Remote Controlled System for 6-axes Articulate Vertical Robot

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Abstract

This research aims to develop program and design remote control system for 6-axes articulate vertical robot in the remote location. The most importance properties of this robot are presented and the application of remote control system is highlighted here.

1. Introduction

The 6-axes articulate vertical robot was designed and made by lightweight material. Stepping motors are used in driving systems with self-locking by interlock-gear. Turbo-C^{++} language program was developed and open-loop control system was used in previous version via parallel transmission. Since in the actual situation, robot often locate in area where cannot access by human and is far from controller unit, such as in industrial factory which has many robots that are located far from controller center. Since in the previous research, Parallel transmission system was applied, which appropriate for short distance connection (inter-communication by through more than 30 cores of cable).This transmission must use many cores of cable for sending the signals. Further more, open loop controlled system was used in the previous that cannot feedback present status of robot to user. To improve the lacks of the previous systems, transmission via I^2C controlled system (inter-communication by only 2 lines of cable) and closed-loop controlled system are used to be solutions. In addition, for easy interface between robot and user, Visual Basic program, which is friendly for user is source-developed program for easy robot controlling by user. Beside that, the objective for this research is development from teach mode to programmable mode for robot motions, which is the important part in program development. In the next steps for improvement this research are using advance methods to reduce time and motion of robot and derive optimize trajectory path in motion of robot, such as, Artificial Neural Network (ANNs) and Genetic Algorithms (GAs) that are used to be the solution methods in the next generation technology.

2. Improvement items from the previous version

- Control system: close loop control system is used for improvement the efficiency of accuracy in motions.
- Interconnection system: I^2C system is used for improvement controlling and expand the efficiency for remote control system.
- Program for controller: interactive program is developed by Visual Basic 6.0 program to the easily use for general operators.

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3. Specifications and work envelopment of robot

The specifications and working envelopment of 6-axes articulate vertical robot in this research that was design and made in the previous research are shown below.

Table1: specifications of vertical robot

1.Positioning Performance - Repeatability	 ± 0.3 mm.
2.Manipulator - Drive type - Load Capacity - Configuration - Coordinate system Joint Tool - Degree of freedom - Gripper Actuation	 DC Stepping motor 0.4 Kg. Joint arm Cartesian Cartesian 6 Axes (D.O.F.) Magnetic, Pneumatics
3.Classification	Point-to-point control
4.Power requirement	220~240V, 50~60 Hz.
5.Working motion - Arm sweep - Shoulder swivel - Elbow extension - Yaw - Pitch - Roll	 -175 TO +175 +45 TO +110 -40 TO +45 -90 TO +90 -180 TO -90 -175 TO +175

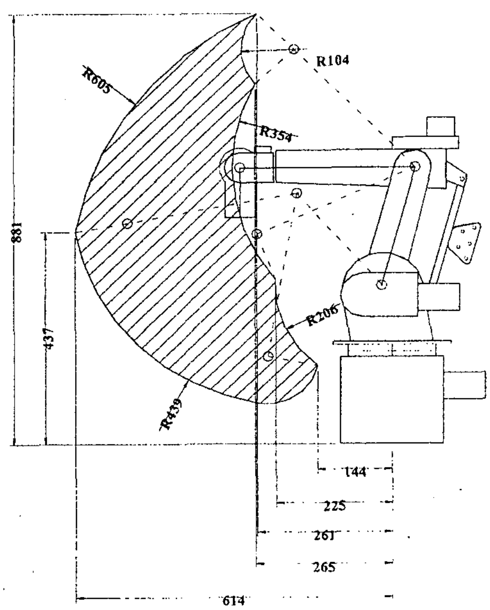


Figure 1: Work envelopment of robot

4. Control system of 6-axes articulate vertical robot

Physical control system is shown as below figure

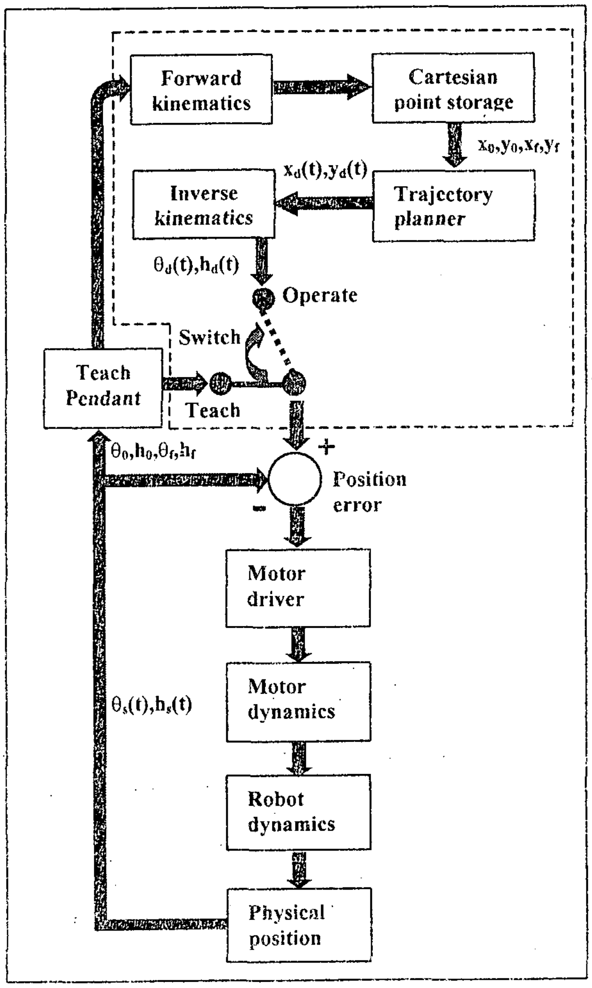


Figure 2: Control diagram for 6-axes Articulate Vertical Robot

5. Forward kinematics for articulate vertical robot

5.1 D-H (Denavit-Hartenberge) Coordinate Transformation for 6-axes articulate vertical robot

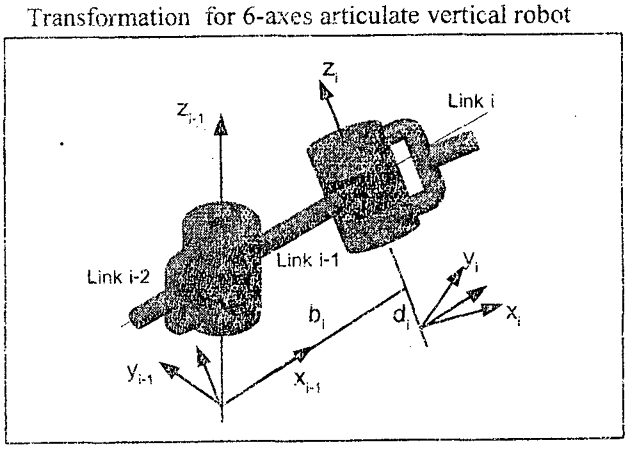


Figure 3: Basic three connected Links for D-H coordinate transformation

Consider the situation depicted above, Let Z_{i-1} and Z_i represent fixed axes at either end (joint) to link $i-1$, about which or along which links $i-1$ and i move, respectively.

- Let X_{i-1} be defined from Z_{i-1} to Z_i and perpendicular to both.
- Let O_{i-1} denote the point of intersection of axes Z_{i-1} and X_{i-1}
- Let Y_{i-1} represent the unique axis that together with X_{i-1} and Z_{i-1} completes a right hand Cartesian coordinate system.
- Let Z_i represent a vector from O_{i-1} parallel to Z_i
- Let X_{i-1} represent a vector from O_i parallel to X_{i-1}

The following four ordered operations completely specify the configuration of the frame i coordinate system relative to the frame $i-1$ coordinate system:

- A constant *twist* of α_i degree about axis X_{i-1} of Z_{i-1} into Z_i
- A constant *displacement* of b_i unit along X_{i-1} from Z_{i-1} to Z_i
- A *rotation* of θ degrees about Z_i of X_{i-1} into X_i
- An *offset* of d_i units along Z_i from X_{i-1}, Z_i intersection to O_i

The overall D-H coordinate transformation matrix is then given by

$$T_{i-1}^{i} = \begin{vmatrix} \cos\theta_i & -\sin\theta_i & 0 & b_i \\ \cos\alpha_i \sin\theta_i & \cos\alpha_i \cos\theta_i & -\sin\alpha_i & -d_i \sin\alpha_i \\ \sin\alpha_i \sin\theta_i & \sin\alpha_i \cos\theta_i & \cos\alpha_i & d_i \cos\alpha_i \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Table 2: D-H transformation parameters of robot

Link i / Parameters	1	2	3	4	5	6
α_i	0°	-90°	0°	-90°	-90°	+90°
b_i	0	b_2	0	0	0	0
θ_i	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6
d_i	d_1	0	0	d_4	0	d_6

By employing above equation, the overall D-H coordinate transformation matrix from base to tool of robot by substitution values in table2 is given as follows:

$$T_{base}^{tool} = T_0^6 = \begin{vmatrix} n_x & s_x & a_x & p_x \\ n_y & s_y & a_y & p_y \\ n_z & s_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

where the nine orientation entries are given by

$$n_x = c_1[c_{23}(c_4c_5c_6 - s_4s_6) + s_{23}s_5c_6] + s_1(s_4c_5c_6 + c_4s_6)$$
$$n_y = s_1[c_{23}(c_4c_5c_6 - s_4s_6) + s_{23}s_5c_6] - c_1(s_4c_5c_6 + c_4c_6)$$
$$n_z = s_{23}(s_4s_6 - c_4c_5c_6) + c_{23}s_5c_6$$
$$s_x = -c_1[c_{23}(c_4c_5s_6 + s_4s_6) + s_{23}s_5s_6] - s_1(s_4c_5s_6 - c_4c_6)$$
$$s_y = -s_1[c_{23}(c_4c_5s_6 + s_4s_6) + s_{23}s_5s_6] + c_1(s_4c_5s_6 - c_4c_6)$$
$$s_z = s_{23}(c_4c_5s_6 + s_4s_6) - c_{23}s_5s_6$$
$$a_x = c_1(c_{23}c_4s_5 - s_{23}c_5) - s_1s_4s_5$$
$$a_y = s_1(c_{23}c_4s_5 - s_{23}c_5) - c_1s_4s_5$$
$$a_z = -s_{23}c_4s_5 - c_{23}c_5$$

and the three position entries are given by

$$p_x = d_6(c_1c_{23}c_4s_5 - c_1s_{23}c_5 + s_1s_4s_5) - d_4c_1s_{23} + b_3c_1c_2 + b_2c_1$$
$$p_y = d_6(s_1c_{23}c_4s_5 - s_1s_{23}c_5 + s_1s_4s_5) - d_4s_1s_{23} + b_3s_1c_2 + b_2s_1$$
$$p_z = -d_6(s_{23}c_4s_5 - c_{23}c_5 + s_1s_4s_5) - d_4c_{23} + d_1 + b_3s_2$$

where $c_n = \cos(n)$, $s_n = \sin(n)$, $c_{nm} = \cos(n+m)$ and $s_{nm} = \sin(n+m)$

6. Inverse kinematics for articulate vertical robot

Inverse kinematics problem is determining a particular set of link value that will produce a known and desired end effector configuration. In the other side, inverse kinematics problem need not be solved in all situations. In particular, teach pendants to move to specific points that are subsequently defined by their sensed link values.

The following equations are inverse kinematics solutions of 6-axes articulated vertical robot for this research:

$$\theta_1 = A\tan 2\left[\frac{p_{yw}}{p_{xw}}\right] \; and \; \theta_1 = A\tan 2\left[\frac{-p_{yw}}{-p_{xw}}\right], both \; \theta \; and \theta \pm 180°$$

$$\sin\theta_3 = \frac{b_3^2 + d_4^2 - (p_{xw}c_1 + p_{yw}s_1 - b_2)^2 - (p_{zw} - d_1)^2}{2b_3d_4}$$

$$\theta_2 = A\tan 2\left[\frac{-(p_{xw}c_1 + p_{yw}s_1 - b_2)(d_4c_3) - (p_{zw} - d_1)(b_3 - d_4s_3)}{(p_{xw}c_1 + p_{yw}s_1 - b_2)(b_3 - d_4s_3) - (p_{zw} - d_1)(d_4c_3)}\right]$$

$$\theta_4 = A\tan 2\left[\frac{a_xs_1 - a_yc_1}{a_xc_1c_{23} + a_ys_1c_{23} - a_zs_{23}}\right], and \; A\tan 2\left[\frac{a_yc_1 - a_xs_1}{a_zs_{23} - a_xc_1c_{23} - a_ys_1c_{23}}\right]$$

$$\theta_5 = A\tan 2\left[\frac{\sqrt{(a_xs_1 - a_yc_1)^2 + (a_xc_1c_{23} + a_ys_1c_{23} - a_zs_{23})^2}}{-a_xc_1s_{23} - a_ys_1s_{23} - a_zc_{23}}\right] and \; -\theta_5$$

$$\theta_6 = A\tan 2\left[\frac{-s_xc_1s_{23} - s_ys_1s_{23} - s_zc_{23}}{n_xc_1s_{23} + n_ys_1c_{23} + n_zc_{23}}\right] and \; \theta_6 \pm 180°$$

7. Characteristics of the remote control (I^2C-bus)

The I^2C bus is for 2-way, 2-lines communication between different ICs or modules, The two lines are serial data lines (SDA) and serial clock line (SCL). Both lines must be connected to positive supply via a pull-up resistor when connected to the output stages of a device. Data transfer may be initiated only when the bus is not busy.

7.1 Bit Transfer

One data bit is transferred during each clock pulse. The data on the SDA line must remain stable during the HIGH period of the clock pulse as changed in the data line at this time will be interpreted as control signals as shown.

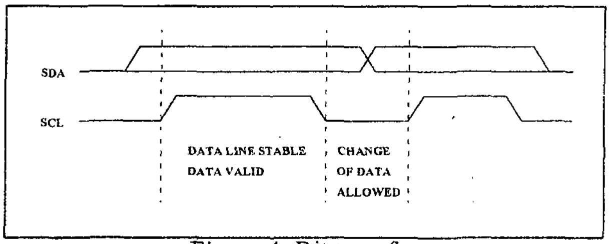


Figure 4: Bit transfer.

7.2 Start and stop conditions

Both data and clock lines remain HIGH when the bus is not busy. A HIGH to LOW transmission of the data line, while the clock is HIGH is defined as the start condition (S). A LOW to HIGH transmission of data line while the clock is HIGH is defined as the stop condition (P).

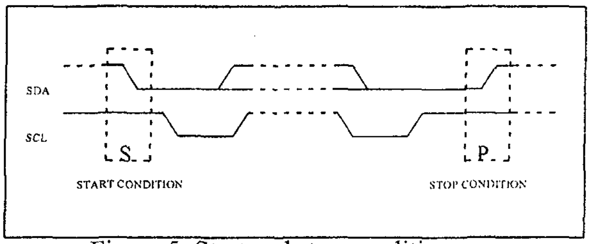


Figure 5: Start and stop conditions.

7.3 System configuration

A device generating as message is a "transmitter" , a device receiving is the "receiver". The device that controls the message is the "master" and the devices, which are controlled by the master, are the "slaves". Figure below present the system configuration for this robot control

7.4 Acknowledge

The number of data bytes transferred between the start and the stop conditions from transmitter to receiver is not limited. Each byte of eight bits is followed by one acknowledge bit. The acknowledge bit is a HIGH level put on the bus by the transmitter whereas the master generates an extra acknowledge related clock pulse. A slave receiver which is addressed must generate an acknowledge after the reception of each byte. Also a master must generate an acknowledge after the reception of each byte that has been clocked out of the slave transmitter. The device that acknowledges has to pull down the SDA line during the acknowledge clock pulse, so that the SDA line is stable LOW during the HIGH period of the acknowledge related clock pulse, set-up and hold times must be taken into account. A master receiver must signal an end of data to the transmitter by not generating an acknowledge on the last byte that has been clocked out of the slave. In this event the transmitter must leave the data line HIGH to enable the master to generate a stop condition.

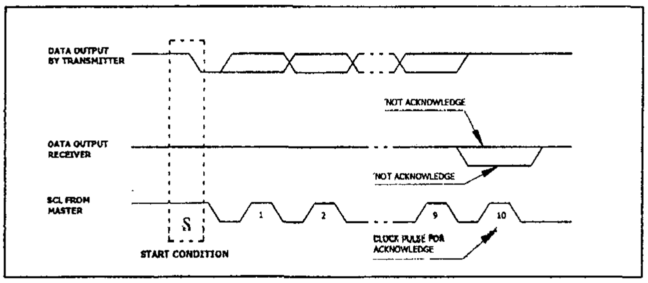


Figure 6: Acknowledgement on the I^2C-bus

The number of data bytes transferred between the start and the stop conditions from transmitter to receiver is not limited. Each type of eight bits is followed by one acknowledge bit. The acknowledge bit is a HIGH level put on the bus by the transmitter whereas the master generates an extra acknowledge related clock pulse.

The slave receiver which is addressed must generate an acknowledge after the reception of each byte. Also a master must generate an acknowledge after the reception of each byte that has been clocked out of the slave transmitter. The device that acknowledge has to pull down the SDA line during the acknowledge clock pulse, so that the SDA line is stable LOW during the HIGH period of the acknowledge related clock pulse, set-up and hold times must be taken into account.

A receiver must signal an end of data to the transmitter by not generating an acknowledge on the last byte the has been clocked out of the slave, In this event the transmitter must leave the data line HIGH to enable the master to generate a stop condition.

8. Control Program

Visual Basic 6.0 program is developed for controlling to remote 8-bit I/O expander for I^2C (Inter-IC Communication) by PCF8574, which is a silicon CMOS circuit. It provides general-purpose remote I/O expansion for most controller families via the two-line bi-directional bus I^2C. Controller program is developed by relate to the forward and inverse kinematics formulation in the first section. This program can operate both teach mode and programmed mode. Teach mode will accept command from operator for guiding manipulator by real time controller.

Procedures for sending data to I^2C expander boards in control system.

1. Send start signals to expander boards.
2. Send address word to expander board.
3. Waiting acknowledge signal from expander board.
4. Send data signal to expander board.
5. Waiting acknowledge signal from expander board.
6. Send Stop signal to expander board.

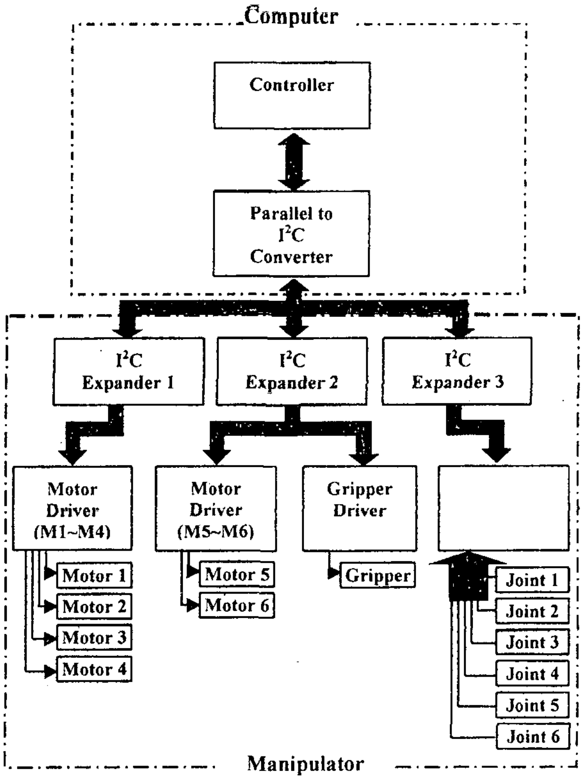


Figure 7: System configuration via the I^2C bus for robot control system

9. Controlled electronic components

Stepping motors are the driving source by worm gear transmission to the each joint of robot. Potentiometers are the feedback equipment for the position control in each joint. Sending pulse signals from controller to each stepping motor can control the velocity of each link of robot unless the feedback. The output signals and feedback signals are send via the I^2C bus by 2 lines of cable (SDA and SCL signal).

10. Testing of 6-axes articulate vertical robot

10.1 Testing Methods

Testing efficiency of robot by programming the motions. After that compares these motions between theory and actual, which are collected in each joint for measurement their accuracy and error are the point of experiments by sending data through the core 100 meters lengths via I^2C bus system.

10.2 Result of testing

The results of testing are distinguished in relation graph between desired rotation and actual rotation in each joint of robot, which all graph are shown in bel

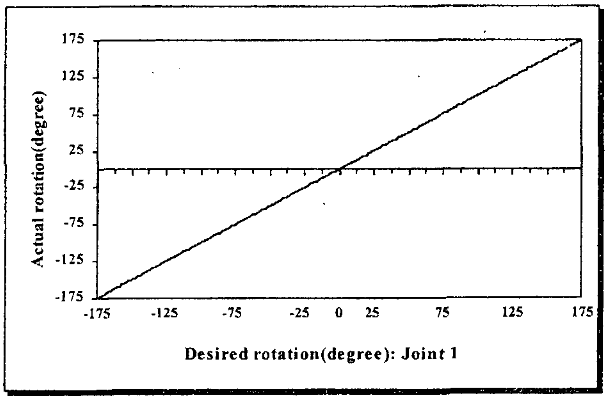


Figure 8: Graph of relationship between desired and actual rotation of joint 1 (Arm sweep)

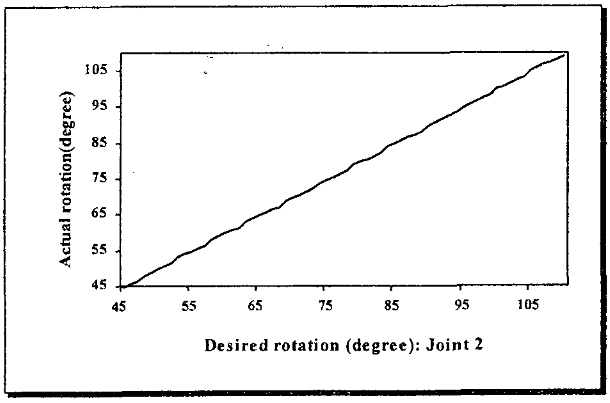


Figure 9: Graph of relationship between desired and actual rotation of joint 2 (Shoulder swivel)

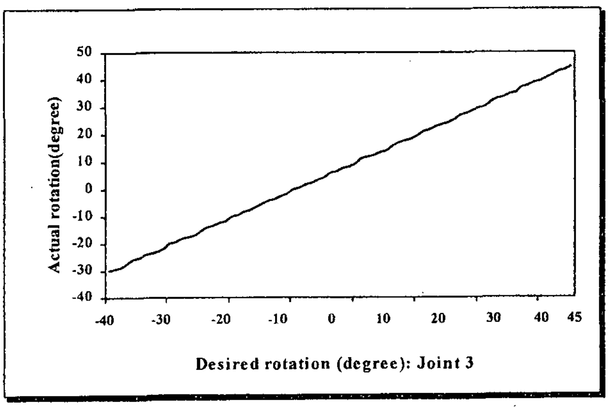


Figure 10: Graph of relationship between desired and actual rotation of joint 3 (Elbow extension)

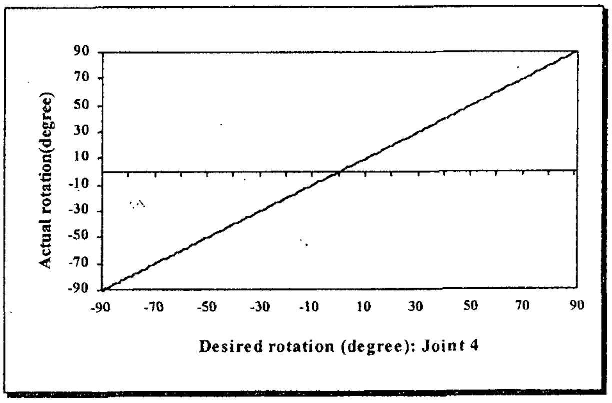


Figure 11: Graph of relationship between desired and actual rotation of joint 4 (Yaw)

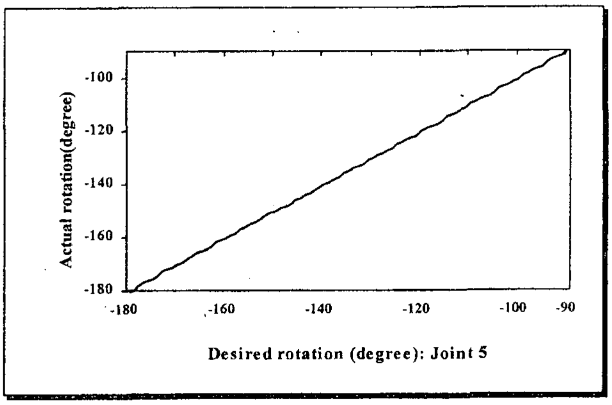
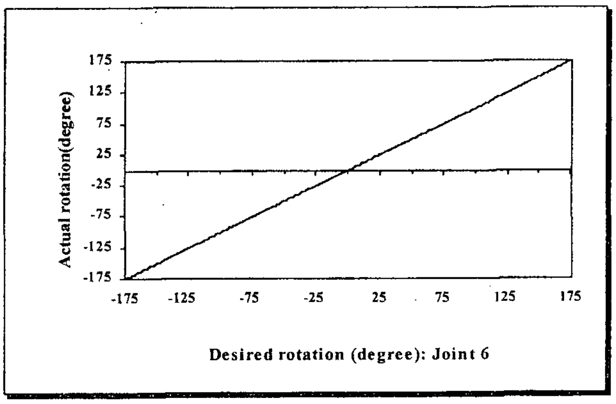


Figure 12: Graph of relationship between desired and actual rotation of joint 5 (Pitch)

Figure 13: Graph of relationship between desired and



actual rotation of joint 6 (Roll)

11. Problems and solutions

Structure: The structure of robot is not rigidity, reinforcements or re-construction should be applied.

Mechanical system: There are backlashes from gear transmission, high efficiency gear should be taken instead the current parts

Programming: The current program applies for point to point control. To improvement this program, contour control and simulation program will be developed.

Feedback control equipment: The resolutions of feedback equipment are only 8-bite. To increase efficiency of motion and accuracy, more resolutions should be applied, such as 16 bite or 32 bite.

12. The future improvement for advance robot

To access the optimization of robot motions by time reduction and optimize trajectory planning according to the customize objective with increase accuracy, the artificial algorithm should be used, such as Artificial Neural Network algorithms (ANNs), Genetic algorithms (GAs) or vision controller will be applied. And to make standardization of programming, the robot programming language will be the future study.

13. Discussions and conclusions

The research of 6-axes articulate vertical robot aims to develop the robot and control system for optimize time and motion of robot. For this research remote control system by I^2C bus is used to communicate with remote robot to expander the control system. Further more, control program is developed with feedback control for this system.

There are error in each joint of motion, which came from the resolution of feedback measurement equipment (potentiometers), resolution of analog to digital converter and the inertia from structure. To solve these problems, increasing resolutions of feedback meters and rigid structure improvement shall be achieved.

14. References

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