A Data Compression Concept For Space Application

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ABSTRACT

In this paper a data compression concept to DSP implementation for future space missions is presented. The status of on-going developments related to data compression systems is first overviewed. Using the lossy and lossless compression, the presented method offers a high compression rate with a minimal loss of potentially useful scientific data. It also provides higher signal to noise ratio than that for standard compression techniques. The various modules of the data compression concept are discussed. We demonstrate the usefulness of the method for limited data transmission downlink.

Keywords: DSP, HW, SW,FIRST, PACS, Data Compression, On-board Software, Infrared Astronomy

1. INTRODUCTION

Uncompressed multimedia (graphics, audio and video) data require considerable storage capacity and transmission bandwidth. Examples of related products are satellite, mobile phones, GPS receivers and Modems. In DSP systems, the signal that contains the information of interest is represented by a sequence of numbers, so called samples. The DSP system operates on this input sequence of numbers to form an output sequence. In general, the overall aim of a signal processing system is to reduce the information content, or to modify it so that it can be efficiently stored or transmitted over a transmission channel. In practice, we will also need to perform auxiliary operations on signals and partition the system into smaller parts that perform elementary functions, in order to achieve the overall goal.
The market of many of these products is highly competitive and the time window in which a particular model can be sold with a profit is steadily decreasing. Hence, electronics companies must rapidly develop new or improved products to stay competitive and deliver these to the market at the appropriate time. Efficient design methodologies that support rapid and error-free integrated circuits to be developed within a given time frame and with a limited amount of people, as well as tools and experience, is therefore of strategic importance to modern electronic companies. Here we are mainly interested in a special class of DSP algorithms, so called On-Board Compression algorithm. The numerical astronomy allows the generation of images in different domains with higher resolution and therefore larger dimensions. This leads to an important increase in terms of data volume and bit rate. Meanwhile, the transmission capabilities did not follow the same capabilities increase. Therefore, compression becomes a requirement for communication systems in charge and/or transmission of these image.

For a satellite, the main subsystems tasks turn around a digital signal processor. In this paper, we will focus on the high level software of a Signal Processing Unit. The aim is the application software, which consists on the compression algorithm.

This paper is structured as follows. In section 2, we present the problem statements and an overview of the related astronomical mission data. In section 3, the descriptions of the proposed data compression concept and its modules. The application of this reduction concept on DSP and transmission capabilities are studied in section 4. We conclude with a short summary.

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2. PROBLEM STATEMENT

The Far InfraRed Space Telescope (FIRST)[1], is one of the future ESA's infrared space-astronomy missions foreseen to be launched on 2007. It will be operated at much larger distances from earth than current projects. The natural application for such an instrument would be observations of Galactic (e.g. search for protostars) and/or Extragalactic sources (e.g. identification/diagnostics of IR-luminous, distant galaxies).These source, on the other hand, will mostly be accessible from SOFIA which will become operational longer before FIRST, with potentially larger detector arrays. Indeed, the main strenght of the FIRST Photoconducteur Instrument will be surveys / mapping and follow-up spectroscopy of weak, compact sources which other missions will be unable to detect. The Photoconductor Array Camera & Spectrometer (PACS)[2] is one of the three instruments operating on board (FIRST). Our task in the framework of the PACS consortium is to implement a robust On-Board Data Compression Software on its DSP yielding a high signal to noise ratio and a commandable compression rate. The FIRST-PACS detector arrays are realized by two extrinsic Ge:Ga photoconductor filled pixel arrays of format 25×16 including integrated crygenic readout electronics (CRE). The two arrays are specialized for two wavelength regimes (40–120 μm and 100–210 μm, respectively) by applying physical stress to the longer wavelength module.

The main challenge is the high data rate of the instrument. The raw data stream consists of $2 \times 25 \times 18$ CRE channels, so a total of 900 channels. With maximum readout rate of 256 Hz we get a sampling rate of 230400 samples/s. Conversion of this analog data stream by means of a 16 bit ADC yields the maximum data rate of the raw data stream of 3600 Kbits/s. For transmission of science data different transmission modes are foreseen. In Science PACS Prime Mode maximum data rate is limited to 200 Kbit/s, while in Science PACS Partner Mode it is limited to 100 Kbit/s. In Science BURST Mode, the maximum data rate is 400 Kbit/s. Therefore for the prime mode, a minimum compression ratio of 36 is required[*]. In addition to that, the detectors are continuously exposed to high energy cosmic particles inducing a disturbance (glitches) of the readout voltage which decrease the signal to-noise ratio and hence the data accuracy level. In the sequel we assume the characteristics as depicted in Tab. 1 of the detector and the signals.

Signal/Noise ratio	≈ 6000
Glitch rate	10s/pixel
Glitch tails	< 0.5s
Detector output	16bit
Significant bits	14bit

Table 1. Assumed data characteristics

In this paper we are only concerned with fixed-function DSP algorithms that can be scheduled at design time. Examples of such algorithms are digital filters, fast fourier transform (FFT), discrete cosine transformation (DCT), wavelet transforms[4], and on board Processing. These algorithms are often used in applications which are characterized by a high, but fixed, throughput, and data-independent operation sequences. Further we are only concerned with hard real time systems. DSP systems are usually used in a hard real-time environment. The system is then required to respond to an input before a given deadline imposed by the application. An unacceptable error occurs if the deadline is not met. It is therefore important for the designer to be able to guarantee that the implementation will fulfill the timing requirements imposed by the deadlines. A constant sample rate implies such a deadline. In most cases the real-time requirements are specified as the minimum number of samples that must be processed per second.

This paper focuses on the on board processing. The compression concept is described in the next section.

3. DATA COMPRESSION CONCEPT

This section reviews the basic concept for PACS data reduction / compression software to achieve the desired downlink data rates. Figure 1 presents the different software modules. First, the data packet received from the Detector Controller/Mechanism Controller Unit, will be grouped into a set of reset interval measurements (useful time). Each one is called Ramp. It contains a measurement samples during one reset interval[†].

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[*] This is for the PACS prime photometry mode, in what follows will only consider this mode, because for the other modes the requirements for the compression are less demanding

[†] In what follows we will consider only one array. The processing for the other array is similar

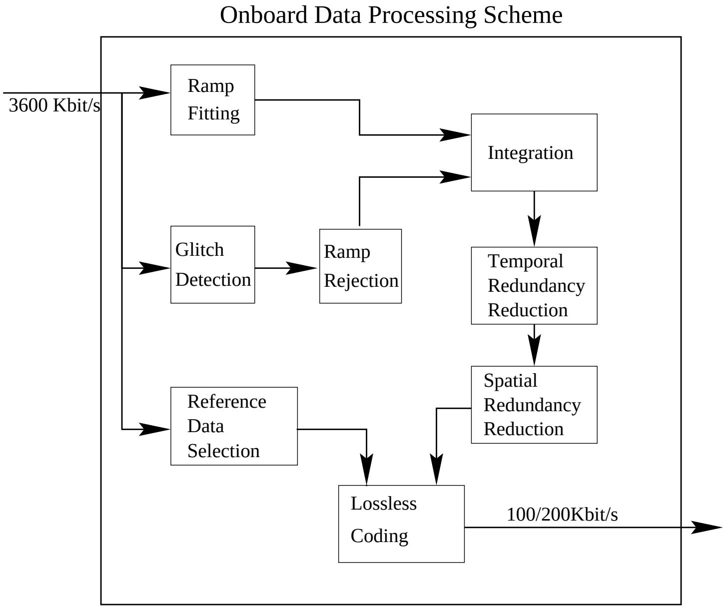

Figure 1. A schematic diagram outlining the data compression software.

The compression concept can be coarsely divided into three modules:

1. Integration: The integration part of the software performs the on-board data reduction. The basic idea is that in order to achieve the high compression ratio we have to integrate several ramps on-board. Since, a ramp maybe effected by glitches, we have to ensure that we do not integrate over this ramps. This is done in the glitch detection and ramp rejection module.
2. Loss-less coding: The loss-less coding part of the software consists of the temporal and spatial redundancy reduction and the loss-less coder.
3. Reference data selection: This module is responsible for transmitting selected ramps without compressing them. The main reason for this module is to check the performance of the compression software on ground. In what follows we will not describe this module further.

The software will consist of following modules:

Ramp Fitting: Linear (Non-linear) ramps are fitted to the sensor readings in order to obtain the flux. Also the residuals of the fitting will be kept in order to allow reconstruction of the original signals. As explained in [5] we have the following possibilities for ramp fitting:

1. Least squares fitting: This type of fitting is very sensible to glitches.
2. Robust fitting using RANSAC [5]: This type of fitting is well suited for detection of glitches. However it has a low efficiency in reducing the noise.
3. Combined RANSAC & Least squares fitting: This type of fitting is a combination of the above two methods, where first RANSAC is performed in order to reject outliers and then least squares in order to reduce the Gaussian noise.

Glitch Detection: Since we will perform on-board integration we have to ensure that we do not integrate over invalid sensor readings (i.e. glitches). The detection of such events will be performed in the glitch detection module. The glitch detection will be done at the individual sample level "Intrinsic Deglitching" using the results from fitting, as well as at ramp level "Extrinsic Deglitching" and by comparing the slope of subsequent ramps. All ramps which are effected by glitches are discarded. Since we have only four points per ramp then, it does not make sense to take those parts of the ramp into account which are not affected by glitches.

Temporal/Spatial Redundancy Reduction: These two modules will eliminate the temporal and spatial correlation of the sensor readings. The main methods used will be temporal and spatial differencing. Since these are fairly standard methods we will not consider them in this paper.

Integration: The integration module will perform on-board integration of the sensor readings in order to achieve the desired compression ratio. This is the lossy compression part of the software. Special emphasis has to be paid in order to guarantee integration over the right readings - synchronized with the positions of the chopper - and not to integrate over ramps affected by glitches. Thus, the integration process first determines whether to discard all data of a CRE integration block if there is a lack of confidence in at least some of the samples. Then slope data of a number of successive ramps within the same chopper position will be added, if they are free of glitches.

Lossless Coding: The lossless coding module will then use a run-length encoding scheme to compress the output further, and eliminate all the redundancies in the data.

4. RESULTS

The on board software will be written in ANSI C language and will follow the pertinent recommendations concerning the process control, on-board memory loading, dumping and autonomy functions. The implementation would be on the SPU which contain two DSP from $TEMIC^{TM}$[‡]. TEMIC semiconducteurs is manufacturing a radiation tolerant version of the $AnalogDevice^{TM}$ ADSP-21020 32/40 Bit Floating point DSP [7]. The program will have a 1 Mbytes size and expected to be stored in the SPU's EEPROM. The data memory provided is about 4Mbytes. Thus, at least data of 26 ramps could be stored and processed as well. The first task is to develop a software simulation using MATLAB before the final implementation. In general the compression ratio is calculated as follow:

$$CR = \frac{\sum \text{input data bits}}{\sum \text{output data bits}} [1]$$

No standard compression method could fulfill the telemetry rate required of about 200kps. Therefore, it is foreseen to adjust the number of ramps to integrate in order to achieve the sollicited compression ratio.

Table 2 lists the compression ratio using the formula [1] and the proposed method.

Ramps to integrate	Maximum CR [1]	Time interval of integration(s)	Achieved Transmission Rate(kbps)
1	18 %	1/8	98.438
2	18 %	1/8	91.406
3	18 %	3/32	121.875
4	18 %	1/16	168.75

Table 2. Compression ratio of scientific data in PACS Prime mode

This table shows the only manner to achieve the desired compression ratio. This is done by on-board integration, e.g. to define the number of ramps to integrate in order to achieve the desired compression ratio. We have to ensure not to integrate over glitches to avoid loss of science data.As glitch detection will not be 100 % correct, so we have to keep the number of integrated ramps as small as possible, because percentage of glitch corrupted data grows with number of integrated ramps.

[‡] TM: Trade Mark

5. CONCLUSION

In this paper we have described a novel On-Board data compression concept for the FIRST/PACS mission of the European Space Agency (ESA). We have described the key-modules ramp-fitting and glitch detection. The presented method offers a Efficient exploitation of the downlink provided. It adapts the available transmission rate to the compression ratio using an efficient integration. It provides a high compression rate with a minimal loss of potentially useful scientific data. It also provides higher signal to noise ratio than that for standard compression techniques.

Acknowledgments

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