EURASIP Journal on Applied Signal Processing 2005:15, 2585–2594

On-board Data Processing to Lower Bandwidth Requirements on an Infrared Astronomy Satellite: Case of Herschel-PACS Camera

Ahmed Nabil Belbachir
Pattern Recognition and Image Processing Group, Vienna University of Technology, Favoritenstrasse 9/1832, 1040 Vienna, Austria
Email: nabil@prip.tuwien.ac.at

Horst Bischof
Institute for Computer Graphics and Vision, Technical University of Graz, Inffeldgasse 16/II, 8010 Graz, Austria
Email: bischof@icg.tu-graz.ac.at

Roland Ottensamer
Institut für Astronomie, Universität Wien, Türkenschanzstrasse 17, 1180 Vienna, Austria
Email: ottensamer@astro.univie.ac.at

Franz Kerschbaum
Institut für Astronomie, Universität Wien, Türkenschanzstrasse 17, 1180 Vienna, Austria
Email: kerschbaum@astro.univie.ac.at

Christian Reimers
Institut für Astronomie, Universität Wien, Türkenschanzstrasse 17, 1180 Vienna, Austria
Email: reimers@astro.univie.ac.at

Received 31 May 2004; Revised 1 March 2005

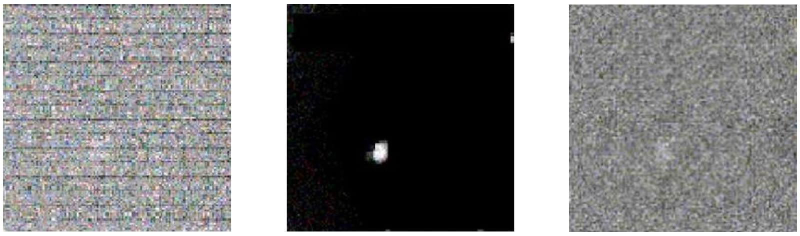
This paper presents a new data compression concept, "on-board processing," for infrared astronomy, where space observatories have limited processing resources. The proposed approach has been developed and tested for the PACS camera from the European Space Agency (ESA) mission, Herschel. Using lossy and lossless compression, the presented method offers high compression ratio with a minimal loss of potentially useful scientific data. It also provides higher signal-to-noise ratio than that for standard compression techniques. Furthermore, the proposed approach presents low algorithmic complexity such that it is implementable on the resource-limited hardware. The various modules of the data compression concept are discussed in detail.

Keywords and phrases: Herschel, PACS, on-board processing, infrared astronomy, compression.

1. INTRODUCTION

Infrared (IR) astronomy requires dedicated data compression for economical storage and transmission of the large data volume regarding the limited budget and resources available for space missions [1, 2]. In fact, this is most demanding for space observatories where images are generated in different domains with higher resolution and therefore larger dimensions. This yields to an important increase in terms of data volume and bit rate. Furthermore, telemetry capabilities did not follow the same performance increase. Therefore, compression becomes a requirement for communication systems in charge of storage and/or transmission of the data.

Infrared detectors consist, as a rule, of fewer pixels than those for visual range, but the design of multisensor instruments leads to even higher data volumes. If multiple detectors are operated in parallel to support multispectral or even hyper-spectral imaging, then the data volumes multiply. Furthermore, small spacecrafts are usually used for deep space missions. They are characterized by being restricted to low budget and consequently a low data rate. Therefore, although many applications exist, which generate or manipulate astronomical data [3, 4, 5, 6], transmitting image information still faces a bottleneck such that this constraint has stimulated advances in compression techniques for astronomy [7, 8]. However, the proposed techniques are often ad hoc



(a) (b) (c)

Figure 1: Example of an infrared image. (a) Raw image at 1500- second integration time. (b) One interesting object in the image "Galaxy SBS-0335-05210." (c) Resulting image after denoising (noise from the electronic).

and sometimes not appropriate for infrared data. For example, in [8], the listed methods involve filtering of information, which is not considered to be of use, by means of object recognition methods that face the background estimation problem to guarantee not to destroy information. Furthermore, this lessens the interpretability of the results and limits the extension of the method to nonimage data structures.

Indeed, thermal infrared (mid and far infrared) imaging is a measure of heat. To capture this energy, a complex instrumentation is used such that the detectors are cooled down to few kelvins. Therefore, a composite signal (source + background) will result. The source is considered as the object heat (observed target). The background is the environment heat whose amplitude is usually far higher than that of the observed target. To capture the infrared image of the wished target, one has to integrate several images over time (usually hours, depending on the wavelength), which is called integration time. Therefore, the infrared image acquired at time "t" has no object structure, which makes compression task challenging, such that it has to ensure that the relevant signal (observed source) is not lost during compression. Furthermore, infrared image acquisition is susceptible to heavy particles (glitches) that might on one side disturb the signal accuracy, changing the electronic characteristics (e.g., detector responsivity), and on the other side, it might increase the signal entropy, and thus decrease the compression efficiency.

Figure 1 illustrates a typical infrared image, as observed by the telescope GEMINI [9]. Figure 1a shows the raw image at 1500 second integration time. One interesting object (galaxy) in the image after a postprocessing can be found in Figure 1b. Figure 1c shows the relevant image for the astronomy expert after removing the noise and the stripping artifact due to the instrument electronic. The challenge of data compression is to preserve as much information from the image as possible such that the relevant image structure (e.g., Figure 1b) can be reconstructed.

Indeed, no real study has been performed for IR astronomical data compression apart from the use of wavelet-based compression techniques [7, 8]. Generally, IR data are collected on-board an observatory (satellite) that can overload downlink bandwidth and on-board memory resources rapidly. Therefore, a significant research effort has to be invested in analyzing the performance of the compression algorithms in terms of results quality and complexity. Such an analysis forms the basis for optimizing the algorithms, and also for determining whether a given algorithm is appropriate for the application at hand. Basically, data compression is a matter of modeling. The more information can be derived from it, the less information has to be transmitted. This paper is concerned with recognizing the best-suited technique for improving the efficiency of bandwidth-limited transmission channels in case of IR space astronomy. We propose a new concept, "on-board processing," which addresses both aspects of data quality and complexity [10]. The photodetector array camera and spectrometer (PACS) [11] is one of the three instruments operating on board the Herschel space observatory (HSO) [12] foreseen to be launched in early 2007. Our task in the framework of the PACS consortium concerns the reduction of the data collected on-board, to fit the available telemetry. This task is of special importance because of the extreme compression ratio (up to 40!) dictated by the combination of a high raw data rate with a relatively low telemetry rate available for an L2-orbit space mission. An on-board processing scheme combining data reduction with lossless compression algorithms for high compression ratio is presented in this paper.

This paper is structured as follows. In Section 2, the challenges of a compression method are presented. We present the problem statements and the characteristics of the astronomical data, from PACS, in Section 3. In Section 4, the descriptions of the proposed approach, on-board processing, and its modules are given. Experimental results of the application of this reduction concept are given in Section 5. We conclude with a short summary.

2. COMPRESSION CHALLENGES

The major concern of a compression method is to recognize and remove all redundancy in order to reduce the data traffic over the transmission channel. The performance of a data compression method for infrared astronomy can be evaluated using the following relevant parameters:

(i) the compression ratio versus the reconstruction error;
(ii) the complexity of the method.

The first criterion (compression ratio) points out the capability of the method to find and remove the redundancy in the data. The more redundancy is removed the better compression ratio is achieved.

The reconstruction error defines the quality of the data after reconstruction. The results quality criteria, which can be retained for estimating the merits and performances of a compression method, in case of astronomy, are visual aspect, signal-to-noise ratio, detection of real and faint objects, object morphology, astrometry, and photometry. Although the upper criteria are very important to design a compression method, the complexity of the algorithm is of bigger importance because it defines the feasibility of the method. As the algorithm has to be run on-board a space observatory computer, then, the implementation of the method has to be part of the design of the method. In this paper, we treat the case of PACS where the photoconductors and bolometers are used as detectors. We focus in this paper on the photoconductors case. When such detectors are receiving infrared photons from an astronomical or internal source, the current I at their output is proportional to the number of photons falling on the detector. As this signal has generally very low amplitude [1], the signal preamplification and sampling are required. Since the output voltage should stay within a quite limited range, a voltage reset pulse is applied in addition to a sample pulse after sampling a number of desired voltages.

An illustration of 1-dimensional signal for selected pixels from Herschel-PACS Camera [11] is given in Figure 2. All plots represent the detector output voltage in bit values (y-axis) against time (x-axis). We can see different signal behaviors that depend on the detector setting and responsivity.

3. HERSCHEL-PACS CHARACTERISTICS

HSO will be equipped with a 3.5 m Cassegrain telescope and house three instruments inside its superfluid helium cryostat covering the spectral range between 55 and 670 μm. The three instruments are built by different European consortia with international cooperation with international cooperation as listed in Table 1.

PACS will conduct dual band photometry and imaging spectroscopy in the 55–210 micron spectral range. The instrument consists of two 25×18 Ge:Ga photoconductor arrays for spectroscopy, read out at 256 Hz and two bolometer arrays with 32×16 and 64×32 pixels for photometry, read out at a frequency of 40 Hz. In both modes, a high raw data flow of up to 4 Mbit/s is generated. This is far above the nominal telemetry downlink bandwidth, which is restricted to 120 kbps, due to the L2-orbit of the spacecraft in about four times the moon's distance.

When the photoconductors are receiving IR photons from an astronomical or internal source, the voltage V at its output will increase as a function of time. The incoming photons excite charge carriers into the conduction or valence band. The voltage increase is proportional to the current through the detector which is in turn proportional to the number of photons falling on the detector. In the case of the PACS instrument, the cold readout electronics (CRE) preamplifies and samples the photo-currents generated in the detector. There will be typically 8 to 1024 samples on each ramp.

An ideal bolometer, by definition, is a device that detects all the radiation falling on it. A typical detector consists of a small chip of the doped material supported by very thin wires which act as electrical conductors for the measurement of its resistance and at the same time connect it to a heat sink with a certain thermal resistance which has to be chosen in advance according to the background level of radiation that is expected to strike it. The doping level of the material is chosen to provide an optimum sensitivity of resistance to temperature at around its operating temperature, which is 0.3 K. The analog signal is buffered, and amplified at 300 K stage, then oversampled at the multiplexer stage while being converted to digital signal.

The main challenge is the high data rate of the instrument. The raw data stream in spectroscopy consists of $2 \times 26 \times 18$ channels, so a total of 936 channels. With a readout rate of 256 Hz we get a sampling rate of 239616 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 3744 Kbits/s. The data stream in photometry consists of $10 \times 16 \times 16$ channels, so a total of 2560 channels. With maximum readout rate of 40 Hz, we get a raw data stream of 1600 Kbps after ADC oversampling.

For science data transmission, different modes are foreseen. In PACS prime mode, the maximum data rate is limited to 120 Kbps, while it is limited to 60 Kbps when PACS and SPIRE share the downlink bandwidth in parallel mode. In the burst mode, the maximum data rate is up to 300 Kbps. Hence, a minimum compression ratio of 40 is required[1] in prime mode. In addition to that, the detectors are continuously exposed to high energy cosmic particles inducing a disturbance (glitches) of the readout voltage, which decreases the signal-to-noise ratio and hence the data accuracy level. In the sequel, we assume the characteristics of the detector and the signalsto be as follows: signal-to-noise ratio $\approx$ 600–11000, glitch rate = 10 s/pixel, glitch tails < 0.5 second, detector output = 16 bits, significant bits = 14 bits.

The maximum possible compression rate we could obtain by a lossless compression (i.e., the original measurements can be recovered) can be computed as follows. A compression ratio of 16/14 is obtained by eliminating nonsignificant bits via spatial and temporal redundancy reduction. An additional compression factor of 4 is obtained by calculating the slope of the sub-ramp, which has to be given at least with the accuracy of the S/N. Therefore, 16 bit for the slope are sufficient. A further lossless compression of the signal is not possible because it contains basically the noise of the telescope, which is by definition, incompressible. This noise cannot be eliminated because we would loose the

[1]In what follows we will only consider the prime mode, on which PACS will operate most of the mission. Furthermore, compression requirements are less demanding in the other modes.

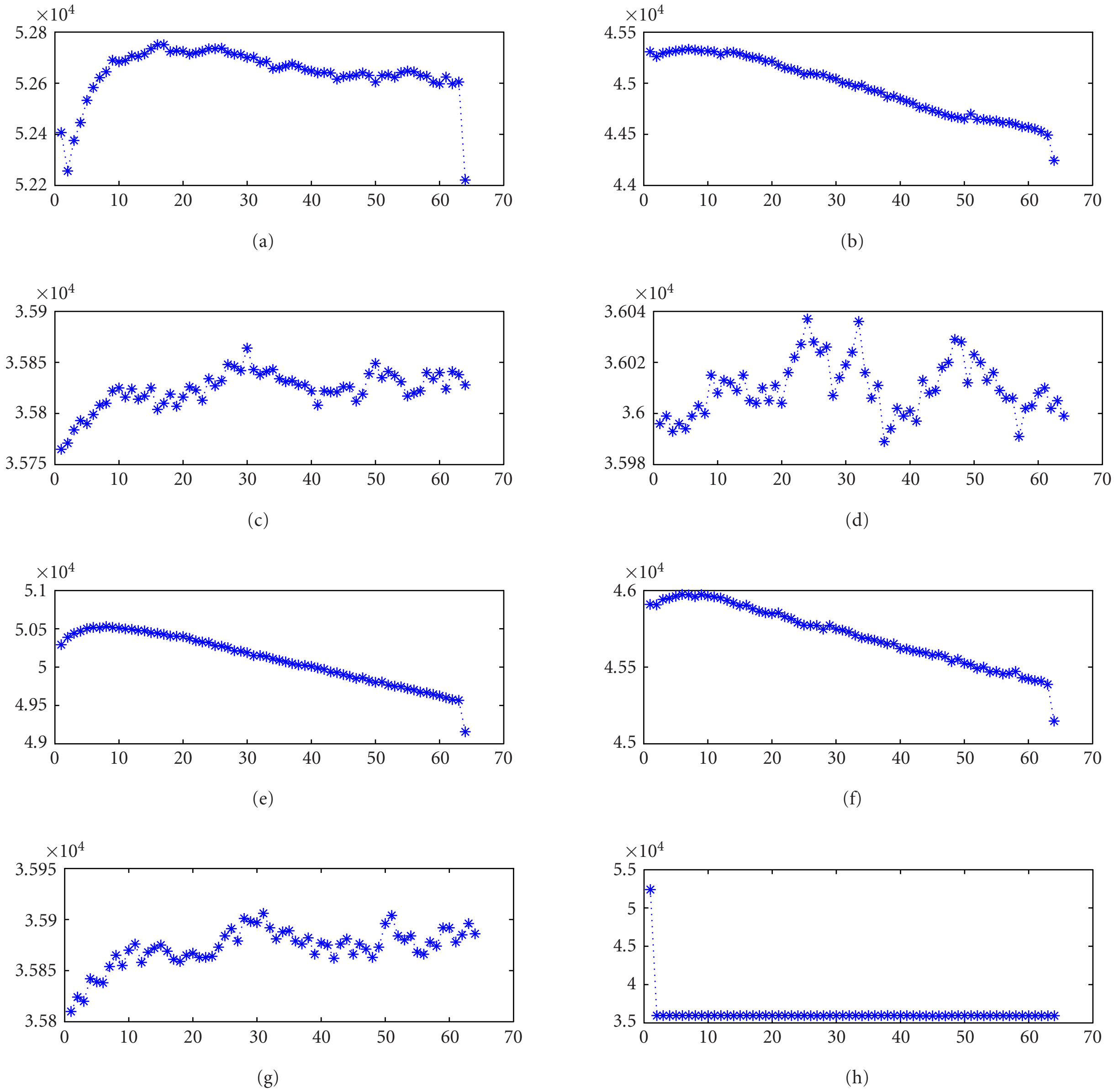


FIGURE 2: Example of different 1D infrared signals for eight selected PACS photoconductors data: (a) active detector 1, (b) active detector 3, (c) blind detector 17, (d) blind detector 18, (e) active detector 18, (f) active detector 5, (g) blind detector 1, and (h) blind detector 2.

TABLE 1: The scientific payload of the Herschel space observatory.

Instrument	PI location	Spectral range
PACS	MPE Garching, GER	55–210 μm
Heterodyne instrument for the far infrared (HIFI)	SRON Groningen, NL	480–1910 GHz
Spectral photometer imaging receiver (SPIRE)	University of Wales/Cardiff, GB	200–670 μm

astronomical signal. Therefore we can achieve a lossless compression factor of 4.57. Since lossless compression is impossible at such rate, we have to perform on-board processing. In the next section we describe our compression concept in detail.

4. DATA COMPRESSION CONCEPT

This section reviews the basic concept for PACS on-board processing to achieve the desired downlink data rates. Figure 3 presents the different software modules. We will consider the case of photoconductors, which is challenging

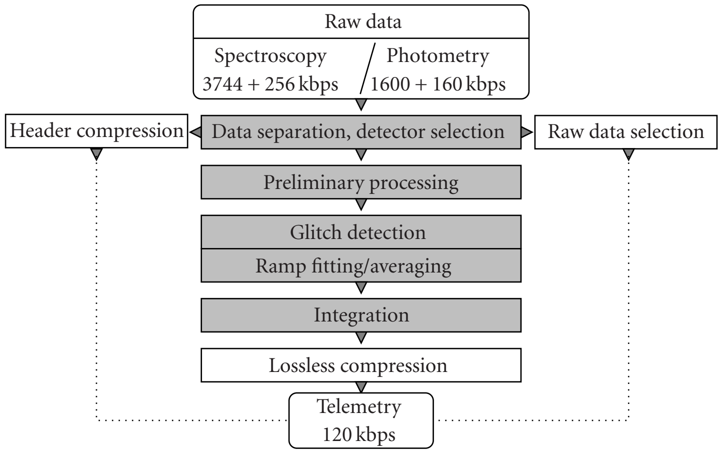


Figure 3: A schematic diagram for on-board processing concept. (Dark grey color indicates the modules where raw data are lossy compressed.)

in term of compression rate. Similarly, the bolometers case can be treated. First, the data packet received from the focal plane unit (FPU) is grouped into a set of reset interval measurements (useful time). Each one is called ramp. It contains measurement samples during one reset interval.

The compression concept can be coarsely divided into four modules.

(1) *Header compression*. Header or control data represent the observation configuration, the detectors setting, and the compression parameters. They are set by ground engineers that are responsible for running the planned observation. The control data are transmitted to PACS within the daily telecommunication period, executed by the detector and mechanic controllers according to the prescribed commanding sequence, and routed again to ground engineers as header information of the science observation data. This header is generated at science readout rate. The goal of this module is to compress the control data (header) lossless as much as possible such that the limited bandwidth can be fully exploited for the science data. In what follows, this module is not described further.

(2) *Integration*. The integration part of the approach performs the on-board data reduction. The basic idea is that in order to achieve the high compression ratio we have to integrate several samples 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 module.

(3) *Lossless compression*. The lossless compression part of the approach consists of the temporal and spatial redundancy reduction and the entropy coder.

(4) *Raw data selection*. This module is responsible for transmitting selected detector data 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.

In the following subsections we describe the individual modules in detail, especially the integration and glitch detection part.

4.1. Detector selection

This module performs the data selection according to the detector tables. The detectors selection tables consist of model sets stored on-board depending on the object to observe or on the detector status. For instance, pixels that represent the object of interest are selected and data from others are discarded. Furthermore, bad pixels (e.g., dead pixels, saturated pixels, etc.) may be deselected and data from those pixels could be discarded.

4.2. Preliminary processing

This module is used to transform the received signal to the appropriate form (e.g., linearization of the ramps). In fact, this is used to reduce the noise (pick up and cross talk noise) in the data. It uses the infrared detectors characteristics where blind pixels (not exposed to the light) are used. They are used as reference for the correlated pick-up noise. A correlation matrix between the blind pixels on the reference lines and the actual pixels is used to remove the correlated noise.

4.3. Ramp fitting

Ramp fitting is one of the crucial steps of the proposed on-board processing concept. In this paper, we will only consider linear ramps. Indeed, an extension to nonlinear ramps could be easily done when analytic model of the ramp is available, or the fitting can be performed over a small part of ramps (sub-ramps), typically 4 samples, such that nonlinear ramps are also considered, if nonlinearity is above the 4 samples. The ramps are fitted to the sensor readings in order to obtain the flux. We consider the samples belonging to a ramp given

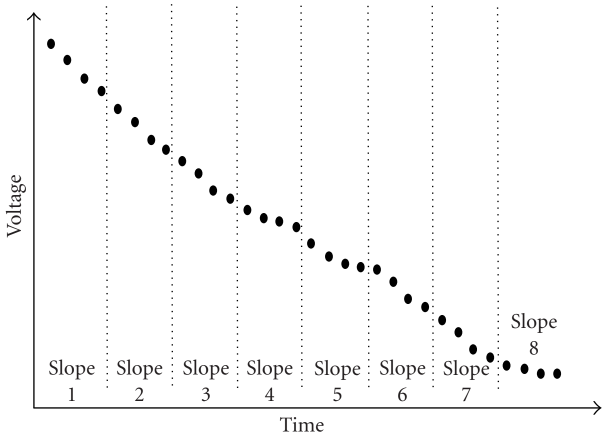


Figure 4: Least squares fitting of sub-ramps for 32-sample ramp over every 4 samples of a ramp.

by a vector $\mathbf{x} = [x_1, \dots x_n]^T$. A linear ramp is given by

$$\mathbf{x} = s\mathbf{t} + o + \eta, \tag{1}$$

where s is the unknown slope, $\mathbf{t}$ are the known instants of sampling, o is the unknown offset, and η is a vector of random variables with distribution of every element assumed to be $N(0, \sigma)$, characterizing the noise process. In order to obtain the parameters of interest, this equation has to be solved in a robust manner. We have following options.

Least squares solution

The least squares solution can be easily calculated in analytic form, and is optimal with respect to the Gaussian noise process. However, this solution is not appropriate in case of outliers (i.e., glitches), therefore, glitch detection module has to ensure the outliers removal before the fitting. Figure 4 shows an example where least squares fitting is successively performed over every 4 samples of a ramp (4-sample sub-ramp).

The result of the ramp fitting are slopes and the offset of the sub-ramps, and for each sample on the ramp we have a flag if it is an outlier or not. If it is not an outlier, we have in addition a residual value. This is the input to the glitch detection module.

4.4. Glitch detection

Since ramp fitting/averaging and on-board integration might be performed, 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" as well as at ramp level "extrinsic deglitching" and by considering subsequent ramps.

Intrinsic deglitching

This is done by the residual and offset information calculated by the ramp-fitting module. All ramps/sub-ramps where an outlier has been detected will be discarded.

Extrinsic deglitching

In this case we have to take into account the difference in slope between two subsequent sub-ramps. If two subsequent slopes differ more than 2σ we have an indication of a glitch.

All ramps which are affected by glitches are discarded. Since we might only have four points per sub-ramp, it does not make sense to take those parts of the sub-ramp into account which are not affected by glitches.

Another critical issue is glitch tails detection. Since the behavior of the detector might change for some time after it has been hit by a glitch, this is a critical issue. At the moment the concept foresees to discard all samples within a fixed time interval when a glitch has been detected. However, in the future we will investigate also methods such that this can be detected automatically.

4.5. 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 an 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.

4.6. Lossless compression

The previous modules represent the lossy, that is, reduction, part of the PACS data reduction/compression system. The further modules constitute the lossless, that is, compression, part. To perform the high compression rate required, several compression iterations should be applied.

4.6.1. Preprocessing

After the integration we have a sequence of arrays we call it frames (i.e., $\mathbf{A}^t$, where $\mathbf{A} \in \mathbb{R}^{16\times 25}$ is an array of integrated slopes at time t). Since temporarily and spatially adjacent measurements will be similar, we can use this fact for further data reduction.

Temporal redundancy reduction

We calculate $\Delta^{t+1} = \mathbf{A}^t - \mathbf{A}^{t+1} \cdots \Delta^{t+n} = \mathbf{A}^t - \mathbf{A}^{t+n}$. If subsequent frames are similar $|\Delta^{t+i}| \ll |\mathbf{A}^{t+i}|$, $1 \le i \le n$, therefore we can gain in the compression ratio encoding $\mathbf{A}^t$ and Δ^{t+i}, $1 \le i \le n$.

Spatial redundancy reduction

After the temporal redundancy reduction, spatially neighboring values in Δ^{t+i} should be similar (in the ideal case they are zero), therefore we can gain additional compression by encoding the difference of neighboring pixels.

Table 2: Potential loss of scientific data.

Number of ramps	No glitch detection	50%	90%	99%
2	9.75%	4.94%	0.99%	0.1%
4	18.55%	9.63%	1.99%	0.19%
8	33.66%	18.33%	3.93%	0.39%
14	51.23%	29.84%	6.77%	0.67%

4.6.2. Entropy coding

Redundancy reduction as outlined above should have reduced the magnitude of pixels values as much as possible. This fact makes it possible to have assumptions about the distribution of the data, which is a prerequisite for efficient lossless compression. Generally, the astronomical images have uniform background, while observing the same target for long duration. Therefore, the data packet related will contain many identical sample values. The redundancy reduction is suitable to optimize the data packet size. A combination between the RZIP [13] and arithmetic encoding [14] algorithms is performed for further compression ratio. The RZIP algorithm is especially developed for PACS data entropy coding. See [13] for further details. Since arithmetic encoding is a standard algorithm, we will not describe it further.

5. EVALUATION OF THE ON-BOARD PROCESSING CONCEPT

The on-board processing concept is evaluated in this section, on a theoretical basis and on NGC1808 IR image from the infrared space observatory (ISO) mission.

5.1. Data reduction evaluation

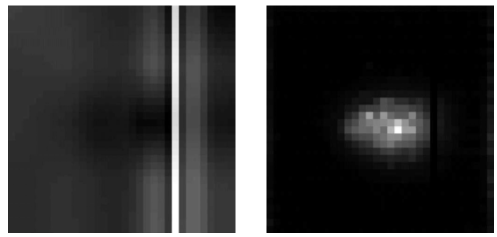
We first consider how many ramps have to be integrated in order to achieve the desired compression ratio of 40. As we have explained in Section 3 with lossless compression, we can achieve only a compression ratio of 4.57. The additional compression factor of 7.8 has to be gained by integration of ramps or fitting bigger sub-ramp length (e.g., 8 samples per sub-ramp). Therefore, we have to integrate over 8 ramps[2].

The next thing to consider is the potential loss of scientific data. Of course, the glitch detection will not be 100% correct. We can quantify the potential loss of scientifically valid data by the glitch detection rate and the number of ramps that will be integrated. Assuming a glitch rate of every 10 s/pixel, with a glitch tail of 0.5 s we get a probability of $p_{\text{glitch}} = 1/20$ that a ramp is affected by a glitch. Then we can calculate the potential loss of scientific data p_{loss} by

$$p_{\text{loss}} = 1 - \left(1 - p_{\text{glitch}}\left(1 - p_{\text{det}}\right)\right)^n, \quad (2)$$

where n is the number of integrated ramps and p_{det} is the glitch detection efficiency.

[2]In fact, integration over 7 ramps should be sufficient because due to the decrease in signal-to-noise ratio we could gain the rest by temporal and spatial redundancy reduction.



(a) (b)

Figure 5: Resulted NGC 1808 image after (a) JPEG 2000 compression (EBCOT method) for a compression ratio of 6 and (b) on-board processing for CR = 15.

Table 2 lists the potential data loss for various numbers of integrated ramps for different glitch detection rates.

A glitch detection rate of more than 95% seems feasible, therefore the potential data loss will be around 1%–3%. In fact, it will be lower because in the above calculations we have assumed for simplicity that a glitch and its tail are independent events, which is not true. In fact, if the glitch is detected, we have also detected its tail. In addition, we have assumed that when we do not detect a glitch, all integrated measurements will be lost. In fact if we miss a small glitch and integrate over it, this just decreases the signal-to-noise ratio. Another thing we have not considered is false negative rate, that is, we discard a ramp even if it is not affected by a glitch, this will of course also lead to a loss of scientific data. But this can be directly estimated. In addition, this has no effect on the other data. From these considerations, one can see that the desired compression ratio can be achieved with minimal loss of scientifically valuable data.

5.2. Quantitative results

For performance evaluation, the proposed approach, on-board processing, is compared with JPEG 2000 [15], ZIP [16], and RAR [17] methods, in terms of compression ratio (CR), processing time, and memory usage, on NGC 1808 raw infrared images (1032 frames) from the ISO mission. Figure 5a depicts the resulted image after JPEG 2000 compression of individual raw images for CR = 6, while Figure 5b shows the on-board processing result for CR = 15. This JPEG 2000 implementation [15] uses EBCOT algorithm (embeded block coding with optimized truncation) [18] for the quantization of the wavelet coefficients and the binary arithmetic coder as backend entropy codec. The white vertical line represents the column 24 with dead pixels, detectors that were lost during the mission. The quality loss is

Table 3: Comparison of compression performances on NGC 1808 raw IR images (1032 frames) between JPEG 2000, ZIP, RAR, and the proposed approach.

Method	CR	Time (ms)	Memory usage (kbytes)
ZIP	1.39	24285	37240
RAR	1.40	34500	18912
JPEG 2000	6.38	158600	4128
On-board processing	15.44	120	1900

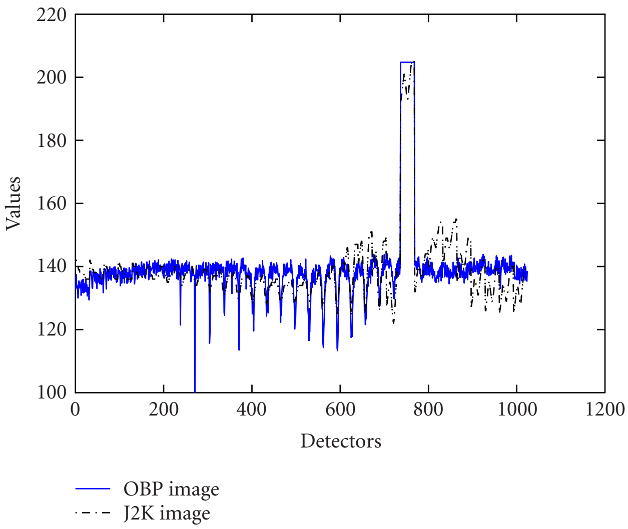


Figure 6: Illustration of the JPEG 2000 compressed image (dashed-dotted line) and the resulted image from on-board processing (solid line) on a 1D plot.

observed compared to the resulted image (Figure 5b) from our proposed approach, which is due to the performed quantization by means of the EBCOT algorithm. For better error display, both reconstructed images are plotted as a 1D signal in Figure 6. On the x-axis, the pixel indexes (1–1024) are represented while pixel values, for both reconstructed images (JPEG 2000 and our approach), are depicted on the y-axis. It is shown in this figure the approximation error due to the EBCOT quantization.

Compression results comparing the above listed methods are reported in Table 3 for comparison purpose. All methods have been run on a 450 MHz Pentium PC with Windows Nt 4, for identical comparison platform, although the on-board processing is dedicated for embedded hardware (DSPs) for space applications. It is noted the highest compression ratio for faster processing time needed by the on-board processing for the reduction of NGC1808 raw images compared to those with the generic compression methods. Our approach makes use of the IR astronomy signal characteristics and the limited resources for better fit the compression needs to the available resources.

6. CONCLUSION

In this paper, a novel on-board data processing concept is proposed, that was dedicated for the Herschel-PACS mission of the European Space Agency (ESA). We have described the key modules like ramp fitting and glitch detection in detail. Our concept combines lossy and lossless compression; the presented method offers a high compression ratio with a minimal loss of potentially useful scientific data. It also provides higher signal-to-noise ratio than that for standard compression techniques. In [19] we illustrate the feasibility of the method presented in this paper on data from Infrared Space Observatory (ISO).

ACKNOWLEDGMENT

This work is supported by a grant from the Federal Ministry of Science, Innovation and Transport and the Austrian Space Agency.

REFERENCES

[1] I. S. Glass, *Handbook of Infrared Astronomy*, Cambridge University Press, Cambridge, UK, 1999.

[2] A. N. Belbachir, H. Bischof, and F. Kerschbaum, "A data compression concept for space application," in *Proc. IEEE Digital Signal Processing Workshop (DSP-SPE '00)*, Hunt, Tex, USA, October 2000.

[3] R. Buccigrossi and E. Simoncelli, "Image compression via joint statistical characterization in the wavelet domain," *IEEE Trans. Image Processing*, vol. 8, no. 12, pp. 1688–1701, 1999.

[4] W. Press, "Wavelet-based compression software for FITS images," in *Astronomical Data Analysis Software and Systems I*, D. M. Worrall, C. Biemesderfer, and J. Barnes, Eds., vol. 25 of *A.S.P. Conf. Ser.*, pp. 3–16, Tucson, Ariz, USA, 1992.

[5] J. Sanchez and M. P. Canton, *Space Image Processing*, CRC Press, Boca Raton, Fla, USA, 1999.

[6] R. L. White, M. Postman, and M. G. Lattanzi, *Digitized Optical Sky Surveys*, Kluwer Academic, Amsterdam, The Netherlands, H. T. MacGillivray and E. B. Thomson Eds., 1992.

[7] M. Datcu and G. Schwarz, "Advanced image compression: specific topics for space applications," in *Proc. 6th International Workshop on Digital Signal Processing Techniques for Space Applications (DSP '98)*, Noordwijk, The Netherlands, September 1998.

[8] M. Louys, J. L. Starck, S. Mei, F. Bonnarel, and F. Murtagh, "Astronomical image compression," *Astronomy and Astrophysics Supplement Series*, vol. 136, no. 3, pp. 579–590, 1999.

[9] J. L. Starck, D. L. Donoho, and E. J. Candès, "Astronomical image representation by the curvelet tansform," *Astronomy & Astrophysics*, vol. 398, no. 2, pp. 785–800, 2003.

[10] A. N. Belbachir and H. Bischof, "On-board data compression: noise and complexity related aspects," Tech. Rep. 75, PRIP, Vienna University of Technology, Vienna, Austria, 2003.

[11] A. Poglitsch, C. Waelkens, O. H. Bauer, et al., "The photodetector array camera and spectrometer (PACS) for the Herschel

space observatory," in *Bulletin of the American Astronomical Society*, vol. 36, 2004, AAS 204th Meeting, Denver, Colo, USA.
[12] G. L. Pilbratt, "The Herschel mission, scientific objectives, and this meeting," in *The Promise of the Herschel Space Observatory*, vol. 460 of *ESA-SP*, pp. 13–20, Toledo, Spain, July 2001.
[13] R. Ottensamer, A. N. Belbachir, H. Bischof, et al., "Herschel/PACS onboard reduction/compression software implementation," in *International Symposium on Astronomical Telescopes*, vol. 5487 of *Proceedings of SPIE*, Glasgow, Scotland, UK, June 2004.
[14] G. Held, *Data and Image Compression*, John Wiley & Sons, New York, NY, USA, 1996.
[15] D. Taubman, E. Ordentlich, M. Weinberger, and G. Seroussi, "Embedded block coding in JPEG 2000," *Signal Processing: Image Communication*, vol. 17, no. 1, pp. 49–72, 2002.
[16] http://www.winzip.com.
[17] http://www.rarlab.com.
[18] D. Taubman, "High performance scalable image compression with EBCOT," *IEEE Trans. Image Processing*, vol. 9, no. 7, pp. 1158–1170, 2000.
[19] C. Reimers, A. N. Belbachir, H. Bischof, et al., "A feasibility study of on-board data compression for infrared cameras of space observatories," in *Proc. 17th International Conference on Pattern Recognition (ICPR '04)*, vol. 1, pp. 524–527, Cambridge, UK, August 2004.

Ahmed Nabil Belbachir received the Electronic Engineering degree in 1996 and the M.S. degree in signal processing, 2000, from the University of Science and Technology of Oran, (USTO) Algeria. In March 2005, he was awarded the Ph.D. degree in computer science from the Vienna University of Technology. Currently, he is a Research Fellow at the Pattern Recognition and Image Processing Group at the Vienna University of Technology and he is involved in the ESA-Herschel Project, where he is responsible for the data reduction and image compression for PACS instrument. He has developed the on-board reduction/compression software for the IR photo-detector camera PACS. His research interests are digital filter design, data compression, signal/image processing, and real-time systems where he has published more than 20 scientific publications. He is a Member of the IAPR TC13 (Technical Committee for Pattern Recognition in Astronomy and Astrophysics), AAPR (Austrian Association for Pattern Recognition), OeGAA (Austrian Association for Astronomy and Astrophysics), and EURASIP. He is also a reviewer for the IEEE Signal/Image Processing, the Elsevier Digital Signal Processing, and the Journal of Intelligent and Fuzzy Systems.

Horst Bischof received his M.S. and Ph.D. degrees in computer science from the Vienna University of Technology in 1990 and 1993, respectively. In 1998, he got his Habilitation (venia docendi) for applied computer science. Currently, he is a Professor at the Institute for Computer Graphics and Vision at the Technical University of Graz, Austria. He is also a key researcher at the recently founded K+ Competence Center "Advanced Computer Vision" where he is responsible for research projects in the area of classification. His research interests include object recognition, visual learning, medical computer vision, neural networks, and adaptive methods for computer vision, where he has published more than 210 scientific papers. He was Cochairman of international conferences (ICANN, DAGM), and Local Organizer for ICPR'96. He is the Program Cochair of ECCV2006. Currently, he is an Associate Editor for Pattern Recognition Journal, Computer and Informatics Journal, and Journal of Universal Computer Science. He is currently the Vice-Chair of the Austrian Association for Pattern Recognition. He has received an award from the Pattern Recognition Journal in 2002, where the paper "Multiple eigenspaces" has been selected as the most original manuscript.

Roland Ottensamer received his M.S. degree in 2004 from the Institute for Astronomy in Vienna, where he holds a research position. During the last four years, he was highly involved in the development of the data compression/decompression software for the IR photo-detector camera PACS and has presented his work at the major conferences for instrumentation in astronomy. He is currently working on the development of the interactive analysis framework for Herschel. His research interests are astronomy and computer science with special emphasis on data mining and processing. He is a Founder Member of OeGAA.

Franz Kerschbaum received his Ph.D. degree with distinction from the University of Vienna in 1993. Between 1997 and 2000, Kerschbaum received an APART-Grant of the Austrian Academy of Sciences. In 2000, he got his Habilitation in observational astrophysics. Since 2001, he has been an Associate Professor at the Institute for Astronomy at the University of Vienna. He is a referee, evaluator, or expert for the Sixth European Union Framework Programme, the European Space Agency, Deutsche Forschungsgemeinschaft, Italian Space Agency, Instituto de Astrofisica de Canarias, Katholieke Universiteit Leuven, Friedrich-Schiller-Universität Jena, A&A, A&A Letters, and MNRAS. His research interests include late stages of stellar evolution, astromineralogy, instrumentation, space experiments, and history of astronomy, where he has published more than 140 publications in scientific journals, and 25 articles in popular media, and he was invited to several lectures. He is the cofounder and Board Member of the Österreichische Gesellschaft für Astronomie und Astrophysik, Member of International Astronomical Union, European Astronomical Society, Astronomische Gesellschaft, Pro Scientia, and Forum Sankt Stephan, as well as Member of ESAs Astronomy Working Group from 1999 to 2001, being also a Deputy Head in the year 2001.

Christian Reimers is an Astrophysicist with special interest in theoretical and computational modelling of radiation hydrodynamic problems and the shaping of planetary nebulae. After graduating from the Technical High School for Communications Engineering in Rankweil, Austria, he entered the studies of astronomy and physics at the University of Vienna, Austria. In 1999, he obtained the M.S. degree in astronomy at the Institute of Astronomy (IfA) from the University of Vienna which was awarded the price of appreciation of the Austrian Federal Ministry for Education, Science and Culture. While pursuing his Ph.D. at IfA, he joined the Herschel/PACS Team to work on the development of the compression software and related documentation for the ESA cornerstone mission Herschel from 2001 to 2003. Since 2001, he is a Tutor for "Introduction to Astronomy: Part II" at IfA. He is a Member of OeGAA (Austrian Association for Astronomy and Astrophysics). His ambition is to finish his Ph.D. in 2005.