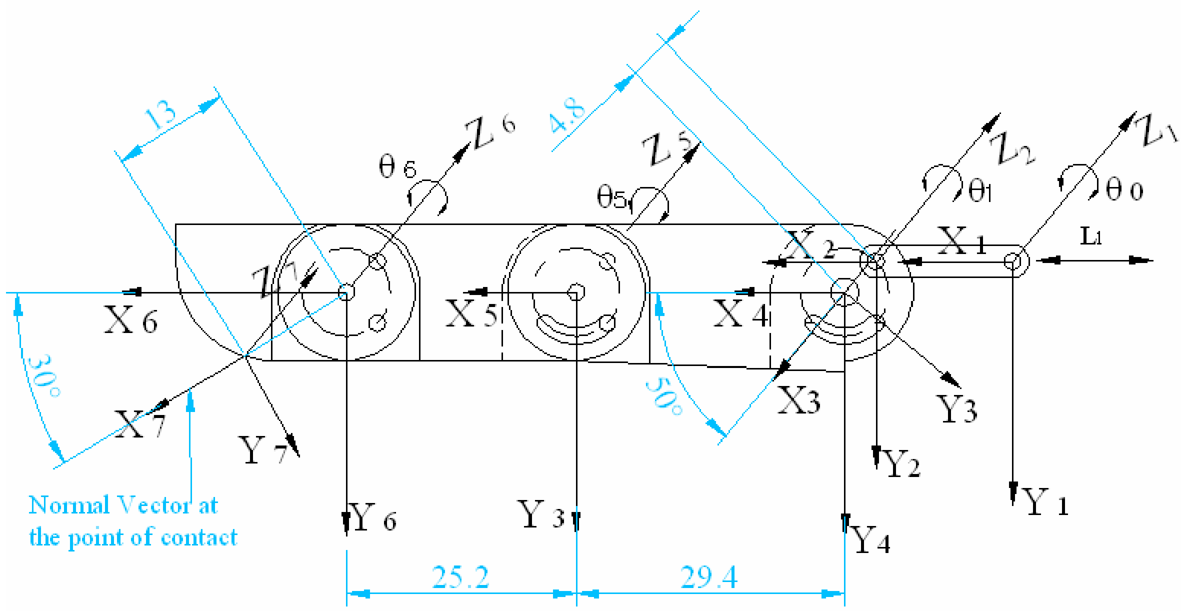



Figure 3. First possible extreme position of MRG Finger Kinematics study of the system offers this access by availing the data in matrix and equation formats.

Above Fig. 3 shows the frames attached to the joints for each axis of d.o.f. for first finger of complete MRG system. Accordingly joint parameter table is obtained for the finger. ( ref. table no. 1 )

Composite Transformation Matrix equation from joint {n} to {n-1} for finger is

$[{}^{n-1}T_n] = R_Z(\theta_n)\, T_Z(d_n)\, T_x(a_{n-1}) R_x(\alpha_{n-1})$ (1)

$$= \begin{bmatrix} C_{\theta_n} & -S_{\theta_n}C_{\alpha n-1} & S_{\theta_n}S_{\alpha n-1} & a_nC_{\theta_n} \\ S_{\theta_n} & C_{\theta_n}C_{\alpha_{n-1}} & -C_{\theta_n}S_{\alpha_{n-1}} & a_nS_{\theta_n} \\ 0 & S_{\alpha_{n-1}} & C_{\alpha_{n-1}} & d_n \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$P_x$ = 13 Cos ( $\theta_5 + \theta_6 + \theta_8$ ) + 25.2 Cos ( $\theta_5 + \theta_6$ )+ 30 + 4.8 Cos $\theta_4$ + 29.4 Cos $\theta_5$ (2)

$P_y$ = 13 Sin ( $\theta_5 + \theta_6 + \theta_8$ ) + 25.2 Sin ( $\theta_5 + \theta_6$ )+ 4.8 Sin $\theta_4$ + 29.4 Sin $\theta_5$ (3)

$P_z$ = 0 (4)

Similar equations are obtained for the thumb of MRG.

These equations of the position vectors help to analyze the orientations of the probable positions.

For the dynamic analysis of gripper, we assume only the three phalanges viz. proximal, middle and distal. ( ref. Fig. 4 ) The links are replaced with equivalent torques about the respective phalanges.

Dynamic analysis also can be completed for simulation purpose which gives the estimated force and torque equations.

## 4. FEA for the critical parts

The finite element method converts the conditions of equilibrium into a set of linear algebraic equations for the nodal displacements. By breaking the total MRG structure into a larger number of smaller elements, the stresses become closer for achieving equilibrium with the possible applied loads.

In this study the proximal phalange, L-plate and angle plate of the MRG is selected as a critical part on the basis of functionality. The proximal phalange has the complex shape and it consists of number of holes and a complicated groove.

The L-plate and Angle plate are two supporting plates, which hold the hand against wrist. So the entire weight lifted by the gripper will directly act on these two plates.

Hence the above components are analyzed to check that whether they can sustain the required amount of force.

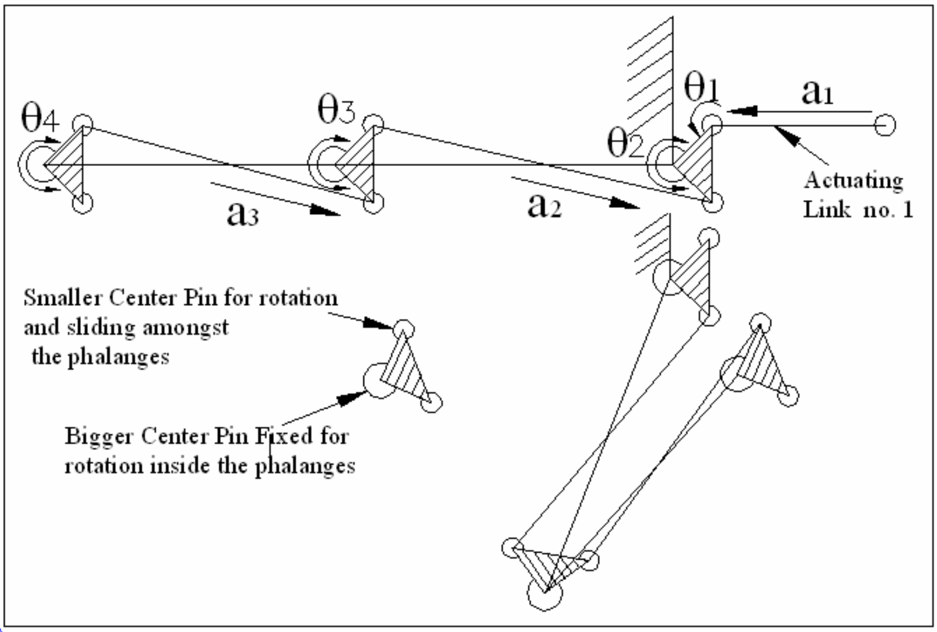



Figure 4. Two possible extreme geometrical conditions of MRG Finger

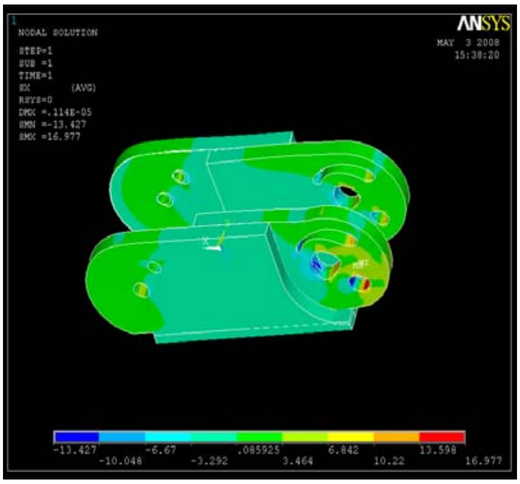




Figure 5. Displacement analysis of proximal phalange. Figure 6. Stress analysis of proximal phalange

From fig. 6, it is seen that the maximum stress induced in the proximal phalange is 16.977 MPa. The failure stress for aluminium is 90 MPa.

Since the maximum stress induced in the proximal phalange is less than failure stress, design of proximal phalange is quite safe.

We can calculate the factor of safety as,

$$\text{Factor Of Safety} = \frac{\text{Failure Stress}}{\text{Maximum Stress}} = \frac{90}{16.977} = 5.301.$$

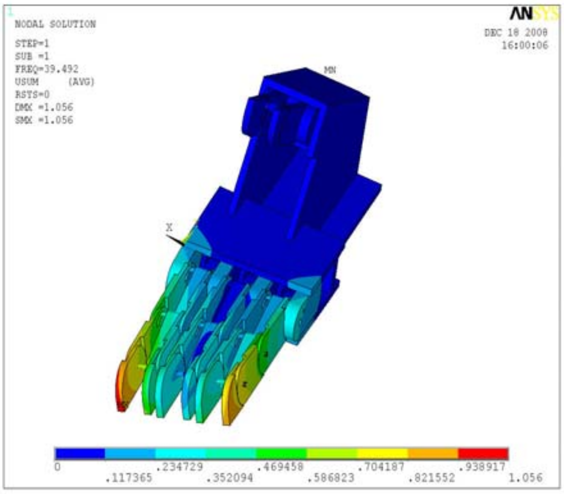
This factor of safety is greater than the recommended factor of safety. Hence design of proximal phalange is safe. Similar results are observed for the L plate and angle plate of MRG and hence the conclusion is

## 5. Mode Shape Analysis of MRG system

A mode shape analysis offers the expected displacement of surfaces of an object vibrating at a particular mode. The mode shapes are dependent on the shape of the surface as well as the boundary conditions of that surface.

For determining the vibration effects for a system under vibration, the mode shape is multiplied by a function that varies with time, thus the mode shape can elaborates the displacement of vibration at various locations in time, but the magnitude of the displacement changes.

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. Opti Struct gives the approximate object pattern as per object parameter defined / selected from the options by user. This predicted output can be observed as complete geometry.



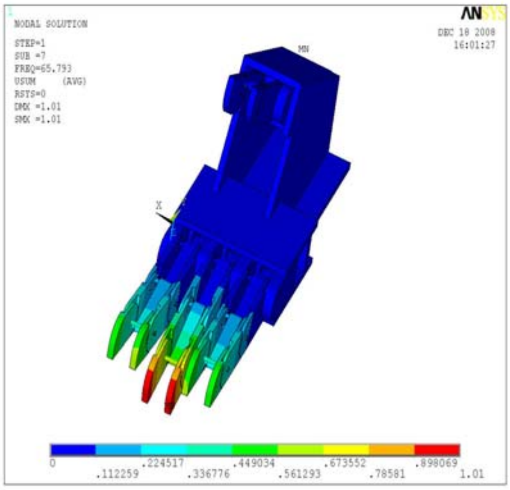




Figure 7. Response at1st Mode Frequency 39.49 Hz Figure 8. Response at 7th Mode Frequency 65.79 Hz

Speed of operation of the MRG is 60 rpm i.e. 1 Hz. Optistruct offers first ten frequencies where significant changes are observed.

Following are the frequencies observed with significant displacements for the modal analysis to identify the effect of vibrations in MRG under varying excitation frequencies.

The excitation frequencies of the systems as observed above are on the higher side than the operating frequencies of the MRG (approx.1 Hz). Hence MRG system is less likely to get excited at operating condition.

## 6. Conclusions

The complex mechanics with biomimetic approach in design of the MRG is not the only factor behind the functional uniqueness but its post analysis for performance confirmation assures the utility for variety of task. FEA and Mode shape analysis supports the safety aspect at the operating conditions.

Further this type of platforms created can be useful to establish integrated systems for the development of universal MRG. Areas of applications of such system covers material handling of delicate, fragile, hazardous and complex shaped objects with dexterous and human like workstyle.

## 7. Future Scope

This presented mechanism posses scope of development. It can grip odd size and odd shape object, and further it can be developed for universal gripper system. Sensors can be added to make advanced gripping system to have active grasping along with corrective feedback sensory system.

Improvements in a mechanical design of the robot gripper can be made so that it can surely be made for universal handling system.

The grasp system can be designed to get perfect grasp points using a vision sensors input can offer an universal biomimetic gripper system.

Table 2 Observed frequencies data

| Mode | Frequency (Hz) | Mode | Frequency (Hz) |
|---|---|---|---|
| 1 | 39.49 | 6 | 61.84 |
| 2 | 42.73 | 7 | 65.79 |
| 3 | 43.66 | 8 | 74.94 |
| 4 | 45.33 | 9 | 77.31 |
| 5 | 45.49 | 10 | 83.21 |

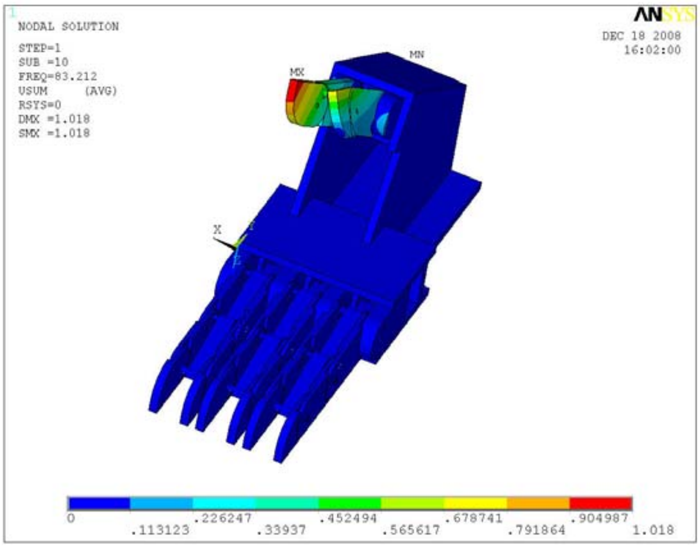



Figure 9. Response at 10th Mode Frequency 83.21 Hz

## 8. Acknowledgment

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