GLORIA: The First Free Access e-infrastructure of Robotic Telescopes for Citizen Science

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Abstract. This paper describes the GLORIA system (GLObal Robotic tele-
scope Intelligent Array), the first worldwide network of robotic telescopes,
which covers four continents with seventeen telescopes, and can be extended.
The network architecture has been designed taking into account the functionali-
ties offered to the community, the number of telescopes, users that will be man-
aged and network compatibility with all kinds of robotic telescopes. Different
kinds of experiments have been designed to support the various requirements of
astronomers. In order to manage the user access to the network resources, an
evaluation system, called karma, has been defined which will operate according
to some established policy.

Keywords: robotic telescope, social network, web 2.0.

1 Introduction

Research in astronomy poses two main challenges; 1) the immensity of the sky and 2)
the huge quantity of astronomical data being gathered. In fact, astronomers are nowa-
days facing great difficulty in finding the resources to analyze the increasing flood of
data generated by modern astronomical instruments. To meet these challenges, an
increasing number of astronomy projects have turned to the public, via the Internet,
e.g. GalaxyZoo [1][2] and Zooniverse [3]. These projects use the collective intelli-
gence [4] of hundreds of thousands of users to analyze huge amounts of data and
achieve results that are otherwise impossible. On the other hand, in recent years, vari-
ous robotic telescope networks have emerged including some that allow access to
users such as students and amateur astronomers as well as professional researchers.
Examples include the eStar [5] project, continued by RoboNet-I [6] and Robonet-II
[7] projects (pure research); Las Cumbres Observatory Global Telescope Network [8]
(for both research and education, with two operational telescopes of 2m and 1m di-

ameter); GTN ("Global Telescope Network") supported by NASA and Sonoma State University (gtn.sonoma.edu); SkyNet [9] which has around eleven telescopes in their network and is intended for both research and educational purposes; the Australia Telescope National Facility [10], which involves an array of six 22-m antennas used for radio astronomy research; the BOOTES network [11], which includes 4 telescopes worldwide for researching purposes; and finally, the TAROT network [12] which has two robotic ground-based telescopes. All these networks are based on their own closed architectures and it is very difficult to integrate a robotic telescope into these networks without using devices compatible with the software of the network. Moreover, although these networks can manage their observing time using an advanced scheduling system, they do not take into account the quantity of information generated and how to process it. On the other hand, for pure educational purposes, there are currently several telescope networks that are trying to develop software specifically for integrating telescopes into their network. An example is the SAROS software system used by APTA [13][14].

The worldwide network of robotic telescopes proposed in this paper is based on the idea: "the more eyes we would put on the sky the more and greater the scientific discoveries that will be achieved". Thus, in order to try to improve the way of doing astronomy research, this work aims to build the first open access worldwide network of robotic telescopes, helping users to get involved in astronomy research, to collaborate in making new discoveries and enabling telescope owners to integrate their instruments into the network using free and open source software.

The GLORIA project is based on experience gained from *Cíclope* [15] and *rts2* [16] and is being developed by a consortium of thirteen members from different countries around the world, which will make their seventeen robotic telescopes available to users.

2 Overview of the System

This section explains the design and network architecture of the GLORIA system, as are the services that will be provided. Later, the concept of a GLORIA experiment is introduced, as well as its classification and description.

2.1 Network Architecture

The GLORIA network consists of three main components: telescopes, users and the core logic that connects them together as a network.

Following a device-driver approach, we decided to split the software into two distinct areas, as shown in Fig. 1. The bottom area, called Robotic Telescope Network, corresponds to the subset of software that is functionally and topologically located in each separate telescope. This software (Robotic Telescope System or RTS) takes the role of a device according to the proposed approach, and offers the possibility of teleoperation of any telescope from anywhere. This telescope network will grow as owner users put their telescopes available in GLORIA.
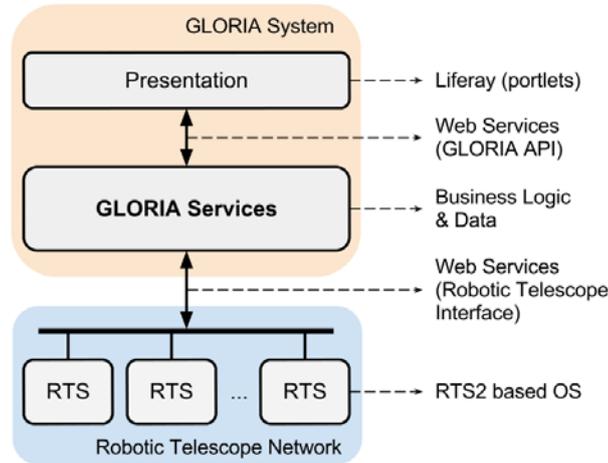
Fig. 1. GLORIA Network architecture.

The upper area, called the GLORIA System, assumes the corresponding role of driver over the Robotic Telescope Network. Communication between these two parts is done via the web, using a high level protocol defined in the GLORIA standards (Robotic Telescope Interface).

The GLORIA System in turn consists of two elements with quite different purposes. The first corresponds to the Presentation layer of the system, i.e. the subset of software that is the interface between the users, and the second element are the services. These services bring together all the business logic of GLORIA and are identified as the core of the whole system. Anything a user may want to do, i.e. control a telescope, run an experiment or vote for an image, will be done through a web service operation included in some service inside the GLORIA Services layer.
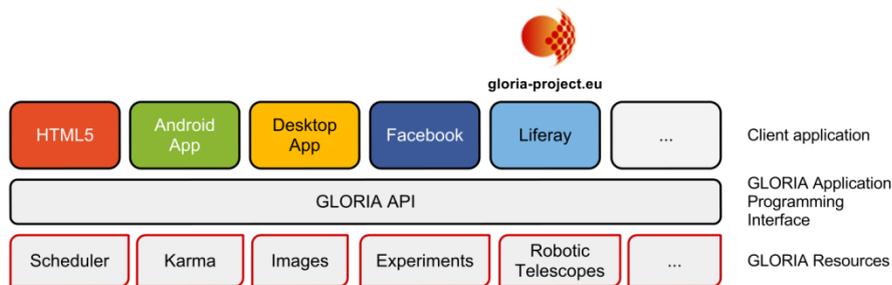

Fig. 2. GLORIA Application Programming Interface.

The architecture of GLORIA Network has been designed according to service oriented methodology (SOA) [17]. The main reason for applying this paradigm is to make GLORIA functionality independent from the various paths or interfaces used by the community. In this way we achieve independence from any particular technology other than the web transport. Therefore, the only thing that requires any client applica-

tion, which is part of the Presentation layer, is to use the GLORIA API to consume any of its services (see Fig. 2).

2.2 Telescopes Network Scheduler

In order to manage all observation requests by users, it is necessary to develop a scheduler that caters for all the robotic telescopes in the network [18], taking into account that each telescope has its own scheduler and observation policy. This core scheduler arranges observations taking into account the distinct telescope properties, the nature of the target to be observed and some constraints set by the astronomers. The scheduler solution is based on these parts:

- Observing plan: this is a package, in the form of an XML file, containing everything the scheduler (and eventually a telescope) needs to know to carry out the observation. An Observing Plan includes constraints (specific time window, specific telescope, specific filters, height above horizon, moon separation, time after dusk/before dawn, etc.) and a sequence of instructions in a basic scripting language of five verbs: Target (what (object or coordinates) the telescope should point at now), Camera (configuration settings such as windowing, binning, etc.), Expose (defining timing, repetitions or duration and filters), Label (marks the beginning of a logical block in the program, but has no physical effect and Repeat (used after a block of instructions to indicate repetitions of the entire block).

- A local scheduler: each telescope has a scheduler of its own (possibly with far more than GLORIA on its mind – i.e. a telescope may be offering GLORIA only a part of its time, and this may be by interleaving GLORIA tasks with its private affairs and not necessarily with a dedicated time slot).

- A central scheduler: this provides the global robotic network schedule.

In this model, considering a job as an execution request of an Observing Plan, the central-scheduler advertises this to the local-schedulers of telescopes that can do the job, and each local-scheduler will reply with either a proposal (for how and when it can do it), or a refusal. The central scheduler accepts the best proposal (determined by policy), and waits for confirmation that the job is complete, or for an apology that the job was not or will not be carried out according to the original proposal. The central-scheduler manages all jobs in the GLORIA system, receiving new jobs from the authoring tool, advertising them (and re-advertising as necessary), accepting the best proposal (taking into account a global policy) and retiring tasks when they are done.

The scheduler policy is based on the Karma (described in section 4.4), but an additional priority layer is required to prioritize some Observing. This layer enables the system to execute alerts i.e. GRB or supernovae observations.

3 Telescopes Management

GLORIA is a heterogeneous network, but all the telescopes must present a common interface in order to integrate itself into the system. This interface is the outer layer of the modular and scalable architecture that all robotic telescope systems (RTS) must fulfill to be included in the network. This section describes this architecture and all steps that a RT has to take to complete the registration process.
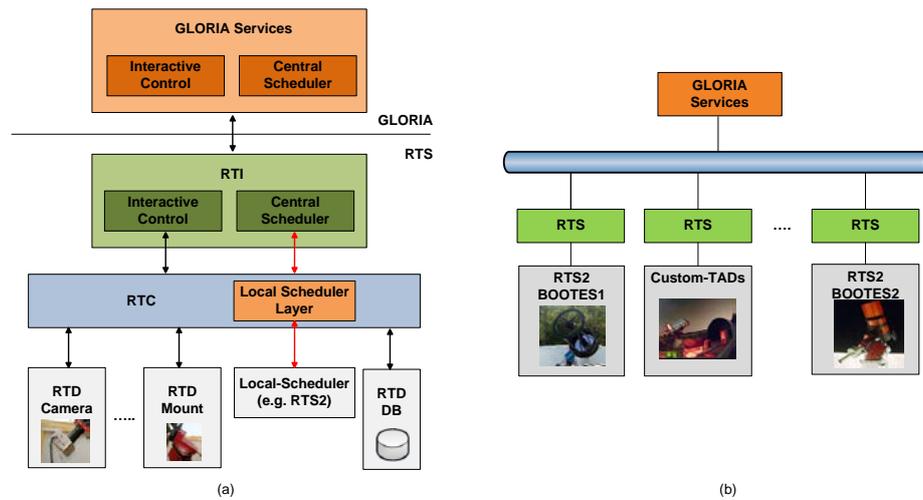

Fig. 3. a) RTS architecture. b) Robotics telescopes in GLORIA Network.

3.1 RTS Architecture

Fig. 3 shows all the components of the robotic telescope system and the communications between them, and they are described in detail below.

A separate Robotic Telescope Device (RTD) controls and monitors each physical device in the robotic telescope (RT), and belongs to one of a number of different classes, taking into account the different devices that a telescope commonly has, i.e. dome, mount, etc. Each RTD type supports the standard properties of the corresponding device, and a distinct interface is defined for each RTD type. These interfaces are used in turn by the Robotic Telescope Controller (RTC). In addition to the RTDs for hardware control, there is also a specific RTD for managing the Robotic Telescope Database (RTDB) which contains the images the system acquires.

The RTC manages the devices (RTD/RTDB) and the communication between the Robotic Telescope Interface (RTI) and the RTDs. It is also responsible of monitoring device state and for security. Using the RTD state information, the RTC is responsible for undertaking all necessary actions to keep the telescope in a stable and undamaged state. Finally, the Robotic Telescope Interface (RTI) is the communication interface between the Gloria Services (GS) and RTS.

All interfaces within the RTS (RTI and RTDs) are technology independent (Java, C++, etc.). Like others telescopes systems [6], these interfaces have been defined

using WSDL (Web Services Description Language). Thus, a telescope owner can develop the entire RTI using any technology that supports web services interfaces.

3.2   RT Registration

In order to make easier the integration of new telescopes into the Gloria network, all the RTS software will be available for owners as well as detailed instructions. The only modifications owners have to make are those related to the HW dependent part of the RTDs. Once the telescope owner has the system installed in his telescope and he is already logged in the Gloria network, the RT has to undergo various stages or phases before being fully integrated in GLORIA network:

- Test: At this step, the RT owner has already fulfilled the GLORIA Network Integration Request, where all the telescope data, the devices and implemented operations are detailed. When the RT enters this phase it becomes Pre-Alpha version, and the system runs some tests to verify critical aspects of the communication with the RT and its basic characteristics. Once the automatic tests have been passed, the telescope is ready to be validated from Gloria System.
- Administrative validation: The owner and a subset of users selected by him/her have exclusive access to verify the operation of the RT. At this step, the RT becomes Alpha version. They compare the available operations offered by the owner to the ones actually implemented and its results. The objective of this phase is to refine the functionality of the RT to the owner's desired quality level, before opening it to the community.
- Collective validation: The use of the telescope is open to the community, but there will be no direct impact on its karma. Every user can operate the RT and report incidences about the problems they have encountered on it. The RT reaches the Beta state. The goal of this phase is to obtain, through all the information gathered from individual experiences, a global validation report that helps Gloria Administrators to decide the final integration of the RT.
- Complete: The RT is completely ready to be used by the community with its karma enabled. Here, the telescope reaches the Release state. An initial value of karma is assigned based on the results given by the last global validation report generated during the Beta phase.

4   User Management and Website

The final users of the network are both the owners of the RTs and anyone who wants to execute astronomical experiments. They have a common point of access to the system based on the Web.

4.1   User Authentication

Authentication and user management is one of the most important things for creating a social network. In the case of GLORIA, which has involved several universities and

research centers, and in the future schools, associations and other, this becomes more important because it's necessary to give access to the network for a large number of users [13].

To make this work easier, a study about the different technologies for authentication (user management and authentication in different web applications) has been made, concluding that the use of a federated authentication service helps for this purpose. Federated authentication allows any organization to deploy its own authentication system, and to connect it to different web applications. The advantages of this type of authentication features are many: easy to implement, scalable approach, integrating a large volume of users, use the same authentication system in different web applications that use different technologies, etc. [19].

There are many examples in which federated authentication have been successful. At European level, the Stork project [20] allows to users to authenticate using their national eID, and nowadays it's using to establish relationships with the public administration. The initiative eduGain [21] is a service that identifies users around the world from the research and education community.

In the case of this project, an authentication provider (SP) that will allow organizations to authenticate users who have made agreements with the GLORIA project will be deploy, for example: you are a secondary education center that has a telescope and wants to share it in GLORIA network, and you want to give access to the network to all the students. In this case the center would install an identification provider (IdP), and they connect it to the GLORIA Service Provider. In the case of users who do not belong to any organization, GLORIA will have its own identification provider that contains the database of registered users.

Fig. 4 shows an example of authentication system architecture that will be implemented in the GLORIA project. User will log into any web application project, it will direct user to GLORIA Federation Service, and the user will be able toauthenticate using his center service provider or the GLORIA user database. Once identified by the system, he will be able to browse between different web applications with his role, and without having to re-identify.
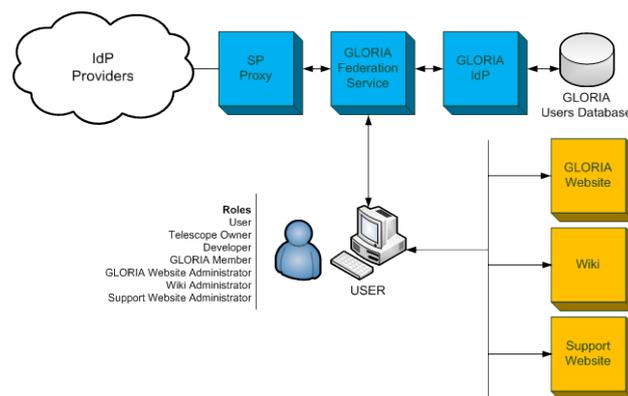

Fig. 4. Authentication architecture.

4.2 Authoring Tool

The GLORIA website provides an Authoring Tool, which integrates the different web components, called portlets, for the on-line and off-line experiments. This Authoring Tool provides a user-friendly web interface for the creation of new experiments.
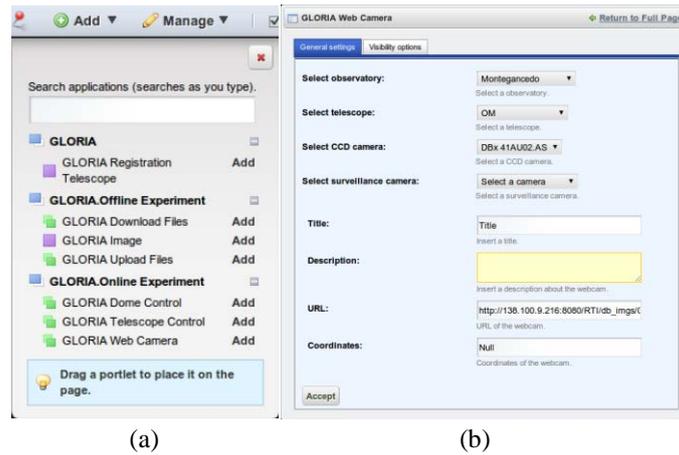

(a)   (b)

Fig. 5. Authoring tool.

The Authoring Tool is mainly a palette of web components organized by category, as can be seen at Fig. 5.a. There are currently three different categories, general purpose on-line and off-line. Experiments are created by simply adding web components can be to any page using drag-and-drop.Furthermore, each web component has a configuration that can be modified by the experiment designer, as can be seen in Fig. 5.b. New web components can be written and added to the palette in any category, but the web administrator is responsible for deploying them through the Liferay [22] control panel.

An example of how to create and configure an experiment can be watched in a video on the GLORIA YouTube channel [23].

4.3 Experiments

GLORIA is going to take science to citizens, by enabling research of a specific astronomical issue via an experiment, in which users will be guided through the different tasks the research requires. These experiments are of two kinds: on-line (which require a telescope) and off-line, which work on existing data produced by the GLORIA network or derived from other databases, such as the European Virtual Observatory.

On-line experiments are based on Observing Plans, defined in Section 2.2, and are classified according to when (Fixed, Scheduled or Alert) and how (Batch or Interactive). Fixed experiments execute at a time chosen by the user, Scheduled one at a time chosen by the system, and Alerts execute when triggered by an external signal. As to how the experiment is carried out: Interactive mode allows teleoperation of the telescope, with semi-direct (mediated by the software on the telescope) access to indi-

vidual devices such as cameras or filter wheels, while batch mode refers to the execution of a pre-programmed Observing plan. This yields six combinations, for all of which there are valid uses.

The Off-line experiments allow users to do it with the information stored in the GLORIA database. There are several types of off-line experiments: the "Find your star" experiment allows a user to get the object description and an image for high quality printing; the target of the "Solar activity monitoring" experiment is the study of the solar activity (sunspots), applying a methodology for calculating astrophysical parameters; the user can verify if a star brightness decreasing is due to the occultation of the star by a Solar System object (e.g. asteroid), requesting a "Occultation of stars" experiment; the user can search for optical transients in a proper sky part requesting an "Optical transients" experiment; the "Prediction of occultation of stars" experiment can predict possible occultation of stars thanks to a Solar System object ephemerides; The "Search for variable stars evolution with time" experiment allows user to decide if a star shows significant changes in variability period and/or shape for time scales of the order of years; the user can classify an object attending its light curve; in this case, the requested off-line experiment is called "Classification of variable objects".

4.4   Karma

Karma is an index that measures the reputation of a user in GLORIA. Users participate in GLORIA by voting for images, including commentaries, etc.., i.e, increasing science contribution. It is used in numerous social networks like Digg, eBay, etc. This index is automatically calculated at intervals by the GLORIA System as a function of each user's participation and the application of specific policies that can be established dynamically.

The Karma component in GLORIA is based on the Social Activity [24] module of Liferay. This module permits valuation rules to be defined as a function of user actions over the website.

Every piece of presented information (called a resource) can be evaluated by users through the execution of actions on over them. For instance, a user can vote an image, write a comment, etc. Valuation rules use two metrics: participation points are awarded to the user doing the action, and contribution points are awarded to the creator of the resource, with a user's total score being the sum of these. The Karma module transforms these points into a karma value in the range 0-10.

Once users are evaluated, GLORIA can assign observation time, but establishing a set of rules to assign this time according to karma is a complex and resource demanding task. Another point of view is needed and the real world can give us an answer.

What do we use in the real world to trade resources? Money, so we propose to introduce a virtual currency, called GLORIUS, to pay for observation time. The quantity of GLORIUS a user earns will depend on their participation in the network, i.e, its karma. They can then spend GLORIUS whenever they make a reservation, thus preventing individual users from taking all the available observation time for themselves. This implies a definition of an economic model. This approach is being used for resource management and scheduling in other fields like Grid computing [25].

This system of reservations and time allocation will be implemented through the use of auctions. This way, users will be able to compete for observation time. Auc-

tions are used in many platforms, such as ebay, to automatically set prices based on valuations made by a community of users. The price of a time slot of observation time on a specific RT will be fixed using this method. All of this process is shown in Fig. 6.
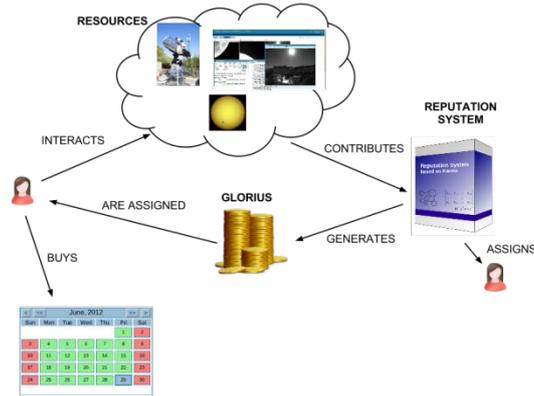

Fig. 6. Interactions between Karma and economic model.

5 Results

During the three years of the project, the GLORIA consortium will integrate 17 telescopes, with 12 of them already commissioned and working in various scientific and public outreach fields, three more beginning operation with GLORIA, and two more that will be installed during the lifetime of the project. Once all RTS software has been developed and tested, a progressive deployment plan will be defined with the aim of integrate it into every RT. At the end, all RTs will be managed by the GLORIA network using the same interface. Moreover, a set of the experiments explained in section 2.2 will be performed to evaluate the overall system's operation.
In the same manner as RT deployment (and earlier), the GLORIA system side will be also progressively launched, with step by step testing and deployment of all the modules of the system.

Up to now, only one experiment has been created through the Authoring Tool described above. This is a solar experiment which is composed by the following web components: CCD camera, surveillance camera, mount and dome (see Fig. 7).

Currently, four telescopes have been integrated into the GLORIA network: OM [26], TAD [27], BOOTES-1 and BOOTES-2 [11]. The solar experiment is running right now through the OM and TAD telescopes, as these are the only solar telescopes of the network.
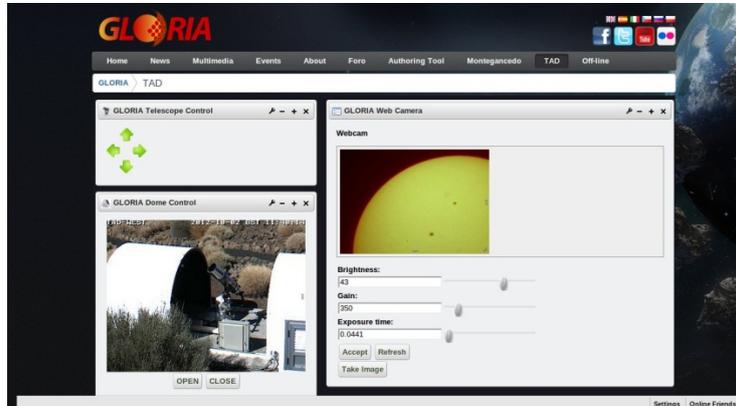
Fig. 7. TAD solar experiment interface.

6   Conclusions and Future Work

This paper has described the first worldwide network of robotic telescope, which intends to give users free access to a network of 17 robotic telescopes spread across 4 continents and both hemispheres. Furthermore, GLORIA will enable more telescopes to join the system. The users of the network will be able to execute two kinds of astronomical experiments: on-line experiments (those that require a telescope) and off-line experiments (those that work on data produced by the GLORIA network or derived from other databases). Thus, the GLORIA websites offers different functionalities, including: a user evaluation system (karma), experiments and telescope management facilities, user authentication, and others tools which allow users to make different actions.

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