LESSONS LEARNED IN ONBOARD SOFTWARE PROCESSING OF XRS-KAGUYA. T. Arai[1,2] , Y. Yamamoto[2], T. Okada[2], and M. Kato[2], [1]Solar Observatory, National Astronomical Observatory of Japan (NAOJ), 2-21-1 Oosawa, Mitaka city, Tokyo 181-8588, JAPAN, arai@solar.mtk.nao.ac.jp, [2]Department of Planetary Science, Institute of Space and Astronautical Science, Japan Aerospace Exploration space Agency (ISAS/JAXA), 3-1-1 Yoshinodai, Sagamihara city, Kanagawa 229-8510, JAPAN.

Introduction: A Japanese lunar orbiter, Kaguya (SELELE), is observing lunar surface, space radiation, and magnetosphere of the earth [1-2]. X-ray fluorescence spectrometers onboard Kaguya (XRS) are also observing lunar surface. XRS observes fluorescence X-ray emission excited by solar X-rays and quantitatively determines major elemental compositions in the surface such as Fe, Mg, Al, Si, Ca, and Ti.

XRS is composed of main detectors (XRF-A), solar monitors (SOL-B and SOL-C), analog and digital electronics, and an onboard computer. XRF-A observes lunar surface by using 16 CCD sensors (4 CCDs x 4 units). These total effective area is 100cm2 (16 CCDs) and field of view is 12.0 x 12.0 degrees. SOL-B directly observes solar X-rays by using two Si-PIN photodiodes. SOL-C indirectly observes solar X-rays by using one CCD chip which is an equivalent CCD of XRF-A, and it monitors a standard sample for comparative analysis. The onboard computer has three CPUs verbose system. These CPUs are Reduced Instruction Set Computer (RISC) type (60MIPS at 60 MHz). All specifications have been introduced in previous papers [3-7].

The primary objective of XRS is quantitatively to determine major elemental compositions of the lunar surface. The onboard software was designed and optimized in order to embody the scientific goal of XRS. In this study, we introduce the functional control, data reduction and observation control by the software processing, and we discuss the lessons-learned in the software processing.

Functional control: The software processing performs communication with Kaguya, error checks of XRS status, and temperature control of XRS.

The software performs communication with the data management system (DMS) of Kaguya. There the software sends house-keeping data to DMS, or receives commands. The software monitors status errors of CPU, DRAM memory and instruments. When the errors occur, the software safely turns off the XRS.

The software controls the temperature because the temperature of XRS is varied in orbits of Kaguya. The software monitors the temperature of the radiator and keeps its temperature by turning on or off heaters.

Data reduction: Onboard data processing is performed by the hardware and software processes. The hardware performs high speed processing by using

FPGA, and the software performs flexible processing by using CPU. They perform data reduction and simple analysis of observation that are inheritance and improved technologies of XRS-Hayabusa [8]. The hardware selects and extracts X-ray events from image pixels data obtained from CCD outputs in order to reduce the amount of data. There need to observe the data in 32 kbps or less, allowed for XRS in lunar day-side observation.

The hardware compares observed image pixel values of CCD and average pixel values as a flat field, and subtracts both for all pixel values. The hardware extracts only the event that exceeds the threshold. Also, the hardware adds information to each data, such as a CCD ID, an event counter, a horizontal pixel coordinate, a vertical pixel coordinate, a left neighbor pixel value of event, an event pixel value, a right neighbor pixel value, and a background pixel for the event pixel value, the left, and the right. The hardware sends these data to FIFO memory (one event is 16 Bytes). The software receives these data and analyzes that.

Observation control: XRS performs lunar surface observation by using 5 observation modes (event mode, spectrum mode, automatic mode, autonomous mode, PIN mode), and two health check modes (image mode and check mode) as shown in Table 1.

The event mode is nominal observation mode. The data of this mode are the same as the hardware extraction data. The software makes a data packet and there 63 events are packed in one packet (1 kBytes).

The spectrum mode is highly compressed about the data amount by making a spectrum. The software performs data reduction in the same method of use in laboratory. Since high energy events are overflowed to some pixels, the software processing adds the center event to the splits events or reduces the split events. It is widely known as reduction method called a grade method in X-ray astronomy. The software processing makes a histogram and it is cropped only 1000 channels histogram (digital unit) from flat field (net observable energy range is 0-10keV). The integration time of the spectrum is 16 seconds which is enough to resolve lunar local area in high spatial resolution, and this data rate is 17 kbps.

The automatic and autonomous modes are the mode that controls observation. In particular, they avoid data saturation as overflow of data memory by changing

from the event mode to the spectrum mode with monitoring the data buffer of XRS every 32 seconds. If there the data buffer is overflowed, the software changes the observation mode from the event mode to the spectrum mode.

The PIN mode is solar X-ray monitoring mode. This mode makes spectra packets of SOL-B whose data rate is 1 kBytes / 16, 32, 64 seconds.

The image mode is the mode that outputs the image of CCD. The software makes raw or background (flat field) image packets. This mode is usually used for health check of CCDs, and monitors charge-traps due to radiation damages as historical changes of sensor performance. The data rate is 128 Bytes/frame in effective area.

The check mode is the mode that outputs a cropped CCD image, including a limited flat field and a limited overclocked region. This amount of data is small size (2 k Bytes / frame) so that it can use simple health check within the data telemetry rates.

Lessons Learned: 1. The functional controls by the software processing was successfully performed in the observation of XRS. There were no errors in the communication and the heater control except trivial errors due to software bugs. Also, XRS was safely turned off when radiation errors occurred, and XRS was safely turned on later.

The temperature of sensor was stable but temperature variation in orbit caused little fluctuation of dark currents, hot pixels or flickering pixels. Therefore, we will mount the function to autonomously control a cooler in future software.

2. In observed data, some events were not fluorescent X-ray events but high energy events so that we want to reduce such fake events. There will be necessary to improve the data reduction by the hardware and software processing in order to reduce the amount of data. One idea for future reduction, an onboard computer searches and extracts an event from CCD image by fitting of two dimensional gaussian. It will reduce fake events like large split events.

3. In the observation, the autonomous mode was rarely used because the decision making by human is better than computer. We could choose the observed area by using time-lines or commands to XRS in real time. However, we believe that automatic and autonomous observations are necessary because transient events will occur some time such as large flare burst and we can avoid it. Therefore, we improve the intelligent observation logics for future software. In particular, we focus attention on a feedback control and an onboard analysis by using intelligent logics such as fuzzy, neuro-fuzzy, and genetic algorithm etc.

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Table 1: Observation Modes

Observation mode	Data format and rate
Event mode	X-ray event pixel value, neighbors (3 pixels), and their dark values (3 pixels) 16 Bytes / event
Spectrum mode	Histogram data Energy spectrum of 1000 channels (digital unit) 2 kBytes / histogram
Automatic / Autonomous mode	Automatically / Automatically change the event mode and the spectrum mode
PIN mode	Histogram data 1 kBytes / 16,32,64 sec
Image mode	CCD image data (flat field or dark frame) 2 Bytes x 1024 x 1024 (64) in effective pixels
Check mode	Cropped CCD image data (flat field and overclocked region) 2 kBytes / frame