# Adaptation Of A Commercially Available Off-The-Shelf Multi Axis Motion Controller For Radio Telescope Control

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## ABSTRACT

*This paper presents the details of the adaptation of a commercially available Programmable Multi Axis Controller (PMAC) for the control of a 12m preloaded parabolic dish antenna operating in the frequency range 0.5 - 8GHz. PMAC offers the capability of controlling multiple axes simultaneously. It is well suited for a cluster of telescopes. Different aspects related to the design, development and testing of the control system are described. The paper also discusses the design and development of a Linux PC based secondary control path, which provides redundancy and enhanced reliability.*

## 1. INTRODUCTION

The basic function of a radio telescope is to track a radio source in the sky in real time. One of its main requirements is high pointing accuracy. The pointing accuracy required is typically of the order of 1/20th of the resolution of the dish or better. The dynamic speed range required is very high. The motor speeds can be as low as stall speeds during tracking and maximum rated speed during slewing. The low speed requirement compels the designer to use gearboxes with a high gear ratio. A system with a large gear ratio tends to have errors due to backlash in gears. Hence backlash elimination techniques play a vital role in the control system design [1]. The load characteristics vary widely over the entire dynamic range, being highly inertial during slewing to highly frictional during tracking. Most often the load is highly nonlinear due to static friction at very low speeds. This necessitates the use of an innermost current loop for torque control. All these factors should be taken into consideration while selecting a position controller for a radio telescope.

A 12m Preloaded Parabolic Dish (PPD) antenna, which operates in the frequency range 0.5 to 8 GHz, is being built at the Raman Research Institute (RRI). The telescope uses an alt-azimuth mount with slew ring drive in the azimuth axis and sector gear drive in the elevation axis. The overall gear ratio used is 14320 on azimuth and 27562 on elevation. The telescope uses a new and an economical concept based on preloading the dish backup structure. The main thrust of the new design is the simplification of the backup structure, which minimizes the inertia and wind loads on the dish [2]. The design can provide a large collecting area over a wide frequency range for the Square Kilometer Array (SKA), at an affordable cost.

A control system for the telescope has been developed in-house. The main requirement of the control system is its pointing accuracy better than 40'', approximately equal to one-twentieth of the half power beam width of the 12m dish at 8GHz, the highest operating frequency envisaged. The expected control system bandwidth is higher than 1Hz. The system should meet the speed requirement of 0.025 to 25 deg/min during tracking and a maximum speed of 40 deg/min during slewing.

## 2. CHOICE OF A COMMERCIALLY AVAILABLE OFF-THE-SHELF (COTS) CONTROLLER.

One of the main design criteria was to develop a control system, which would initially be used to control a single dish and could later form a basic building block of the SKA. The control topology could be a single controller, controlling several telescopes from a centralized control room or could be a distributed controller. Multi-axis controllers that are available off-the-shelf correctly fit into the scenario of a centralized control for an array of telescopes. Most of these commercial controllers are tailor made for CNC machine control and other control applications like robotics. The programming is either through standard G-code or M-code, which are rarely used by the scientific community. The Programmable Multi Axis Controller (PMAC) provides programming capability, in a C “look alike” native programming language [3] with a wide variety of mathematical functions. This made us to consider PMAC as a candidate for the telescope control application.

## 3. FEATURES OF PMAC.

PMAC is a family of high performance servo motion controllers based on Motorola DSP 56303 at 80MHz. It is capable of controlling up to 32 axes of motion simultaneously. This multi-axis control feature is very attractive when looked from the array point of view. It can run up to 256 motion programs and 32 PLC programs simultaneously and can provide a servo update rate of 440μs. PMAC comes with a wide variety of accessories like encoder interface, real time clock, A/D, D/A and DIO cards. Internally, PMAC is a multi processing system with dedicated ASIC's handling different tasks. On this hardware platform resides a pre-emptive type multitasking operating system, which uses priority scheduling. This scheduling scheme helps each task, program or PLC to run independent of each other in real time. PMAC incorporates features like advanced PID control algorithms, "lookahead" feature for highly accurate acceleration and velocity control and "S-curve" acceleration and deceleration. It also supports a dual feedback system, which takes position feedback from both the motor end and the load end. These features make PMAC an ideal candidate for telescope control applications.

## 4. OVERVIEW OF THE 12m TELESCOPE CONTROL SYSTEM

In the 12m radio telescope control system, PMAC acts as the position controller. We are using brushless DC motors as prime movers and PWM based brushless DC drives for velocity control. Brushless DC motors have the advantage of less wear and tear due to the absence of brushes. The low rotor inertia helps in the design of high bandwidth systems. PWM based drives work at switching frequencies in the kHz range. This avoids excitation of the natural frequency of the mechanical structure. Two 17-bit absolute single turn encoders, provide position feedback on azimuth and elevation axes.

One of the major problems faced in a radio telescope control system is the backlash in gears. In our design, the method adapted to minimize the effect of backlash is called backtorquing. In our system, two motors driven with an offset in their commanded velocities are used to control a single axis, thereby minimizing the backlash in gears .The method is usually called the biased motor method.

Fig. 1 shows the basic block diagram of the 12m radio telescope control system. A PC on the Observer's desk sends source coordinates (RA and DEC) to the PMAC Control PC. The PMAC Control PC takes these coordinates and passes it on to the PMAC motion program control variables. The astronomical co-ordinate system conversions have been implemented inside PMAC, in its own native programming language. The actual sidereal time information required for the conversions is calculated from PMAC real-time clock. The program continuously calculates the expected azimuth and elevation angle from the source coordinates and passes it on as position command to individual PMAC servo channels.

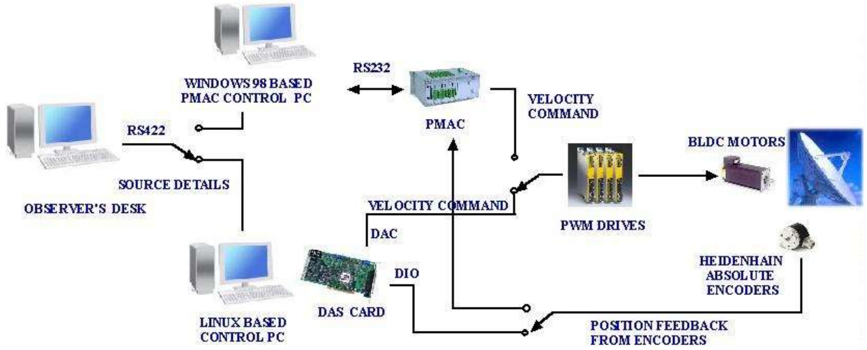

*Fig.1: Basic block diagram of the 12m radio telescope control system*

## 5. MAIN CHALLENGES IN ADAPTATION

The main challenge in the design involved adapting PMAC meant for structurally stiff CNC machines to a highly inertial system like a radio telescope. Most commands in PMAC are designed for machine tool requirements and are in the form of X-Y move commands or start-stop commands. In order to achieve continuous motion out of these X-Y move commands, we have split the motion into infinitesimal segments and repeatedly executed X-Y move commands. Thus a continuous tracking motion profile was achieved.

Most CNC machine tool systems are designed with ball screws, which have virtually zero-backlash. Hence the position feedback is taken directly from an incremental encoder fitted directly on the motor itself and the position loop is closed using this feedback. However, radio telescopes, which make use of huge gear ratios with high backlash, cannot take position feedback from the motor encoders. This forces one to use an encoder, which takes position feedback from the load end. In our system, we are using an ENDAT (Encoded Data) type encoder of 17-bit resolution. However PMAC provides accessories for interfacing SSI (Synchronous Serial Interface) type encoders only. Hence an interface circuit for adapting ENDAT type encoders to the SSI interface of PMAC has been developed in-house.

## 6. THE LINUX PATH

As a part of increasing the reliability of the system and taking into consideration the advantages of an open source [4], an alternate control path, which makes use of a Linux based PC as position controller has been developed. The Linux path could also act as a single dish controller for an array when considering a distributed control topology. Being built in-house it provides the flexibility in implementation of different control system methodologies and architectures. The system consists of a centralized Linux PC which interfaces to the control system hardware through commercially available PCI based Data acquisition card and Digital I/O card. The Data acquisition card interfaces with position encoders for acquiring position feedback. It also commands the motor drives for motion control. The Digital I/O card interfaces with the safety interlocks and focus control systems. The software modules developed in C has been divided into different processes, which communicate with each other through shared memory. The major design criteria have been to separate the non-critical time consuming tasks from critical servo tasks, thereby achieving a faster servo update date (at present 10ms).

## 7. TESTS CONDUCTED

As a part of testing the entire control system in closed loop, a control system test rig (See Fig.2a) that simulates conditions similar to an actual telescope system, has been developed. The setup consists of two Brushless DC motors connected to a common loading shaft by means of high backlash love-joy couplings. The couplings introduce a backlash of approximately $34^0$. This common loading shaft is connected by means of a belt drive to a gearbox arrangement with an overall ratio of 1:25000. The output of the gearbox is connected to a 17 bit absolute encoder, which gives position feedback. The system can be loaded electrically by means of a DC Motor run in current control mode. The electrical load imparted by the DC Motors in current control mode is reflected as a mechanical load on the brushless motors. Hence the actual load conditions as seen at the motor in the telescope can be simulated. Using this test setup, we have carried out tests for checking the tracking accuracy of the system under simulated constant load conditions, with PMAC as the position controller. We have been able to achieve a tracking accuracy within one bit of the encoder resolution i.e. ±10" (See Fig.2b).

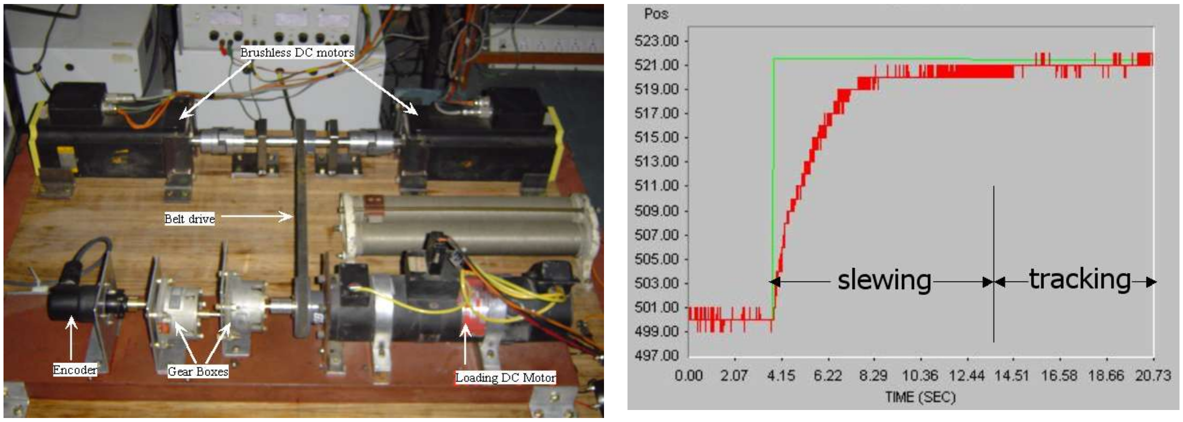

*Fig.2a* *Fig.2b*

*Fig.2a: The control system test rig. Fig.2b: Response of the system to a step excitation. Y-axis shows position in encoder counts. System slews from a position of 500 counts to the source at 520 counts.*

We have also carried out tests to check the performance of the control system during backtorquing in biased motor method. We have been able to reverse the direction of rotation of the load without any zero velocity dead band usually caused by backlash. (See Fig.3a and Fig.3b)

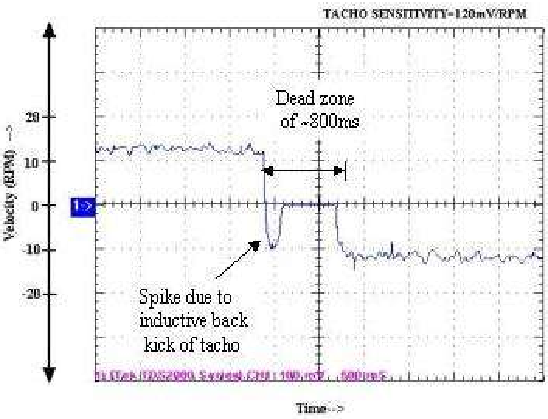

*Fig.3a*

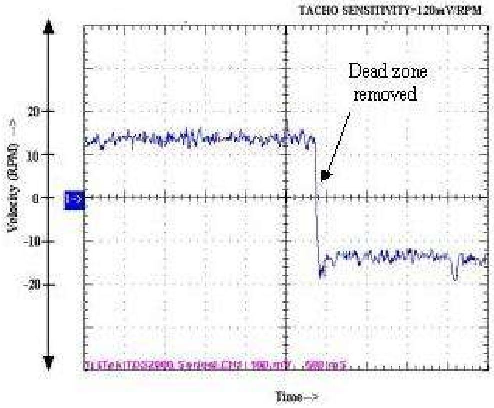

*Fig.3b*

*Fig.3a: Velocity of loading shaft without backtorquing. The dead zone of 800ms is caused due to the backlash in love-joy coupling. Fig.3b: Velocity of loading shaft with backtorquing. The smooth reversal of the velocity indicates successful backlash elimination.*

## 8. PRESENT STATUS AND CONCLUSION

The control system for the 12m radio telescope has been configured using both the PMAC and the Linux paths. It has been tested using simulated conditions. In terms of achievable servo update rates, the hardware path using PMAC far out beats the PC based Linux path by a factor of 100 or more. The development time for interface hardware as well as control algorithms is much less compared to the PC based path. It could be an ideal candidate for the control of small arrays with 10-16 telescopes or can act as a controller for a sub array, forming part of a larger system like the SKA. The cost per axis will be comparable to a PC based control strategy. However, adaptation of the controller to telescope scenario still takes considerable development time mainly due to the interface with non-conventional subsystems associated with telescope control. Introducing changes in the control flow or trying out new control algorithms is almost impossible. Many advanced features provided in the controller for CNC applications do not prove useful in the telescope control scenario. However, the high servo update rate still makes it, an preferred choice for an array with a centralized control.

The 12m Radio telescope fabrication work is in the final stages of completion and the next step is to try out the control system developed, with the actual telescope.

## 9. REFERENCES

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