An Embedded Computer Controlled Four Fingered Robot Hand

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ABSTRACT

When people interact with intelligent agents, they likely rely upon a wide range of existing knowledge about machines, minds, and intelligence. This knowledge not only guides these interactions, but it can be challenged and potentially changed by interaction experiences. The science of computation has systematically abstracted away the physical world. Embedded software systems, however engage the physical world. Human beings interact physically with environment using their hands. Robotic hand systems can be used in hazardous environments such as those encountered in nuclear, military, chemical, underwater, and space applications. Robots have the potential to play a large role in our world. However, as the potential use for robots grows, so does their need to interact with objects in their environment. An embedded computer controlled four fingered robotic hand is designed and developed with a simple and minimal control strategy to pick and place applications. The approach is based on anthropomorphic design with three fingers and an opposing thumb. Each finger has three links and three double revolute joints. Each finger is actuated by a single antagonistic pair of tendons. The robot hand system is interfaced to embedded computer with software control by means of 14 independent commands for the movement of fingers. Reliable grasping and releasing is achieved with simple control mechanism and IR sensors/push-button switches. The hand can pick a variety of objects with different surface characteristics and shapes without having to reconstruct its surface description. Picking of the object is successfully completed as long as the object is within the workspace of the hand and placed the object at the desired position within the workspace by relevant software control using keyboard commands. Details of hand control hardware and software for mainly pick and place applications are presented in this paper. Results of the experimental work for pick and place applications of different objects are enumerated.

Keywords: Robot hand, IR sensors, Pick and Place

1. Introduction

Robots have begun to perform various tasks on replacing the human in the daily life. In order to accomplish the effective performance of intricate and precise tasks, robot hand must have special capabilities, such as decision making in given condition, autonomy in unknown situation and stable manipulation of object. It must also possess the information to be able to carry out complicated manipulative tasks in a natural environment. Consequently, the sensors and the necessary software are required to support natural interaction between the robot and the environment. Many researchers on the anthropomorphic multi-fingered robot hand have been reported up to now [1,2,3]. The Utah/MIT hand developed by Jacobsen *et al.* is driven by actuators that are located in a place remote from the robot hand frame and connected by tendon cables [4,5] Jacobsen et al., 1984; Jacobsen et al. 1988). Hirzinger *et al.* developed DLR-Hand II, which build the actuators into the hand. Each finger of robot hand is equipped with motors, 6-DOF fingertip force torque sensor and integrated electronics [6,7]. Kawasaki *et al.* presented anthropomorphic robot hand called the Gifu hand III, which has a thumb and four fingers [8]. The thumb has 4 joints with 4-DOF and each of the fingers has 4 joints with 3-DOF. Moreover, the distributed tactile sensor which is made of conductive link is arranged about 859 sensing points on the palm and the fingers. Shimojo *et al.* utilized the pressure conductive rubber as a pressure sensitive material [9]. They attached the sensor onto a four finger robot hand and demonstrated its grasping operations with a column, sphere, etc.. Although a number of researchers have been done up to now, however, their motion of robot hands is unlike that of the human because the mechanism of robot hands is different from that of Utah/MIT hand. Jacobsen S C et al., utilizes 32 pneumatic actuators to drive three fingers and a thumb through a system of cables [10]. A dense sensing system is integrated with vision to perform trajectory planning.

Robotic hands share with the human hand, some of the fundamental primitives of motion, grasping, and manipulation. A deeper understanding of the human way to move their hands could suggest an approach to programming hands that allows users to more easily control the different devices that may be used in a robotic system, by encapsulating the hand hardware in functional modules, and ignoring the implementation-specific details. Recent results on the organization of the human hand in grasping and manipulation have demonstrated that, notwithstanding the complexity of the human hand, a few variables are able to account for most of the variance in the patterns of human hands configuration and movement. These conclusions were based on the results of experimental tests in which subjects were asked to perform grasping actions on a wide variety of objects. DIST hand [11], utilizes Bowden cables to provide extrinsic actuation to a four fingered 16 DOF hand with 20 brushless DC motors (BLDC). Fingertip force, joint angle and a novel conductive rubber tactile sensor greatly increase the sensing capability of this hand. Robot hand created by NASA uses 14 DC motors to control 14 DOFs[12]. Flex shafts and lead screw assemblies are used instead of cables to eliminate frictional problems. Gifu hand III was developed as a prosthetic device driven with servo motors, with 16 degrees of freedom (DOF), five fingers, actuated through four-bar linkages and a large area tactile sensor [13]. DLR hand II [14], is a four fingered hand with 16 DOF is driven with 13 DC motors with under-actuation provided by a four-bar linkage of two distal joints. Over 90 sensors and an impressive electronics packaging give this hand great potential for conducting research. RCH-1 [15] . This ultra-light (320 g) with 16 DOF hand was intended for prosthetics. High under-actuation through a passive cable–pulley system allows control of five fingers with six DC motors. This paper focuses on structural, hardware and software design considerations of a paradigmatic hand model.

2. Structural Design of FFRH

A robot can be defined as a reprogrammable multifunctional manipulator designed to move material, parts, tools, and specialized devices through variable programmed motions for the performance of a variety of tasks [16]. The aim of this paper is to present the design and construction of multi-fingered gripper as a robot hand for mainly general purpose manipulation/pick and place applications and has four fingers interfaced to palm and wrist.

The design of mechanical structure for FFRH incorporates four digits: three fingers and one thumb, as shown in figure 1. 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 [17]. 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

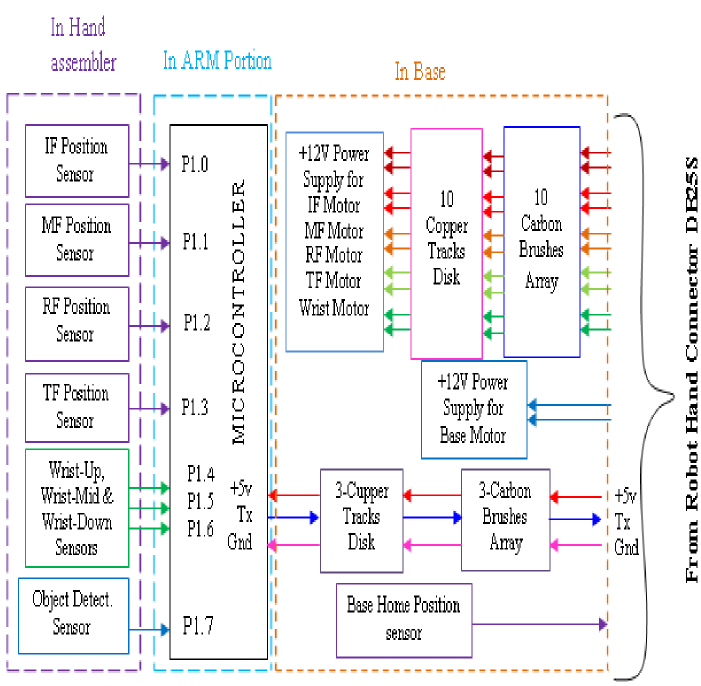


Figure 1: Functional Block Diagram of FFRH

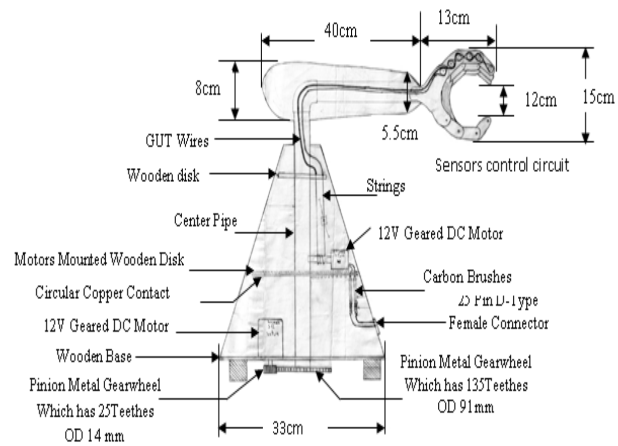


Figure 2: Mechanical structure of Robot Hand

The complete mechanical structure of robot hand system is shown in figure 2. 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 and/or gut wires with small diameter plastic tubes as sleeves are used for the tendons of the digit since these are flexible. The Grasper robotic hand differs from many other hands [18,19] 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 there Index does not collide. The motion of a Grasper finger as the digit's driving motor is activated by the keypad with feedback network. The figure 2 gives the details of mechanical structure and the figure 3 gives the overall view of the hand with the axes of rotation of individual components of the hand.

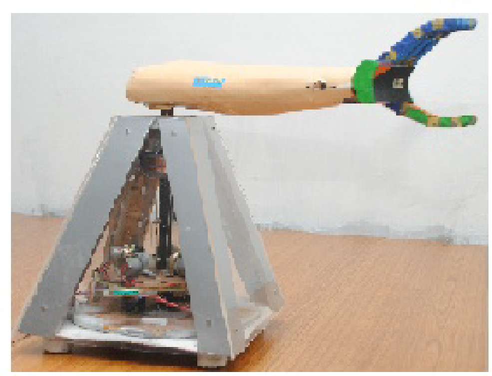


Figure 3: Overall view of the hand with axes of rotation

3. Embedded Controller Hardware Design

Designing hardware is much more constrained than designing software, while one may sometimes have great influence on the design of a chip many months in advance of availability. We can get in the volumes required at prices that we can afford. Unavailability of even a single component in required quantity may lead to difficulty in implementation based on the design. In this context the design of body part like human hand is much more difficult.

The functional block diagram of the Control unit is shown in the figure 4. The key commands from the Keyboard are encoded and are fed to the Robot Hand (RH) controller. The RH controller unit consists of the necessary electronic hardware required for driving all the geared DC motors. It also consists of the interface through decoder for transferring the control bits generated out of the control software from the Microcontroller, to the respective activator units located on the robot hand unit. Each finger consists of joints, for activating the motion; the geared DC motor is energized through Hand Motor Driver circuit. The driver circuit, as shown in the figure, supplies the required voltage at the appropriate current rating as per the specifications of the DC motors through connector. The Robot Hand Controller circuit diagram contains the Microcontroller, 8255 interface, Key board interface, Serial to Parallel Converter, Hand Motor Driver, Buzzer and LCD modules as shown in figure 4. Each module is circuited separately and are interconnected with one another and the modules are shown in the following figure.

The structured design approach involves solving a large problem by breaking the problem into several modules and works on each module separately and to solve each module, treats it as a new problem that can itself be broken down into smaller problems. Repeat the process with each new module/until each can be solved directly, without further decomposition. Structured software design is arranged hierarchically i.e. modules are arranged hierarchically. There is only one root (i.e., top level) module. Execution begins with the root module. Program control must enter a module at its entry point and leave at its exit point. Control returns to the calling module when the lower level module completes execution. In the RH controller, the main module has a major role, initialization and wait for one of the 14 key commands and if any key pressed, the corresponding module to the key is executed.

The flowchart for complete control software is shown in figure 5. When the power is on, the initial module code is run and displays the message “welcome” for a duration of 5 seconds and

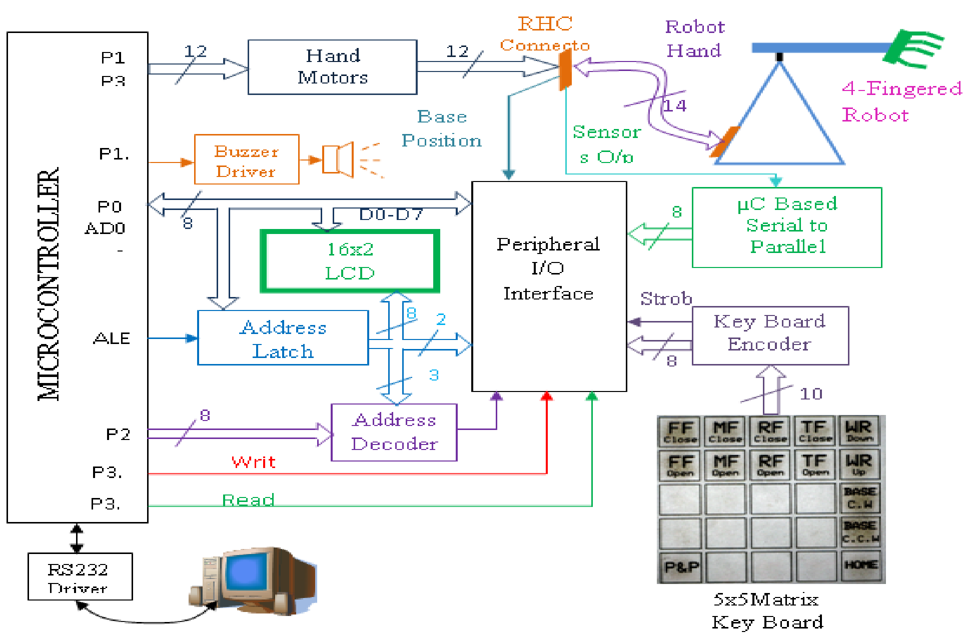


Figure 4: Functional Block Diagram of FFRH System

4. Embedded Software Design

Embedded systems are electro-mechanical products which relate mechanics, hardware and software. Examples of embedded systems are mobile phones, medical instruments and petrol dispensers etc. An embedded system contains a computer which is a part of a larger system that provides non-computing features to the user. The size of an embedded system might vary from a small thermometer to a chemical plant’s process controller.

then the LCD displays a message “Please Press Any Key”. RH controller system waits for an external event to occur. If any key is pressed, the data(code) is read from one of the ports of 8255 IC, depending on the address, the respective finger or wrist or base is identified. The addresses vary from digit to digit, for base and wrist and they differ even to open or close. For example, the key data is 1E, the operation is Fore Finger close where as the data is 1F the operation is FF open. An infinite loop executes until any key is pressed.

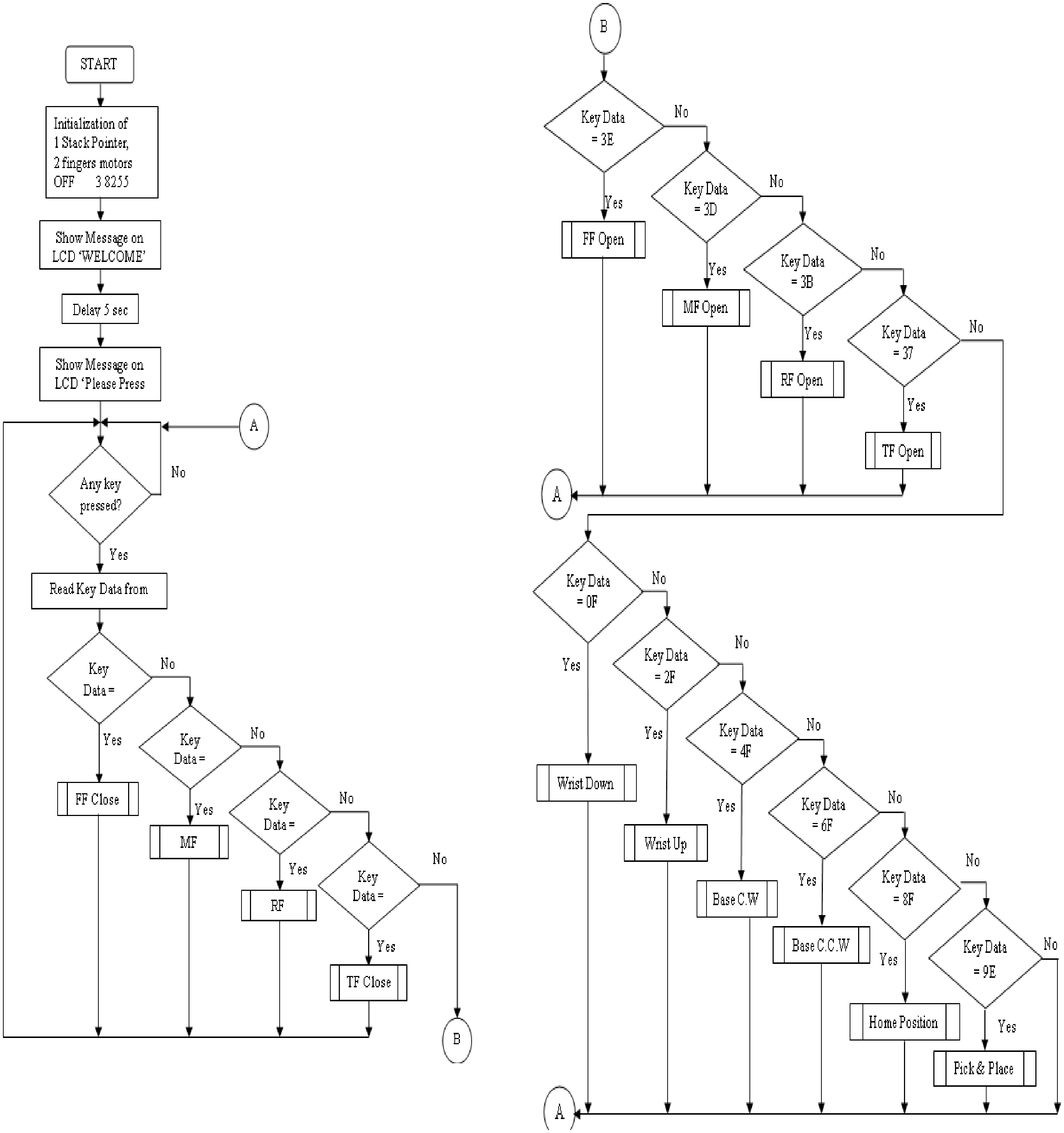


Figure 5: Complete Control Software

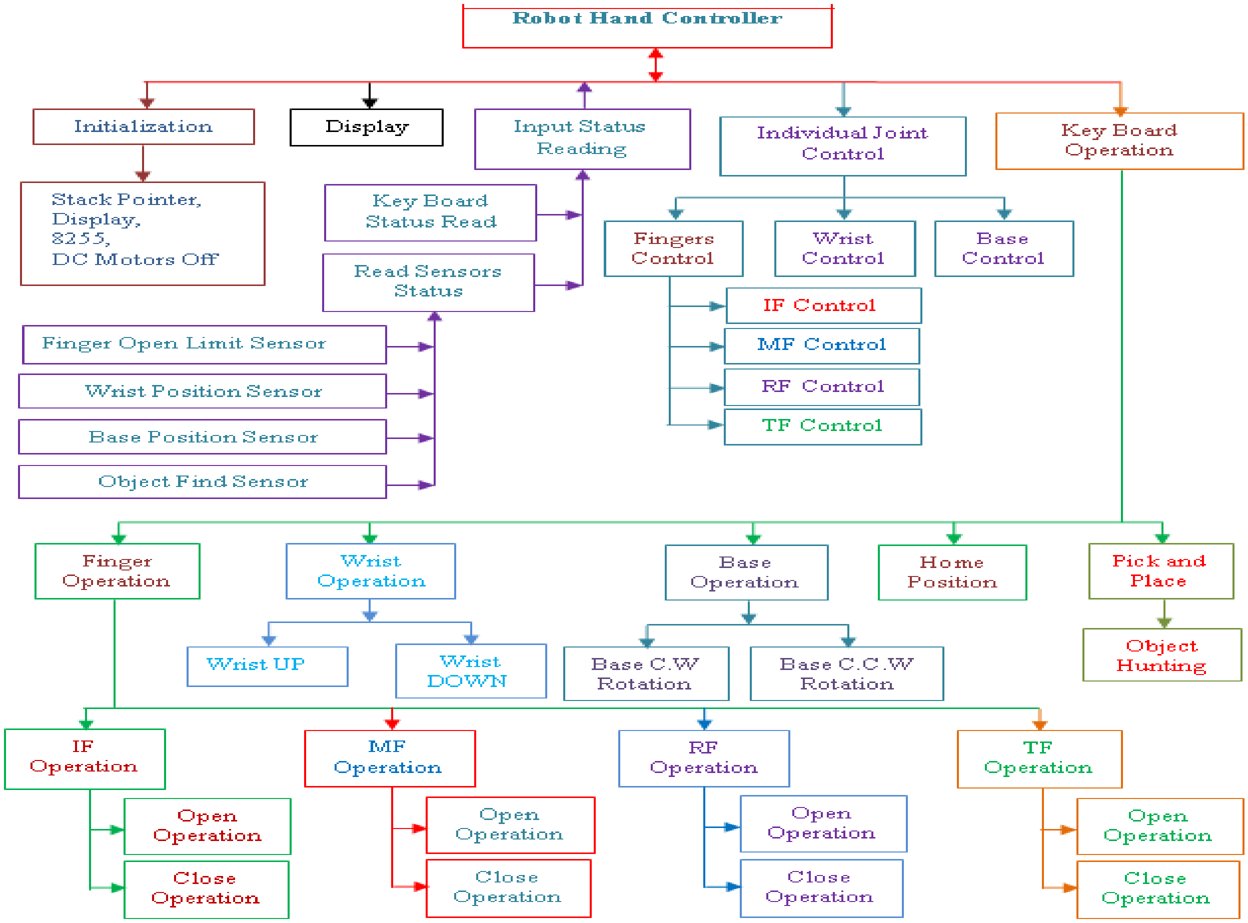
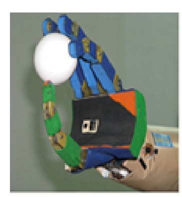
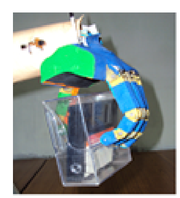
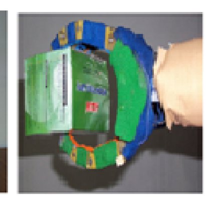


Figure 6: The structured chart of control program of the FFRH

Figure 6 shows the structured chart of control program of the Four Fingered Robot Hand (FFRH). The control software for FFRH is developed in 89V51RD2 ASM language. Software tool used to debug the program is Keil-IDE. Hex Code is generated by the Keil-IDE and it is burned into flash memory of 89V51RD2 using the Flash Magic Software. RH controller contains five major software modules such as Initialization, Display, Input status reading, and Individual joint control using Key Pad. The key board module is subdivided into small tasks like finger module, wrist module and base module.

5. Experimental Results

To test the grasping ability of the Robot 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 hand, the hand was issued a pick and place command from the key board of the FFRHC system. Different objects such as a) Egg b) Floppy box c) Mouse d) Wipro Pen Stand e) Power Supply Box f) Spray Can g) Tool Box and h) Electric Bulb are selected for object hunting and pick/place tasks. Figure 7 shows grasping of these objects. The test results are photographed and they are indicating that the FFRHC system grasping the objects irrespective of shapes, surfaces and hardness.

a) Egg b) Floppy box c) Power supply Box



d) Mouse e) Pen Stand f) Spray Can

Figure 7: FFRHS grasping a variety of objects.(Egg, Floppy Box, Mouse, Pen Stand, Power supply Box, Spray Can).

6. Discussions

It is important to quantitatively compare the design and similarities of the DART hand to the human and other robotic hands. Factors included in the comparison are weight (with actuators), number of fingers (including thumb), DOF per finger and wrist, number of sensor types and fingertip force. DOF per finger means adding every DOF, including the thumb, and dividing by the number of fingers. The wrist is included in this calculation because it considerably amplifies the manipulation capabilities of the hand and is essential to many of the hand's useful actions. The equation Functional Potential Index (FPI) used in comparison with the other hands is given below:

$$\left(\frac{\text{No. of fingers}}{5}\right)\left(\frac{(\text{DOF/finger})+(\text{DOF/wrist})}{7}\right) \times \left(\frac{\text{No. of sensor types}}{6}\right)\left(\frac{\text{fingertip force}}{50.9\text{ N}}\right)\left(\frac{15\text{ N}}{\text{weight}}\right) =$$

4/5 x (1+1)/7 x 3/6 x 5/50.9 x 15/2.5 = 0.067

Table 1: Comparison of AU Hand with others

Hand parameters	AU HAND (4-Fingered)	DART HAND (4-Fingered)	HUMAN(Male)
Hand size (mm)	140x140x100	180 × 90 × 50	189 × 84 × 48
Forearm size (mm)	420x100x80	315 × 100 × 85	275 × 88 × 75
Hand weight (kg) Including Actuators	2.5	0.09	0.40
Forearm weight (kg)	0.5	0.96	1.13
Degrees of freedom	6	19	23
Joint ranges of motion DIP, PIP, MP) (deg)	60,70,90	70,90,90	70,110,90
Grasp speed (s)	15	0.35	0.15
Fingertip force (N)	5	15	50.9

Table 1 shows the comparison of hand parameters of AU Hand with DART Hand and Human Hand. The parameters like Forearm size, Hand weight, Degrees of freedom, joint ranges of motion, Grasp speed and Fingertip force are tabulated. A graph is drawn for Functional Potential Index comparison of the AU hand with other hands reported in the literature on the human hand and shown in Figure 8.

Table 2 shows design specifications of the Four Fingered Robot Hand system. Basic specifications targeted here include shapes and motor functions nearly identical with those of human fingers. It has been designed to provide comparable force output and movement sensitivity to the human hand. All design measurements were taken directly from the corresponding body parts of the human hand. The Robot Hand contains three fingers and one opposing thumb and mechanical specifications of each digit are mentioned in the table. The Robot Hand system incorporates all necessary control systems including hardware and software. The sensors, workspace, speed of the each digit, and wrist, motor capacity and motor speed are listed in Figure 8.

Table 2. Specifications of FFRH System

Item	Specification	Remarks
Controller	Embedded Computer	Stand Alone System With key Commands for operation
Mechanical structure	Cylindrical articulated Four Fingered Robot hand	Two axes plus four axes for four fingers
Operating range: Axis 1: Axis 2: Axis 3: Axis 4: Axis 5: Axis 6:	360^0 $\pm 180^0$ $\pm 90^0$ $\pm 90^0$ $\pm 90^0$ $\pm 90^0$	Base/Arm/Hand Wrist UP/Down Index finger Open/Close Middle finger Open/Close Ring finger Open/Close Thumb Finger Open/Close
Radius of operation	350 mm	Circular Rotation
Work Space for Fingers:	12cm Maximum 3cm Minimum	Volume for Object
Sensors	Position sensors Reed switches IR Sensor	Fingers Wrist Wrist & object Dete
Vision Sensor	IR LED Tx/Rx in	By means of software
Hand home	Fixed reference po on all axes	By means of software
Feedback	Sensors Serial Dat	Parallel Sensors Data data Converter
Actuators	Electrical Geared I	
Motor capacity	1Kg cm Torque M	12V, 0.2A Power Supply
Motor Speed	100rpm 30rpm 10rpm	Base Wrist Finger
Transmission	Idlers / Pullies	Gut Wires
Maximum workload	0.75 Kg	Any Shaped Object
Repeatability	±8 mm	Object Detection
Maximum path velocity	170 mm/sec	Grasping/Releasing
Weight	7 Kg	FFRH Arm/Base

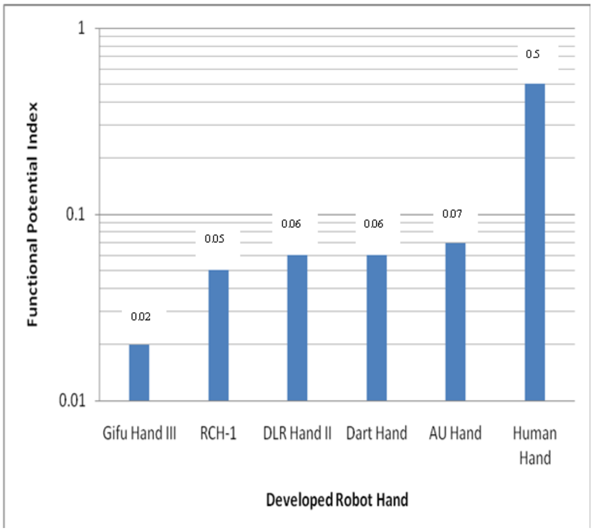


Figure 8. Functional Potential Comparison of the AU hand and other hands reported in the literature to the human hand

7. Conclusion

FFRH has been designed, built, and tested completely. The operation of Robot Hand movement in respects of all joints and object detection, grasping and releasing various types of objects are tested. A good repeatability for every task performed is observed. A Pay load of maximum 0.75kg is tested and succeeded in lifting the object of same pay load. Object topology is arbitrary and tested the same and the results are photographed and are presented. To test size restrictions on objects, experiments are performed at grasping spherical objects. Maximum diameter of sphere is 120 mm, and minimum diameter of sphere is 30 mm, is observed for any object. 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. It has been 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.

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