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# CONSIDERATIONS ON AUTOMATING OLDER TELESCOPES: THE BOYDEN 1.5 M TELESCOPE

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RESUMEN

En este momento, el desarrollo y la puesta en servicio de un nuevo sistema de telescopio autónomo o remoto es fácilmente realizable debido a la cantidad de opciones disponibles para el constructor. Las consideraciones más difíciles serían la ubicación del sitio y la disponibilidad de servicios. Teniendo en cuenta el telescopio en sí, existen multitud de tecnologías como monturas, sensores, software de control y controladores disponibles, lo que supone pueda convertirse en un ejercicio complejo el encontrar cómo ajustar todo de la mejor forma. La pregunta que debe hacerse al considerar la automatización de un telescopio tan antiguo es: ¿Cuáles son los parámetros que deben investigarse? ¿Cuáles son los pros y los contras a considerar para el proceso? ¿Cuál es el estado tecnológico actual del telescopio? Con estas preguntas, y otras muchas, se examina el estado actual del telescopio reflector de 1,5 m del Observatorio de Boyden, así como lo que se necesitaría para hacerlo operativo bien de forma remota o bien completamente autónomo.

ABSTRACT

At this point in time, the development and commissioning of a new autonomous or remote telescope system is easily achievable due to the number of choices available to the builder. The most difficult considerations would be site location and availability of services. Considering the telescope itself, there is such a multitude of technologies such as mounts, sensors, control software and drivers available that it can become a complex exercise to find the best integrated fit. The question that must be asked when considering the automation of an older established telescope include: what are the parameters that needs to be investigated? What are the pros and cons to be considered for the process? What is the current technological state of the telescope? With these questions, and many more, the 1.5 m Boyden Reflector telescope will be examined as to its current state, as well as what would be required to either make it remotely operable, or fully autonomous.

*Key Words:* history of astronomy — instrumentation: photometers — instrumentation: spectrographs — instrumentation: polarimeters — software: development — telescopes

## 1. INTRODUCTION

### 1.1. *Boyden Observatory and 1.5 m telescope*

The Boyden Observatory is currently located 24 km to the east of Bloemfontein, South Africa (Boyden GPS: -29.0382 S, 26.4036 E). The history of the observatory can be traced to 1879 when Uriah A. Boyden left funding for astronomical research to Harvard College. The observatory was first established on Mount Harvard during 1889 in South America, but within a year moved to Arequipa, Peru where it was run until its relocation. The relocation to South Africa in 1927 led to the opportunity to establish a 1.5 m (60 inch) telescope which was built between 1930 and 1933. The initial optical configuration of the telescope was a Newtonian focus (775.6 cm) telescope on an English equatorial mount. During the 1960s the mirror cell and optics were upgraded to allow for a Cassegrain focus (2382 cm). In 2001 the telescope control system was upgraded to a DFM[3] telescope control system (TCS) interface. During it's operational lifetime the telescope also hosted various instruments, including photo-metric plates, a Zeiss spectrograph and up to recent developments an Apogee U55 CCD. More information regarding the observatory's history and equipment can be found in Van Heerden (2008), Jarret (1979) and Andrews (1998).

### 1.2. *Current state of the 1.5 m telescope*

The telescope is operational and is used for Astrophysical Research inline with the research interests of the Department of Physics' Astrophysics group. These include transient phenomena, cataclysmic variable (CV) systems, quasars and active galactic nuclei (AGN) as well as occasional occultation events. The telescope is also used for

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[3]`https://www.dfmengineering.com/index.html`.

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student training during undergraduate and postgraduate research programs. The telescope has 2 instrument configurations or "packs" available that can be mounted on the back-end. A photometer with either an Apogee U55 CCD or a new Finger Lakes Instrumentation Kepler KL4040 sCMOS[4] sensor and Johnson-Cousins UBVRcIc filters & a Spectro-polarimeter with a microline CCD[5] and various gratings and wave-plates available. The observations are undertaken using a custom built python GUI that interfaces between the TCS and the instrument hardware (see Figure 1).

The various systems are continually optimised as better solutions or processes are found during operational use and active Research and Development (R&D). Components that are currently actively being worked on are: optimization of the autoguiding capabilities, best observational parameters and equipment settings relative to instrument pack being utilised; as well as data analysis pipelines. Recent upgrades and maintenance services include the re-aluminization of the primary mirror, the commissioning of the spectro-polarimeter, the testing of the FLI sCMOS, and general maintenance to the mount and turret dome.

## 2. UPGRADE PROJECT

The addition of the spectro-polarimeter as well as recent developments in the research group regarding observational requirements and opportunities for collaborative work have resulted in the identification of a need for remote observing capabilities. This requirement will also then be inline with recent international trends regarding remote or even automated observations. This has resulted in a new project being initiated with the goal of making the 1.5 m telescope remotely operable, with full automation a final endeavor. The project will be implemented using a phased approach, as the telescope is an operational system, and cannot be put in an offline state for long periods to allow for a single long continuous upgrade and commissioning process. Observations still need to be made by researchers and students alike. The 5 phases that have been identified will be discussed in more detail next.

### 2.1. *Phase 0: Research, funding, planning and testing*

The start of the project, as with any project, is to do thorough research on what is available, what has been done and how it matches with the requirements and expected outcomes of said project, or to put it more basic: What is required to convert the current system to a remotely operable telescope and prepare for full automation.

The 1.5 m telescope system was compared to known systems that the team has either collaborated with or utilised. These include the Watcher Robotic Telescope (Martin-Carrillo 2019) and BOOTES-6 which is part of the BOOTES network (Castro-Tirado 2023; Hu et al. 2023), which are both hosted at and maintained by Boyden Observatory. Utilisation and collaborations with the South African Astronomical Observatory (SAAO)[6] also give the group access to telescopes at SAAO such as the 1.0 m, Lesedi and the 1.9 m Telescopes. These telescopes are either in process of becoming or are already remotely operable. The research as well as in-house knowledge by professional staff, especially in the divisions of Instrumentation and Electronics, on development of research equipment has led to the identification of core components that will have to be addressed, as well as some preliminary solutions. These include: fixing the dome, fixing the telescope controls, programming and prepping for remote observing and finally coding and commissioning for full automation. Each of these components will be addressed in more detail in the following sections and will become additional phases of the project.

### 2.2. *Phase 1: Fixing the dome*

The turret dome of the telescope building currently uses a 2-motor push-pull cable design to rotate the dome. The motors are housed 180 degrees apart at north and south, with the north motor hosting a relative encoder on the connection rod between the motor and cable pulley. This encoder counts pulses, with a set ratio converting rotational motion to angular motion on the dome. This encoder also determines direction of rotation. Because the encoder is relative the dome does not have a set zero or home position and needs to be "told" where it is pointing. This can be corrected by mounting "home" position indicators or limit switches on the dome at north and south, or even north, south, east and west. The dome system can therefore re-orientate itself if it loses its "known" position by just rotating until it finds the nearest position indicator.

There is an additional problem with the dome in that the determined azimuth position of the dome based on the right ascension - declination of the telescope pointing does not match for certain positions.

[4] https://www.flicamera.com/kepler/kepler.html.
[5] https://www.flicamera.com/microline/index.html.
[6] https://www.saao.ac.za/astronomers/#tab-1567162218737-5-7.

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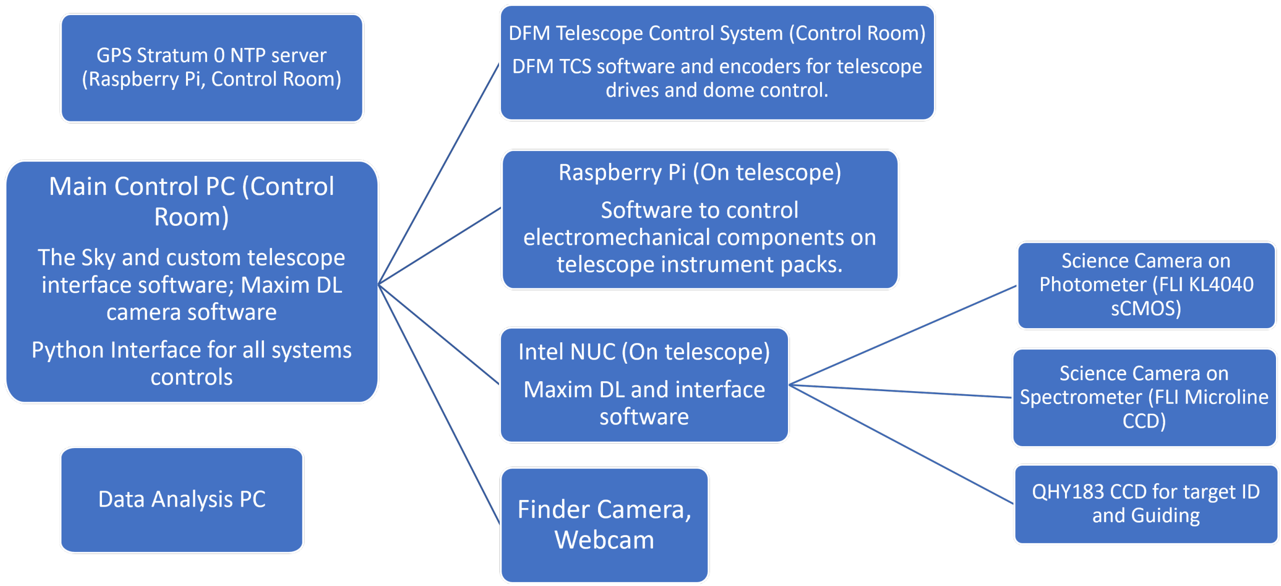


Fig. 1. A schematic layout of the various system components and their interfaces/connections utilised on the 1.5 m telescope.

This discrepancy in the synchronizing could be an inaccuracy in the geometry calculation of the telescope pointing, or a time or epoch miscalculation or even an error in the electronics. This problem has to be corrected. The conversion calculations is complicated by the fact that the dome centre and therefore dome azimuth and geometric pointing centre of the telescope (centre of the primary mirror) has an offset. The telescope centre and azimuth also moves relative to the stationary dome centre. A basic principle of how to match the telescope azimuth and dome azimuth can be found in (Suszynski 2009). Referring to figure 2, the horizontal telescope coordinates, can be used to calculate the dome azimuth through the use of the following equations:

$$\beta = \alpha - \varphi$$

where

$$\sin\varphi = \frac{r}{R}\sin\alpha\,.$$

The final problem with the dome is that there is no electrical power on the dome. Because of this the dome shutters are still opened and closed manually with a hand lever and pulley system. To make the system remote operable will require the dome shutters to be powered and controllable from a computer interface. There are various options to get power on the dome to operate the shutters electromechanically. Options include: slip rings, wiping contacts, battery system with charging contacts or solar cells on the roof are the most commonly used. An optimal solution is still to be determined, but a solution on how to operate the shutters has been proposed, which is 24V DC Centurion Shutter roller door motors and controllers with a 500 kg rating. These are off the shelve systems that come with relative easy to integrate and monitor controllers that have already been utilised onsite at another telescope building with success. Adaptation of the mechanical components to integrate with the motors, i.e. how to drive the pulley and cable system using the motors, could also provide its own challenges.

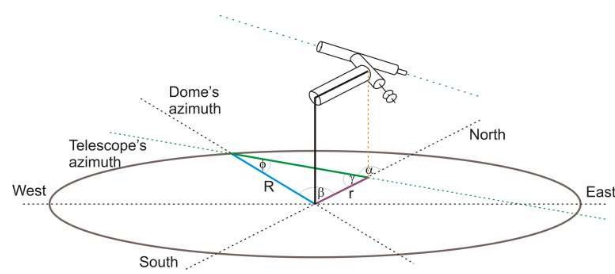


Fig. 2. Geometric calculation to match dome and telescope azimuths. Adapted from (Suszynski 2009)

The current dome motion and positioning is controlled via the DFM TCS. For optimal system design and future proofing the new dome control systems will be required to run independently from the current DFM TCS, with dedicated dome software developed that can integrate into the current user interfaces, or even integrate into potential future robotic

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control systems or standardised software such as ASCOM[7].

### 2.3. *Phase 2: Fixing the telescope controls*

There are various components on the telescope that needs attention to optimise the system for remote and potential automation. The first that needs attention is to convert the telescope tube shutter from a manual control to an elctromechanical system that is controlled via a computer. The most difficult part could be exactly what mechanical changes would be required for a smooth operation (open and close) of the shutter within the cylindrical structure, and whether the current shutter would require extensive modification?

The second main component that would need attention is the Right Ascension - Declination (RA & Dec) encoders. The telescope system currently uses relative encoders without a "home" position indicator or limit switch. Thus if the telescope experiences a system shutdown without adequate parking procedures, the telescope loses its position. Re-pointing of the telescope then requires the use of finder telescopes for field identification and fine adjustment or re-centering with the main camera system. This would prove to be a major problem for remote or automation purposes.

The TCS system used on the telescope is a PC Dos based application developed by DFM Engineering. Although the TCS still functions adequately the hardware running the TCS is beyond end of life and the danger lays in that if the hardware fails, the telescope becomes inoperable, as the TCS cannot be run on newer computer hardware. The options available are to get an upgraded DFM system (which takes control and adaptation out of the owner's hands), or to develop a whole new custom TCS system that matches what is required by the research group in terms of control of the telescope and peripheral systems. A custom TCS could also be made to match standardised protocols better for future remote or automation purposes.

The new TCS will have to control the following components:

- RA and Dec motors. Slew speed and direction.
- RA and Dec encoders (will have to upgrade to absolute, or add limit/home position switches).
- Current dual speed focus driver.
- Tracking control. Rated tracking or interface with auto-guider cameras.
- Pointing model. Optimization of pointing model based on feedback from imaging systems.
- Telescope tube shutter.
- Interface with the dome control driver for effective telescope-dome syncing.
- Accurate time systems and coordinate calculators for target acquisition and tracking given any standard astronomical target parameters.

### 2.4. *Phase 3: Commissioning remote observing*

Once all manual systems have been "converted" to computer controllable and current systems upgraded and optimised to match newer available technologies (hardware and software) then the system can be set up for remote capabilities. The various system interfaces will have to be adapted for optimal remote interaction, which will require an analysis of best operating procedures: What experience will make the remote observer effective and comfortable. The system must be easy to use, which will require some systems to run as black boxes. The remote observer must have adequate control with a simple command interface.

The remote observer must also have adequate feedback from site, i.e. what is the status of the various telescope systems and environment. This will require status values such as telescope pointing, telescope motion, various science camera values and imaging as well as guiding systems. Or simple feedback, such as a live webcam showing the telescope in the dome. Other environmental feedback systems should include a live weather update (connect with the weather stations onsite or a dedicated station such as a Davis[8] weather station specifically just for the 1.5 m telescope) as well as a live star-cam system to check sky quality and seeing conditions.

On the other end must be an effective remote observing computer station. Fortunately this has already been acquired and configured. A new remote observing station consisting of a high end multi screen computer system with a quality internet connection has been established at the Department of Physics in Bloemfontein. This system has already been used to do remote observations utilising telescope systems at SAAO, with the experience used to start planning the interface requirements for a remote observer session from Bloemfontein to Boyden Observatory.

[7] `https://www.ascom-standards.org/`.

[8] `https://www.davisinstruments.com/collections/weather-stations`.

### 2.5. *Phases 4&5: System automation*

For full system automation the observer needs to be replaced by an automated system that can manage the observations. Robotic systems manage the respective observations via a queue or scheduler. This scheduler uses parameters to determine observation setup, i.e. camera settings, filter or grating selection, telescope position and tracking, etc. The scheduler will be monitored by a master control system that monitors environmental parameters that determines whether the telescope and weather conditions are conducive for observations or not, and can start or stop the scheduler as needed. With subsystems interfacing in an interconnected web of links that communicates various statuses and events that can impact the scheduled observations, thus replacing the human link.

Such a complex system can be designed from scratch to fit exactly to a custom setup, but it would be better to utilise systems that are already being used. A system that was developed for various robotic telescope systems and initially used on Watcher was RTS2 (Kubánek et al. 2004). It is a very comprehensive control system coded in C++ that have been tested over many years, but at the same time very complex to manage and maintain and could be daunting for a first time user that needs to setup and manage queues and schedules. Another option that is python based and that could fit better with the more modern mix of science and python is pyobs (Husser et al. 2022). Whichever system is to be implemented, a thorough schedule of testing and debugging will have to be planned during commissioning, and might have to be done in stages.

## 3. FINAL THOUGHTS

The project is daunting, but nothing is impossible. The options are: Buy a new telescope system already fully robotic and just use as is, OR, use what is available in a new configuration after a period of R&D and hard work and perseverance. Old does not mean cold. Stars are millions of years old, and they still burn bright. Therefore the case can be made to upgrade, develop and re-utilise older telescopes for more advanced work than that for which they were initially build.

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