Flight results of SpaceCloud Machine Learning and Containerization on the ION SCV-003 Mission

Dr. Fredrik C. Bruhn(1), Simon Reid (2), Dr. Tom George (3), Alice Anlind (1), Dr Cormac Purcell(4)

(1) Unibap AB (publ.), Västra ågatan 16, SE-753 09 Uppsala, Sweden, +46 18 320330, f@unibap.com
(2) D-Orbit UK, Harwell, UK, simon.reid@dorbit.space
(3) SaraniaSat Inc, 9235 Scotmont Drive, Tujunga, CA 91042-3336, USA, tom@saraniasat.com
(4) Frontier Development Laboratyory/Trillium Technologies Australia, 1-45 Normanby Rd, Notting Hill, Victoria, 3168, Australia, cormac@trillium.tech

ABSTRACT

Unibap and D-Orbit with support by the European Space Agency have demonstrated low-latency information made in orbit using SpaceCloud containerized application deployment during fall 2021 on D-Orbit's "Wild Ride" ION SCV-003 mission. By combining internal efforts and support from several ESA programs the team successfully demonstrated in-orbit orchestration and execution of 23 different containerized applications covering a wide range of areas, e.g. Earth Observation, solar physics, image processing, video compression and communication. These applications have been provided many different international organizations, companies, and research institutions. The operations have demonstrated the ability to re-train neural networks and upload new networks to leverage very different sensor inputs. The demonstrated applications have successfully leveraged all available compute resources.
Two machine learning application examples are highlighted as references. Frontier Development Laboratory (FDL) / Trillium Technologies provided "Worldfloods" and SaraniaSat mid-air/airborne aircraft detection.
The Worldfloods application was demonstrated with preloaded Sentinel 2 multispectral imagery and "D-Sense" navigation sensors while the aircraft detection application used preloaded World View 3 multispectral data in combination with L3Harris Geospatial ENVI®/IDL® software.
An overview of health data from the SpaceCloud iX5-100 hardware on SCV-3 and the successor mission D-Orbit ION SCV-004 launched in January 2022 is also presented.

1 INTRODUCTION

With the rapid advancements of remote-sensing technology, optical remote-sensing imagery processing is playing an important role in many application fields, such as geological exploration and natural disaster prevention. Traditionally, remote-sensing data are downlinked to the ground station, preprocessed, and distributed to users. This process can generate long delays, which is a major bottleneck in real-time applications for remote-sensing data. However, because raw image data without pre-processing will cause poor performance during application it is necessary to perform on-board data processing to enable low-latency information. Many efforts to perform on-board data processing uses field programmable gate arrays (FPGAs) which are very effective for certain tasks. [1]. There are many applications where low latency is important, for instance ocean surveillance. The activity includes control and monitoring of illegal fisheries, manmade ocean pollution and illegal sea traffic surveillance, etc. The key problem in this case is how to identify ships and ship-like objects

accurately and in a timely manner [2]. Similarly, detected airborne aircraft, forest fires, flooding are examples of applications with low latency processing requirements.
FPGAs are powerful and highly optimized compute units, however the programming development tends to be costly and time consuming while modern computers often use a heterogeneous architecture consisting of a combination of central processing units (CPU), FPGA, graphical processing units (GPU), and various neural network accelerators (NNA)/or vision processing units (VPU). Heterogeneous architectures offer more versatile software development platforms where different parts of the software solution can run on different hardware with low development overhead. Bruhn et al have developed a heterogeneous radiation tolerant compute architecture based on CPU, GPU, FPGA, and NNA that provide the core hardware for SpaceCloud in-orbit processing [3].

Cloud computing is a major part of digitalization on earth. Many satellite companies are turning to Cloud to create digital operations centers or transition their existing operations. Cloud capabilities like high performance computing help engineers streamline satellite design, development, and simulation, which allows them to continue product development and testing from anywhere. Unibap is pursuing the ability to use terrestrial cloud computing in space. However, there is a major difference, the cloud capabilities in space must be able to handle the background radiation effects and space environment. To allow cloud computing in space, the SpaceCloud framework (SCFW) has been developed to allow application orchestration on heterogeneous architectures in space. The SCFW software layer which provide the ability to quickly develop applications that can be uploaded to satellites and executed in-orbit has been developed with support of the European Space Agency. The SCFW is further presented in this paper.

2 HETEROGENOUS CLOUD COMPUTING HARDWARE

D-Orbit's ION SCV-003 mission features a SpaceCloud iX5-100 radiation tolerant heterogeneous cloud computing solution as seen in Figure 2-1. The iX5-100 incorporates edge computing, storage, and cloud software at a weight of 600 grams, dimensions of 100 x 100 x 50 mm^3, and up to 20 W of power. Cloud software can make use of CPU, GPU, FPGA, NNA resources and 256 GB of solid state storage. In the iX5-100 the compute resources are provided by AMD 64 bit system-on-chip CPU and GPU, Intel Movidius Myriad X, and Microsemi FPGA.

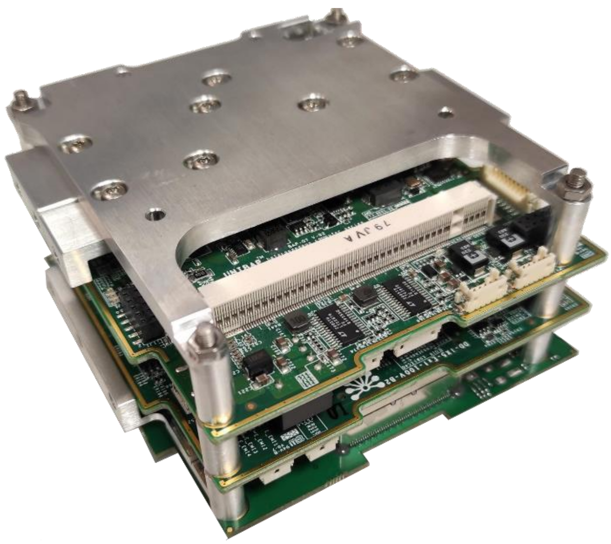

Figure 2-1. Photograph of SpaceCloud iX5-100 radiation tolerant cloud computing solution.

3 NEW SPACE LOGISTICS SATELLITE PLATFORM

The SpaceCloud iX5-100 solution was integrated into D-Orbit's ION SCV-003 during spring 2021 and launched as part of the "WILD RIDE" mission as shown in Figure 2-2. The WILD RIDE mission is still operational as of April 2022.

Figure 3-2. Photograph of D-Orbit ION SCV-003 before launch.

ION is a space vehicle that can transport satellites in orbit and release them individually into distinct orbital slots, reducing the time from launch to operations by up to 85% and the launch costs of an entire satellite constellation by up to 40%. ION is a platform able to modify its own orientation, altitude, and local time of ascending node (LTAN) to quickly deploy CubeSats and microsatellites into precise and independent orbital slots, allowing customers to start their missions faster and in optimal operational conditions.

The SpaceCloud iX5-100 used D-Orbit's plug-and-play mechanical, electrical, and data interface to quickly integrate instruments and experiments onboard and operate it from the ground as subsystem of ION itself. This payload hosting capability represents the "second life" of the ION spacecraft after cubesat delivery is completed and is being expanded with inter-satellite links to offer networked cloud-computing services from space.

4 SPACELOUD FRAMEWORK

SpaceCloud framework is riding ontop of a tailored Ubuntu Linux distribution. Hence, most x86-64 "PC" compatible software may be used. Figure 3-1 illustrate the SpaceCloud software stack with typical Linux compatible libraries and specific ones. An example of a specific software package is L3Harris Geospatial's ENVI®/IDL® geospatial software suite. This is not always available, but it was included for the purpose of demonstration on SCV-003 [4].

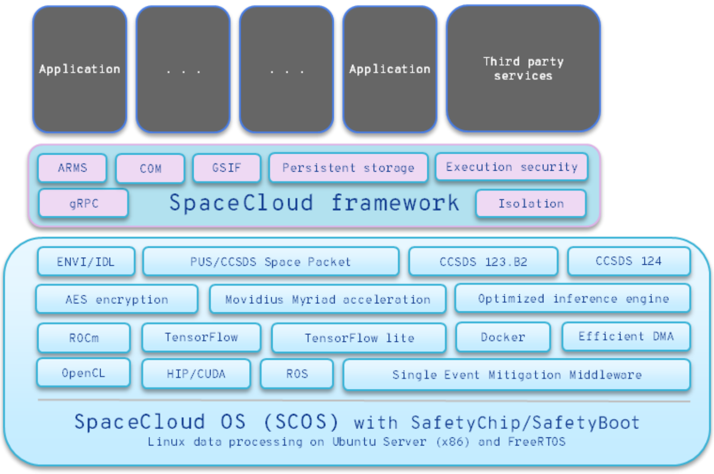

Figure 3-1. Illustration of the SpaceCloud software stack.

SpaceCloud framework has a minimal set of microservices that leverage Google Remote Procedure Calls (gRPC) and Docker containerization [5, 6]. The most common microservices are:

- ARMS scheduler
- Communication (COM) interface
- Generic Sensor Interface (gSIF)
- Persistent storage
- Execution security

SCFW allow containerized applications or cloud services from big cloud computing providers to be executed in orbit with standardized interfaces to access data from sensors, navigational instruments etc. Using gRPC calls it is possible to communicate and exchange information between applications as well as managing resources, perform uplink/downlink operations. The SCFW also allow local or remote testing and a containerized software development kit (SDK). An example application that uses the gSIF interface and multi-containerization is shown in Figure 3-2.

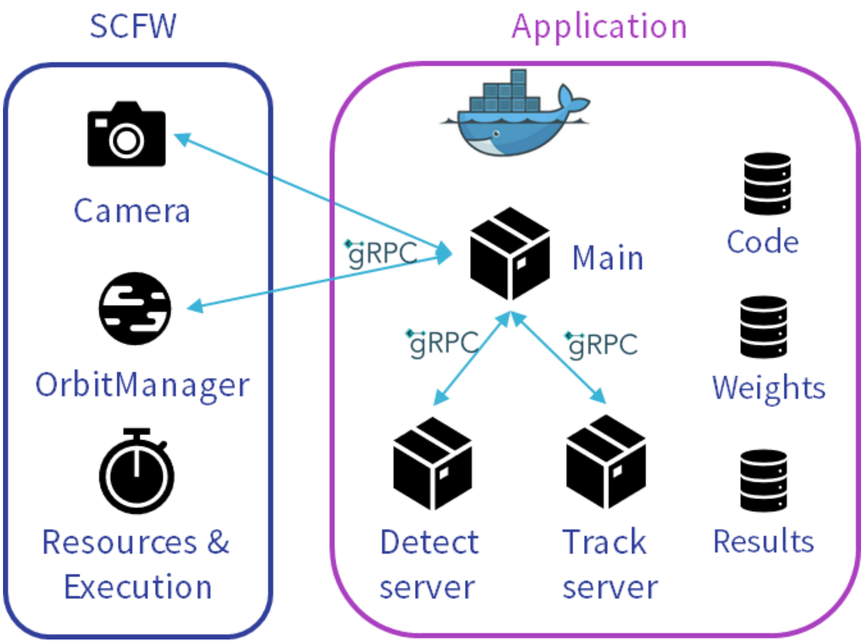

Figure 3-2. Illustration of a SpaceCloud application setup.

Terrestrial cloud applications can often request and assign different hardware resources. In a similar fashion this is also possible in SCFW. Figure 3-3 illustrates excerpts from a SCFW application manifest that define what resources this application requests and would like assigned. The application is requesting 4 cores, 1 GB of RAM, camera sensor input, a disk mount for storage and a volume that will be synchronized over the communication interface.

To automate and simplify the development of SCFW application, a conformance test environment has been developed. Figure 3-4 illustrate the conformance environment, with features for

- Test a SCFW Application locally using the Testing Framework
- Conformance testing on flight hardware / digital twin
- Conformance testing on satellite
- Load in application and data
- Execute in-orbit

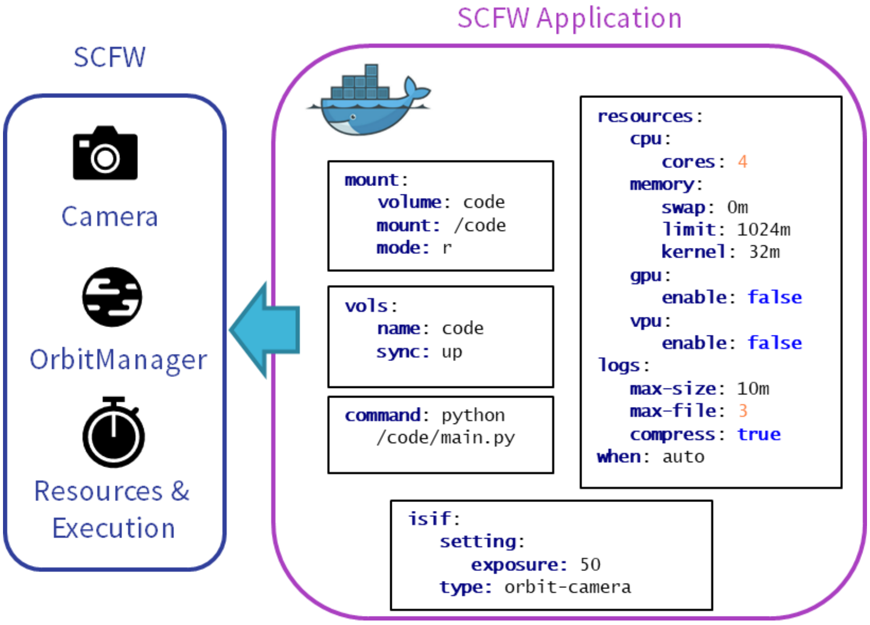

Figure 3-3. Illustration of a SpaceCloud application configuration.

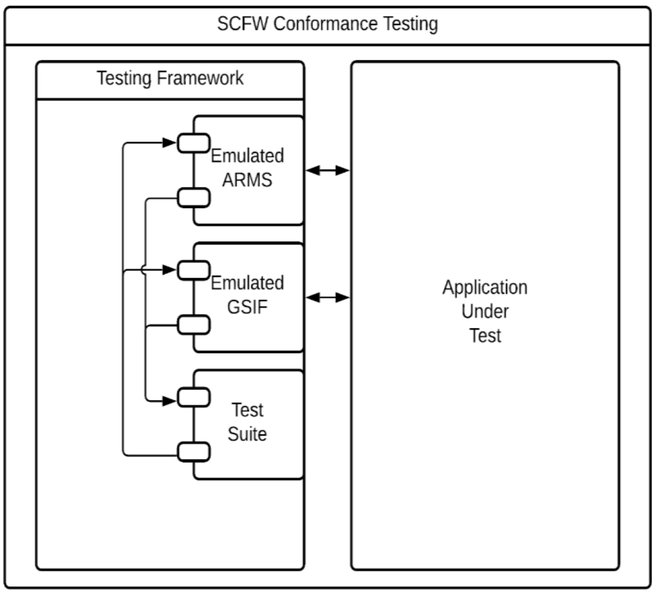

Figure 3-4. Illustration of SpaceCloud conformance testing environment.

5 FLIGHT RESULTS AND APPLICATIONS

The WILD RIDE mission was the first SpaceCloud enabled satellite mission to be launched and have demonstrated so far, a total of 23 different SpaceCloud Applications (SC-App) using SpaceCloud framework.

These includes:

- 3 SC-Apps from Unibap using CPU, GPU, and NNA/VPU for object tracking and detection
- 4 SC-Apps from D-Orbit
- 2 SC-Apps from ESA ESTEC (Scientific workloads for solar physics and particle physics)
- 1 SC-App from 12G Flight Systems (PUSopen)
- 1 SC-App from Ubotica (ship segmentation)
- 1 SC-App from ENEA (CCSDS-123-B2 image compression)
- 2 SC-Apps from V-NOVA (video compression)
- 1 SC-App from Trillium Technologies/Frontier Development Labs (Worldfloods)
- 1 SC-App from SaraniaSat/L3Harris Geospatial (Airborne aircraft detection and localization)

To illustrate the flight results, the Worldfloods and airborne aircraft detection applications results are presented.

The WorldFloods application was developed by Trillium Europe in partnership with University of Oxford, ESA, and Frontier Development Laboratory with the goal of demonstrating a path to next-generation intelligent constellations. The demonstration of WorldFloods in orbit was performed on pre-loaded Sentinel 2 multi-spectral reference imagery. Figure 4-1 shows downloaded water masks based on onboard automatic flooding analysis using the SpaceCloud WorldFloods application. A data reduction of 99.9% was demonstrated. In addition to the direct possibility of processing local sensor data, this demonstration demonstrates how machine learning (ML) in orbit can act a processing node for other earth observation (EO) assets.

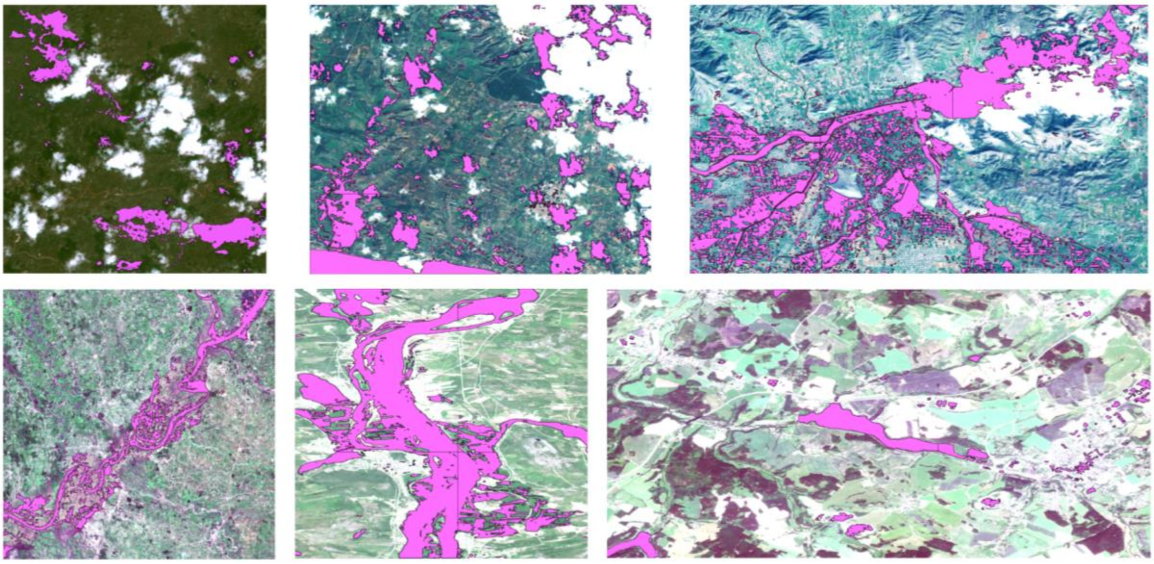

Figure 4-1. Downloaded water masks from Sentinel 2 reference imagery using the SpaceCloud WorldFloods application.

The second application example was developed by SaraniaSat in partnership with L3Harris Geospatial. This application detects aircraft aircraft in pre-loaded Maxar World View-3 reference imagery and generate geolocation + a thumbnail image of all detected airplanes. The output is a tightly cropped image with position in kmz format that can be overlayed on Google Earth once downloaded. A combination of Tensorflow and L3Harris Geospataial ENVI®/IDL® was used in-orbit to perform the aircraft detection [7, 8]. Figure 4-2 shows a downloaded output of the SpaceCloud aircraft detection application. The application was able to analyse and cover an area of 100 km^2 in 43 seconds.

Figure 4-2. Downloaded geolocated image of an airborne aircraft detected in reference Maxar World View-3 multispectral imagery using SpaceCloud SaraniaSat application. The downloaded geo image has been overlayed on Google Earth.

The heterogeneous iX5-100 cloud computing solution has operated nominally on the WILD RIDE mission since June 2021. Figure 4-3 shows a typical temperature profile of a 12-minute SpaceCloud operation. The AMD CPU and AMD GPU temperatures are the junction temperature measured inside the AMD compute system-on-chip. The Q7 temperature 1-3 represents the printed circuit board (PCB) temperature and the average represents the unit overall temperature.

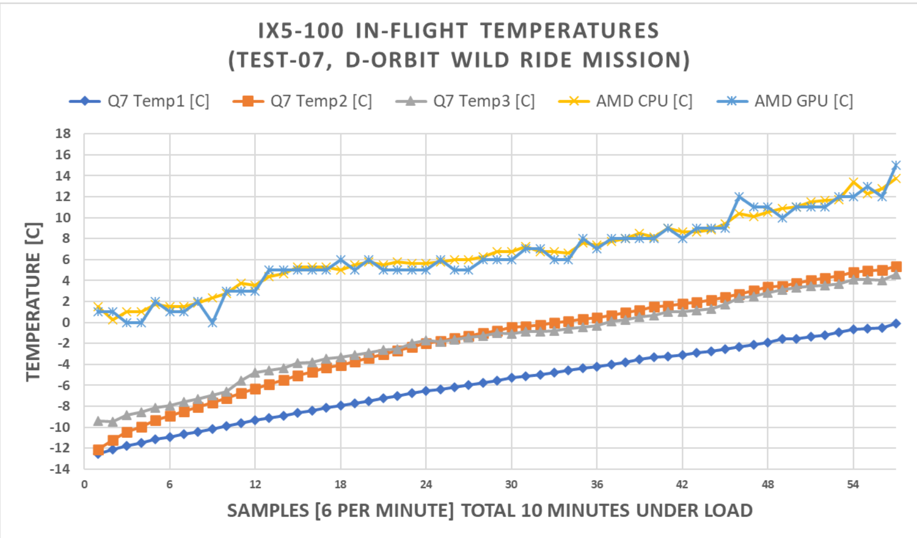

Figure 4-3. Health data from SpaceCloud iX5-100 on WILD RIDE mission.

D-Orbit's ION SCV-004 "Dashing Through the Stars" mission also carry a SpaceCloud iX5-100 solution to enable cloud computing. Figure 4-4 shows a temperature snapshot from the SCV-004 mission, taken during operations on February 8th, 2022 when the spacecraft passed over the north polar region. During the pass it seems that single event effects (SEE) was observed as the built in AMD system-on-chip temperature sensors gave two clearly erratic data points. However, the system operated through the events.

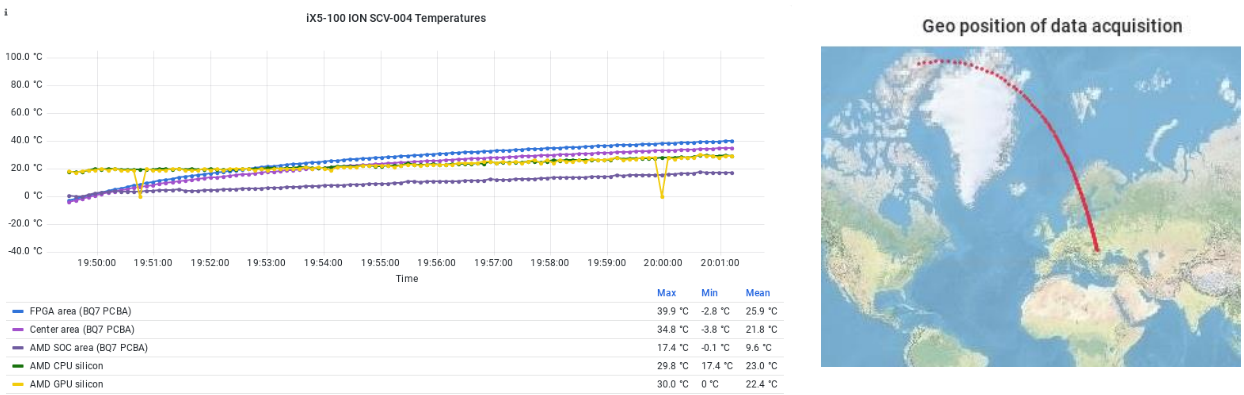

Figure 4-4. Health data from SpaceCloud iX5-100 on Dashing Through The Stars mission.

6 CONCLUSIONS

It has been shown that cloud computing is possible in orbit in much the same way as terrestrial clouds. Advanced low-latency, near real-time earth observation applications using heterogeneous computing have been demonstrated.

7 ACKNOWLEDGEMENTS

This work was sponsored in part by the European Space Agency InCubed, GSTP, and Artes BASS programs. Unibap® and SpaceCloud® are trademarks of Unibap AB (publ.)

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