HIPNOS: Evaluation of Computing Platforms and Accelerators for High-Performance Avionics in Space

by GMV

The Clean Space initiative of the European Space Agency (ESA) seeks to decrease the environmental impact of space programmes by focusing, among others, on Active Debris Removal (ADR) and the e.Deorbit mission. In this direction, one of the main challenges is to autonomously track and approach a big non-cooperative satellite such as ENVISAT.

To achieve the high level of autonomy and reliability required in this phase of the ADR mission, vision based navigation will guide a chaser spacecraft in real-time based on high-definition images acquired and processed on-board at high frame-rates. The increased complexity of these computer vision algorithms mandates the development and use of high-performance avionics to provide one order of magnitude faster execution than today's conventional space-grade processors. In the context of ESA's project HIPNOS (HIgh Performance avionics solutioN for advanced and complex GNC Systems), we study computer vision algorithms and design avionics architectures suitable for high-performance embedded computing in space, such as in the ADR mission scenario.

The rendezvous phase of the e.Deorbit mission will rely on sophisticated imaging sensors and advanced autonomous control to continuously estimate the distance/pose of the target and synchronize to its spin.

The chaser will be equipped with sensors such as LIDAR, far range and close range cameras, multispectral camera, and infrared camera. The acquisition rate and the high- definition resolution of these cameras will result in a huge amount of data to be processed on-board, at real-time, which together with the complexity of the related computer vision algorithms, will increase the demand for processing power to unprecedented levels for space applications. Conventional space-grade processors, such as LEON3 and RAD750, can provide only a very limited amount of performance, e.g., in the range of 50–400 DMIPS (with 50–200MHz operating frequency). Put into perspective, for image processing, such performance is 10–100x lower than that of contemporary desktop CPUs, which are used today by the algorithm designers during the early development stages of the Vision-based Navigation blocks (VBN). Even with the latest devices, such as LEON4 and RAD5545 that achieve 10x more speed than their predecessors, the space-grade CPU performance seems to be one order of magnitude less than what will be needed to run highly-accurate vision algorithms on-board the future spacecrafts. Therefore, building blocks for Advanced Image Processing Systems and complex Guidance Navigation Control (GNC) mandate the design of new generation space avionics to include hardware accelerators, e.g., FPGAs, GPUs, or multi-core VLIW DSP processors.

Overall, the results show that new generation space-grade CPUs are 10x faster than their predecessors, however, they are still one order of magnitude slower than what will be needed for reliable autonomous VBN. Separated by orders of magnitude, the FPGA accelerators provide the highest performance per Watt than all platforms, whereas the CPUs provide the lowest (any CPU type). In terms of speed, alone, the desktop GPUs and the FPGAs are difficult to distinguish (as groups, they provide similar clouds of results).

Likewise, high-end mobile-GPUs and many-core DSPs are difficult to distinguish, although the latter have the potential for slightly better performance and power. In terms of speed, alone, desktop GPUs and FPGAs are clearly better than mobile-GPUs and many-core DSPs. In terms of power, a 10 Watt budget is enough to allow many-core DSPs or mobile-GPUs or FPGAs to accelerate a conventional space-grade CPU by 1⍰3 orders of magnitude. In a high-performance embedded computing scenario of limited power and mass availability, it would be preferable to utilize COTS 28nm SoC FPGAs, which provide 2⍰29x faster execution than 28nm DSPs. Following the analysis, in HIPNOS, we selected a SoC-FPGA (Zynq XC7Z100, on MMP board) to HW/SW co-design and accelerate a proof-of-concept algorithm for the pose estimation of ENVISAT. The computer vision algorithm bases on edge detection, rendering of a-priori known 3D models of the satellite, and linear algebra techniques to extract a 6D pose vector. The achievement is processing rates of 10-12 FPS for 1024x1024 input images (monocular camera, 8-bit values).