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Title: A Dual Axis Control Servo System* for Feed Positioning

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A dual axis control servo system* for feed positioning

Kamaljeet Singh Saini George Behrens

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1 Introduction

The antenna test facility at the NRAO Green Bank observatory has the test antenna mounted on the receive table, which sweeps it through the transmit beam of the standard antenna, to measure the beam pattern. The receive table has to be moved axially and laterally with respect to the transmit antenna to correctly locate the phase center. Previously, this was done manually by cranking the adjustment screws that move the table along the orthogonal axes to achieve the desired positioning. This note describes the dual axis servo control, implemented for positioning the receiver table via a command from the control computer. The implementational (both hardware and software) details are discussed and a brief “How to . . .” user introduction is provided as well. The user interface of the software is intended to be intuitive and requires little (if any) explanation.

2 System Overview and Operation

The linear motion of the table, on which the receive antenna is physically mounted, is effected by turning the screw corresponding to the desired axis. The screw is driven by a DC motor¹, which is controlled from a remote PC via a servo amplifier².

2.1 Servo Amplifier Adjustments

The gains and offsets of the amplifier are adjusted so that a zero input voltage to the amplifier produces no motor rotation, a $+10V$ produces the fastest possible revolution rate from the motor in one direction, while a $-10V$ produces the fastest revolution in the other direction. This is done by setting the amplifier

*Based on 5638 PC plug in card, from Industrial Computer Source. This particular implementation is “PID” type.

¹The DC motor is a brushless type from Globe Motor

²The amplifier is a 12A Series PWM Servo Amplifier from Advanced Motion Controls.

gain so as to produce a 24V output(maximum input rating for the motor) corresponding to a 10V input to the amplifier. The 5638 controller card is configured to produce a control signal with a maximum symmetric swing of $\pm 10V$ around zero to match to the servo amplifiers' requirement. The amplifier current limits are set so that the current sourced by the amplifier into the motor never exceeds the maximum rated motor current. The amplifier implements current limiting by decreasing the output voltage when the limit is reached.

2.2 Position Encoder, Feedback and Control

The change in position is sensed using a 750 line resolution incremental encoder located at the other end of the shaft. The 5638 PC plug-in card implements a servo loop using this position feedback as explained later. (The card provides a PID control signal, though the encoder provides only incremental position signal to the 5638 controller.) The commanded destination is converted into the required number of revolutions by the computer, while the controller makes the required trajectory calculations to determine the optimum velocity profile needed to execute the move. Appropriate voltage is then output by the controller to move the motor. The actual move really consists of a series of smaller moves with appropriate velocities as computed by the controller. The controller constantly monitors the deviation of the current position from the expected position and generates a drive signal having its components proportional to the error, proportional to the integral of the error, as well as proportional to the rate of change of error. The feedback gain factors; K_P , K_I , K_D as well as the time period of error integration, I_L have been optimized for optimal loop performance without oscillations.

2.3 Co-ordinate System Convention

We shall use the right handed cartesian coordinate system to describe the movement axes. The movement to or away from the transmit antenna will be considered as movement along the Y-axis, while that transverse to this will be considered to be along the X-axis. We shall consider the *home* position to be the origin: the point located midway between the extreme positions along either axis. As usual, movement towards the transmit antenna shall be deemed positive Y-motion, and that towards the right as positive X-motion.

2.4 Determining the Reference Home Position

Since the position encoder is incremental, the system has no way of knowing its home position at power up. This problem is solved by locating an index³ switch, near the positive extreme of each axis. The logic for either axis is similar, so only details for Y-axis will be described hereafter. At power up, the controller commands the motor to move towards the positive end of the axis till it hits

³ Actually, this is an extra limit switch located just inside the positive extreme limit switch of either axis.

the index switch located there. The index is sensed by the controller, which then computes the location of the zero of the axis relative to the position of this index, and commands a move to that position. Once the above procedure is completed for both of the axes, the current position becomes the known home position. This procedure will be referred to as *homing* in the further discussion.

3 Control Software and the User Interface

On starting up, the program initiates the homing procedure⁴ to establish the origin. This procedure could take up to about five minutes⁵ depending upon where the antenna carriage was at last power down. While executing the homing procedure, messages are continually displayed on the console indicating the current status of the procedure. Once the homing, as described already, is complete, the software brings up the user interface, and is ready to take commands from the operator. This section describes the Version 1.12 of the control software, which is the first release.

3.1 The Control Menu

The following options are available to the user from the control menu, which comes up by default after the homing procedure is completed. The commands selected from this menu are issued to the currently “active” axis controller. Which of the two axes is “active” is displayed on the first line of this menu. After the powerup and homing procedure is complete, the Y-axis is active by default, till it is changed by a selection from the system menu (see later.)

[Execute an absolute move] Use this option to indicate the *absolute* position of the desired destination along the chosen axis, in inches, in accordance with the coordinate system convention described earlier.

[Execute a relative move] This option can be used to specify the desired destination position with respect to the current position, again in inches. The sign of the offset thus specified is used to decide the direction of the move, and is consistent with the coordinate system convention being used.

[Return to home position] This is used to move the carriage to the zero of the selected axis. To position the carriage at the origin, execute this command once for each axis.

[Index current position] This causes the current position on the axis to be remembered, and makes it easy to return to the same position later on by issuing a *Move to index position* without having to actually provide the coordinates.

⁴Prior to starting the program it must be ensured that the “mode” selector switches on the front panel are toggled to “auto” for both axes.

⁵The homing operation can be aborted by hitting any key. The program stops the motors at their current locations and exits to DOS.

[Move to index position] This moves the carriage to the previously saved index position for the current axis. If no index position has been saved, index position defaults to the home position of the axis. Therefore, issuing this command without previously having saved an index position along the axis would move the carriage to the zero position of the axis. Note that the currently marked index position is indicated at the top of the menu, along with the current absolute position for the active axis.

[Goto system menu] This option brings up the system menu, which provides options to switch axis controllers etc. and is described in the next subsection.

[Exit to DOS] This ends the user interface, issues a motor shutdown command and exits to DOS. Issue this command to end a session. This causes the program to lose the home position and index positions, if any. Restarting the program would cause another homing procedure to be initiated afresh.

As soon as an option is selected and the data prompted for supplied, the controller initiates the move towards the requested destination position. The direction of the move is indicated on the console by a suitably oriented arrow, and the progress of the move is indicated by a bar which “fills” up to indicate the percentage of total distance traversed. Once the move is complete, the controller computes the error between the attained position and the requested position in units of encoder counts and displays this number as *Position error during previous move*. It then waits for another user command. Note however, that the request may be denied if the destination position is beyond the software limits for the selected axis. Such illegal requests are discarded, and the program waits for a valid request after issuing a warning message.

3.2 The System Menu

This menu provides the following options when invoked from the control menu:

[Select X-Axis controller] After powerup when the homing procedure is complete, the Y-axis is active by default. This option allows the user to switch the active axis to X-axis. All the control commands issued henceforth go to the X-axis.

[Select Y-Axis controller] This selects Y-axis to become the active axis, causing all control commands to be issued to this controller. Notice that both the control and the system menus display the current active axis prominently.

[Return to position menu] This option returns to the control menu, leaving the active axis status unaltered. Further positioning commands can then be issued from the control menu.

- [Exit to DOS]** This ends the user interface, issues a motor shutdown command and exits to DOS. Issue this command to end a session. This causes the program to lose the home position and index positions, if any. Restarting the program would cause another homing procedure to be initiated afresh.
- [Modify upper SW limit for X-axis]** There are four “modify SW limit” commands including this one, and are not meant to be used during normal operations. The limits can be altered, and any further movement of the axis is restricted to within the limits that were most recently set. Do not alter these limits, and *never* request values which exceed the default values. That could cause the carriage to hit the limit switch (which would require a manual over ride to correct) or even derailment of the carriage. This option is used to modify the positive software limit for the X-axis.
- [Modify lower SW limit for X-axis]** This option is used to modify the negative SW limit for the X-axis.
- [Modify upper SW limit for Y-axis]** This option is used to modify the positive SW limit for the Y-axis.
- [Modify lower SW limit for Y-axis]** This option is used to modify the negative SW limit for the Y-axis.
- [Restore all SW limits to default]** Selecting this option causes all the four SW limits to be restored to their default value. The default values are: ± 2.3 inch for the X-axis and ± 10.0 inch for the Y-axis.
- [Display the co-ordinate system]** This causes the user co-ordinate system convention (as described earlier) to be graphically displayed on the console.
- [Temporary exit to system shell]** This suspends the program and provides a DOS shell by spawning a new copy of the command interpreter. Once in the shell, type “exit” to return to the program.

3.3 The Service Bypass Mode: A Backdoor Entry

When the controller software is first started, it normally initiates the homing procedure without any intervention. However, it is possible to intervene and bypass the homing procedure. This is done by keying in the magic word “bypass” (lowercase letters only) before the homing procedure begins. Note that after the software starts, about two seconds elapse before the homing procedure initiates. (The controller hardware is initialized during this period.) All the six letters in the magic word should be keyed in before the homing procedure initiates, otherwise they will be discarded as stray keystrokes, and homing will begin as usual.

The user is cautioned against using this option, as it forces the current position of the carriage to become the home position. This may be different from the

true origin of the coordinate system. Thus the software limits are meaningless, and it is possible to drive the motor into limits while operating in this mode. The mode was originally incorporated to save time, by bypassing the homing procedure, during the developmental phase. However, the facility was allowed to remain as it was found to be useful, particularly during installation, when it was sometimes necessary to just run the motor in a particular direction. (The homing procedure became a nuisance under such circumstances.) The words, "System in service bypass mode", continually flash on the top bar on the console when operating in this mode. (The line normally reserved for displaying the software version number etc.) The remaining functions are however unaltered.

In view of a possible hazard while operating in this mode, it is recommended that the user exit as soon as the housekeeping operations are over, and restart the control software in the usual user mode before commencing with the regular experimental work.

4 Safety Features

To ensure the safety of operation at all times, several checks have been built into both the software as well as the hardware of the system. These are described in the following paragraphs.

4.1 The Watchdog Timer

Should the controller computer hang while a move is in progress, the motor would turn endlessly, eventually derailing the table. This is overcome by enabling the watchdog timer on the 5638 controller card. The timer is refreshed at a regular rate, and should a refresh fail to happen, as would be the case if the computer hung up, the watchdog timer automatically generates a control signal to switch off the motor through a switch. This would cause the motor to coast to a stop as soon as the computer happened to hang and thus prevent any damage.

4.2 Operator Error and Software Limits

Once the homing procedure has been successfully completed, the computer knows the maximum limits to which the table can be moved along each axes. It compares the destination requested by the operator with these limits and *refuses* to accept any command which would require movement beyond these limits. These limits are what are termed as the "Software Limits". Should the operator issue a command to move beyond these limits, the program discards the command, issues a warning message, and requests another command. It leaves the table at its previous current position.

It is to be noted that these software limit checks are invalid if the software is put in the "Service bypass mode" as described earlier.

4.3 Limit Switches and Manual Over-ride

In case all the above safety features fail to contain the movement within the safe limits, there is a provision of limit switches and a manual over-ride. There is a limit switch located at each end of the axes, and the motor power is fed through the “normally closed” contacts of these switches wired in series. Should the table hit one of the limit switches, it will open the circuit, cutting off power to the motor and causing it to stop. This lights up an LED on the control panel indicating which limit has been violated, and then it is possible to manually operate a switch and move the motor back along the axis to a safe position. For instance, if the “right” limit is violated, the table may be moved left by depressing the switch labeled “left”. Three other switches labeled “right”, “front” and “rear” provide the other desired directions of movement. (Moving the table manually in this fashion requires that the “mode” selector switch corresponding to the desired axis be toggled from “auto” to “manual”).

Since this would happen only under unforeseen circumstances, there is no way the software could be made to handle the situation. Under such a circumstance, the software issues a warning that an “unexpected” limit has been reached, issues a software motor shutdown command (a precautionary measure) and aborts. It is then necessary to re initialize the system, and perform another homing operation before continuing.

5 Software Development and Hardware Configuration

The control software and the user interface were written in C and compiled and linked using Turbo-C Release 2.0. Interrupts are used, to enable the signals from the limit switches to notify the CPU. The watchdog timer is also refreshed by an interrupt handler. As such the program restores the original interrupts when exited by the *Exit to DOS* command. However, exiting the program by “brute force” methods like CTRL-C, CTRL-BREAK etc. may terminate the program without updating the interrupt vector table. This may cause the PC to hang later, besides the risk of leaving the motor running—if it was in that state when the CTRL-C was issued. This could cause hitting the limit switches, and require a manual over ride later to correct the situation. So a graceful program termination by proper selection from the menu is recommended. The 5638 controller card is configured to use the interrupt line IRQ5 to interrupt the processor, and software handlers are provided for the same. This IRQ line was chosen, since IRQ5 is normally bound to an exception processing for LPT2, and would normally not be used. Any change to the IRQ configuration on the card, will require an appropriate update to the variables in the source code, followed by a recompilation⁶. This is true for the board address as well. Currently the board is configured to use the board address 0x390, global address 0x380,

⁶Recompilation will require the header file 5638inc.h and the library file t5638s.lib, both of which are provided on the 5638 cards' companion software disk.

IRQ5, limit active with current, and a single ended (non differential) quadrature encoder with index line. See the 5638s' documentation for configuration details.

Should any change be made to the interrupt routines, it is to be remembered that DOS interrupts are not re-entrant, so calling any function (like printf() etc.) inside the ISR will cause the system to hang. Such functions are not to be used inside the ISRs.

6 Acknowledgments

We would like to thank Rich Hall, who wired up the system in its final form, once the prototyping and testing phase was over.

Simplified signal diagram showing components for one axis of motion.

(Similar loop exists for the other axis. The 5638 is able to process signal for both the axes.)

12A series PWM servo amplifier:
It accepts the error signal from the controller card provides the drive signal for the DC motor. It has built in current limit so that the maximum current limit of the motor is never exceeded.

5638 PC plug-in controller card:
The various servo loop constants are programmed in this card. It performs the necessary calculations and provides the signal to drive the motor via the servo amplifier.

