Implementing Fault Tolerance and Radiation Hardening on a Commercial Off The Shelf Accelerated Computing Processor in Space

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Introduction

Satellite data gathering capabilities have improved significantly in the recent past. With vast amounts of data being gathered, satellites are increasingly being bottlenecked by their ability to transmit that data back to Earth to be processed. One solution to this bottleneck is to provide satellites with the capability to process and analyze this data onboard while in orbit. In the case of the UGA Small Satellite Research Laboratory's MOCI (Multiview Onboard Computational Imager) satellite mission, reconstructed models of surface landmarks are derived from processed images, performed on an NVIDIA Jetson TX2i graphics processing unit (GPU). However, using accelerated computing platforms means ensuring correct operation in a high radiation setting. This research assesses the radiation sensitivity of the NVIDIA Jetson TX2i and proposes several techniques that are used to mitigate the effects of radiation on the GPU in Low Earth Orbit.

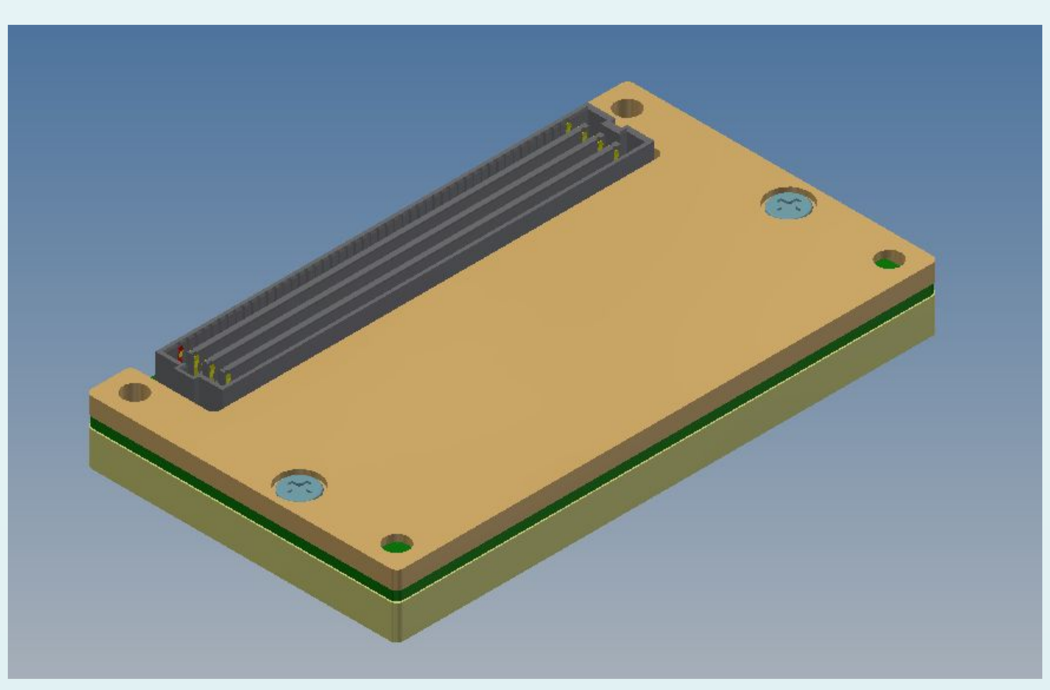

Figure 1, CAD rendering of TX2i

Approach

The TX2i, while it has flight heritage from past missions, lacks easily available radiation data for a LEO environment that we can utilize. This is due to the scantness of successful missions making use of the GPU and most of the existent data being classified. Through consulting with industry experts, we were able to estimate the performance of the TX2i in a space-like environment and address problems that appeared in prior testing with our proposed measures.

Radiation Analysis

Preliminary test results of the TX2i under various doses show that the TX2i is susceptible to reboot failure at high moderate dosage rates, though the devices-under-test could continue operating at those same rates. We hypothesize that the reboot failures occur due to radiation induced corruption of the Operating System and other critical memory sectors in the persistent flash storage on the TX2i. Additionally, the dosages used for testing were significantly greater than those that would actually be encountered while in Low-Earth Orbit.

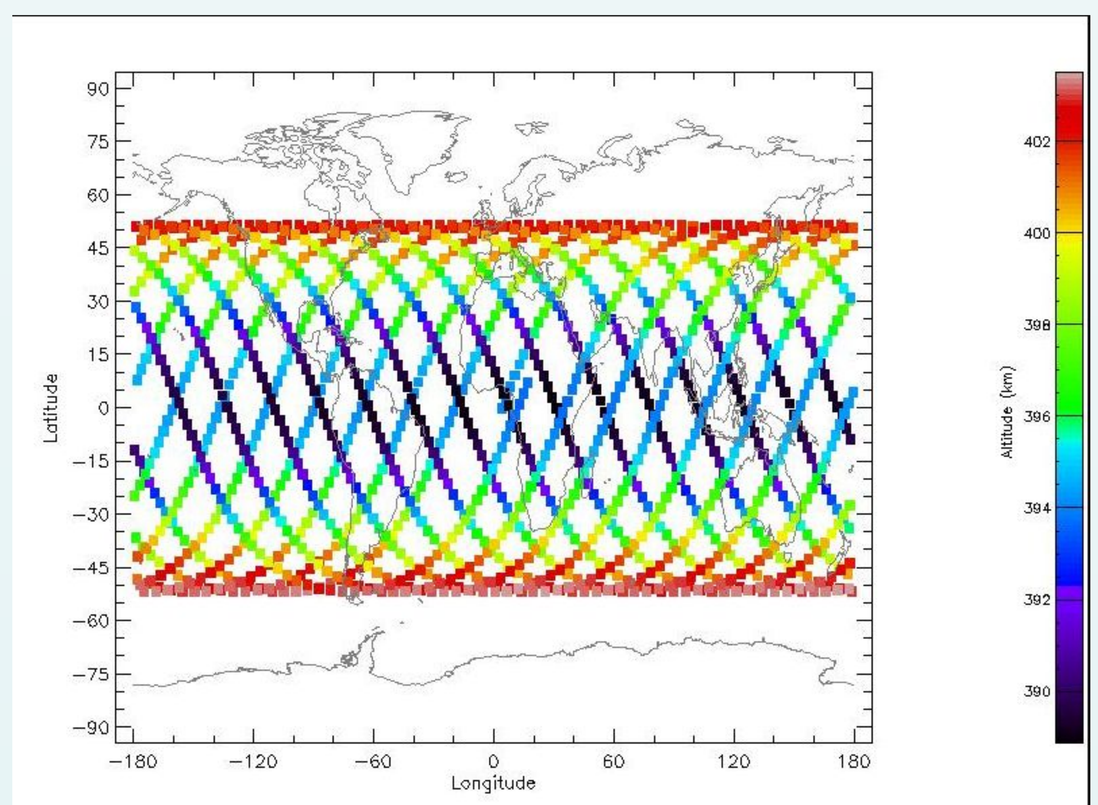

Figure 2, expected rad. dose in orbit

Hardware Mitigation

We plan to use two main approaches to hardware radiation mitigation: adding shielding and replacing radiation-weak components on the TX2i with components better able to tolerate high radiation environments. For shielding, we concluded that the Dunmore Aerospace Satkit is the best choice due to its size, inexpensiveness, and versatility for small satellites. Additionally, it was observed that the Integrated circuit responsible for power conditioning in the TX2i System-on-Chip is especially vulnerable to failure, and will have to be manually replaced with a less susceptible component prior to flight.

Software Mitigation

One of the major problems that radiation presents to electronic components in space is data integrity. Without software protection measures, components vulnerable to effects such as potentially destructive latchups can be rendered unusable due to corrupted information as random bit flips in memory accumulate over time.

Although hardware mitigation techniques can provide some protection to a system, software mitigation techniques are needed to ensure stability.

To address the data integrity issues, we propose modifying both the system's bootloader and the filesystem to make it more resilient against radiation through redundancy. By triplicating the filesystem, the TX2i can identify and correct any corruption that might have occured in memory. We apply that same principle to the bootloader, which will store three operating system (OS) images with a hash associated with each image. The TX2i can compute a hash for the image it attempts to load and determine the validity of the image by comparing it with the stored hash: if it detects that all stored OS images have been corrupted it will attempt to build an uncorrupted image through bit voting.

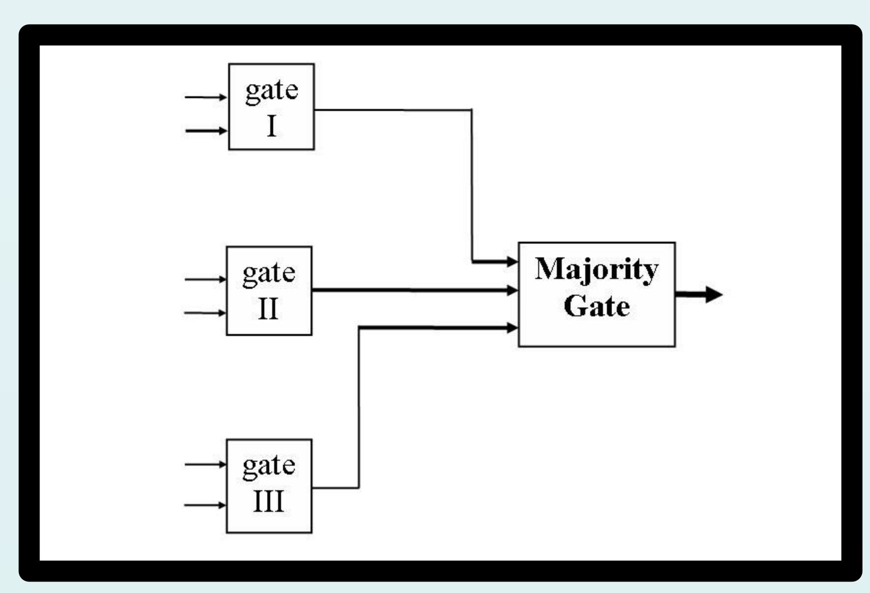

Figure 3, ex. of TMR

Discussion and Future Work

When we can successfully implement these methods on the TX2, we will analyze how the system performs in low earth orbit under radiation exposure and submit a paper for publication that analyzes the effectiveness of these mitigation measures.

References

C. Adams, et al., "Towards an Integrated GPU Accelerated SoC as a Flight Computer for Small Satellites", 2018

Wikipedia, "Triple Modular Redundancy", Article, 2018