Radiation testing of robotic systems – LiDAR as a case study – Abstract

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***Abstract* — The UKRI funded Robotics and Artificial Intelligence in Nuclear (RAIN) Hub objective is to perform R&D to create intelligent robots that can operate in nuclear environments. The radiation environment damages sensors, cables and mechanical systems, and micro-controllers and microprocessors. It is important to identify key components and find Commercial Off-The-Shelf (COTS) solutions that enable robots to work for sufficient periods in nuclear radiation environments. This is especially important for nuclear decommissioning. As a first case study, the radiation tolerance of a COTS LiDAR system has been evaluated. Laser light detection and ranging (LiDAR) systems are widely used in robotics to build up an image of the environment in which the robot is operating. The LiDAR module tested was the STMicroelectronics VL53L0X, a new generation Time-of-Flight (ToF) laser-ranging module housed in a very small package. The package includes a 940 nm VCSEL (Vertical Cavity Surface-Emitting Laser) laser, SPAD (Single Photon Avalanche Diode) array, on-board memory and microcontroller. Beta (Strontium-90) and gamma (Cobalt-60) sources were used to evaluate the LiDAR for Single Event Upset and Total Ionizing Dose Effects. This complicated but inexpensive system was found to show no degradation in performance up to the maximum ionising dose achieved of 5800 Gray. This is more than adequate for nuclear decommissioning applications.**

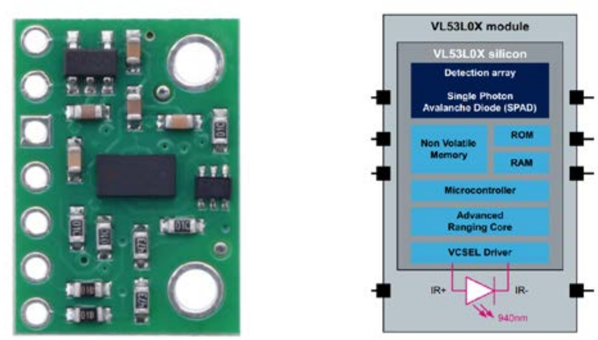
***Index Terms*— Robotics, LiDAR, Nuclear Decommissioning**

I. Introduction

Robotics is a fast developing subject and there is now much effort being devoted to developing radiation tolerant autonomous robots for use in the nuclear industry. They are especially required for nuclear decommissioning for tasks such as inspection and remote handling. Often robots are mobile, entering dangerous areas in terms of risk of physical accident, chemical contamination, and radiation damage. For some typical radiation environments see references [1, 2]. Radiation levels typically vary from 0.1 Gy/h to 10 Gy/h. Robots typically need to survive for around 100 hours to achieve their mission. Moreover, failing components can be replaced provided the robot returns from the radiation area. In some cases, they cannot be recovered and add to the waste. The strategy is thus to build cost effective robots using Commercial Off-The-Shelf (COTS) components. A reasonable target Total Ionizing Dose (TID) to achieve is ~ 1000 Gy. This is a very different approach to that used in High Energy Physics, where experiments are fixed in position for many years and specialized and often expensive components are produced that can withstand very high radiation doses.

II. Description of the COTS LiDAR Module

Robots like people need sensors to build up a picture of the environment. Key sensors are cameras and laser light detector and ranging (LiDAR) systems. As a case study to illustrate the strategy outlined above, a STMicroelectronics VL53L0X, Time-of-Flight laser-ranging module [3] was evaluated for radiation tolerance. Figure 1 (a) shows the module mounted onto a board [4] with key support electronics (voltage regulator, MOSFET drivers for the I2C bus). The LiDAR module has dimensions of just 4.4 x 2.4 x 1.0 mm and uses time-of-flight measurements of infrared laser pulses for ranging, allowing it to give accurate results independent of the target's color and surface for distances up to 2 metres away.



(a) LiDAR set on the breakout board (b) LiDAR module

Figure 1 Left: VL53L0X module (centre) mounted on support board (18 mm x 13mm), ref. [4]. The laser aperture is slightly smaller than the SPAD array entrance. Right: Despite its small physical size, the LiDAR module has several components, ref [3].

Figure 1(b) shows that inside the module there is a 940nm Vertical Cavity Surface-Emitting Laser (VCSEL), a Single Photon Avalanche Diode (SPAD) array plus on-board memory and microcontroller. The distance measurement is the key output, which is transmitted via an I^2C bus. All this technology is delivered for around $6.00.

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III. Irradiation Details

Up to ten LiDAR modules were irradiated whilst *powered and operating* using the Cobalt-60 irradiator at the Dalton Cumbrian Facility [5]. Each module was mounted inside an aluminium build-up box which also provided a laser target for the LiDAR to measure. Throughout the irradiation, a computer recorded the total electrical current drawn by all the components and the distance measurement from the LiDAR module.

Dosimetry was provided by a Farmer ionization chamber supplemented with Gafchromic film [6] to measure radiation dose profiles. Dose rates from 5 Gy/min to 50 Gy/min were used, although no dose rate effects were observed.

IV. Results

A. Total Ionising Dose (TID) Effects

Initial irradiations showed the total circuit current increasing with dose and then the voltage supply failing at around 400 Gy. This was due to the on-board LDO voltage regulator. In further tests, the voltage to the board was supplied externally. Fig 2 shows the current drawn by the whole board up to 5800 Gy, the maximum achieved during the test. The LiDAR continued to function. As there are several components on the board, the exact source of the current was not established.

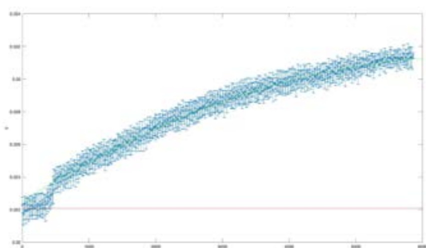

Figure 2 Current drawn by the entire circuit versus radiation dose. The current starts at ~22 mA and finishes at ~ 28mA. Maximum dose was 5800 Gy.

B. Single Event Upset with Cobalt-60 and Strontium-90

No SEU effects were seen with the Cobalt-60 irradiation. The LiDAR continued to output consistent results throughout the irradiation. Note that the radiation environment consists of a “sea” of Compton scattered electrons with a broad energy spectrum up to around 800 KeV. As there was still concern about the SPAD array sensitivity to electrons, a highly collimated 37 MBq Strontium-90 source was set-up directly in front of the LiDAR in the laboratory to look for SEU.

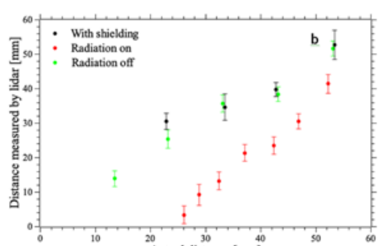

Figure 3 LiDAR distance to target with and without a collimated Strontium-90 source. Glass shielding was placed in front of the SPAD array and the effect was eliminated.

Fig. 3 shows that an unusual radiation source geometry was able to upset the LiDAR measurement. However, the on-board algorithms that reject infra-red photons in the surroundings clearly helps to remove SEU effects as is shown by the Cobalt-60 null result.

C. TID for lead glass samples

To evaluate whether lead glass could be used as a radiation shield in front of the SPAD array, to reduce SEU and total dose effects, three samples (LPX-650, LPX-700 and Novashield®) from Lemer Pax [7] were irradiated using the Cobalt-60 source and their optical transmission measured. Fig. 4 shows the result for LPX-650 which has a density of 4.36 g.cm^{-3}. The sample became brown after irradiation and showed some thermal annealing.

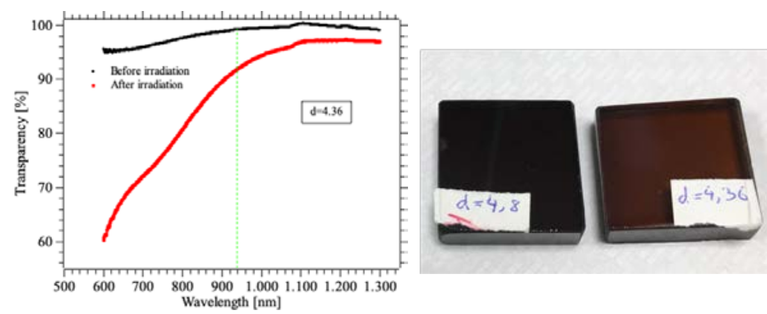

Figure 4 Left: Transmission of Lemer Pax LPX-650 before and after irradiation. The total dose was 955 Gy. Right: Two irradiated samples.

The key point to note is that the transmission loss is mainly in the visible wavelengths and that at the laser wavelength of 940 nm, the transmission is still excellent even after 955 Gy.

V. Conclusion

This test of the STMicroelectronics VL53L0X LiDAR module shows that there is good reason to expect that radiation tolerant robotics systems can be built using COTS.

Acknowledgment

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