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A complete automatization of an educational observatory at INAF-OATs

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ABSTRACT

The Astronomical Observatory of Trieste (OATs), part of the Italian Institute for Astrophysics (INAF), hosts a Celestron C14 telescope, equipped with a robotic Paramount ME equatorial mount, used for public outreach. The telescope is installed inside a dome, recently upgraded with a Beckhoff PLC control system, a SIEMENS inverter for the communication with the motor of the dome's roof, and further equipment to allow the complete automatization of the system. A peculiarity of the system is that, when operating, the telescope may exceed the height of the roof: due to this fact the telescope pointing is constrained by the full opening of the roof and, oppositely, the closing of the roof is allowed only when the telescope is in park position. Appropriate sensors are installed to monitor the position of the telescope to properly handle the complete opening or closing of the roof. Several emergency operations are also foreseen, for example in case of bad weather or lost connection with the user.

The PLC software has been developed using TwinCAT software. An OPC-UA server is installed in the PLC and allows the communication with a web interface. The web GUI, developed in PHP and Javascript, allows the user to perform the remote operations like switching on all the instrumentations, open the dome's roof, park the telescope and view the status of the system. Furthermore through TheSkyX software it is possible to perform the pointing of the telescope and its set up. A dedicated script, interfaced with TheSkyX, have been implemented to perform a complete automated acquisition. An appropriate data storage system is foreseen.

All these elements, that cooperate to create a fully remoted controlled system, are presented in this paper.

Keywords: Educational observatory, Beckhoff PLC control system, Web GUI interface, INAF-OATs

1. INTRODUCTION

Since 10 years the INAF–Astronomical Observatory of Trieste (INAF-OATs) offers the opportunity to perform a live astronomical observational session from the schools. This educational project¹ proposes a modern tool to support the teaching of astronomy, through the study and experimentation of its observation methods.

The main scope of this project is to offer to schools and teachers a remote laboratory with which carry out real observation sessions, managed in real time by the students under the supervision of the teacher, in the classroom, and of an astronomer, at the OATs, thanks to the telematics link between the school and the observatory. Students and teachers experience real astronomical observations, through the interactive participation to the different steps of planning, observing, acquiring and analyzing the data. Every observation is previously planned together with the teachers, according to age and curriculum of the students, with the aim to maximize the results. The observing activity, lasting about 90 minutes and led by an astronomer of the OATs, can be done during the morning (observation of the Sun) or in the evening (observation of moon, planets, stars, nebulae, clusters and galaxies).

The remote controlled telescope is a member of the Italian Remote Network of Educational Telescopes (IRNET), managed by INAF.

Until the middle of 2016, the instrumentation required the presence of an operator on site to switch on the devices, activate the movement of the roof and park the telescope.

In the last year, the control system of this facility has been fully upgraded by INAF–OATs with a PLC-based architecture, allowing the complete remote operation of the system^{2,3}.

Thanks to this upgrade, besides the original educational purpose, the telescopes are now ready to be used for scientific research also.

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Two programs are already foreseen:

- transient event observations: following alerts from other telescopes, to observe transient events and measure their light curves (e.g. Gamma-Ray Bursts, Supernovae, asteroid occultation's, etc.);
- Active Galactic Nuclei (AGN) monitoring: a systematic survey of AGN in order to detect significant variations of the luminosity and to send alerts to other (much larger) telescopes able to perform spectroscopic follow up. This program is particularly important for the reverberation mapping studies of AGN, where a continuous coverage of photometric data is required on many objects. Moreover, if a strong variation should occur in the continuum emission of an AGN, it would provide a unique opportunity to study how the reprocessing material responds to a step impulse.

Further programs may be added in the future.

In the following chapters all the features of the new control system and data storage are described.

2. OVERVIEW OF THE TELESCOPES

Two telescopes (one for night observations and one for the Sun), both installed on the same equatorial mount, are located in the Basovizza observing station of the INAF-OATs (see Figure 1).

The main telescope is a catadioptric Celestron C14, in Schmidt-Cassegrain configuration. It has 356 mm of diameter and 3910mm of focal length, with a f/11 focal ratio.

A CCD camera Apogee Alta U8300 (3326 x 2504 pixel) and a filter wheel are attached to the telescope, in order to acquire high resolution images in different wavelengths of the observed objects. Available filters are RGB to take color images and standard UBVRI for photometry.

The telescope dedicated to the Sun is a Coronado HELIOS 1 solar telescope, fixed in parallel to the main telescope. It is an achromatic refractor of 70mm diameter and 400mm focal length. This instrument is equipped with a frontal energy rejection filter (ERF) that prevents ultraviolet and infrared radiation from entering the instrument and allows to check the image luminosity. Inside the optical tube a narrow band filter provide a pass band of 0.8 angstrom centered on the 656.28 nm wavelength (H α line of the Balmer series of hydrogen). Thanks to the H α filter it is possible to see both prominences and the other features of solar chromosphere, like faculae and filaments. A CCD camera Starlight XPress able to acquire color images of the entire solar disk is attached to the telescope.

The optical instruments are installed on a "Paramount ME" german equatorial mount that allows the automatic pointing of the telescope and to compensate the apparent motion of the celestial sphere. It is a totally robotic mount that, through an appropriate control system, allows the remote management of the telescope with the software TheSkyX (see Figure 2).



Figure 1 Image of the telescope

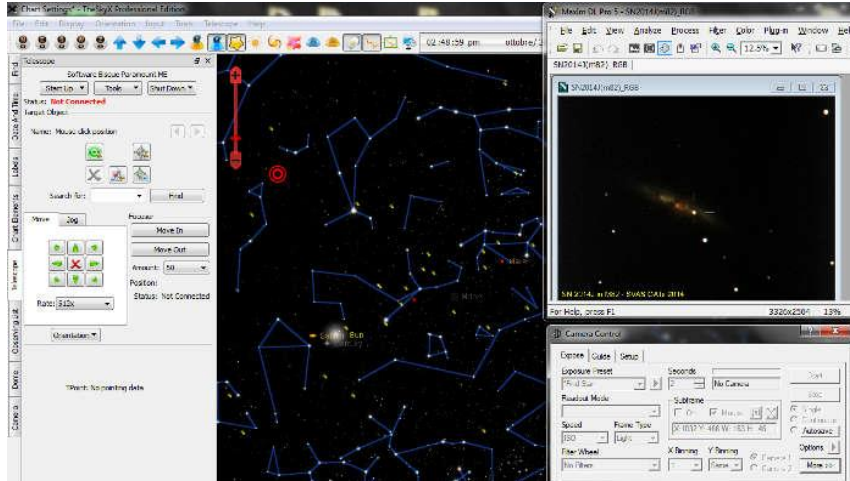


Figure 2 TheSkyX software

The correct object tracking is guaranteed by a small guider scope and camera that allow to perform exposures of several tens of minutes with no star shift. Longer exposures mean that more light is recorded in a single frame. More light means the ability to capture fainter nebulae, galaxies, and all of the other amazing deep-sky objects.

3. HARDWARE CONTROL SYSTEM CONFIGURATION

The control system is based on Beckhoff CX1030 series CPU and EtherCAT interface modules that are installed in two cabinets: one with the main CPU and inverter for managing the roof movement, the second with the control functions to manage the telescope mount and instrumentation (see Figure 3).

The premise where the instrument is hosted is of sliding roof type and has some physical constraints that must be taken into account. Since the height of the telescope and the mount during standard operation exceeds the height of the roof, it is very important that the roof is fully open before operating with the telescope. At the same time the telescope must be parked before closing the roof, thus an interlock between the two functions has been implemented.

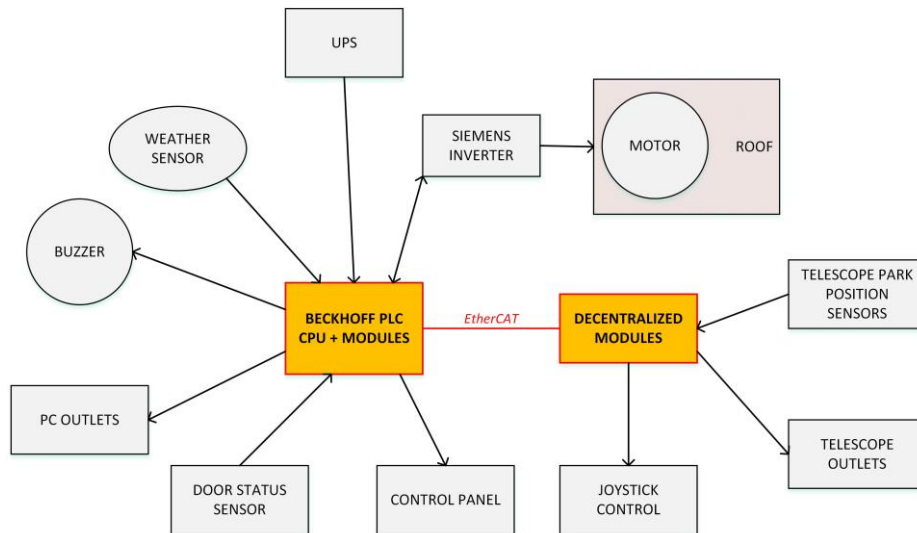


Figure 3 Block diagram of the control system

A similar interlock is implemented also for the remote operation of the whole facility. The “*Remote*” operation is permitted only when no operator is present in the telescope room, and can be armed on a control panel just outside. Any access to it is monitored by a proximity switch on the entrance door. Should this happen, any remote operation or roof movement is immediately stopped and a buzzer sounds to alert the user. The “*Remote*” operation can then be recovered by rearming it after having left the telescope room empty and closed the door.

The roof of the dome is moved by a three-phase motor, controlled by a SIEMENS inverter that also monitors two position limit switches to sense the end of travel in both directions. The PLC controls then the inverter’s main functions by means of a ProfiBUS type interface. With a relay it can cut the supply to the power section putting it into standby when the system is not used for a longer period of time, to lower consumption and dissipation.

The inverter can be operated manually with local command switches that by-pass the PLC interface. While in this mode, the roof can be moved even when the PLC is not operational.

All the observatory components are powered by PLC controlled outlets, allowing the stage power up and full remote control in case a component needs to be restarted. The whole facility is connected under uninterruptible power supply (UPS).

The observatory conditions are monitored by the “Boltwood Cloud Sensor II” that monitors cloud coverage, rain and high wind occurrence. If any of the monitored parameters exceeds a pre-determined threshold, the PLC triggers an immediate closure of the roof and switch off the system to protect it from damage. The autonomous shutdown is started also in other special cases like the loss of connectivity from the controlling client, the power loss and a pre-set time limit. Since the telescope mount uses a proprietary control interface, it is not possible for the PLC control system to trigger the parking procedure in case of need. For this purpose a custom interface (Figure 4) has been built to intercept the manual commands (joystick) of the mount. The parking is managed by sending the control pulses through a series of relays and simulating a physical user operation. The correct parking position is sensed by proximity sensors that were custom installed on both of the mount declination and RA axes since the mount does not provide this function on its own. The correct parking position detection is also used for stopping the movement of the roof whenever the telescope is not in the parked state.



Figure 4 The custom interface built to control the park of the telescope

4. CONTROL SOFTWARE FULL OVERVIEW

4.1 The PLC control software.

The core of the project control system is given by the Beckhoff CPU. The CPU mounted host a Windows CE platform with an OPC-UA server installed.

The PLC code is developed in Structured Text, using the Beckhoff ⁴ proprietary TwinCAT 2 software.

The elements that are monitored and controlled are:

- the local weather sensor
- the park of the telescope
- the access to the main control room (reading the use mode on the control panel)
- the moving/position of the roof
- the power on/off of the main outlets
- the detection of a lost connection with the web GUI user
- the automatic closing of the system in particular conditions
- the automatic closure in case a preset time is reached, to protect the Celeston C14 from the sun light after the sunrise

A waiting time and visual warnings have been implemented before switching the system off.

PLC GUIs have been created for tests during development and maintenance operations, but they are not exposed to the standard user, since there is no local GUI.

The main variables of the PLC project are exported via OPC-UA library.

4.2 The web GUI development.

In order to communicate with the PLC, which exposes an OPC-UA interface, a Python HTTP server has been developed, based on the FreeOpcUa⁵ Python library. The simple usage of the library didn't perform well enough, since for each call it kept connecting to the OPC-UA server over and over again. The web server solution allows to keep an open connection, which results in high performance HTTP to OPC-UA calls, and decouples the OPC-UA client from the web application.

The web based interface has two modes of operation: an easy mode (Figure 5) and an expert mode (Figure 6). When using the easy mode the user can switch the entire system on and off by just clicking one button. The web app then performs the appropriate steps in order to bring up the system, checking the PLC status step by step. In particular, the web app first checks whether the roof is open, and if the roof is closed then the open roof command is sent, and then the application waits until the roof is open before turning on the outlets. When turning off the system the opposite checks are done: first of all the telescope must be parked, then the roof must be closed, and last the outlets need to be turned off.

The button in the easy mode is enabled when the automatism setting is on, the weather conditions are good, the connection is open, and the global system status is off or ready for night observations. The connection can also be manually closed to enable automatic observations during the night.

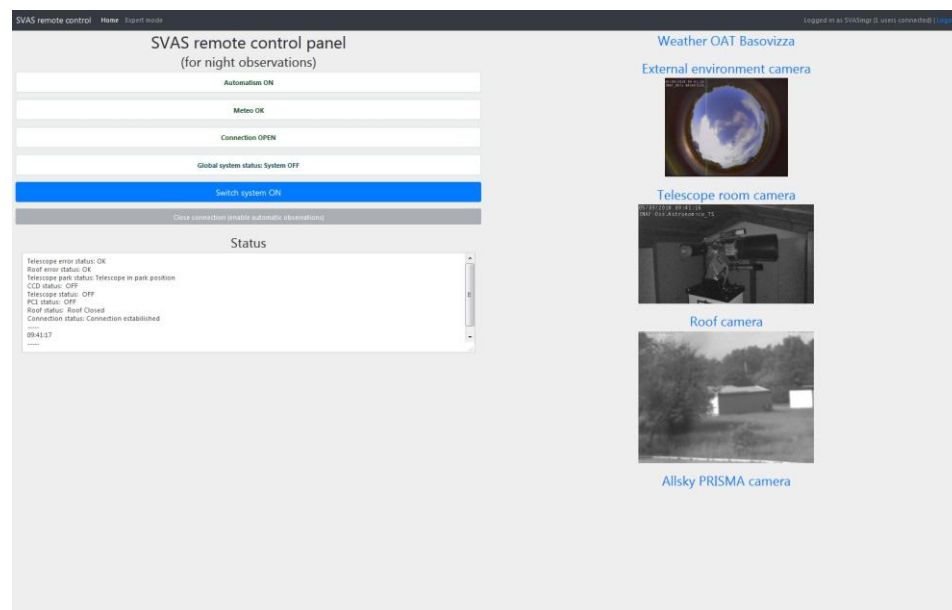


Figure 5 Web-app easy mode overview

The expert mode instead enables the user to play with every setting, regardless of the system status. The user has complete control over the system, enabling him/her to open or close the roof, do an emergency stop, turn the outlets on or off and park the telescope. Here the user can also set the autoclosing time. Both the easy and the expert mode have a global status textarea where the status of the system is printed every predetermined amount of seconds. There are also three cameras displayed on the page, which allow the user to see the external environment, the telescope room and the roof. A link to the local weather station webpage is also present.

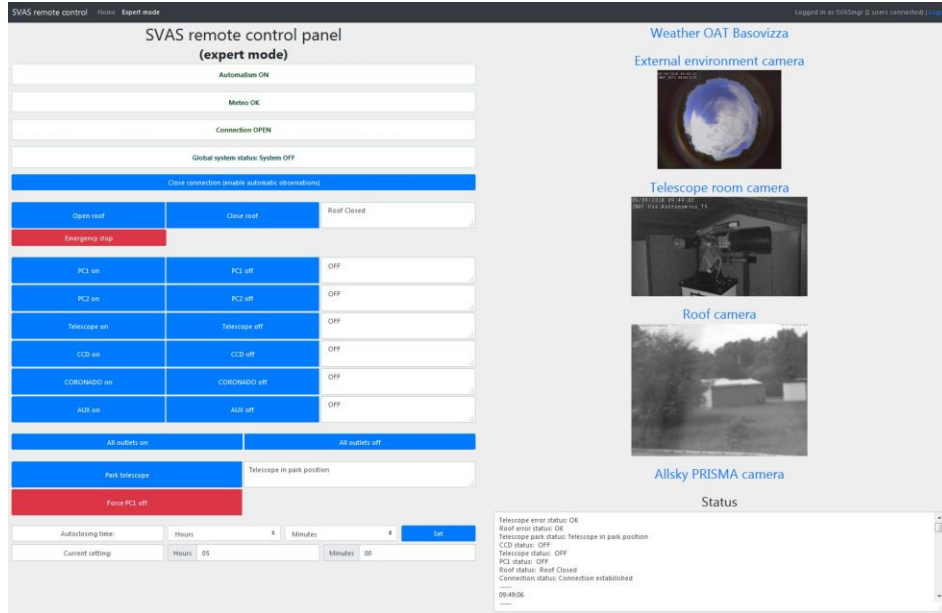


Figure 6 Web-app expert mode overview

4.3 A script developed as interface to TheSkyX software for the telescope remote control.

A very important feature of TheSkyX application is its possibility to be remotely controlled through a common TCP/IP socket by means of a simple scripting language⁶. An high level interface to access the scripting facility has been developed, which allows to carry out completely automatic observations starting from a very simple schedule file such as the following:

```
#Program | Object | raj2000 | dej2000 | exptime | options
#string | string | hh:mm:ss.sss | sdd:mm:ss.sss | sec | semicolon separated list of options
AGN monitor | object 1 | 09:43:45.4686 | 55:57:09.0758 | 60. | bias=5; dark=(2, 60); focus=5000; pointexptime=10
AGN monitor | object 1 | 09:43:45.4686 | 55:57:09.0758 | 60. | filter=R; nexp=3; bin=2; offset=(1, 2)
```

The resulting FITS files are stored locally in a temporary directory which will feed the database archive during the next day. As soon as a new FITS file is ready, a new script is executed which performs the following operations:

- it calibrates the image by subtracting a bias and normalizing it with a flat field;
- it search for an astrometric solution of the observed field using the software available in <http://www.astrometry.net/>;
- it computes the position on the image of the target and of the photometric reference stars (from the APASS catalog, <https://www.aavso.org/apass>);
- it performs an automatic fit of the PSF of the instrument at the target and reference positions. The sky background is also modeled as a component in the fit as an offset+slope component;
- it computes the relative photometry of the targets and write the outputs in the night log file, to be visually analyzed by the astronomer in the next morning.

All the scripts are implemented in Julia language⁷.

5. STORAGE OF THE SCIENTIFIC DATA

Data reusability for scientific or didactic purposes is fulfilled by making the astronomical images collected at the telescope publicly available. To this end, an archiving software, a database and an interface for data retrieval are needed. The main challenges when developing an archiving software are connected to data evolution. For example, there may be

issues comprising changes in data format, variations in publication policy and in metadata content. A software that is flexible, modular and configurable can overcome these problems, moreover, it can be reused in different contexts, it is easily deployable and has scalability potential.

The New Archiving Distributed InfrastructuRe (NADIR⁸) was developed within the IA2 (Italian Astronomical Archive) project in order to take all these requirements into account. It is based on TAcO Next Generation Object (TANGO⁹), inheriting its main points of strength. TANGO is essentially a control system for the management and monitoring of devices over a distributed network. A service can be directly associated and implemented in a device which is the fundamental element in TANGO. This offers a convenient way to uniformly interact with all the devices hiding network complexity and devices inhomogeneity. Building an archiving software based on TANGO provides automatically standardization of logging, high scalability, modularity and robustness. In our context, each TANGO device is an archiving module. The devices fulfill a number of tasks, from selecting the correct data format and checking its consistency to transferring the data and metadata over the network to the archiving sites. Device properties are modifiable at any time through a graphical interface. The flexibility deriving from these conditions sets the basis for a robust and reliable service. Furthermore, TANGO distributed control system is responsible of services start up, shut down and keep alive processes.

More in detail, the data resulting from an observing session are placed in a dedicated folder on a machine at the telescope building. A data transfer towards a machine hosted at the archiving station in Trieste is performed periodically. In the incoming folder on the archiving machine a TANGO module called *preProcessor* is active. This device performs a selection of the correct file format and checks the conformance to the FITS standard. In case of a positive outcome, the files are copied to a second folder. A second TANGO device called *fitsImporter* acts at this point. This device extracts the metadata from the FITS cards of the selected files according to the keys stored in the datamodel and fills the instrument tables of a MySQL database. Finally it moves the file to the storage.

5.1 The data archive web interface overview.

Database generated by NADIR can be queried using a TAP service. TAP stands for Table Access Protocol and is a Virtual Observatory (VO) standard which allows performing custom queries on astronomical databases using ADQL, an astronomy-oriented SQL-like language. The archive web interface (Figure 7) is built on top of the TAP service using APOGEO (Automatic POrtal GEneratOr), a wizard for the creation of astronomical web portals, which has been used to generate all the most recent IA2 portals. Using the portal, the users can apply various filters to their searches on the archive and download the files included into the search result. Moreover it is possible to select multiple files and download a tar archive of all of them or export the search result in CSV or VOTable format. A VOTable is a XML file format standardized by VO in order to store tabular data in an interoperable way. VOTables and FITS files can also be sent to external VO applications using SAMP (Simple Application Messaging Protocol), another VO standard for exchanging astronomical data between VO-compliant applications. A typical use case can be sending a VOTable to TOPCAT, an application for performing operations on catalogues and tables. It is also possible to download a list of all the files resulting from a search. This can be useful if it is necessary to download a set of files using a non-browser client (e.g. wget).

Each file in the archive can be associated to an observational program and some of the files can be private (only the Principal Investigators of the program or their collaborators can download private files). For this reason the portal provides also a login button which redirects to the Remote Authentication Portal (RAP), the portal used by all IA2 services for performing authentication. RAP supports multiple authentication mechanisms like the eduGAIN federation, most common social networks, X.509 certificates or even self-registered accounts. The association between an observational program and its PI is done inside Grouper, a group management system. Each observational program corresponds to a group inside Grouper. The portal retrieves user groups calling the Grouper web services after the authentication step is completed. Internally, the web portal is composed by multiple web services working together: the TAP service mentioned before, a File Server (for retrieving FITS files and their preview images), an User Space service (for storing user generated temporary files, like VOTables or tar files) and the web application containing the search form. All these applications are written in Java EE and can be deployed both on GlassFish or Tomcat servers.

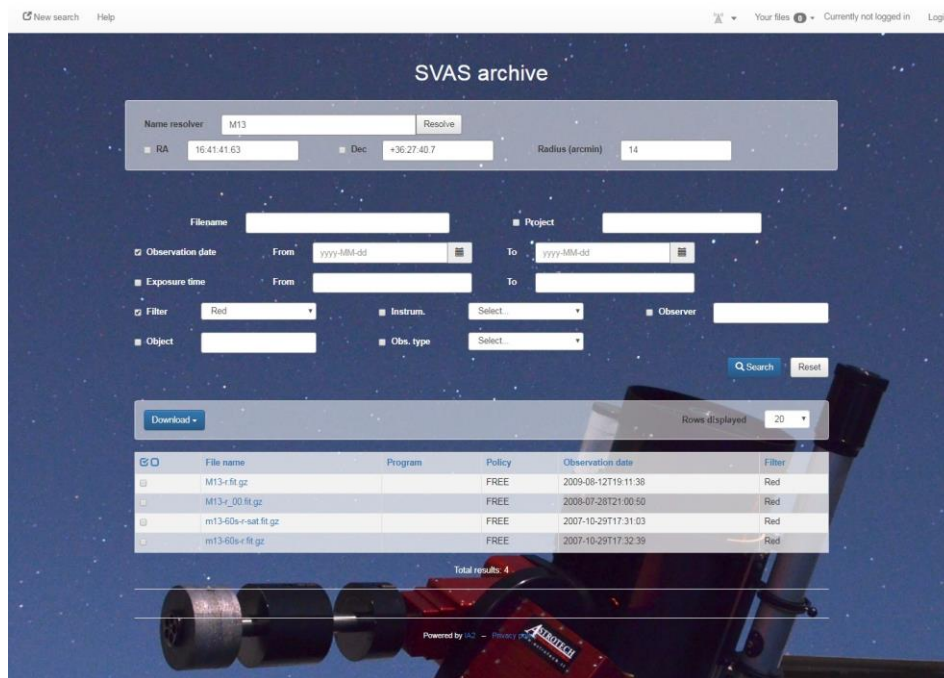


Figure 7 The archive interface

6. CONCLUSIONS

INAF–OATs hosts a Celestron C14 telescope, equipped with Coronado Helios solar telescope. This telescope is mainly used for educational purposes, offering remote live sessions from the schools.

Thanks to a new automatization of the control system, completely developed within INAF–OATs, is now possible to perform the remote observations with the telescope without the presence of an operator on site.

The new control system is based on Beckhoff PLC, programmed through TwinCAT 2 software. The PLC–based system manages the power outlets and the sliding-roof movements, controls the park position of the telescope and guarantees safety functions. The PLC is interfaced with a Python HTTP server through OPC-UA library. The web-app allows the operator to remotely control the system, in “easy mode” or “expert mode”.

The telescope pointing is controlled by TheSkyX software, which can be remotely controlled through a common TCP/IP socket by means of a scripting language. A high level interface to access the scripting facility has been implemented, in order to carry out completely automatic observations.

The data resulting from an observing session are placed on a dedicated machine. A data transfer towards a machine hosted at the archiving station in Trieste is performed periodically. The archiving software is based on TANGO, and provides automatically standardization of logging, high scalability, modularity and robustness.

All these upgrades represent a big step forward to this educational-born project: it is now more accessible and easy to use, and may also become a useful instrument for the production of new science data.

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