

UTHM Hand: Mechanics Behind The Dexterous Anthropomorphic Hand

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Abstract—A multi fingered dexterous anthropomorphic hand is being developed by the authors. The focus of the hand is the replacement of human operators in hazardous environments and also in environments where zero tolerance is observed for the human errors. The robotic hand will comprise of five fingers (four fingers and one thumb) each having four degrees of freedom (DOF) which can perform flexion, extension, abduction, adduction and also circumduction. For the actuation purpose pneumatic muscles and springs will be used. The paper exemplifies the mechanical design for the robotic hand. It also describes different mechanical designs that have been developed before date.

Keywords—Robotic hand, Multi-fingered hand, dextrous hand, anthropomorphic hand, pneumatic muscles.

I. INTRODUCTION

HUMANS from the start of this world have been using slaves. The concept of slave is the person who obeys the master to perform some profitable work for the master. As now the slave culture has faded the man has got the equivalent to slave, a robot. With this technology humans can again have something totally under their control satisfying their sense of being master. A robot can be a dumb device that can be taught and asked to follow the master commands.

Hands are the vital organs that humans have, constituting of fifty four bones out of two hundred and six in whole adult human's body [1]. They are used in our daily life to perform most of the tasks like gripping, grasping, handling things, sensing tasks etc. Hands have been linked to the intelligence of humans by the great Greek philosophers Aristotle and Anaxagoras [2]. As the humans are most intelligent and superior to all the living beings in this world so we see this difference of dexterous manipulation from our hands as one major example of being superior.

The need for the robotic hand is increasing day by day as more and more automation is being introduced in industry. The industrial losses involving human errors are being tried to get rid off by using robotic hands in manipulation of delicate things and repetitive assembling tasks both for accuracy and speed of work. The risk of human operator working in hazardous environments is also being removed by introducing use of

robotic hands in space, high radiation environments, metal melting industry, chemical industry, cutting industry, automobile industry and the list goes on with different types of environments.

In order to match the needs of industry and knowledge exploration, the research in the field of robotics was started long ago and has been going on for many decades now. Researchers and developers have been trying harder getting closer to the characteristics of human hand. The artificial hands made can be stronger and faster than the human hand but only in some specific tasks; the performance of human hand is by far greater than these artificial hands if a broad scope of manipulation tasks is considered [3]. The robotic hands have evolved from the very basic two fingered design for gripping to fully anthropomorphic robot hands that can perform a very good grasp. Grasping is one of the major topic in the field of robotic hands. Researchers have been using different techniques in order to strive for better grasping.

The authors aim to develop a robotic hand that can be used anywhere as a human replacement especially in industrial applications as well as the prosthetics and rehabilitation purposes. Yet the shape, size and weight of the hand should be comparable to actual human hand, for it to be an anthropomorphic hand. The joints and parts assembly for the hand should be offering more flexibility for dextrous manipulation so that it should be able to pick and hold a needle, ball etc. The hand should offer an adjustable/flexible grasp to different type of objects like human.

II. LITERATURE REVIEW

There has been much research conducted on robotic hands. The history of robotic hands can be dated back to 1961 when Heinrich Ernst develops the MH-1 a computer operated mechanical hand at MIT [4]. This hand was also a gripper that used two fingers to pick and could hold some blocks using electric motors as actuators and touch sensors for the object identification.

Grippers are very application specific so they don't try to mimic the actual human hand. Mostly the finger count is two or three summing to a low DOF which causes the robot hand unable to act dextrously. Theoretically the least number of degrees of freedom to achieve dexterity in a robotic hand with rigid, hard-finger, non-rolling and non-sliding contacts, is nine [5]. The proof for this theory was the development of Stanford/JPL hand.

Many research works had been done on grippers [6], [7], [8], [9] and many companies started production for grippers. Universities, automotive companies, other industries and even

space programs for some countries are involved in buying these grippers. The concentrated research work for grippers was done in 1980s and early in the decade of 1990 the idea for gripper robotic hands was well established.

The development of MIT/UTAH hand [10] was the beginning of more complex robotic hand structures. This hand was capable of dexterously manipulating objects. It had four fingers and over twenty five DOF including the wrist joint. Much research work has been done in dexterous manipulation done by robotic hands and highly manoeuvrable and anthropomorphic hands have been reported. By anthropomorphic we mean to be same as human in all aspects like number of fingers, size, shape and the ability for flexible movement to perform humanly tasks like grasping. Compared to the grippers, the anthropomorphic hands are much more complex as they require increased number of actuators and more limitations on size and shape. With the passage of time, the complexity has been increasing as researchers are unfolding more and more dexterous capabilities of human hand. But still no robotic hand has been able to stand the actual human hand in a wide spectrum of tasks because of the difference of toolbox of nature and researchers. A much detailed study on the robotic hands performing dexterous manipulation can be seen in [3].

Through the life of robotic hand research many techniques have been used for the actuation and many different mechanical designs has been put forward by the researchers. The actuators vary from completely electrical to completely mechanical ones incorporating the combination of electrical and mechanical parts. But every actuator has its limitations and restrictions like the space required for the actuator sometimes causes the hand size to go much bigger than the human hand size or sometimes causing the actuator system to be placed outside the hand making it an extrinsic type of robotic. The force applied by the fingers is limited for the intrinsic type of robot hands where the actuator system is placed inside the fingers. Extrinsic and intrinsic designs have their advantages depending on the application of robotic hand. If the hand is required to be anthropomorphic with no extra outer components then intrinsic design is preferred where as extrinsic design can be useful in applications which require high precision and even the vibrations of the hand is not tolerable. With the extrinsic design the researchers can get the maximum DOF as there is no such restriction for size.

Electric motors are most commonly used choice for the artificialists in order to move the joints [11], [12], [13], [14]. Electric motors have been proved to be very accurate in position and velocity control and also provide much force for the grasping function achieved by the robotic hand. The use of electric motor also simplifies the mechanical design of the hand. Also when using electric motors different approaches has been seen where some attaching the motors directly to the joints avoiding the extra mechanics involved, some using tendon cables with motors, some using tendons and pneumatic actuators, some using gearing with motors and some others are the hybrid of these approaches.

By using the tendon cables with electric motors the overall structure of the robotic hand is simplified. They are very low in

mass and can provide stiff transmission of energy. But with using tendon cable there are some problems as well like the elasticity issues that causes inaccurate angle control for the joint. Another big problem with using tendon cables is pulleys as pulleys occupy much space and cause difficulty in routing the tendon cables.

The MIT/UTAH hand had three fingers and one thumb [10]. They removed the little finger to avoid complexity in their dexterous robotic hand. Each finger had four DOF and four joints, three for the flexion and extension and the fourth one for abduction and adduction. Each joint is separately controlled by a pair of tendon cables so total eight cables are routed for each finger. Pneumatic actuators were used for the finger movements.

NASA's Robonaut Hand had twelve DOF and five fingers like human hand [15]. But the DOF varies through the fingers as the fingers are grouped in two sections namely dexterous and grasping fingers. The dexterous fingers (index and middle) and thumb had three DOF each while the ring and pinkie with one DOF and one palm DOF were used for grasping. Brushless DC motors and gear head were used for the finger actuation. The motors were placed outside the hand for keeping the size of hand small. The mechanical design for these fingers was very complex but very well planned to match the size of an astronaut glove. The geometry of the components was extremely complex so putting them altogether inside was much difficult task.

The anthropomorphic NTU hand had seventeen DOF with five fingers and was comparable to the size of human hand [16]. The thumb and index finger had four joints each and can perform all the actions as the dexterous human fingers while the other three fingers had three joint each and are not able to perform abduction and adduction. This hand had very complex gearing involved in its fingers as it had a special set of arranged gear trains present in for every joint along with a smart motor that was performing the joint actuation.

The DIST-Hand was developed with sixteen DOF and high level of dexterity [17]. It had four fingers actuated by tendon drive and DC motors. The tendon cable needed pulleys which caused friction so in order to reduce the friction a combination of pulley and ball bearings was used. The DLR-Hand also used dc motors with transmission tooth belt and harmonic drive gears [18]. This hand had thirteen DOF with three fingers and a thumb.

Compact fluidic hand had been developed and reported with fourteen DOF [19]. The hand is powered by fluidic actuators and a miniaturized hydraulic system was developed to be embedded inside the robot hand. The hand is reported to be anthropomorphic and dextrous with purely mechanical actuation system. But the strength of the grasp achieved is small.

The Keio hand had been developed having twenty DOF almost the same as human hand [20]. It is reported to be dextrous and anthropomorphic as the size of hand is same as that of a grown up human. This hand has been actuated uniquely using ultra-sonic motors along with elastic elements. Another unique design using spring as actuating element has

been reported [21]. The said robot had three fingers and was reported achieve very high acceleration. This robot was reported for capturing purposes.

III. MECHANICAL DESIGN

The inspiration of the design has been taken from human hand. Since the goal of robotic hand is to be dexterous as well as anthropomorphic so the size and number of fingers should be same as human hand. All the fingers in human hand exhibit nearly the same structure. The human hand with finger parts labelled can be seen in Fig. 1. The mechanical design starts from designing of one finger and then replicating the same design for developing the full hand. The weight of the hand is important when it has to be used for rehabilitation purposes whereas in industrial applications the weight is not an important factor.

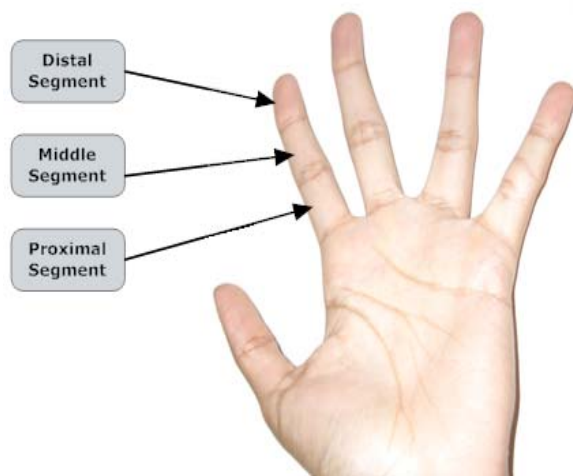


Fig.1 Finger parts

A. Finger Design

The finger of UTHM robotic hand has three parts which are distal segment, middle segment and proximal segment like in a normal human hand shown in Fig. 1. Each finger has four DOF with four joints. The fingers have the same structure but with different sizes. The shape of fingers is made similar to the human fingers considering the curvatures, bends and the pointing shape on the distal segment. This similarity of shape to the human hand will make the grasp of our robotic hand stronger and more efficient. The width and depth of finger has been kept constant in all segments but the segment lengths are different according to the front face of human hand as this is the face which is used for gripping and catching anything. These lengths are different from the size of bones present in the human hand. The complete designed finger assembly is shown in Fig. 2.

Joints are located between the distal and middle, middle and proximal and two between the proximal and upper portion of palm. The two joints between the proximal and upper portion of palm are required to match one joint in the human finger that can perform flexion, extension, abduction and adduction. The combination of all four movements will

perform circumduction. For the above said joint a single ball joint was also designed and simulated that can perform the

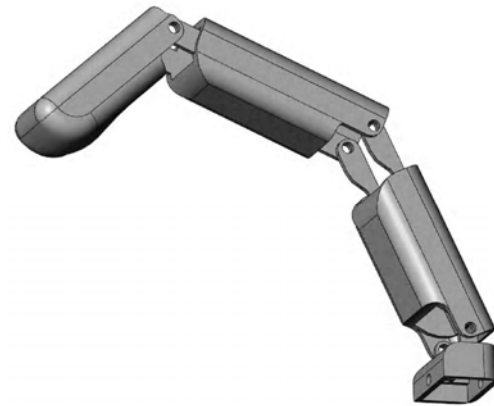


Fig. 2 Designed Finger

required two way motion just like the human joint. But the ball joint made things complicated in terms of routing the wires and tendons. So we preferred to make two joints instead of one ball joint but to keep the distance between the two joints as small as possible in order to make it felt like a single joint. To keep things simple we used pin joints between the segments so that the finger segments can move smoothly. The fingers are attached to the upper portion of palm using pin joint.

B. Thumb and Palm Design

The joint between thumb and palm is complicated as it can be seen from its movements. It can be observed that the human thumb surface is neither parallel nor perpendicular to the palm surface. The joint between the thumb and palm is at an intermediate angle making the thumb a vital element in achieving strong grasp. In designing we took this angle as 45° as shown in Fig. 3. The palm depth tends to increase as we go from fingers toward the wrist. In the mechanical design, the increasing thickness has been taken into account.

The overall DOF of full hand is twenty excluding any wrist or forearm DOF. With this number of DOF dexterous manipulation is achieved easily by our anthropomorphic hand. The assembled complete hand, along with the pins placed in pin joints is shown in Fig. 4. Simulations have been done to check if the thumb can reach all the fingers like human hand as shown in Fig. 5. The result of simulation was positive so we can perform a powerful full hand grasp like a human hand.

IV. MOTION MECHANISM

Many mechanical designs fail when considered for efficient motion mechanism. For our dextrous and anthropomorphic hand we have designed all the joints to be independent of each other. Combination of pneumatic actuators and springs will be used for the actuation of all the joints. The pneumatic muscles placed outside of the hand (possibly in the forearm) are attached to tendon cables which are routed inside the finger to move each finger segment separately.

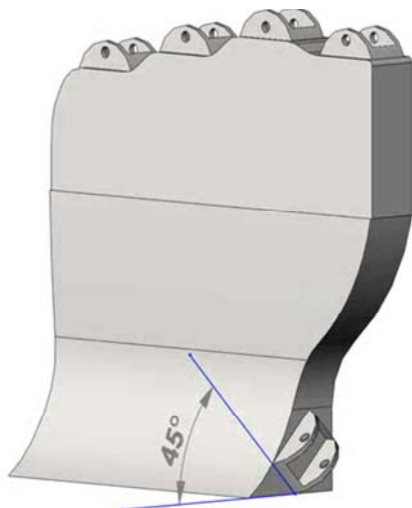


Fig. 3 Thumb Palm Joint

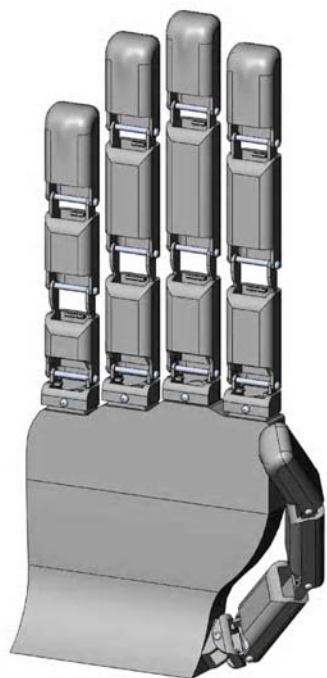


Fig. 4 UTHM Hand

The pneumatic actuators are mostly cylindrical in shape and are widely used in factory floor automation [22]. But in the evolution of robotic hands these were also used as a main power source for actuation. The pneumatic actuators are operated by air pressure. The main component of the pneumatic actuator is a flexible rubber tube. It can be wrapped in a tough plastic or metallic weave. The tube when inflated with compressed air shortens in length and restored back to the original length when the air is sucked out of the pneumatic actuator as shown in Fig. 6 and Fig. 7. They can cause great force and are light weighted as well.

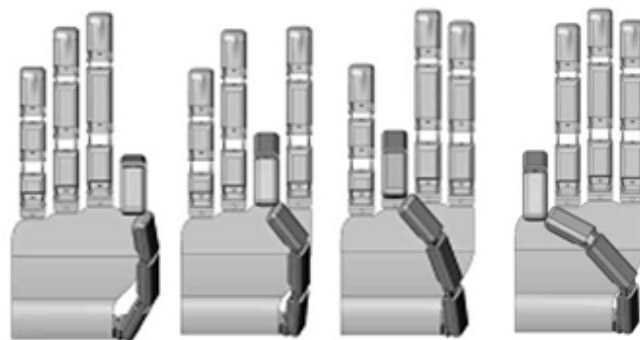


Fig. 5 Simulation result: Thumb reaching out to fingers

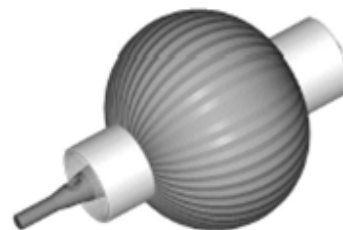


Fig. 6 Inflated muscle [22]



Fig. 7 Deflated muscle [22]

Solenoid valves are used for controlling the air to flow in and flow out from the pneumatic actuator as they work on the base of air pressure inside them. The switching of the solenoid valve can be controlled by using pulse width modulation (PWM).

The pneumatic muscles will be used for flexion motion of finger segments. The finger segments will get back to their default position by the help of springs present at each joint exhibiting the extension motion. Researchers have, quite frequently been using two pneumatic actuators for each joint whereas we have reduced the number of pneumatic actuators and replaced them with springs. This result in low cost, lower complexity and reducing the number of solenoid valves which can minimize the space.

The mechanism for routing the tendon cables and motion of each segment is shown in Fig. 8.

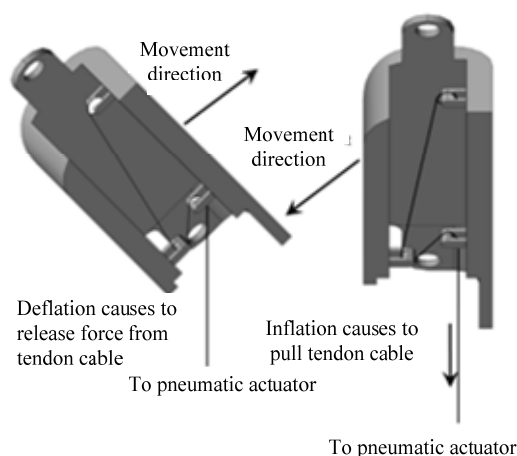


Fig. 8 Tendon routing

There are three hooks in each segment for one sided movement. The tendon cable will be tied with the top hook on the internal side of segment's back and then it will be passed through the hook on the internal side of segment's front. After passing through the front hook, it will be passed through the lower hook on the back. When the tendon cable will be pulled downward by the pneumatic actuator, the tendon cable from upper back hook to the lower front hook will try to be in parallel to the portion of tendon cable which starts from the lower front hook to the lower back hook. As the lower back hook is designed to be placed higher than the lower front hook so this will allow the movement of the segment for more than ninety degrees. This tendon cable structure is replicated for the movement of all the segments. The tendon cables are routed to avoid any motion coupling between the joints. So when one actuator is pulled only the corresponding joint is bent. This motion uncoupled design will also help in the control part as we can get the feedback only from the particular joint when moving and neglecting all the other finger joints.

V. CONCLUSION

The mechanics behind the dextrous anthropomorphic robotic hands has been explained in this paper with elaboration of major design techniques. The mechanical design of UTHM hand has been explained in this paper. The design is targeted to be made simpler from previous design of robotic hands by using combination of pneumatic actuator and springs. The hand development is in progress and work on the control part of this hand will be done in the next phase.

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