Mem. S.A.It. Vol. 96, 57

Memorie della

IMAGO: an Augmented Reality Project to support scientific outreach using dedicated telescopes.

E. Di Carlo[1], F. D'Alessio[2], M. Dolci[1], R. Buonanno[2], I. Di Antonio[1], M. Di Carlo[1], A. Valentini[1], P. Harden[3], G. Valentini[1], and R. Leoni[2]

[1] Istituto Nazionale di Astrofisica – Osservatorio Astronomico d'Abruzzo, via Mentore Maggini, Teramo (TE), 64100, Italy e-mail: elisa.dicarlo@inaf.it
[2] Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Roma, via Frascati 33, Monte Porzio Catone, 00078, Italy
[3] ACKAGI Visual Arts

Received: 17-12-2024; Accepted: 20-01-2025

Abstract. IMAGO (*IMAGer with mOdified eyepiece*) is a project whose aim is to develop an Augmented Reality (AR) optical device that can be matched to historical telescopes and is also adaptable to most telescopes used for scientific outreach, meant as a tool to support science communication and educational activities for generic public and schools. The instrument consists of an opto-mechanical system designed to capture, through a CMOS camera, the astronomical image and relay it to an optical viewer, or a screen, on which the image is displayed. Visitors can enrich their visual experience by overlaying additional real-time AR content onto the image from their direct observation through the telescope. The IMAGO prototype is here described and possible future enhancements are also discussed, along with some of the main challenges of the project, such as the design of a compact, portable and user-friendly system, and the creation and management of the AR contents.

Key words. Astronomy, Augmented Reality, Public Engagement, Telescopes, Eyepiece

1. Introduction

According to the Lisbon EU strategic plan, a modern society is expected to increasingly rely on culture. However, it cannot be ignored that modern approaches to knowledge are largely based on images and direct experience, both real and virtual. The Abruzzo Observatory took advantage of the Ministerial programs *"PCTO"*(*Percorsi per le Competenze Trasversali e per l'Orientamento*, formerly known as *Alternanza Scuola-Lavoro*) in order to develop a number of activities for young people. Special attention was paid to the topics of Augmented Reality and virtual experiences in science – in particular, technology and cosmology. We have constantly been looking upon the historical framework of astronomy.

A technologically advanced structure, however, requires to be continuously updated. This is mandatory if the goal is to capture the interest of young people and students, for whom modern advanced media are easily available. These requirements meet the fact that many INAF structures own and manage historical telescopes, in addition to the availability of modern commercial instruments, all of them dedicated to public engagement. The problem is that, while commercial telescopes are simple to use and easily adaptable, the historical ones are regarded as impressive and evocative by visitors, but are obviously impossible to modify. On the other hand, these old refractors are particularly luminous and, given the typical focal length which is of the order of meters, allow people to observe planets with full satisfaction of those who put their eye to the telescope. Unfortunately, the accessibility of the historical instrumentation is often restricted to daytime visits (mainly school groups) or, when star-gazing nights can be arranged, may be hindered by weather conditions or light pollution, thus limiting the possibility to directly experience what was seen in their Golden Age.

In view of these reasons, we decided to create a device that, designed to only match the exit pupil of the instrument, would actually allow the application of innovative technologies to these large nineteenth-century refractors (while also extending the adaptability to more recent commercial telescopes available on the market). This will increase their usability and versatility, enabling observational experiences that would otherwise not be possible.

As it is well known, Augmented Reality (Hsin-Kai Wu (2013)) is one of the most powerful technologies used to convey information in real time. The AR technology is usually exploited by apps, and used in mobile devices to merge digital components and the real world in such a way that they enhance one another.

In the IMAGO project, AR is used to give the observer additional information on the astronomical object observed by the telescope. In addition, IMAGO will allow an innovative view from AR. In particular, it will be possible to use an archive of images from historical instruments, a Digital Virtual Legacy Archive, to show how the sky appeared to a nineteenth-century astronomer, compared to the present-day perception of the night sky. This will allow visitors to travel in time and “realistically” use the same instruments of well-known astronomers of the nineteenth century, while at the same time being able to personally experience the fascination, the difficulties and the technological evolution which have characterized the last two centuries of astronomical research.

Ultimately, IMAGO represents an original tool, which combines a long-term strategic vision with new technologies, designed to enhance a human sensory experience. The project aims at sparking the interest of a wide range of public, from young people to any kind of visitors (pupils, students, and general public), who are simply curious about Science, and provides them with what they expect from Science.

2. The PRIN INAF Project IMAGO

Started on February 25, 2021, the PRIN DIV INAF Project IMAGO involves two INAF Structures: Astronomical Observatory of Abruzzo (OAAb) and Astronomical Observatory of Rome (OAR).

Taking advantage of the experience gained over the years by researchers, technologists and technicians of the two institutes in designing exhibits based on emerging technologies - such as AR and Virtual Reality (VR) - the IMAGO project was set up to design, build, and test a small and light enough device to be mounted at the focal plane of almost every telescope commonly used for public education and outreach. This device allows one to capture the images obtained with the telescope in real-time via a digital camera, and to display them to an observer in an ocular-like layout, properly adding extra-contents to the image displayed.

The idea behind the project can be easily illustrated by considering a frequent situation in which some visitors have an astronomical experience at one of the INAF local telescopes. As an example, they might be observing a given planet, e. g. Mars. Unfortunately, Mars will only appear as a small red circle because of the seeing, which, at the sites hosting our observatories, will be around 3 *arcsec* at best. We can envisage that at first visitors

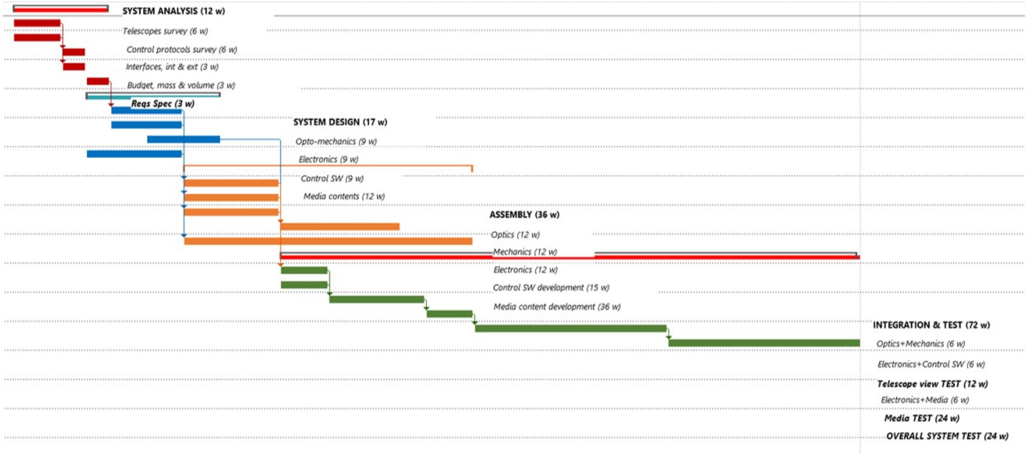


Fig. 1. The project development plan (Gantt chart).

who put their eyes to a telescope may be fascinated, but soon, when they realize that nothing else occurs, they might rate this experience as unsatisfactory and boring. According to common experience, this occurs even with visitors of average education and good knowledge of Astronomy, as based on illustrated books and documentaries.

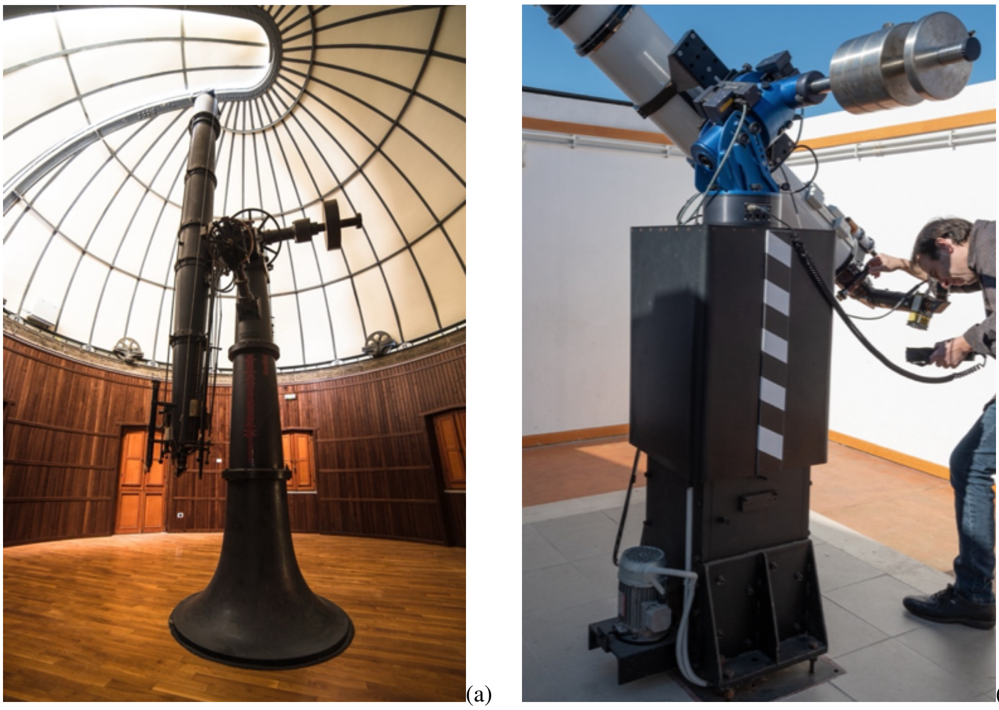
The basic idea of this project is to enhance the image appeal through a modified eyepiece, which gives the impression of improving the seeing and removing atmospheric effects. By using such a device, which allows us to project digital photos and short movies, the visitor will experience a gradually improving resolution, and will be able to look at finer details on the planetary surface. This is not meant as a fairground gimmick, but as a means of overlaying a series of images obtained with the HST or other space telescopes on a real-time image from a ground telescope. We think that this might represent a significant experience for visitors, in that they could fulfill three main expectations, namely:

a) Put their eye to a real telescope;
b) See finer planetary surface details as they would have been expecting to see;
c) Realize, in the end, that they took part in a real scientific observation (even if through a remote telescope).

This is by no means different from looking at a picture or cartoons. Similar sensory paths can of course be developed through observations of Jupiter, Saturn or the moons of the largest planets. Depending on the educational level of the audience, the experience can be complemented with short lectures on space telescopes or on adaptive optics. In addition, in case of large audiences, it would be really simple to simultaneously display the sequence starting with a real observation first and then going on with the in-eyepiece projection on a large screen, so that the whole audience can share the enhanced reality experience.

The IMAGO project over its planned two-years (+1) duration was initially structured in four main stages: 1) analysis; 2) design; 3) assembly; 4) integration and test (1).

However, a subsequent downsizing of the project goals following a fund reallocation, shifted the focus of the activities towards a feasibility study of the IMAGO concept, completed with the creation of a fully functional prototype, suitable for the many historical telescopes of INAF, such as the Cooke Telescope sited at the Astronomical Observatory of Abruzzo, and the Monte Porzio Telescope of the Astronomical Observatory of Rome, currently exploited to spread the knowledge of Astronomy and of the development of new technologies in schools and public events. This



(a) (b)

Fig. 2. (a) Cooke & Sons Refractor Telescope located in Teramo (INAF-Astronomical Observatory of Abruzzo); **(b)** MPT Telescope located in INAF-Astronomical Observatory of Rome.

is part of the so-called III Mission activity of INAF, enforcing research, education and outreach.

Other objectives of the IMAGO project are: promoting science cultural heritage, developing scientific contents through the exploitation of AR technologies, transferring the obtained know-how inside INAF, sharing the acquired expertise with other specialists of III Mission and new technologies, highlighting the obtained results in national and international meetings as well as scientific papers.

2.1. Basic concepts of the technical project

From a technical point of view, building a system suitable for all telescopes available for public outreach is impossible. Thus, the outreach telescopes at the Teramo and Rome observatories were initially chosen as reference instruments.

The first Observatory hosts the historical Cooke Telescope, a refractor with a 400*mm* lens diameter and a focal length of about 6 meters. The latter Observatory, on the other hand, exploits an apochromatic refractor telescope with a 199*mm* aperture and a focal length of nearly 2 meters.

	Cooke	**MPT**
Focus	5910 *mm*	1800 *mm*
Aperture	394 *mm*	199 *mm*
Fn	15	9
Scale	$28.7\mu m/arcsec$	$8.7\mu m/arcsec$

Table 1. Main features of the telescopes shown in figure 2.

Developing a device suitable for two telescopes with such different optical designs, sizes, and performances makes IMAGO also adaptable to a wide range of telescopes with optical designs in between those of these two telescopes. Furthermore, a major goal of the project remains the revitalization of historical telescopes that are still potentially operational. IMAGO enables adding scientific content and interest to direct astronomical observation through immersive experiences and virtual reality without altering the mechanics or optics of a historical telescope. Thanks to IMAGO, even the most classic telescopes can enhance contents and increase the observer engagement.

Consequently, IMAGO is designed with a user-interface optics, a direct image-processing electronic section, and a software infrastructure to augment astronomical information with interactive multimedia content.

Since it is designed to replace a standard telescope eyepiece, IMAGO is compact and lightweight. Therefore, only those components essential to the observer's experience are mounted at the telescope focal plane near the optical output. Other accessory parts, such as the power supply, are located elsewhere. Auxiliary support systems will certainly be needed, but they should have a mechanically light and agile structure, as well.

IMAGO is non-intrusive, it is not equipped with other modern devices that would spoil the originality of directly observing the sky through a telescope. Thus, it is designed as a small piece of equipment, nearly invisible to the observer, and it only adds contents if requested by the observer. For this reason, as a basic requirement, IMAGO must guarantee an unobstructed view of the targeted celestial field, as it appears, without any virtual overlays enhancing the image.

When requested, however, it will allow the observer to enrich their experience by utilizing immersive virtual and AR contents. This transition from direct viewing the observed field to AR contents linked to the observed celestial source is gradual and almost seamless.

2.2. Principal issues to deal with

To meet all the characteristics and goals of IMAGO, it was necessary to deal with several challenges related to optics, mechanics, electronics, and software. Specifically, an optical coupling system was initially conceived and developed to enable both direct viewing of the astronomical field and processing of the same image, while still ensuring adaptability to various telescopes with their differing optical features.

Mechanically, the system needs to be robust, compact, and lightweight. Since adaptability to historical telescopes is one of the project's objectives, it's crucial that, once mounted, the system does not visually clash with the aesthetic lines of a historical telescope.

When designing IMAGO, the tracking capability of the Cooke and MPT telescopes was taken into account. Both these telescopes are equipped with efficient equatorial mounts that allow an observer to keep the field in the eyepiece for extended periods. They are not equipped with autoguiding, but once an object is pointed at, it stays in the field for more than 30 minutes. It is clear that a system like IMAGO needs a stable pointing, and both telescopes meet this constraint. However, in view of making IMAGO available for other telescopes, an equatorial tracking system becomes an essential requirement.

Therefore, IMAGO will only work properly with telescopes equipped with an equatorial drive, or if the operator can manually track the object during the observations and the AR phases.

In IMAGO, electronics play a key role, as only an image acquisition system can fulfill the project requirements. Therefore, in addition to dedicated optics, an image acquisition system with substantial onboard processing power is required for AR software operations.

2.3. General system layout and adopted solutions

The initial concept of IMAGO consisted of five subsystems:

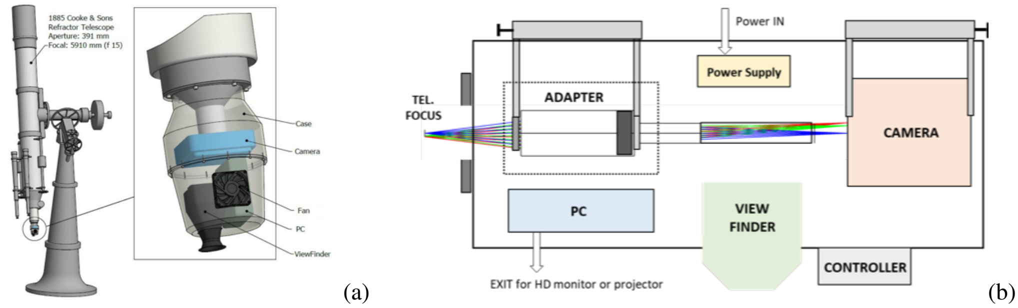


Fig. 3. (a) CAD rendering of the historical Cooke & Sons Refractor Telescope located in Teramo (INAF- Astronomical Observatory of Abruzzo), with a CAD view of IMAGO, mounted on the telescope exit focal plane flange (with its main components inside); **(b)** Conceptual scheme of IMAGO, with the optical adapter to fit different telescopes f-ratios.

- Optical Adapter
- CCD Image Capture Camera
- PC
- Professional Viewer
- Mechanical supporting structure and envelope, including mechanical interface to the telescope

The system concept layout is shown in figure 3.

The first component of IMAGO is the Optical Adapter: this is a telecentric lens allowing one to obtain 1 to 3 magnifications, matching the internal optics of the device to those of the telescope. The possibility to invert the position of the Adapter allows one to extend its magnification from 0.33 to 3. The guiding concept is that IMAGO should adapt to the telescope, not the other way around.

On the new focal plane, located inside IMAGO and generated by the Optical Adapter, a CCD camera captures the images of the celestial field pointed by the telescope: they are captured in real-time in order to be presented to the observer as if they were directly viewing the field through the telescope eyepiece. The Optical Adapter + Camera system layout is shown in figure 5.

A mini PC controls the capture camera, transferring video-rate images. In the initial IMAGO setup, without Augmented Reality, it simply sends images to the viewer, so the observer can experience the field view as if they were looking through the telescope. In virtual mode, IMAGO processes real-time images of the observed celestial object with dedicated software, enriching them with additional contents. As a result, the observer will see the image gradually and naturally enhancing in resolution and information.

All this is possible thanks to a set of activation buttons and a paddle that allows the observer to navigate the image, selecting regions of interest and accessing related information.

A Professional Viewer, based on an equipment for television cameras, facilitates the experience, with both screen mode and an eyepiece style attachment for a one-eye view, heightening the observational realism.

Finally, the system includes a power supply unit, to be located at the base of the telescope due to its size and weight.

All the devices that are part of IMAGO are commercial components, while the mechanical parts (interface with the telescope, camera mount, case) are designed and built in house.

2.4. First tests at the telescope and modified concepts

The earliest optical image acquisition tests were carried out by installing a basic IMAGO prototype at the Cooke Telescope of INAF-Astronomical Observatory of Abruzzo (Figure 4).

Although successfully confirming the efficiency of the optical adapter and the image acquisition system through the CCD camera, the

Fig. 4. The CMOS camera mounted on the optical bench for preliminary laboratory tests, in Teramo; and CMOS camera mounted on the focal plane of the Cooke Telescope for the acquisition of astronomical images of Mars and Jupiter. The optical adapter is placed between the camera and the focal plane to test different magnifications.

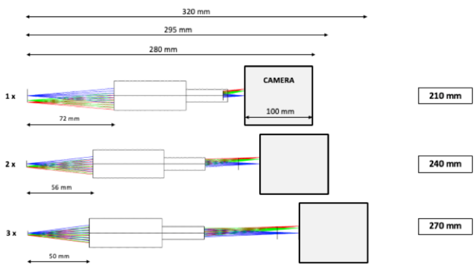


Fig. 5. Optical Adapter and Camera system layout.

tests showed that the telescope pointing was challenging.

In addition, the resulting overall system was too cantilevered from the telescope, so it did not comply with the basic requirements of compactness and discreteness.

For these reasons, the IMAGO concept was modified as to the part concerning the optical interface. Indeed, since the basic requirement is to start the augmented content with the same plate scale of the telescope, such an adaptation has been eventually devoted to the software managing the augmented content rather than to the optical adapter. Therefore, the final IMAGO concept does no longer include the cumbersome, focal length-varying telecentric lens plus a fixed image size at the onset of the AR content; rather, the focal length is that of the telescope, which produces a focal plane image whose size is different from one telescope to another, and the initial image of the AR content is rescaled accordingly by the software, which includes this functionality in the general transition from the real to the augmented regime.

2.5. Video-zoom on Mars

A first software, developed for Mars, involved the creation of a video that simulates a zoom-in on a point of the planet's surface, starting from live images acquired with the Cooke & Sons Telescope through the CMOS camera (Figure 4).

This work was divided into two main stages.

The first one was an analysis of possible sources from which to get images of Mars. A report was issued identifying some possible points of interest and sources of information, and Mars Global Data Sets (`http://www./mars.asu.edu/data`) was identified as the most important source.

In the second phase of the software development, a complex pipeline architecture was required to appropriately modify the input from the telescope and prepare it for the creation of the video-zoom. The target selected on the Mars surface was the Olympus Mount and after a preliminary video created with blender (`http://www.blender.org/`), an earlier software version was obtained in order to check the performances required for the visualization of the (simulated) camera images and the 3D videos. This initial software exploited the OpenCV Python Library (`http://www.opencv.org/`) and Ubuntu Operating System (`http://www.ubuntu.com/`). The architecture is modular with a pipeline stream where different components are used to modify the input from the telescope in view of the video transition (each component accepts one or more inputs and yields a single output). Many components have been created and tested for different purposes, namely:

- *Augment*, which allows one to add information to the image being displayed;
- *AverageBlend*, which from a set of images as input yields an output image that is the average of the input images;
- *BackGroundRemoval*, which allows one to remove the background from the input image;
- *Blur*, which blurs the input image;
- *CameraInput*, which provides an output image taken from a video input (camera) or from a file system (in the case of simulations);
- *ContourDetection*, which provides an output image in which the objects included in the input image are highlighted;
- *CookeCentering*, a component specifically created keeping the Cooke telescope in mind, yielding an output image centred on the main object of the input image (it is in fact possible that the image from the Cooke is not centred on the planet);
- *CornerDetection*, yielding an output image that identifies the corners based on the Harris function (Harris Corner Detector in OpenCV);
- *MemLogs*, a debugging component that shows as an output (on the console) the application performance values;
- *OpenCVDipslay*, which allows one to display an image on the video screen;
- *Resize*, yielding a resized output image;
- *UserInput*, showing in the output the user inputs for application control (such as a zoom input);
- *AddWeighted*, yielding the weighted sum of two input images based on a percentage;
- *Zoom*, allowing one to zoom in on a point of the input image.

As the most critical component is probably *CookeCentering*, its functionality is detailed in the figure 6. This component utilizes the Satoshi Suzuki computer vision algorithm (Satoshi & Keiichi (1985)) to detect the location and size of the largest object in the input image. Then, an offset is applied to the image to keep the object centered.

The software has been tested with a Raspberry Pi 4 Model B with 8*GB* RAM which proved to be not enough performing for the image treatments carried out.

Fig. 6. Image from the telescope: not centered on the planet (top) and centered using the *CookeCentering* component (bottom).

2.6. The real-to-virtual content transition

The software development is the key part of IMAGO. The quality of AR multimedia contents and graphic interface drives the quality of the whole system. The development of both AR contents and user interface has been challenging and required the support of the specialized company ACKAGI Visual Arts[1].

To obtain a continuous zooming in on Mars starting with an image acquired from the telescope and ending with the highest magnification level required by handling a set of heterogeneous objects with several resolutions, the following steps were required:

1. Retrieving average resolution images from Google Mars[2]: we obtained screen shots of the highest resolution images of the equatorial area and of average resolution images of the polar areas. We then arranged a 30000*x*30000 pixels mosaic from which we constructed an as accurate as possible Mercator projection (Figure 7);

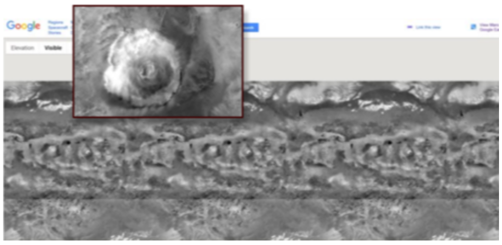


Fig. 7. Martian view downloaded from Martial Global Data Sets

2. Mapping: the texture obtained in this way was 3*D* mapped on a sphere, from which we subsequently got a mosaic render of four 15000*x*15000 pixels images;

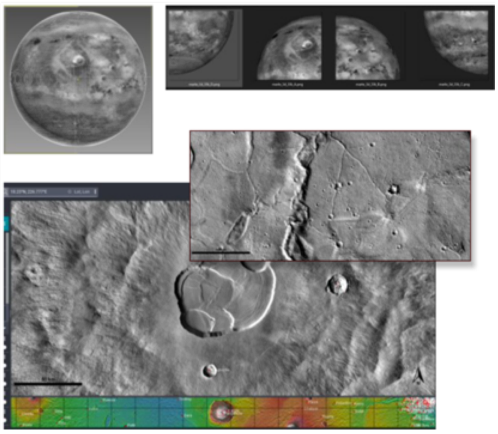


Fig. 8. Mapping (top) and Mosaic of the Mount Olympus area using Jmars (bottom).

3. Retrieving close images from Jmars[3] software: for the final close-up of the zoom we constructed another mosaic of the Mount Olympus area using the software Jmars (Figure 8). The latter bitmap has a resolution of 20194*x*13034 pixels.
4. Color setting: we obtained a chromatic transition starting from the real telescope

[1] `http://www.ackagi.com/mainsite/index.htm`

[2] `https://www.google.com/mars/`

[3] `https://jmars.asu.edu`

Fig. 9. Color setting

image and ending with a reference image of the planet surface (Figure 9);

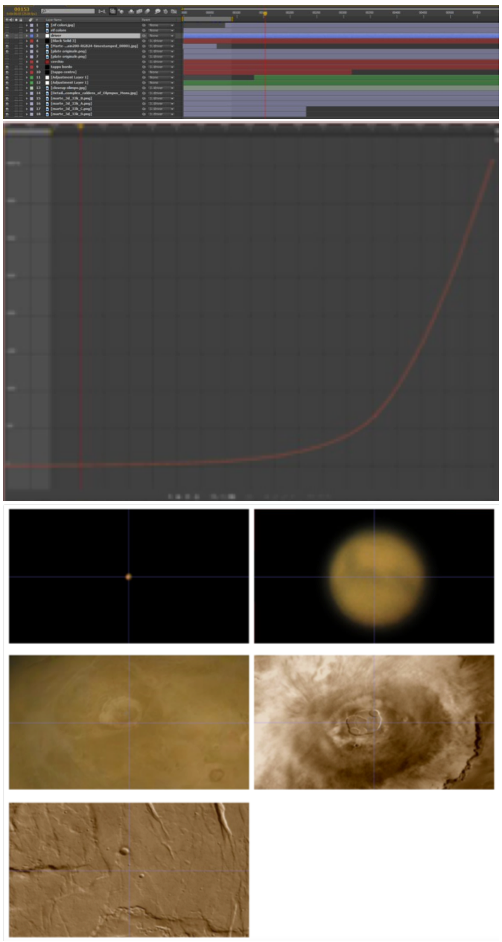


Fig. 10. Compositing software and animation.

5. Animation: the three images yielded from the previous steps were imported and registered as 3*D* levels in the compositing software and the camera moving action was arranged caring to linearize the perception of the action.
   The images were then de-focused, faded and masked appropriately to generate a continuous movement.

2.7. Interactive installation

Following the above steps, we subsequently obtained AR contents also for Jupiter, developing an upgraded version to circumvent a few critical issues of the previous one.

The zoom-in on Mars described in the previous section was obtained using a non-continuous set of images. Although this architecture has the advantage of simplifying the implementation, the images are read from the disc in real time and the lack of a steady flux can cause short pauses in the zooming if the knob controlling the zooming is turned too fast.

Instead, the procedure adopted for Jupiter makes a photo compositing in real time from images at several zoom levels, appropriately masked and registered. As these frames are generated in real time at millisecond frequencies, the motion smoothness is improved.

We implemented this upgrade by introducing a video acquisition interface, providing a live image from the telescope, and a controller that through a knob allows one to manage the image calibration and magnification sequence, hence to control the zooming with good accuracy (Figure 12).

The controller exploits a high-resolution industrial rotative encoder linked to a microcontroller Arduino Nano, which is in turn connected to a computer via USB. A buzzer provides indications on the controller status. As an alternative, one can use the mouse wheel instead of the controller, as well as pre-recorded movies instead of the video acquisition.

At the moment the software only allows zooming; navigation on the planet surface is not implemented yet, so the position shown cannot be changed, both for Mars and Jupiter.

The adopted software development platform is Unity(`Unity.com`), a state-of-the-art game engine, complemented with the Open CV libraries(`opencv.org`) for the computer vision. As schematically shown in figure 11,

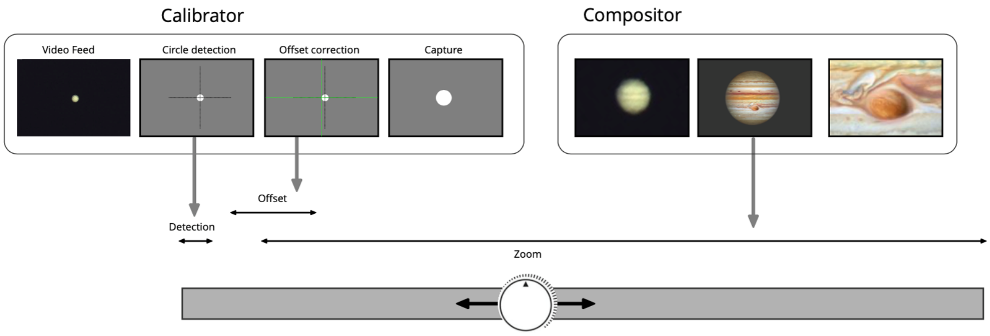


Fig. 11. Conceptual scheme of the zoom level control introduced in the development of the AR content.

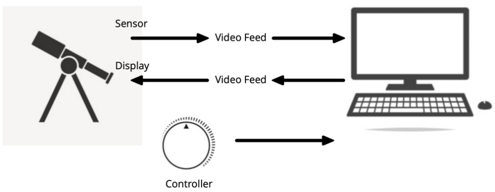


Fig. 12. Working principle: IMAGO uses the input signal from the sensor on the telescope and output the processed signal to a viewer inside the same telescope.

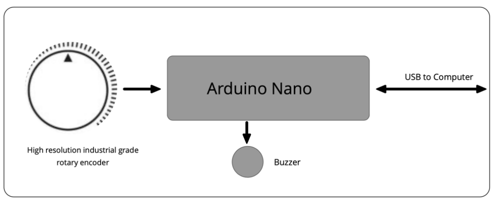


Fig. 13. Schematic representation of the controller.

the timeline is managed by the USB controller that provides information about the knob rotation speed and direction. If the knob is turned forward the timeline will increase, otherwise the timeline will decrease.

In the timeline, calibration and zoom are managed in a sequential way. First, the signal from the sensor is output. Then, a computer vision algorithm (based on *Hough transform*) detects location and size of the largest circle in the input signal, which is identified as a planet (*circle detection*). As the knob is rotated, the video image is offset so that the planet center is kept in the center of the frame (*offset correction*) and the zooming is started.

The user can manage the zoom level through the controller, but does not directly control the transition between real image and digital content, happening at a pre-defined zoom level. During the detection phase, a still frame is captured from the input signal in order to free up computational resources and avoid flickering effects (*capture*).

This still frame is steadily combined with the input signal. From that moment on, a planet image is overlayed on the input signal. The image background is transparent in order to maintain a chromatic continuity with the background and the image edges are faded.

If the knob keeps being rotated, the zooming will go on and a new image with higher resolution is overlayed on the previous one and the magnification increases up to the end of the timeline. By rotating the knob backward, the timeline is unwrapped in the opposite direction and all the zooming events occur backward, down to the initial point where the real video stream is shown again.

2.8. The user interface

In order to manage simultaneously the AR content created for Mars and Jupiter, a user interface was developed, designed to allow both

maximum flexibility of use and good reliability, considering it is not a commercial item.

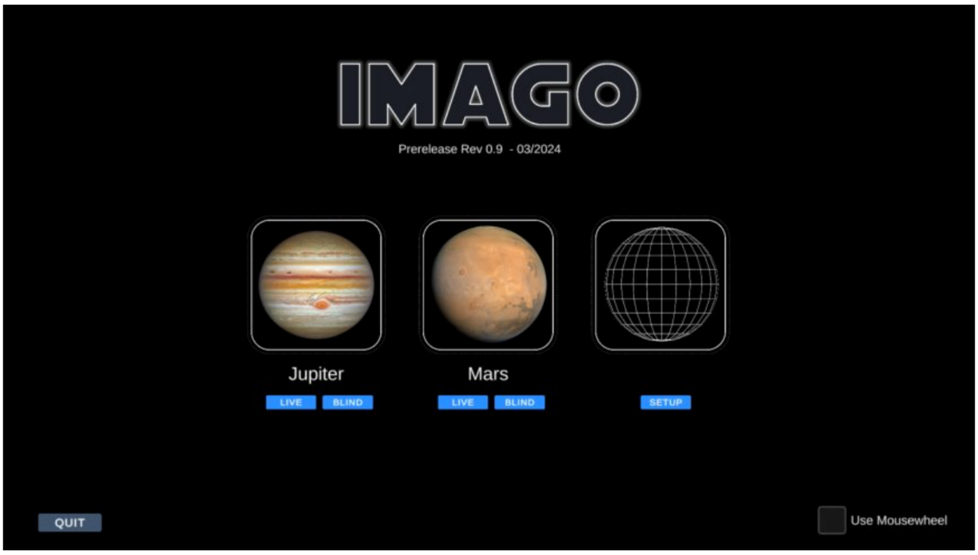


Fig. 14. The current version of user interface of IMAGO.

At the current stage, the procedure based on real-time images compositing, adopted for Jupiter, has not yet been implemented for Mars, for which, as described earlier, the zoom-in is achieved using a set of single images instead.

From a startup screen (Figure 14) the user can select which planet to explore between Jupiter and Mars, being available two exploration modes: LIVE, using the real-time input from the telescope (that represents the primary use of IMAGO), or BLIND, using a set of prerecorded images (a useful option in case of bad weather conditions, daytime visits, or in case of technical acquisition problems).

In the same screen the user can select the option *"Use Mousewheel"*) to use the mouse wheel instead of the USB controller.

Finally, by selecting the SETUP option, the user can access a configuration screen where they can calibrate the computer vision system to enable it to identify the planet with high accuracy.

The setup screen is divided into three main interactive areas (Figure 15):

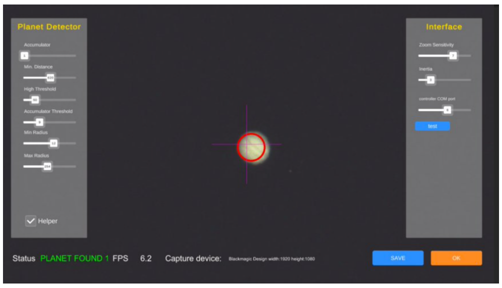


Fig. 15. The configuration screen of IMAGO. In the image the screen backup shows the telescope input and a magenta cross marks the screen center.

1. *Planet Detector panel* which, through six sliders, allows one to select the calibration parameters for planet detection. The *"helper"* shows (or hides, if not selected) a red circle around the detected planet (Figure 15). This option is useful in case of *"false positives"*, which may occur if the settings have not been properly configured.
2. *Interface panel*, where the interface commands are located, to: set the zoom sensitivity (the zoom response speed to the mouse wheel); manage the controller (or the mouse wheel) parameters to ensure a smooth experience for the user; test the

COM port to which the controller is assigned;

3. *Status bar*, displaying information on the number of detected planets, which must not exceed one; on the frame rate (FPS,*Frames Per Second*), which must never drop below a certain threshold); and on the capture device. These parameters have been introduced to create filters, as planet detection requires significant computational resources.

   After adjusting all the parameters on the screen, the settings can be saved by pressing the SAVE button, or the initial settings can be restored by pressing the OK button.

3. Conclusions and future developments

The IMAGO project involved several scientific research branches and has proven a valuable tool able to promote the technical expertise within the Astronomical Institutes of INAF, particularly Teramo and Rome.

The project work has resulted in the construction of an IMAGO prototype device positively tested with preliminary AR contents. All the system components will be enclosed in a case and equipped with a mechanical interface. Once fully developed, the device could be matched to historical (or other kinds of) telescopes owned by many Italian Astronomical Observatories to support the outreach activity with schools and general public.

Being established as one of the initial goals of the project, the IMAGO prototype was presented to the community "III Mission" at the INAF annual general meeting, and at two other National and International technical meetings (Di Carlo & D'Alessio (2024), Di Antonio et al. (2024)).

The IMAGO prototype has the potential for further future developments. Next enhancements will include a software upgrade to enable navigability within the astronomical image, with new content and selectable hotspots. Since content is currently available for Jupiter and Mars, initial Augmented Reality features will focus on these celestial objects. Subsequent targets will be added to expand the catalog of accessible objects. Once developed for the initial set of content, the system is expected to be replicable for additional targets, utilizing the structure and methods established with these initial examples.

We aim to improve the present IMAGO version by developing a flexible platform where other planets can be implemented, along with new features, and alternative solutions can be tested in terms of sensors, video acquisition, and video rendering.

Acknowledgements. This work has been supported by the Italian Ministero dell'Istruzione, Università e Ricerca (MIUR) through PRIN-DIV INAF 2019 *"IMAGO (IMAGer with mOdified eyepiece): a Project of Augmented Reality applied to telescopes"*.

References

Di Antonio, I., Di Carlo, E., Di Carlo, M., et al. 2024, *"Applying Augmented Reality to historical telescopes images: the IMAGO Project"*, Proceedings SPIE .13100, 1310078 (2024), Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation VI (DOI: http://dx.doi.org/10.1117/12.3018892) Poster + Paper

Di Carlo, E. & D'Alessio, F. 2024,*"IMAGO: un Progetto di Realtà Aumentata applicata ai telescopi per la Divulgazione"*, Videomemorie SAIt Vol.2 (DOI: https://doi.org/10.36116/videomem_2.2024.18)

Hsin-Kai, W. 2013, *"Current status, opportunities and challenges of augmented reality in education"* 2013, Computers & Education, Vol 62, 41-49

Satoshi, S. & Keiichi, A. 1985,*"Topological structural analysis of digitized binary images by border following"*, Computer Vision, Graphics, and Image Processing, Vol.30 (1), 32-46 (DOI: https://doi.org/10.1016/0734-189X(85)90016-7)