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Creation and Development of the Software Complex for Scheduling Observations in the RadioAstron Project

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Abstact—In preparation for launching the space radio telescope as a component of the ground–space radio interferometer (the RadioAstron project) software was developed for scheduling observations of radio sources. A set of instruments was produced for solving various tasks of modeling the space mission in the context of radio interferometry with super-long bases when a radio telescope is launched into space. The software structure and applications are described that allow scheduling observations of sources by means of a ground–space radio interferometer.

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1. INTRODUCTION

In the last decade of the last century the development of two projects of ground–space interferometers in Russia (RadioAstron) and in Japan (VSOP) gave rise to the problem of producing software for various tasks of modeling the conditions of observation with using these interferometers. Such software packages were developed in Russia, the USA, Canada, and Hungary. These ones are as follows: ASTRON, RASS (L.I. Gurvits, V.E. Yakimov, FIAN ASC, Russia), Fakesat (D.W. Murphy, Jet Propulsion Laboratory, USA), RPIS (A.R Taylor, University of Calgary, Canada) and SPAS (I. Fejes, SGO, Hungary) [1–3].

The specificity of radio interferometers with a telescope launched into space claims specific requirements for scheduling and performance of observations with this instrument. In order that all elements of an interferometric system operate properly and efficiently, it is necessary that, during observations, a particular set of conditions is fulfilled related to the orientation of a space telescope and other devices on-board the satellite, as well as to ground-based supporting means related to them. In the case of the RadioAstron interferometer these conditions were discussed in detail in the paper [4]. The consideration of constraints represents a very important part of the software functional for scheduling observations with the ground–space interferometer.

When the space radio telescope of the RadioAstron project was prepared for launching into space, two packages were used for solving various tasks related to observation modeling—the RASS (RadioAstron Scheduling Software) and the Fakesat. While having almost identical functionality, these packages differed in one important aspect. The RASS software package has been produced and developed to solve various tasks of modeling predictable situations that could arise at implementing the RadioAstron project. For this reason, the emphasis was placed here on the possibility of detailed analysis of the configuration of all interferometer's components. The Fakesat package was produced as an instrument to aid the observer in scheduling observations of a radio source studied by means of the ground–space radio interferometer. In this connection, the package was equipped with several visual means to facilitate preparing the application for scheduled observations.

The Fakesat package was produced at the Jet Propulsion Laboratory for operation on computers of SUN/Hewlett Packard/DEC companies under the guidance of OC Solaris/HP-UX/Open VMS. This package was written in a Fortran programming language dialect that was not supported by the ANSI f77 Standard. In the course of practical work with the Fakesat package at the Astro Space Center there arose the need to improve it in order that the package could be used on computers running with the Linux operation system. However, the direct compilation of the original code with using the g77 compiler was impossible for the above reasons. So, in 1999[1] the package was modernized with the purpose of installing it on computers running OC Linux.

The next important stage of modernizing the RASS and Fakesat packages was associated with transferring, in the RadioAstron project, into the orbit with the space radio telescope's period of revo-

[1] Promyslov V.G., Yakimov V.E., and Sergeev A.N., Modernization of the Fakesat software package (JPL) for modeling radio sources observations with using the ground–space radio interferometers. // FIAN ASC Science-technological report, 1999.

lution within 8–9 days and high apogee. This circumstance demanded deep restructuring of packages both at the algorithmic level and at the level of the means for visualizing the final results of packages operation. In the case of the Fakesat package this work was done by V.I. Zhuravlev, the ASC specialist [5].

The RASS package has undergone many modifications in the process of using it for solution of a variety of modeling tasks within the framework of the project. In fact, the new software package was produced for solving modeling tasks in the astronomy: SSAM—Software System for Astronomical Modeling. In this new package the following principles of code organization were implemented: modularity, extensibility and possibility of generating binary files of the applications for the Linux and MS Windows operation systems, virtually on the basis of the same code base with the exception of calls of system functions. In addition, the package made it possible to read the initial data in a free format regardless of the type of their representation in the input stream. One can acquaint with the package in more details on the information resource of the RadioAstron project: webinet.asc.rssi.ru/software/AstroCom.

2. DESCRIPTION OF THE SSAM SOFTWARE COMPLEX

On the top level the complex consists of two directories, namely data and AstroCom. The first directory contains many subdirectories with initial data for various applications, as well as subdirectories for the final results of their work.

The second directory contains, in essence, the "engine" of the complex, and it includes the command shell, the applications developed within the SSAM complex framework, and the set of libraries. There may also be two additional subdirectories: bin and lib for external applications and the scripts subdirectory for scenarios. External applications and scenarios, if necessary, run in the AstroCom under the guidance of the analog of a command shell, which represents, in essence, one of the internal applications of the complex.

Any application developed for the SSAM complex, at the top level has an identical structure that includes two configuration files, the main program file written on the standard ANSI f77 language, and the set of libraries that specify the application functional. The Fortran 77 programming language was used for the purpose of compatibility with the extensive library of programs for scientific research developed in previous years. In the case of generating applications for the MS Windows operating complex, the main program may contain extensions to the language standard typical for the Fortran Power Station compiler.

The names of configuration files are identical in every application: "app.cfg" and "task.ini." Both files are text ones with the lines, which contain the data required for configuration and determination of the current state of the application. The data representation format is typical for configuration files: "key = value" or "key = value_1 value_2 ...value_n." The data type in the "key" variable is text one. The admissible types for the "value" variable are text, integer or real (of double precision), which are placed in a line without restrictions on the position and order of succession. To optimize the reading of configuration files, lines with keys can be arranged into sections.

The "app.cfg" file contains global actual parameters that define the work of the application as a whole. In addition, this file may indicate the state of the application for the current task specified by the "task.ini" file. For example, having selected the key value of "mode = ground," "mode = space," or "mode = ground + space" in the "app.cfg" file of the zROSSAT application (see below), the task will be solved for the ground-based network of radio telescopes, for the space segment or for the ground–space radio interferometer as a whole, respectively. The "task.ini" file includes the actual parameters for the current task.

The application file in the Fortran 77 language contains only the main program and several auxiliary programs that define the specific features of the application. And, again, as in the case of configuration files, all applications have, structurally, nearly identical main programs; the only distinction consists in calls of procedures from the additionally loaded libraries, which just determines the functional of a particular application. Each application contains reusable code at the level of the main program. Unification of structures of various applications facilitates their supporting throughout the life cycle and the development of new applications.

And the last thing that should be mentioned in the general description of the SSAM software complex is the rules of attributing the names of applications inside the AstroCom directory. The name of any application, which has a meaningful sound determined by the application specificity, contains the prefix in the form of one of symbols: *x*, *y* or *z*. Prefix *x* in the application name indicates that it possesses the graphical user interface or GUI. Only one application, namely yash, has the prefix *y* in its name. This is a special application, the command shell, under guidance of which one can run to operation several applications in the package mode. Prefix *z* in the name indicates that this application uses a command-line interface, or CLI.

3. SCHEDULING THE OBSERVATIONS IN THE RADIOASTRON PROJECT

The zROSSAT application of the SSAM software complex represents a natural development of the RASS package within the framework of the new approach to developing software for scheduling observations.

The scheduling of radio sources observations with using the ground–space RadioAstron interferometer, as it was presented in the pre-launch project preparation period, consists of several stages. The initial and final stages of the scheduling procedure are described below. These stages are sufficient in the case of the so-called standard mode of a scheduling procedure. In the exceptional, atypical cases of the ground–space radio interferometer configuration, there arises the necessity in the detailed analysis of the conditions of studied source visibility by various interferometer's systems, and in developing the acceptable scenario of performing observations. For this purpose the zROSSAT application possesses special options that are specified in the "app.cfg" file.

At the first stage of scheduling, for the date specified in the "task.ini" file, the whole celestial sphere or a part of it is looked through. The corresponding option and the necessary parameters are set in the "app.cfg" file. Here it is worth it to comment on the style of output files containing intermediate or final results of any application of the SSAM complex. Typically, these files are accompanied by a header with text information explaining the sense of the obtained result. It is important to note that the result of any application can serve as the initial data to process by another application. The software package possesses the appropriate means.

In the nodes of the celestial sphere's grid, defined by the equatorial coordinates RA/Dec, are represented the time intervals in hours, during which the operation of the space segment (the space telescope and one of related science data receiving stations) of the RadioAstron interferometer is possible. One should emphasize that this option allows one to reveal the possibility of observing the source with RA/Dec coordinates only. The fact is that, at this stage, one takes into account only the constraints on the position of the Sun and the direction to the working data receiving station on the Earth, which are determined by the orientation of the space telescope observing the source under study. These constraints are most significant ones from the long list presented in the Protocol of functional constraints [4].

At the next scheduling stage the zROSSAT application is fulfilled for the chosen source. Its equatorial coordinates are specified in the "task.ini" file. In addition, this file includes the date of observation (start and end), the name of the file containing the state vectors of the predicted orbit of a space telescope for the time interval including the scheduled observation, as well as the names of stations receiving scientific data and the ground-based radio telescopes selected for participation in the joint work.

The key information at this stage is the time interval, when the space radio telescope can work jointly with the science data receiving station in Pushchino or Green Bank (USA). If the observation of the chosen source by a space telescope at the given date is confirmed, then one should search for joint time intervals, when the source is visible both by space- and ground-based radio telescopes. This searching can be done either visually (the corresponding file is generated by the application), or by means of software. If the source is not visible by the space-based radio telescope (though at the first stage it was found that the source could be observed for the incomplete set of constraints), the means for clarifying the reason of the lack of visibility are provided in the zROSSAT application.

For the majority of configurations (the mutual positions of a studied source, the Sun, Moon, and Earth, the possibility of participation of selected ground-based radio telescopes in the joint work with the space segment of a radio interferometer) it is sufficient to take into consideration the constraint on the position of the Sun and find out whether the communication with any scientific data-receiving station does really exist. In these cases the second stage is the last one in the scheduling procedure.

In the prelaunching period of the RadioAstron project preparation a great number of tasks on modeling radio sources visibility had been performed with regard to all constraints formulated in the Protocol [4]; and, further, the comprehensive testing of the software complex was performed in collaboration with the staff of the Lavochkin Research and Production Association (the Lavochkin RPA).

Before the space telescope launching, the choice of the optimal orbit was performed by the criterion of science research efficiency based on calculation of radio sources visibility conditions for the whole celestial sphere over a period of a year.[2] According to the results of analysis, it was found out that the situation is extremely undesirable for the project when the interferometric observations have fallen on the June–August period. According to the flight test schedule, the interferometric stage should occur in 2 months after launching the space telescope. Thus, the favorable launch window lies within the June–August intervals. The choice of the launch date within this interval provides best conditions for efficient performing the scientific program of observations during a year.

CONCLUSION

In the course of preparation to launching the space radio telescope as a component of the ground–space radio interferometer, software was developed for scheduling observations of radio sources. Actually, the set of instruments (the so-called toolkit) was produced for solving various tasks of modeling the space mission in the context of radio interferometry with super-long bases, when one or several telescopes were launched into space.

This set of instruments can be used for developing new applications, because the SSAM software com-

[2] Yakimov V.E., Popov M.V., Litovchenko I.D., and Sheikhet A.I., Choice of the optimal orbit by the criterion of science research efficiency in accordance with the launch window // FIAN ASC Science-technological report, 2011.

plex is based on the principles of modularity, extensibility and code reuse. And, from this point of view, the complex represents a framework for developing applications for solving a wide range of tasks—from the analysis of an arbitrary text in the input and/or output data stream up to model calculations with different degree of complexity. The structures of any applications at the top level, the types of configuration files, and the main program are virtually identical. The functional of applications is determined exclusively by the choice of existing or newly developed libraries.

Possible perspectives of use and development of the software complex are defined by the current tasks of the RadioAstron project on the basis of existing applications and generating new ones, if necessary. The SSAM software complex can be used for analysis and modeling of new space missions projected to solving astrophysical problems with regard to instruments' location in near and far space.

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