

CLOSED LOOP POSITION AND  
FORCE CONTROL OF  
ANTHROBOT III ROBOT HAND

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Abstract

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Anthrobot III is an anatomically correct, dexterous robot hand. In the original version of this robot, only feed-forward position control is possible, which is not enough for effective use of the hand in manipulations. In our work, we aimed to achieve closed loop position and force control of Anthrobot III, which will enable it to operate more effectively. To achieve this goal, we have made some upgrades on the robot-hand itself as well as designing and realizing some additional components.

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## **1. INTRODUCTION**

### **1.1. OBJECTIVE**

As of March 1995, Anthrobot-III had only feed-forward position control, and no control on force or torque. For the robot hand to be efficient such that intelligent grasping and dexterous manipulation can be achieved in a controlled manner, the hand must have been equipped with a closed loop control for force and position. Accuracy and precision in grasping and re-grasping can only be attained by such a closed loop control. The objective of the project is to realize the necessary hardware and software in order to have closed loop control for force and position of the fingertips of the Anthrobot-III robot hand.

### **1.2. PROJECT GOALS**

#### *1.2.1. Position Feedback:*

The position data are acquired from the potentiometers mounted on the DC servo motors of the fingers. The position signals are voltage levels between 0-10V. These signals are passed through antialiasing filters, and then fed to an inputs of an A/D card (PCL 1800), through multiplexing circuits. The motors are driven according to the computer outputs, through the Closed Loop Interface Board (Black Box). The loop is closed over the computer and closed loop position control is achieved with a suitable software.

#### *1.2.2. Force Feedback:*

Within the framework of the project, we aim to mount force sensors on the robot fingertips, such that we do not control the force at joints, but at fingertips. These sensors are composed of whetstone bridges, where one of the resistors is changing with the changing force applied on the sensor. The output signals of sensors are voltage levels between 0-100mV. These signals

are amplified and fed into antialiasing filters. The filtered outputs are then fed to A/D card (PCL 1800), again through multiplexing circuits, and digitized. These digital data are used in the calculation of driving signals. Consequently, the loop is closed and closed loop force control is achieved.

As a result, within the scope of this project aiming at closed loop force and position control of the Anthrobot-III robot hand, an input board consisting of amplifier stages, antialiasing filter stages, and multiplexing circuitry, an output board consisting of D/A converters, and digital output stages, an A/D converter + digital output board (PCL-1800), and a closed loop interface board are added to the existing system. These subsystems are presented in details in the next section.

### **1.3. SOFTWARE**

The control strategy is based on the implementation of a PID controller. PID parameters will be determined through system identification. The driving signals are generated by a program which is written in assembler and works as a background process. There will also exist a high level control which will take the data for a predefined path and force goals, generated by last level control, and produce set points for low level control.

## **2. ANTHROBOT III**

### **2.1. GENERAL DESCRIPTION**

In robotics applications, end effectors are selected based on two separate objectives: the use of special purpose end effectors and general purpose end effectors. Multi-fingered mechanical hands are of the family of general purpose end effectors. A robot using special purpose end effectors requires a different effector for each different task. In contrast a dexterous hand has more flexibility when coping with unforeseen situations and unstructured environments. A robot hand with anatomical consistency with a human hand will also have a special advantages during teleoperation, since it will be easier and will require minimum previous training for a human to control a robot hand that operates like his or her own hand. Also, if a robot has a human-like hand, it could use the human interfaces available (Ali 1993).

Anthrobot-III, currently available at the Robot-Hand Laboratory of the Electrical and Electronics Engineering Department of the Middle East Technical University is a fully functional, anatomically correct, tendon driven, five fingered robot hand. Anthrobot is specifically designed for anatomical consistency with the human hand. This includes the number of the fingers, the placement and the motion of the thumb, the proportions of the link lengths, and the shape of the palm. This structure is capable of supporting a wide variety of dexterous manipulation tasks.

The Anthrobot robot hand has four fingers and a thumb. Each finger has four joints as in the human hand; two at knuckle (lateral and vertical motion), one between proximal and middle finger segments, and one between middle and distal finger segments. The thumb has four degrees of freedom (DOF), allowing it to approximate human thumb motion (the human thumb has five degrees of freedom). Although there are twenty joints in the Anthrobot robot

hand (four for each finger and for the thumb), there are only sixteen servo motors. Like the human hand, the last two joints (distal and middle joints) of each finger are mechanically coupled. This reduces the total controllable degrees of freedom from twenty to sixteen. The servo motors move the joints via a system of steel tendons. The Anthrobot also has a two DOF wrist driven by two brushless DC motors.

## 2.2. SPECIFICATIONS

### 2.2.1. *Hand Specifications:*

Degrees of freedom: 20 (16 controllable)

Finger and thumb joint specs:

range of motion: same as human hand

finger tip force: 2.2 lb./finger

thumb tip force: 6.3 lb.

hook grip force: 4.5 lb./finger (ex: holding a briefcase)

Joint bandwidth: 2 Hz

Motor power consumption:

all fingers loaded: 40W (5V@8A)

no load: < 5W (5V@1A)

Feedback: position servo in each package (provided by Futuba)

### 2.2.2. *Wrist Specifications:*

Degrees of freedom: 2 (yaw and pitch)

Yaw joint specs:

range of motion: +/- 20 deg.

torque: 50 lb.-in.

speed: 170 deg./sec. (no load)

Pitch joint specs:

range of motion: +/- 60 deg.

torque:50 lb.-in.

speed:170 deg./sec. (no load)

Joint bandwidth: 10 Hz

Motor power consumption: 24W/motor

Encoder: 1250 lines and zero reference

### **2.3. MECHANICAL DESCRIPTION**

The Anthrobot robot hand is designed to have the same size and shape as the human hand. The linkage portions are based on data from the U.S. Air Force, the U.S. Army, and some in-house measurements. The proportions reflect those given for the 50th percentile male armed forces recruit. The following are the dimensions for the hand (not including the actuator housing and wrist):

Length: 7.5 in.

Width: 3.5 in.

Thickness: 1.1 in. (max.)

Overall length from the tip of the middle finger to the rear of the actuator housing is 18 inches. The entire package-meaning the hand structure, wrist, and actuator-will fit on the need of the variety of industrial manipulators. The total package weight is just under 10 pounds. The mechanical structure currently is 6061-T6 aluminum. The use of the other materials (plastics, rad-hard steel, space alloys, etc.) is possible. Fingertips are made of a silicone gel. The tendons consist of aircraft-quality steel cable. The cables have an ultimate tensile strength of 150 pounds. The tendons are housed in coiled steel springs.

## 2.4. PARTS

### 2.4.1. *Servo-motor Packages*

#### 2.4.1.1. *Finger and Thumb Servos*

The hand uses 14 Futuba FP-S125 servo motors for the fingers and two of the thumb joints. Two of the more powerful Futuba FP-S134G motors control the other two axes of the thumb. The servos has the following features (Futuba [1989]):

FP-125: Arm-type sail control servo rotation: 140 degrees (max.)

size:0.88" X 1.75" X 1.69"

weight: 2.3 oz.

output torque: 129.3 oz./in.

speed:0.62 sec./60 degrees

FP-S134G: Quarter scale retract rotation: 140 degrees (typ.)

size:1. 14" X 2.3 2" X 1. 97"

weight: 2.8 oz.

output torque: 173.8 oz./in.

speed:.33 sec./60 degrees

The servo package includes a motor, gear train, a potentiometer, and servo electronics (where servo electronics is removed after the installation of upgrade hardware - black box).

#### 2.4.1.2. *Wrist Servos*

The wrist servo-motors are Pittman brushless DC motors with 325:1 planetary gear reduction. These motors are controlled via a brushless amplifier which controls speed and commutation based on a command voltage from the computer. An encoder is mounted on the motor shaft for closed loop control.

#### *2.4.2. Closed Loop Interface Board (Black Box)*

Closed Loop Interface Board is intended to allow computer to drive the servo motors through a set of analog and digital signals, when the servo electronics of Futaba packages are removed for closed loop position control. The board accepts 16 analog voltage inputs that command motor currents and output the 16 signals from the potentiometers. The board contains PWM motor drivers and signal conditioning circuitry for the potentiometer signals.

#### *2.4.3. PCL 1800*

PCL 1800 is a 16 channel A/D converter. It has also 2 channels for digital data. For more information please refer to Manual for PCL 1800.

### **3. “WORK DONE”**

#### **3.1. Upgrade of ANTHROBOT**

Essentially, what is done during this phase of the project is to make the necessary changes on the Anthrobot to allow closed loop position control, as directed by Anthrobot Closed Loop Interface Board Upgrade Manual (Ali [1995]). First the Futaba motors mounted on the Anthrobot are opened and the servo electronics are removed. Then the necessary wiring is soldered to the motors, and the motor boxes are closed after completing connector soldering. (For further details, refer to the Anthrobot Closed Loop Interface Board Upgrade Manual. See tables 1 through 4 for the connections of the cables from motors to the Black Box, and from pots to the Input Board.)

#### **3.2. Output Boards**

Output boards are designed to perform two functions. The first one is to produce analog voltages in the range 0-10V (magnitudes of rotation of motors) to send to the inputs of the Closed Loop Interface Board (CLIB), by converting the digital signals supplied by the computer. The second function the output boards the production of digital signals (the direction of rotation signals) which are also inputs of CLIB. Those signals are created by processing the digital signals produced by the backplane (the computer). These operations are performed by two output boards those of exactly the same. Two boards are distinguished by a jumper on them. Each board have eight 8 bit D/A converter connected to a 8 bit register (at the input side) and an op-amp buffer (on the output side). The schematic of one channel of D/A conversion circuitry can be found in figure 1. Each board also has an 8 bit register + digital buffer for digital outputs. The buffers are put in order to avoid the loading problems, as the specs of the black box are not known. The registers for the eight D/A converter and one digital output circuitry are all connected to a common 8-bit data bus, and addressed through a 4-bit local address bus.

To handle the sixteen D/A converter and the two 8-bit digital outputs on both boards, a 5-bit global address bus is used at the computer side (only 4 out of 5 address bus lines are active on each card). Also, a 1-bit active low VMA (valid memory address) signal is used to indicate that a valid address is available at the address bus. The necessary 14 bits of digital data (8 for data bus, 5 for address and 1 for VMA) is supplied through the digital outputs of the PCL-1800 board and connected again through digital buffers to the output boards. The mapping between the channel numbers on the output board and joints on the Anthrobot is given on table 7. Some channel numbering convention is used for both digital and analog outputs. The PCAD 7.0 schematic and PCB files are attached via a floppy disk. The C files to send commands to these outputs is also available. You can see tables 5 and 6 for the wiring information for the output boards. *Note: We have made some alterations on the boards after the assembly. So, there are some minor, but important differences between the schematics and the actual boards. First one is a set of capacitors added before buffers of the analog outputs, to avoid unstable oscillations generated. Second change is the replacement of one of the resistors on D/A conversion circuits with short circuits, to get a unipolar voltage output instead of a bipolar one.*

### **3.3. Input Board**

Input Board is used as an interface in between finger motor potentiometers, load cells and PCL1800. The output voltage level of the load cells are very low (maximum 100mV), so they are amplified by instrumentation amplifiers. The outputs of all load cells and potentiometers are fed to antialiasing filters (which are simple RC low pass filters of first order). The input board is consist of 5 instrumentation amplifiers and 21 antialiasing filters (16 for potentiometers and 5 for load cells). The cut-off frequency for antialiasing filters is chosen suitable to our intended operating frequency. The circuit diagrams of amplifier and filter circuitry (one samples of each) can be found in figure 2(?). We have

constructed 5 circuits for the load cells because of the possibility of buying two more load cells to accommodate on the remaining fingers. In order to be able to sample  $16+5=21$  signals using a 16 channel A/D converter, we have used a set of analog multiplexers for selection of signals. The multiplexers used are 2-to-1, allowing two set of possible choices, to selected using a 1-bit digital signal. This signal is also supplied from the PCL-1800 board and fed to the input board through a digital buffer. See table 8 for the mapping between the channel numbers and signal names. Also note the availability some free A/D channels that might be needed for later practices. The PCAD 7.0 schematic and PCB files are attached via floppy disks.

### **3.4. Outline of the Resulting System**

The overall system structure and wiring (excluding power cables) can be seen in figure 3. A complete list of cables is given in table 9 for reference. Also for completeness, a block diagram showing the inside of the closed loop interface board and the tables for internal wiring are given in figure 4 and tables 10 through 13.

## 4. FUTURE WORK

### 4.1. HARDWARE

#### 4.1.1. Load Cell Installation:

In order to achieve closed loop force control, the Anthrobot-III robot hand must be equipped with force sensing instruments. Such pressure sensing instruments, namely 3 load cells are bought from a US company ENTRAN. One for the thumb and two for being used on two other fingertips. The choice of which two fingers will carry the load cells depends on the application. These pressure sensors will be embedded within the rubber of the relevant fingertips. The sensors are temperature compensated and have four cables, two for power supply and two for signal output. The load cells are to be connected to the input board which is designed to supply the necessary power, filter and amplify the signals, and to feed them to the A/D converter (PCL-1800). Load cell to input board connections are given in table 6.

#### 4.1.2. Input Board Assembly:

The PCB for the input board is to be printed but its assembly tests have not been completed. All the schematics and components are available for completing this part. *Note: The input board we have designed is optimized for our control strategy. For further work, it might be better to redesign this board for better performance under designed control strategy and operating conditions.*

### 4.2. SOFTWARE

#### 4.2.1. Low Level Controller:

Low level controller takes set points as joint angles from the high level controller. It compares these set points with the sensory data and generates an error signal. This error signal is put into a PID controller which is a part of the low level controller. The output of the PID controller is fed to the D/A board by the low level controller. One more duty of the low level controller is to pass

data for synchronization to high level controller continuously. In our design, the low level controller was intended to be a set of pseudo-parallel working background processes, to make the design and programming of the higher levels in the hierarchy easier and more independent. This would also teleoperation and supervisory control easier. Although the complete low level controller have not been implemented, the kernel which would make the pseudo-parallel background processes possible is prepared in 80486 assembly language and tested.

#### *4.2.2. High Level Controller:*

The main function of the high level controller is to synchronize the fingers and the joints in specified ways. It should take data from the last level controller and low level controller, manipulate the two, and generate new data (as set points for joint motions) to achieve the desired movement of fingers. Some constraints -like maximum closeness of fingers for no coupled motion, maximum force not to burn the motors, maximum/minimum force at finger tips- should be defined in this level of control. In our design, the high level control is also intended to be executed as a background process.

#### *4.2.3. Interface :*

A user interface must be prepared in order to achieve communication between last level control and synchronization algorithm (look at block diagram).The interface should take data from the last level controller, and rearrange them, so that they can be passed to high level controller. This is essentially a C procedure to transmit data between the foreground process (last level control) and the background processes (high and low level controls).

#### *4.2.4. Last Level Control:*

Last level control means, the pre-shaping, path planning, fingertip force planning, grasp and re-grasp planning of the robot hand for a predefined task.

Last level control should generate the fingertip paths, joint angles, fingertip forces at impact and post-impact data. High level control programs are commonly based on artificial neural network and/or fuzzy concepts.

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