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Big Data in space

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ABSTRACT

Over the last decade, the development and use of small satellite missions for new space-born applications has grown dramatically. Small satellite driven missions are poised to become the largest growth market in space, driven by the upcoming "Commercial Space Gold Rush" and a true enabler of Big Data.

A natural progression from technology and concept demonstration to operational missions has taken place in the Smallsat segment. This is not only true for the ever so popular CubeSats, but also for the micro-satellite segment. After having played an important role in changing space economics and demonstrating commercial mission capabilities, microsat platforms provide an interesting balance between capability, reliability and SWaP, allowing for an instrument/payload capability that can satisfy many different applications including constellation-based Earth Observation, Situational Awareness and Communications.

Given the advances in (commercial re-usable) technology and concepts such as In-Orbit reconfiguration and the current state of the art in reconfigurable hardware such as FPGAs, System on Chip (SoC) and Massive Parallel Processing (MPP), the concept of a Software Defined Payload (SDP) becomes increasingly interesting and feasible.

The Software Defined Payload approach does require changes to the traditional Mission, System Engineering and instrument development approach. It also imposes challenges on the technology used and when properly (and suitably) applied, can lead to standardization and re-use of building blocks in electronics and software.

Besides flexibility, a more pressing reason for using reconfiguration is the need for on-board processing. Modern payloads and sensors (e.g. Hyperspectral, SAR, Wideband Data, Software Defined Radio) generate data at data rates and volumes, that not only require on-board (Mass Memory) data storage, but more and more rely on on-board processing to reduce, format, filter/select, compress, encrypt and meta-tag data as well as process it to a higher (smaller) data product level, before it is sent to the ground.

HEAD Aerospace Netherlands' answer to this "Big Data in Space" handling is a standardized framework of hardware and software that represent the on-board functionality for payload / instrument / sensor data handling and processing, referred to as the Payload Interface & Data Processor (PIDP).

INTRODUCTION

Over the last decade, the development and use of small satellite missions for new space-born applications has grown dramatically. Small satellite driven missions are poised to become the largest growth market in space, driven by the upcoming "Commercial Space Gold Rush" and a true enabler of Big Data.

A natural progression from technology and concept demonstration to operational missions has taken place in the Smallsat segment. This is not only true for the ever so popular CubeSats, but also for the micro-satellite segment. After having played an important role in changing space economics and demonstrating commercial mission capabilities, microsat platforms provide an interesting balance between capability, reliability and SWaP, allowing for an instrument/payload capability that can satisfy many different applications including constellation-based telecommunication and Earth Observation.

When considering the implementation of not only typical applications such as Earth Observation but also situational awareness (e.g. shipping, air travel) and space-based support for the Internet-of-Things (IoT) a traditional approach would be to search for the optimum implementation of different instruments and payloads for this purpose.

Given the advances in (commercial re-usable) technology and concepts such as In-Orbit reconfiguration and the current state of the art in reconfigurable hardware such as FPGAs, System on Chip (SoC) and Massive Parallel Processing, the concept of a common instrument core or Software Defined Payload (SDP) becomes increasingly interesting and feasible.

Although placing an important and long-lasting role on the enabling technology used, the advantages of a common team and engineering (skill) focus, the build-up of long-term experience and most importantly future capability enhancement easily outweigh this.

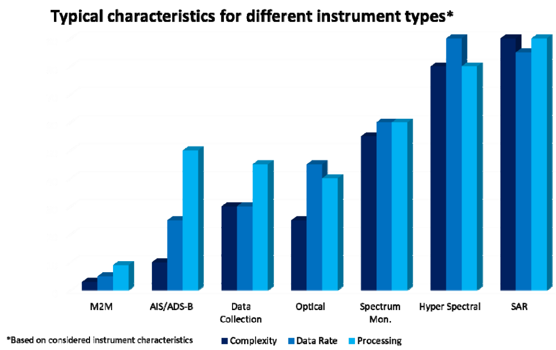
In fact, given the fact that a targeted space technology is also (readily) available in a commercial form or 'non-space' variant only helps in setting up rapid development, prototyping and test environments to assist in a proper yet flexible development and validation approach.

The use of open standards, proven software & firmware frameworks and existing (development, simulation and test) methodologies only add further to a shorter yet high-quality and sustainable development cycle.

The Software Defined Payload (SDP) approach does require changes to the traditional Mission, System Engineering and instrument development approach. It also imposes challenges on the technology used and when properly (and suitably) applied, can lead to standardization and re-use of building blocks in electronics and software.

SOFTWARE DEFINED PAYLOAD

As part of an ongoing constellation design and tradeoff, a Software Defined Payload approach has been applied for the implementation of a number of different instruments.



Whereas at first glance these may seem to have quite some differences, in fact they exhibit a high degree of commonality. This aspect is also highly welcome when it comes to the instrument development roadmaps. Certain applications will fit in a first-generation architecture whereas others will naturally evolve as capability and maturity increases.

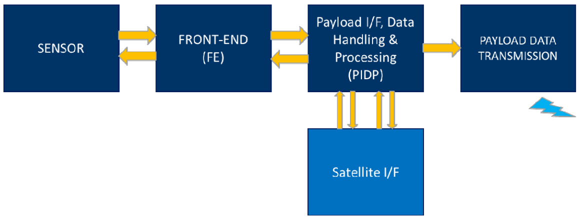
A mandatory requirement being that any existing implementation or application remains supported through 100% backward compatibility. This also guarantees that in the case of constellation maintenance no long-term dependency on a single technology is created and in fact capability and performance enhancement can be expected as a natural progression.

Within the instrument roadmap a number of highly potential applications are considered. Some based on ongoing work for new instrument design and others based on previous work that can be 'ported' or readily accommodated within the SDP-concept.

These applications being: - Low-rate Machine-to-Machine communication - AIS / ADS-B monitoring - High-volume sensor read-out from space - Hyper Spectral imaging (HSI) - Synthetic Aperture Radar (SAR) - Spectrum and RF-Signal Monitoring

Within the SDP concept an initial analysis of instrument, platform and data product requirements is made which is subsequently mapped to a standard architecture in which as much common aspects and building blocks are used.

Typically, this results in a high-level block diagram as depicted in the figure below.



In here, the building block that contains and implements a lot of the SDP functions is referred to as the so-called Payload Interface & Data Processor (PIDP)

Note that separate boxes do not necessarily imply different physical implementation. Due to high bandwidth demands and data intensive interaction, in fact an integration of functions and physical electronics (SoC or board-to-board interconnects) is desired.

The use of industry standards such as OpenVPX and its newly introduced SpaceVPX (VITA 78) derivate only allow for a further future-proof deployment of Software Defined Payloads.

The Core Instrument capability is referred as the fundamental heart of an instrument (or sensor) since it determines the actual use/capability as well as exhibits specific instrument characteristics such as optics, detector, antenna etc. It also has the most driving impact on the platform (like any other instrument) since it involves electro-mechanical interfaces, size/weight, placement, power, thermal control etc.

The Instrument Front-End effectively implements a coupling between the native instrument electronics and the digital domain in which the SDP Core operates. Sometimes this can be an almost native interface (e.g. SpaceWire, standard data-buses) whereas in other cases an as-optimum-as-possible conversion must take place. Both the physical layer interface as well as data formatting (or exchange standards and protocols) are considered.

Next to the instrument Front-end interfacing, the SDP core also interfaces with the satellite platform. Typically in the form of the On-board Computer or Data Management System. Although this could be considered as a more stable or 'under own control' interface, standardization and Open Protocols are preferred for the previously mentioned reasons of standardization, ease of portability, simulation & testing, future evolvement and even possible changes in platform selection and use.

The SDP Core implements most of the instrument and application specific processing functions. This may vary from the ability to handle low and very high-rate data streams to the implementation of signal processing functions in the form of a Software Defined Radio, data stream filtering/reduction, data compression or onboard data processing (as per table at the end of this paper).

When considering end-to-end design and implementation of payload data processing, the (re)use of standard processing blocks also aids in the potential (re)mapping of traditional pre-L0, L0, L1 and L2 data processing functions between space and ground.

As a fundamental principle, the insertion of metadata such as avionics/platform data, position and time-tagging as well as synchronization with common (clock) sources is applied. This to allow not only for easier ground-based processing, but also to allow (more sophisticated) data processing and decision taking on-board.

This is also important for the implementation of a data-driven processing chain, which when considering the Big Data aspect of Hyperspectral, Microwave (SAR), RF sensors and the overall data volume produced by a constellation clearly is mandatory to allow distributed, parallel and on-demand processing.

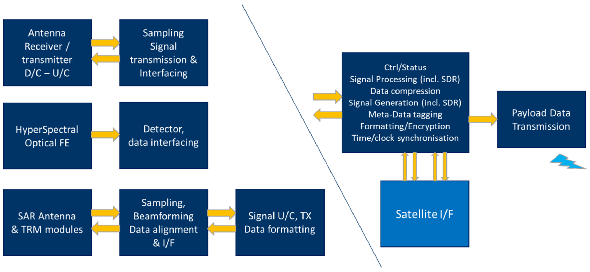
PIDP MAIN FEATURES AND INTERFACES

When considering typical LEO satellite interfaces and functions to be provided by the PIDP, the following can be defined:

- Concentrate I/F, Data Handling and Processing as a re-usable, standardized block
- Based on scalable hardware and software architecture
- Support different Interfaces (front-ends) to sensors
- Acquire and (pre) Process Payload Data
- Provide Integrated Data Storage
- Retrieval, formatting (if applicable) and output streaming to a Payload Data Transmitter / Transponder

- Instrument configuration, control and monitoring
- Interface to host satellite (e.g. On-Board Computer / TTC Transponder / Payload Data Transmitter)
- Meta-data collection and insertion
- Time / clock synchronization

An example of different instrument profiles supported by a common PIDP architecture is presented in the figure below.



It should be noted that the optimum PIDP implementation has to trade between performance, flexibility, power and reliability and is highly impact by the technology available or used.

TECHNOLOGY & IMPLEMENTATION

The main aspects related to the technology and implementation approach selected for a SDP are:

- Interface types
- Data type & volume
- Data rate
- On-board processing & storage
- Complexity
- Flexibility in design, test and deployment
- In-orbit reconfiguration
- Re-use / Standardization
- Reliability / Radiation Hardening / Lifetime
- Cost

On top of this, in order to promote and guarantee the world-wide use (and launching) of the system, a mandatory requirement for the technology used is to be ITAR (or dual-use constraints) free.

Suitable space technology satisfying all the above is not readily available today, specifically in the domain of parallel processing. There are however interesting developments ongoing in Europe on both reconfigurable FPGAs and Massive Parallel Processors that should become available as of 2018+.

One of the attractive, yet less 'radiation proof' options is to explore the use of commercially available components. Especially in the parallel processing domain, ground-based technology is many years ahead and multiple times more mature.

Specific interest is given to GPU accelerators and the next generation of components optimized for low-power, embedded data processing and machine learning. This is especially interesting when considering the development and operational software framework and applications. The use of the same family or processor architecture on-board will allow for a distributed processing chain, where software components and functions can be seamlessly relocated between space and ground, thus providing the optimum handling of the overall Big Data chain.

The use of commercial components in space comes with the usual constraints of the exposure to the space (radiation) environment, specifically for high-density / high-performance devices

This can be partly mitigated by standard techniques but not likely for long lifetime / reliability. That being said, the first generation PIDP is developed for Smallsat-based LEO missions with a design lifetime of 3-5 years.

The answer is in scalability, standardization and re-use whilst carefully testing and evaluating upcoming technologies (preferably in-flight).

The trend and need for multi-sensor, constellation-based systems will allow for a roadmap-based development and deployment with full re-use of experience and building blocks.

BUSINESS REASONS FOR ADAPTING THE SDP / PIDP CONCEPT

Not only is the adaptation of a Software Defined Payload concept of interest from a system and technical point of view, it also plays a large role in tackling essential elements of the business case, especially when considering development, operational, integrity, control and maintenance / lifetime arguments.

Main advantages of adapting the SDP concept are:

- Support for future enhancement and updating of a payload (incl. different applications)
- Flexibility and adaptability
- Allows for the implementation of an optimum space-to-ground-to-product chain
- Distributed & parallel development of payloads (collaboration)
- Common hardware/software environment
- Standardization
- Re-usable repository of frameworks, building blocks, functionality
- Long-term maintenance and deployment
- Strategic, common-core that guarantees data / service integrity even when considering the use of different partners & suppliers over the constellation / mission life-time

CONCLUSION

Through the combined application of open standards, COTS and Space technologies and a standardized approach to instrument design, validation and operation, it is possible to accommodate different instrument types and capabilities within a common (expandable) architecture.

When considering data type, speeds, volume and processing characteristics (typically one-way) a scalable and common Software Defined Payload concept can be implemented for a multi-sensor smallsat constellation covering sensors for land, maritime and airborne situational awareness, emergency recovery, Satellite IoT and spectrum/signal monitoring as well as high-value Earth Observation products provided through Hyperspectral and Synthetic Aperture Radar (SAR) imaging.

The gradual (or roadmap based) implementation of different instruments and the related technologies from within a common concept and architecture allows for a highly focused and value-building implementation with sufficient provisions for the introduction of emerging space technologies and open standards.

Maintaining a close link between ‘on-ground’ commercial technologies & frameworks and the early consideration of Big Data and cloud-based processing approaches is equally important to be able to provide the most optimum and integrated solutions to satisfy the ultimate goal of all this technology: Providing the (paying) end-user with an optimum, trusted and high-value Service, Data Product or Application.