VMS STUDY EXECUTIVE SUMMARY

(WP 620)

(ESTEC Contract No 15296/01/NL/JA)

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ABBREVIATIONS

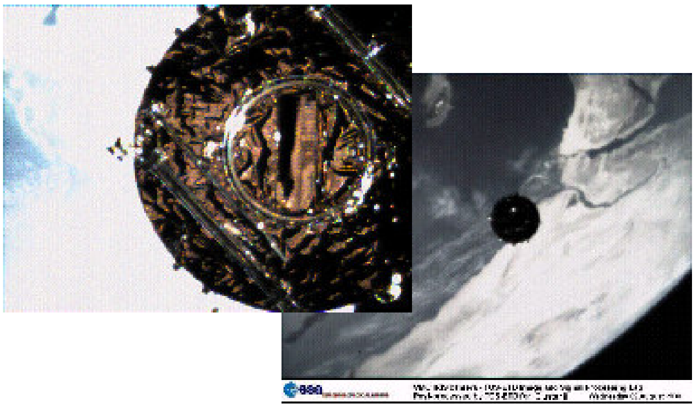
APS	Active Pixel Sensor
CAN	Controller Area Network
CODEC	COder DECecoder
COTS	Commercial Off The Shelf
DPU	Data Processing Unit
DSP	Digital Signal Processor
FIFO	First-In First-Out
FOV	Field Of View
ISS	International Space Station
MCM	Multi-Chip Module
OBDH	On-Board Data Handling
PCB	Printed Circuit Board
PFM	Proto-Flight Model
ROM	Rough Order of magnitude
SSMM	Solid State Mass Memory
SSR	Solid State Recorder
VMS	Visual Monitoring System
WP	Work Package

1. VMS STUDY OVERVIEW

The main objectives of the VMS Study were to establish the specifications for digital imaging systems for space applications, and then to design modular systems to meet a number of applications.

The specifications cover functional, performance and interface requirements in a wide range of fields. The fields include: Public Relations, Protocol associated with launch, deployment and long term behaviour, Robotics, Rendezvous, Imaging of the Earth and planets, and to support Scientific Instruments. The work embraces the requirements for operation in conjunction with other sensor types.

The study builds upon key previous experience and earlier developments such as the Visual Telemetry System (VTS) and the Visual Monitoring Camera (VMC) system for ESA.



The solutions proposed take advantage of available COTS items where suitable elements have been identified. End-to-end architectures have been produced providing a modular design such that the system can be adapted for all of the defined applications. Each of the main elements, both hardware and software, is defined.

The Study has provided information on possible in-flight demonstration scenarios. It has also provided plans and ROM cost assessments for the development of the VMS system concepts derived.

The results, findings and conclusions from the activities performed have led to the conclusions on feasibility and the recommended way forward presented later in the report.

1.1 STUDY TASKS FLOW

The tasks performed were divided into the main work packages identified in Figure 1. In general the work was performed in the work package sequence shown.

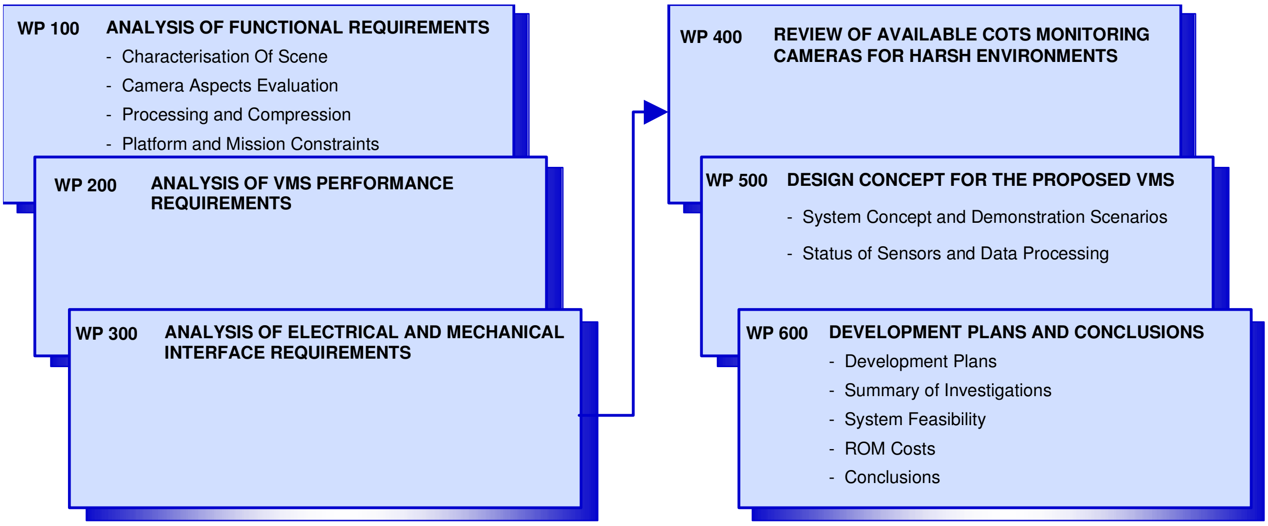


Figure 1 VMS Study Flow

The main findings and outcomes from the work packages identified are provided in the following sections.

The VMS teaming arrangements to undertake the tasks were as follows:

Astrium Ltd	Overall Study management, application and scene definitions, processing data handling, platform constraints, electrical interfaces, system design and demonstration, development planning, and overall conclusions.
OIP Sensor Systems	Camera aspects, optics and other sensors, mechanical and opto-mechanical interfaces, review of COTS, support to system design and demonstration, and development planning.
University of Dundee	Support to Astrium on processing, compression and data handling, electrical interfaces and SpaceWire, system design and demonstration, and development planning.
FillFactory	Support to OIP Sensor Systems on CMOS camera technology.

2. VMS FUNCTIONAL REQUIREMENTS

The process of deriving the functional requirements of the electronic imaging systems for a range of applications was performed by undertaking the following tasks:

- **Characterisation Of Scene** – evaluation, for a set of potential VMS applications, of the parameters which characterise the scene to be imaged and evaluation of any additional user requirements.
- **Camera Aspects Evaluation** – initial assessment of the camera specific requirements emerging from the scenes of the applications.
- **Processing and Compression** – review of data processing and compression requirements coming from the applications
- **Platform and Mission Constraints** – assessment of specific application examples to derive a representative set of environmental requirements and other constraints.

2.1 CHARACTERISATION OF SCENE

Table 1 identifies potential VMS application fields which will utilise a digital imaging system and in each case their requirements have been assessed. Where possible, applications have been assessed by examining specific mission examples otherwise they have been assessed as a generic application type.

A set of characteristics has been produced for each of the scenes presented by the applications, i.e. the camera target. These characteristics have formed key functional requirements used to establish the specifications for the digital imaging system.

The characteristics specifying the camera target cover:

- the information that is to be extracted from the scene,
- specification of the object space and the observation distance,
- required imaging resolutions: spatial-, spectral- and time-resolution,
- requirements for handling variation in the object space, e.g. region of interest (ROI) selection and zooming requirements.

Several application types require VMS to be a system which supports multiple cameras. Prime examples are a robotic arm, experiment monitoring, stereo imaging (e.g. for rover control) and large deployments such as the sunshield/solar array on the GAIA spacecraft.

The use of VMS on-board formation flying spacecraft is seen as being particularly interesting. This is not only for publicity and confirmation of relative position but may also be specifically useful for initial acquisition of the formation.

The range of applications requires the use of black and white imaging and colour imaging.

Application Field	Application Examples	Mission Examples
Public relations	Spacecraft separation	Beagle 2 separation from Mars Express
	Launch phases	
	In-orbit pictures	
Protocol with the purpose of real time monitoring and later analysis	Launch phases	
	Deployment of appendages	GAIA sunshield/solar array deployment.
	Long term behaviour of satellites and payloads	
	Formation flying	SMART2
Robotic applications and their control	Robotic manipulator being used in the servicing of another satellite	European Robotic Arm
	Rover control	Imaging System of Mercury Surface Element (MSE) of BepiColombo
Navigation and Rendezvous	Service vehicle for ISS	Automated Transfer Vehicle (ATV)
	Service vehicle for other spacecraft	
	Landing/planetary approach	Descent Camera of Mercury Surface Element (MSE) of BepiColombo
Qualitative visual imaging and quantitative visual imaging	Earth	
	Surface operations (planets & moons)	Imaging System of Mercury Surface Element (MSE) of BepiColombo
	Orbital operations (planets & moons)	
Real-time recording of the data from scientific instruments	Photogrammetry	Experiments on ISS
	Star Tracker	

Table 1 VMS Applications Analysed

2.2 CAMERA ASPECTS EVALUATION

For the range of applications identified, initial tabular listings of the derived user requirements for the cameras were established. Much of the information derived was subsequently elaborated upon in the process of establishing the VMS performance requirements.

In addition to the cameras, the possible need for other types of sensors (temperature, pointing direction, etc.) and other facilities such as illumination or calibration target have been addressed.

2.3 PROCESSING AND COMPRESSION

The different types of application have been analysed to determine the processing and data compression requirements. Key image processing parameters and requirements have been identified.

The analysis of applications identified three levels of compression as requirements for VMS:

- low-level compression (less than 4:1) – no compression, loss-less compression or lossy compression with a low compression ratio - information content of the imagery unaffected;
- moderate-level compression (around 10:1) – single image compression using a lossy algorithm where some compression noise is acceptable;
- high-level compression (100:1) – image sequence compression where advantage is taken of correlation between successive images in a sequence.

A key issue for the VMS architecture is the question – does the image data need to be compressed in real-time prior to storage in on-board memory in order to reduce the size of the memory required? The answer to this question can vary between VMS application hence a parametric approach was provided from which it is possible to determine under what conditions it is more efficient to compress data at the full-frame rate before storage rather than simply store the un-compressed data.

2.4 PLATFORM AND MISSION CONSTRAINTS

An analysis has been made of the interface parameters and constraints coming from the platforms – parameters covered were environmental constraints, platform resources available, position constraints and data downlinking constraints.

The following missions were used as sources of information:- Mars Express; SMART 2; Bepi-Colombo MSE (Mercury Surface Element); LEOSTAR type satellites; ISS. This set provided a good representation of the platforms for different mission types:- Earth orbiting (manned and unmanned); inter-planetary missions; lander missions.

For a number of applications, the data handling and downlinking constraints made it clear that VMS must include the possibility of having built-in memory for storing a sequence of images.

3. VMS PERFORMANCE REQUIREMENTS

The functional requirements have been built upon to derive end-to-end VMS system performance requirements for the range of applications and missions targeted. This assessment of the performance requirements has been sub-divided into:

- Performance of Optics and Sensors;
- Performance of Processing (incorporating Data Compression) and Data Handling.

These specifications, along with the associated interface requirements specifications, were used to derive the VMS design concepts.

3.1 OPTICS AND SENSORS

For the different VMS applications, the performance requirements relating to the optical and image parameters of the required VMS camera have been assessed.

It was determined that the range of applications needed 3 sizes of image sensors: 512 x 512 pixels, 1024 x 1024 pixels and 2048 x 2048 pixels. The 2048 x 2048 pixels sensor is required for a specific type of application namely a Qualitative Imaging camera, whereas the other applications can accept the 2 smaller sensors.

Synthesising the requirements of the applications utilising the 2 smaller sensors resulted in two sets of specifications of cameras that are valid for most of the applications and these specifications are given in Table 2.

To cover the range of the Resolution / FOV and Focal length requirements specified in Table 2 for the applications, a set of 7 different objectives are needed and the characteristics of each have been defined. In order to be able to define the optical parameters of the objectives, assumptions had to be made regarding the characteristics of the sensors, e.g. pixel size, etc. The optical parameters of the objectives assume the use of the Fillfactory STAR 250 and the STAR 1000 sensors.

	Performance Requirement Parameters								
	Resol./ FOV	**Focal length**	**Object distance**	**F number**	**Focusing**	**Spectral range**	**Illumin -ation**	**Detector**	**ADC**
Generic 1	0.35-4 mrad 15°-111°	6-70 mm	50 mm/ infinity	2 - 12	Fixed focus/ re-focusing	UV-VIS-NIR	Yes	512 x 512 pixels	10 bits
Generic 2	7-70 µm 0.55°-5.5°	225 – 2250 mm	Infinity	10 - 20	Fixed	UV-VIS-NIR	No	1024 x 1024 pixels	10 bits

Table 2 Optics and Sensors – Requirement Parameters

3.2 PROCESSING AND DATA HANDLING

The performance requirements under the heading "processing and data handling" concern the issues involved in receiving the image data (pixels) from the sensor and delivering it to the end user. Specific parameters considered are image data generation rates, imaging sequence length and resulting data volumes.

3.2.1 Image Data Handling Rates and Volume

The evaluation of these parameters is shown in Table 3 for the different applications. The following observations are made:

Frame Store Size — A frame store size of 42 Mbits would accommodate all the applications investigated.

Raw Image Data Rate — A scalable raw image data handling capability up to 105 Mbps covers all the applications investigated apart from the most demanding applications identified in the European experiments on-board ISS.

Sequence Store Size[1] — Modular design to provide different memory capacities starting at 320 Mbit and going up to at least 10 Gbits.

It can be seen that there is a large variation between what is required for most of the identified potential applications for VMS and that required to support the most demanding experiments on ISS (Columbus). It was agreed that taking the ISS requirements as a VMS design driver was likely to push the design too far in a particular direction therefore the study has concentrated on the more modest requirements of the other applications.

[1] The sizes assume storage of raw image data before compression.

Application	Sensor size (Mpixels)	ADC bits	Frame Store size (Mbits)	Frame rate (Hz)	Data rate Mbps	Imaging sequence length (frames)	Sequence store (Mbits)
Public Relations - S/C separation	0.26	10	2.62	<1	<2.62	120	315
Public Relations - In-orbit pictures	0.26	10	2.62	1	2.62	120	315
Real Time Mon - Launch phases	0.26	10	2.62	1	2.62	120	315
Real Time Mon - Deployment of appendages	0.26	10	2.62	1	2.62	120	315
Real Time Mon - Long term behaviour	0.26	10	2.62	O.R.			
Formation: 1) Acquisition. 2) Monitoring of separation	0.26	10	2.62	O.R.			
Robotic - Manipulator	0.26	10	2.62	1	2.62		
Robotic - Rover Control	0.26	10	2.62	1	2.62		
Service vehicle for ISS	0.26	10	2.62	<1	<2.62		
Navigation - Planetary approach	1.05	10	10.5	10	105		
Navigation - Vision guided lander	1.05	10	10.5	10	105		
Navigation - Landing Site survey	0.26	10	2.62	1	2.62	3600	9437
Qualitative/Quantitative - orbiting imaging camera	4.19	10	41.9	1	41.9		
Star Tracker	0.26	10	2.62	10	26.2		
Photogrammetry	0.26	10	2.62	25	65.5	3000 (2)	7860
High rate ISS experiment	1.05	8	8.39	500	4194	60000 (2)	503316

Table 3 Data Handling Parameters

Notes:

O.R. = Individual images provided on request.

(1) Store sizes are without any compression/processing.

(2) Based on 2 minutes of operation.

3.2.2 Image Data Handling

The set of potential applications present VMS with 5 basic types of image data management and these are indicated in Table 4. The VMS performance requirements have to fit within the contexts of the architectures, and associated constraints, imposed by these data management scenarios.

Data Handling	Operations
1) Real time downlink	Image data is transmitted in real time from the camera via the OBDH for downlinking: • either, a) direct to Earth Ground Station; • or, b) to Earth Ground Station via a data relaying satellite.
2) Off-line downlink of image data	Image data sequences are stored in real time: • either, a) in a specific image data sequence store (part of the VMS); • or, b) in a SSR/SSMM shared with other payloads or subsystems. Image data is later transmitted to ground.
3) Real time local control.	Image data is delivered in real time to an on-board controller which uses the image information as part of a control function, e.g. vision guided Lander.

Table 4 VMS Image Data Handling

Each application was assessed regarding which type of data management was required and the following observations were made:

- Examples of all of the types of data handling scenario have been identified in the applications.
- The ability to do any real-time downlinking is extremely limited by the data rates of the available telemetry links – only a very low frame rate is achievable and data compression is vital.
- Most applications require the use of a SSR to record a sequence of images – the only exceptions are those which undertake real-time processing e.g. Star Trackers.
- In some instances VMS can use, potentially, a SSR shared with other payloads and sub-systems. This may be mandated where resources are very tight such as a lander.
- Traditional OBDH busses (MIL-STD-1553B, ESA OBDH bus) and similar busses (e.g. CAN bus) are very constraining on the frame rate – drives the need for using point to point links to transfer image data to the memory resources.

3.2.3 Image Data Compression and Image Processing

Compression

Setting aside the High rate ISS experiment, from the analysis of the data handling parameters it is clear that the applications can accept offline data compression. This is because:

1. The number of images that need to be stored is relatively low – results in a fairly modest storage requirement.
2. The data rate into the image store is not high by modern standards (105 Mbps) and can be provided by a range of interface types.

The data handling and downlink constraints mean that many of the applications require moderate to high levels of compression, with moderate to high levels of resulting image quality. This means that advanced and complex image compression algorithms need to be employed to give good quality with high levels of compression. Wavelet based compression and motion compensation for image sequences need to be considered.

A programmable processor, either a DSP processor, like the Atmel 21020, or a general purpose processor, like the LEON SPARC or ERC32, would be adequate to perform the compression offline and flexible enough to handle either single image (JPEG type) compression or image sequence (MPEG type) compression.

In order to evaluate the level of processing power needed, measurements were made on an existing example of JPEG compression, implemented in software on the Atmel 21020 DSP, to see how much of the processing resource being used. The result obtained was as follows:

- JPEG compression of a microCamera image (640 * 480 pixels) to 50% quality factor would require a processing power of 92 Mips per Hz of image (frame) rate.

In summary, the Image Data Compression requirements call for a modular design which allows incorporation of image data compression in different forms:

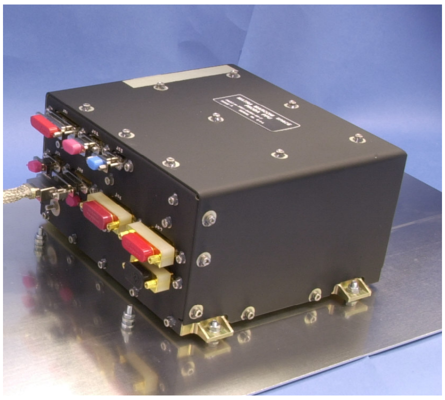
- Off-line processing.
- Single image (JPEG type) or image sequence (MPEG type).
- Variable compression ratio.

Image Processing And Pre-Processing

The VMS has to provide an image processing facility for applications requiring feature detection, object rate detection, star sensing, etc.).

To examine what level of processing performance can be required from the processing function within the VMS, an example of a common processing task was investigated namely determination of the attitude quaternions from star field image data. The processor loading was determined by making measurements on the same working imaging system as used for the JPEG compression. The result obtained was as follows:

- determination of the attitude quaternions, from pixel blocks of a star field image frame, would require a processing power of 2 Mips per frame.



Existing Astrium Processing Unit

3.2.4 Additional Requirements

In addition to the performance issues already discussed the VMS performance has to encompass additional requirements in order to provide a complete end-to-end system. These requirements are listed in Table 5.

In some instances, the requirements can be satisfied by functions which could be located in the camera itself or by a separate DPU which receives the image data. In other cases, the requirements specifically imply the use of a DPU.

Requirement Topic	Requirements
Data Formatting	Provide CCSDS source packet formation. Allow frame grabbing (for downlinking) of non-recorded image data. Provide datation of the acquired images.
Control and monitoring	Provide command and telemetry interface to Control Unit. Modular design for additional interfaces: • For control of illumination facility. • For synchronisation of cameras and other sensors.
Multiple camera architecture	Modular design to accommodate multiple cameras. Provide data routing and multiplexing for concurrent camera operation.
Management of other sensors	Modular design to accommodate additional sensors conditioning and acquisition Provide data routing and multiplexing for incorporating data from other sensors with the image data. Provide a modular design which allows incorporation of compression of data from other sensors – lossless compression (e.g. use of the PRDC product).

Table 5 Additional VMS Requirements

4. VMS ELECTRICAL AND MECHANICAL INTERFACE REQUIREMENTS

A detailed investigation of all opto-mechanical and electrical interfaces of the imaging system has been performed.

4.1 OPTO-MECHANICAL AND MECHANICAL INTERFACES

The type of objective lens mount, camera body and camera mounting bracket suitable for a VMS camera has been addressed. Ease of lens interchangeability and mechanical robustness for the space environment have been considered.

A "CS mount" is considered most appropriate for the objective lens. This mount is an industry standard lens mount based on a 1" x 32 threads/inch ring.

The mechanical and thermal interfaces and environment for the identified applications have been analysed and their impact on the camera body design have been assessed. A modular camera body concept has been proposed which allows many configurations to be achieved using standard mechanical parts and so can be quickly and easily adapted for many applications.

The basic camera housing incorporates several mounting pads to allow the camera to be oriented in a limited number of directions. If a different orientation is required, a universal mounting bracket has been proposed that allows many different angles of mount. In some cases, this bracket would need to be customised for the particular application.

4.2 ELECTRICAL INTERFACES

Several electrical interface types of have been assessed for their suitability for use in a VMS system. Interface standards from commercial, industrial, military and space fields have been considered, including SpaceWire, MIL-STD 1553, CAN Bus, Camera Link, Panel Link and IEEE 1394. Aspects such as data rate, number of wires, fault tolerance, implementation complexity and maturity of standard have been considered.

SpaceWire has been recommended as the optimum choice for the majority of applications. The interface can carry image data, telecommands and telemetry and is suitable for the link from camera to spacecraft, camera to DPU and DPU to spacecraft.

The CAN Bus has been identified as a suitable alternative to SpaceWire for applications which output processed data instead of a raw image (and hence has a much a lower data rate).

Camera Link is suggested as an appropriate interface between camera and DPU for very high data rate applications (eg. ISS experiments).

The power interface of VMS equipment is recommended to accommodate a 22V to 37V unregulated bus.

5. REVIEW OF AVAILABLE COTS MONITORING CAMERAS FOR HARSH ENVIRONMENTS

In work package WP400 a search was made for COTS Monitoring Cameras and in particular for cameras for use in harsh environments.

A list has been made of industrial cameras that fulfil certain rough selection criteria on mass, volume, thermal environment, radiation tolerance and interfaces. Information about 15 cameras is presented.

The conclusions from the investigations were that:

- Most of the COTS cameras are based on CCD sensors, which are sensitive to blooming effects and have a low radiation tolerance.
- It is almost impossible to obtain information on the components that are used in these cameras.
- No camera can be found that fulfils all the goal specifications of the potential VMS modular camera concept.

The work package also investigated some COTS components that could be integrated in a VMS camera. These COTS components concern:

- Optical and mechanical components as lenses, filters, objectives, camera housing.
- Some important electronic components.

A list of suitable industrial objectives and their supplier was made. Because no design details of these objectives can be obtained, environmental tests will have to be performed to prove their space qualification for a given application. For the long focal length objectives no supplier could be found. As a consequence they have to be custom made.

For most applications COTS lenses can be found. Note that most COTS filters have a poor radiation tolerance.

It is expected that the camera housing will have to be custom made.

As for COTS objectives, it is very difficult and nearly impossible to obtain full information about the properties of the electrical components (e.g. radiation tolerance, etc.)

In general industrial and military electronic components, which are specified for use in extended temperature ranges, can be used for a space instrument. Most probably, more shielding against radiation will have to be foreseen for these COTS components.

6. SYSTEM CONCEPT AND DEMONSTRATION SCENARIOS

6.1 STATUS OF CAMERA ITEMS

All the required types of objective lenses and filters can be manufactured using space quality materials. Some lenses and filters are available as COTS but in this case the materials are largely unknown and not radiation hard. The camera mechanical design can be based on existing products (e.g. OIP VMC camera) and this will be adequate for most application environments. The Bepi-Colombo environment is very harsh and requires further development of the housing design.

An adaptation of the VMC design has been proposed as a baseline modular camera concept suitable for future VMS. The camera can accommodate different numbers and types of board with virtually no change to the housing. It can also accommodate different optics with no change. This is shown in Figure 2.

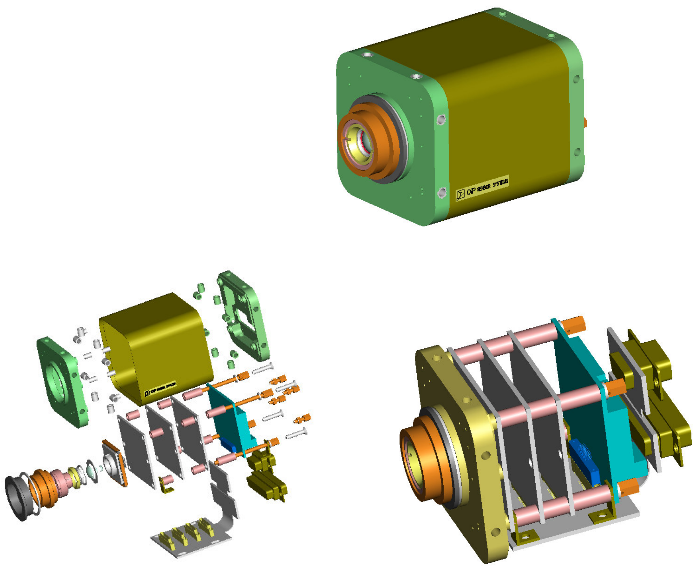


Figure 2 Modular Camera Concept

6.2 STATUS OF DATA PROCESSING ITEMS

It has been identified that most of the camera electronics can be implemented today using currently available space quality components. Some elements of the camera modules already exist within current development programmes although a complete design of any one of the module types does not exist today.

It is currently not feasible to implement a wavelet based compression module small enough for the camera. However, a compression module using a less advanced algorithm (e.g. JPEG) may be possible. Likewise, current DSP modules are marginally too large to fit into the intended camera body, but the next generation of devices should overcome this.

6.3 VMS SYSTEM CONCEPTS

The application types and requirements identified by the preceding work packages have been used to develop an end-to-end VMS architectural concept. A modular design has been developed which allows 3 overlapping concepts to meet all potential applications. These three concepts are:-

- **Standalone Camera with no DPU**: with sensor, sensor control and interface modules as mandatory in a minimal system, and optional modules such as sequence store and compression for an extended system (Figure 3).
- **Camera and Separate DPU**: with the Standalone Camera forming part of the system, probably with minimal functionality, and a separate DPU to perform functions such as compression, sequence store and specialised processing (Figure 4).
- **Standalone Camera with integrated DPU**: with sensor, sensor control, DPU and interface modules. Optional functions such as sequence store and compression can be performed by the DPU (Figure 5).

The three architectures can be implemented using just 5 types of camera module which are annotated M1 to M5 in the diagrams and are as follows:-

- M1: Sensor and Sensor Control Module
- M2: Compression Module
- M3: Sequence Store Module
- M4: Interface Module
- M5: DPU Module

As part of the architecture definition, a trade-off has been performed to assess the best type of interface for the high speed image data and the low speed commands and telemetry between the internal camera modules. SpaceWire has been identified as the best solution. SpaceWire has also been selected as the best camera external interface and so the system has maximum flexibility regarding the physical partition between the camera and the platform or DPU. The standardisation throughout the entire system maximises the reuse of technology.

The software modularity for the DPU has also been defined.

Potential in-flight demonstration scenarios have been identified and these include PROBA II, SMART 2, TerraSAR and the Columbus External Payload Facility.

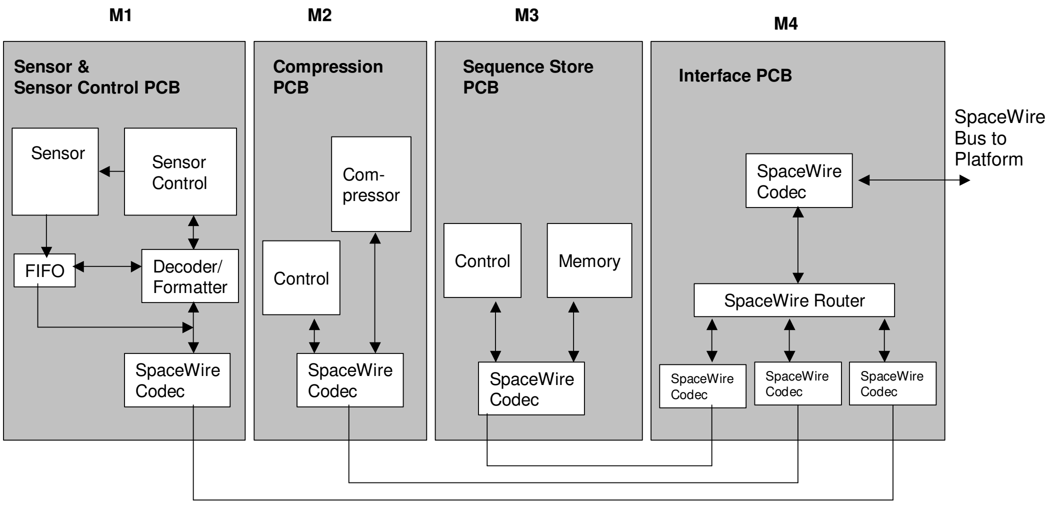


Figure 3 Standalone Camera with no DPU

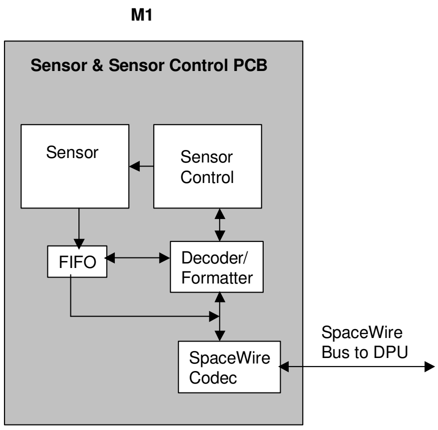


Figure 4 Camera with Separate DPU

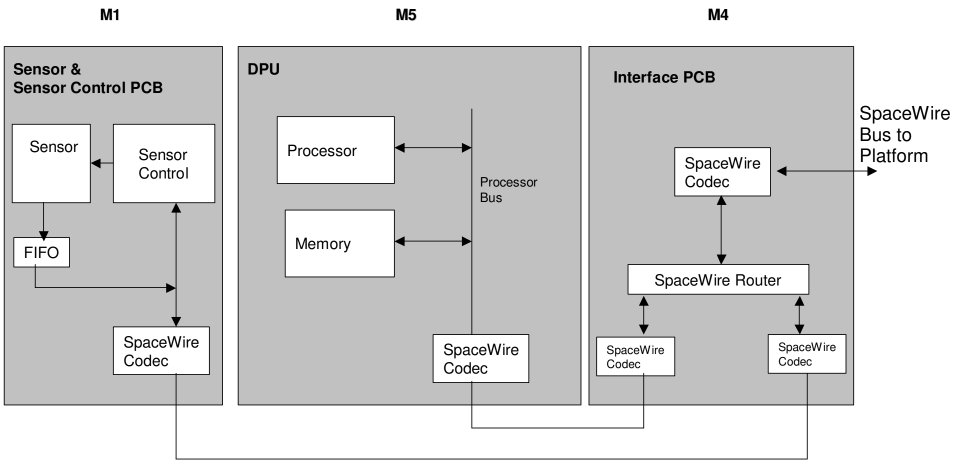


Figure 5 Standalone Camera with Integrated DPU

7. VMS CONCEPTS FEASIBILTY ASSESSMENT

The main feasibility issues arising from the concepts are:

(1) suitability of COTS lens and filter for the camera – impacts all concepts;

(2) inclusion of an image compression function (hardware implementation) in the camera – impacts the Standalone Camera concept;

(3) inclusion of a DPU in the camera – impacts the Standalone Camera with integrated DPU concept.

The suitability of the COTS lens and filters is of concern because of its impact on costs if they are not suitable and specific flight items need to be produced. The universal nature of this means that it should be a prime focus of the development activities.

Initial investigations into the incorporation of advanced compression, such as the wavelet approach based on the Astrium Gmbh CWIC compressor raised concerns about achieving the desired packaging dimensions at this time. Hardware implementations based on JPEG are likely to be feasible but less interesting as developments. The recommendation is to treat this issue separately from the main VMS development so that further investigation and evaluations can be performed. Note that the proposed concepts' use of Spacewire for interfacing would simplify an extension of the developments to add a compression function at a later stage with minimum disturbance.

The feasibility concerns regarding the inclusion of a DPU in the camera are:

- choice of processor – the Atmel 21020 DSP is currently preferred but it is a single-source item hence consideration has to be given to its long term availability;
- packaging - achieving the desired packaging dimensions;
- thermal – temperature control with the additional power dissipation.

In the longer term the risks associated with these issues will reduce but for a development in the short term it is proposed the VMS concept incorporating a DPU in the camera is set aside and priority given to the other two concepts.

8. DEVELOPMENT PLANS

Consideration of system concept feasibility led to the selection of 2 of the VMS concepts for proposed developments namely:

(1) Stand-alone Camera System – a camera capable of being directly connected to and operated by the satellite's resources - i.e. direct connection to the OBDH bus (for image data transmission and command and telemetry operations) and the primary power bus of the satellite.

(2) Central DPU Imaging System – VMS services (data compression, image sequence store, camera operation, power conditioning, other sensors monitoring) provided by a separate centralised DPU which can be shared between several cameras.

A list of the modules/elements to be produced for the development of the Stand-alone Camera system is given in Table 6. The table also identifies aspects which are key to the development of the element/module.

The Central DPU Imaging system concept uses the modular camera described for the Stand-alone Camera system concept above however the functionality in the separate DPU allows the camera to be simpler in terms of the number of modules – potentially, the Sequence Store Module and the Interface (Data/Cmd/Tlm) Module do not need to be in the camera.

For the development of the centralised DPU, two approaches can be considered:

(1) adaptation of existing conventional DPU such as Astrium's UNINAV DPU (based on PROBA PPU) or Mosaic020 processing module,

(2) miniature modular approach in conjunction with a miniaturised processor, e.g. Astrium's MCM DSP or 3D Packaging Micro DPU.

In the examples given, the software is expected to be quite similar because they all utilise the 21020 DSP.

Stand-alone Camera Modules/Elements	Key Development Issues
Lens	COTS item with CS mount.
Baffle	Mounting with COTS lens.
Filter	COTS item.
Sensor and Sensor Control	Contemporary radiation tolerant sensor. Spacewire interfaces.
Sequence Store Module	Spacewire interfaces. Contemporary high density memory devices.
Interface (Data/Cmd/Tlm) Module	Spacewire Router and interfaces.
Power (DC-DC) Module	Efficient generation of 3.3V and 5V.
Backplane	Spacewire signals.
Mechanical Housing	Vibration tolerance.

Table 6 Camera Modules/Elements

Development Approach

Certain VMS camera items need further developments and tests in order to prove the concept particularly the use of COTS elements and the CS mounting of the lens. The preferred approach is to produce a complete “test” camera.

The “test” camera is not made for a particular application but is optically and mechanically representative and contains all items needed for performing tests (particularly optical and mechanical tests) and modularity checks. The development proposed is a plan for the production of an initial ‘test camera’ which is evaluated then partly re-used in the production of a flight unit (i.e. a PFM) which can be used for in-flight demonstration.

The DPU development covers the production of an initial DPU followed by the production of an initial flight unit (i.e. a PFM) which can be used for in-flight demonstration of the concept. There may be scope for optimisation of this, e.g. a straight-to-PFM option, depending on the underlying status of the DPU technology on which the development would be based.

The duration of the camera development activities up to the PFM being available is estimated at 12 months. The duration of the DPU development activities up to the PFM being available is estimated at 15 months.

ROM cost estimates have been provided for the developments outlined above together with ROM estimates of the recurring cost of subsequent flight models.

A key aspect of the concepts is the use made of the Spacewire products anticipated to be available in the next few years – specifically a VHDL model for the Spacewire CODEC core and a Spacewire Router product.

9. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The main findings from the study have been:

- Confirmation of existence of a wide range of potential applications for VMS and a consequent wide range of requirements, constraints and context architectures.
- In number of the applications it can be expected that there will be serious constraints on data transfer rates from the telemetry systems both on-board the spacecraft and in the downlink to ground.
- Many of the applications have relatively modest requirements in terms of data rates and data volumes – a decision was made not to be driven by the most demanding requirements as it was believed that this would not lead to the most useful and versatile VMS concepts.
- The use of a data store for recording a sequence of images has been identified for several applications – the ability to provide this facility is an important feature of the VMS.
- A consequence of the modest data rates and data volumes, together with the use of image sequence memory, has meant that there is no big demand for performing image data compression in real time before storage.
- The review of COTS cameras has not identified any examples which are judged acceptable for space flight – evaluations have been particularly constrained by the limited information available for assessing the camera.
- The use of COTS lens and filters is of particular interest and a key aspect of any development should be the demonstration of their suitability.
- A selection of promising opportunities for useful in-flight demonstrations have been identified.

A set of VMS concepts have been derived which satisfy the requirements using designs which are open and modular thus providing for future expansion and giving VMS the flexibility to cover the range of applications. This open architecture approach applies to both hardware and software.

The use of Spacewire within the concepts brings with it some specific benefits:

- its physical layer provides flexibility regarding physical partitioning into units – this assists openness and modularity;
- as a Space standard, it assists development, integration and inter-changeability;
- its current capability, and continuing performance evolution, mean that it will be good for a long term.

Development plans have been outlined with useful flexibility allowing the scope of the development to vary from simple camera development (with or without a built-in image sequence store) to a development which produces all the elements for a flexible multi-camera system.

The level of risk in the developments has been lowered by separating out some of the feasibility concerns from the main development. However the design of the VMS concepts is such that they allow simplified later inclusion of new elements.

DOCUMENT CHANGE DETAILS

ISSUE	CHANGE AUTHORITY	CLASS	RELEVANT INFORMATION/INSTRUCTIONS
Draft 1 Rev 1			Draft Issue for review
1 Rev 0			First formal issue

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