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Space data and information transfer systems — Image data compression

*Systèmes de transfert des données et informations spatiales —
Compression des données d'images*



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Foreword

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ISO 26868 was prepared by the Consultative Committee for Space Data Systems (CCSDS) (as CCSDS 122.0-B-1, November 2005, incorporating the Technical Corrigenda CCSDS 122.0-B-1 Cor.1, July 2006, and CCSDS 122.0-B-1 Cor.2, July 2008) and was adopted (without modifications except those stated in Clause 2 of this International Standard) by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 13, *Space data and information transfer systems*.

This corrected version of ISO 26868:2009 also incorporates the corrections of Technical Corrigendum CCSDS 122.0-B-1 Cor.3, September 2011. Corrections are identified by a bar in the margin and the designation "Cor.3"; a summary of corrections is given on page v of the enclosed CCSDS publication. In addition, the information in Clause 2 of this International Standard has been updated.

Space data and information transfer systems — Image data compression

1 Scope

This International Standard establishes a data compression algorithm applicable to two-dimensional digital spatial image data from payload instruments and specifies how this compressed data is formatted into segments to enable decompression at the receiving end.

Source coding for data compression is a method utilized in data systems to reduce the volume of digital data to achieve benefits in areas including, but not limited to:

- reduction of transmission channel bandwidth;
- reduction of the buffering and storage requirement;
- reduction of data-transmission time at a given rate.

The scope and field of application are further detailed in subclauses 1.2 and 1.3 of the enclosed CCSDS publication.

2 Requirements

Requirements are the technical recommendations made in the following publication (reproduced on the following pages), which is adopted as an International Standard:

CCSDS 122.0-B-1, November 2005¹⁾, *Image data compression*

For the purposes of international standardization, the modifications outlined below shall apply to the specific clauses and paragraphs of publication CCSDS 122.0-B-1.

Pages i to v

This part is information which is relevant to the CCSDS publication only.

Page B-1

Add the following information to the reference indicated:

- [B2] Document CCSDS 121.0-B-1, May 1997, is equivalent to ISO 15887:2000.
- [B3] Document CCSDS 133.0-B-1, September 2003, is equivalent to ISO 22646:2005.
- [B5] Document CCSDS 732.0-B-2, July 2006, is equivalent to ISO 22666:2007.

1) Incorporating the Technical Corrigenda CCSDS 122.0-B-1 Cor.1, July 2006, CCSDS 122.0-B-1 Cor.2, July 2008, and CCSDS 122.0-B-1 Cor.3, September 2011.

3 Revision of publication CCSDS 122.0-B-1

It has been agreed with the Consultative Committee for Space Data Systems that Subcommittee ISO/TC 20/SC 13 will be consulted in the event of any revision or amendment of publication CCSDS 122.0-B-1. To this end, NASA will act as a liaison body between CCSDS and ISO.

Recommendation for Space Data System Standards

IMAGE DATA COMPRESSION

RECOMMENDED STANDARD

CCSDS 122.0-B-1

Note:
This current
issue includes
all updates through
Technical Corrigendum 3,
dated September 2011.

BLUE BOOK
November 2005

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This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and represents the consensus technical agreement of the participating CCSDS Member Agencies. The procedure for review and authorization of CCSDS Recommended Standards is detailed in *Procedures Manual for the Consultative Committee for Space Data Systems*, and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the address below.

This Recommended Standard is published and maintained by:

CCSDS Secretariat
 Space Communications and Navigation Office, 7L70
 Space Operations Mission Directorate
 NASA Headquarters
 Washington, DC 20546-0001, USA

STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of its members. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **Recommended Standards** and are not considered binding on any Agency.

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- o Whenever a member establishes a CCSDS-related **standard**, that member will provide other CCSDS members with the following information:
 - The **standard** itself.
 - The anticipated date of initial operational capability.
 - The anticipated duration of operational service.
- o Specific service arrangements shall be made via memoranda of agreement. Neither this **Recommended Standard** nor any ensuing **standard** is a substitute for a memorandum of agreement.

No later than five years from its date of issuance, this **Recommended Standard** will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or canceled.

In those instances when a new version of a **Recommended Standard** is issued, existing CCSDS-related member standards and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each member to determine when such standards or implementations are to be modified. Each member is, however, strongly encouraged to direct planning for its new standards and implementations towards the later version of the Recommended Standard.

FOREWORD

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, which are defined in the *Procedures Manual for the Consultative Committee for Space Data Systems*. Current versions of CCSDS documents are maintained at the CCSDS Web site:

<http://www.ccsds.org/>

Questions relating to the contents or status of this document should be addressed to the CCSDS Secretariat at the address indicated on page i.

At time of publication, the active Member and Observer Agencies of the CCSDS were:

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- Swedish Space Corporation (SSC)/Sweden.
- United States Geological Survey (USGS)/USA.

DOCUMENT CONTROL

Document	Title	Date	Status/Remarks
CCSDS 122.0-B-1	Image Data Compression, Recommended Standard, Issue 1	November 2005	Original issue
CCSDS 122.0-B-1 Cor. 1	Technical Corrigendum 1	July 2006	Changes text on pages 1-1 and 4-3
EC 1	Editorial Change	July 2008	Updates Secretariat address on page i and references in annex B
CCSDS 122.0-B-1 Cor. 2	Technical Corrigendum 2	July 2008	Changes text in table 4-10
CCSDS 122.0-B-1 Cor. 3	Technical Corrigendum 3	September 2011	– Corrects 4.2.5.2.11 to refer to Segment Header Part 4 rather than Part 2; – Corrects wording in 4.3.1.6, 4.3.3, 4.3.1.7, 4.3.3.1, and 4.3.3.2 where a literal reading of the (uncorrected) standard would have had a user encode a negative number of bits.

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to establish a Recommended Standard for a data compression algorithm applied to two-dimensional digital spatial image data from payload instruments and to specify how this compressed data shall be formatted into segments to enable decompression at the receiving end.

Source coding for data compression is a method utilized in data systems to reduce the volume of digital data to achieve benefits in areas including, but not limited to,

- a) reduction of transmission channel bandwidth;
- b) reduction of the buffering and storage requirement;
- c) reduction of data-transmission time at a given rate.

1.2 SCOPE

The characteristics of instrument data are specified only to the extent necessary to ensure multi-mission support capabilities. The specification does not attempt to quantify the relative bandwidth reduction, the merits of each approach discussed, or the design requirements for coders and associated decoders. Some performance information is included in reference [B1].

This Recommended Standard addresses image data compression, which is applicable to a wide range of space-borne digital data, where the requirement is for a scalable data reduction, including the option to use lossy compression, which allows some loss of fidelity in the process of data compression and decompression. Reference [B1] gives an outline for an implementation.

1.3 APPLICABILITY

This Recommended Standard applies to data compression applications of space missions anticipating packetized telemetry cross support. In addition, it serves as a guideline for the development of compatible CCSDS Agency standards in this field, based on good engineering practice.

1.4 RATIONALE

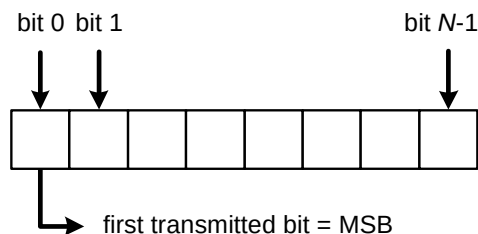
The concept and rationale for the Image Data Compression algorithm described herein may be found in reference [B1].

Cor. 1

1.5 CONVENTION

In the specification of headers for compressed data, the following convention is used to identify each bit in an N -bit word. The first bit in the word to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0'; the following bit is defined to be 'Bit 1' and so on up to 'Bit $N-1$ '. When the word is used to express an unsigned binary value (such as a counter), the Most Significant Bit (MSB) shall correspond to the highest power of two, i.e., 2^{N-1} .

NOTE – This bit numbering convention applies to segment headers described in 4.2. A different numbering convention is used to index magnitude bits in Discrete Wavelet Transform (DWT) coefficients, as described in 4.1.



In accordance with modern data communications practice, spacecraft data words are often grouped into eight-bit 'words' that conform to the above convention. Throughout this Recommended Standard, the following nomenclature is used to describe this grouping:

8-Bit Word = 'Byte'

1.6 DEFINITIONS

In this document, for any real number x , the largest integer n such that $n \leq x$ shall be denoted by

$$n = \lfloor x \rfloor,$$

and correspondingly, the smallest integer n such that $n \geq x$ by

$$n = \lceil x \rceil.$$

The modulus m of a number M with respect to a divisor n is denoted by

$$m = M \bmod n.$$

The statement that a value M is coded mod n means the number

$$m = M \bmod n$$

is coded instead of M .

1.7 NOMENCLATURE

The following conventions apply throughout this Recommended Standard:

- a) the words ‘shall’ and ‘must’ imply a binding and verifiable specification;
- b) the word ‘should’ implies an optional, but desirable, specification;
- c) the word ‘may’ implies an optional specification;
- d) the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

In the normative sections of this document (sections 3 and 4), informative (i.e., non-normative) text is differentiated from normative text through the following convention:

- a) notes introduce brief informative statements;
- b) the following headings introduce one or more paragraphs of informative text:
 - Overview;
 - Rationale.

1.8 REFERENCES

This Recommended Standard contains no normative references. Informative references are listed in annex B.

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2 OVERVIEW

2.1 GENERAL

This Recommended Standard defines a particular payload image data compression algorithm that has widespread applicability to many types of instruments. This Recommended Standard does not attempt to explain the theory underlying the operation of the algorithm, which is partially addressed in [B1].

There are two classes of data compression methods: lossless and lossy. Under lossless compression, the original data can be reproduced exactly, while under lossy compression, quantization or other approximations used in the compression process result in the inability to reproduce the original data set without some distortion. The increased information content of data subjected to lossless compression results in a larger volume of compressed data for a given source data set.

The compression technique described in this Recommended Standard can be used to produce both lossy and lossless compression. An alternative lossless compression technique, which has lower complexity but is not specifically tailored for imagery, has been previously adopted by CCSDS (see reference [B2]). The JPEG2000 standard is another image compressor (see reference [B6]). The present Recommended Standard differs from the JPEG2000 standard in several respects:

- a) it specifically targets high-rate instruments used on board of spacecraft;
- b) a trade-off has been performed between compression performance and complexity with particular emphasis on spacecraft applications (cf. a);
- c) the lower complexity of this recommendation supports fast and low-power hardware implementation;
- d) it has a limited set of options, supporting its successful application without in-depth algorithm knowledge.

The compressor consists of two functional parts, depicted in figure 2-1, a Discrete Wavelet Transform module that performs decorrelation, described in section 3, and a Bit-Plane Encoder which encodes the decorrelated data, described in section 4.

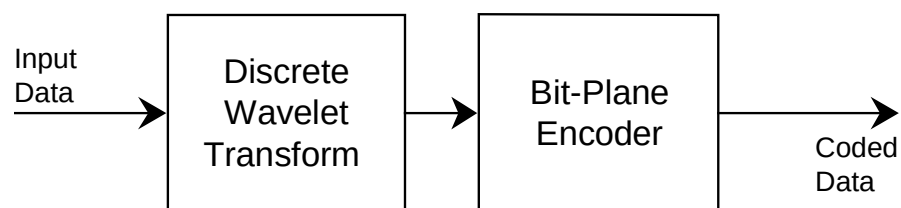


Figure 2-1: General Schematic of the Coder

This Recommended Standard supports both frame-based input formats produced, for example, by CCD arrays (called image frames) and strip-based input formats produced by push-broom type sensors (called image stripmaps). An image pixel dynamic range of up to 16 bits is supported. The algorithm specified supports a memory-effective implementation of the compression procedure which does not require large intermediate frames for buffering (see reference [B1]).

2.2 DATA DELIVERY

The encoded bitstream corresponding to an image frame or stripmap, consists of a single segment or a sequence of segments. Each segment consists of a header followed by a coded data field. A segment can have either fixed length or variable length depending on the operational mode selected. Values of algorithm parameters used in encoding can be specified using the header defined in section 4.

The effects of a single bit error can propagate to corrupt reconstructed data to the end of the affected segment (see reference [B1]). Therefore measures should be taken to minimize the number of potential bit errors on the transmission link. The transport mechanism for the delivery of the encoded bitstream shall support, in the event of a bit error, the ability to relocate the header of the next segment.

In case the encoded bitstream is to be transmitted over a CCSDS space link, several protocols can be used to transfer the sequence of segments. Those protocols are specified in references:

- reference [B3], Space Packet Protocol;
- reference [B4], CCSDS File Delivery Protocol (CFDP);
- reference [B5], packet service or bitstream service as provided by the AOS Space Data Link Protocol.

Interface to those space link protocols and related issues are discussed in reference [B1].

3 DESCRIPTION OF THE DISCRETE WAVELET TRANSFORM

3.1 OVERVIEW

This Recommended Standard for the decorrelation module makes use of a three-level, two-dimensional (2-d), separable Discrete Wavelet Transform (DWT) with nine and seven taps for low- and high-pass filters, respectively. Such a transform is produced by repeated application of a one-dimensional (1-d) DWT described in 3.3, 3.5, and 3.7. Two specific 1-d wavelets are specified with this Recommended Standard: the 9/7 biorthogonal DWT, referred to as ‘9/7 Float DWT’ or simply ‘Float DWT’, and a non-linear, integer approximation to this transform, referred to as ‘9/7 Integer DWT’ or simply ‘Integer DWT’.

The definition of the functional inverse of either DWT is included in 3.4, 3.6, and 3.8.

While the Float DWT generally exhibits superior compression efficiency in the lossy domain, only the Integer DWT supports strictly lossless compression.

Image data is assumed to use R -bit pixels to represent either signed or unsigned integer values, where $R \leq 16$.

The values output from the 3-level 2-d DWT (see 3.7) are converted to appropriate integer values before applying the Bit Plane Encoder (BPE—see section 4). Each integer is represented using a binary word consisting of a single sign bit along with several magnitude bits. The maximum word size necessary to store each such integer depends on R .

In the case of the Float DWT, the computed wavelet domain values are rounded to the respective nearest integers before applying the BPE. A corresponding word length of $R+5$ bits is adequate to store these integer values.

In the case of the Integer DWT, before applying the BPE, the computed wavelet domain values are multiplied by integer weights that are uniform in each subband (see 3.9). A corresponding word length of $R+4$ bits is adequate to store such integers before the weighting factors are applied. Following the weighting operation, longer words might be used to store wavelet coefficients in some implementations.

Implementation schemes and image reconstruction methods are not part of this Recommended Standard, although some approaches are outlined in reference [B1]. Compressor implementations can differ considerably depending, for example, on whether the implementation waits for an entire frame to be formed before beginning compression.