

ENZCon: Teleoperated Robotic Arm with Force Feedback

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Abstract: This paper details methods for solving problems that occur when human beings teleoperate robots. Specifically, ease of use and force sensation. Through the use of a rigid control rig fitted to the user's arm it is possible to easily control an anthropomorphic robot arm using master slave control. Also, measuring the force being exerted by the arm can be used to give force feed back to the user.

Keywords: Teleoperated, Force, Feedback, Robot, Arm, Sensing.

1. INTRODUCTION

Robots are perfect for doing work that human beings either can not or will not, such as working in a nuclear waste site or performing pick and place operations in a factory. They do, however, have one significant problem; most automatic robots are not adaptive, they require an environment with a high level of structure to be able to operate and they will malfunction if that structure is removed. An example of this would be that if a component was moved from where pick-and-place robot expected it to be then the robot would not be able to place the part and the circuit board would be incomplete (or the robot may give an error message).

With the current level technology it is very difficult to make reliable adaptive robots; to do so would require complex programming to give the robot the power to make decisions based on the environmental conditions. It should be noted that in situations where it is easy to structure the environment it is better to use a non-adaptive robots.

One solution for this lack of adaptability is to have human beings operating the robot remotely (teleoperation), but this causes new problems. The first is that the ease of operation of a teleoperated robot depends greatly on the interface presented to the user and the second is that it can be difficult of the user to manipulate the robot's environment without any kind of feed back about how much force the arm is exerting.

This paper gives solutions to both of these problems. The solution to the first problem is to use an

anthropomorphic robot arm and a master slave control system and the solution to the second problem is to implement force feedback to the user through the control rig that they use.

This paper will give a short introduction to teleoperation, show the system that has been implemented, give a detailed description of each block and the equipment used in each, discuss the advantages and disadvantages of this system and the future work that could be done to develop it further.

2. TELEOPERATION

Teleoperation is simply the name given to the process of controlling a robot remotely [1].

The idea of teleoperation has been around since the 1970s in a time when it was totally unfeasible to program adaptive robots, instead it was decided that it would be easier to allow human beings to control the robots from afar [2].

The main advantage of this is that humans are adaptive and so are better able to deal with unstructured environments. The main disadvantage is that it can be difficult to use this type of system if the interface is not designed properly.

An example of this disadvantage would be a robot that is controlled via a wireless link from a computer that accepts numerical input from the user's keyboard that represents the special coordinates of the desired position of the robot. It can clearly be seen that a large amount of training would be necessary to get a

human operator to the stage where they could fluently and effectively manipulate the robot's environment.

3. MASTER SLAVE CONTROL

The best type of interface would be one in which the user moves in a natural way and the robot follows those motions. This type of control is called master-slave control and has been implemented in this project.

Most people find using their arms incredibly easy as they have had so much practice. This natural ability of most human beings can be exploited to give a human operator an easy to use interface to control a robot.

The system that has been implemented in this project allows the user to move in a natural way and the robot will move in the same way. In this fashion the user is able, with very little training, to effectively and precisely manipulate the robot.

The following section describes the system that was implemented.

4. IMPLEMENTED SYSTEM

The block diagram of the master-slave system that has been implemented is shown in figure 1.

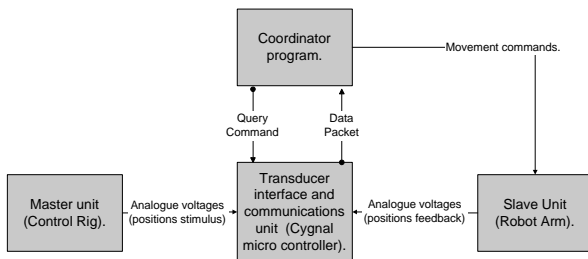


Figure 1: Functional block diagram of the implemented system.

A more detailed description of each of the blocks in figure 1 is given in the following sub-sections.

4.1 Slave unit.

In general, this block represents the robot that is being teleoperated. Specifically, this unit is an anthropomorphic robot arm.

The requirements of this arm were: that it be similar to a human arm with respect to the number and position of the joints; that it be small, light and easy to transport; that it be usable in any orientation; that it

cost less than \$500 NZ (this requirement stems from the budget given by the institute and the supervisors).

The arm that was obtained met all of these requirements. It was called 'Lynx 6' and was imported from an American company called Lynxmotion, a picture of the Lynx 6 is shown in figure 2.



Figure 2: Lynxmotion Lynx 6 robot arm [3].

Note that the robot shown in figure 2 is placed next to a Coke can for size reference.

The slave unit could be mounted upside down by means of a bolt through the base. Once mounted in this fashion the movement of the joints resembled that of a human arm.

The unit had six joints (and therefore, six degrees of freedom). Table 1 gives the names of the joints and the combination of actuators that controlled the movements of that joint (note that all actuators were servo motors manufactured by Hitec, Korea).

Table 1: Arm joints and actuators.

Joint Name	Actuator
Shoulder rotation	HS-422
Shoulder	2x HS-422
Elbow	HS-422
Wrist	HS-422
Wrist rotation	HS-81
Gripper	H-81

As has been stated, the actuators used were servo motors. There was also the option to use a similar arm that had stepper motor actuators; it was decided that the servo motors were a better option since servos have absolute positioning where steppers only have incremental positioning. The practical aspect of this decision is that if the load of the servo motors is increased beyond their maximum they will not lose their position, if the same is applied to a stepper motor it will slip and will have wrong data on its position.

The commands to the arm are transmitted through an RS-232 interface. Each command is three bytes. The first byte must be the value 255 for synchronization of the servo controller board (an SSC-001, supplied with the arm kit and mounted on the base of the arm). The second is the identification of the joint to be moved, the exact value depends on which output the servo is plugged into. The third represents the position the specified joint is to move to (0 – 255). With 256 steps possible on each servo and a 180 degree range of movement, this means that each joint has a resolution of 0.7 degrees/step (except for the gripper which has 0.35 degrees/step due to the mechanics of the ‘fingers’)

The commands for the slave unit are issued by the coordinator program based on a PC (see section...), and measurement of the actual position of the joints is monitored by the transducer interface running on the micro controller (see section...).

4.2 Master unit.

This block represents the control mechanism that is used by the operator to provide the slave with movement commands. For this implementation, this unit is an aluminium frame that the user wears over their right arm (see figure 3).

Figure 3: The master unit for this implementation.

The master unit has only three joints (elbow, wrist and gripper) to reduce the complexity of the construction of the frame and also the complexity of the control software. Three joints were considered suitable for testing control and feedback methods. The position of each joint is measured (absolutely) by the rotational potentiometers (pots) mounted at the axis of rotation of each joint. The pots are connected to ground and 3.3 V (the maximum measurable input of the analogue to digital converter in the transducer interface). With the pots wired in this configuration the output voltage will be between ground and 3.3 V and it will be dependant only on the position of the potentiometer.

The purpose of this master unit is to measure the position of the joints of the user’s right arm. These positions will be transmitted, as voltages, to the transducer interface.

4.3 Transducer interface.

This block is running on a Silicon Laboratories (formerly Cygnal) micro controller. The purpose of this block is to convert the input voltages from the master and slave pots from analogue to digital and

communicate those digital values to the coordinator program (when that program requests them).

It was deemed that a micro controller was necessary because the PC platform that the coordinator program was running on did not have the capability to perform the analogue to digital conversions on the number of channels required, also analogue to digital conversions are time intensive. The best solution was to use a controller that was working independently of the coordinator program, which had the capability to handle multiple channels, and was readily available. The Silicon Labs micro controller was chosen because it fit all of these criteria.

The program running on the micro controller simply converts all of the analogue inputs to their corresponding digital values, one by one, and stores the results in internal memory; when a query for data comes from the coordinator program the micro controller communicates the digital data back to the coordinator (communication takes place via UART through an RS-232 interface).

4.4 Coordinator program.

This block represents the software between the master and the slave units that monitors the positions of the joints on the master unit and commands the slave to move. In this system, this block has been implemented on a PC running Windows XP. The Microsoft Visual C++ 6.0 programming tool was used to design the control and the user interface.

Figure 4 shows the interface as it appeared in the design tool. Note that this figure shows the positions of each of the control buttons and display boxes that are present in the interface, but when in use not all of these controls are visible simultaneously.

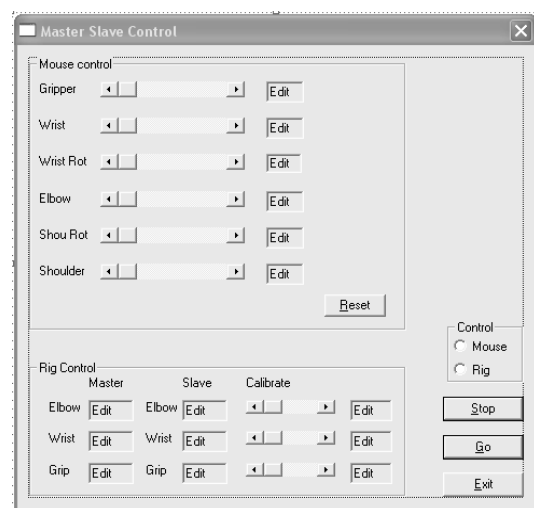


Figure 4: Graphical user interface of the coordinator program (design view).

The graphical user interface (GUI) allowed for easy development of control and testing facilities for the system. In the top half of figure 4 are six scroll bars that allow the user to test the movements of the slave independent of the master, instead the user can move these scroll bars and the joints of the slave unit will be moved, this can help to identify problems in the slave or the coordinator. Once the slave and the coordinator have been shown to be working the user can switch to using the master unit for control and the GUI will present the user with a series of boxes that show the positions of each of the joints on each of the units; there are also some calibration controls that allow the user to correct for errors in the positioning of the pots on the master and slave unit.

It should be noted that a PC based coordinator program was only used because of the GUI that it provided. All of the operations that the coordinator performs could be scaled down and ported to the microcontroller (see ...).

5. FORCE FEEDBACK

Unfortunately, master slave control is not enough to allow the user to work productively with the robot. The motion of the joints of the robot will be easy to control but the user would have to be very careful not to exert too much force on the objects that the arm is manipulating as this could damage either the object or the arm.

A good example of this would be if the user needed to move an egg using the arm; if the user exerted too much force on the egg then it would crack and if they used too little force then the arm would not be able to grip the egg and the arm would drop it (probably breaking it).

So, the question is: how does the user gauge how much force they are commanding the arm to apply to an object?

Possibly the best solution would be to give the user a physical sense of how much force the arm is exerting by applying to the joints of the master unit a force that is proportional to the force that is being exerted by the slave. This process has been called 'force feedback' and is currently used in video games to give the player a better sensation of what is going on in the game.

There are three main ways of measuring the force that the slave unit is exerting; each of these is briefly described in the following subsections.

5.1 Current sensing.

In this method the force fed back to the user is made proportional to the current that is being drawn by each of the joints. The current drawn by a motor is proportional to the torque that is exerting, and therefore it can be used as a measure of force (since torque is simply force of rotation).

This method would be the best as it is based on actual force measures and does not require extra force sensors to be added to the arm. The disadvantage of this system is that it requires that the current draw of each of the servo motors be monitored and this is difficult to do without interfering with the operation of the motor (by putting a resistance in series with it for instance); additionally the Lynx 6 is unable to monitor current. Therefore, a different method needs to be found (or a new arm purchased).

5.2 Force sensors

In this method force sensors would be mounted to the material between the joints. These sensors would measure the amount of strain placed on each of these joints, the higher the strain the greater the amount of force that joint must be exerting.

The advantage of this system would be that it is, again, measuring actual forces and that the measuring of the force would not interfere with the operation of the joints themselves. The disadvantage would be that most force sensors are difficult to mount to the arm due to the need to ensure that there is no preload on the sensor.

This method has been selected for use on the gripper (see section....)

5.3 Positional error

In this method the force that is fed back to the user is made proportional to the difference in positions of the master and the slave units. If the positions are very different it is assumed that the arm is under strain and unable to reach the master's position therefore a force should be applied to the master unit.

This method has the advantage that it does not require any extra sensors to be added to the slave unit (the whole calculation can be done by the coordinator program). The disadvantages of this method are that it is not working with measured force values on position values and the assumption stated above may not be appropriate and therefore the system would feed force to the user when the slave is not under force.

Note that the force sensor method has been adopted for feedback from the gripper and is described in the following section, current sensing has been chosen for the remaining joints but its implementation has been postponed until an arm that has current sensing built into the servo controller is obtained.

6. GRIPPER FORCE FEEDBACK

It is appropriate, for this joint, to use a force sensor to measure the amount of force the slave is exerting on an object in its grip.

To measure the force a sensor is attached to the inside of one of the gripper prongs. When the gripper closes around the object the sensor is compressed between the object and the gripper prong. From this force can be measured.

The sensor that was used was a Tekscan FlexiForce force sensor (pictured in figure 5)



Figure 5: Tekscan FlexiForce force sensor [4]

These sensors are mounted on a flexible circuit board and have a small circular dot of force sensitive ink (shown on the far right of figure 5). The resistance of this ink increases as the force applied to the ink increases. By using a simple op amp circuit this force can be converted into an analogue voltage that can be inputted into one of the ADC inputs of the transducer interface (see section 4.3).

Once the force data is accessible by the coordinator program there are two things that can be done with the data. It could be displayed to the user as another box in the GUI of the coordinator program and it could also be used to drive a motor attached to the gripper joint of the master unit thereby giving the user a sense of how much force they are applying to an object.

Tekscan have several sensors available, each with different sensitivities to force. The sensor chosen would depend on the maximum grip force of the arm on which the sensor was mounted. For this implementation the 0.45 kg sensor was the most appropriate.

It should be noted that while the sensors for this part of the project were obtained they were not implemented in the system due to time constraints.

7. RESULTS OF SYSTEM TESTS

To date all of the tests that have been performed on this system have been subjective. They have involved trying the system with different users to gauge how fast they can become proficient enough with the system to be able to accurately and quickly pick up and put down an object place in the robot's path. From observation it was found that most users could become proficient in the system to the required level in approximately 2 minutes.

8. FUTURE WORK

The system that has been implemented was only designed to prove the concept of an anthropomorphic master slave interface was an effective way to control a robotic arm; hence there is much that could be done to improve the system, some such improvements have been discussed below.

The system is currently only implemented with three degrees of freedom available from the master unit. By changing the design of the master unit it would be possible to implement the other three joints available on the Lynx 6.

Currently when the arm moves it is greatly affected by its own momentum, as the arm accelerated from rest or comes to rest from movement it appears very unstable. An effective way to fix this that would also allow the user a greater level of control would be to implement speed control on the servos. By controlling the speed of acceleration and deceleration the unstable effect observed would be lessened and the user would be able to specify a desired speed for the arm to move at.

In some applications of this system it may be desirable to have the user at a distance from the slave unit (such as when it is being used to disarm a bomb). Currently all of the blocks of the system are hard wired to each other, limiting the maximum feasible distance between master and slave. A wireless or Internet link block could easily be inserted into the system. By combining this with a coordinator program that is scaled down to fit on a micro controller the block diagram of the future system could look similar to the system shown in figure 6.

Figure 6: Future block diagram of the system.