MULTI FINGERED ROBOTIC HAND IN INDUSTRIAL ROBOTIC APPLICATIONS USING TELE-OPERATION

TN HJ AMRAN MOHD ZAID
DR. DIRMAN HANAFI
IGNATIUS AGUNG WIBOWO
MOHAMAD FAUZI BIN ZAKARIA
MOHAMED NAJIB BIN RIBUAN
SUMAIYA BINTI MASHORI
MUHAMMAD ATIF YAQUB

FRGS GRANT
VOT. NO. 0715

UNIVERSITY TUN HUSSEIN ONN MALAYSIA

ABSTRACT

This research focuses on the working and development of wireless robotic hand system. In this research previously developed models have been studied. After analysis of those models, a better approach has been presented in this research. The objective of this research is to design and develop a tele-operated robotic hand system. The robotic hand is intended for providing solutions to industrial problems like robot reprogramming, industrial automation and replacement for the workers working in hostile environments. The robotic hand system works in the master slave configuration where Bluetooth is being used as the communication channel for the tele-operation. The master is a glove, embedded with sensors to detect the movement of every joint present in the hand, which a human operator can wear. This joint movement is transferred to the slave robotic hand which will mimic the movement of human operator. The robotic hand is a multi fingered dexterous and anthropomorphic hand. The hand is designed by using commercially available version of SolidWorks2010. The robotic hand comprises of five fingers (four fingers and one thumb), each having four degrees of freedom (DOF). All the fingers are capable of performing flexion, extension, abduction, adduction and hence circumduction. A new combination of pneumatic muscles and springs has been used for the actuation purpose. This combination reduces the size of the robotic hand by decreasing the number of pneumatic muscles used. The pneumatic muscles are controlled by the opening and closing of solenoid valves. A novel technique has been used in the robotic hand for tendon routing, which gives the ability of independence to all finger joints. Each of the finger joints can bend independently. The heart of all the control mechanism is mbed microcontroller. The sensors used in the glove for sensing the joint angles are BendSensors. The controller processes the angles provided by these sensors and then transmit to the robotic hand. The robotic hand also has mbed microcontroller to acquire the angles from master and control the opening and closing of solenoid valves according to the required angle.

CONTENTS

CHAPTER 1

INTRODUCTION

Robots have become an integral part of modern human life. With every passing year the population of robots is being increased. The industry has replaced a large number of human workers with lesser number of robots on the grounds of economy and efficiency. A robot is a modern version of slave, which perform any task in its capacity satisfying the old human instinct to rule. A robot follows the command as ordered by the human master. Therefore the humans can still enjoy mastering a thoughtless, speechless but efficient slave under their authority.

Hands have been thought of being the key to the intelligence of humans. Aristotle and Anaxagoras had been discussing this matter hundreds of years ago [1]. Among all the creatures inhabiting this earth, humans are the only living being that have been gifted with this kind of hands. These hands are capable of doing many tasks in our daily routine like dexterously handling different things and even sensing. Human hand has been an area of interest and research since the advent of intellect and has been considered to be one of the reasons that human intelligence is superior to all living creature on Earth. It has been confirmed by the several findings of paleoanthropologists, showing that the mechanical dexterity of the human hand has been a major factor in allowing Homo sapiens to develop a superior brain.

Our hands are the most complicated and delicate part of our bodies, which consist of fifty four bones in a variety of size and hold the capacity to perform a great range of tasks. The research on humanoid robotic hand has been developed for the past few decades which range from the simplest design of parallel jaw grippers to complex configurations of dexterous multi-fingered hands.

While the dexterity of the human hand has been admired since the oldest times, it is still an unmatched standard for artificialists. There have been many artificial hands made till date that have been showed to be stronger and faster than the human hand but still in the broader spectrum of dexterous manipulations it cannot match the human hand. It is therefore natural for an engineer to take inspiration from such a design success, and set forth for himself the goal of building hands that achieve, though partially, such capabilities. The toolbox of Mother Nature containing actuators, sensors, and control elements is unmatchable and superior to the resources of latest technology. Hence, the question whether artificial hands should look like those of humans is not quite settled. The answer is application specific and depends on what is expected from the hand. Because functions of human hands are multi faceted and variable, therefore there is no robotic hand that can compete with it. Only for specific application the robotic hands are more robust, strong and efficient.

In tele-operation normally the master-slave configuration is used. Master is a human operator that commands the slave robotic hand to do useful work. In this project the human operator will wear a master glove that will be embedded with sensors to detect the motion of the human operator. The data from the motion of the fingers of human operator will then be sent to robotic hand that will follow the motion.

1.1 Problem statement

Nowadays robots are present in automobiles industries, electronic equipment assembly line and other state of the art industries. They are faster and accurate than humans. But the robots have to be reprogrammed every time when their task has to be changed. For example, a robotic hand was programmed to pick a steel rod from one table and put it on another table. Now to perform the same task for a plastic pipe, the robotic hand has to be reprogrammed, because if it applies the same amount of force to grasp the plastic rod that it applied on steel rod, it will damage the plastic rod. Therefore it can be seen that even for a little change, the robot has to go through lengthy reprogramming process. Solution for this problem is tele-operation in which the robot can be controlled by a human from a certain distance.

We have to design and develop an anthropomorphic dexterous multi-fingered hand, for the industrial purpose, in order to get the precise and accurate grasp. It should mimic flexibility and sensitivity of the actual human hand. Also as mentioned before, the reprogramming problem of robots must be overcome. There is lot of losses that the industry faces due to human errors so they have to discard a certain number of damaged products. The robotic hand will also overcome this problem as it will be precise in handling objects. Also there are certain places that are harmful for humans like very high temperature or any hostile environment where there is a risk of injury to the worker, so in these places our robotic hand will replace the human operator. As it will be controlled using tele-operation by a human therefore it will act like the worker is handling the objects in that hostile environment.

1.2 Robot Reprogramming

This robotic hand system also provides the solution for the robot reprogramming system. The robotic systems are programmed for their specific use. Therefore when there is a change in the task, the robotic system must be reprogrammed or replaced by new robot. To fix this problem, this project has used tele-operation.

Consider an assembly line where a robot hand is being used for pick and place operation. The robotic hand picks steel pipes and places them to another place. After some time plastic pipes are also added to the assembly line with same size and shape as steel pipes. But the robotic hand system is programmed to pick a steel pipe. When this robotic hand grips the plastic pipes with the same amount of force as it did for the steel pipes, the plastic pipes will be damaged as they cannot stand the force applied by the robotic hand to grip it as shown in Figure 1.1.

- Atomic reactors where high radiation levels are observed
- Space Exploration
- Mining

The metal melting industry puts workers in very high temperature environments. They deal with metals with very high temperature that can easily subject them to burning. In the chemical industry the workers are dealing with highly acidic chemicals and other highly reactive materials. The processes inside the chemical industry can produce harmful gases that the workers are subjected to inhale. In cutting industry the workers are using big and high speed blades and even lasers. They are subjected to the cutting injuries from the blades. In the atomic reactors the workers are subjected to high radioactive environments. The radioactivity can cause many health problems even cancer. In the space exploration the astronauts that are sent to the space require a lot of things to survive whereas a robot is independent. When the astronauts are working outside their shuttles in open space they are attached by a rope like link. If this link is broken they will be out of the reach of the world forever. In the mining industry the workers are subject to breathing problems because of the environment inside the mines. The workers are often subjected to the fatal accidents that are caused by the mine collapse. The list for this kind of industries and their hostile environments is too big to be covered here. This is just a brief summary of actual facts to prove the severity of problem.

With this tele-operated robotic system the worker can sit inside a safe room whereas the robotic hand can perform the workers tasks. The robotic hand is anthropomorphic as well as dexterous; therefore it is capable of doing the industrial tasks just like the worker. The worker will be wearing the master glove and dynamically control the robotic hand. Therefore the tele-operated robotic hand is also providing safety of the workers in hostile environments.

1.4 Objectives of the Project

The main objectives of this project are defined as follows:

1. Develop a dexterous robotic hand that can replace actual human hand in industrial applications.
2. Designing and fabricating the mechanical hardware for the robotic hand.
3. Design and implementation of electrical hardware schematics for the control of robotic hand.
4. Design of firmware that commands the control circuitry.
5. Design of the master glove that human operator will wear to guide the robotic hand movement.
6. Establishment of communication channel, between the master glove and the slave humanoid robotic hand, for the transfer of information about motion of master hand.
7. Integration of complete system and achievement of required results.

1.5 Scope of the research

The research work will focus on development of robot hand that works with master slave configuration. In this configuration master controls the slave movement. Master will be a glove that a human can wear and move the hand in the way he wants the slave robotic hand to be moved. The glove containing sensors will detect the movement and transfer that motion in the form of digital data to the robotic hand which will mimic that movement. The master slave communication will be through Bluetooth channel. The [illegible] of the robotic hand will be approximately similar to actual human hand. The anthropomorphic robotic hand will be used for gripping applications. SolidWorks 2010 is used to design and simulate the mechanical design of robotic hand. Mbed LPC 1768 rapid prototyping board is used to control robotic hand as well as the communication flow *between the master and slave devices.*

1.6 Thesis Structure

Chapter 1 provides brief description to the robotic systems. It describes the link between the hand and human brain. The chapter briefly compares the work of artificialists and Mother Nature. It introduces to the problem faced in this field and the objectives of this project. It describes about the system configuration and its scope.

Chapter 2 describes the literature review in the field of robotic hand and grippers. The analysis and discussions about the robotic hands made till date from the very beginning has been provided in this chapter.

Chapter 3 provides the information of the process of research and development used in this project. It builds the theoretical foundation of the project. It completely describes the flow of progress of this project.

Chapter 4 provides the information about the detailed mechanical design of the project. It depicts all the fingers and their joints with their motions. It describes the complete structure of the robotic hand and its motion mechanism. It also gives the detailed description of the pneumatic muscles used and their assembly. Finally it provides the mathematical modelling of the fingers according to their movements.

Chapter 5 provides the full information of all the electronics involved in the system. It describes the working of all the components used in the system. It establishes clear views of the working and flow of the firmware of both the master and slave. Finally it provides the mathematical modelling of the torque produced at the robotic hand.

Chapter 6 discusses the integration of complete system. It provides the information of the testing methods and the debugging tool. It also mentions the problem solved by the system in detail.

Chapter 7 provides the results and analytical discussion on the achieved results from the robotic hand system. It provides the modelling of the fingers and their motion. It also *builds the model of finger positions according to the theoretical foundation* established in chapter 3. It provides the torque analysis and forces applied by the fingers segments.

Chapter 8 presents the conclusions and recommendation after analysing the complete project.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a detailed overview of different techniques used in developing the robotic hand. It will also help in understanding the different types of hand that were in use throughout the history of robotics and the problems that arise.

2.1. Types of Robotic Hands

There are different types of robotic hands, such as for industrial purpose, for rehabilitation and for the purpose of research to understand the human structure and functioning of hand. The focus in this project study will be on the anthropomorphic hands and grippers. If the system is to use the same interface with the environment that was designed for the human hand (such as handles, consoles, tools etc.), then an anthropomorphic hand can best fit the task. Anthropomorphic hand is one that mimics an actual human hand. So anthropomorphic hands are dexterous in nature as they have the tendency to dexterously manipulate the objects they come in contact with.

Anthropomorphic design makes it easier for the human operator to map his natural manipulation behaviours and skills into commands for the device [2]. Planning and programming actions of kinematically complex robotic hands has always been a difficult task, which contributed to the scarce penetration of robot hands in practical applications. On the contrary, an anthropomorphic machine hand can be taught directly by "*demonstrating*" *the desired human behaviours in manipulation and grasping*. In such systems, easily available sensorized gloves, or in some cases mechanical masters, are used to provide measurements of the master's hand movements.

2.2. Techniques for Dexterity in Robotic Hands

For the object manipulation different techniques had been practised by researchers. One of the techniques is regrasping [3] and finger gaiting [4]. It comprises of a sequence of grasps until the object is held firmly in hand. But regrasping can be time consuming as there can be a need for grasping and releasing until the final firm grip. Also there can be problem when manipulating irregular shaped 3D objects which have quite little number of stables grasp position as the hand can leave the object during the process of regrasping.

Both the finger gaiting and regrasping involves kinematics and dynamics of manipulation, effect of gravity, slipping and the contact or detachment of one finer from the object. So this comprise of a hybrid system with some part event-driven and some part time driven. Thus the stability analysis and verification of these techniques are tricky.

The degree of flexibility of manipulation can be certainly increased if the hand is allowed to slide some contacts with the object. Humans also can be observed to do this kind of manipulation. People have been actively researching in this technique as this can very much enhance the manipulation capability of the robotic hand [5]. The prediction of occurrence of slippage is instrumental in order to use and control it. This implies the need for an accurate analysis of friction and slippage phenomena. In particular, in the case of combined torsion and shear loading, evaluating from sensor readings a "margin of stability" for the contact before slipping is a very important but rather difficult task, for which only partially satisfying solutions are known so far [6].

Another problem in this area is the synthesis of sets of contact locations for selectively preventing and allowing slippage motions of grasped objects. The modelling for this technique *is also difficult as modelling the friction at different surfaces has always been* a big challenge for researchers.

In tele-manipulation/tele-operation [7], [8], [9], [10] and [11] movements of the master hand are replicated by the anthropomorphic slave device. A feeling of "immersion" of the operator in the remote (possibly virtual) environment may be enhanced by the good match of the machine hand functions with the natural ones, although there exist examples of non strictly anthropomorphic hands intended also for remote operation.

In between the completely unstructured world and the perfectly defined environments, there is a whole gray scale of applications where the familiar flexibility/efficiency tradeoffs have to be sought for actively. This concept is well rooted in the robotics community. Design of devices for this class of problems usually obeys the good old engineering principle of minimalism: choose the simplest mechanical structure, the minimum number of actuators, the simplest set of sensors, etc., that will do the job, or class of jobs. For the complexity measure the number of actuators for manipulation in one robotic hand can be seen. The minimum number of actuators in the hand for dexterous manipulation is nine, but for a complex hand structure the number of actuators can go up to 32 [2].

2.3. History of Robotic Hands

The field of robotics is evolving day by day as new problems arise for automation. 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 [12]. From this date we can imagine how much grown up and mature is the field of robotic hands. People from a long time have been fascinated by the human hand and its ability of dexterous manipulation of objects.

2.3.1. *MIT MH-1*

In Heinrich's MH-1 a mechanical servo manipulator has been adapted for operation by the TX-0 computer [12]. The sensors on the mechanical hand gave information to the computer; the program processes this information, and the computer controls the motors that move the hand. The MH-1 system performs more than just the speed control and position control; it performs in accordance with a pre-recorded program that has been written by a programmer after a careful analysis of the real world with respect to the broad description of the tasks to be performed. Thus it could select appropriate routines by itself and find out what to do in unexpected situations for which the programmer has not provided an explicit instruction.

For example one program consisting of nine statements will make the hand do the following: Search the table for a box, remember its position, search the table for blocks, collect them and put them in a box. As a test of built-in mechanical intelligence if the box was taken away from the original position while the hand is searching for blocks, MH-1 will remember the new position of the box and continue to work with it as soon as it realized the change in the position by bumping into the box while searching for blocks.

2. Soft Gripper

After Heinrich's MH-1, Soft Gripper was reported to be developed by Hirose-hima Lab at Tokyo Institute of Technology in 1976 [13]. The soft gripper was a like mechanism that could flexibly grab an arbitrary shaped object. To flexibly n object, it must be possible to create a uniform grasping force on all the gripper s while wrapping around the object.

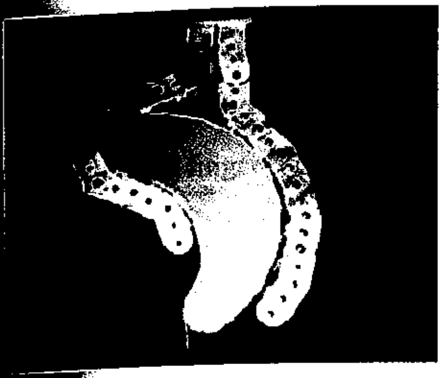

Figure 2.1 Soft Gripper 1

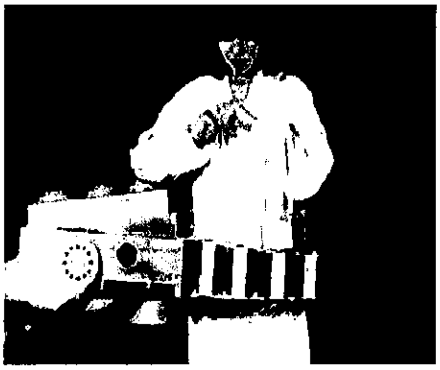

Figure 2.2 Soft Gripper 2

Figure 2.3 Soft Gripper 3

gripping function is realized by means of a mechanism consisting of multi-links series of pulleys. It was a mechanism in which the joints and pulleys were all ected to rotate independently, and the wire fixed to the head joint was pulled by ing around all the pulleys. In that mechanism, when the wire was pulled, a bending ment proportional to the radius of the pulley was generated on each joint. For that on, when the pulley radius is designed to change in terms of secondary functions the wire coiling around the pulleys is pulled, then the uniform grasping is possible. grip release motion was conducted by pulling the series of pulleys of the same us in the opposite direction. When this was done, the device was housed by winding p in a coil shape from the tip. Soft gripper 1 was the primary model developed which grasp small objects like snake. Soft gripper 2 was a large scale model developed to d up a human body from the assistance of human commands. The drive system for *vertical and horizontal grasps was also developed. Soft gripper 3 was a belt driven* model with three fingers.

2.3.3. Stanford/JPL Hand

Salisbury and Mason 1985 showed first that 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 [14]. From this statement we can extract that there should be three fingers with each finger exhibiting three degrees of freedom for complete manipulation or gripping of an object. The practical demonstration of this work is the development of Stanford/JPL hand. The Salisbury or Stanford/JPL Hand was consequently designed to have nine joints, evenly distributed in each finger so as to optimize a measure of individual "manipulability" of the finger. Each finger had three DOF and is driven by four motors through tendon cables, two parallel axis joints provide rotation and the third proximal joint, perpendicular to the other joints, provides sideward motion.

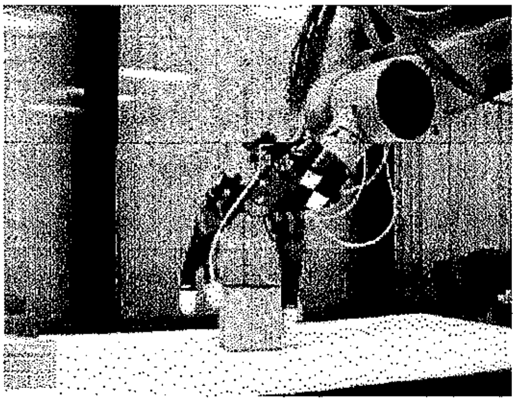

Figure 2.4 Stanford/JPL Hand

rge number of motors and strong coupling in the tendon configuration, the tem of JPL/Stanford hand was very complicated. In addition, it was also maintain calibration using the tension of four cables in a finger.

2.3.4. *Okada Hand*

Some researchers developed their version of hands by adding more degrees of freedom instead of just 3. By adding more degrees of freedom they can have more flexibility of use. Example of one successful design is from Tokyo, Japan in 1979 by Tokuji Okada [15]. He developed a three finger design but with different number of joints and hence different degrees of freedom in each finger. He added four joints in two fingers and one thumb with three joints. This hand also uses finger gaiting in the process of manipulating the held object. Finger gaiting is the technique in which one finger is repositioned on the surface of the object. By using this technique Okada hand can grip the objects more firmly.

To make the fingers flexible and to make the finger subsystem more compact, the cables, hoses, and signal lines of sensors were passed through the finger tubes. Each joint of the mechanical hand is driven by a dc motor. Motors for driving the finger joints are located within a trunk separated from the fingers. The bending angle of each joint and the corresponding torque were indirectly detected from a potentiometer and a value of the motor current in the trunk, respectively. The torque of the finger joint was controlled by changing the magnitude of a motor armature current, and the fingers were controlled flexibly by suitably changing the mode between position and torque control. This robotic hand was able to perform not only simple motions as bending and extending but also flexing motions as adduction and abduction. Cooperative motions among the fingers were easily realized by means of the hardware servo system. In an experiment of swing motion, cooperative motion based on a force control was accomplished between the right and left fingers without dropping the object. Bar turning and sphere turning were accomplished smoothly by a computer control in which control signals for finger joints are generated by interpolating a sequence of set points that has been stored in the computer in the teaching process.

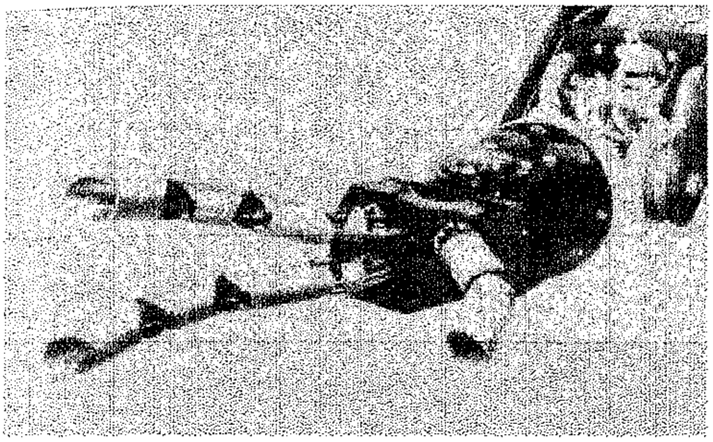

Figure 2.5 Okada Hand

2.3.5. Utah/MIT Hand

After the seminal work done with the Utah/MIT Hand [16], hands of this type have been built in several labs. The objectives of this hand were; firstly, it will permit the experimental investigation of basic concepts in manipulation theory, control system design and tactile sensing and secondly, it will expand understanding required for the future design of physical machinery and will serve as a "test bed" for the development of tactile sensing systems. The Utah/MIT had three fingers and one thumb each having four joints and in total having 16 degrees of freedom with 32 tendons. Two tendon cables for each joint were used and each tendon cable was attached to the tendon tension sensor to track the torque imposed on individual joints. The positioning and tension sensing of this anthropomorphic robotic hand was done by using magnetically sensitive Hall Effect sensors. The actuators for the robotic hand were placed outside of the hand due to space requirements. Complex actuation pneumatic system is used for the actuation consisting of actuating cylinder, adjustable pneumatic dampers and spring tensioning systems within cylinders. The Tendons are routed throughout the hand via sequences of pulley induced bends and axial twists.

The Low Level Control System included 16 variable-loop-gain position servos to operate finger joints and 32 variable-loop-gain tension servos to modulate actuator viour *such that tendon tensions were closely controlled. The system also provided* the analog outputs of all sensor signals generated within the hand. Many control ts were supplied to the robot hand as 16 inputs for control of angular position, 32 ts for control of desired tendon tension, 16 inputs to vary position servo loop gain 32 *inputs to vary tendon tension servo loop gain. The digital system consisted of* Motorola 68000 microprocessors, a multibus card cage, 40 channels of digital to og conversion and 320 channels of analog to digital conversion.

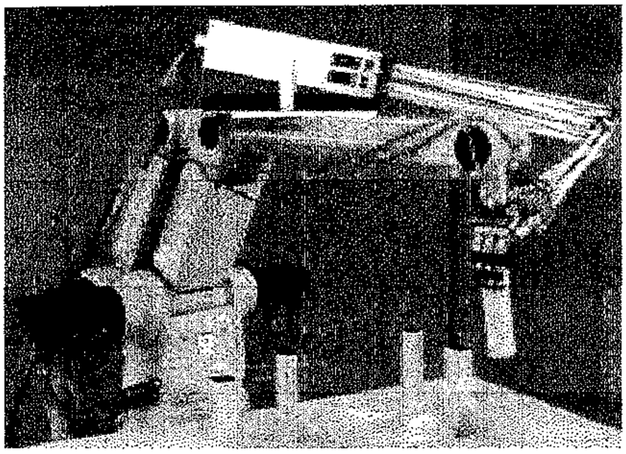

Figure 2.6 Utah/MIT Hand

3.6. Toshiba Hand

1993 Toshiba Corporation in Japan made a robotic hand with finger tactile sensors The hand consisted of four fingers each with four joints, which were actuated by motors, and had the tendency for abduction and adduction just like humans. In the loped hand, each DC motor unit consisted of a DC motor, a reduction gear and a o-generator, which was built in the back of the hand. By putting the actuators at the of the hand the weight of the hand became 1.71 kg. Each finger had tactile sensors their tip which had silicon rubber cap with cavity that was filled by an non-pressible fluid. The fluid transferred a contact force with an object to a conductor pressure gage. Using these sensors and potentiometers mounted at one *of each finger joint, contact forces with an object and angles of the fingers are olled.*

controller for this system was composed of 22 servo amplifiers (16 for fingers and arm) and a multiprocessor system. The multiprocessor system was composed of 6 microprocessor boards (Motorola 68030 with 6SSS2 and 25MHz) and interface ds (three 32-channel A/D boards, two 12-channel D/A boards, two 3-channel DOWN counter boards and two 64-channel DIO boards). Four computer boards e used for single finger control, one for task planning and making references, one arm control, supervision of this computer system and man-machine interface.

this robotic hand showed that it can pick a pen and then manipulate the pen dextrously order to make the pen in vertical position so that it can write some characters. The icking of pen was helped by an image processing system which guided the robotic ystem to the place and orientation of the pen.

Figure 2.7 Toshiba Hand

3.7. *National Taiwan University (NTU) Hand*

five finger anthropomorphic hand was developed by National Taiwan University in 96 with seventeen degrees of freedom [18]. In contrast to previous tendon-driven bots, the NTU hand had an uncoupled configuration that allowed each finger and joint be driven individually. Completely intrinsic design was developed by putting all the uators, mechanical parts and sensors inside the robotic hand. The size of this hand is most the same as human hand. Due to the small size this hand was suited for industrial well as for rehabilitation purposes. The hand was easily mountable to the wrist of dustrial arm or the casualty.

e actuators were micro motors but a lot of gearing were present in each finger. The sign of all the fingers was same therefore all the fingers were independent and changeable making it easier for the maintenance and reducing the hand cost. The intenance was simply replacing the damaged finger assembly without recalibration whole system. The performance of the hand system was enhanced once the material r the hand was improved. The thumb and first finger had four joints while the maining fingers had three. Each finger was equipped with the tactile sensor to detect e grasping force. Each finger segment, except the distal segment, contained one high rformance micro motor that drove a set of specially arranged gear trains to rotate the evious finger segment. The assembling of these fingers was very complex as a lot of aring was involved inside each finger segment. Due to the gear trains the accuracy of e joint position was a problem.

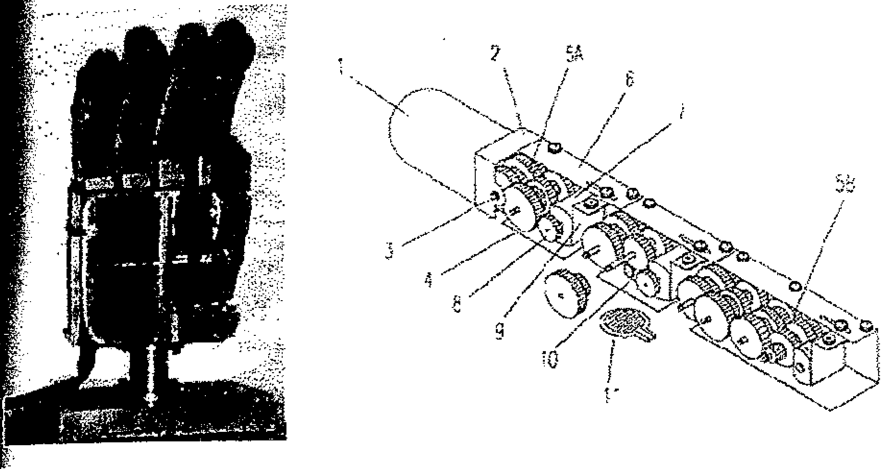

Figure 2.8 NTU Hand

3.8. DIST Hand

1998 University of Genova developed DIST hand [19] and [20]. The DIST-Hand was four fingered mechanism with sixteen degrees of freedom with a high degree of xterity. The main goal pursued during the development of the DIST-Hand was signing a small and lightweight dextrous gripper with anthropomorphic kinematics, hich could be easily ported and installed even on small robot manipulators. The velopers tried to develop with possible cheap off-the shelf components where ailable to reduce the overall cost of robotic hand.

Each finger had four joints each and each joint was able to move more than 90° cording to the human hand. Each finger was actuated through 6 tendons made of lyester, routed through pulleys and driven by 5 DC motors. In particular, tendons 5 d 6 driving the first joint were actuated by a single motor. The routing of the tendons ables the decoupled motion of each finger joint, and the control of the fingertip ffness. All the idle pulleys were mounted on miniature ball bearings as well as the nt supports in order to reduce the friction effects. The problem of tendon coupling s also present in this robotic hand as well. Due to the coupling problem the mapping tendon tension and joint torques was also difficult.

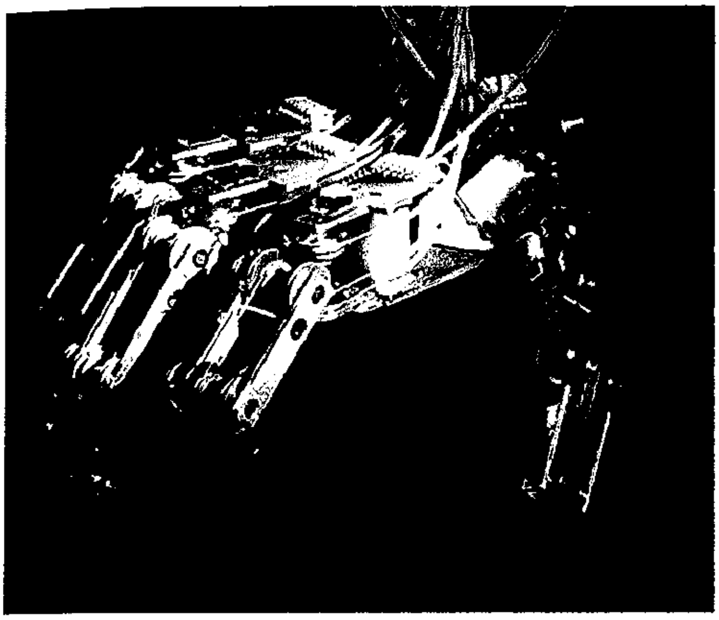

Figure 2.9 DIST Hand

e tendons and relative sheaths produced elastic perturbations in the position of the ger which made the control of the fingers' motions, using position and velocity edback directly from the motor axes, critical. To address this problem, they developed d hoc rotation sensors mounted on each joint. Using these sensors it was possible to mplement servo loops around the perturbations due to the elasticity and in part to iction. The sensor was based on the use of a solid state Hall Effect transducer. The ensor was contactless therefore it does not affect the motion of the joints. Furthermore, it had a significant immunity to noise with respect to other transducers of comparable size (e.g. micro/mini potentiometers, encoders).

The control hardware was VME based and it included two Motorola 68040 based CPU boards and four IP modules for I/O purposes. Two IP Precision ADCs were used for *sampling both hall sensors and potentiometers* and two *DENSE-DACs* were used for sending torque commands to the various motors. The Simulink and Real Time Workshop MATLAB's Toolboxes jointly with the Wind River's TORNADO development environment were used to design and implement the real controllers. Later in 2003 they presented the control based on FPGA of the DIST-Hand (Casalino G. et.al. 2003). The controller adopted for the DIST-Hand presented a multi-layered hierarchical

In that structure they had Medium Level Control (MLC), Low Level Control d Very Low Level Control (VLLC). Each finger had LLC and VLLC. The ectly interacted with the physical systems. Whereas the LLC provided input to the form of joint position reference signal to drive the fingertip. The purpose *LC layer was to make all the fingers accomplish, in a cooperative way, an* common task (i.e. objects grasping or manipulation), without dealing with the and kinematic structure of the underlying robotic system. MLC also provided esian position references to LLC according to the task performed. FPGA was used to perform the hardware *parallel* processing to implement the complex hms requiring a number of matrix multiplications. The design and mentation of the real controller was made possible by the use of the System rator, a tool developed by Xilinx in partnership with The Mathworks that enables ners to develop high-performance systems for *Xilinx FPGAs* using the popular LAB/Simulink environment.

9.Robonaut Hand

meet the requirements for extra-vehicular activity (EVA) onboard the International pace Station (ISS), NASA developed and presented an anthropomorphic robotic hand [21]. Both power and dexterous grasp were the requirement for this space bound robot and. As this hand was supposed to interact with the EVA crew tools, therefore it was required to perform dexterous manipulation by single or multiple fingers while grasping.

The Robonaut hand was closest in size and capabilities like kinematics and strength to a suited astronaut's hand and wrist. The hand along with the wrist had fourteen independent degrees of freedom. The hand alone has five fingers with twelve degrees of freedom. It consisted of a forearm in which the motors and drive electronics were placed, a two degree of freedom wrist, and a five finger, twelve degree of freedom hand. The forearm, which was four inches in diameter at its base and was approximately eight contained all fourteen motors, 12 separate circuit boards, and all of the the hand. The finger drive mechanism consisted of brushless dc motor and r head.

Figure 2.10 Robonaut Hand

itself was broken down into two sections; a dexterous work set which was manipulation, and a grasping set which allowed the hand to maintain a stable while manipulating or actuating a given object. This was an essential feature for se. The motors were mounted outside the hand, and mechanical power was mitted through a flexible drive train. The drive train consisted of flex shafts and crew assemblies. By using this they avoided the use of tendon cables which red a complex system of pulleys.

hand was equipped with forty-three sensors not including tactile sensing. Each joint equipped with embedded absolute position sensors and each motor was equipped h incremental encoders. Each of the leadscrew assemblies as well as the wrist ball nt links were instrumented as load cells to provide force feedback.

2.3.10. Distributed Touch Sensor Hand

A control system for multi-fingered robotic hand with distributed touch sensor has also been proposed [22]. The hand along with the arm had twenty two DOFs while sixteen for the robotic hand alone. The hand was meant as a prototype for the control k *execution system. The hand was anthropomorphic in nature as it had five* but the size was twice the size of normal human hand which made it ersial to be called as anthropomorphic. Each finger had four joints; the thumb ur DOFs while the other fingers had three only. The hand surface was covered oft rubber *sheet. The distributed touch sensor was placed under the soft rubber* This sensor had more than 500 measuring points on overall surface. The actuators finger joints were the servo unit of radio control model and all arm joints were n by AC servo motor. The weight of this robotic hand was about 2.5kg. The servo of each *finger joint was able to exert enough torque to handle the object within* and its movable angle range was around 120 degrees.

Figure 2.11 Hand with distributed touch sensor

The distributed touch sensor used had 64 lines and 16 lines of electrodes, which were placed on the both side of the pressure sensitive conductive rubber sheet. The maximum number of pressure measure points was 1024 (64 times 16). The pressure of each point was acquired in 12 bits resolution through ADC board. The whole surface was scanned within 20ms.

In the hand control system, the position and force references of control points were transformed to the velocity references of corresponding control points. The velocity references of all control points were then transformed to the joint angular velocity reference vector by using the Jacobean matrix. The sampling period of the control system was 5ms but the processing time for calculation limits the number of control

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