Nano-JASMINE: A 10-kilogram satellite for space astrometry

Yukiyasu Kobayashi(ab), Naoteru Gouda(a), Takuji Tsujimoto(a), Taihei Yano(a), Masahiro Suganuma(a), Masahiro Yamauchi(ba), Naruhisa Takato(a), Satoshi Miyazaki(a), Yoshiyuki Yamada(b), Nobutada Sako(c) and Shin'ichi Nakasuka(c)

National Astronomical Observatory(a), Kyoto University(b), The University of Tokyo(c) (JAPAN)

ABSTRACT

The current status of the nano-JASMINE project is presented. Nano-JASMINE — a very small satellite weighing less than 10 kg — aims to carry out astrometry measurements of nearby bright stars. This satellite adopts the same observation technique that was used by the HIPPARCOS satellite. In this technique, simultaneous measurements in two different fields of view separated by an angle that is greater than 90° are carried out: these measurements are performed in the course of continuous scanning observations of the entire sky. This technique enables us to distinguish between an irregularity in the spin velocity and the distribution of stellar positions. There is a major technical difference between the nano-JASMINE and the HIPPARCOS satellites--the utilization of a CCD sensor in nano-JASMINE that makes it possible to achieve an astrometry accuracy comparable to that achieved by HIPPARCOS by using an extremely small telescope.

We developed a prototype of the observation system and evaluated its performance. The telescope (5cm) including a beam combiner composed entirely of aluminum. The telescope is based on the standard Ritchey-Chretien optical system and has a composite f-ratio of 33 that enables the matching of the Airy disk size to three times the CCD pixel size of 15 μm. A full depletion CCD will be used in the time delay integration (TDI) mode in order to efficiently survey the whole sky in wavelengths including the near infrared.

The nano-JASMINE satellite is being developed as piggyback system and is hoped for launch in 2008. We expect the satellite to measure the position and proper motion of bright stars ($m_z < 8.3$) with an accuracy of 1 mas, this is comparable to the accuracy achieved with the HIPPARCOS satellite.

Mission System

The observation system is very simple. It comprises a small telescope with a CCD sensor attached at its focal plane. The nano-JASMINE observations system consists of a telescope, a CCD, a stellar image extractor and a system control processor. The current design will use a 1 k × 1 k CCD with a pixel size of 15 μm.

Telescope

The main part of the nano-JASMINE observation system is a 5 cm reflective telescope. The focal length is determined from the diffraction size that fits the lengths of three pixels at the focal plane. The optical system is very similar to the standard Ritchey-Chretien Cassegrain system, which can form diffraction limited images. Note that the three additional mirrors are flat. The telescope has a beam combiner, two flat mirrors positioned at different angles, in front of the primary mirror: this enables us to observe two different directions simultaneously. In order to reduce the actual length of the telescope, the optical beam is bent twice by using two flat mirrors. The telescope is made of aluminum. The mirrors, telescope tube and all telescope components are made of aluminum. This renders the telescope free from degradation in image quality caused by temperature changes, because the whole system contracts and expands homogeneously. The optical components are configured by using a super high precision diamond turning machine. Fig.1 shows the proto-type of a telescope fabricated after several trials with sufficient optical quality. Optical support mechanisms and the machining sequence are key points. We will examine the thermal behavior of the telescope, which is the most challenging aspects of the nano-JASMINE project. We have confirmed that the telescope is sufficiently rigid by performing a vibration test. The Only moving part of the telescope is a focusing system. The secondary mirror can be adjusted by using a piezoelectric actuator. We expect the focus adjustment to be required only once in the initial set up period: following this period the telescope's thermal environment is sufficiently stable.

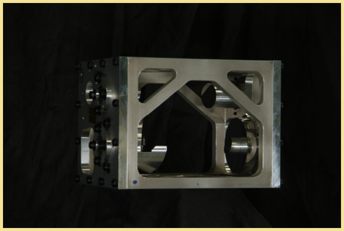

Figure 1. Telescope

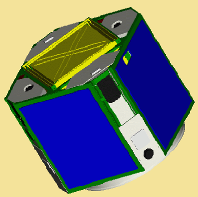

Figure 2. Current satellite design

CCD and On-board processing

The data recording section consists of the CCD, CCD controller and stellar image extracter(SIE). We would like to use a full depletion type of CCD which has a thick reaction layer and a large quantum efficiency particularly in the longer wavelengths. The full depletion CCD has been developed at Hamamatsu Photonics in collaboration with a team from the National Astronomical Observatory of Japan. A 1 k × 1 k format CCD provides a field of view of ~30' x 30' in the case of nano-JASMINE.

The satellite spins slowly and scans the sky along a great circle. A CCD is operated in the TDI mode which produces endless stripes of an image. A star passes through the CCD's field of view in approximately 8 s and the integration time is then 8 s. Charges accumulated along the CCD columns reaches the edge: they are digitized by an AD converter equipped in the TDI controller. The TDI controller (Fig. 6) controls the timing of the charge transfer of the CCD and digitizes the CCD output that is transferred to the SIE. The output data rate is nearly constant and high with data being generated every 2 μs: this is too high for a mission control computer to handle directly and the amount of data is considerably larger than the available data transfer rate to a ground-based station. The SIE can select parts of images that contain the stellar image and route these data to the mission control system. Since the system is constructed by using an FPGA system, it works at high speed and is able to process all the data in real time, provided the processing is sufficiently simple .

Fig. 3 shows a block diagram of the SIE unit. The SIE unit is constructed using simple functions such as adder, abstractor, comparator and FIFO (first in first out) memory. The FIFO memory is used to provide sequential data that actually is a raster scan image of a two dimensional image. If the lengths of the FIFO is set to be equivalent to an image width, it's first output is at the same line but in the previous column. The FIFO memory can works as a column shift device.

The upper part of Fig. 3 shows one of the functions, an averager that is used to determine the sky level. An example is the averaging of 256 columns right before the current pixel. Every time a new pixel data is digitized, the SIE adds current value to the column memory and subtracts 256th old data point: this retains the summation of the last 256 data points. Removing the lower 8 bits from this summed value is equivalent to obtaining the mean of the last 256 data points. If the SIE add the current value to 256 long FIFO memory, the output of FIFO is the 256th old data point: thus this process continues. Next the SIE subtracts average from the current data and compares it with the threshold value, which can be set at any value. A value that is a few times the noise value is favorable, which can be set at any value. Pixels whose signal values exceed the threshold will be flagged after the sky subtraction. Flags are saved to the same width plane. In the next step, the SIE checks whether the eight neighboring pixels have flags. If more than two pixels have a flag, then the pixel data should be transferred to the mission control system with the address. An address X is the line position and address Y is column position, which is a 64 bit data, because it has capacity of whole mission life. In these sequence, FIFO memory with the length equivalent to the image width used to transfer one dimension to two dimensional.

Mission Controller

The major role of the mission control system is to receive data from the SIE, treat the data and store them in the satellite common storage system. SH-2 is a Renesas Technologies 32 bit microprocessor which will be used for mission control system. SH-2 has been proved to have a good performance against the radiation environment in space. SH-2 has also been proved to be workable in space by several small satellite missions. It also create tracking information from the shape of stellar images and conveys these to ACS.

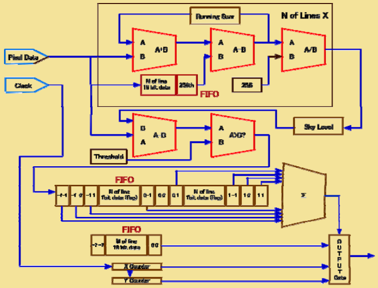

Figure 3. Functional Block Diagram of Stellar Image Extractor

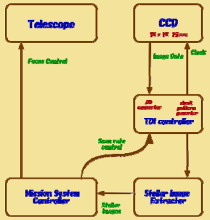

Figure 4. Block Diagram for Observation system

Nano-JASMINE System

Data communication between the nano-JASMINE controllers is performed through a CAN (controller area network) bus as shown in Fig.5. CAN (Controller Area Network) is a serial bus system, which was originally developed for automotive applications in the early 1980's. The CAN bus is one of the standard LAN systems developed for car control by Bosch in Germany. It has sophisticated error detecting mechanisms and re-transmission of faulty messages. This bus also guarantees data integrity. The CAN bus is used in small satellite systems, because of its compact and simple structure and reliability. A block-diagram of the nano-JASMINE system is shown in Fig.5. The nano-JASMINE control system except for the mission control system comprises the main controller , attitude control system , communication control system and power control system. These bus systems are based on the system originally developed for the PRISM project, which is a remote sensing satellite aiming to take earth images with a 30 m resolution.

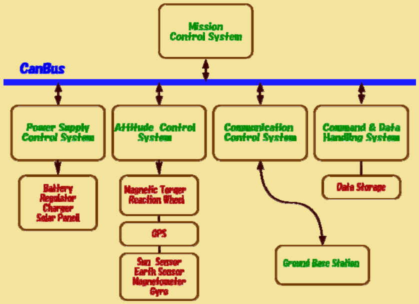

Figure 5. ystem Block Diagram

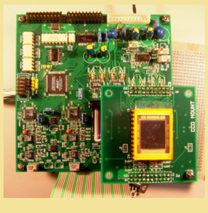

Figure 6. CCD & TDI control board