Design, Modeling, Kinematic performance and prototype development of a Bionic Hand

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Abstract : Human hand is the most complex and highly dexterous organ in the body. It allows humans to accomplish movements and perform task with power and precision. Developing a bionic hand requires understanding of human hand physiology and its motion. Much research has been taken place in this field and few companies made it commercially available, but present day bionic hand have few limitations and are not suitable for Indian context. This thesis work attempts to design and develop an effective bionic hand while performing its kinematic simulations. Based on the Indian human anthropometry a conceptual design is developed, bionic hand is used for grasping and manipulation. Grasping forces are computed using force formulas. Kinematics of the hand are evaluated through D-H algorithms using ADAMS. Based on the forces calculated for various gripping actions, selection of motors for actual hardware development for the bionic hand. CAD model developed for the hand using SOLIDWORKS was eventually used for 3D printing. The 3D printed model was wired with all the procured motors and electronic hardware to make it as a working prototype. The built prototype was tested for various haptic actions and gripping actions. The prototype worked as expected performing the desired actions. It however has to be tested for the gripping forces and for varying payloads as a future work. The developed Bionic hand is suitable for Indian context and affordable

IndexTerms - **Bionic hand, Design, Development, Kinematics and Prototype.**

I. INTRODUCTION

Bionic hand is an artificial substitute for missing hand. It is an electromechanical device and used for functional reasons. The word bionic was coined by Jack E Steele in 1958 which means "unit of life". In medicine the term bionic means as replacement or enhancement of organs or other body part by mechanical version. The development of bionic hand was started in 16th century by Ambroise pare. The reason for developing bionic hand is, in America around 541000 people suffered from upper limb loss and expected to be double by 2050(Ziegler-Graham et al., 2008), In Italy approximately 3500 and in UK approximately 5200 upper limb amputations people are recorded and with respect to world population of 6.7 billion around 3 million amputees are present worldwide in which 2.4 million are from developing countries.

When it comes to India, as per the census 2011 out of 121cr population about 2.81 persons are disabled which is around 2.21% of total population in which 20.27% are disabled with movement (Indian census 2011). For this reason in 2007 the company called touch bionic has launched the first commercial bionic hand named as iLimb and according to the firm it was fitted to 1200 patient worldwide by May 2010Artificial hands are available in India but few are used as support structure and few has got motion based on electronic devices. Despite of advance in technology, today's upper limb prostheses are still affected by relevant limitation.

One of the greatest challenges is to embed actuators, sensors and electronic component in one hand without affecting the size and the weight of normal human hand.The work presents the detail about the literature review and commercially available bionic hand, based on that a bionic hand has been design and developed which should be able to lift a weight of 200gm and used for Indian contest.

Literature Review

Several researches have been carried out in this field and there are number of researchers who are into research of design and development of bionic hand. In 1997 Lin and hung explained the design and implementation of dexterous artificial hand. They named the hand as NTV hand which was used as prosthetic. The NTV hand has 5 fingers and 17 DOF. The size of the hand was comparatively equal to human hand size. All the actuators, the mechanical parts and the sensors are on hand. In their design they considered 2 DOF at MCP joint of thumb and the index finger and only one mcp joint for the remaining 3 fingers. In the hand they used gear drive mechanism. In 2006 Huang et al designed and developed a five finger bio-prosthetic hand which was named as HIT/DLB hand. This hand was based on mechanism of under actuation, it has 13 joints and simple in construction they claimed. The thumb and the index finger were driven by individual motors each whereas the other three fingers were driven by single motor. Dragulescu et al proposed a hand model which represents the new solution when compared to the existing one. The hand model proposed was capable of making special movements like power grip and dexterous manipulation. Tarmizi et al stated a robot hand that has similar movement like that of the human hand in operation. They considered a model having 4 fingers and thumb. The kinematic and dynamic models were carried out using D-H algorithm. Kriegman et al has developed a hand which approximates anthropomorphic size. It has three fingers and a thumb. It is designed for grasping of arbitrary objects. Bergamasco and marchese gives the description about the mechanical design for the development of three fingered ploy articulated myo electric prosthesis. Renault and ouezdou has presented an anthropomorphic model of human hand. The hand model is having 27 DOF in which 4 DOF for the wrist. The model was designed with ADAMS and was based on bio-mimetic approach. Kurita et al has proposed a multi fingered robot hand which is of human size hand and it has detachable mechanism at the wrist. The actuator was placed on the arm and the joints were connected to the actuator with the help of tendon driven wire. With the literature survey it has been seen that, it is very difficult to get the functionality of the bionic hand as that of the human. Still lot of gap is there where the work can be done, mainly in the design part and the selection of the mechanism. Other than these, literature on bionic hand there are few companies which have developed the bionic hand and made it commercially available. A comparative study has been carried out between the different available bionic hands.

Design and Development of Bionic Hand

The main function of bionic hand is to lift the object and manipulate. According to the objective the proposed bionic hand should be able to lift a weight of 200gm. With the advancement of industrial robot the grasping and manipulation has got new importance. The main purpose of industrial robot is to pick and place the object , for picking it requires to grasp the object and for placing it has manipulate and place, but these robot are designed only for particular shape object and the gripper has only two or three fingers. So an alternate solution is to build a more flexible and versatile gripper, universal gripper can able to grasp any part which the robot might encounter. The source of inspiration for the universal gripper is the human hand. The human is also like general purpose end effector. As we know that human hand has abundant potential for grasping the object of several shape and dimensions and also manipulating them in a dexterous manner.

For grasping and manipulation of the object, it should be ensured that the object is grasped perfectly by applying sufficient amount of force on the object. The characteristic of the grasp and the force applied will differ with respect to the shape and size of the object. For grasping any object it is necessary that each finger and the hand must be moved. These motions of the hand are classified into two categories: 1. free motion, 2. Resisted motion.

Basically for grasping any object there are five basic properties

Force/form closure: If a grasp can resist any applied force only by its contact point then these grasp are called as force closure, and if the object is firmly grasped by many contact point and the motion of the object is totally constrained then these type of grasp is known as form closure.

Equilibrium: As the name indicates, if the sum of forces and moment acting on the grasp object is zero then it is called as equilibrium.

Stability: In this property the grasp will pull the object back to its original place, if the object is moved due to friction in any direction.

Dexterity: The ability of the grasp to import motion to the object grasper.

Compliance: The grasp is said to be compliance if the object grasped is behaving like a spring or a damper.

The mathematical form for the different shape objects under force close condition of the grasp has been developed. When any object is grasped by frictionless contact there will be provision that the contact forces should act in the normal direction or else the grasping will be possible and therefore these frictionless grasping had got limited application such as pushing. Whenever any object is grasped and manipulated there is always some friction between the object and the hand and therefore it is important to analyze the effect of friction on the object. It is a fact that force of friction mainly depends on amount of applied force, the direction of the force and the interfere material. The maximum force that a finger can exert on the object to grasp will be at the normal direction. For grasping any object minimum one finger and one thumb is required. So by considering this a simple case of grasping an object is taken as example. It is assumed that the equal amount of force will be applied by finger and thumb, and both are inclined equally to the normal of the surface and friction force will be acting in upward direction.

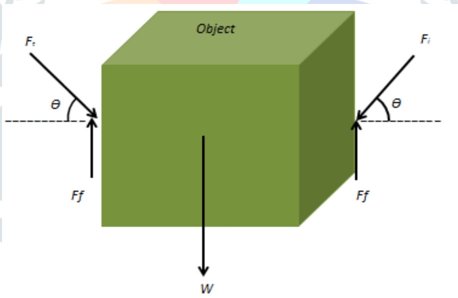

Fig 1: Forces Acting on Object

The general expression for equilibrium for grasping is given by

W= $(\mu Ficos\theta + \mu Ftcos\theta)$

As the forces will be divided equally and the angle of inclination then the equation becomes

W= $2\mu Fcos\theta$

W= weight of the grasped object
Ff= frictional force
μ= coefficient of the friction between the object and finger tip
F=force applied by thumb and finger
θ=angle of inclination of finger and thumb.
As per the objective the hand should be capable of handling the weight of 200gm.
Therefore w=200gm=1.96N.
Considering different angles

W= $2\mu Fcos\theta$

1.96/2*0.25=F$cos\theta$
F=3.92N

Motor Selection

Motor is the important part of the bionic hand and selection of motor was done by comparing their speed, torque, size and cost. By studying different motor the Pololue Dc brushed gear motor are the best suitable form the application. (Pololu, 2012)These motors are tiny and required small space, these motors are powerful and the best part is pololu offers different gear reduction in the same motor package size. These motor has high power to weight to ratio. These motors can be easily fitted in the finger as the dimensions of the motor are less and a worm can be attached to the output shaft which is flatted.

Fig 2: Pololu Motor

Design Methodology

Before starting of design necessary background research was performed and studying of available product in the market, the available product are carefully evaluated for their function and key attributes. The aim of the design is that the bionic hand dimension should be approximately equal to Indian human anthropometry. Different concepts were developed, for placing of motor in palm or in the finger and the type of mechanism to be used, all the necessary elements of the hand within the available space. A rough pencil sketch was made for each concept and the final detailed computer aided design was developed by using solid work CAD software.

Finger Design

Design of one finger was the starting point for the entire design process. In the last chapter the human physiology has been studied to recognize the different motion of the finger. As the hand consist of four finger and thumb, it was very logical to conclude that only one finger is to be design and that can be replicated four times. The human finger consists of three interlinking segments that are proximal, intermediate and distal phalanges, the dimensions of these three links were measured and converted into drawing.

By studying the fingertip, it can be view that DIP joint present in the finger rotates only for small amount so for the simplification of the design the distal and the intermediate phalange is considered as only one link. The small angle is given near the tip for the appearance purpose. The model of these two links is developed and the assembled in solid works which allows the motion study of the joint. In the human finger the MCP joint rotates approximately 90 degree from full extension to full closure and similarly the DIP joint does at the same time. when the finger slowly flex from full extension to fully closure it is clear that both the joint moves at the same rate at around 1:1 ratio, with this there are many mechanical possibilities to provide the simple linkage between these two joint which will for the MCP joint to be rotated actively while at the same time the PIP joint also rotate passively with respect to MCP joint. The link designed is placed between the MCP and PIP joint. then the motion study of finger which is developed was done in solid work assembly, the MCP joint was attached to palm and the rotational movement was given and there after the link motion of fingertip was achieved, for fixing the link a pinhole was provided at the palm and near the PIP joint. The distance between the pinhole and the point of rotation was maximizing to avoid the stress in the product. By movement of MCP joint of model the movement of fingertip relative to MCP joint was achieved.

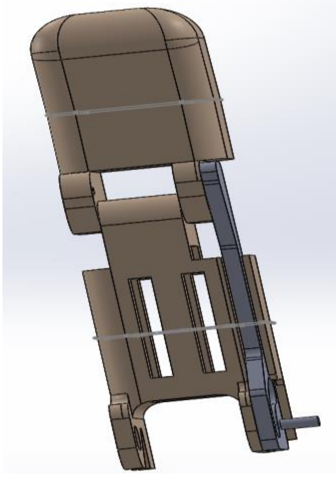

Fig 3: Index Finger Design

Finger Joint

Once the finger assembly was done, the next step is to choose the power system to drive the finger, there are different option available such as hydraulic, pneumatic and electric motors, but electric motors are simple and best option and also they are available in multi size and power. The first thing in the motor was the size as it should be able to fit within the finger which is design.

As the motor is placed in the finger and it has to rotate around the axis which is located between the finger and the palm. Here a proper mechanical drive system is required to perform the operation. A worm gear is the clear option to use as it provides the high reduction in small space and they also have non-back drive technique. Worm gears have one screw start or lead and rarely it has any sliding friction between the input worm and the driven worm gear. But in this case as the motor will be placed in the finger, therefore the worm gear is too kept fixed and the worm which is attached to the motor will rotate over it along with motor when the motor starts.

With this design and transmission concept it allows us to reduce the number of parts required as gear and transmission component are very expensive and are rarely available due to its small size. The standard gears were selected and the design of the finger was refined again so as to fit the gear system within the available space. The dimension of finger was increased by 3mm so as to fit the gear and also the linkages which will drive the PIP joint. The holes were created according to the dimension of the gear and the proper distance is provided so as to reduce the stresses which are developing near the holes section

Thumb Design

The thumb is very important component of bionic hand; it is required to hold any object. The design of thumb is similar to finger but in thumb two motors are used. The thumb has got only two joints that is MCP and PIP joint and for both the joint motor is used with same worm gear arrangement , for MCP joint of thumb the rotation axis is perpendicular to the rotation axis of MCP joint of index finger. The other rotation axis is at an angle to the index finger.

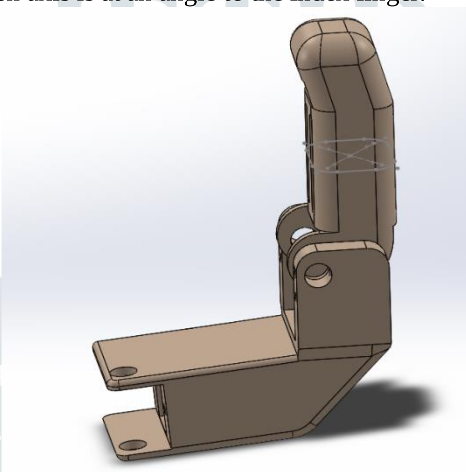

Fig 4: Thumb Design

Palm Design

Palm is the part of bionic hand to which all the fingers and thumb is attached. The control system of entire hand is placed within the palm. The sixe is approximately equal to Indian human anthropometry. The fingers are attached to palm and have a rational joint between them. The front and back cover are used for covering the palm and are bolted. the thickness of the cover is taken as 2mm and the front cover is flat according to shape of human palm whereas the back cover is design at an angle .the design of both the covers are best suited with the palm.

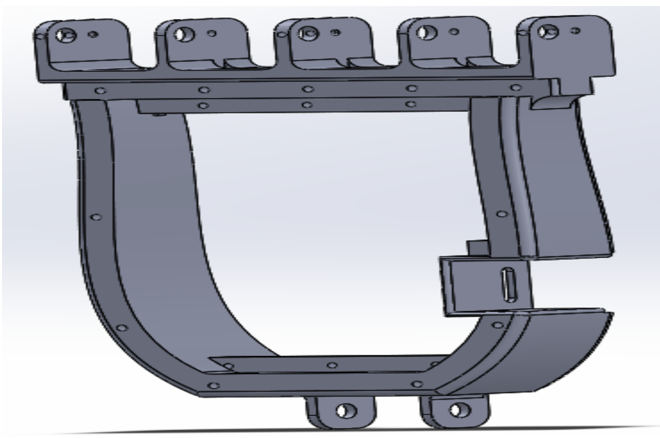

Fig 5: Palm Design

Assembly

The assembly was done of bionic hand with the entire necessary component to verify the constrain and to check if there is any part which is overlapping.

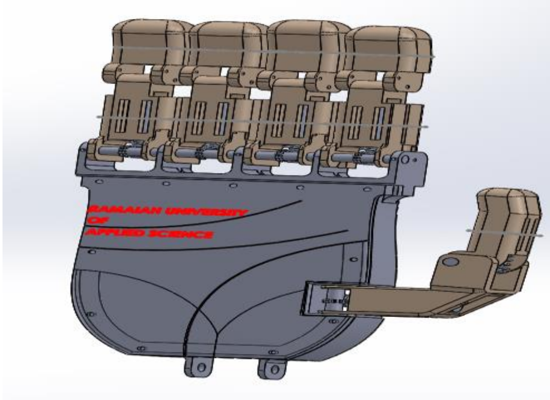

Fig 6: Assembly of Hand

Prototype

In order to develop a prototype of bionic hand a 3D printer called as Prusa i3 is used. The printer is fused deposition modeling type and is Cartesian axis printer.

Table 1: 3D Printer Specifications

Brand	Tronxy
Printing Area Dimensions	220*220*240mm
Position accuracy	Z0.004, X and Y 0.012mm
Print precision	0.05mm
File print format	.STl, G-code
Maximum speed	120m/s
Support material	PLA, ABS, Nylon, PETG and ASA.

Printing Material

Acrylonitrile butadiene styrene (ABS) is thermoplastic polymer. ABS is made up of polymerizing styrene and acrylonitrile with the presence of polybutadiene. The ABS material has good impact resistance, toughness and light in weight. The ABS material is available for 3D printing in foam of filament having a diameter of 1.75mm. ABS material is harmless and it doesn't have carcinogen which is having the effect on human health.

Table 2: ABS material properties

Chemical formula	(C8H8) X-(C6H6) Y-(C3H3N) Z
Glass transition	105°c
Injection moulding temp	204-238°c
Tensile strength	46MPa
Flexural strength	74MPa
Specific gravity	1.06
Shrinking rate	0.5 to 0.7 in/in

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