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Scientific data products and the data pre-processing subsystem of the Chang'e-3 mission

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Abstract The Chang'e-3 (CE-3) mission is China's first exploration mission on the surface of the Moon that uses a lander and a rover. Eight instruments that form the scientific payloads have the following objectives: (1) investigate the morphological features and geological structures at the landing site; (2) integrated in-situ analysis of minerals and chemical compositions; (3) integrated exploration of the structure of the lunar interior; (4) exploration of the lunar-terrestrial space environment, lunar surface environment and acquire Moon-based ultraviolet astronomical observations. The Ground Research and Application System (GRAS) is in charge of data acquisition and pre-processing, management of the payload in orbit, and managing the data products and their applications. The Data Pre-processing Subsystem (DPS) is a part of GRAS. The task of DPS is the pre-processing of raw data from the eight instruments that are part of CE-3, including channel processing, unpacking, package sorting, calibration and correction, identification of geographical location, calculation of probe azimuth angle, probe zenith angle, solar azimuth angle, and solar zenith angle and so on, and conducting quality checks. These processes produce Level 0, Level 1 and Level 2 data. The computing platform of this subsystem is comprised of a high-performance computing cluster, including a real-time subsystem used for processing Level 0 data and a post-time subsystem for generating Level 1 and Level 2 data. This paper describes the CE-3 data pre-processing method, the data pre-processing subsystem, data classification, data validity and data products that are used for scientific studies.

Key words: Moon: data products — methods: data pre-processing — space vehicles: instruments

1 INTRODUCTION

The Chang'e-3 (CE-3) mission is China's first lunar surface exploration mission. It has both a lander and a rover (Sun et al. 2013). Launched at 17:30 (GMT), 2013 December 1, the mission is part of the second phase of China's Lunar Exploration Program (CLEP) that has the ultimate goal of launching manned flights to the Moon. Previously, the first phase of China's robotic lunar exploration program had two orbital probes, Chang'e-1 (CE-1) and Chang'e-2 (CE-2), that were launched in 2007 and 2010, respectively (Ip et al. 2014).

The Data Pre-processing Subsystem (DPS) is a segment of the Ground Research and Application System (GRAS) of CLEP. DPS has two main components, (i) construct an advanced system designed to support the production of data produced by the Chang'e series of probes, (ii) form teams of scientists who are developing the algorithms to the data products. DPS has successfully pretreated the datasets from the CE-1 and CE-2 missions, and they are categorized into Level 0, Level 1 and Level 2 data products. These products have been archived in the data archive center at GRAS, and are openly accessible to the whole science community. A series of studies (Ouyang et al. 2010; Li et al. 2010a,b; Wang et al. 2011; Wang et al. 2012; Zheng et al. 2012) has been conducted using these products, and further application is still ongoing.

CE-3 data products are stored according to the Planetary Data System (PDS) archiving standard (Planetary Data System Standards Reference[1]; McMahon 1996; Hughes & Li 1993). PDS format is widely used in the archiving of datasets from space science missions, especially planetary missions launched and administered by different agencies. Some examples include NASA's Lunar Reconnaissance Orbiter (Vondrak et al. 2010), JAXA's Kaguya (Haruyama et al. 2008), ESA's Mars Express (Zender et al. 2009), and CNSA's CE-1 and CE-2 missions (Zuo et al. 2014). For the design of data storage facilities used by CE-3, the administrators of data products should consider not only the similarity with data products from other missions, but also the different purposes for various application fields, in order to provide appropriate information.

After the CE-1 and CE-2 missions were completed, a common processing flow and product structure had been formed. However, the CE-3 mission has its own set of unique challenges.

This paper is organized as follows: Section 2 describes the Exploration Mission and data. Section 3 gives the DPS, and methods of unpacking and fusion, calibration, and determination of observation geometry. Section 4 designs CE-3 data products. Section 5 describes how data products are constructed. Section 6 concludes the paper.

2 CE-3 SCIENCE EXPLORATION MISSION AND DATA

The CE-3 rover was designed for a mission that would span three lunar days, but only operated for two lunar days. The lander was designed for operate for 12 lunar days and completed its planned mission. Eight instruments that constitute the scientific payloads cover the following scientific objectives: (1) investigation of morphological features and geological structures at the landing site; (2) integrated in-situ analysis of minerals and chemical composition at the landing site; (3) integrated exploration of the structure of the lunar interior; (4) exploration of the lunar-terrestrial space environment, lunar surface environment and acquisition of Moon-based ultraviolet astronomical observations. Instruments on the lander are the Landing Camera (LCAM) (Liu et al. 2014), Terrain Camera (TCAM), Extreme Ultraviolet Camera (EUVC) (Chen et al. 2014) and Moon-based Ultraviolet Telescope (MUVT) (Wen et al. 2014). The four instruments on the Yutu rover are the Panoramic Camera (PCAM) (Ren et al. 2014). Visible/Near-Infrared Imaging Spectrometer (VNIS) (He et al. 2014), Active Particle-induced X-ray Spectrometer (APXS) (Fu et al. 2014) and Lunar Penetrating Radar (LPR) (Fang et al. 2014). Table 1 describes CE-3's science exploration tasks and data types by instrument.

3 CE-3 DATA PRE-PROCESSING SUBSYSTEM AND METHOD

CE-3 data are firstly packed according to standards advocated by the Consultative Committee for Space Data Systems (CCSDS). Then the data from both the lander and the rover are transferred to a ground station through multiple virtual channels, which are in the format of raw data. This is followed by the subsequent pre-processing of the raw data including Reed-Solomon (RS) decoding, descrambling, extraction of each instrument's scientific data by virtual channel and source packet

[1] *http://pds.nasa.gov/documents/sr/stdref2003/stdref_030801.pdf*

identification, reformat, conversion of physical quantities, calibration and correction, identification of geographical location, calculation of probe azimuth angle, probe zenith angle, solar azimuth angle, solar zenith angle and so on, and conducting quality checks. The data pre-processing has the following characteristics:

(i) Multiple data sources
The whole CE-3 dataset contains data from four sources: two probes (lander and rover) and two ground stations (Miyun Station and Kunming Station). In particular, data from the rover are first transmitted to the lander through the Ultra High Frequency (UHF) antenna (Sun et al. 2014), and then transmitted to Earth in the same data package as the lander data. Because the package structures of the data from the lander and the rover are different, the unpacking methods for the two probes are completely different. How to design a pretreatment process that can fuse the data is the primary consideration.

(ii) Various types of data
Since there are various types of data, including images in visible, EUV and NUV bands multi-spectral data, radar data and spectral data, these should be presented in various formats, metadata, and corresponding auxiliary information.

(iii) The exploratory investigation of data pre-processing methods.

Although all instruments have been comprehensively calibrated on the ground, differences still exist between measurements made on the Moon and those made on the ground. For example, images from the MUVT and EUVC were contaminated by stray light depending on the local topography of the landing site; LPR data also need extra normalization and gain removal. Therefore, the DPS must be flexible enough to support implementing new data processing methods.

Table 1 CE-3 Science Exploration Tasks and Data Types by Instrument

Instrument	Data Type	Science Exploration Task
LCAM	Visible image of the landing area, effective pixel number: 1024×1024, pixel size in the focal plane: 6.7 μm	Analysis of surface topography around the landing area
TCAM	Provides image of the landing zone data at high resolution, effective pixel number is 2352×1728 (static mode), 720×576 (dynamic mode), the pixel size is 7.4 μm	Investigation and study on the lunar surface topography
MUVT	Continuous near-ultraviolet (NUV) images at a detection limit down to magnitude 13; collects images over a year in a selected area	Continuous long term measurements of brightness variations of various astronomical sources in NUV; conduct a survey of a selected area
EUVC	Continuous wide-field image data of Earth's plasmasphere in extreme ultraviolet (EUV)	EUV band imaging of Earth's plasmasphere
PCAM	High resolution image data of the area traversed by the Yutu rover, effective pixel number is 2352×1728, the pixel size is 7.4 μm	Topographic research about the area traversed by the Yutu rover; investigation and study of crater geological structure
LPR	Radar data of the Moon, center frequency: 60 MHz (1st channel), 500 MHz (2nd channel)	regolith thickness and subsurface structure exploration
VNIS	Optical spectral data, effective number of pixels is 256×256	In-situ measurements of mineralogical composition (mineralogical content and distribution)
APXS	Spectral data, energy resolution: 80–150 eV at 5.9 keV FWHM	In-situ measurements of chemical composition (element content and distribution)

3.1 The Design of the Data Pre-processing Flow for CE-3

The CE-3 data processing flow is categorized into three levels, Level 0, Level 1 and Level 2 (Table 2). Level 0 is further divided into Level 0A and Level 0B. Level 0 and Level 1 processing is applied to all instruments onboard, but Level 2 processing varies among different instruments (Table 3).

Table 2 Definitions of the Processing Levels

Processing Level	Processing Steps Since the Last Level
Level 0A	Channel processing, unpacking, time-tagging and grouping by payload
Level 0B	Package sorting, optimal splicing, removal of duplicates, source package header removal and generation of data blocks by science payload. Moreover, the TCAM, LCAM and MUVT data are decompressed.
Level 1	Conversion from raw measurements to physical quantities, framing by observation cycles. (An observation cycle for the lander is an Earth day, and that for the rover is the period of a planned exploration project.)
Level 2	Usually divided into L2A, L2B and L2C. Payload dependent. L2A mainly includes system calibration. L2B mainly includes geometric positioning. L2C varies according to users' requirements.

Table 3 Level 2 Data Processing of Payloads

Payload	Data Level	Data Processing
PCAM /TCAM	L2A	Dark current calibration, relative radiometric calibration and normalization.
	L2B	Add a vector that contains the geometric information about the observed image including four corner points and the center point, camera center position, camera rotation angle, solar incidence angle, solar azimuth angle, mast pitch angle and mast yaw angle.
	L2C	Based on Level 2B data, color restoration and color correction.
LPR	L2A	Normalization according to cumulative number of channels, gain removal and DC removal.
	L2B	Add the position of a reference point relative to the current position; Add the attitude of the reference point relative to the current attitude.
	L2C	Band-pass filter.
VNIS	L2A	Salt-and-pepper noise subtraction, dark subtraction, temperature calibration, flat field calibration and radiance conversion using preflight and in-situ calibration coefficients.
	L2B	Add the instrument's parameters: focal length, pixel size and principle point position. Add the rover location and center point location. Add the geometric information including the center point and incidence angle, azimuth angle and phase angle of the four corner points.
APXS	L2A	Working distance calculation, energy calibration and dead-time correction.
	L2B	Add the geometric information, including the longitude, latitude, elevation and attitude of the rover.
LCAM	L2A	Relative radiometric calibration.
	L2B	Geometric distortion correction with the longitude and latitude of the grid spacing with 32×32 pixels. The incidence angle, azimuth angle, phase angle, solar incidence angle and solar azimuth angle of the central point.
EUVC	L2A	Radiometric calibration, geometric distortion correction, image resampling, dark current calibration, image rotation, image cropping and stray light reduction.
	L2B	Add the geometric information, including camera observation vector in the solar magnetic coordinates (SM).
MUVT	L2A	Overscan correction, stray light reduction and flat field calibration.
	L2B	Add the geometric information, including gimbal azimuth, gimbal pitch, right ascension and declination in J2000

3.2 CE-3 Data Pre-processing Methods

3.2.1 Methods for unpacking and fusion of lander data

The structure of the source data package from the lander is complex. Besides the scientific data, each data record also contains information about the status of the payload (e.g. exposure time, gain, voltage, etc.). They are transmitted to the ground after being split into a series of packages. Those packages must first be spliced into the original order. Duplicate bytes must be removed to ensure the uniqueness of the data product. Suppose DATA0 represent the raw data, then the processing method is illustrated in Figure 1.

Step1 Channel processing: the effective data from each channel, DATA1, are extracted according to the virtual channel identifiers. Each payload in the lander occupies a virtual channel, therefore the data from a single payload can be extracted directly after channel processing.

Step2 Scientific data extraction and time definition: the length of scientific data in DATA2 is determined according to the data pointer in DATA1. The time in the header of the frame is defined as the data acquisition time.

Step3 Image data decompression: Images from LCAM, TCAM and MUVT are decompressed. Due to probable loss in the data transmission link, the decompression method focuses on the compensation of data loss. For LCAM and MUVT, missing pixels are filled with zeros. TCAM produces true-color images in Bayer format, and the G component and RB components of which are transmitted independently. If the RB component is missing during transmission, image information can be somewhat retained by the G component.

Step4 Merging and optimization of data copies transmitted from two stations. Two copies of the same data from two ground stations are first merged. Then the copy with the better quality is retained and duplicate data are trimmed. The data are sorted according to the time and frame number.

Step5 Framed by an Earth day.

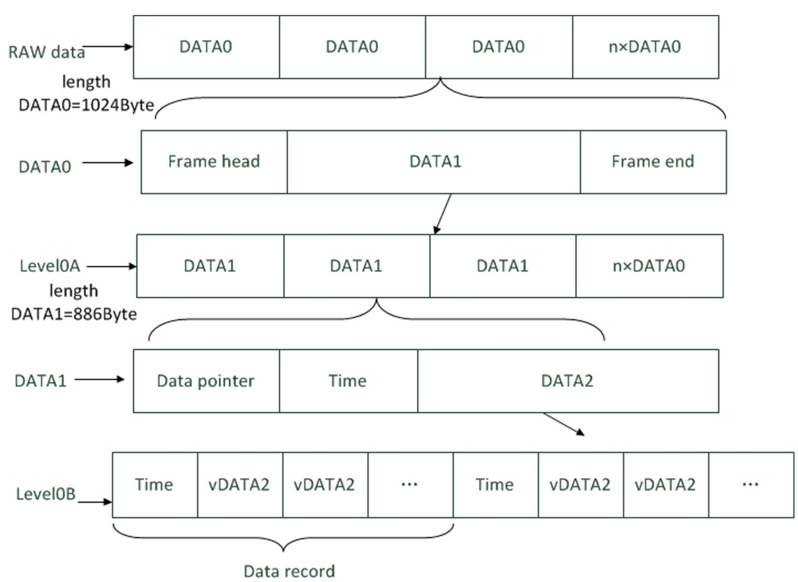

Fig. 1 The process of unpacking raw data from the lander.

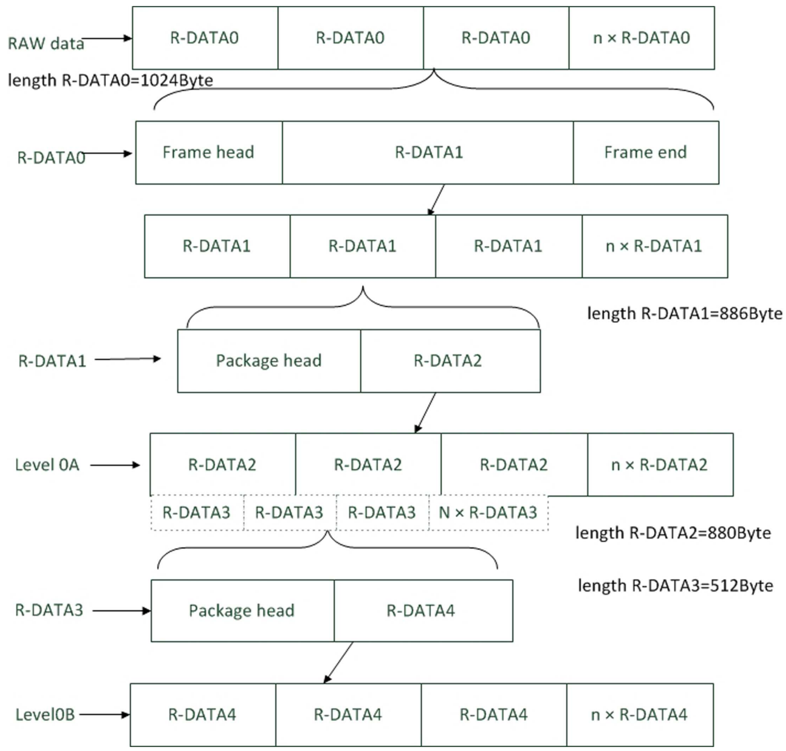

Fig. 2 Process of unpacking raw data from the rover.

3.2.2 Methods for unpacking and fusion of rover data

Unlike the package structure of the lander, the rover payload data are packed into 512-byte packages by the electronic control unit on the rover before being transmitted to the integrated electronic system of the rover. Then the integrated electronic system will pack it again for transmission. There are two routes of ground transmission from the rover: independent transmission and via the lander using its UHF antenna. The merging of data from these two routes is central in this step. Details are shown in Figure 2.

R-DATA1, R-DATA2 and R-DATA3 are sequentially extracted from R-DATA0. The inclusion relation of the three is R-DATA3⊂R-DATA2⊂ R-DATA1. Lengths of the three data blocks are: R-DATA1 = 886B, R-DATA2 = 880B and R-DATA3 = 512B. Then, according to the label associated with the R-DATA3 source package, R-DATA4 are extracted, which become a block of scientific data from the payload.

The fusion of rover data consists of two steps. The first step is the fusion of the two copies of data received by two ground stations in the Level 0B process, identical to that of the lander. The second step in the fusion uses similar methods, but between the two data copies that are downlinked directly from the rover via the lander. This is done during the Level 1 processing. After this step, the rover data are organized by specific tasks involved in scientific exploration.

3.2.3 Methods for calibration

According to the characteristics of a particular payload, the calibration methods used are different. Optical instruments such as LCAM, TCAM, PCAM and VNIS use the same calibration methods. The calibration methods include dark current calibration, relative radiometric calibration and normalization (brightness adjustment for different exposure times). VNIS needs extra calibrations which are salt-and-pepper noise reduction for the visible band and temperature correction for the near-infrared band.

For MUVT and EUVC, stray light is a critical source of interference that needs to be reduced. For a series of n ($n \geq 3$) images in the same group (same type of observation and same gimbals' point) of MUVT, the stray light image stray_k for a target image obj_k is calculated by the $n-1$ images except for the target image. The $n-1$ images in the group are first aligned by the characteristic features that need to be observed, and then points that are outside the confidence interval are eliminated. Then, the median value of the overlapping pixels in these images is taken to be the pixel value in the stray light image. EUVC, on the other hand, will take dedicated reference stray images for various scanner positions with respect to various solar altitude angles. Therefore the stray image of a specific observation image is the most recent reference image multiplied by the stray light coefficient.

The calibrations of LPR data include the gain reduction, and direct current reduction. The calibrations of APXS data include the determination of detection mode, dead time correction and energy calibrations.

3.2.4 Methods for determining observation geometry

The principle of determining observation geometry is to give the position and attitude of the observation point as a function of ephemeris time. The processes involve the various parameters including ephemeris (or position), attitude, sensor used and the transformation between various coordinate systems. The rotation and shape of the Moon are also taken into consideration.

During the descent phase, the only instrument that operates is LCAM. The geometric positioning of the LCAM is based on a triangle formed by the CE-3 lander, the Moon's centroid and a feature point on the lunar surface. The geometric positioning model is generated by a vector in the direction of the sensor, lander position vector and feature point position vector which also form a triangle. Then parameters describing the position of the feature point can be calculated. After the probe lands on the surface of the Moon, the seven other instruments begin to work. Information about the observation geometry at the time of observation then includes the observation direction, the solar elevation angle and the solar incidence angle.

3.3 Data Pre-processing Subsystem of CE-3

DPS is established by GRAS to support data pre-processing associated with the project. It has two functions: (1) real-time monitoring of downlinked data and feedback through adjustment of parameters associated with instruments, and (2) development, implementation and maintenance of pre-processing methods. Therefore the DPS is divided into two subsystems: a real-time subsystem and a post-time subsystem. In the real-time subsystem, the pre-processing module for Level 0 data is driven by confirmation of the arrival of raw data according to the operation plan. The processed data are stored after quality inspections. In the post-time subsystem, we have designed a workflow management system to complete the Level 2 data processing. The DPS architecture is shown in Figure 3.

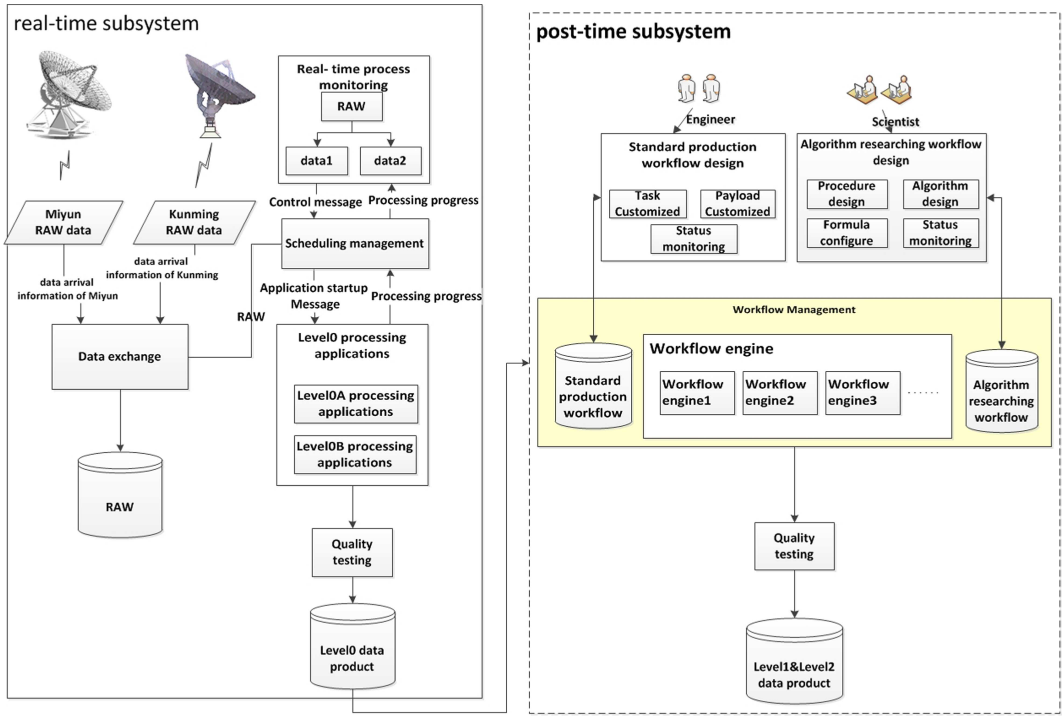

Fig. 3 DPS architecture.

4 DESIGN OF CE-3 DATA PRODUCTS

Three kinds of properties are needed to define the data used in exploration, including a description of text, auxiliary information and the data validity. Since there are huge differences in properties of the data and differences between available auxiliary information on the lunar surface and in the lunar orbit, the storage format and the auxiliary information of exploration data for CE-3 must be redesigned, in addition to taking data inheritance into account.

4.1 Data Classification

Level 0 data are the raw instrument data, just as they were collected at the sensor. They are stored in a binary format to improve the efficiency of data processing, but which cannot be used by scientists directly. The DPS reformats Level 1 and Level 2 data into more user-friendly formats following the PDS standard. This is because the PDS standard contains descriptions of the observed data and auxiliary information, such as the number of records, the size of data, information about the sensor, the data context, how to update the data and so on. These pieces of information are helpful for data indexing and analysis. Figure 4 shows the typical structure of the PDS standard.

The available data produced by six out of eight payloads carried by CE-3 are image data. Although there are differences among each exploration target, the data can be described in a uniform format. Hence, the type of these PDS data objects is a binary image. The data of one image is output as one data file, and the data time and image sequence are noted in the filename. The description of image data, including the number of rows, the number of the pixels in each row, the number of bits in each pixel, the type of pixel, and the order and storage format of the band, are written in the PDS label, in front of the data object. Besides that, the LPR PDS data and the near infrared band PDS data of VNIS are in binary format, and the APXS PDS data are in ASCII format. For CE-3

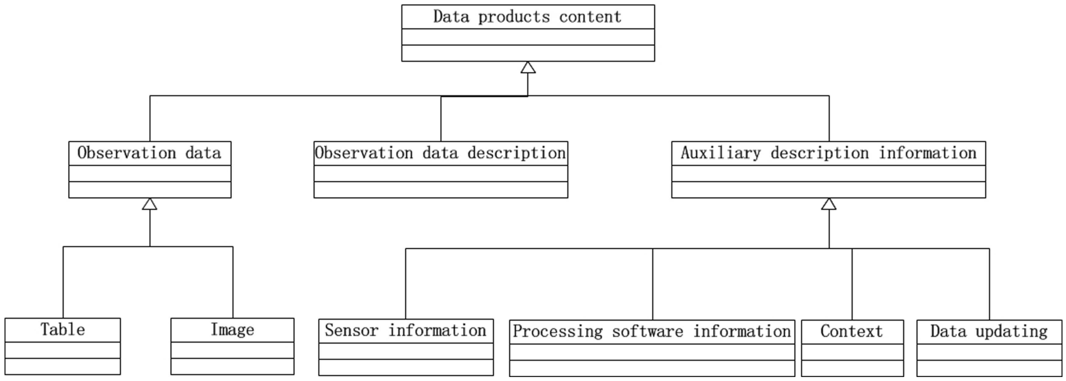

Fig. 4 The typical structure of PDS data products.

Table 4 Types of Data Products produced by CE-3

Product Type	Payload	Characteristics of Products	Auxiliary Information
Image	LCAM, TCAM, PCAM, Visible band data of VNIS	The visible band image data, mainly landing process data/ data about landing zone/ data about area that is traversed by the rover/ spectral data	Payload working parameters, including temperature, working mode, exposure mode, exposure time and gain. Payload parameters, including focal length, the detector's pixel size, principle point coordinate and bands. The visible band image data have geometric positioning information that includes the lander or rover position, images of the four corners and the center point of the observation vector, exterior orientation elements, solar incidence angle and azimuth angle.
	MUVT	Image in the spectral range of the NUV band image from 245 nm to 340 nm	The geometric positioning result of MUVT is the right ascension and declination of each corner in the image which is fixed in the J2000.0 Sun-centered Earth Mean Equator and Equinox Equatorial System (Vaughan 1995).
	EUVC	Center frequency of the measurement band is 30.4 nm	The geometric positioning result of EUVC is the position and direction of the camera's optical axis which is fixed in the SM.
Table	LPR	Most include radar data of 8192 detection points, including two channels	Includes speed, position, attitude and payload working parameters.
	Near infrared band data of VNIS	Spectral data in the near infrared bands from 900–2400 nm, spectral resolution is 3 nm–12 nm	Payload working parameters, including temperature, working mode, exposure time and position of the calibration target. Payload parameters, including focal length, detector pixel size and bands. The geometric positioning information including the rover position, the solar incidence angle and azimuth angle, and the instrument incidence angle and azimuth angle.
	APXS	Spectral data	Position parameters of the robotic arm, payload working mode and temperature.

data, the data description includes (i) the numbers of records, the number of bytes in each record, (ii) the data name, type, Level and version number, (iii) the names of the exploration target, spacecraft, payload and ground station, and the time required for data processing, are all given in the PDS label as a file header. Table 4 describes the classification and auxiliary information about exploration data from CE-3.

Table 5 Level 1 Data Validity Definition

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	Instrument
Level 0A validity	Level 0B validity					Camera temperature	Effective camera temperature	PCAM
						RF power amplifier temperature	Detector temperature	VNIS
		Robotic arm yawing of shoulder joint position	Robotic arm pitch of shoulder joint position	Robotic arm pitch of wrist joint position	Spectrum with 2048 channels	Probe temperature	Effective probe temperature	APXS
		Radar controller voltage	Radar receiver voltage	Radar transmitter current	Electric cabinet total current	Electric cabinet power unit temperature	Radar transmitters 1 and 2 temperature and Radar receivers 1 and 2 temperature	LPR
						Camera temperature	Effective camera temperature	TCAM
								LCAM
						CCD temperature 2	CCD temperature 1	MUVT
			MCP Voltage	Opening angle	Pitch angle	Azimuth angle	EUVC temperature	EUVC

4.2 Data Validity

Data validity is the most important information for scientific research, since it is the foundation of evaluating data and application. Moreover, ensuring the integrity of data acquired during explorations can create more opportunities to understand new phenomena in space. For this reason, we develop a mechanism of evaluating data quality to indicate the validity of data that are preprocessed from CE-3. In this way, users can give attention to both the validity and integrity of the data collected from this mission. One byte is allocated to each item in the data validity record to indicate properties of the original data, the loss of integrity, an exception message sent by the instruments and any errors in data caused by abnormal data processing. In particular, each characteristic element above is represented by the value of the corresponding bit ('0' is normal, '1' is abnormal). The most significant bit represents the validity of data from the previous level through the 'logic-AND' operation. Moreover, different considerations are given for the validity of each level of data: (i) the data integrity for Level 0 data, including the RS decoding, Cyclical Redundancy Check decoding, loss of data packet and the state of data decompression, (ii) the impact of temperature on the instrument and the validity of data sources for Level 1 and Level 2 data. Table 5 shows the details about attributes shown in data validity for Level 1 data.

5 DATA PRODUCTS

The data products from CE-3 are categorized into seven levels: RAW data, Level 0A, Level 0B, Level 1, Level 2A, Level 2B and Level 2C. All the instruments onboard share the same definitions of Level 0A, Level 0B and Level 1 data, but the definitions of Level 2 data vary among different instruments.

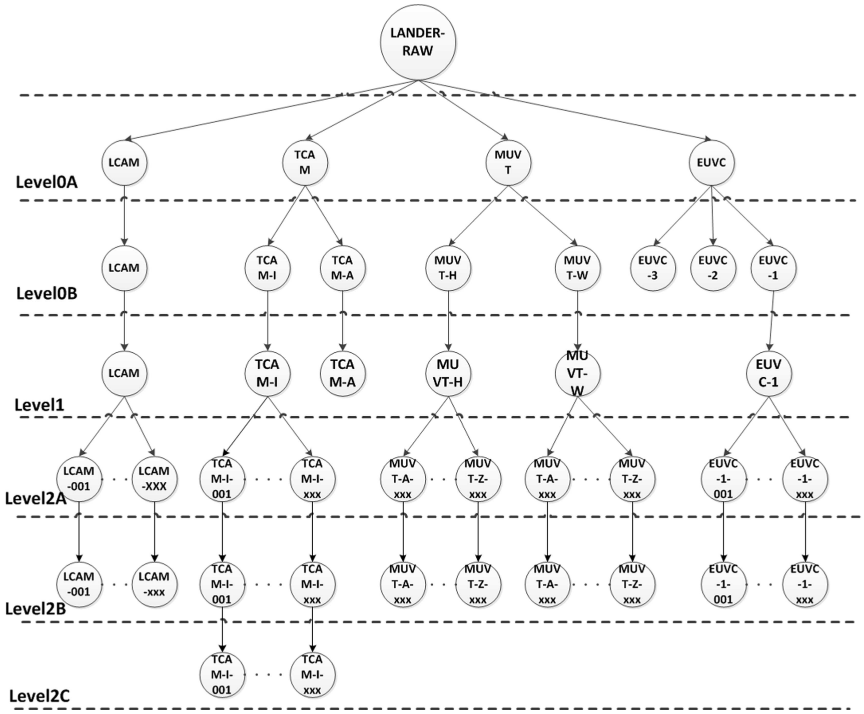

Fig. 5 Constructing data products from the lander.

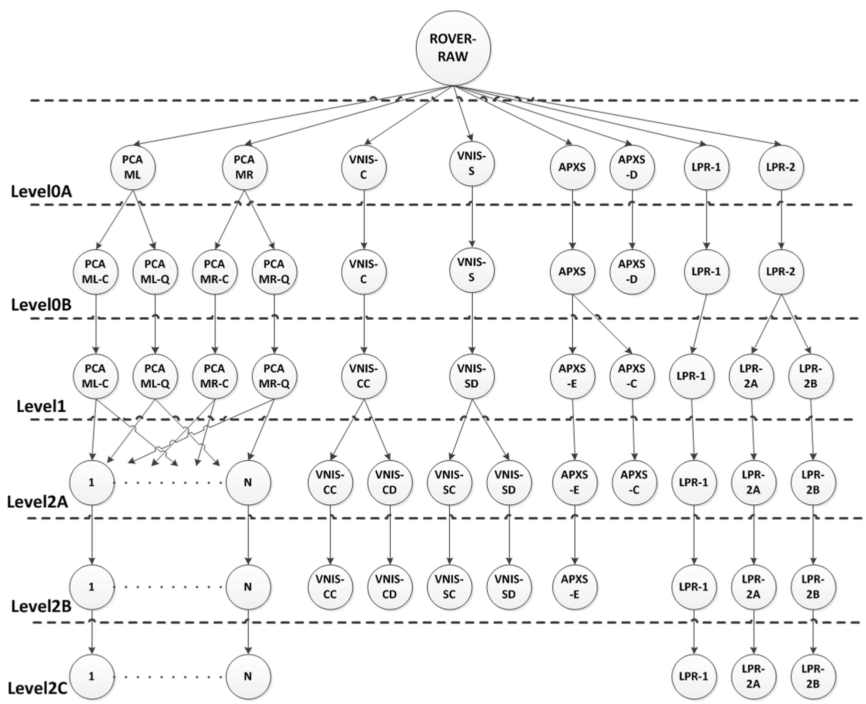

Fig. 6 Constructing data products from the rover.

Figures 5 and 6 show how data products are constructed from the CE-3 lander and rover respectively, using a top-down tree structure. The root node represents the RAW data and the leaf nodes are the products after data processing. Each layer represents a data level.

The raw data of the lander are unpacked to generate Level 0A data products of four payloads: LCAM, TCAM, EUVC and MUVT. The Level 0A data are then merged, sorted, and duplicates are removed and uncompressed to generate Level0B data products in various data acquisition modes, including LCAM data products, TCAM static acquisition mode data products (TCAM-I), TCAM dynamic acquisition mode data products (TCAM-A), MUVT whole picture acquisition model data products (MUVT-H), MUVT window picture acquisition mode data products (MUVT-W), EUVC normal acquisition mode data products (EUVC-1), EUVC original acquisition mode data products (EUVC-2) and EUVC self inspection acquisition mode data products (EUVC-3). The Level 1 data in various modes are generated from the Level 0B data after daily reorganization of the data. For EUVC data, only the data collected in the usual acquisition mode generate Level 1 data, because the data collected under the original acquisition mode and the self inspection mode of EUVC are used to check the status of the instrument, and not used for scientific research. The data generated by four of the payloads are images.

In order to conveniently use these data, the data products are organized into one image after calibration. The TCAM dynamic mode data are only used for making videos for popularization of science, therefore these data do not generate Level 2 data products. For CE-3 data, only TCAM, PCAM and LPR are used to produce Level 2C data products, with the color restoration and color correction processing for TCAM and PCAM, and with band-pass filtering for LPR. Due to different packing methods used by the lander, rover data in Level 0A are categorized into different data files according to the different package identifications, including the left/right panoramic camera source package (PCAML/PCAMR), infrared imaging spectrometer of the visible band/near infrared band source package (VNIS-C/VNIS-S), APXS detecting/distance sensing source package (APXS/APXS-D) and 1st channel/2nd channel LPR source package (LPR-1/LPR-2). The Level 0B PCAM data are categorized according to color mode (PCAML-C/PCAMR-C) and panchromatic mode (PCAML-Q/PCAMR-Q). The Level 1 APXS data are categorized as spectral data (APXS-E) and counts (APXS-C), and the 2nd channel of LPR data are categorized by A antenna (LPR-2A) and B antenna (LPR-2B). The Level 2A PCAM data products are organized one image at a time, and the VNIS data are categorized into calibration data (VNIS-CC/VNIS-SC) and detection data (VNIS-CD/VNIS-SD).

Finally, because the APXS-C does not generate geometric information, it does not generate Level 2B products. Because of the need for color restoration and band-pass filtering, only the PCAM and LPR generate Level 2C data products.

6 CONCLUSIONS

At present, the CE-3 has sent back large amounts of data. GRAS has been pre-processing and generating data products from raw data and providing scientific data for different kinds of research, such as 3D imagery of the lunar surface, information about geological structure near the landing area, study of the content and distribution of major elements in the excursion area, study of the content and distribution of major minerals in the excursion area, study of the complete dynamic processes during the initial phase, growth phase and recovery phase of a geomagnetic storm, etc. To date, the CE-3 rover has ended work spanning two lunar days and completed it scientific research mission. The lander will continue to operate and send back more scientific data. In the mission scheduled for next year, GRAS will deal with all the data that are sent back and provide a complete collection of scientific data which can be used to guide scientific exploration missions in the future, and provide more data support for further scientific research.

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