A RAD-HARD MANY-CORE COMPUTING PLATFORM FOR ON-BOARD QUICK HYPERSPECTRAL IMAGE PROCESSING AND INTERPRETATION

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ABSTRACT

QI2S is a project financed in the frame of the European FP7 funding programme, developing the prototype of a lightweight low-power on-board processing platform that operates with a massively parallel many-core technology based on Ramon Chips ITAR free RC64 architecture. This technology will be able, in the future, of reaching performances of hundreds of GOPS and tens of GFLOPS, although for demonstrational purposes it is now implemented on a downscaled FPGA. The hardware platform is demonstrated for real-time on-board analysis of hyperspectral data. QI2S was developed to ensure parallel computational capabilities and an easily reconfigurable architecture, able to generate on-board products in real-time or near real-time. QI2S is a prototype developed and validated in laboratory with a TRL 4.

Index Terms — hyperspectral imaging, on-board processing, parallel architectures, multicore processing, reconfigurable architecture.

1. SYNOPSIS

Next generation satellites need intensive real-time onboard processing capabilities in order to fulfill demands of compute intensive image and signal processing workloads such as hyperspectral imaging [1]. In order to satisfy the community's demands for such we are creating an innovative rad-hard, lightweight, low-power and massively-parallel many-core computing system augmented by specialized parallel processing software aiming for near real-time, hyperspectral image processing and interpretation in spaceborne remote sensing missions.

The Quick Imaging Interpretation System (QI2S) FP7 research project, has designed, developed and validated a technological concept prototype in a laboratory environment. The prototype system provides a representative onboard image processing suite including radiometric and atmospheric corrections followed by straightforward yet useful and distinctive object/material spectral detection algorithms. This is all implemented for a parallel-processing, reconfigurable architecture, to demonstrate on-board real-time / near real-time end-user product generation capabilities. The QI2S project has brought together Ramon Chips and Elbit Systems Electrooptics from Israel, DSI and TU Braunschweig from Germany, CGS from Italy and ARTTIC from France. QI2S, which strictly focuses on civilian applications, represents a major step for the development of future payload processors.

2. BACKGROUND

Satellites for earth observation (EOS) featuring hyperspectral imaging employ cameras, which typically sense radiation at wavelengths of 0.2 µm to 2.5 µm (UV-VNIR-SWIR), 3 µm to 5 µm (MWIR) and/or 8 µm to 14 µm (LWIR or TIR) and scan in up to thousands of pixels within one spatial dimension at once. Furthermore, per spatial pixel Hundreds of narrow bands (10-50 nm) collect highly precise information about the radiance spectrum of one image pixel (100-900 m^2 on earth). This enables image-based detection of various materials and objects through the identification of their unique spectral radiance signatures. Such a strong concurrent differentiation regarding spatial as well as spectral information creates large signal data streams. The processing of such large data streams according to [2] typically includes: radiometric correction for sensor-specific distortions and artifacts (sensor bias, gain and charge transfer) and radiometric calibration for upwelling radiance signals; cloud screening and atmospheric correction, which computes the spectral reflection or emission profiles based on upwelling radiance and respecting features of the atmosphere; and information retrieval algorithms, for specific material or object spectral identification (e.g. anomaly detection, matched filters based etc.).The resulting thematic maps and mosaics with different layers of extracted information can be rectified and geo-referenced to create a final information product for the end-user. The need for spaceborne hyperspectral remote sensing emerges dramatically and is driven by a continuously increasing range of important applications in various fields. Many evolving applications require fast imagery data exploitation to support real-time decision-making. For example the cases of monitoring evolving incidents and disaster analysis: e.g. for fighting wild fires (real-time information on expected spreading directions based on forest biomass analysis and humidity conditions is highly desired), or furthermore for search and rescue in case of accidents in remote or maritime locations and scenarios. Such rescue operations demand immediate detection of drifting fragments, survivors or bodies (spectral anomaly detection can be highly effective in these cases). Additionally, water contamination, air pollution, atmosphere conditions monitoring and precise agriculture (disease/stress precise detection, customized fertilization etc.) are also some of the many fields that can significantly benefit from real/near real-time spaceborne hyperspectral imagery data exploitation which is accessible and affordable.

However, the potential of spaceborne global hyperspectral imaging is far from being fully realized. One of the main bottlenecks is the long delay in response time, typically measured in weeks, caused by extremely large data volumes that need first to be transmitted to ground, then mobilized to the mission's data exploitation center, where they are prioritized, then submitted to effortful processing and only then distributed as useful (usually basic) products to the end-users. For example, a satellite orbiting at 680 km above earth having a ground speed of ca. 7000 m/s, typically acquires imagery at rates of more than 2 Gbit/s, resulting e.g. in 20 Gbit of data for only one 70 km long ground image. Thus many terabits of data need to be downloaded at Gbit/s rates to facilitate near real-time hyperspectral data exploitation. Another reason why spaceborne hyperspectral imaging is far from being realized is of economical nature. Nowadays, most satellite compute systems rely on the use of hardware accelerators (i.e. FPGAs or ASICs [3][4][5]) serving mostly a single purpose such as image compression. Even though FPGA accelerators are reconfigurable to some extent, it is very complicated and thus costly compared to designing or updating a software algorithm for an application specific or general-purpose processor (between which the RC64 [6] and the QI2S prototype fall). The QI2S prototype demonstrates the potential for significant reductions of delay in the delivery of spaceborne hyperspectral imagery extracted information to the end-user on the ground – from many days or weeks to real-time / near real-time (application-wise i.e., from few dozens of minutes to few hours at most) with effective on-line hyperspectral processing to be performed on-board. Only extracted information will then be downlinked for fast "packaging" and delivered to end-users, postponing full-volume raw imagery downlinking to be performed off-line and used at the mission's data exploitation ground center for generation of more advanced, added-value products. An improvement factor of ca. 100x in delay and 400x in effective bandwidth (~5 Mb/s vs. >2.0 Gb/s) can potentially be achieved.

3. THE QI2S SOLUTION

Reducing delays in the delivery of useful information from spaceborne hyperspectral missions, approaching (near) real-time delivery of results from applications presents a major challenge and nowadays leads to significant compromises. Although hyperspectral remote sensing is well established and many important real/near real-time applications already apply straightforward data exploitation algorithms, a commercial and global spaceborne mission that realizes the tremendous potential of hyperspectral imaging, making it accessible to a wide public with various needs and the ability to deal with evolving incidents as well as day-to-day operations, is still absent and out of sight in the near future. So far, the high-performance computing necessary for onboard interpretation in space has been unavailable. The hyperspectral imagery processing is intensive and resource consuming. This requires the onboard computing platform to be compact, power-efficient and of course rad-hard to be able to function in a space environment. The present spaceborne computation power is a fraction of what would be needed for the processing and interpretation tasks involved. As evident from ESA's analysis, this might take up to 10 years to obtain. The QI2S technological concept combines a novel compute-hardware architecture and advanced image processing software leveraging a custom programming model demonstrating the potential to carry a computing performance to electric power ratio of approximately 15 GOPS/Watt or 2 GFLOPS/Watt. The QI2S prototype concept's foundation technology is a lightweight, low-power, massively parallel many-core computing platform adapted to onboard massively parallel processing and interpretation of hyperspectral imaging data. The QI2S demonstrator is a customized platform that enables scalable performance using multiple chips communicating and processing concurrently, which can reach 10's of GFlops and 100's of GOPS [6], and is based on Ramon Chips RC64 IP chip architecture and implemented with a downscaled FPGA version for concept demonstration purpose. The many-core computing platform is integrated with a software interpreter with a finite number of finely designed software building blocks for fundamental processing and interpretation of hyperspectral imagery. These building blocks are designed to form the fundamental toolbox comprising essential mathematical operations and filters which will accommodate radiometric correction, atmospheric correction and materials/objects detection by identifying characteristic spectral signature features within a certain spectral range and threshold. In hyperspectral imagery, different processing procedures that usually make use of similar mathematical functions but use different parameters, variables, thresholds and apriori data, need to be applied for extraction of different types of information from the same data set. These procedures must be tailored by simple mission commands and therefore a flexible mission definition language is also proposed to enable fast-turnaround reconfiguration of the QI2S hyperspectral imaging interpretation process, setting different processing chains for different hyperspectral detection scenarios.

4. EXPECTED RESULTS

The QI2S project's expected result is the development of a demonstrator to evaluate performance of processing software beyond simulation. The QI2S prototype is implemented in a high-performance FPGA (Xilinx Virtex 7) featuring a downscaled version of all the RC64's circuit functions. For data stream emulation a personal computer, equipped with a high-speed serial card (Xilinx KC705), represents the payload system and enables the emulation of a hyperspectral sensor array with high data rate (2 Gb/s), controlling and monitoring the QI2S prototype as well as analyzing the results and performance. The software for hyperspectral image processing can be easily modified and loaded into the QI2S prototype to demonstrate a suite of hyperspectral onboard processing and interpretation comprising of radiometric correction and calibration, atmospheric correction, and material detection, which are representative for image processing algorithms compliant with demands from European space agencies. Hence, it will open the space sector to a wider range of new applications and also to a new way of delivering space application to the community and potentially to new user markets. The main result of this project is that QI2S will demonstrate that it is possible to provide the broad public with new services matching evolving application requirements and retrieving huge amounts of data directly in space.

5. REFERENCES

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