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The Green Bank Telescope Laser Metrology Computer Control System

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Abstract. To use the 100-meter Green Bank Telescope at millimeter wavelengths, the antenna surface must be continuously adjusted to compensate for environmental effects. The metrology system, comprising a network of infrared laser rangers, has been developed to measure the position of the surface to an accuracy of 50 microns. The metrology computer control system is described here. The embedded systems which point the 18 lasers and take range measurements are based on Intel x86 computers. The central control of these computers is done using a Pentium PC running Windows NT. Engineering displays of the data are produced by piping the data in real-time to Microsoft Excel.

1. Introduction

The GBT is a fully steerable, offset paraboloid radio telescope currently under construction at the National Radio Astronomy Observatory's Green Bank, WV site[1]. It has a main reflector that is 100 by 110 meters in aperture, with a 60 meter focal length. As this massive telescope is moved in elevation, the main dish backup structure will deform. To bring the main reflector surface back to an acceptable parabolic shape, the GBT will feature an active surface, which consists of 2209 panels (each with a surface accuracy of 100 μm RMS) joined at the corners by actuators designed to provide approximately $\pm$ 1 inch of travel. In addition, the massive feedarm assembly will bend, causing the receivers to move relative to the telescope's prime focus. To compensate for this, and other factors such as thermal expansion of the structure, the GBT will have an ellipsoidal secondary reflector that can be driven to maintain the Gregorian focus on the desired receiver.

The telescope will feature a laser metrology system (Payne, Parker, & Bradley 1992) that will be used to quantify these deformations, and also to locate cardinal points on the structure to enable high precision pointing of the telescope. The laser metrology system consists of 12 individual laser rangefinder units located on the ground in a 240 meter diameter circle centered on the telescope's pintle bearing, and six more mounted on the telescope's feed arm. The ground based rangefinders will measure the cardinal points on the telescope, allowing the position of these points to be fixed with great accuracy. The feed

[1] `http://www.gb.nrao.edu`

arm based rangers will measure the position of 2209 corner cube retro-reflectors mounted on each panel near the actuators.

2. Metrology Computer System

The metrology system is controlled by several computers arranged as a distributed system. The basic unit of the metrology system is the laser rangefinder itself, known as the ZY unit (Parker 1991). This unit is mounted at a known location either on the ground or on the telescope and can measure ranges to pre-determined targets. These units are controlled over an ethernet connection (using TCP) by a master process known as the ZIY, whose job it is to unify the various rangefinders to provide a complete system. This system in turn provides ONC RPC interfaces to the rest of the telescope system.

Early in the development of the metrology system, the decision was made to use commercial off-the-shelf (COTS) components whenever possible, as overall cost and development time were important considerations. Because the system did not have any real-time requirements, and because the data throughput for this system would be quite low, x86 ISA bus components were selected to control the hardware and DOS and Windows NT were used to run the software.

2.1. Laser Ranger Computer Hardware

The laser ranger system's mission is to measure a range from a reference point located on the instrument to the selected target retroreflector. The laser itself is a modulated semiconductor laser whose beam is placed in the instrument's optical axis by a system of mirrors and prisms. A 2 axis mirror then redirects the beam to the chosen retroreflector target. The return beam is redirected to the detector optics by the same mirror. The detected return signal is demodulated and mixed, and the resulting signal is then sampled by a 100 kHz 16 bit A/D converter. The ZY software then converts these data into raw phase and amplitude, and from there these data are further refined into a range measurement.

The following components accomplish this task:

- A 2 axis motion control board from Octagon Systems is used to control the 2 axis mirror that the ZY uses to aim the laser at targets. This controller is based on the National Semiconductor LM628 Precision Motion Controller.
- A Quatech DAQ-16 100 kHz, 16-bit A/D converter is used to generate reference signals and to digitize the detected and converted phase signal.
- A Bancomm bc630AT Real Time Clock, connected to an IRIG-B time signal, provides accurate time stamps and allows the scheduling of operations.
- A 24-bit digital I/O adapter is used to read switch positions and operate the RF Oscillator and servo amplifier power supplies.
- A 130 MHz AMD 5x86 based Single Board Computer (SBC) from Industrial Computer Source provides ample processing power and control over the peripherals.

All of these components are mounted in an industrial ISA card cage and enclosed in a weather proof enclosure.

3. ZY Software

When the decision was made to use x86 hardware for the ZY prototypes, no real-time requirements were identified for the software and therefore DOS was initially used for the ZY system's OS. Initially, this decision was driven by the desire to keep costs down. At the time, the ZY system was experimental, its ultimate success very much an open question. As the system evolved from an experimental, proof-of-concept system to near production prototype status, DOS has continued to serve well.

To avoid losing hardware events, all hardware devices are supported by interrupt service routines. Other time critical tasks are also performed in interrupt service routines, and assembly language is used in areas where high performance was critical.

This x86/DOS system has proven to have certain advantages:

- Excellent, inexpensive software development tools were readily available.
- The ZY program code has proven remarkably immune to processor/SBC upgrades. The ZY software has run on processors ranging from a 4.77 MHz 8086 all the way to an 133 MHz AMD 5x86 based SBC with only minor changes to the sources.
- The GBT Metrology Group relies a great deal on temporary employees, such as co-op and summer students, to meet some of its manpower needs. The simplicity of DOS systems allows these team members to get up to speed quickly.

4. ZIY Software

The ZIY software currently consists of two main components. The main process, known simply as the ZIY, acts as the brains of the metrology system. It is in charge of orchestrating the actions of all of the ZYs that it connects to, and it provides the ONC RPC[2] interface to the metrology system through which any other GBT process must access this system. The second component, the ZIY Client, is an engineering client to the ZIY process. It is used for system tests and to conduct the pre-commissioning measurement program (Hall et al. 1998). The ZIY Client communicates with the ZIY through the interface provided by the ZIY. (This ZIY client will eventually be replaced by a GBT M&C client.)

Microsoft Windows NT was chosen to run both of these programs. In addition to being readily available and relatively inexpensive, NT has qualities that are well suited for both of these very different programs. For the ZIY, NT offers the following services:

- A capable threading API
- 32-bit flat address space
- Native TCP/IP support
- Service API
- Remote administration of service processes

[2] `http://set.gmd.de/~mfg/oncrpc.html`

In addition, NT provides the following services useful in the implementation of the ZIY client:

- A rich GUI API
- DCOM (Distributed Component Object Model) support

This last item has proven most useful for the Metrology Group. It has allowed us to automate data gathering and processing, using widely available and understood data analysis tools such as Microsoft Excel. Using DCOM, the ZIY client can automatically start Excel, and pipe data directly to the spreadsheet as they become available. The Excel spreadsheet itself is programmed (in Visual Basic for Applications) to place the data in appropriate worksheets and cells, and display real-time stripcharts of the data as they are received. Once all of the data have been received by the spreadsheet, our co-op student operators can run pre-written Excel VBA routines to further process the data and make it ready for initial presentation and analysis.

5. Conclusion

As the Green Bank metrology system shows, the use of inexpensive embedded PC components for computer control is a viable alternative to the more traditional solutions (VMEbus, StdBus), provided that the requirements are not extraordinary. The wide availability of ISA, PC-104 and CompactPCI components means that there is a large array of COTS components to choose from, allowing the embedded systems engineer to concentrate on the problem at hand rather than designing and constructing custom components. This abundance in hardware components is now complemented by the availability of solid, capable operating systems and tools, including commercial and freely available RTOSes for these systems. The result of this is the ability to create a computer control system quickly and inexpensively.

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