Wireless Master-Slave Embedded Controller for a Teleoperated Anthropomorphic Robotic Arm with Gripping Force Sensing

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Motivation

- Teleoperation of robotic arms that mimic human like appendages has become a reality

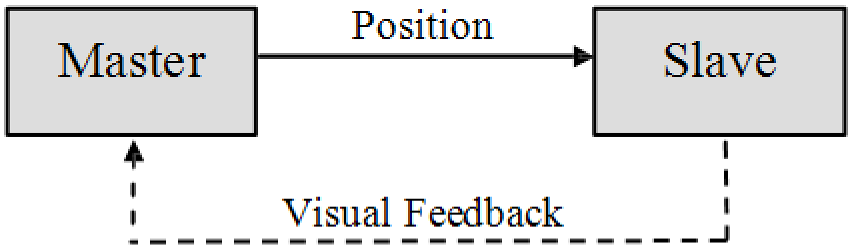
- The advantage of these manipulators is that a high level of precision can be achieved

- The disadvantage, however, the sacrifice of the user's ability to have haptic (force and tactile) feedback

[1]

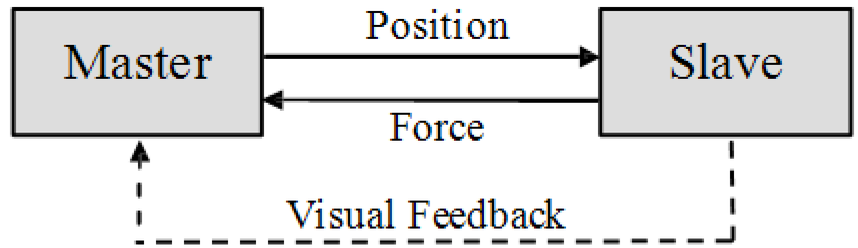
Da Vinci Surgery Robot

Master-Slave Control System



(a) Unilateral System

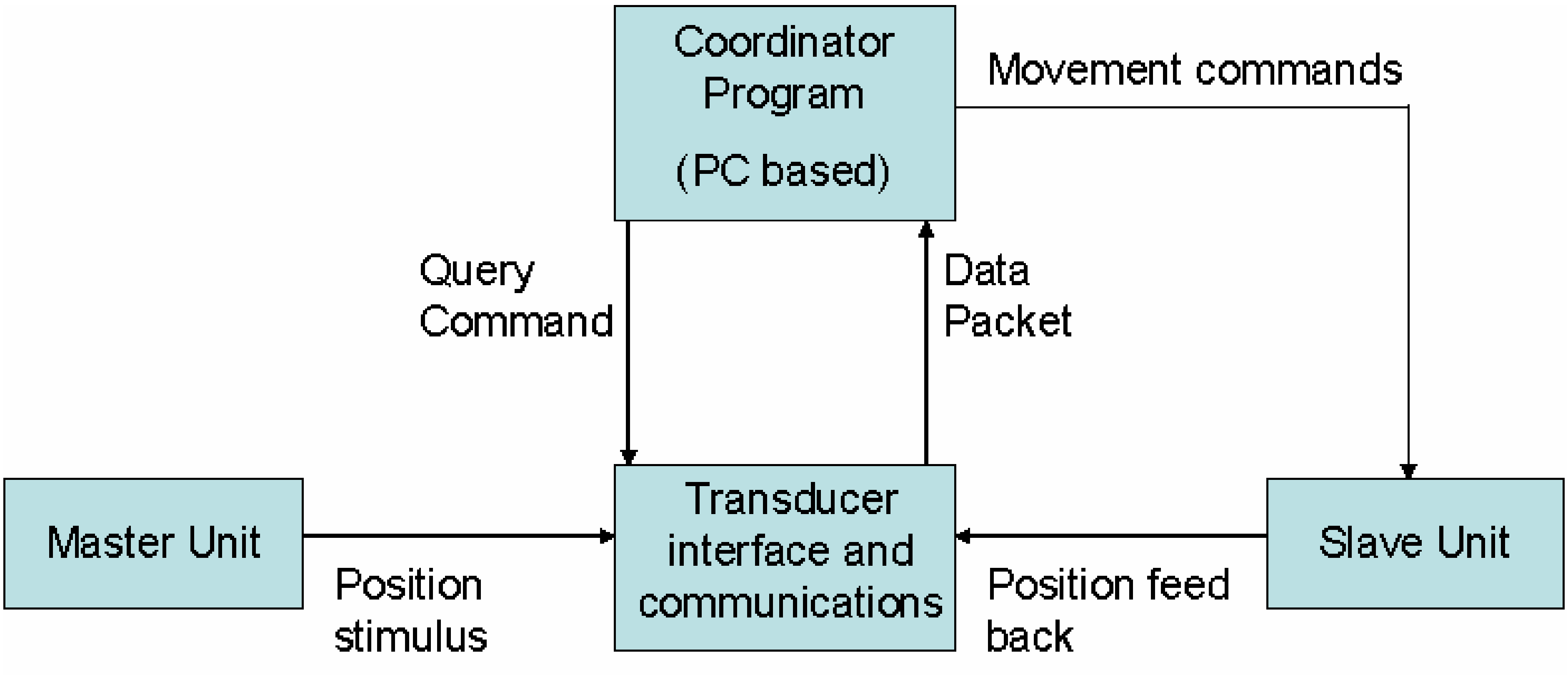
- ❑ Unilateral control systems are how current anthropomorphic robotic arms operate
- ❑ There is only visual feedback to the operator
- ❑ No tactile feedback to the user



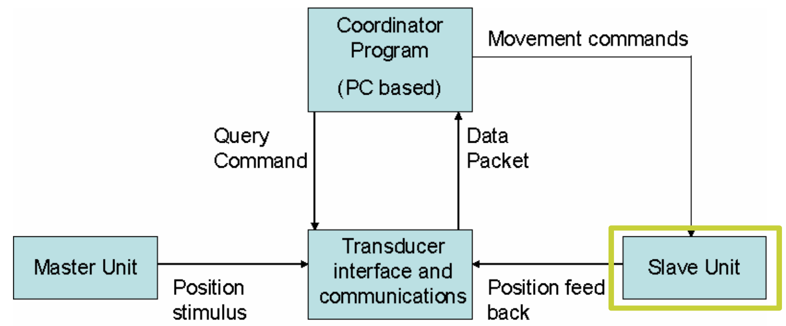
(b) Bilateral System

- ❑ A bilateral control systems are how current anthropomorphic robotic arms operate
- ❑ There is visual feedback and force feedback to the operator
- ❑ This tactile feedback to the user results in a more fluid operation

Functional Block Diagram Wired



Slave Unit

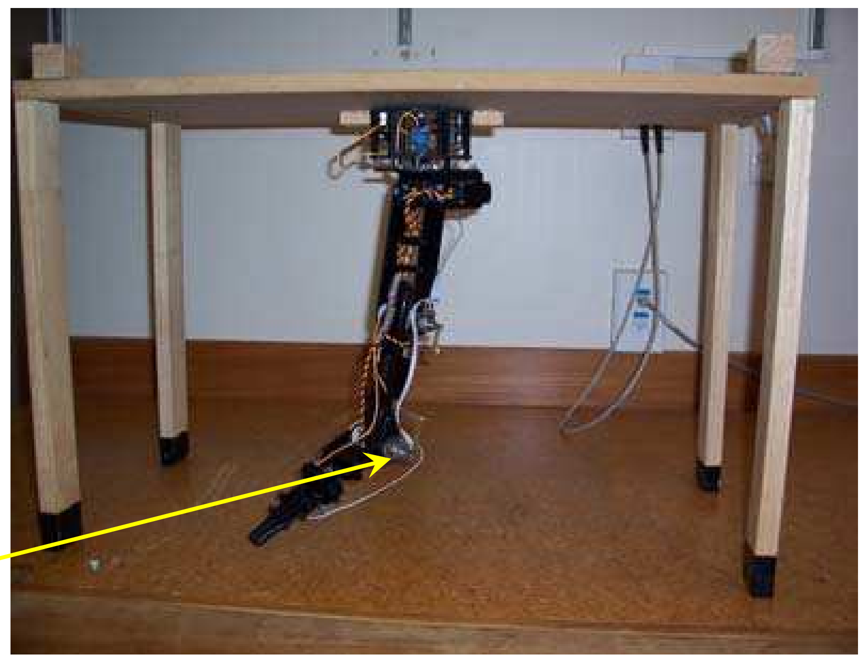


- The slave unit is a robotic with 6 degrees of freedom (DOF)

  1. Shoulder rotation
  2. Shoulder back and forth
  3. Elbow
  4. Wrist up and down
  5. Wrist rotation
  6. Gripper (Hand)

- The actuators for all joints are servo motors

[2]



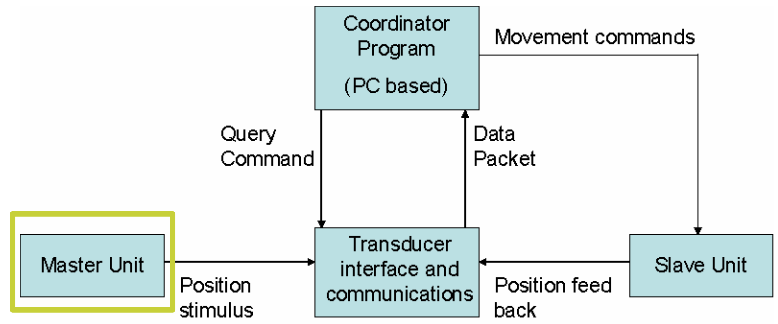
Slave (robotic arm)

Master Unit

- The low cost master unit only uses two technologies to translate movement

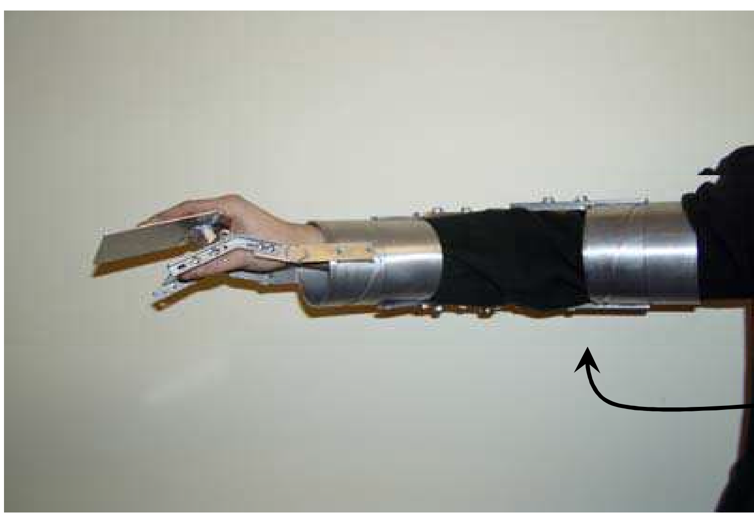
1. Potentiometers
    a. Linear (Shoulder and wrist joints)
    b. Rotary (Axis of each joint)

2. Accelerometer (Shoulder back and forth motion)

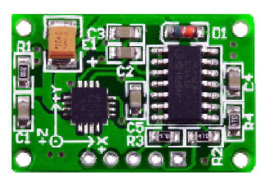


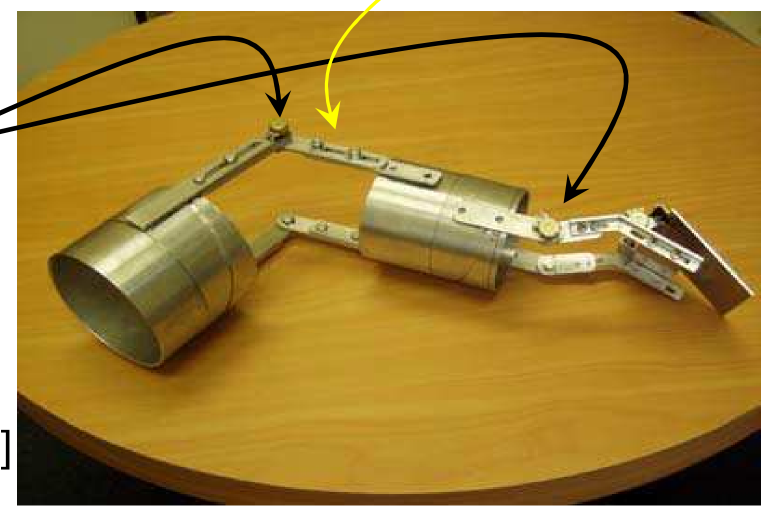
Linear Potentiometer

[3]



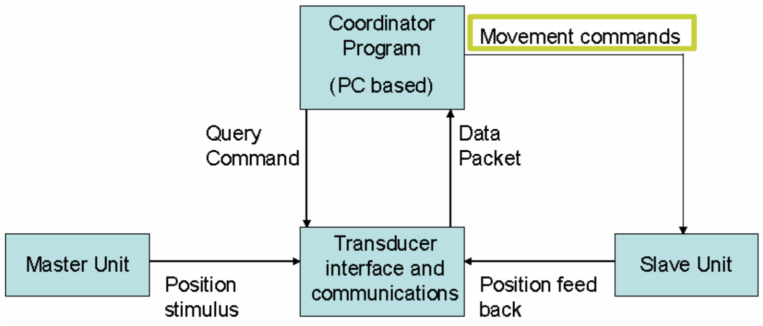

[4]
Rotary Potentiometer


[5]
Accelerometer



Command Structure

- The commands to the robot are sent from a PC via COM1 RS-232 at 9600 Baud rate

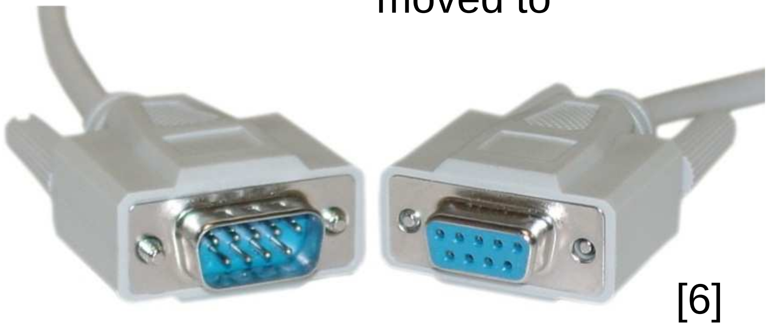


- Each command is 3 bytes long

1111 1111	1111 1111	1111 1111
First byte value sent is always 255 for synchronizing the Servo controller board	Second byte value sent is used to identify which joint is to be moved	Third byte value sent represents the angular position that the specific joint will be moved to

- With 256 steps possible on each servo and 180° range of movement yields a resolution of 0.7 degrees/step (deg/step)

(The gripper only has 0.35 deg/step due to the mechanics of the 'fingers')

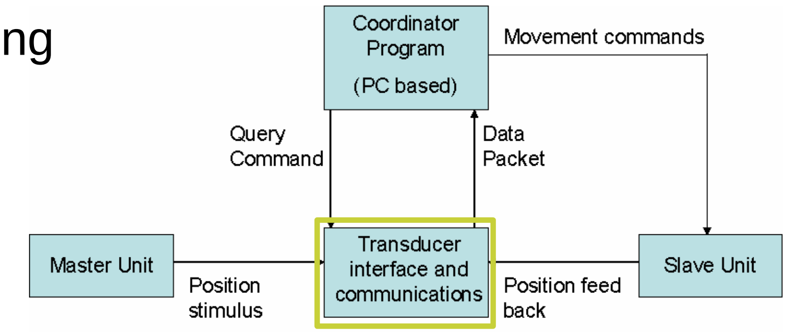


[6]

RS-232 Cables

Transducer Interface

- The C8051F020 micro controller has the following features:
  - 64KB Flash memory
  - 4532 B RAM memory
  - 16 MHz clock speed (Max)
  - 2 – 12 bit DAC's
  - 100 ksps 12 bit ADC

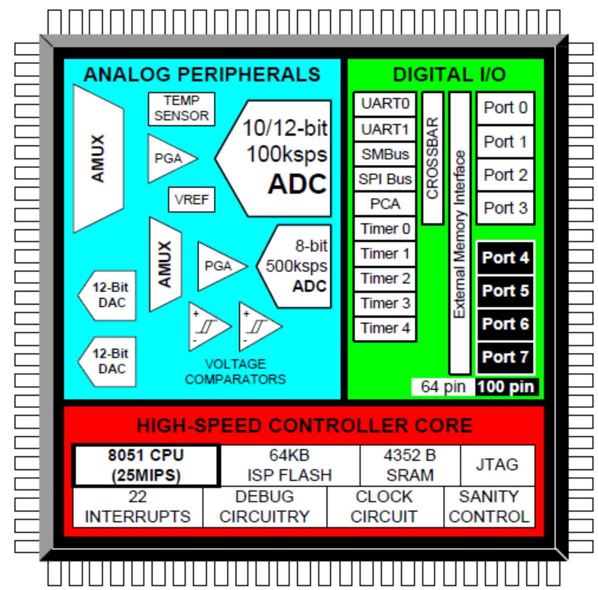


[7]

- The communication between the coordinator program and the transducer interface is in the form of data packets using COM2 RS-232 at 28800 Baud rate

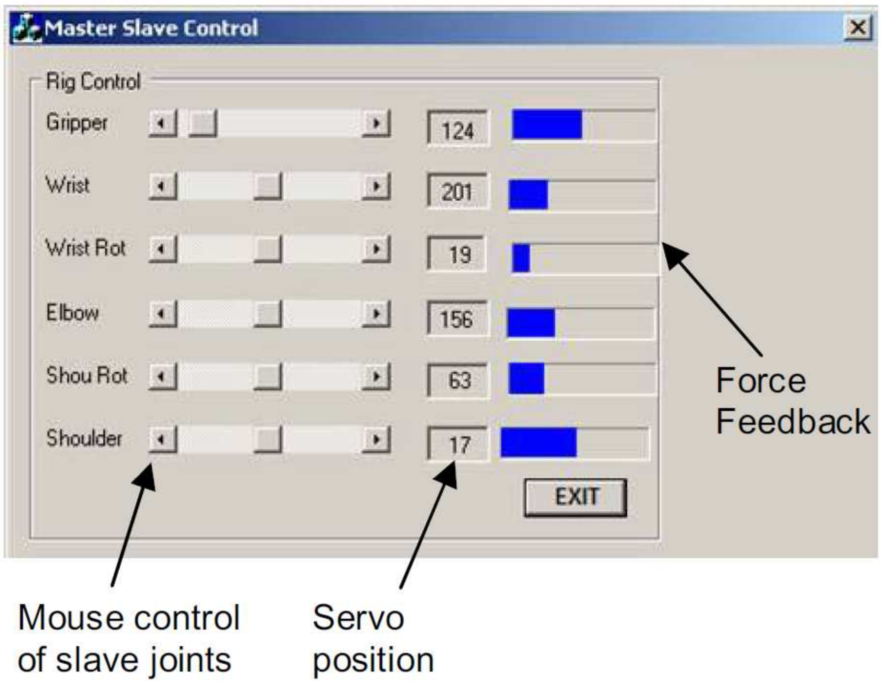
- Coordinator
  - Replies with a 10-byte packet which contains a header (0x55), RobotID (0x33), and the position of all servos

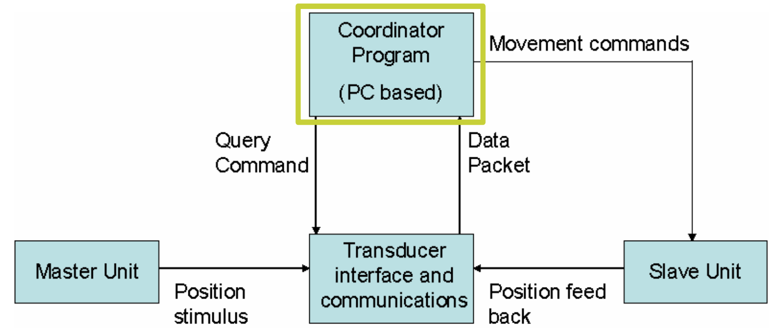
- Transducer
  - Transmits a 3-byte packet when a query of positions is required



Silicon Laboratories C8051F020 micro controller

Coordinator Program





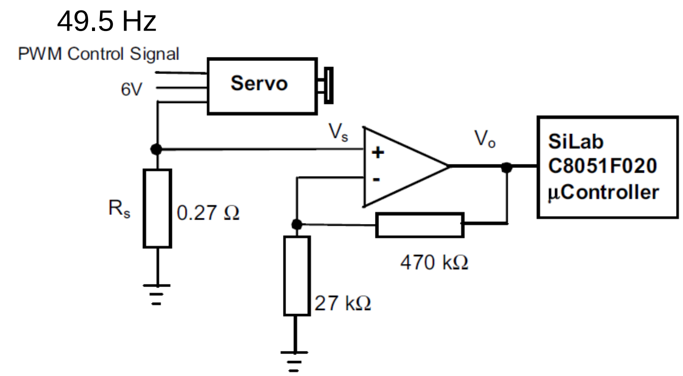
[8] [9]

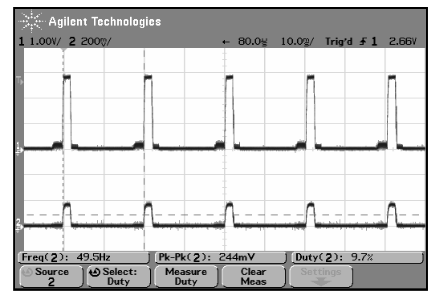
- The coordinator program was implemented on a PC running Windows XP and developed using Microsoft Visual C++ 6.0

- The 6 scroll bars Allowed for testing the servos and performed as a redundant control system for the robotic arm

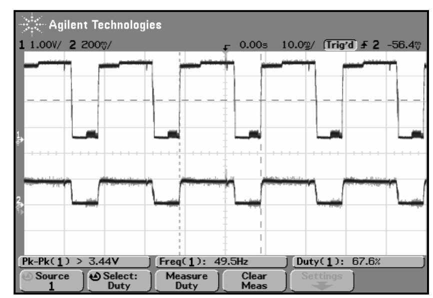
Force Feedback Mechanisms (Current Sensing)

- The force fed back to the user is proportional to the current that is being drawn by each of the joint motors
- The duty cycle varies proportional to the motor torque.
- The micro-controller's 12-bit counters/timers, measures the duty cycle, effectively indicating the motor torque
- The torque is measured with a resolution of 0.1%





Duty Cycle 9.7%



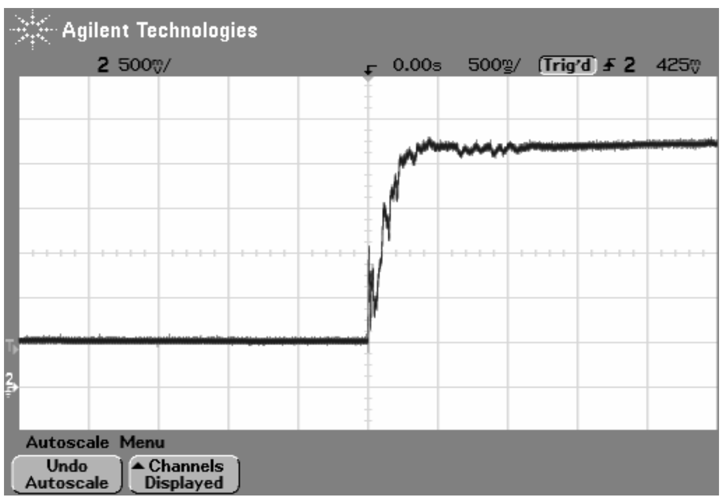
Duty Cycle 67.7%

Force Feedback Mechanisms (Force Sensors)

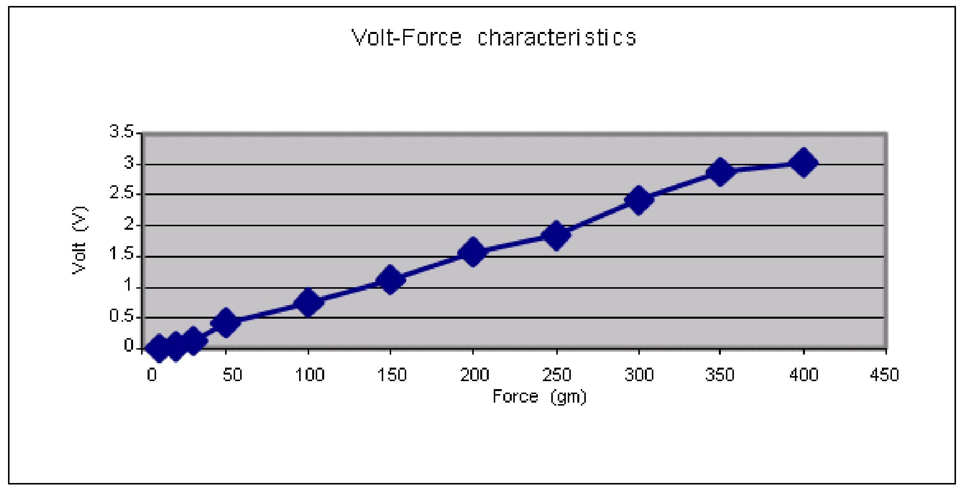
- The force sensors are mounted on the material between the joints
- These sensors measure the amount of strain based on a varying resistance value proportional to the forces exerted

[10]

Tekscan FlexiForce force sensor

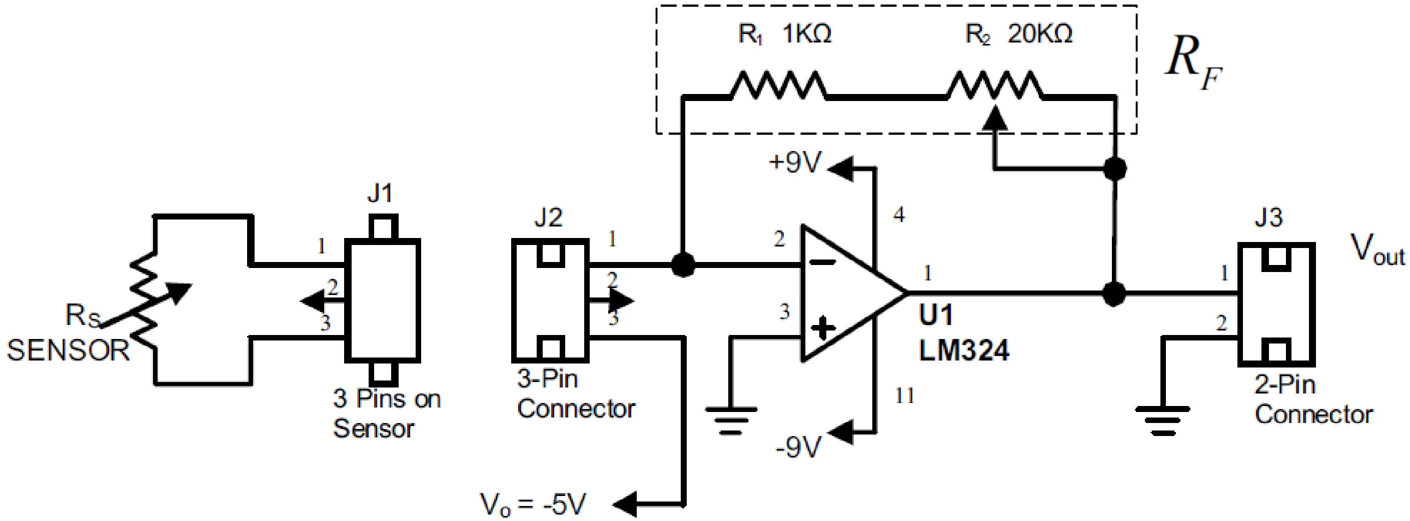


Force sensor's transient response
Step load of 300gm (100gm to 400gm)



Force sensor transfer characteristics

Force Feedback Mechanisms (Force Sensors) Cont.



Where:

$$V_{out} = -V_o * \left(\frac{R_F}{R_S}\right)$$

$$R_F = R_1 + R_2$$

Amplifier for force sensor output

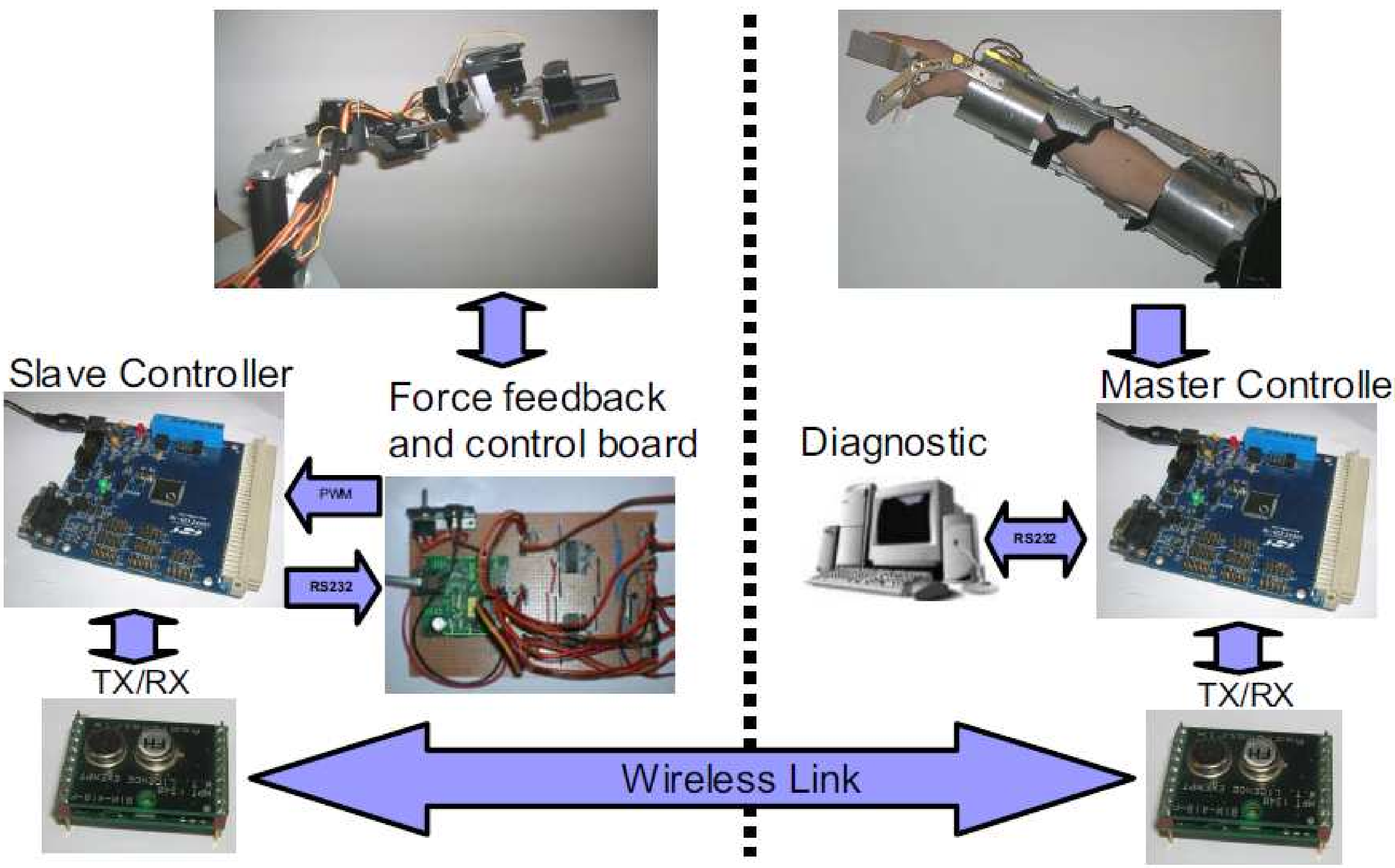
- The force sensor, which is essentially a variable resistor, is used to change the gain of the inverting amplifier

- The potentiometer (R_2) is used to vary the gain based on a replacement sensor with different gain than the previous one

Force Feedback Mechanisms (Positional Error)

- The force fed back to the user is made proportional to the difference in positions of the master and 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 reflective force should be applied to the master unit to restrain it
- All the calculations are done by the coordinator program

Wireless Embedded Design

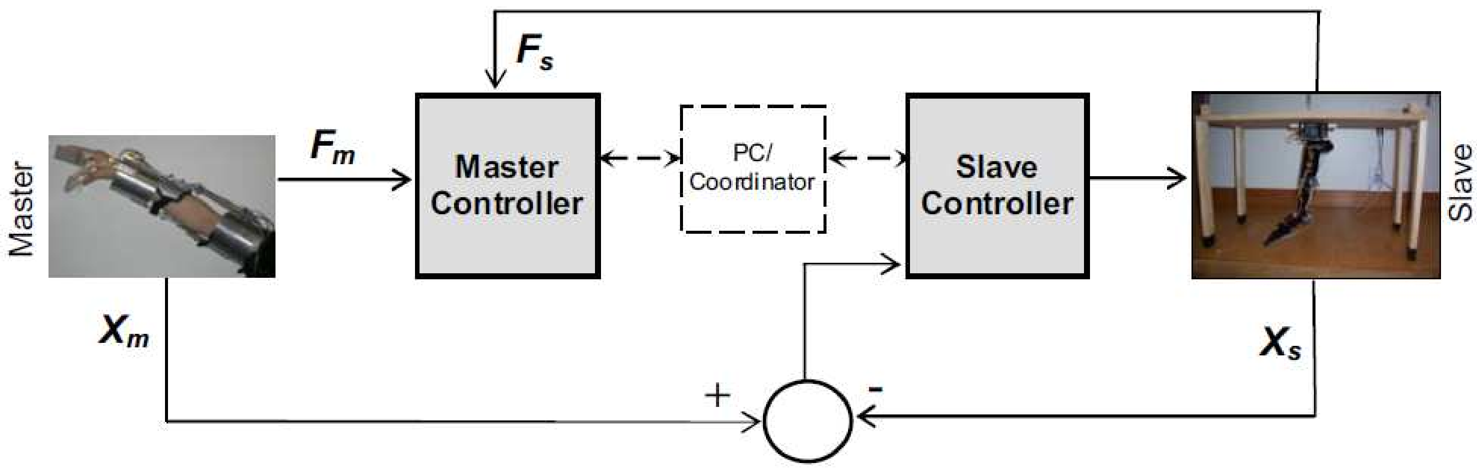


Results / Conclusions

- Most users could become proficient in using the system in approximately 2 minutes

- Using the wireless link, the slave was able to be controlled by the master from approximately 50 meters indoors

- Future applications could include areas such as, medicine, manufacturing, security, entertainment and space exploration



Force reflective bilateral Master-Slave control

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