Upgrade of the LARES-lab Remote Controllable Thermo-vacuum Facility
Lab Improvements for Remote Testing and e-Learning

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Abstract: The LARES-lab facility was specifically designed to perform tests in simulated space environment on the optical payload of the LAser RElativity Satellite (LARES). Since the facility was intended to perform demanding tests, it was equipped with the best technology available at the time. After the launch of LARES the facility was used both for testing payloads and small university satellites and for didactic activities. Testing in simulated space environment is fundamental for the development of a space mission, so a well equipped facility in a university is a precious resource for teaching. At the moment, room dimension and the location limit the access to the lab to a small number of students per lesson. To fully exploit the didactic potential of the LARES-lab an improvement over the remote control operation of the thermo-vacuum chamber is planned. The project, which has been described in a previous paper, is currently under development. A new device implemented is a robotic arm to manipulate some mechanisms and to gain experience for remote controlling other servo mechanisms. This way both researchers and students can operate the facility remotely with minimal need of on site operations. Once the improvements will be fully operational, LARES-lab will allow access to the laboratory didactic activities to a much larger number of students.

1 INTRODUCTION

LARES-lab facility was designed for performing tests on the optical payload of the LAser RElativity Satellite (LARES) (Paolozzi et al., 2012a; Paolozzi et al., 2012b). LARES mission was supported and funded by the Italian Space Agency (ASI) (Paolozzi et al., 2011), while the European Space Agency (ESA) provided the launch with the maiden flight of the new launcher VEGA (Paolozzi and Ciufolini, 2013). The goal of the mission is the precise measurement of frame-dragging (Ciufolini et al., 2012b), predicted by General Relativity, improving the previous 10% accuracy obtained with data from LAGEOS and LAGEOS 2 satellites (Ciufolini and Pavlis, 2004; Ries et al., 2011). The LAGEOS satellites are two passive spherical spacecrafts tracked by the ground stations of the International Laser Ranging Service (ILRS)(Pearlman et al., 2002) by means of the laser retroreflectors mounted on the satellites. The addition of data from LARES is expected to bring the accuracy toward 1% (Ciufolini et al., 2013; Ciufolini et al., 2012a). To reach that precision the spacecraft was designed for reducing the non-gravitational perturbations by means of a very high mass-to-surface ratio (Paolozzi et al., 2015a). The particular material chosen for obtaining a high density satellite, a tungsten alloy, was challenging for manufacturing (Paolozzi et al., 2009; Paolozzi et al., 2012c) and for modelling the surface thermal-optical properties. Thermal testing was needed for verifying that the laser retroreflectors could work on a wide range of temperatures, and in particular at the very high temperatures expected because of the optical properties of the bare tungsten alloy (Paolozzi et al., 2010; Paolozzi et al., 2012b). Indeed, even if higher temperature increases the thermal thrust (Bosco et al., 2007; Ciufolini et al., 2014), a passive thermal control by painting the satellite body could have been even more dangerous for the results because the thermo-optical properties of the coatings were expected to change dramatically during the operational life of LARES (Marco et al., 2003; Pippin, 1995; Jaggers et al., 1993). Tests of the LARES retroreflectors mounted in uncoated tungsten alloy breadboards were successfull and qualified the final design. After the launch, the ILRS

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ground stations are receiving good reflected signals from LARES, which demonstrates to be one of the best laser ranging targets and the best test particle for studying the gravitational field of the Earth (Pavlis et al., 2015a). LARES is also a useful addition to the constellation of geodetic satellites for environmental monitoring (Pavlis et al., 2015b). Once the satellite was sent in orbit, the LARES-lab was used for further measurements on the retroreflectors of LARES and of other laser ranged spacecrafts (Paris and Neubert, 2015). Because of the small dimensions, low cost operation and the wide equipment of LARES-lab, it is particularly suited for testing small payloads (Di Roberto et al., 2015a; Di Roberto et al., 2015b) and microsatellites (Paris et al., 2015a; Paris et al., 2015b). The tests sometimes require long duration, for example when performing thermal cycling in vacuum; when needed it was possible a basic remote control of the tests (mainly to check the temperatures), but the presence of at least one operator was still needed. Furthermore the presence of a well equipped space environment simulation facility in a university is a great opportunity for teaching. However the limited space in the lab does not allow to accommodate more than very few students at a time. Also, sometimes the didactic activities needs to be planned according to the time schedule of the university courses to allow the students to participate. Nevertheless the experience with university courses that are using LARES-lab for lessons and seminars showed a good appreciation both from professors and students, and a good potential for increasing the didactic activities. Therefore turning LARES-lab into a remote controllable lab will be useful both for testing and for teaching. However the two fields require different capabilities. Indeed while it is acceptable for a remote operator to have full access to the lab equipment for a test, safety reasons require to limit the access privileges for students. Feasibility of remote labs for e-learning and teaching have been demonstrated by a number of experiences worldwide (Casini et al., 2001; Gustavsson, 2003; Aliane et al., 2007; Eslami et al., 2008; May et al., 2013), however no project based on thermo-vacuum testing was found in the literature. The upgade of LARES-lab has been already discussed on a previous paper (Paolozzi et al., 2015b); in the meanwhile some upgrades described in the 2015 paper have been discarded or changed. In the next sections the state of the project and the changes made will be discussed.

2 SHORT DESCRIPTION OF LARES-LAB

LARES-lab was designed with the goal of performing optical tests in simulated space environment according to the standard requirements of ESA for space testing (ECSS, 2012; ECSS, 2002). The items to be tested are put in a cubic vacuum chamber, where the pressure can be maintained below 10^{-6} mbar by two pumps. The first is a dry scroll pump (Edwards XDS5) that brings the pressure below 2 mbar, that is the limit required to start the turbomolecular pump (Edwards EXT255DX). The turbomolecular pump brings the pressure to the operational value. The time to reach the ultimate pressure depends on the volume and the materials of the item under test: large surfaces and materials which have not been degassed before the test need more time to reach the ultimate pressure. A pressure gauge allow to monitor pressure inside the chamber and is used to decide when starting the turbomolecular pump. The turbomolecular pump and the pressure gauge are connected to a controller (Edwards TIC Instrument Controller), which is connected to a personal computer. A software (TIC PC monitor) is installed on the PC for monitoring the pressure and the pump parameters. The TIC PC monitor allows also to switch on and off the turbomolecular pump. The dry pump, instead, is not controlled by the TIC Instrument Controller. Figure 1 shows the vacuum chamber and some components discussed in the paper. The vacuum chamber is cubic. The length of the internal edge is 60 cm but the presence of a cooling shroud on five walls shortens the length to about 55 cm. The cooling shroud is composed of five copper plates cooled by an open circuit liquid nitrogen coil. Liquid nitrogen is fed from a pressurized container. Temperatures down to -192 °C can be reached when the liquid nitrogen valve is fully open; partly closing and fine tuning the valve allows to set the temperature to a higher value. To simulate the heath exchange toward a black body, the shroud is painted with Aeroglaze Z307, a vacuum compatible black paint having high absorbivity and emissivity ($\varepsilon = 0.89, \alpha = 0.97$) (Persky, 1999). Sun and Earth radiation are simulated by means of a Sun simulator with AM0 spectrum and a Earth infrared radiation simulator disk. The Sun simulator lamp projects a beam with AM0 spectrum and a constant power over a 12x12 cm surface. The lamp is positioned outside the chamber, and the light enters through a fused silica window with low absorption also in the ultraviolet portion of the spectrum. The Earth infrared simulator disk is positioned inside the chamber; temperature on the disk is controlled by resistive heathers and set

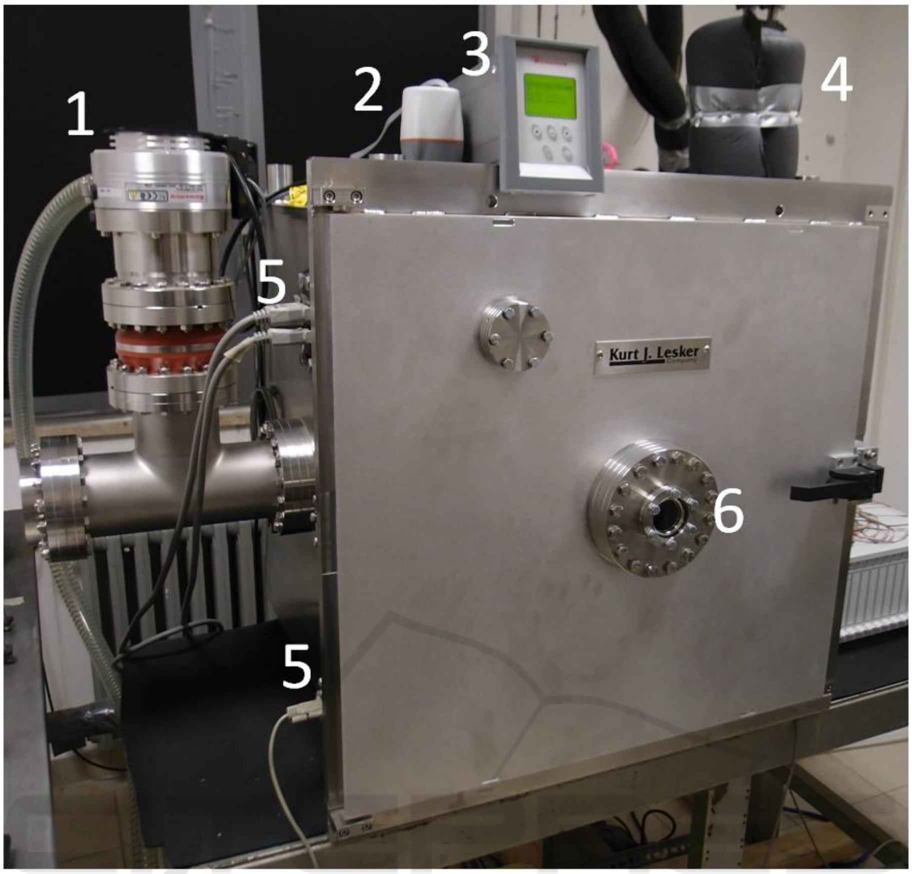

Figure 1: LARES-lab vacuum chamber. 1: turbomolecular pump; 2: pressure gauge; 3: TIC Instrument Controller; 4: liquid nitrogen pipes; 5: electrical feed-throughs with multi-pin connectors; 6: inspection window.

to -18 °C, that is the blackbody equivalent temperature of Earth (Macdonald and Badescu, 2014). Resistive heathers are used for additional thermal inputs. The temperatures are recorded by platinum resistance thermometers PT100. Two monitoring systems, a HBM MGC-plus modular data logger and a PicoTech PT104, allow to record data from up to 12 PT100 sensors (8 by the MGC-Plus and 4 by the PT104). The same PC that controls the TIC Instrument Controller also controls both the monitoring systems at the same time. Three multi-pin feed-throughs (two 25-pins connectors and one 9-pin connector) provide electrical contact with sensors, heathers and instruments inside the chamber. A programmable power supply is used to feed the heathers. Specimen under test can be rotated by a one-degree-of-freedom manipulator. Optical testing in vacuum is possible by means of a high quality optical window with a very accurate surface finish (lambda/20 peak to valley at 632.8 nm).

3 REMOTE CONTROL OF LARES-LAB

A Virtual Network Computing system (VNC) installed on the laboratory PC, allows simple control of the turbomolecular pump and recording the temperatures. We have tried different open source and freeware software to find the best solution for remote control. For testing, any VNC is adequate but for e-learning more control is needed over the students privilege. We are still experimenting with Team Viewer remote access software to configure safe access to the lab. In the meanwhile, we are testing a simpler configuration for providing remote access during a lesson to a room of students under the supervision of a teacher.

4 UPGRADES OF LARES-LAB

In this section the upgrade with respect to what proposed in (Paolozzi et al., 2015b) is described.

4.1 Dry Pump Control

The dry pump is not controlled by the TIC Instrument Controller. The electric switch on the pump remains in the ”on” or ”off” position when manually operated. To have the possibility to remotely control the dry pump it is necessary to leave the switch in the ”ON” position, then a single-board microcontroller (Arduino Uno) with AC 220 V relay module controlled by the lab PC can be used to close or open the power circuit of the pump.

4.2 Lights and Webcam

A strip of LED lights illuminates the vacuum chamber. A webcam positioned on the door inspection window will show to the classroom the experiment inside the vacuum chamber.

4.3 Robotic Arm and Manipulator

A small six degree-of-freedom robotic arm was purchased for didactic activities and to gain experience about servo-mechanism controls. The arm is controlled by a 6 channel Pololu Micro Maestro controller (Figure 2). The controller is connected with a USB cable to the PC and can be remotely controlled by the VNC system. In the previous paper we described the planned remote operation of the manipulator using a stepper motor coupled to the manipulator drive; here we propose instead the use of a robotic arm. The manipulator drive has several screw holes that can be used to mount knobs. A simple knob has been screwed on the drive and allows to move the manipulator using the robotic arm (Figure 3).

A second robotic arm to be mounted inside the chamber is under study. The major difficulty being to find a device that can operate under vacuum.

4.4 Sun Simulator Screen

Another change to the previous plan regards the system to cut the Sun beam. Initially we proposed a sliding screen operated by a stepper motor. Learning from the experience gained with the robotic arm, a more cost effective solution will be using a servomechanism operated by a second Pololu Micro Maestro controller to move a smaller screen in front of the Sun window. Using the same components and control software for both the robotic arm and the Sun screen allows an easier integration of the subsystems on the remote controlled architecture.

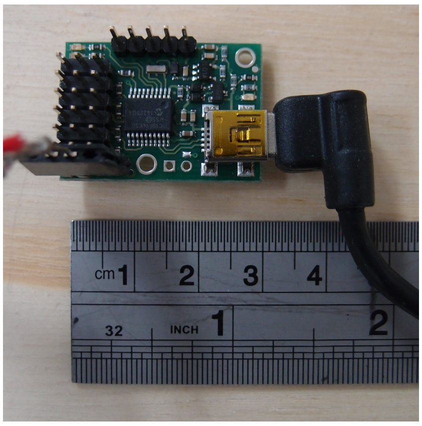

Figure 2: The 6 channel controller for servomechanisms (Pololu Micro Maestro). The controller is connected with a USB cable to the lab PC.

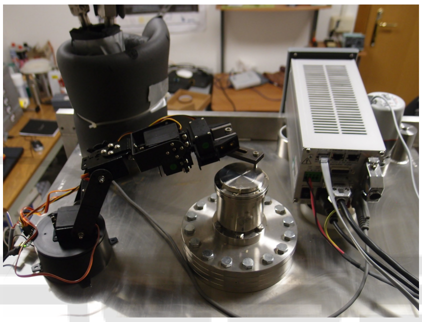

Figure 3: The 6 degrees-of-freedom robotic arm operating the manipulator drive using a simple knob. A better knob will be created and mounted soon.

5 CONCLUSIONS

LARES-lab space environment simulation facility was created for testing satellite components. Since it is a university facility it is an important resource for teaching. For fully exploiting the didactic potential of LARES-lab, an upgrade of the facility for creating a remote controlled testing and teaching platform is under development. The plan presented in the 2015 paper has been modified and some systems have been already installed and tested, including a robotic arm for moving the manipulator and for gaining experience for other remote controlled systems based on servomechanisms. Further improvements are under study, including the use of a second robotic arm inside the chamber. Once the improved lab will be fully operational, the number of students that would have access to the didactic experiments will be much increased.

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