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COMPONENTS OF A SCALE TRAINING TELESCOPE FOR RADIO ASTRONOMY TRAINING

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Abstract

To establish the engineering and science background of Radio Astronomy in SKA African partner countries, a need was identified to develop a training telescope which would serve as a vehicle for demonstrating the principles. The Scale Training Telescope (STT) will be used as an interactive teaching tool for experiencing the basics of a radio telescope structure and control system development as well as its operation in practical applications, tracking sources and finding stationary satellites. The telescope aims to work as closely to a real radio telescope as possible. The STT allows students at various academic levels in different educational institutions the ability to access a scale version of a radio telescope design that can be assembled and operated by the students.

The paper describes the mechanical, electrical, electronics and software elements of the STT. The mechanical elements range from the structural base to the rotating dish of the radio telescope. The electrical elements incorporate the electromechanical components used to move the telescope as well as the wiring and powering of the telescope. The software is used to control the telescope system as well as collect, process and visualize the resulting data. A software-based user interface will allow the students to control and monitor the telescope system. The PLC-based (Programmable Logic Controller) control system facilitates the motion control of the telescope, in both the azimuth and elevation axes.

BACKGROUND OF THE STT PROJECT

The establishment of the Square Kilometer Array (SKA) Telescope in South Africa has provided an opportunity to develop Radio Astronomy not only in South Africa but also in the SKA African partner countries. As a result, an interactive training tool is required to assist in the introduction of radio astronomy.

By demonstrating the engineering and science of a full-scale radio telescope through a scaled model, radio astronomy on the African continent is given the opportunity to grow. Both the final product and the development processes are replicated [1].

The project is currently run at the Cape Town South African Radio Astronomy Observatory (SARAO) offices as part of a graduate-in-training group assignment designed to allow the graduates to explore the workings of an engineering project, collaboration between the different disciplines and, most importantly, the workings of a radio telescope. The departments that the graduates are in include project management, mechanical engineering, civil engineering, software development and electronic engineering.

The platform allows the graduates to network in the workplace as well as gain valuable experience in working in multi-disciplinary teams, all while in the learning phase of their employment. The current STT project is under construction.

While an overview of the mechanical and electronic systems will be given, it should be noted that the focus of this paper is the control system of the STT.

OVERVIEW OF STT PROJECT

A radio telescope is broken down into several subsystems that work together to achieve functionality, namely the telescope structure, the signal chain, the software system and the control system. In each of these subsystems there are hardware, specifically mechanical and electronic components, and software elements.

These subsystems are adapted for the scaled model to functionally resemble a full-scale telescope as closely as possible. The components are scaled down in size but retain functionality, allowing the possibility of the telescope software to be integrated to an extent that provides a further training platform for telescope operators.

The functions of the telescope include rotation of the dish in both azimuth and elevation, location of true north and 0° elevation, stowing, and displaying position as well as speed in both the azimuth and elevation positions. The telescope design also accounts for protection from damage during use in both elevation and azimuth directions, including an emergency stop feature.

MECHANICAL SYSTEM

By considering the mechanical functionality of a full-scale telescope, the sub-systems for the scale telescope are derived and designed. The main mechanical subsystems to be considered are the yoke and pedestal assemblies, the elevation drive assembly and the reflector assembly. In order to allow for maximum pointing and tracking accuracy, anti-backlash mechanisms are implemented in both the azimuth and elevation directions. The overall STT design can be seen in Figs. 1 and 2 [2].

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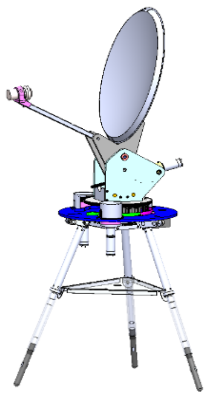

Figure 1: Planned STT mechanical structure.

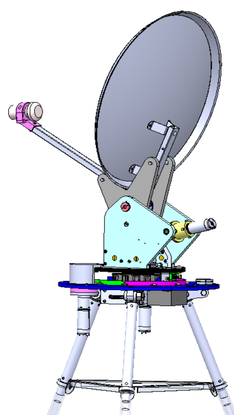

Figure 2: Side view of the STT.

The lower section of the telescope structure is the pedestal assembly, consisting of leveling tripod legs and a platform incorporating the azimuth motors and bearing for the main azimuth gear and location for the part of the control system electronics and cable wrap, as seen in Fig. 3, below.

Figure 3: STT pedestal assembly.

Attached to the pedestal assembly, the yoke wall assembly (see Fig. 4) provides support for the reflector assembly and elevation drive assembly. The azimuth bearing as well as the stow assembly are also incorporated in this assembly.

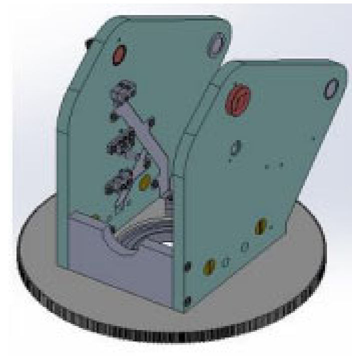

Figure 4: STT yoke assembly.

To make the implementation of the STT easier, a commercial 54 cm Digital Satellite Television (DSTV) dish and low-noise block downconverter (LNB) is used as part of the reflector assembly (Fig. 5). The dish and LNB receiver are attached to the yoke wall assembly as well as the elevation drive assembly, which drives the movement in the elevation (Fig. 6).

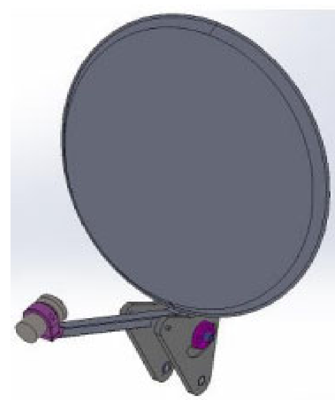

Figure 5: STT reflector assembly.

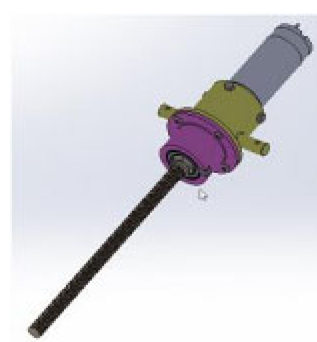

Figure 6: STT elevation drive assembly.

ELECTRICAL SYSTEM

In addition to the mechanical system being similar to a full-scale telescope assembly, the electronics are also mimicked by the scale telescope. Interfaces between the different electronic components are noted in Fig. 7, below,

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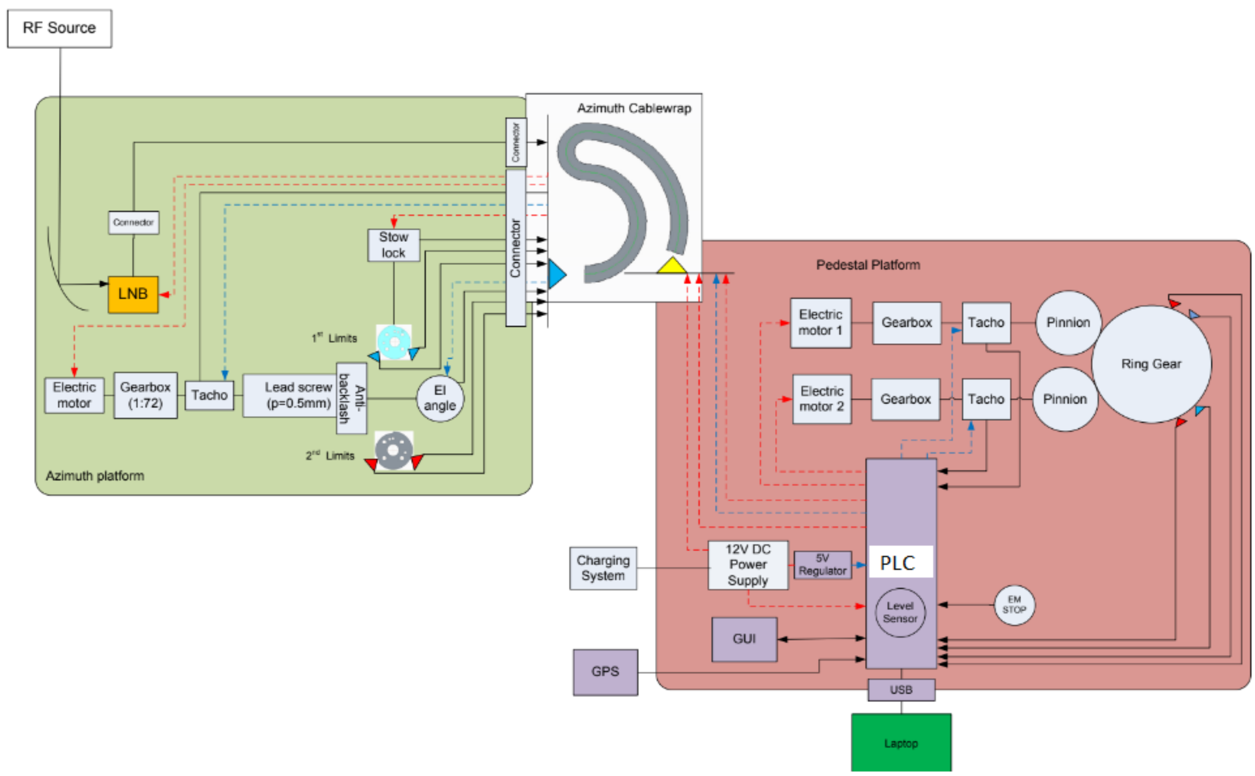

Figure 7: Block diagram for STT [2].

indicating the limit switches, motors, tachometers and encoders on the STT and the 12V DC power supply.

Limit switches provide the limits to the STT movement. The limits are split into 2 sets, first and second limits. The first limits being registered by the control system and the second limits acting like an emergency stop, protecting the telescope structure from damage. The limit switches in the stow assembly ensure alignment of the STT and the stow pin.

Both DC and stepper motors are incorporated in the STT. DC motors move the STT in azimuth and elevation directions, following the full-scale telescope design. The stepper motor is used for the stowing action.

In order to establish speed and position control of the azimuth and elevation axes of the STT tachometers and encoders are implemented in the design.

SOFTWARE SYSTEM

Telescope Control Software

The telescope control system software is a Programmable Logic Controller (PLC)-based controller system. The programmable controller utilizes the CANopen communication protocol for networking and communication with other components.

Currently a CANopen Control Simulator is being developed and used for testing prior to the physical PLC implementation into the training telescope. In conjunction with the simulator being developed from the software side, programming tests on the PLC have been taking place to verify the working of the PLC.

The PLC being implemented in the STT project is the Barth STG-800, later to be replaced with the Barth STG-850 as it is larger and allows for fewer to be connected in series. The PLCs are able to be daisy chained with each other through an CAN interface.

The PLC will interface all the electronic components with the software. The PLC is used in this case to make the interface with existing full-scale telescope software and protocols easier to integrate. The PLC consists of digital, analog as well as PWM pins that can be used to connect up the motors and sensors. The PLC interfaces with the laptop through a USB interface.

CANopen Interface

CANopen is a communication protocol based on the Controller Area Network protocol that is used in a control system. CANopen enables the connection and control of devices such as sensors and PLCs. A Virtual CAN (VCAN) was created which is used to initiate communication with the simulator and link the STT-PLC. When pointing and tracking the target, this enables for real-time data interchange.

Control and Monitor Software Architecture

Current Architecture The present architecture of our Telescope Simulation and STT CAM system is centered around a simulated environment, with a focus on precision telescope simulation and testing. The system comprises three core components: a Graphical User Interface (GUI), a Component Manager, and a Telescope Simulator. The

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GUI, developed using Python Flask, serves as the user interface for controlling the simulation process. Users interact with this web-based interface to input commands, configure simulation parameters, and initiate simulations. The Component Manager, implemented in Python, plays a pivotal role in managing the communication between the GUI and the Telescope Simulator. Using the Python CANopen library, it interfaces with the Telescope Simulator, a C++-based module responsible for performing accurate telescope simulations and generating results. The system leverages GPS data to ascertain real-time location information, including longitude, latitude, and altitude, enhancing the precision of simulations. Fig. 8 shows the current architecture more clearly.

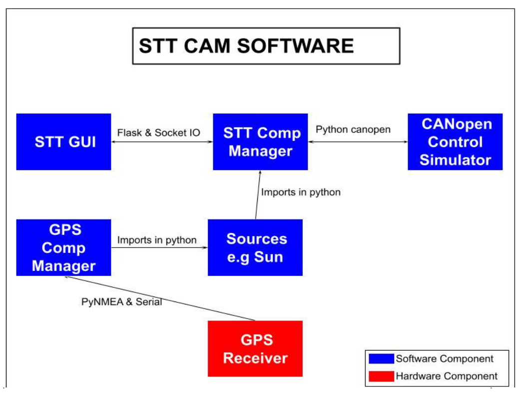

Figure 8: STT CAM.

Future Architecture In the future architecture, a transition from simulation to real hardware is envisioned, ushering in a new stage of practical experimentation and testing capabilities. The central shift revolves around replacing the Telescope Simulator with a real telescope system. The real telescope will be interfaced with a Programmable Logic Controller (PLC) using CANopen for communication. The GUI and Component Manager will remain integral components, serving as the user interface and control hub, respectively. The PLC will act as the bridge between our software system and the real telescope, with embedded control logic that interprets commands and orchestrates the telescope's azimuth and elevation movements. Safety measures will be a paramount consideration in the control logic, ensuring secure operations and emergency stop capabilities.

The introduction of a real telescope system necessitates careful testing, calibration, and validation to ensure its precise response to commands and alignment with our system's expectations. Furthermore, the GPS data will continue to play a crucial role in real-time location and time information, ensuring the accurate positioning of the real telescope. The evolution in architecture represents a significant leap forward, allowing our system to conduct practical experiments with real-world telescopes, ultimately enhancing the versatility and applicability of the STT CAM system in various domains, including telecommunications, satellite tracking, and telescope performance analysis.

Graphical User Interface

This section introduces the GUI component of the CAM Software used for interacting with the telescope control system. The GUI is an integral part of the CAM software responsible for facilitating user interactions with the telescope control system. The interface enhances the ease of controlling and monitoring the STT. Below the architecture, technologies, functionality, and protocols utilized in the GUI, highlighting its role in simplifying user interactions with the control system, are discussed. An example of the GUI is shown in Fig. 9.

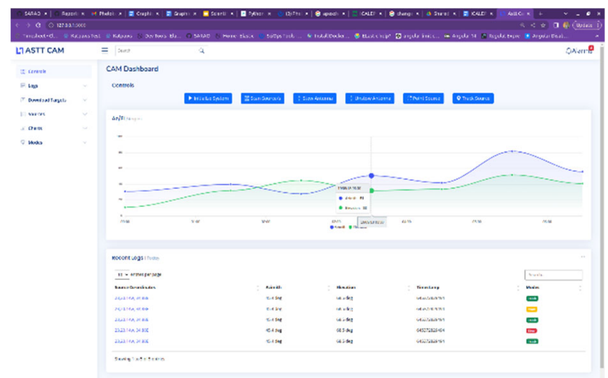

Figure 9: Graphical user interface.

1. **GUI Technologies** The GUI uses a combination of modern web technologies to ensure a responsive and intuitive user experience. The key technologies include: HTML: HTML forms the foundation of the GUI, providing the structure and content for web pages. It enables the creation of interactive elements and facilitates data input from users.
2. Flask: Flask, a lightweight web framework for Python, is employed to handle web requests and responses. It ensures the seamless flow of data between the front-end and back-end components of the CAM software.
3. Bootstrap CSS: Bootstrap CSS is utilized for styling and layout. Its responsive design ensures that the GUI is accessible and functional on various devices and screen sizes.
4. JavaScript: A minimal amount of JavaScript is integrated to enhance interactivity, enabling features such as updates and dynamic content loading.
5. Ajax: Enables users to interact with the GUI without the interruption of constant web page reloading.
6. ApexCharts: The charting library is utilized to create the graph that displays the angles of the azimuth and elevation against the time the telescope took to point to the desired position/(source).

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GUI functionality The GUI serves as the user's portal to cam, offering the following functionalities:

1. User Interface: The front-end component of the GUI provides an interface that offers intuitive controls and informative displays to facilitate user interactions.
2. Command Propagation: When users initiate commands through the GUI, such as specifying desired azimuth and elevation angles, the GUI propagates these commands to the underlying control system. This ensures that user intentions are accurately conveyed to the system.
3. Updates: The GUI continuously retrieves and displays relevant information about the telescope system's status. This includes logs, modes, azimuth and elevation and the current position of the telescope. Users can monitor these updates as the system operates.

Protocols

To establish seamless communication with other components of the CAM, the GUI employs standard communication protocols. These include:

1. HTTP: The GUI uses HTTP protocols for communication between the front-end and back-end components, ensuring secure data exchange.
2. Python CanOpen Protocol: The GUI employs Python CanOpen protocol to connect with the simulator and other CAM components. The protocol facilitates the transmission of commands and the reception of system status updates.

CONCLUSION

For the project to be a success, system requirements were drafted and broken down into functions. Through functional analysis, the functions are then cascaded down to sub-functions, allowing for a broad overview of the project to be seen. Although the error estimation is predetermined, an error budget is set up to ensure that the target is met in all the different subsystems.
Testing, both through test benches and simulations, will allow for the verification of the system functionality and requirements.

The STT provides a good opportunity to develop skills and to teach the functioning and design process of a radio telescope including operation and construction. By using similar components to a full-scale radio telescope, the complexity of radio astronomy is carried over and made tangible. By considering the mechanical, electrical as well as the control system, the full functioning of a radio telescope is explored.

REFERENCES

[1] A. C. Linde, J. Ludick and T. Maretela, "AVN Scale Training Telescope System User Requirement Document", unpublished.

[2] T. Maretela, "AVN Scale Training Telescope Antenna Structure System Description Document", unpublished.