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A POSSIBLE WAY OF EXCHANGING FOLLOW-UP DATA

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ABSTRACT

The Astronomical Institute of the University of Bern (AIUB) plans, performs, and processes space debris surveys on behalf of the European Space Agency (ESA). The surveys are performed using the ESA Space Debris Telescope (ESASDT) on Tenerife. AIUB also has its own optical sensors observing space debris at the Zimmerwald Observatory near Bern, Switzerland. Routinely, AIUB contributes to joint observation campaigns, in particular with the Keldysh Institute of Applied Mathematics (KIAM), Russian Academy of Sciences.

Within these projects we must highly automate the observation planning, data acquisition, and data processing. In addition, some observation scenarios require immediate, reliable, and robust exchange of data, in particular for near-realtime follow-up observations of newly discovered objects. It has been shown recently, that the newly detected population of high area-to-mass objects cannot be catalogued (or studied) without follow-up observations shortly after discovery. Additionally, the cataloguing of objects in geostationary orbits (GEO), in medium Earth orbits (MEO), and in geostationary transfer orbits (GTO) is not possible without scheduled follow-up observations. If several sensors share the tasks of acquiring follow-up observations, the needed automation requires a coordinated approach.

In this study we present a possible architecture for a flexible, transparent, and robust exchange of observations and follow-up requests between a set of heterogeneous sensors. We develop the user requirements and analyse the a possible system architecture. A central element of the architecture is a so-called exchange server that coordinates the exchange of observations between the partners. Participating authorized sensors can access the central observation pool provided by the exchange server. The exchange server also maintains a list of objects needing follow-up observations, which the participating sensors can include into their observation schedule on a voluntary basis.

We discuss a possible command set for the communication between sensors and the exchange server and present scenarios for implementation. This concept for the exchange of follow-up requests in a network of sensors could in particular be an option in a future European space surveillance system.

FULL TEXT

1. Introduction

The Astronomical Institute of the University of Bern, Switzerland (AIUB) utilizes the facilities at its Zimmerwald observatory [1] to participate in international observation campaigns and collaborations. The main research focus at Zimmerwald is on satellite laser ranging and on optical observations of fast moving objects, such as minor planets, comets, artificial Earth-orbiting satellites, and space debris. The current optical observation campaigns aim to characterize artificial space objects in high altitudes. Newly detected objects stem from surveys of the high altitude region, as for example the ESA surveys using the 1-m ESA space debris telescope (ESASDT) installed at the Teide observatory on the island of Tenerife, Spain. The ESA surveys are planned, run, and processed by AIUB on behalf of ESA.

In this paper we will use the term follow-up observation for pre-scheduled, intentional observations of previously discovered objects. With follow-up request we describe a message to a sensor willing to acquire follow-up observations.

Newly discovered objects, currently the survey focus is on objects with potential high ratio of area-to-mass [2], must be followed-up shortly after the initial discovery in order to secure the orbits and to build-up and to maintain a catalogue of orbital elements and other object characteristics [3]. Such a catalogue is needed to ensure the possible re-acquisition with other sensors or observation techniques in the framework of more detailed studies. The ESASDT is used to carry out follow-up observations during the monthly campaigns, spanning about 2 weeks centered at New Moon. However, as the ESASDT is not continuously available and weather conditions may prevent from acquiring the needed observations, AIUB schedules also the facilities at Zimmerwald for follow-up observations. Currently, some manual interaction is required to prepare the follow-up schedule, which usually allows for first additional follow-up observations in Zimmerwald in the subsequent night after the initial discovery. Similar limitations apply to the data exchange in ongoing international campaigns observing space debris objects.

From the current status of collaborative optical observations of (space debris) objects in high altitudes we conclude that there is a need for the establishment of near-realtime, guaranteed, controlled, and reliable exchange of follow-up requests between collaborating entities. The exchange procedure shall, however, not be limited to the exchange of follow-up requests, but shall also allow the exchange of raw observations or determined orbits on request. Two possible data exchange scenarios (or policy levels), the “internal exchange” (Tenerife-Zimmerwald) and the “collaborative exchange”, must be considered while developing a concept for data exchange. At this point, the discussion of the application of such a concept to co-located telescopes (examples are the two AIUB telescopes at Zimmerwald observatory [1] or the proposed optical observation sites in a future European space surveillance system [4] must be considered. It is important to develop a solution that keeps the manual interactions at a minimum. But also ideas and experiences gained in ongoing collaborations of the AIUB should be considered, such as in particular with the Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences [5]. From the “High Geocentric Orbit Space Debris Circulars” published by KIAM [6] it can be read that (as example) all “E*” objects were provided AIUB to the collaboration.

Concluding this short introduction to the problem it must be stated clearly that the scope of this study is not to develop a part of the architecture or outline the data processing of a space surveillance system. The concept is intended as a first rough idea, how distributed observers with common goals and problems may work together and exchange data and some analysis results on an informal basis, rapidly and reliably. It is hoped that the study may become the basis for improvements in the existing and future ad-hoc collaborations, with advantages for all partners. Major expected benefits are the possibilities to circumvent unfavorable weather conditions and telescope availability limits, to cover larger arcs in longitude, and to acquire observations in a geometry optimized for orbit determination. It is, however, clear that some aspects will become relevant for a future European space surveillance system, too.

2. User requirements

In this section we derive the user requirements for the exchange of follow-up requests and observation data based on describing typical use cases (section 2.1) and the definition of the acting entities (section 2.2). The requirements are then listed in section 2.3.

2.1. Use cases

During typical collaborative observations the sensor sites get assistance in the planning and scheduling of follow-up observations. The assistance should include the provision of up-to-date (propagated) orbital elements or at least the provision of quality-checked observation data of objects. The users may exchange their acquired observations via an observation pool and will be provided with a feedback reflecting checks of the data quality after submit. They can ask other sites to perform follow-up observations of particular objects. The users might also be interested in receiving statistics on their contributions to the collaboration. An option allows the observing sites to voluntary operate in a “remote requests only” mode, i.e. to operate according to an externally provided observation schedule.

It is clear from these use cases, that to some extend coordination between the users is needed. From the user point of view it is irrelevant, whether a central instance or a distributed service performs the coordinator tasks.

A coordinator monitors the gathered follow-up requests, and has the means to maintain the observation and follow-up pool (i.e. supervise the build-up and maintenance of a catalogue of orbital elements through continuously performed orbit determinations). Both pools physically exist at agreed sites, not necessarily at the coordinator. The coordinator is also responsible for providing performance-monitoring capabilities to the users.

The system architecture connecting pools, users, and coordinator ensures that data exchange is possible at any time, which means that the pools and the coordinator tasks are redundant.

It is worth noting that these use cases show some analogy to other scientific observation programs, like the observation of minor planets coordinated by the IAU minor planet center (MPC) or the tracking of satellites equipped with laser retro-reflectors coordinated by the international laser ranging service (ILRS), to name only two examples.

2.2. Definition of entities

From the use cases we identify the acting entities in the data exchange as the user, the sensor, and the coordinator. In addition an exchange server is needed to provide the technical framework for the exchange. We expect that a peer-to-peer (P2P) network would fulfill the required redundant operation of the data exchange optimally and would be well-suited to provide guaranteed monitoring and processing capabilities. However, as the effort for the development of a dedicated P2P-client that can be installed on all user sites is significant, the set-up of a P2P network is expected to be more complicated compared to a centralized exchange server. For a central service, the main development effort for the incorporation of remote observation scheduling, data acquisition, processing, and provision resides on the user side.

The entity “user” is understood as being in fact an observing site providing observations to a common data pool, and requiring the acquisition of follow-up observations from other sites. Technically speaking, the user - in terms of communication with the exchange server - is either an external client program, or even a human operator manually interacting with the exchange server.

The “sensor” always belongs to a user in a 1:n relationship. It is assumed that in a collaboration usually no users without own observing sites are involved.

As easiest solution the “coordinator” might be one dedicated central instance. It seems, however, reasonable to go for a solution where the coordinator role is alternated between the users to ensure best redundancy and coordinator availability.

The exchange server is a demon-like instance running on a dedicated host (at the coordinator’s premises), which is listening to a dedicated port. It provides the user and the coordinator access to the observation and follow-up pools.

2.3. Requirements

Using the definition of acting entities and the description of use cases allows deriving requirements for the exchange server.

The exchange server shall be accessible from any authorized host for authorized users using a simple and straightforward set of commands. The exchange server must accept and serve multiple connections in parallel. The list of authorized hosts, users, permissions etc., shall be maintained outside the exchange server, using the capabilities of the host operating system. The client/server connection between user and exchange server shall use a secure protocol (as ssh with a dedicated port) as basic layer. In particular the use of authentication mechanisms that allow automated connections shall be possible. A limited set of commands shall be used to interface with the exchange server. Default interaction shall utilize the standard in/standard out channels (STDIN/STDOUT). A graphical user interface (GUI) is not foreseen to be provided by the exchange server, but should be easy to implement on the user side. It is under the responsibility of the user to integrate the GUI into a framework of existing site-specific tools. The exchange server shall provide an interface to an archive consisting of

- A complete set of observations within the project (*observation pool*),
- A complete set of tasking requests (scheduled follow-up observations) within the project (*follow-up pool*).

Multiple observation projects (where observations shall not be exchanged in between) require the set-up of multiple instances of the exchange server (one exchange server / port per project). There are no user-related access limitations within a observation project. The format of the exchanged observation data shall follow a mutually agreed format. In particular, the user shall be responsible to assign object identifications to new objects.

The user shall be allowed to request data from the exchange server. The data is primarily observation-centered. Mainly, the ephemeris computation, orbit determination, and visibility calculation (i.e. the observation planning and telescope/camera control) shall be carried out at the users own facilities/observatories. Optionally, the user may use the monitoring checks and orbit determinations provided by the exchange server. The monitoring of the exchange server shall indicate the data quality to the user. A possible criterion could be the residuals of an automated orbit determination by the exchange server. In addition to formal errors and variance/covariance information, the exchange server shall add the arc length and the epoch of the last observation to any distributed set of orbital elements in order to allow the user to evaluate the quality of the data. The user shall be allowed to limit the obtained requests to observations within a particular time interval, to observations of defined objects (lists), and to requests from selected observatories. Further, the user shall be allowed to request a list of all pending (open) follow-up requests. A limitation of the listing to specified time periods should be possible. At any time the user shall be allowed to upload observation data to the exchange server. Any upload shall be logged. The user shall be allowed to send messages in a defined format to the exchange server, in particular to indicate required follow-up observations, and accordingly the exchange server shall be capable to issue messages that are either distributed to all connected users or to a defined subset of the connected users. The user shall be allowed to respond to a follow-up request by 'accept' or 'deny' messages. The server shall log those messages and update the follow-up pool accordingly.

The coordinator shall be allowed to mark (enable/disable) selected observations. Marked observations shall not be output as a result of user requests. Re-assigning object IDs to objects shall made by the coordinator and the users shall be informed. The coordinator shall be able to disable, enable, delete, and insert additional follow-up request into the pool of follow-up requests. The exchange server shall issue the according messages.

3. System architecture

A possible system architecture that meets the developed requirements is described in section 3.1 and the related interface description in section 3.2.

3.1. Exchange server

The architecture of the exchange server may be easily split into the parts describing the interaction with the user and the interaction with the coordinator.

Figure 1 gives an outline of a possible architecture of the user-related part of the exchange server. Central elements are the data archives (pools): one for the observations, one for the maintained list of objects needing follow-up observations. Authorized users may send observations to or may select observations from the observation pool with possible filters on objects, observatories, and time spans. The architecture allows further that the users obtain orbital elements generated from the observation pool for selected objects, and to receive observation-related and follow-up related statistical information that is generated from both pools. The architecture considers that authorised users may receive a list of open follow-up requests. Using the unique follow-up IDs from this list, the user is able to accept or deny follow-up requests. The user may post follow-up requests to the pool, where a follow-up ID is assigned to the request.

Figure 2 gives an outline of a possible architecture of the coordinator-related part of the exchange server. The architecture foresees that the coordinator re-assigns object identifications in the observation pool and issues messages to the users accordingly. The coordinator is able to work on the two pools - to delete, insert, disable, or enable observations and follow-up requests. To some extend, the coordinator may be seen as a (temporary) super user of the collaboration.

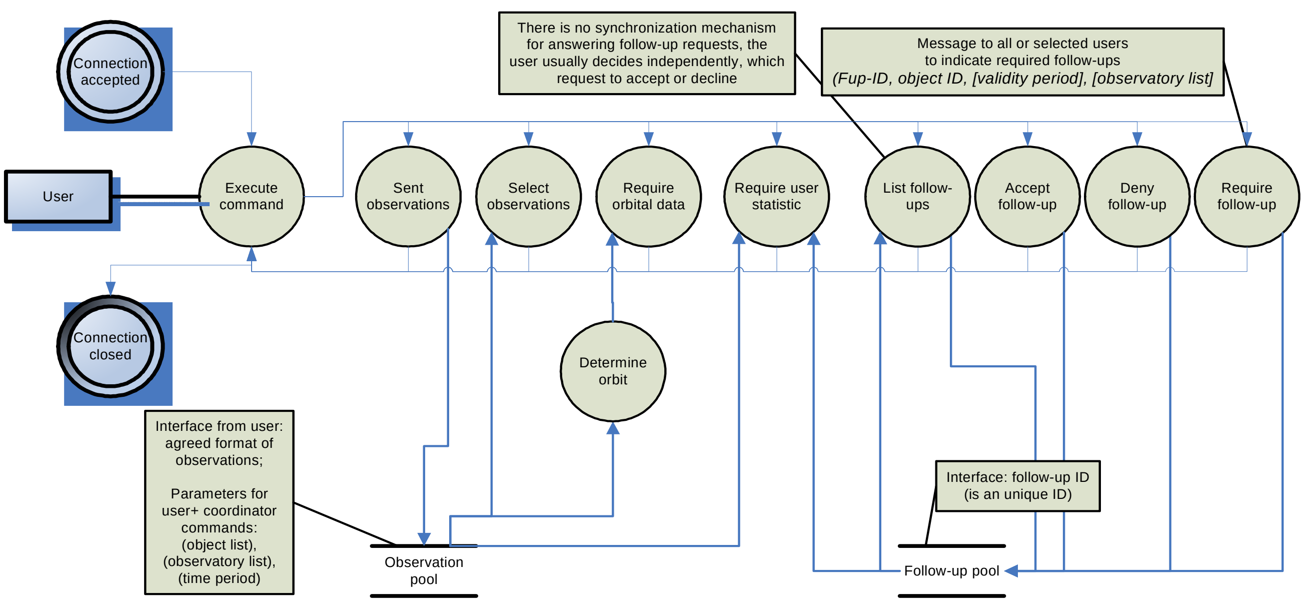

Figure 1: Architecture of exchange server, user-related.

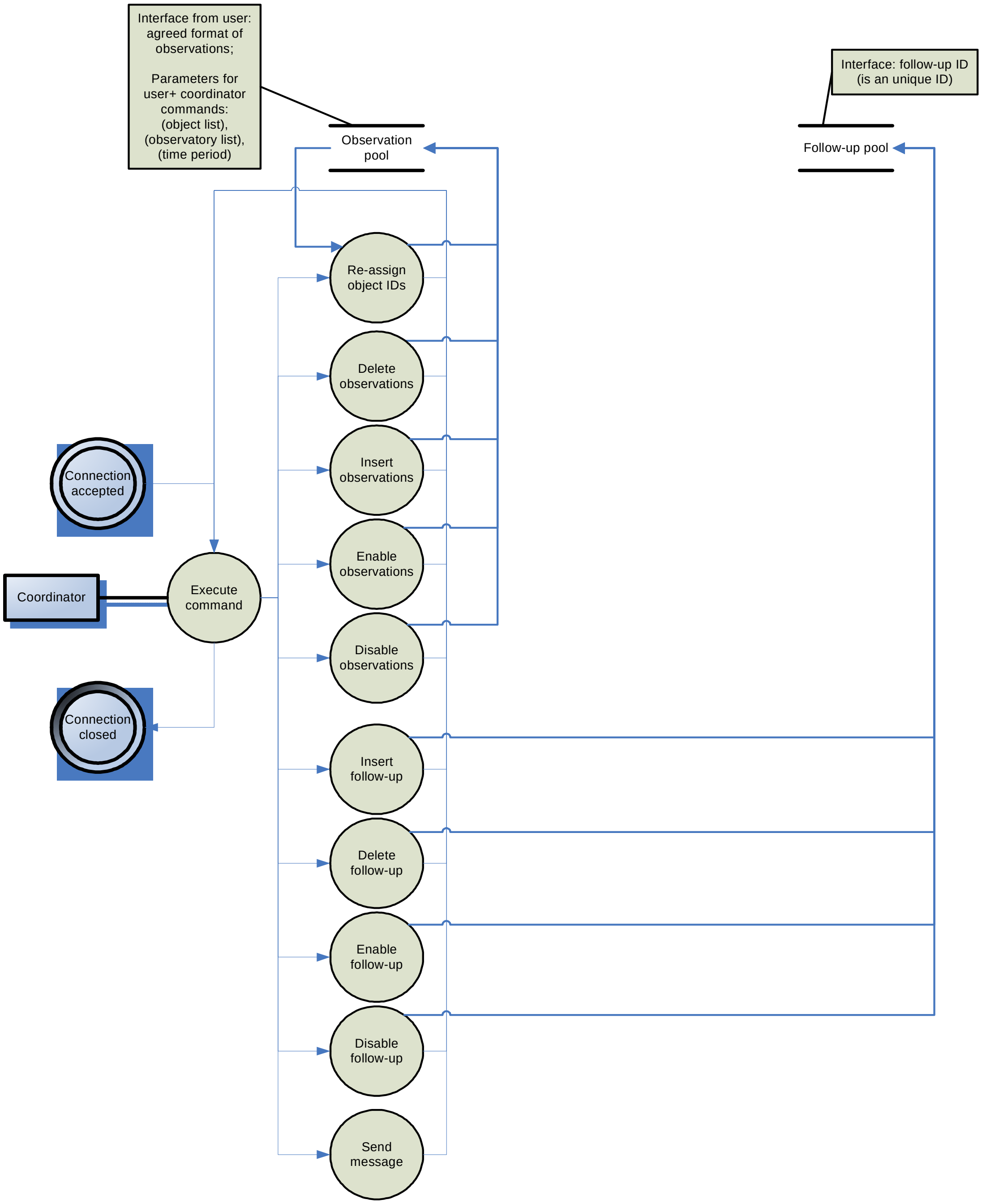

Figure 2: Architecture of exchange server, coordinator-related.

3.2. Interface description

Using the proposed architecture, it is possible to describe a command set for the communication between the exchange server and the users/coordinator entities. As required the command set should be kept simple and straightforward, allowing manual and GUI-assisted communication with the server.

From Figure 1 and Figure 2 we propose command-parameter(s) structure and derive the following commands:

- User-related:
  - `Send_obs` with the mandatory parameters `[object_ID]` and `[observation_data]`
  - `Select_obs` with the optional parameters `[time period]`, `[object_IDs]`, `[sensor_IDs]`; the server shall answer with the list of observations
  - `Require_orb` with the mandatory parameter `[object_IDs]`, the server shall answer with the required set of orbital elements and quality informations
  - `Require_stat` with the mandatory parameter `[sensor_ID]`
  - `List_fup` with the optional parameters `[time period]`, `[fup_ID]`, the server shall answer with the list of follow-up requests
  - `Accept_fup` and `Deny_fup` with the mandatory parameter `[fup_ID]`
  - `Require_fup` with the mandatory parameter `[object]`, and the optional parameters `[time period]`, `[priority]`, `[sensor_ID]`
- Coordinator-related:
  - `Insert_obs, Delete_obs, Enable_obs, Disable_obs,` with the mandatory parameter [`obs_IDs`]
  - `Insert_fup, Delete_fup, Enable_fup, Disable_fup` with the mandatory parameter `[fup_ID]`, (NB: the `[fup_ID]` is assigned by the server)
  - `Send_msg` with the mandatory parameter `[“text”]` and the optional parameter `[sensor_IDs]`

Where not stated differently, the server shall simply acknowledge the receipt of a command.

4. Conclusions

Highly automated observation planning, data acquisition, and data processing are a driving need in order to improve the available optical observation capabilities for space debris objects, as well as for space surveillance. Modern observation scenarios require the immediate, reliable and robust exchange of data, in particular for near-realtime follow-up observations of newly detected objects. In particular, the newly discovered population of high area-to-mass objects cannot be catalogued (or studied) without ensuring the acquisition of follow-up observations shortly after discovery. Space surveillance observation strategies involve scheduled follow-up observations by optical means for the cataloguing of objects.

We have presented a possible solution of flexible, transparent, and robust exchange of observations and follow-up information between a set of heterogeneous sensors. The proposal relies on using standard computer and operating system environments. User requirements were derived from typical use cases and from the identification of acting entities in a possible data exchange scenario. Central components of the architecture are data pools for observations and follow-up requests, an exchange server, and a coordinator. The coordinator role may alternate between the collaborators.

This concept for the exchange of follow-up requests in a network of sensors could in particular be an option for the coordinated efforts to determine highly accurate orbital elements and object characteristics of objects with high ratio of area-to-mass, as well as in a future European space surveillance system.

5. References

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