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# MODERNIZATION OF COLOTI OPTICAL OBSERVATORY: REMOTE CONTROL AND AUTOMATION FOR MULTIMESSENGER FOLLOW-UP

P. Cristarella Orestano[1,2], S. Cutini[2], S. Germani[1,2], S. Palmerini[1,2,3], and G. Tosti[1,2]


## RESUMEN

En 2017, dos eventos cósmicos nos condujeron a la era de la astronomía de multi-mensajeros: por un lado, el evento de ondas gravitacionales GW 170817 (detectado por LIGO y VIRGO) con contrapartida electromagnética en todo el espectro y por otro, el evento de neutrinos cósmicos IC 170922A (detectado por IceCube) y asociados a una llamarada de un blazar. Ambos también fueron detectados por *Fermi*-LAT en el rango de los rayos gamma. El estudio de este tipo de eventos transitorios necesita de observaciones coordinadas entre los telescopios o detectores espaciales y los terrestres. El objetivo de este proyecto es contribuir a la comprensión de los eventos de multimensajeros mediante la restauración del Observatorio Coloti, permitiendo el control remoto y la automatización: desarrollando estrategias observacionales, sistemas de adquisición de datos y automatización de análisis de imágenes. El paso obligatorio para ello es una actualización del hardware y, con ello, también es necesaria una renovación del software. Todos los subsistemas del observatorio estarán conectados entre sí a través de un Internet de las Cosas por medio de un protocolo de Arquitectura Unificada de Comunicaciones de Plataforma Abierta (OPCUA). Los programas de control de cada objeto están escritos en `JAVA`, desde las comunicaciones serie de bajo nivel hasta la Interfaz Gráfica de Usuario (GUI). El protocolo OPCUA permite una personalización completa y un control remoto flexible de cada objeto. En el futuro próximo, la automatización se implementará fácilmente en el nuevo software y consistirá en la búsqueda automática de objetos para ser monitoreados y la respuesta automática a alertas de multi-mensajeros.

## ABSTRACT

In 2017 two cosmic events led us into the multimessenger astronomy era: the gravitational wave event GW 170817 (detected by both LIGO and VIRGO) with electromagnetic counterpart in the whole spectrum on one side, and the cosmic neutrino IC 170922A (detected by IceCube) associated to a blazar flar on the other side, both also seen by *Fermi*-LAT in the gamma-ray band. This proved that the study of transient multimessenger events needs synergy between space-borne and ground-based telescopes or detectors. The goal of this project is to contribute to the understanding of multimessenger events by restoring the Coloti Observatory, enabling remote control and automation: develop observation strategies, data acquisition system and image analysis pipeline. The mandatory step is a hardware upgrade, and with it a software renewal is necessary too. All the objects of the observatory will be connected to each other in an Internet of Things via a protocol of Open Platform Communications Unified Architecture (OPCUA). The control programs for each object is written in `JAVA`, from the low-level serial communications to the Graphical User Interface (GUI). The OPCUA protocol enables complete customization and flexible remote control of each object. In the next future the automation will be easily implemented in the new software, and it will consist of automatic search for targets to monitor and automatic response to multimessenger event alerts.


*Key Words:* Multimessenger — Optical Observatory — Remote Control and Automation

## 1. INTRODUCTION

In 2017 two cosmic events led us into the multimessenger astronomy era (Branchesi et al. 2016): the gravitational wave event GW 170817 (Abbott et al. 2017) detected by both LIGO (Harry et al. 2010) and VIRGO (Acernese et al. 2014) with an electromagnetic counterpart in the whole spectrum on one side, and the event of cosmic neutrinos IC 170922A (IceCube Collaboration 2018) detected by IceCube (Aartsen et al. 2017) and associated to a blazar flare on the other side. Both events were also seen by *Fermi*-LAT in the gamma-ray band. This proved that the study of transient multimessenger events needs synergy between space-borne and ground-based telescopes or detectors.

[1]Università degli Studi di Perugia, Italy.
[2]Istituto Nazionale di Fisica Nucleare, Sezione di Perugia, Italy.
[3]Istituto Nazione di Astrofisica, Osservatorio Astronomico di Roma, Italy.

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Fig. 1. The observatory is located near Perugia (Italy), alt-azimuthal mount telescope with Cassegrain configuration ($f/10$) and 80 cm primary mirror.

## 2. INITIAL STATE

The Coloti Observatory was inaugurated in 1999 in Coloti, an ancient uninhabited village near Perugia, in central Italy, 470 m a.s.l., and far from the light pollution of the cities. Unfortunately, it closed its scientific and divulgation activities in 2010.

The telescope (Figure 1), inside a rotating dome, has an alt-azimuthal mount and a Cassegrain optical configuration with an 80 cm primary mirror having a focal ratio of $f/3$; the resulting focal length of the telescope is 8 m ($f/10$). Considering the CCD detector size, we have a current field of view of $7.7' \times 5.1'$.

The telescope has a motorized analog focuser that works on the position of the secondary mirror, not the optimal way to focus since there is only one position of the mirrors where the number of photon captured is maximized. In the room below the telescope there are three motor encoders: for dome, azimuth and elevation.

The original telescope control program was written in `Microsoft Visual C++ 6.0`.

In the multimessenger astronomy era, ground telescopes can contribute to the study of extragalactic transient sources with more focused and long-duration observations. With these purposes, it was decided to reactivate the observatory, hence the need for upgrades to respond to alerts from gravitational wave interferometers and neutrino detectors. We need hardware upgrades (Figure 2) to improve observation quality and software upgrades for a fully automated remote control of the observatory.

## 3. HARDWARE UPGRADE

The first step of the upgrades was to replace the old workstation, which previously managed the telescope directly, with a Main Workstation (MW) in the observatory control room and two industrial computers: Telescope Motors Controller (TMC), Camera and Data acquisition Controller (CDC).

The MW and the TMC are both placed inside the control room, so we do not drastically change the position of the serial cables that run from the wall down into the room below the telescope, where there are encoders that communicate with the telescope motors. The CDC on the other hand, being connected to the camera subject to three movements (azimuth, elevation, and field rotation), will be attached to the telescope to decrease cable movements. The data acquisition camera, a Charged Coupled Device (CCD), and the Pointing Monitoring Camera (PMC) are connected to the CDC, this means we are going to manage many cables around the telescope. The PMC uses a $12,5\ cm$ diameter refractor telescope; so, thanks to the larger field of view, it is used for astrometry.

The primary mirror had to be re-aluminized, a needed process to restore the mirror to the original condition: vaporization of aluminum inside a vacuum bell, which will uniformly cover the entire surface of the mirror.

The ruined Weather Station is replaced by a newer one (WS). A Field Derotator (FD) is going to be added to the telescope where the camera will be mounted, and in the future also a new focuser to be managed digitally to allow remote and automated focusing. All these objects form a complex structure, schematized in Figure 3, they will be connected to each other in an Internet Of Things via the Open Platform Communications Unified Architecture (OPCUA) protocol, all controlled from the MW.

## 4. SOFTWARE RENEWAL

We are currently developing the new software in `JAVA`, starting from the low-level programming with the serial communication for many objects (motor encoders, WS, CCD, FD, PMC) up to the high level Graphical User Interface (GUI).

The hierarchy tree is shown in Figure 4, at base level we have a serial communication protocol common to all objects, then we have the Axis Control

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Fig. 2. (a) Two identical industrial computers (TMC, CDC). (b) CCD: Moravian G2-1600 Mark II: Full Frame, $9 \times 9$ $\mu m$ pixels, resolution $1536 \times 1024$ pixels, it has a Bessel filter wheel (U, B, V, R, I) and a cooling system. (c) PMC: FLIR FL3-U332S2M sensor CMOS 1/2.8", resolution 3.2 MP. (d) Davis Vintage 2 Weather Station.

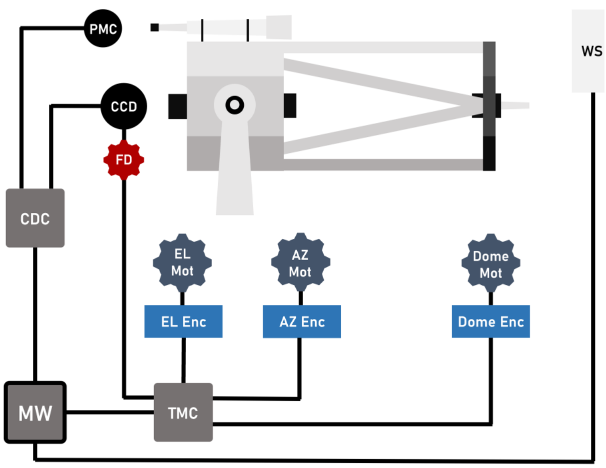


Fig. 3. Observatory hardware scheme. All the objects are connected to the main workstation in the control room. The PMC uses the refractor Apo ED Tecnosky 125/975. For each motors (Mot) there is an encoder (Enc).

System (ACS) for controlling each axis (azimuth, elevation and dome motors), above it the Telescope Control System (TCS), which manages the logic and the complex functions of the telescope-dome system. The Weather Control System (WCS), the Pointing Control System (PCS) with the astrometry and the Camera Control System (CCS), for data acquisition, complete the observatory logic. A state machine structure is used in the TCS, to make the system

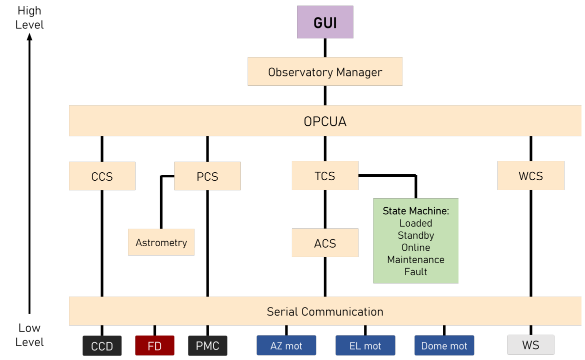


Fig. 4. Software hierarchy tree. From the low level we have the Serial Communication, then many programs converge in the TCS, above it we have the OPCUA server where everything is mapped, and then the GUI.

more organized and secure, it has 5 states: Loaded, Standby, Online, Maintenance, Fault, the same state machine structure will be added in the other scripts too.

In order to write the ACS and the TCS it was necessary to work directly with the previous scripts doing a massive translation process, from `Visual C++ 6.0` to `JAVA`, starting with the serial communication with the encoders up to the complex pointing functions.

The tracking program is already implemented in the encoders, as is the *set-zero* command, which searches for the telescope limit switches to calibrate the positions of the axes.

`JAVA` turned out to be perfect for the software since it simplifies the development of the GUI and the management of the low-level communication, indeed the debugging process was very easy and short and during the preliminary tests we were able to move the telescope without any problems.

Above all the other programs there is the OPCUA, where nodes corresponding to each individual high-level function are created, thus the objects can communicate with each other.

## 5. CONCLUSIONS

The observatory is already reactivated, especially for outreach activities. The hardware upgrade is in the assembly phase. It is also necessary to replace the analogue focuser with a new, more precise electronic step-by-step focuser.

Currently, it is difficult to correctly measure the seeing, the sharpness of astronomical images, from the observatory, because the focus still needs to be improved and the primary mirror re-aluminized. The seeing depends on atmospheric turbulence and is measured as the Full Width at Half Maximum

(FWHM) of the star profiles and is therefore expressed in arcseconds. Considering the observatory site and the pictures taken in these months, we can expect to measure a the seeing at least under $4''$.

Concerning the renewal of the software, we are close to achieving the remote control and automation objectives. Thanks to the OPCUA protocol the remote control is already usable. We are completing the GUI and we have to implement the data acquisition software, then we will organize everything in order to automate the observatory with scheduled observation and with automatic response to multi-messenger event alerts.

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