A Microcontroller Based Four Fingered Robotic Hand

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Abstract:

In this paper we deal with the design and development of a Four Fingered Robotic Hand (FFRH) using 8-bit microcontroller, sensors and wireless feedback. The design of the system is based on a simple, flexible and minimal control strategy. The robot system has 14 independent commands for all the four fingers open and close, wrist up and down, base clockwise and counter clockwise, Pick and Place and Home position to move the fingers. Implementation of pick and place operation of the object using these commands are discussed. The mechanical hardware design of the Robotic hand based on connected double revolute joint mechanisms is briefed. The tendoning system of the double revolute joint mechanism and wireless feedback network provide the hand with the ability to confirm to object topology and therefore providing the advantage of using a simple control algorithm. Finally, the results of the experimental work for pick and place application are enumerated.

Keywords: *Object Hunting, Wired and Wireless feedback, Robotic Hand*

1. Introduction

Robotics is an hodgepodge of topics, including geometric transforms, control theory, real time operating systems, DC and stepper motors, and digital signal processing etc. A Robot is a reprogrammable, multifunction manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks. Robots can be classified according to their method of control pathway, structural design, or level of technology. The two major types of control are servo and non-servo. The path way of the robot may be either point- to-point or continuous. The volume of the workspace of a robot is rectangular, cylindrical, spherical, or jointed spherical. Finally, a robot may be classified as low-, medium-, or high-tech, based on its number of axes and its level of sophistication in respect of end effectors and grippers. The gripper is similar to the human hand just as the hand grasps the tool to perform the work the gripper grasps and secures the robot's work piece while the operation is being performed.

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A robotic hand is an electro-mechanical system comprised of many parts. The two main parts to such a device are the electrical components and the mechanical structure that allows motion. Human hand is one of the most complex organs of the human body after brain, thus, we understand why its behaviour had intensively interested former philosophers, and in the past decades has been object of study and research not only in the medical field but also in the engineering field. Earlier research work relating to the development of robot hands is based on general purpose end-effectors by using the human hand as inspiration. In many of these configurations, the robot hand has the same kinematic structure as a human hand, and can independently control the joints of each finger.

Examples for such robot hand are the Utah/MIT hand [1], the Salisbury hand[2], five-digit hand at University of Belgrade[3,4], grasping device designed by the University of Pennsylvania[5]. In most cases, the fingers are actuated through antagonistic tendons routing to a motor for each finger joints. The difficulty with these flexible mechanisms is that one must compute a desired position or torque for each joint of each finger. A four-fingered hand with three joints on each finger would require twelve desired positions or torques to be computed for control. This flexibility is needed for manipulation, but for grasping, the robot does not necessarily need to have independent control of all of the finger joints. Therefore, many researchers have been investigating and building hands with fewer controllable degrees-of-freedom and more compliance to object shape. Renssclear Polytechnic Institute has also implemented a robotic grasping device where each finger has two controllable degrees of freedom, requiring a total of 6 motors to drive a three-fingered hand [3]. This hand also uses an antagonistic tendoning system, but it has more controllable degrees of freedom that must be individually controlled.

The main object of this paper is to design and implement a Four Fingered Robotic Hand (FFRH) for providing a simple reflexive grasp that can be utilized for a wide variety of objects. The FFRH is designed based on servo, point-to-point, and cylindrical robot structure with four-pronged grippers(four fingers).This approach is focusing primarily on the task of grasping objects of different shapes and not that of manipulating or assembling objects. This type of a grasping device has a variety of applications in object retrieval systems for the handicapped, planetary, underwater exploration and robotic surgery.

To fulfill the objective, authors designed a new general purpose FFRH that grasps a wide variety of objects with possibly complex shapes, adjusts the grasp using a feedback and if unexpected external forces cause the object to slip during grasping, and has a simple control scheme that has 14 independent commands for fingers, wrist and base including pick and place. Grasping various objects requires generic end-effectors for the robot manipulation system. Most general purpose grippers are anthropomorphic and mimic human hands. This is because human hands are the most nimble and flexible manipulation system in existence, and because many objects are designed for human use. Therefore, a robot hand designed to have size and force generation capabilities similar to a human and can be expected to manipulate many existing objects. The hand, however, is not to manipulate objects, but only to grasp objects reliably. Therefore, there is no need of all the complex characteristics of the human hand or many existing anthropomorphic robot hands.

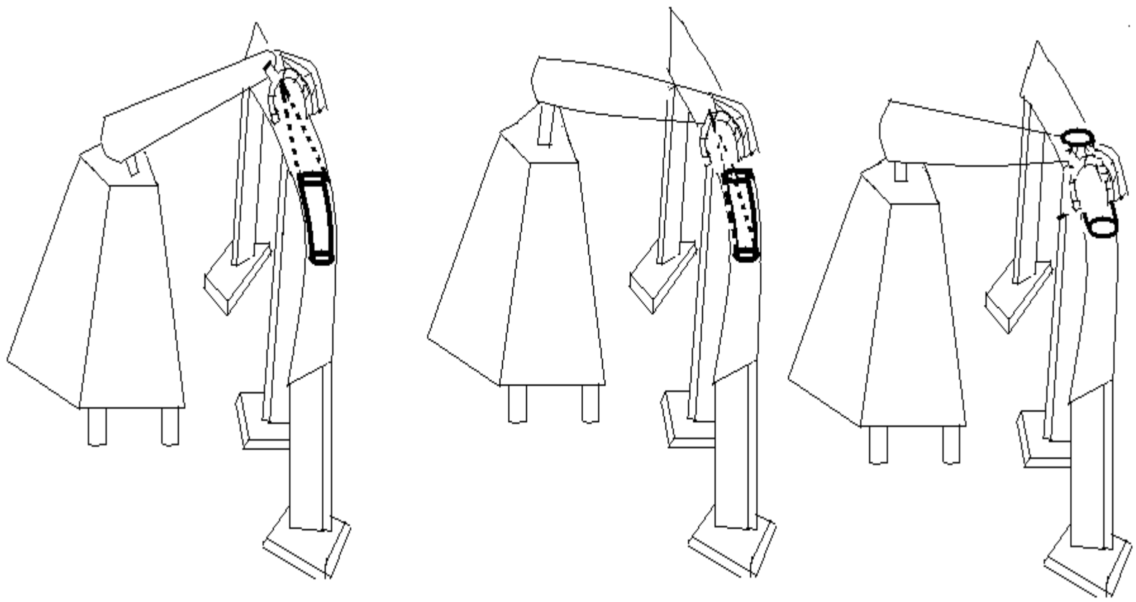
The methodology adopted is a simplified anthropomorphic design with three fingers and an opposing thumb. Each finger has three links, or phalanges, and three double revolute joints, almost similar in structure to the human finger. The thumb has two links and two double revolute joints. Each finger is actuated by a single opposing pair of tendons. One tendon curls the finger toward the palm and the other opposing tendon extends the finger away from the palm so as to grasp the objects.

In this paper, the design and implementation of FFRH is discussed. Section 2 deals with the design aspects of mechanical hardware for the robot hand and outlined comparison of earlier design specifications of robot hands. The functional block diagram and description of total robot hand system are explained with electronic hardware design in section 3. Section 4 addresses the software design part of controlling the hand structure for mainly pick and place application for an arbitrary topology of the objects. Finally, the results of the experimentation and conclusions are outlined.

2. Mechanical Hardware Design:

The mechanical hardware design of FFRH consists of **1.** Base structure, 2. Elbow, 3. Wrist, 4. Palm, 5. Fore Finger, 6. Middle Finger, 7. Ring Finger, 8. Thumb. The movement of all the joints in respect of base, wrist, and four fingers is achieved through individual geared DC motors. The whole structure of the hand consists of the digits, sensors, and wires for the other units of the hand. The base is capable of rotating the arm through 360 degrees in both the directions. The arm/elbow of the FFRH contains all the hardware with the motors and the allied mechanisms necessary for the motion of the fingers and the wrist. The control hardware is used for the forefinger, the middle finger, the ring finger, the thumb and the wrist controlling the movement of the palm. Each finger is controlled by geared DC motor. Limit sensors are used to control the motion of all the fingers. The hardware responsible for the control of the wrist is located in the arm /elbow. The wrist motion is in up and down direction with maximum 180 degrees in either clockwise or anti-clockwise directions. The palm holds all the four fingers. The palm is capable of moving both in the upward and downward direction by an angle of 90 degrees in either way.

All the fingers, the fore finger, middle finger, ring finger and thumb, are provided with three phalanges except the thumb which has only two phalanges. Separate geared DC motors (+12V, 10 rpm, 1 kg-cm torque) are used for controlling all the joints. The simplest possible general-purpose robotic end-effectors is the parallel-jaw gripper. This mechanism consists of two parallel structures and the robot can control the distance between the two jaws. Many researchers have outlined algorithms for grasping objects of various shapes with these grippers [6,7,8]. While this is possible, the robot must compute where to position the jaws relative to the surface and center of mass of the object. To hunt for the presence of an object on workspace, IR sensor is placed at the central position of the palm as shown in the Fig.1.



(a) First edge detection (b) Second edge detection (c) Back to Mid Position (Ready to Pick)

Fig.1 Object Hunting

A five-digit hand is designed at University of Belgrade which uses three motors: one to control the thumb and the other two to control two fingers each [3,4]. The thumb can rotate from a position aligned with the four fingers to opposing positions with three of the four fingers. The other motors control two fingers which use a differential lever to rotate about the finger joints. A differential lever allows the motions of the two "connected" fingers to adapt to the differential forces acting on the finger pair. This design is particularly flexible in its ability to grasp an object in a variety of configurations.

An unique grasping device is designed by the University of Pennsylvania, in that it has a stationary thumb and two rotating fingers that can either be positioned in line with the thumb for hook grasps or on the opposite side of the thumb for enclosing grasps [5]. The hand also uses a clutch mechanism to control the fingers during grasping of the objects.

The FFRH is a simplified anthropomorphic grasping device which has one motor per finger. FFRH's fingers naturally comply to the surface of the object thereby minimizing the computation typically needed to compute surface geometry. The authors feel that this mechanism is simpler than other general purpose grasping devices and that it provides an alternative to the other available mechanisms and their comparisons of specifications of the developed robot hand and previously developed robot hands [9]-[18] are shown in Table 1..

Table 1

Name	Fingers	DOF	Payload[Kg]	Driving Mechanism
Developed robot hand-FFRH	4	6	0.5 max.	Built –in actuator
Wendy hand[9]	4	13	1.7	Built –in actuator
COG hand[10]	4	12	-	Built –in actuator
DLR hand[11]	4	13	1.8	Built –in actuator
Gifu hand [12]	5	16	1.4	Built –in actuator
Utah/MIT hand[13]	4	16	-	Wire –driven
Shadow hand [14]	5	21	-	Wire -driven
Stanford-JPL hand[15]	3	9	-	Wire -driven
Anthrobot hand[16]	5	16	4.5	Wire -driven
Robonaut hand [17]	5	12	-	Flex shaft
Robot hand[18]	5	20	0.85	Built –in actuator

The design of mechanical structure for FFRH incorporates four digits: three fingers and one thumb, as shown in Fig. 2 Three digits are positioned at the corners of an inverted triangle and one digit is at the center of base of the triangle, since this geometry leads naturally to stable finger contact positions for an enclosing grasp [8]. Each finger consists of three rigid links (the proximal, intermediate and distal phalanges) constructed from two parallel plates. The phalanges are connected by three joints (the proximal, intermediate, and distal joints) which have parallel axes of rotation and are responsible for curling the finger tip toward the palm The thumb is similarly configured except that it consists of only two rigid links(the proximal and distal) connected by joints (the proximal and distal). The dimensions of FFRH are selected to be approximately the size of an adult human male hand.

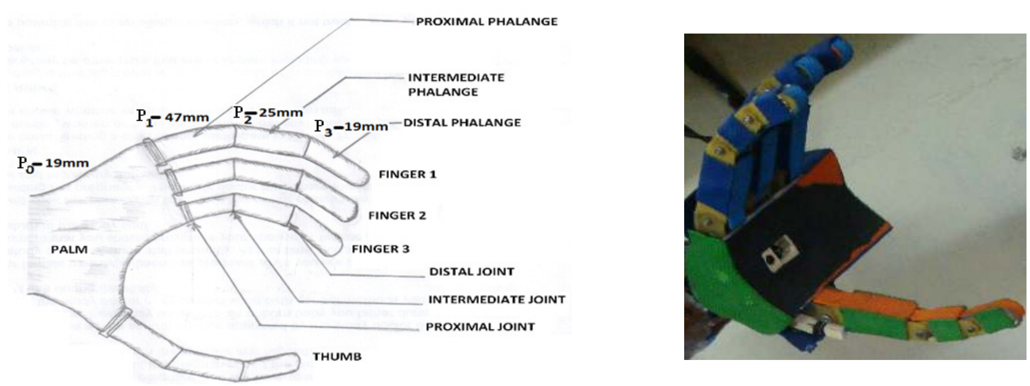


Figure 2. a) Conceptual FFRH Structure b) Actual FFRH

The phalange lengths, P_1,P_2 , and P_3 , phalange width, w, and the distance between the finger and the thumb, d_f, were as shown in Table. 2.

Table 2: Measurements of the various parameters of Robotic Hand

Distance between joints	Value(mm)
Palm to proximal joint – P_0	19
Proximal to intermediate joint – P_1	47
Intermediate to distal joint – P_2	25
Distal joint to digit tip – P_3	19
Joint to end of phalange – l	9
Phalange width – w	19
Finger to Finger - d_{ff}	44
Thumb & fingers - d_{ft}	75
Support thickness – t	3
Proximal joint pulley radius – R_1	9
Intermediate joint pulley radius – R_2	8
Distal joint pulley radius – R_3	6

The distance between the two fingers, $d_{ff,}$ was computed to be the distance between the fourth and index finger to give the largest human finger displacement. The thickness of the supports t, was chosen for availability and strength. To reduce construction costs, we configured the three fingers identically and the thumb to have identical link lengths as the proximal and intermediate links of the fingers.

Each digit is controlled by a single antagonistic pair of tendons which are routed over a system of pulleys and idlers as shown in the Fig.3. The pulleys act as routers to create angular displacement of the link , but do not transfer any torque to the joint. Each phalange consists of a pulley located at the joint and an idler located at the center of the phalange. The opposing tendon controlling the finger are routed in opposite direction over the pulley and idler. The path of the tendon to this system works as a differential mechanism. One end of each tendon is attached to the tip of the distal phalange and the other is wound about a spool attached to the shaft of a single remotely located geared DC motor. Using feedback sensors, the finger joint motion is controlled by relays which are in turn controlled by microcontroller and also the finger can be locked at any stage within the workspace. The tendons in each finger are wound in both directions depending on the DC motor direction. In this configuration, the motors control the relative length of the tendons when irregular object is selected. The complete mechanical structure of one finger's joints movement and lock control mechanism is shown in Fig. 3.

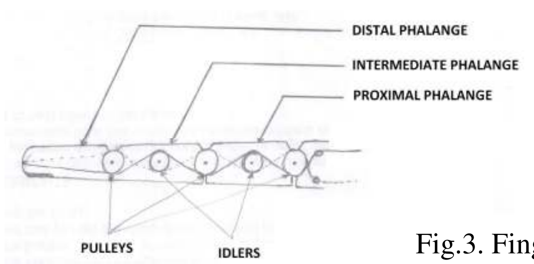


Fig.3. Finger Structure

For practical reasons, epoxy is selected as the material for the plates (fingers) since it is strong, rigid, lightweight, relatively in expensive, and easy to machine. We also choose epoxy for the arm, wrist, and palm plates since it is not as susceptible to wear. Dial cords with small diameter plastic tubes as sleeves are used for the tendons of the digit since these are flexible. The Graspar robotic hand differs from many other hands [19,20,21] in that the joints of each finger are independently controlled for motion. Since the joint axes of each digit are parallel, the motion of each finger lies on a plane. The digits are mounted such that their planar workspaces are parallel and therefore do not collide. The motion of a Graspar finger as the digit's driving motor is activated by the keypad or wireless feedback network.

3. Electronic Hardware Design:

The Electronic hardware design consists of three main parts namely Four digit Robot hand, Control unit and a Feedback unit. The Four digit Robot hand consists of three fingers and an opposing thumb and each digit is connected to the geared DC motor. The movements of the digits are controlled by the geared DC motors. The geared DC motors are controlled by the Control unit. The functional block diagram of the Control unit is shown in the Fig.5. The Controller unit has 5x5 Key Pad, Decoders, an 89v52 Microcontroller, Relay Drivers for geared DC motors, LCD display, and a 433 MHz Receiver for feedback. The Key Pad is interfaced to Microcontroller via key decoder logic, parallel I/O interface 8255. The keypad consists of Keys for opening and closing of each digit, wrist up and down, Base clockwise and counters clockwise, Pick and Place and Home position. The digit or base or wrist is moved, whenever the corresponding key is pressed. The signals from the Keypad are fed to 8255 IC(PPI) through Key decoder. The decoded signals are given to the Microcontroller and the corresponding relays are activated. The relays in turn energize the geared DC motors. All the Four fingers use DC geared motor drivers with relays, for motion control of finger joints with pitch of 45 degrees maximum. Wrist geared DC motor drives the wrist with roll and pitch of maximum 180 degrees. The opening and closing of any digit indicated on the LCD display(Fig.4). The hand moves after getting a signal from the Key Pad and rotates up to 360 degrees (free rotation).The input from finger limit sensors placed on palm is used to control the free rotation of the finger.

Figure 4. a)Controller unit b) Keypad c) LCD Display

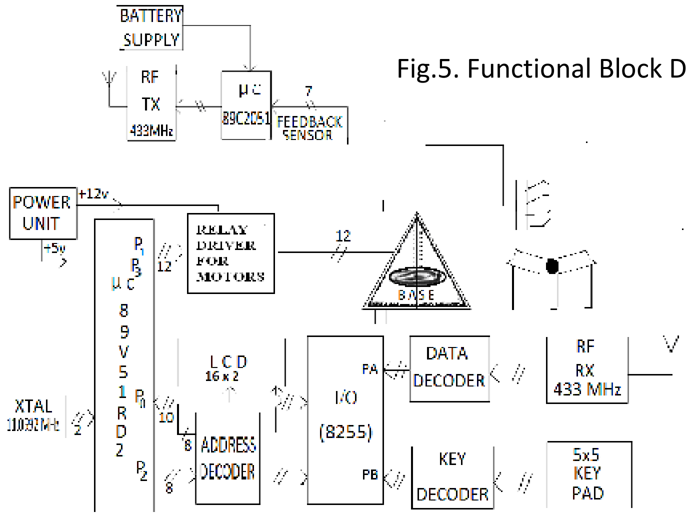


Fig.5. Functional Block Diagram of FFRH

The feedback unit consists of IR sensor placed on the palm, a microcontroller, a 433MHz transmitter and a 433MHz Receiver. IR sensors placed on the Palm are used to sense the presence of an object. Whenever an object is identified on the workspace and is sensed by the sensor, the object is hunted and the process of object hunt is shown in Fig.1. The operation of Microcontroller-based robot hand is achieved through control software written in Assembly Language. Fourteen independent commands are incorporated into this for the following joints: Fore finger close and open, Middle finger close and open, Ring finger close and open, Thumb finger close and open, Wrist up and down, Base clockwise and counter clockwise, Pick and Place and Home position.

4. Software Design

The goal in software design of FFRH is to have a simple, minimal computation control strategy[21,22]. The design of the control program is divided into different subroutines namely initialization subroutine, keypad subroutine, fingers and palm subroutine, sensor and feedback subroutine and object hunt subroutine. The robot system interfaces to FFRH using 14 independent commands for the following joints: Fore finger close and open, Middle finger close and open, Ring finger close and open, Thumb finger close and open, Wrist up and down, Base clockwise and counter clockwise, Pick and Place and Home position. Fig.6. shows the control program of the FFRH.

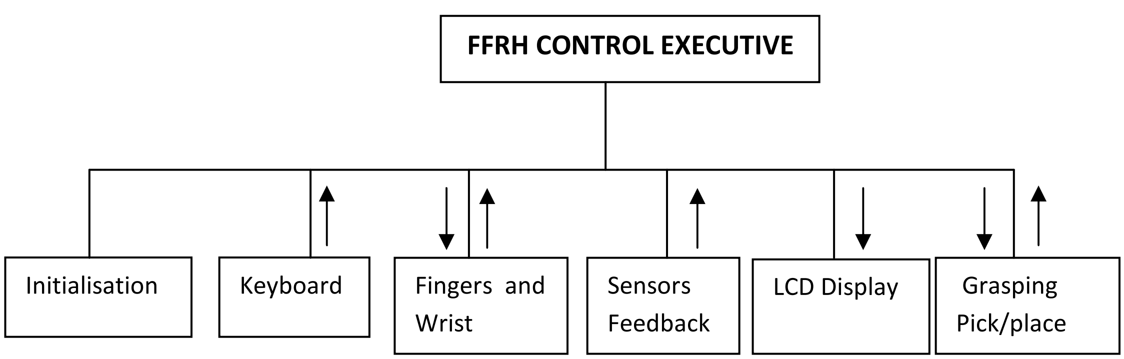


Fig.6. Control Program

Feedback to the motors is provided by IR sensors/simple contact switches mounted on the grasping surface of palm. The FFRH is currently using slightly modified contact switches mounted in parallel along the length of each phalange and added rubber sheathing under the lever of a generic limit switch and over the surface of a small push button switch to increase the amount of pressure needed to close the switch, to dampen bouncing often associated with switches, to increase the area in which the contact can be sensed, and to provide additional friction between the finger tip and the object.

Similarly, contact switches/IR sensors are used for grasping. Each phalange has contact switches mounted on the grasping surface of the finger. When IR sensor identifies an object within the workspace, the corresponding relays will operate to Grasp the object, it shortens the grasp tendon of each finger until a certain contact pattern is noticed on the digits. To execute a finger tip grasp, Graspar shortens the grasp tendon until the contact switches on the distal phalanges of all three digits are closed. For an enclosing grasp, Graspar shortens the grasp tendon until contact is made on all of the phalanges. If at any time the contact position is lost, grasper then continues to shorten the grasp tendon of the digit until contact is re established. Therefore, when a pick and place command is provided by key from keypad is issued to the Graspar hand, it simply moves simultaneously the motors to shorten the release tendons until contact is made on all the phalange mechanical stops.

5. EXPERIMENTAL RESULTS

The authors have constructed and tested a prototype version of this robot hand as shown in Fig 5. The robot hand system performs a finger tip grasp of a screwdriver and an enclosing grasp of a tin. The controlling software has been written in the Assembly language to control it. The hand has been mounted on the Microcontroller-based Robot hand fabricated as shown in Fig. 5. The hand weighs around 4 kgs and the motors are mounted on the base of the robot.

To test the grasping ability of the hand, it was made to grasp different objects, each having different shape, size, surface conditions and hardness. The object was held so that the center of mass was within the workspace volume of the thumb and fingers and oriented to grasp so that the major axis of the object was parallel to the palm and aligned with the fingers. Once the objects were crudely positioned in the work space of Graspar, the hand was issued a pick command switch. The grasp was determined to be successful if the hand correctly held the object autonomously.

The performance specifications of Graspar that is implemented and tested are as follows: Maximum weight/payload is 1 kg, Object topology is arbitrary, independent degrees of freedom are 6, maximum diameter of sphere is 120 mm, and minimum diameter of sphere is 30 mm. An interesting aspect of this design is that the ranges of weight can be increased by adding more powerful motors and cables of higher tensile strength. Since these motors are mounted remotely, they do not add to the load of the manipulator. This enables the hand to be configured for the application by the selection of the appropriate motors. To test size restrictions on objects, experiments are performed at grasping spherical objects.

6. CONCLUSIONS

A four fingered robotic hand has been designed, built, and tested. The hand design is based on connected differential mechanisms and has been designed to be inexpensive, mechanically simple, and easy to control. The tendoning system of the differential mechanism provides the hand with the ability to conform to object topology and therefore providing the advantage of using a simple control algorithm. The achievement of this hand is to demonstrate that reliable grasping can be achieved with inexpensive mechanisms and IR sensors. The authors have demonstrated that this hand can grasp a variety of objects with different surface characteristics and shapes without having to reconstruct a surface description of the object. This grasp is successfully completed as long as the object is within the workspace of the hand.

The control algorithm used by FFRH is extremely simple as was the goal of the design. The controller takes a high-level command from the user and produces a successful grasp of the object that is within the workspace of the hand. Unlike most robot hands which use joint position measurement for control feedback, it uses only inexpensive simple contact/IR sensors. These sensors are being used primarily due to cost considerations, but have certain limitations. The advantage of designed robot hand is its simplicity and inexpensive cost. However, this hand does have some limitations. It cannot be controlled to perform fine manipulations like writing. The Graspar robotic hand was designed as a first step in a future project that will integrate vision and grasping to control a robot to grasp objects and the future work will use a simple stereo vision system to determine the topology of the desired object and to visually move the robot hand so that the desired object is aligned within the workspace of the Graspar. The simple control algorithm developed in this project will be applied to the future project in order to grasp an arbitrary object. As the robot hand system moves the contact switches/IR sensors will be monitored to determine the successful grasping. This method is relatively simpler than the hugging algorithm presented for a robot hand configured as Graspar which relies on dense contact sensing [5,13]. The total robot hand system has independent control of finger joints of each finger leading to flexible control of finger motion as compared to the three fingered grasper [23,24,25]. Fig.7. shows the robot hand grasping different objects of different geometry.

Fig.7. The FFRH grasping a variety of objects.(Bulb, Bottle, Ball, Tin, and Duster).

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