LARES-lab: A Thermo-vacuum Facility for Research and e-Learning
Tests of LARES Satellite Components and Small Payloads for e-Learning

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Abstract: LARES, an Italian Space Agency satellite, has been successfully launched in 2012. A small thermo-vacuum facility has been specifically designed and built for testing the optical components of the satellite in simulated space environment. Due to the extremely demanding performances of LARES satellite, the facility has been built using the most up-to-date technology available. In particular Sun, Earth and deep space can be simulated in a ultra high vacuum. When the tests connected with the LARES mission reduced, it was decided to devote the thermo-vacuum chamber also to didactic activities. The facility was designed to be operated remotely only for some basic operations. The full automation of the facility is in progress in order to provide the students and the researchers with easy and long term access, including also the possibility to operate remotely from the internet and perform complex tests. The students will then have a big opportunity to learn in practice all the aspects of thermo-vacuum testing, which are of paramount importance in the space industry. It will be possible to perform thermal tests from either the classroom or home, by exposing the specimen for a specified amount of time, toward Earth, Sun or deep space simulators. They will collect pressures and temperatures and will input additional thermal power through resistive heaters. The paper will first describe the facility and its capabilities showing the tests performed on the LARES satellite components, then will focus mainly on the planned upgrades that will improve its remote use both for research and e-learning.

1 INTRODUCTION

The Italian Space Agency (ASI) supported the LARES mission (Ciufolini, 2011) including, among other things, the design (Paolozzi, 2011) and the construction (Paolozzi, 2009) of a 400 kg satellite for testing "frame-dragging" (Ciufolini, 2007), predicted by General Relativity. On the 13th February 2012 the new ESA launcher VEGA inserted perfectly in orbit LARES (Paolozzi, 2013), the main payload, and eight small satellites built by different universities. It was an outstanding result considering that it was an inaugural flight, initially devoted exclusively for qualifying this new launcher. In 2008 ASI proposed to ESA to add a further objective to this launch: contribute to fundamental physics (Ciufolini, 2013a) with a very reliable satellite. Despite the increase of complexity of the qualification launch, ESA accepted, being also responsive, through its educational office, towards the university requests and allowing on board eight more payloads.

Indeed a measurement of frame dragging with an accuracy of about 10% was already obtained (Ciufolini, 2004) (Ries, 2011) with the two LAGEOS satellites. But, as anticipated in several papers over the years (Ciufolini, 1996), with the use of a combination of three satellites, the LAGEOS satellites plus LARES (Ciufolini, 2003), it will be possible to improve by one order of magnitude the accuracy of the measurement (Ciufolini, 2012) (Ciufolini, 2013b).

During the development of the LARES program a critical issue arose whether it was necessary to passively control the satellite temperature by painting it (Paolozzi, 2012a): a high temperature of the satellite body could both spoil the Cube Corner Reflectors (CCRs) and increase the thermal thrust (Bosco, 2007). Unfortunately the thermo-optical properties of the paint are not stable in time (Marco, 2003), especially when exposed to space

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environment (Jaggers, 1993) (NASA, 1995). A large degradation of the paint properties could dramatically change the values of the non gravitational perturbations such as the radiation pressure. That was not acceptable for the high accuracy required in estimation of the classical forces acting on the satellite. It was then necessary to perform dedicated tests in order to completely clarify such a specific issue. To this purpose a small but very well equipped thermo-vacuum chamber was built. The final result was that painting was not necessary.

Subsequently the thermo-vacuum chamber has been also used to test the university CubeSats (Paris, 2014) and the relevant components (Cappelletti, 2011), the first Iraqi satellite (a 3U CubeSat) built at Sapienza University of Rome within an Iraqi-Italian cooperation (Testani, 2013), the components of the EduSAT, a high school satellite (Graziani, 2009), and the CCRs from the CHAMP satellite (Paris, 2015) thus showing capabilities not only for very high standard research activities but also for didactic purposes. More recently it was decided to increase the potential of the chamber by enabling its full remote use over the internet for teaching activities through the acquisition of actuators and motors, that need to be mounted on the facility. In the paper it is described how the upgrade will be performed and what the students will be able to monitor, control, acquire and command.

2 THERMO-VACUUM FACILITY

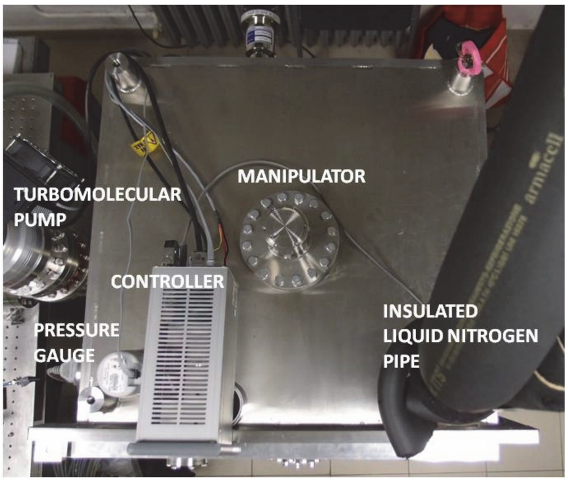

Figure 1: Top view of the vacuum chamber.

The thermo-vacuum facility is mainly composed by a cubic chamber of 0.6 m side (Figure 1). A first pump (scroll pump) brings the pressure typically in the range 10^{-2} – 10^{-1} millibar. The second pump (turbomolecular pump) can operate at low pressure and brings the pressure to the final value in the range 10^{-9} -10^{-6} millibar. The pressure is monitored with a wide range gauge, that is constituted by a combination of a Pirani sensor to monitor pressure between 10^{3} and 10^{-4} millibar, and an inverted magnetron sensor for the range 10^{-4} to 10^{-9} millibar. A controller on top of the chamber connected to the pressure gauge and to the turbomolecular pump, transfers pressure data to the computer, allowing to remotely operating the turbomolecular pump. A sun simulator with an extra-atmospheric (AM0) spectrum is fed into the chamber through an optical window with low solar spectrum absorption. Opposite there is another optical window with a very accurate surface finish (lambda/20 peak to valley at 632.8 nm) used for testing, with an outside optical circuit, the optical performances of the specimens inside the chamber.

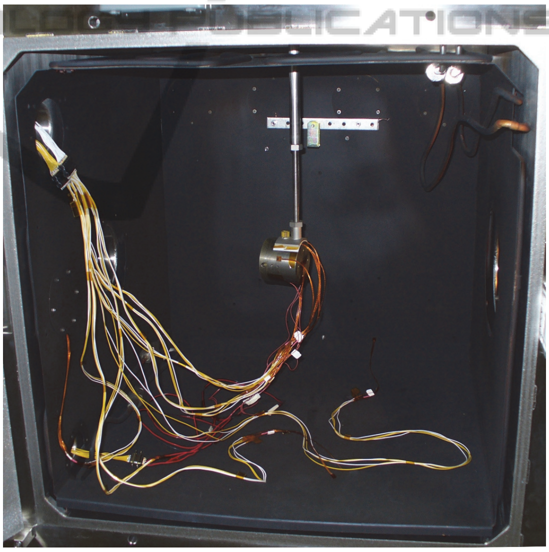

Figure 2: Front view of the open vacuum chamber. The specimen under test, is mounted on the axis of the manipulator. The cables connect the temperature sensors and the resistive heaters to the external acquisition system. The black walls are the liquid nitrogen cooled shrouds. The sun simulator is outside of the right window.

A single degree of freedom manipulator allows moving, about a vertical axis, from outside, a specimen placed inside. An illumination system with led stripes allows seeing inside through a small optical window mounted on the front door of the chamber. A number of electrical feed-throughs with multipin connectors are used for temperature sensors (50 pins) and resistive heaters (9 pins); the multipin connectors can withstand a current of 5 A and a voltage of 500 V. Two independent acquisition systems are available: the Picotech PT-104 is specifically used for the platinum resistance thermometers (PT100 and PT1000) and has four channels; the HBM MGCPlus, is a 16 slot modular acquisition system that can be used for any type of transducers from strain gages to temperature sensors and accelerometers. At the moment the MGC-Plus has one slot with eight channels dedicated to PT100 sensors, three slots for a total of 24 channels for the strain gages and one slot for the accelerometers. A cryogenic plant completes the facility. It is an open circuit plant. The liquid nitrogen flows through several, in series, cryogenic coils, welded in the back of five copper shrouds which can reach temperatures as low as -192 °C and cover the five walls of the chamber (Figure 2). To approach, as closely as possible, the deep space behaviour, the shrouds are painted with Aeroglaze Z307 with emissivity ε= 0.89 and absorptivity α= 0.97 in order to be considered approximately as a black body (Persky, 1999).

3 EXPERIMENTAL TEST

The facility has been designed and built for the specific purpose of testing the Cube Corner Reflectors (CCRs) mounted on the surface of the LARES satellite. The CCRs reflect back to the ground stations, laser pulses allowing a ranging estimation with accuracies that can reach few millimetres, from the best stations. There are about 60 stations all over the world organized in the International Laser Ranging Service (ILRS) (Pearlman, 2002). Orbital predictions of the LARES satellite are provided to the ILRS by the International Space and Time Analysis Research Centre (ISTARC) located in Rome at the Sapienza University (Sindoni, 2014). The LARES CCRs rely on three total internal reflections from the three back faces (Figure 3 left); regardless of the CCR orientation the laser beam is reflected back at 180 degrees. Since the satellite moves at a speed of several km per second, the reflection direction needs to be changed slightly to compensate for this motion. That was achieved for LARES by increasing the dihedral angles of the CCRs by an amount between 1 and 2 arcseconds. As a consequence, the energy distribution on the ground (called more technically Far Field Diffraction Pattern or shortly FFDP) re-distribute, shifting from the centre to an annulus where the ground station is expected to be, relative to the satellite. Due to the extreme environmental conditions in orbit, the temperature gradients on the CCR could introduce an additional dihedral angle offset that could prevent the reflected laser beam to hit the ground station (Figure 3 right). Given a temperature difference ΔT between the front face and the apex, the change in the dihedral angle induced by the ΔT is proportional to $\alpha_T \Delta T \cdot L$, where L is the front face diameter and α_T = 5.1x10^{-7} K^{-1} is the coefficient of linear thermal expansion of the Suprasil (the special glass used to manufacture the CCRs). Therefore the first tests, performed on the CCRs were aimed to the determination of the experimental value of ΔT (Paolozzi, 2012b). Since those values were exceeding the conservative threshold fixed by the aforementioned considerations, a much more complex test was required for verifying directly the FFDP of the CCR under the best possible simulated operational conditions (Paolozzi, 2012c).

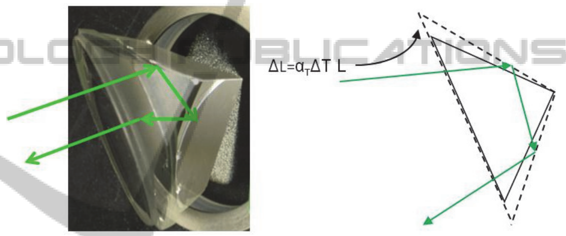

Figure 3: LARES CCR. Reflections on the three back faces send the laser beam back to the station (left). Thermal gradients cause a malfunctioning of the CCR (right).

4 IMPLEMENTATION FOR e-LEARNING

Remote labs for teaching and e-learning have already been proposed by several projects (Herrera 2006) (Sancristobal, 2011), including also remote operations for controlling test machines and manufacturing processes in engineering courses (Casini, 2001) (Aliane, 2007)(May, 2013); however in the literature we did not find anything available about experiments in simulated space environment.

Besides testing and research activity, the lab is used also for teaching to the students of the courses in Aerospace and Astronautical Engineering. The didactic activities involve testing small spacecraft components, such as university microsatellites. Also more research oriented activities, such as experiments to understand the heat transfer and the behaviour of materials in simulated space environments, are performed. Currently the facility is not fully automated and the operations over the internet are limited. Some experiment and tests can span over several hours or even days, so it is not very profitable for the students to stay long in the lab after the scheduled lessons. Thus, in order to improve the teaching capability, an upgrade of the facility for remote control aimed at e-learning is under development. Presently, the data acquisition systems, the pressure meter and the pump status are operated via USB cable by a laptop computer (the server) where remote access software (a Virtual Network Computing system, VNC) is installed. With the VNC on the client it is possible to visualize the server desktop (Figure 4) and make the acquisition both of the temperatures and pressures as well as switching on and off the turbomolecular pump. Figure 4 shows the remotely controlled desktop with the temperature sensors reading and pump controller. This configuration is limited since the current software allows only one client at a time to connect to the server. Since the system was devised to be operated by the personnel in charge of the lab, it gives too much freedom to the client user on manipulating or deleting files and closing programs on the host PC. The planned improvement aims to allow a large number of students to connect to the lab and to perform operations such as temperature and pressure control, orientation of the object under test and data recording. To reach such an objective the full automation of the operations of the thermo-vacuum facility is under consideration; this will allow operating the facility remotely, so that both students and also researchers could perform tests directly from anywhere using internet connection. It is under consideration the possibility to use software assigning different reading and writing privileges to different users. Furthermore there will be also the possibility of sharing many read only accesses. For instance, while a teacher operates, many students can observe directly on their desktop the measurements in progress. At the moment, we are verifying the possibility to apply this approach using one of the many desktop sharing applications available (such as TeamViewer). It would be desirable that the user with primary write access privilege can authorize other users to temporary write privileges: this could be very useful to let students operate on the system under the remote supervision of the tutor while other people in read only mode can observe the performance of the experiment.

What mentioned so far is relatively convenient because of low installation cost and manpower. On the other side, the automation of: manipulator, cryogenic remotely controlled valve, power control of resistive heaters, scroll pump and Sun simulator switching on/off is more demanding.

While the parts connected via USB can be controlled by a single computer, once provided that enough USB ports are available (left side of Figure 5), other components (power supply to heaters, liquid nitrogen valve, switching on and off sun simulator and scroll pump) need dedicated external controllers, operated by the computer (right side of Figure 5).

4.1 Manipulator

A stepper motor coupled with the manipulator through a drive belt will be controlled by the computer. The stepper motor will be mounted with the rotation axis parallel to the manipulator axis. The motor can be either mounted co-axial to the manipulator drive, to reduce lateral footprint, or side mounted and connected to the drive by a pulley. The design of the coupling between the manipulator and the motor shall reduce the vibration transmission to a minimum, although in case the transmitted vibration will be still too much, it is possible to mount the manipulator on a passive vibration damper similar to the one mounted on the turbomulecolar pump. The stepper motor will be controlled by an external controller, connected to the PC by a USB cable.

4.2 Cryogenic Remotely Controlled Valve

Since small temperature variations of the shroud do not have a significant impact on the thermal behaviour of the specimen, a precise temperature control of the shroud is not required. The main need is to avoid waste of liquid nitrogen that is directly poured outside the lab in the air, being the plant an open circuit. Two families of remotely controllable valves are available: electrically actuated and electropneumatic actuated valves. The electrically controlled valve needs a high peak power to be started and a high power to be maintained in the open position (about 100 W), so a power relay is needed to connect the valve to the power line. Electrically controlled valves usually do not offer the possibility of controlling the flow of the liquid/gas, but can be either full open or full closed. The models with the option of flow control are very expensive. Furthermore the power relay needs to be very reliable, to avoid damaging the actuator.

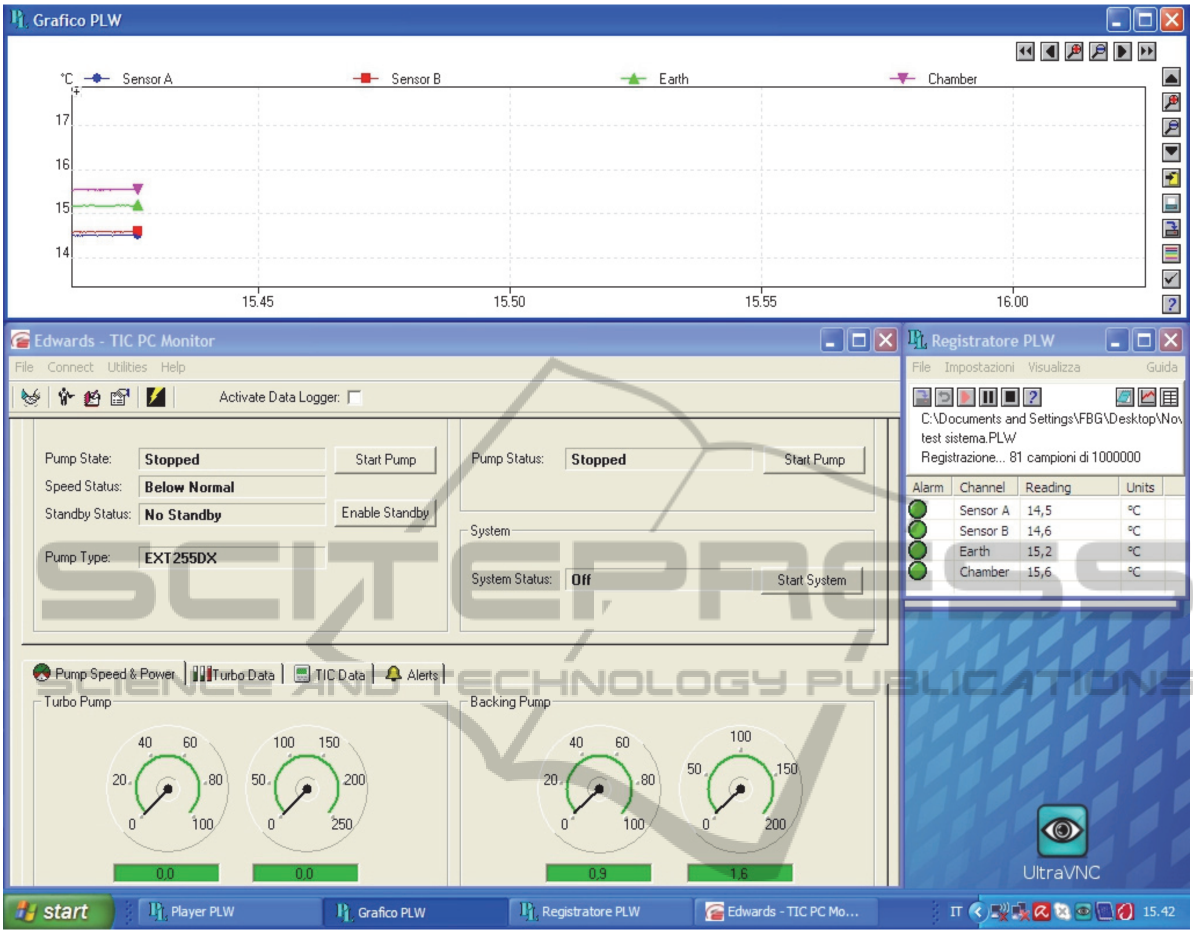

Figure 4: Remote controlled desktop. Temperature sensors behaviour (top), table of temperatures (centre right), monitors and controls of turbomulecular pump (bottom left), UltraVNC freeware software for remote operations (bottom right).

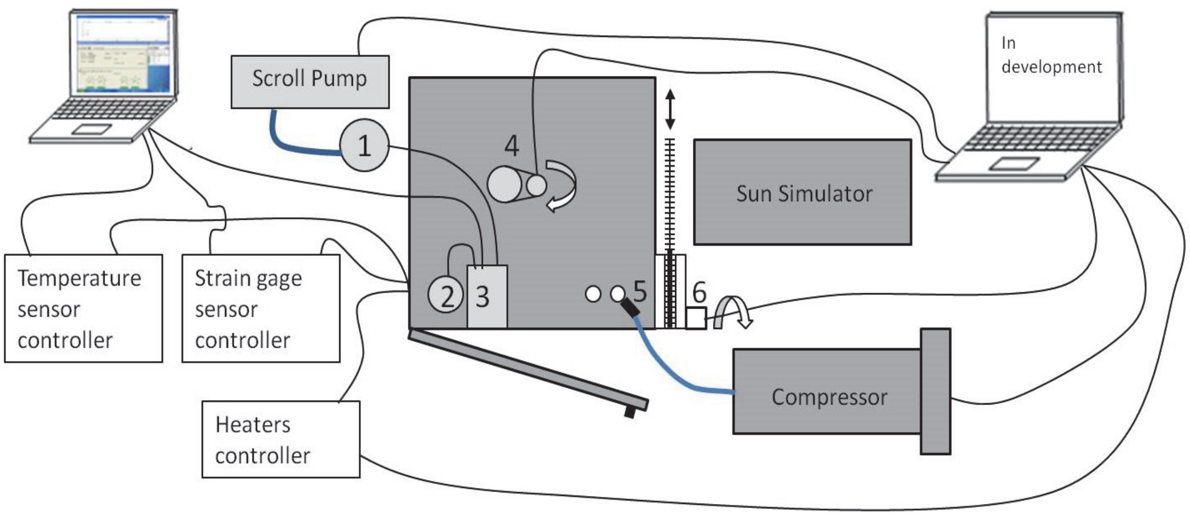

Figure 5: Full automation of thermo-vacuum facility. Left part is operational, right part is under development. 1- turbomolecular pump, 2- pressure gauge, 3- turbomulecular pump and pressure gauge controller, 4- manipulator and stepper motor, 5- cryogenic valve with pneumatic actuation (see Figure 6), 6- stepper motor for sun simulator diaphragm.

On the other hand, electropneumatic valves are not only cheaper but are safer and more versatile. This kind of valves needs to be connected to an air compressor or to a pressurized air line; the pressurized air provides the power to operate the valve and to control the flow of the liquid nitrogen (Figure 6). Therefore the pneumatic valve is considered more versatile and convenient for e-learning. In this case an additional compressor with relevant remotely controlled switch is required. Although the temperature of the shroud could be automatically controlled with temperature feedback on the valve, for the time being it is preferred to have, though remotely, manual activation of the valve.

4.3 Power Control of Resistive Heaters

Also in this case, as in the previous paragraph, a manual control, though remotely, will be performed. In fact during the tests, described in a previous section, it has been realized that specimen temperature did not vary when the proper voltage and current are fed to the heater, i.e. no need of automatic feedback control was required.

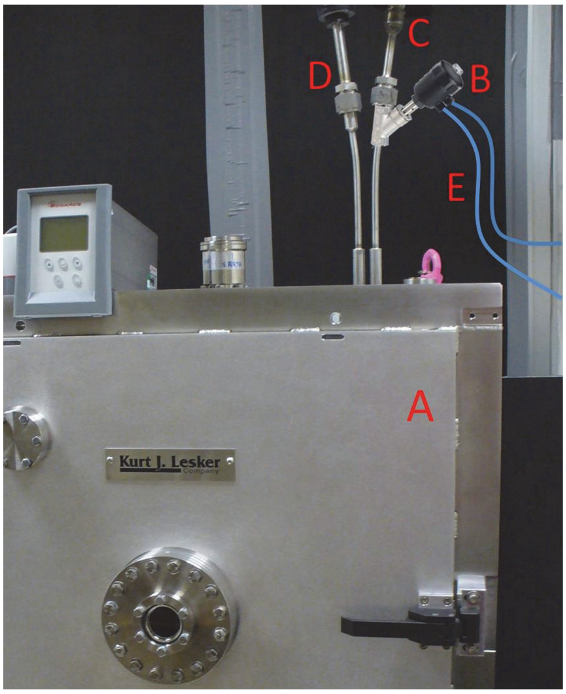

Figure 6: Pneumatic actuated valve. The vacuum chamber (A) is equipped with liquid nitrogen cooled shrouds. The valve (B) will be fitted to the input nitrogen pipe (C). The nitrogen leaves the cooling circuit from the output pipe (D). The valve is operated by controlling the flux of pressurized air, in the blue pipes (E).

Furthermore from a didactic point of view a too much automated facility will be less effective. The heaters are powered by a programmable laboratory power unit. The power unit can be controlled by a computer, using its software, to set the voltage and a limit to the current. The software that programs the power unit can be operated remotely using the VNC system or a desktop sharing software mentioned in a previous section.

4.4 Scroll Pump Switching

The thermo-vacuum facility does not have the possibility to control the pressure therefore the scroll pump needs only to be switched on before the test and off at the end of it. The scroll pump currently mounted does not allow remote control of the switch. However, the pump is designed to operate continuously for days, so a remotely controllable simple switch on the power cable can be inserted to serve the purpose.

4.5 Sun Simulator Switching

The sun simulator does not have a standard switch. A simple but not straightforward procedure needs to be applied. Also on top of this it has to be considered that 6kW power is required to operate the lamp. Two solutions are being considered. The first one needs a contactor to switch on and off the Sun simulator. The main disadvantage is the possibility to damage the Xenon arc lamp if it is switched on and off too often. The second solution considers a moving screen to stop the sun simulator beam when needed. The movement of the screen will be operated by a servomechanism controlled from the computer and through the VNC system also remotely. The disadvantage of this solution is the power consumption of the lamp that remains on also when it is not required.

5 CONCLUSIONS

The thermo-vacuum facility created for the LARES mission is under modification for e-learning activities. Presently the facility can be operated remotely only for sensor reading and for switching on and off the turbomolecular pump. Freeware software is installed on both the server and the client. The improvements described in this paper will allow the full remote access to the facility, for both research and didactic purposes. In addition to the present, somewhat limited capabilities, it will be possible to control the mechanical manipulator, the heaters and the flux of liquid nitrogen Also the sun simulator beam will be controlled with a diaphragm and the scroll pump will be turned on and off with a switch on the power line. In this way both the students and the researchers will have the possibility of carrying out experiments of a certain complexity also remotely.

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