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High Rate Data Broker for FSL Operations

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Abstract

In 2018 the European Space Agency overhauled the Columbus Fluid Science Laboratory (FSL) on board the International Space Station in order to operate the experiment containers Soft Matter Dynamics (SMD) and Reference mUltiscale Boiling Investigation (RUBI). The upgrade of the FSL Video Management Unit for the acquisition of the high-rate data images or science data produced during the scientific runs, introduced the need of an upgrade of the FSL ground segment to cope with the operation concept requirements. A near-real time integrated visualization and interpretation of FSL high-rate data and telemetry simultaneously are difficult since the FSL high-rate data stream and the FSL telemetry follow different paths. To address this problem, a tool has been designed and developed to ingest and archive the FSL high-rate data stream, to create Processed Parameters outlining the high-rate data stream content, to support the operational display of high-rate data snapshot, and to disseminate the data to the science teams. The Processed Parameters have been defined in such a way that they can be handled by the tools and displays originally developed for the medium- and low-rate telemetry. After a brief summary of the high-rate data stream produced by the FSL experiment containers SMD and RUBI, this paper presents the architecture of the new data broker tool which allows the coupling of high-rate data with medium-rate telemetry, the resulting ground segment modifications, and how the design is taking advantage of the different working modes of the FSL Video Management Unit. The paper also discusses the lessons learned and challenges encountered during the tool development and validation phases: the ground segment network performance, the wider range of data formats and the data distribution to the science teams.
Keywords: International Space Station; Fluid Science Laboratory; High Rate Data; Ground Segment

1. Introduction

The Fluid Science Laboratory is a payload rack of the European Space Agency (ESA) housed in the European Columbus module of the International Space Station (ISS). With the objective to host Experiment Containers (EC) studying dynamic fluid phenomena under microgravity, FSL is equipped [1] with an Optical Diagnostics Module (ODM), the Microgravity Vibration Isolation System (MVIS) provided by the Canadian Space Agency, and functional subsystems such as a Video Management Unit (VMU). As part of the ESA decentralized approach for ISS operations, the Microgravity Advanced and Research Center (MARS) in Napoli was initially the Facility Responsible Center (FRC) for FSL [2,3] during which the experiments GEOFLOW-II and FASES were hosted and experiment runs successfully executed. However in March 2014 the FSL operations went on hold [4] due to issues affecting the VMU and the FSL high rate data link (HRDL). While a troubleshooting plan was implemented, the Belgian User Support and Operations Centre (B.USOC) became the FRC for FSL. Given the severity of the issues, a substantial overhaul of FSL was decided including the replacement of the VMU and the decommissioning of ODM. The overhaul would allow the operations of two new ECs, Soft Matter Dynamics (SMD) and Reference mUltiscale Boiling Investigation (RUBI), and the download of the remaining MVIS data via a data transfer through the MIL-STD-1553 bus between the Remote Terminals (RT) of MVIS and the new VMU (VMU MkII).

The upgrades foreseen for VMU MkII and the operation concept requirements of SMD and RUBI introduce the need of an upgrade of the FSL ground segment in order to secure the acquisition of the high-rate data images or science data produced during the scientific runs and to allow their visualisation in near-real time and simultaneously with the medium-rate telemetry. This paper presents the resulting ground segment modifications and in particular the architecture of the new data broker tool allowing the coupling of high-rate data with medium-rate telemetry. Since both the VMU MkII and the SMD EC have been successfully installed by the astronaut Alexander Gerst in July 2018 [5], a first evaluation of the ground segment network performance and the first lessons learned are also presented.

This paper is divided as follow: Section 2 presents the data path from space to ground for both the FSL high rate and medium rate data streams; Section 3 explains the new enhanced expectations of the users of the FSL ground segment; Section 4 details how the High Rate Data Broker has been designed in order to address those expectations; and, Section 5 highlights some challenges and lessons learnt.

2. FSL Data path overview

2.1 High rate data

In FSL since the ODM decommissioning, high rate data are originated from the Microgravity Measurement Assembly (MMA), the optical diagnostics and science data acquisition directly embedded in the EC, and post processing generated inside VMU MkII. For SMD, the optical diagnostics include an overview monochrome camera, two CorrTectors performing Diffused Wave Spectroscopy in transmission and in backscattering respectively, and a line camera allowing Speckle Variance Spectroscopy. For RUBI, the diagnostics include an high speed camera, an IR camera and a rack of four micro-thermocouples.

Using those data sources, the VMU MkII can operate in three different modes (mutually exclusive):

- the recording mode where data streams are optionally compressed and stored into the VMU internal hard-disks;
- the processing mode where already recorded data are post processed and stored as a new virtual data source;
- the playback mode where recorded or processed data are optionally compressed and downlinked through the HRDL.

The processing mode is envisaged to compute on-board the time-resolved correlation curves from the SMD Line Camera in order to reduce the size of data to be downloaded. When the VMU MkII operates either in recording or processing mode, some data sources can be configured for real-time downlink through the HRDL. Due to the bandwidth limitation, this real-time downlink may suffer of data loss and may only be used for sample monitoring of the experiment run. During playback mode or real-time downlink, the data stream are transmitted to the Columbus Video/Data Processing Unit through the Transparent Asynchronous Transmitter/Receiver Interface (TAXI) protocol. The VMU MkII supports up to six data channels. However in order to ensure some degree of backward compatibility with the header format of the former VMU, the six data channels are mapped into the three channels before transmission.

The playback or real-time FSL high rate data stream is wrapped into Channel Access Data Units (CADU) [6] and transmitted to the Data Services Subsystem (DaSS) of the Columbus Control Centre (Col-CC) through the ISS/NASA infrastructure. The DaSS transfers the CADUs to the B.USOC segment of the ESA Payload Data Centre (PDC) where they are archived by the High Rate Data Processor (HRDP). On request the CADUs are reassembled into VMU high rate data packets by the PDC High Rate Data Front End (HRD-FE) and delivered to a plug-in of the Stream Extractor either in near real-time or in replay mode. While the CADU archive at PDC is consolidated by the HRDP after loss of signal (LOS) events, the completeness of the CADU archive is not guaranteed, even in replay mode.

During the past FSL experiments, the Stream Extractor plugin converted the high rate data into files that were saved and transferred off-line to the scientists. For SMD and RUBI experiments a new Stream Extractor plugin has been configured to forward directly VMU high rate data packets to the B.USOC facility through the Columbus Interconnection Ground Subnetwork (IGS), a Wide Area Network (WAN) connecting the different sites associated with the ISS Columbus ground segment.

2.2 Medium rate data

The FSL medium-rate science data, health and status telemetry and housekeeping data, coming from the EC and from the facility subsystems/units are collected by the FSL Rack Interface Controller (RIC) through the MIL-STD-1553 bus and transformed in CCSDS packets for the transmission via the Columbus payload bus. After reception from the ISS/NASA infrastructure, the Col-CC DaSS transfers the CCSDS packets to the dedicate Columbus Decentralized Mission Control System (CD-MCS) located in the B.USOC segment of the PDC. In the B.USOC ground segment setup, the CCSDS packets are redirected in a cascading chain of three YaMCS servers [7]: the first one located at PDC; the second one located at the B.USOC facility and connected through the IGS; and the third one also at the B.USOC facility but in a separated Local Area Network (LAN). The FSL monitoring displays are implemented through YaMCS studio [8]. The displays of the FSL operators are connected to the second YaMCS server while the scientists are connecting their displays to the third YaMCS server through their Users' Home Base (UHB) via a Virtual Private Network (VPN) across Internet.

3. Operation concept constraints

The two FSL experiments, SMD and RUBI, by taking advantage of the VMU MkII features are introducing arduous constraints on the operation concept. Compared to the former version, the VMU MkII has an higher storage capacity (2 TB instead of 300 GB), more channels (6 instead of 3+1) and a better throughput (180 Mbit/s against 30 Mbit/s). The VMU MkII also includes the software functions for the post processing of the recorded data and for the triggering and synchronisation of the EC cameras. Those improvements allow new developed ECs working at a finer resolution and/or at a higher frequency and/or during longer runs. For instance the SMD Line Camera and the RUBI Infrared Camera have a throughput that can reach up to 80 Mbit/s and 295 Mbit/s, respectively. On the other side, the Columbus HRDL remains with an effective throughput of about 16Mbit/s. Consequently in some cases the downlink duration may largely exceed the duration of the science runs. To accommodate the operations with this unbalanced situation, the FSL operators and/or the science teams require the provision of a tool helping them

- to get a preview of the measurements in near-real time (e.g. to save operations time by quickly aborting a failed run);
- to correlate the different measurements over the duration of a science run;
- to visualize the downlink status of each science run; and,
- to identify the different remaining data gaps.

Such requirements are already fulfilled for the medium rate telemetry by the YaMCS suite [7,8] but didn't apply to the high rate data. The High Rate Data Broker aims to extend the FSL ground segment in order to address this shortage and to improve the FSL monitoring capacities.

4. High Rate Data Broker Design

This section summarizes the different steps allowing the processing of the VMU high rate data packets, their archive, the data distribution service for their retrieval, and the generation of processed parameters supporting the operational display of high rate data snapshots and statistics.

4.1 VMU high rate data packet ingestion

The VMU high rate data packets are transferred to the High Rate Data Broker by the stream extractor plugin (or any other client) through a unidirectional TCP connection without any session handshaking and where each VMU packet is just preceded by a short header and followed by a checksum. The header is limited to a synchronization word, a version for future extensions, the version of the VMU (1 or 2) from which the packets are issued, the mode of the DaSS instance, a sequence counter to be incremented by the client and the length of the VMU packet. Unsupported value for either the protocol version, the VMU version or the DaSS mode causes the immediate closure of the connection. Other malformed, uncompleted or unrecognized packets are discarded silently.

The High Rate Data Broker can be configured to listen to multiple connections.

4.2 Data storage

The High Rate Data Broker converts each valid VMU packet into a binary file made of two sections: a header and a body. The body section contains the data carried by the VMU packet. The header section differs whether the VMU packet contains science data or an image. For the science data, the header includes a Four Character Code (FCC) identifying the type of data, the sequence counter generated by the VMU and the timestamp contained in the science packet header. For the images, the header also includes the number of pixels along the *X* and the *Y* axes. The data types supported by the High Rate Data Broker are listed in Table 1.

The binary files are stored in a directory tree structure under a configurable base directory. The directory tree structure is built from the mode of the DaSS instance (ops, sim1, sim2 or test), the type of VMU packet (science or image), the VMU mode (real-time or playback), the identifier of VMU data source, and the VMU timestamp up to the minute. The filename of the binary files is built from the VMU data source identifier, the VMU field "User Provided Information", the channel number, the VMU sequence counter and the timestamp included in the image or science data header.

For each image file archived in its data storage, the High Rate Data Broker generates a metadata file in XML including properties extracted from the VMU headers.

Table 1. Data format supported by the FSL High Rate Data Broker

Data type	FCC value (hex)	VMU version	VMU Packet type
MMA	4d4d4120	1+2	science
SVS	53565320	2	science
SYNC	53594e43	2	science
CORR	434f5252	2	science
RGB	52474220	1+2	image
I420	49343230	2	image
YUY2	59555932	1+2	image
GRAY8	59383030	1+2	image
GRAY16	59313620	2	image
JPG	4a504547	1+2	image
PNG	504e4720	1+2	image
H264	48323634	2	image

TIFF	54494646	1	Image
RAW	52415720	1+2	image / science

4.3 Data distribution services

The High Rate Data Broker implements four HTTP services:

- the "monitor" service providing a monitoring of the broker latest activities;
- the "browse" service allowing to navigate through the broker data storage described in subsection *4.2*;
- the "product" service returning the high rate data converted according to the HTTP Accept header of the request;
- the "archive" service fetching a set of binary and/or metadata files into a single TAR or ZIP archive.

The "product" service is supporting the conversion of the science data into either an octet stream (no conversion) or a comma-separated values text, and the conversion of the images into either JPEG, PNG or GIF, except for the images initially provided in TIFF, GRAY16 and H264 for which no conversion is available.

4.4 Processed parameter generator

For each VMU data source identifier, the High Rate Data Broker may be configured to generate at regular interval a set of processed parameters (PP) available either via UDP stream or via logging. The processed parameters include the last value of the VMU sequence counter, the DaSS instance, the VMU channel, the VMU mode (real-time or playback), the number of packets received during the interval, the elapsed duration covered by the received packets, the timestamp of the last received packet, the associated filename in the data storage, and the content of the "User Provided Information" field.

The PPs generated by the High Rate Data Broker can be use by an external application to monitor the reception of the FSL high rate data and to display snapshots of an image channel by calling the "product" service described in subsection *4.3*. In particular the PPs have been defined in a dedicated auxiliary mission database and injected in the second YaMCS server of the B.USOC chain. The YaMCS server synchronises automatically the PPs with the regular FSL medium rate telemetry. This integration allows the operators and the scientists to monitor the broker PPs in the displays of YAMCS studio such as any medium rate telemetry. A widget has also been developed that implements the preview of the high rate image stream by calling the "product" service of the High Rate Data Broker.

5. Challenges and lessons learnt

The time constraint was the main challenge in the implementation of the FSL High Rate Data Broker. The concept of the FSL ground segment adaption was accepted in October 2017 and the verification and validation of its implementation was already successfully tested in March 2018 in order to be in due course for the Experiment Sequence Test of SMD scheduled in April 2018. The time constraint could have been relaxed if the impact on the operation was considered at an earlier stage of the payload development.

The software development was further compounded by inaccuracies in some documentation such as the Application Programming Interface (API) of the Stream Extractor, the format specification of the VMU MkII packet, or the YaMCS API.

Another challenge was the troubleshooting of some image corruptions that could be due either to a software bug in the High Rate Data Broker, or to a CADU loss upstream, for instance in the HRD-FE due to a processing speed limitation or on the IGS network where the CADUs are carried over UDP.

Despite the successful validation of the High Rate Data Broker, few problems remain like the loss of VMU packets transmitted at the begin of a LOS that can only be recovered by a VMU playback. Some small timestamp inaccuracies are also still investigated.

6. Conclusions

The development of the High Rate Data Broker [9] and its deployment in the FSL Ground Segment have grandly improved the monitoring and handling of the FSL high rate data. By embedding an outline of the FSL high rate data in the medium rate telemetry, the tool allows the direct monitoring and the visualization of all FSL data streams in a synchronous and uniform way.

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