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Robotic Hands a Base for Prosthetics - A Review

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ABSTRACT

This review paper reports the findings of previously designed robotic hand and summarizes the advantages and limitations for modeling a robotic hand and proposes methods to overcome the limitations of the previously designed hand models. A robotic hand forms its base by mimicking the structure and motions of a Human hand and all studies are focused on improving the current models to have similar dexterity as of the human hand. Many Robotic hands have been created to mimic the human hand functions and gestures but they still lack the dexterity, compactness or affordability for prosthetic use. In this paper we have reviewed recently designed rigid robotic hands having rotating finger joints and soft robotic tendon actuated hands that use a single elastic block to create the whole finger so to reduce the rotating finger joints after reviewing the designs we have compiled a set of points that can be used as the framework for a design that can overcome the limitations of the previous designs.

Keywords: Dexterity, elastic, finger joints, prosthetic, rigid robotic hands, Soft robotic hand, tendons

I. INTRODUCTION

Human hands are one of the most intricate designs of the nature and of utmost importance to a human himself. A human utilizes his sheer workforce in generating his revenue and to perform his daily errands and they do this by converting the metabolic energy into mechanical work[1]. Studying the biology and structure of the hands has helped in designing of various robots that has eased the work load for humans and as a matter of fact it has also helped in designing of prosthetic and bionic robotic hands for those who have lost their hands or fingers due to some accidents or defects.

Many designs have come very close to the human hand that has DOF equal to the human hand but still they either lack the dexterity or flexibility of the natural state of the human hand. This paper studies some of the rigid and soft robotic hand models so far created and implement this data to create a model that can perform power grip, spherical grasp and pinch grip.

In this paper we have reviewed various robotic hand designs, studied their DOF, working mechanism, flexibility, dexterity and their feasibility towards human hand prosthetics. The review focuses mainly on the working of some of the robotic hands, their properties, the advantages of their design and structures as well as their limitations.

This paper reviews various designs and draws references from them to model an under-actuated robotic hand for specific gripping actions.

II. HUMAN HAND DESIGN

A hand basically consists of four fingers (index, middle, ring and pinky) and a thumb and the movement is flexion/extension and adduction/abduction that helps us to grab things, hold them, pick them and drop them at a certain point. A single finger consists of 4 DOF-three for flexion/extension and one for adduction and abduction while the thumb consists of 5 DOF. [2]

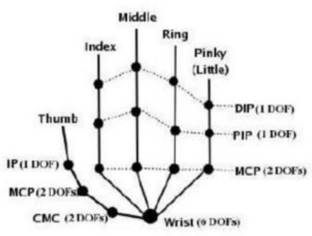

Fig 1: The simplified representation of the human hand structure. [19]

A human hand has almost 27 DOF (considering from the tip of the finger to the shoulder) depending on the ligaments and muscle flexibility but most sophisticated robotic and prosthetic models use only up to 23 DOF to attain the flexibility and the type of work they need to perform [2]. The various robotic hands are designed for different types of motions, grasp and gripping. Some robots are only for mimicking the gestures.

Fig 2 : A scheme of bones and joints in the human hand.

[4] The metacarpus and CMC bones are in the palm and they provide a rigid structure to the hand. Ideally we can consider that the MCP, PIP and DIP joints as revolute that can rotate 90° around the perpendicular axis. The MCP can be considered as an universal joint that rotates in and out of the plane parallel to the palm.

A human finger is divided into three parts MCP, DIP and PIP and a robot mimics these by three joints but these joints are eliminated or reduced in an under-actuated model to reduce the complexity though it also reduces the DOF enabling the dexterity of the hand but the proposed motions are accomplished. The fingers grasp an object by covering the outer surface of the object.

There are various types of grasp a hand can perform. Some of these studies refer to the categorization of six basic types of grasp: cylindrical, fingertip, hook, Palmer, spherical and lateral [5].

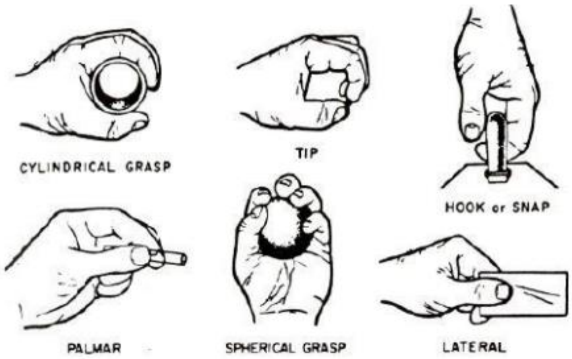

Fig 3: Six basic types of grasp

III. KINEMATICS OF FINGERS

The kinematics for the fingers except the thumb is as follows:
M. Z. Hussain [13] presented the forward kinematic to determine the position and orientation of the fingertip relative to the robot base coordinate system. The derivation of forward kinematic equation is done as follows.

Let
θ_i = Joint angle of the finger
d_i = joint distance of the finger
a_i = link length of the each joint
α_i = link twist angle.

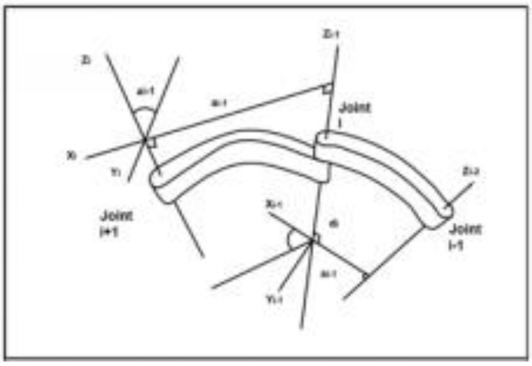

Fig 4: Denavit Hartenberg(DH) frame [20].

Forward Kinematic is used to determine the position and orientation of multi fingered robotic hand to determine the position and orientation of the robot hand relative to the robot base (Palm) coordinate system.

IV. REVIEWED LITERATURE

Laboratory of Robotics and Mechatronics designed a three fingered robotic hand for grasping objects with regular and uniform geometries. This hand was made of rigid fingers with rotating members at the joints and the fingers were actuated using gear trains. [6]

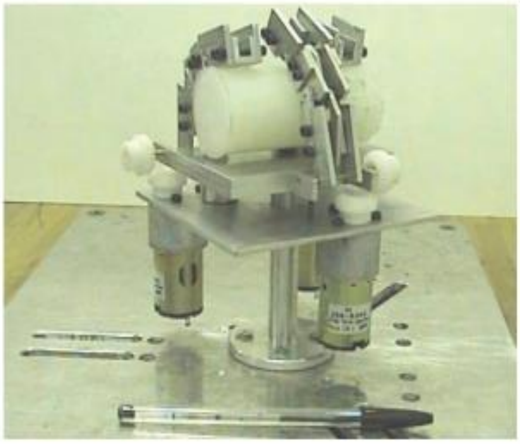

Fig 5: Human sized LARM hand

Though the LARM hand has only 1 DOF for each of its fingers it is capable of holding things, this is achieved by the opposition of the fingers and this property is similar when a human hand holds things with its fingers and the thumb.

The disadvantage of LARM hand is that it has only 3 fingers and their arrangement is in the form of a gripper rather than a normal human hand.

Yingtian Li , YingWei, Yang Yang and Yonghua Chen designed a robotic hand with soft material which focused on shape adaption of the object by the palm region using jamming particles enclosed inside a particle sac. This robotic hand utilized shape memory technique to grasp the object by confirming to the outer surface of the object. The fingers and thumb were made with silicone rubbers that were driven with the help of reinforced fiber. This method provides enhanced firm grasping of any object by taking the outer form of the object gripped by vacuuming the palm sac. [7]

Fig 6: Grasp demonstrations: (a)a hot water cup. (b) an apple. (c)a cylindrical water bottle and (d)a lotion tube.

As this design has actuation of the palm region the approach is quite different from the normal human hand as the palm region mostly has a compressive effect when objects are held but the approach has an advantage that the gripping is purely based in shape memory, this factor reduces the chance of overloading the object held.

The fingers have only flexion/extension motion but the human hand has abduction/adduction motion also as to grab spherical, UN-uniform objects as well as object having size larger than the palm area.

Alireza Mohammadi, Jim Lavranos, Hao ZhouI, Rahim Mutlu, Gursel Alici, Ying Tan, Peter Choong, Denny Oetomo designed X-Limb that is based on tendon actuation of the fingers and the motors are implanted inside the palm of the robot hand.[8] The fingers are designed by [1] using flexure hinges replacing the rotary joints MCP,DIP and PIP.

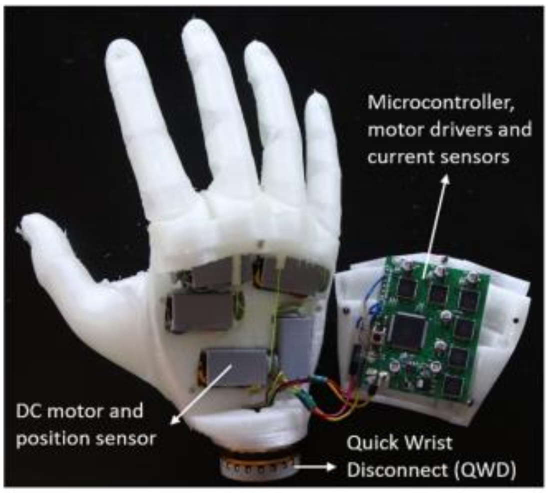

Fig 7: X-Limb model showing actuation mechanism and control system.

The X-Limb has 13 DOF[16] for its actuation and is close to a prosthetic hand and can be used by the amputees for doing some of the normal chores but the X-Limb has two limitation, the fingers do not have the abduction/adduction motion and the thumb also has only motion in one direction as compared to the human thumb that has a ball and socket joint member at the MCP this limits the opposition of the thumb with all the fingers and full extensive reach of the grip.

George P. Kontoudis, Minas Liarokapis, Kyriakos G. Vamvoudakis and Tomonari Furukawa designed a robotic hand that has soft monolithic fingers that can perform both flexion/extension and adduction/abduction with tendon-driven actuation mechanism having two independent tendon routing system where the flexion/extension is actuated by the artificial tendons and flexion material and the adduction/abduction is accomplished using spring loaded pin joint. This system has an increased dexterity as compared to the previous model presented by Mutlu [1].[9]

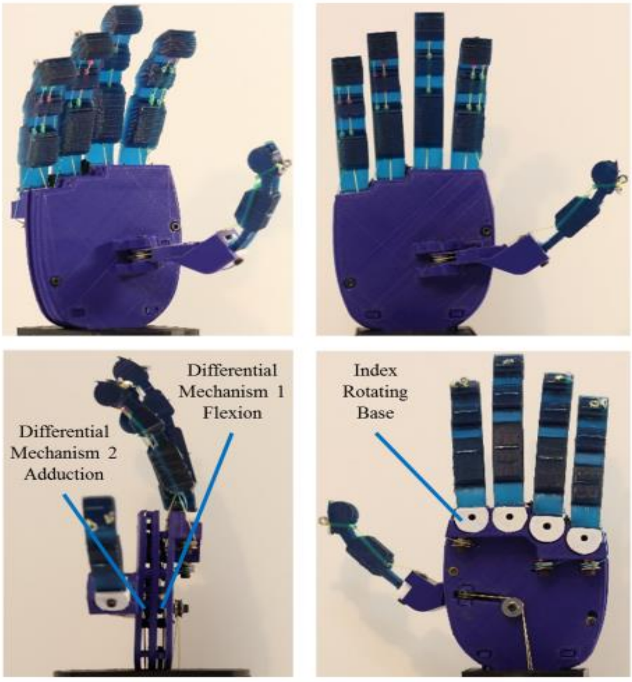

Fig 8: The adaptive robot hand in various views. The two parallel differential mechanisms for flexion/extension and abduction/adduction are demonstrated in the side view. Lever-based differential mechanisms reduce the fabrication complexity and the weight. The rotating bases of the MCP joint for the abduction/adduction are illustrated in white.

This design by Kontoudis has a more practical approach; the fingers have two tendons except the middle finger that helps it to grip objects with larges surface area also the thumb has one additional rotating joint that helps to achieve an opposition of the thumb against all fingers. The limitation of Kontoudis design is that the tendons are routed and then connected to a differential mechanism and then the mechanism is actuated with actuators outside the hand, so it is difficult to use this as a prosthetic hand.

The DEXMART Hand is also based on the tendon-based(sliding tendons) transmission system. In DEXMART the actuators are remotely located in the forearm. [10] The Wrist of DEXMART hand has 2 DOF for flexion/extension and the adduction/abduction movements. Also it has 2-DOF CMC joint for the thumb and 2-DOF MC joints of the other fingers.

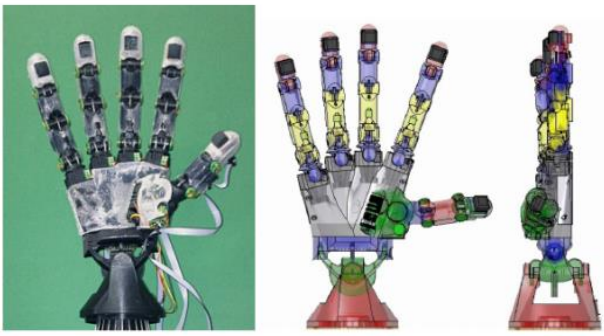

Fig 9: DEXMART Hand- Detailed view of the hand design.

The DEXMART uses four tendon routing system for the motion of each finger.[10] This method helps in increasing the dexterity and precision gripping of the objects but it also complicates the mechanism and increases the number of independent DOF that need to be actuated thereby increasing the number of servos to serve this purpose.

DLR/HIT Hand I is a 4 fingered robotic hand that uses gear transmission for finger actuation that helps the fingers to achieve force capacity of 10 N at its fingertips.[11]

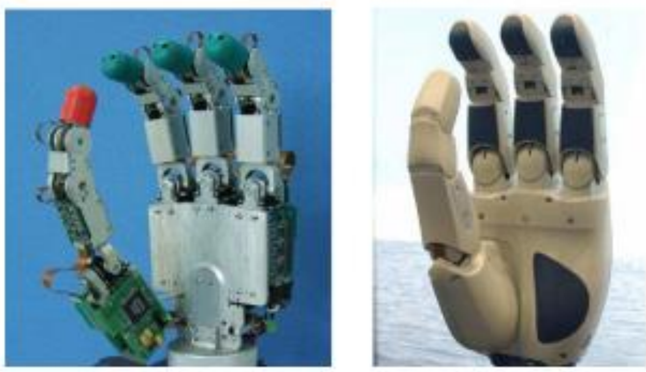

Fig 10: DLR-HIT I Hand.

DLR/HIT Hand I designed in 2004 has 13 DOFs actuating four fingers.3 DOFs for all four fingers and 1 additional DOF in the thumb for the motion relative to the palm. The size of this hand is bigger than the size of a normal human hand also it has only 4 fingers (including the thumb) that have only the flexion/extension motion.

DLR/HIT Hand II also has a force capacity of 10N in its fingertips and to achieve that the fingers are actuated with the help of mechanical transmission by timing belt in the base of each finger. This robotic hand falls under the category of rigid robotics. This hand has five fingers and is 1/3 smaller than the DLR/HIT Hand I but with same force capacity in its fingertips.[12]

Fig 11: Comparison of the DLR/HIT Hand I and II(right).

The DLR/HIT Hand II has 15 DOF and is smaller than the first one also its anatomy and size is similar to that of a human hand. Apart from this the limitation remains the same for hand also as the fingers only have the flexion/extension motion.

V. TENDON ACTUATION SYSTEM

The tendon driven actuation system is most commonly used method for soft robotic hands and the type of actuation highly depends on the orientation of the tendon routing lines.

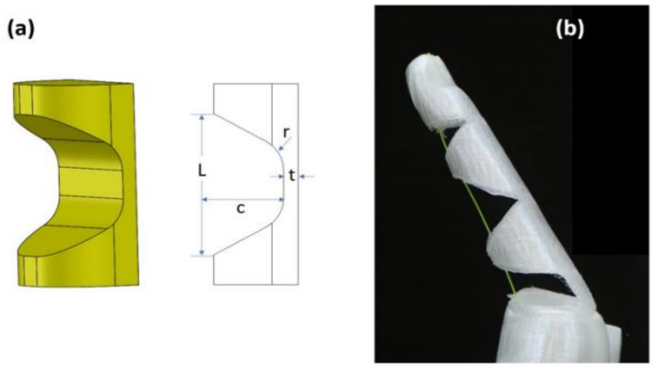

Fig 12: A soft monolithic finger with flexure joints: (a) Corner-filleted flexure joint and design parameter; (b)Finger with three corner-filleted flexure joints (one actuation cable is threaded through the 3 flexure joints). https://doi.org/10.1371/journal.pone.0232766.g005

One tendon routing system: The primary intention of using tendons is for actuation the flexion/extension of the fingers to grab an object. [1][8][18] This can be done either by routing the tendons through the joints or by constructing 'flexure hinges' in the fingers to provide space for compliant intermediate bending of the elastic finger.

Two tendon routing system: The index, ring and little finger need to have an abduction/adduction motion hence an extra tendon is needed for that the routing for this tendon is at an offset from the largest length along the finger so as to provide a rotary motion along the finger base. As the adduction/abduction needs to be away from the centre of the palm hence the tendon cavity is on the outer side of the fingers considering the interior side towards the mid longitudinal axis of the palm. [9][18]

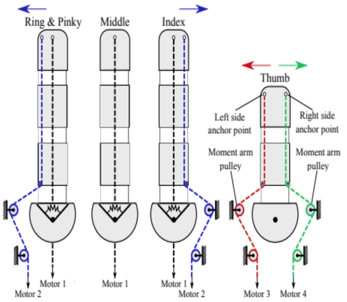

Fig 13: The finger structure and the tendon-routing system structure. Right-side anchor points enforce clockwise adduction. Left-side anchor points impose counterclockwise adduction. Both sides anchor points allow for bi-directional motion.

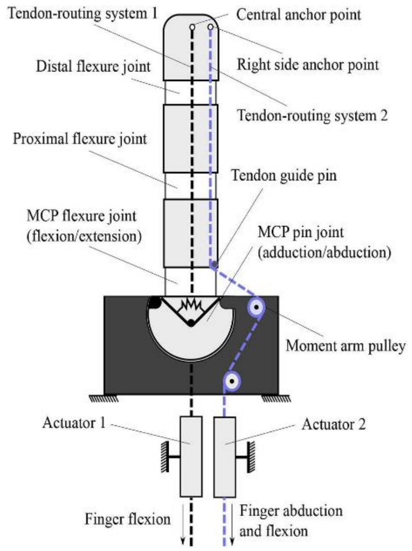

Fig 14: The actuation mechanism that allows for flexion/extension and adduction/abduction concurrently. This finger operates a clockwise motion. For counterclockwise motion, the right side anchor point needs to be swifted on the left side. For bidirectional abduction, the central anchor point needs to be placed on the left side of the finger.

The DEXMART uses four tendon routing system for the motion of each finger.[10] This method helps in increasing the dexterity and precision gripping of the objects but it also complicates the mechanism and increases the number of independent DOF that need to be actuated thereby increasing the number of servos to serve this purpose.

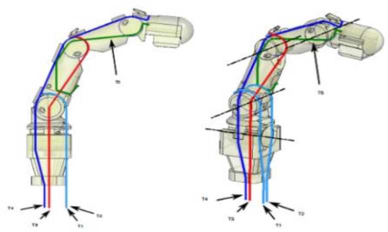

Fig 15: Details of the tendon network inside the finger.

VI. CONCLUSION

The robotic hands developed before are emerging as a solution for new age human hand prosthetics, we now know that most basic grips only need a certain number of DOF and that can be achieved if we couple the motion of the fingers and by making an under-actuated hand. [14] Presented that for power grasp only 1-6 DOF are required when the precision and skill are not important and for precise power grasp a model with 9-14 DOF is sufficient. For a higher level of sensitivity models with 15-24 DOF is needed to perform dexterous tasks and hand gestures.

1. Some other models and their DOF are shown below:[15]

Table 1. Robotic hand models and their DOF

Name of the Hand	# DOF
SensorHand (OttoBock)	1
i-limb Ultra Revolution (Touch Bionics) [16]	6
Bebionic (RSL Steeper)	6
Michelangelo (OttoBock)	2
Remedi	6
MANUS Hand	3
Smart Hand	16
Fluid Hand III	8
SoftHand Pro	2

(a). Tendon systems can help to achieve this under-actuation and dependent DOF.

(b). Use of soft material components for the fingers can have a more similar effect as human ligaments.

(c). Use of flexure hinges can help to achieve bending of the fingers at the MCP, PIP and DIP joints to resemble the rotating component of the finger joint and also elimination the need for complex actuation and parts for the fingers.

(d). Use of motors embedded in the palm reason and a place to mount the electronic components on the palm or on any human body for easy to carry it can be enormously helpful for a robotic hand to be used as a prosthetic substitute.

VII. FUTURE ENDEAVORS

Our proposed work will emphasize and will try to eliminate the limitations of previous work and will make a design to overcome all the above limitations.

This paper only reviews the previous designs and draws reference from them to propose a suitable design for the robotic hand that can also be substituted as a prosthetic hand.

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