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IRAIT telescope and enclosure: engineering aspects for antarctic operation

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Abstract. Aim of this work is to present the current status of the engineering activities related to installation and operation of the IRAIT telescope in the Antarctic environment. Different solutions, which have been studied until now for the enclosure architecture, mechanical subsystems and control electronics, are presented herein. Antarctic environmental characteristics have been underlined in the work as the main constraints for design of components associated to these systems. Moreover, the main features of the tele-operation system have been analyzed and a simple client/server application has been developed to enable telescope operation by a remote user.

Key words. Telescopes – instrumentation: miscellaneous – space vehicles: instruments

1. Introduction

The Antarctic continent offers ideal atmospheric conditions to carry out observations at 5 microns infrared wavelengths (mid-infrared range). In the framework of the Italian Antarctic Program, the project IRAIT (Italian Robotic Antarctic Infrared Telescope, wwwospg.pg.infn.it) is aimed at the development of a permanent observatory at the Italian-French Concordia base (Dome C). IRAIT is based on a 80 cm telescope presently under test at the Coloti-Montone site, operated by the University of Perugia (Busso et al. 2002; Tosti et al. 2003). The system shall be operated in a fully robotic, remotely-controlled way. Aim of the present work is to give an overview of the engineering work carried out until now to upgrade the existing telescope components, to develop its control system and to design an enclosure suitable to be operative in Antarctica.

2. Environmental conditions and logistic

Environmental conditions constitute the main constraints for engineering design of the diverse components required for telescope operation in Antarctica. These components comprise structural and mechanical parts as well as control hardware, which have to be designed and/or tested in order to operate supporting adequately the

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Table 1. Environmental conditions

Temperature	−50°C mean, −80°C min
Wind	2.5 m/s mean, 16 m/s max
Absol. humidity	2 g/m^3
snowfall duration	35 day/year eq. to 10 water mm/year
height	3280 m above s.l.

rough low temperatures of this environment. In addition, many of the activities related to the transportation, maintenance and installation became more difficult, if not impossible, than habitual practice in a more favourable ambient. Table 1 summarises Dome C environmental conditions, which have to be considered as a part of the design requirements for the whole telescope system. Another unusual constraint to take into account in this project is represented by the transportation and installation facilities. Ship transport constitutes an intrinsic dimensional constraint imposed by standard container dimensions. This factor is relevant for the enclosure of the telescope which have to present a modular design. The same criteria has to be applied to the other parts such as to the levelling system, telescope, etc., which have to be designed taking into account an eventual need of dismounting.

3. Telescope enclosure

3.1. Main Functions

Main functions of the telescope enclosure are:

- (in closed position) to protect the telescope and its instrumentation against adverse weather conditions and dust;
- (in open position) to allow a free field view, also providing adequate protection from wind.

Moreover, the system must be transportable. This requirement arises from the environmental conditions due to the accumulation of snow in the near surrounding

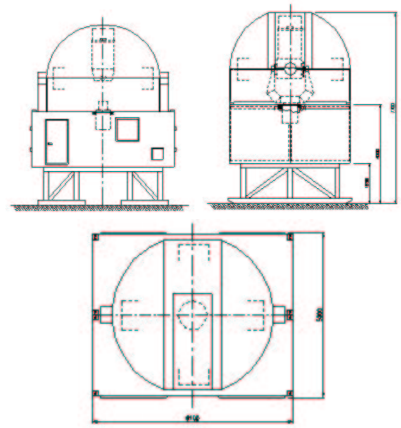

Fig. 1. Parallelepiped shape configuration.

of the enclosure. After a period of about three to four years this snow accumulation must be removed and the system must be re-installed in a new clear area.

3.2. Design

The telescope enclosure is composed of two basic subsystems:

- the upper hemispherical cover;
- the lower support structure.

Different configurations for both are presently under study and evaluation; in particular two alternatives have been identified both for the cover (fold-off canopy and rigid dome) and for the structure (cylindrical and parallelepiped shape). The final solution to be developed for the telescope enclosure shall be chosen after completion of a dedicated phase in which the alternatives studied shall be cross-compared against given criteria (such as cost, easiness of transportation and assembly, etc.). A general overview of the most significant characteristics of the alternatives studied till now is given in the following. More emphasis is dedicated in this work to the description of the rigid dome combined with a cylindrical support structure. This is because this solution is considered as the most innovative. A brief description of the other alternatives is also given, with some comments about their advantages and disadvantages.

3.3. The hemispherical cover

The fold-off canopy hemispherical cover is a solution which has been adopted for the AST/RO telescope (Stark et al. 2001) currently operating at the South Pole Base. This solution appears convenient for relatively small covers as the case mentioned above (about 3 m diameter). Besides that, the AST/RO canopy is manually operated and no automated mechanisms are involved in these operations. This is not the case of the IRAIT telescope, where a highly reliable and fully automatic opening/closing mechanism for the hemispherical cover is required, since the system has to be teleoperated. A comparative analysis between the fold-off canopy and rigid cover configurations has been carried out, concluding that implementation of a reliable automated opening/closing system is more difficult to achieve in the first case. Difficulties in the automation of a fold-off canopy system increase with the dimensions, while in general the reliability level decreases owing to environmental aspects (consider for example the emergency situation of an unexpected storm with the canopy open).

3.4. Parallelepiped configuration

The lower support structure constitutes the part of the enclosure from the ground level to the telescope fork level. The first configuration studied for this part is shown in Fig. 1, and refers to a parallelepiped shape configuration. This structure is basically constituted by the assembly of two blocks characterized by standard ISO 20 container size. This ensures an easy transportation and installation, considering also the possibility of pre-assembly of some internal mechanisms such as the levelling system. The containerized modules are mounted on a base frame that increases the telescope base height at the value required for the observations (4 m).

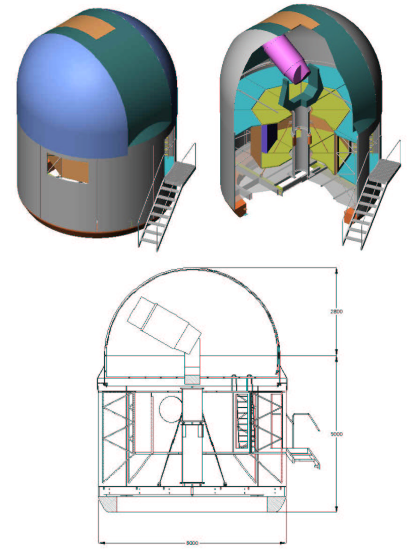

Fig. 2. Cylindrical shape configuration.

3.5. Cylindrical shape configuration

The second alternative studied (see Fig. 2) is a cylindrical shape enclosure combined with a rigid dome cover. This enclosure consists basically of a fixed cylindrical part of 3 m radius rising from the ground level up to approximately 4 m height. At this level an upper hemispherical rotating dome with the same radius of the cylinder covers the structure. The fixed cylindrical part of the enclosure covers the lower part of the telescope and contains another internal cylindrical volume (see Fig. 2) surrounding the telescope levelling system. This internal room is intended to contain electronic packages and facilitate the access to the levelling and azimuth systems for visual inspections or maintenance. A rigid heavy circular platform constitutes the floor of the enclosure. This platform incorporates a sled system to facilitate transportation of the telescope and its enclosure. The platform is the only structural link between the enclosure and the telescope. As it represents

dome	aluminium alloy
external cylinder	aluminium alloy
base	steel

Fig. 3. Table of the materials for the cylindrical shape enclosure.

dome	1600 kg
cylinders (ext.+int.)	2000 kg
base	3800 kg
telescope system	1600 kg
TOTAL	9000 kg

Fig. 4. Table of the mass estimation for the cylindrical shape enclosure configuration.

a relative large mass with respect to the enclosure, the configuration ensures the telescope an isolation of vibrations induced on the enclosure by external factors (mainly wind). As shown in Fig. 2 doors, walkways and ladders inside and outside the enclosure permit access to the internal cylinder and to the level at the base of the telescope fork. Furthermore, windows on the walls of internal and external cylinders permit the operator to notice unexpectedly weather changes, which can compromise operations safety. The upper rotating part (the dome) presents a 1 m wide observing slit. The observing slit is equipped with a sliding door. The dome has the same rotation axis as the telescope azimuth and is able to rotate independently of the telescope, without any physical interference at any position of the telescope. The external shape represents one of the advantages of the configuration shown in Fig. 2 with respect to that of Fig. 1. The cylindrical shape is characterized by a smooth profile, which avoid snow accumulation and presents a low aerodynamic drag. Fig. 3 shows the material list for the enclosure.

Use of aluminium alloy for shells, beams and stiffeners of the dome and the external cylinder shells results in a relative lightweight structure (about 8 tons). Moreover, since aluminium presents a good corrosion resistance, maintenance activities such as painting became completely unnecessary. Fig. 4 gives a general mass distribution. An assembly sequence has been defined, taking into account the difficulties to operate in the Antarctic environment. However, as said before, the entire system must be transportable during the operative life. This can be achieved pulling the whole structure with the caterpillars or dismounting and mounting it again in other area. In both alternatives, the base of the structure shall be dimensioned according to the overall final weight estimation, which includes not only the enclosure and telescope mass but also the electronic packages, mechanisms, ancillary equipment, etc. As a general requirement, the base area shall guarantee a pressure on the ground not greater than 100 g/cm^2 (value adopted for the design of the Concordia Base buildings).

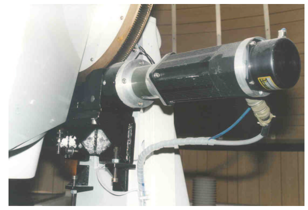

Fig. 5. Existing mechanism configuration.

3.6. Thermal insulation aspects

A thermal isolated room must be present inside the enclosure architecture. This space has the main function of containing all the electrical packages necessary for the telescope operation and telecontrol, ensuring appropriated thermal insulation from the low temperature external environment. To do this the walls, floor and ceiling of this volume are made of extruded rigid polystyrene foam panels. These panels have no structural function, only thermal insulation. Closed-cell foams have the lowest thermal conductivity of any conventional non-vacuum insulation. Several factors combine to limit heat flow in foams: the low volume fraction of solid phase; the small cell size which virtually suppresses convection and reduces radiation through repeated absorption and reflection at the cell walls; and the poor conductivity of the enclosed gas. Gibson & Ashby (1988) gives an exhaustive treatment of the argument, establishing the rules for an adequate design of these panels.

4. Pointing system mechanism

The pointing system of the telescope (azimuth and elevation movements) is based on two electrical motors with worm-gear reducers. The configuration currently in use at Coloti observatory (see Fig. 5) has been accurately redesigned in order to minimise pointing errors, taking into account the requirements deriving from the assembly procedures and the severe environmental aspects. This section presents a description of the upgraded system and points out diverse factors to be considered in the design related to a low temperature environment.

4.1. Requirements

Fig. 6 summarises minimum requirements which must be satisfied by the mechanism configuration.

These requirements constrain both mechanical and electrical parts of the pointing mechanisms: the whole design therefore must properly consider the size tolerances either in the worm-gear couplings and in the motor. However the required angle accuracy in the motor position takes advantage of the reduction ratio of the mechanism which allows a larger motor angle accuracy (reduced by the same factor) as shown in Fig. 7.

4.2. Mechanical components design

Worm-gear mechanisms of the azimuth and elevation axes have to be designed taking into account the requirements mentioned above. Moreover, thermal aspects arising from environment conditions exposed before cannot be ignored during design: besides the differential expansion of diverse materials present in the mechanism there is the problem of an adequate lubrication. A chemically inert lubricating grease for general use in the mechanical interfaces present in the whole system, and particularly for the mechanism described in this section, could be the Fomblin® PFPE grease. In particular the ZLHT series of this lubricant can be used in continuous operating conditions from -80°C to 200°C.

pointing accuracy	30 arc seconds
tracking accuracy	+/- 0.5 arc seconds

Fig. 6. Table of the output axes requirements.

pointing accuracy	180 arc min
tracking accuracy	+/-3 arc min

Fig. 7. Table of the electrical motor requirements.

Fig. 8 shows configuration of the worm housing. The housing is made of A286 stainless steel. This material gives good corrosion resistance and is ideal for cryogenic applications. Adequate surface treatment of those parts which presents a relative motion is necessary in order to avoid seizing of these parts. The housing incorporates a backlash reduction mechanism through an axial displacement of the worm. In this manner the backlash effect can be reduced up to 10 arc sec.

4.3. Drives and positioning

The motion control is crucial in the implementation of the telescope Antarctic base as it manages all the positioning mechanisms:

– telescope positioning; dome rotation; dome aperture; levelling system.

The most demanding task is of course the telescope positioning system due to the accuracy requirements of the pointing and tracking tasks. This is not a hard work for the control system if the telescope would have been installed in a “friendly” environment but it is indeed in the hostile Antarctic weather.

Very few electrical motors are available and are suitable to operate at very low temperature and all of them are therefore custom products, mainly derived from aircraft

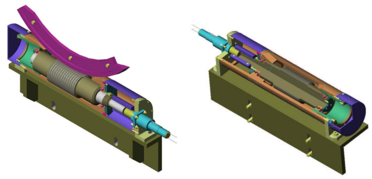

Fig. 8. Worm-gear reducer mechanism designed for Antarctic environment.

Fig. 9. Brushless DC motor.

and space applications. Brushless DC motors (Fig. 9, referred to a customised CDA Intercorp product derived from space applications) have been selected due to the advantageous control capability and positioning accuracy. Their motion control is performed by a digital multi-axis control board that includes the regulation tasks for all the motors involved (telescope, dome, levelling). The control board is a stand-alone product (for independent and autonomous working condition) and it is connected to the industrial PC running the scheduling and control supervision tasks through a fast Ethernet connection. The current/torque regulation loop is performed by dedicated drives that obtain the phase switching information from additional field detecting windings in the motors (4 Vrms excitation, 20 kHz frequency, 2 Vrms signal output). This is necessary in order to avoid the use of hall effect sensors (commonly used to drive brushless DC motors) due to their working limits ad low temperature. For the same reason it is not advantageous to include optical encoders in the position control loop: special resolvers (like customised CDA Intercorp products that can be easily integrated with the motors) have been selected that are suitable for the Antarctic temperature; their accuracy is increased to satisfactory values by the mechanical reducers so that the effective telescope position information is within the required limits. The motors selected for the dome actuation and in the levelling system are of the same type of the ones used in the telescope, even if the related precision requirements are not so demanding: this helps to have common spare parts thus reducing the overall cost.

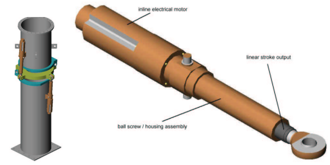

Fig. 10. Left: Levelling system. Right: Linear actuator.

5. Base levelling system

After installation the system (telescope plus enclosure) could be inclined with respect to the horizontal level. This could be happen due to irregularities of the ground floor or loss of level due to the sinking of the ground. The base levelling system of the telescope is therefore intended to compensate these effects.

5.1. Requirements

Requirements for the base levelling system are less restrictive than those imposed to the pointing mechanism mentioned above (see Fig. 8). In this case standard mechanical tolerances can be considered for construction. The mechanism must compensate an angular loss of level of 10°.

5.2. Mechanical design

The levelling system configuration is shown in Fig. 10 (left). The system consists basically in an orthogonal hinged set of flanges which work as a gimbal mechanism ensuring a free angular movement of the telescope fork. The mechanism is actuated using two irreversible ball screw motorised actuators. A general description of these actuators is shown in Fig. 10 (right).

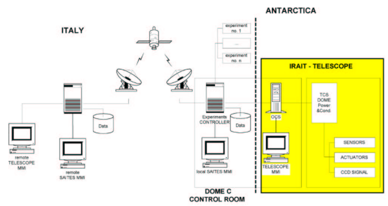

Fig. 11. SAITES block diagram.

6. The observatory and telescope control system

A control system software is being developed in order to operate IRAIT both from Italy and from Antarctica. The system layout is described in Fig. 11: it can be noted that IRAIT is part of a wider set of experiments to be teleoperated in the framework of project SAITES (Sviluppo di un sistema Autonomo per la Telegestione di Esperimenti Scientifici). IRAIT control system includes two main subsystems:

- TCS (local control system);
- OCS (supervisor system).

The remote operation capability of the system is mainly characterised by the following functionality.
◇ From the Italian Base Control System it will be possible to:

- collect the user requests;
- analyse and filter the requests;
- manage the communication with the Antarctica;
- produce the scheduling for the observations;
- control the progress of the schedule;
- manage the results of the observations (images, reports, etc).

◇ From the Observatory Control System (OCS) it will be possible to:

- communicate with the Antarctic Base Control System, which manages the communication between Italy and Antarctica;
- command the telescope control system on the basis of the schedule;
- store the data concerning the observations and the conditions of the system;
- perform preliminary data reduction.

◇ From the Telescope Control System (TCS) it will be possible to:

- arrange the schedule received by the OCS;
- control the emergency to grant the functionality of the telescope;
- collect the environmental data and provide the timing synchronisation;
- open/close the primary mirror cover;
- move the secondary mirror;
- manage the autoguider;
- manage the elevation/azimuth motion of the telescope;
- set the chopping parameters and enable/disable chopping;
- open/close the dome;
- control the power and conditioning of the system components in reference to the climatic condition of the Antarctic base.

7. User interface software

The remote operation of both the telescope and dome in the Antarctic base requires the development of suitable software to permit the execution of the commands listed in the previous paragraph. For easy and flexible operation by the user, the software must be accessed with Internet or modem connection. Both modes now usually included in every PC operating system and supported by standard programs (browser, dialup software, telnet, ...). The scheduling task can receive the user input through a web-based interface as it doesn't involve time-crucial events: appropriate scripts manage, update and query a database that contains the operations to be executed. For a real-time operation of the system (mainly motion commands) however the link to the control software must be highly reliable and immediate as the commands must be immediately verified for correct operation (e.g. to be sure the telescope points to the right co-ordinates

Fig. 12. Interface software screenshot.

so that the retrieved data are the desired ones). The web-based interface (http protocol), is not suitable and flexible to program this requirements and therefore a proper application must handle the communication in TCP/IP protocol with additional timeouts checking, command acknowledgements and verification of the command executions. This organization requires:

– a server application that manages the connection with the user and sends the commands to the control system with appropriate messages and parameters;
– a client application through which the user can operate the system remotely.

For an initial testing phase a simple application has been developed (screenshot in Fig. 12) to provide the following capabilities:

– telescope motion control;
– dome opening/closing and rotation;
– meteo data acquisition;
– setting of the connection parameters.

Other than to operate with a "user friendly" interface where the command messages are built based on the parameters inserted in the appropriate fields, the user has the capability to view the sent messages (presented in the "Message history" window) and to keep track of the system messages and events such as acknowledge message and confirmations of command execution. Every communication message (command, parameters, etc.) includes also the server and client IP addresses and other security fields to prevent undesired

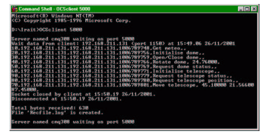

Fig. 13. The console application.

operation and to detect and warn about problematic working conditions (interruption and low transfer rate in the network connection, etc.). The server application that accepts incoming connections from the users has been developed as a console application (Fig 13). Its main feature are:

– reliability (it doesn't have to crash as it operates without supervisor);
– security: it must record all the communication messages and events in a log file and it must verify the identity of the connected client machines.

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