LOW-COST AND HIGH-PERFORMANCE VISUAL GUIDANCE AND NAVIGATION SYSTEM FOR SPACE DEBRIS MITIGATION

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Shinichi Kimura[1], Eijiro Atarashi[2], Taro Kashiwayanagi[3], Kohei Fujimoto[4], Ryan Proffitt[5]

[1]Tokyo University of Science, 2641 Yamasaki, Noda Chiba 278-8510, Japan, E-mail: skimura@rs.tus.ac.jp
[2]Astroscale Japan Inc., 1-16-4 Kinshi Sumida-ku, Tokyo 130-0013, Japan, E-mail: e.atarashi@astroscale.com,
[3]Astroscale Japan Inc., 1-16-4 Kinshi Sumida-ku, Tokyo 130-0013, Japan,
E-mail: t.kashiwayanagi@astroscale.com
[4]Astroscale Japan Inc., 1-16-4 Kinshi Sumida-ku, Tokyo 130-0013, Japan, E-mail: k.fujimoto@astroscale.com
[5]Astroscale Japan Inc., 1-16-4 Kinshi Sumida-ku, Tokyo 130-0013, Japan, E-mail: r.proffitt@astroscale.com

ABSTRACT

A highly intelligent visual guidance navigation system that can autonomously identify the client space debris and realize a controlled rendezvous maneuver with it is urgently required to realize space debris mitigation. We developed a visual guidance and navigation system for space debris mitigation that combined autonomous control software technologies and COTS devices. We plan to demonstrate the orbital performance of the COTS-based intelligent camera system on the End-of-Life Services by Astroscale-demonstration (ELSA-d) mission (Astroscale), a technical demonstration mission for satellite end-of-life services. For this mission, ASTROSCALE has been collaborating with Tokyo University of Science to develop a visual guidance and navigation system for space debris mitigation. In this paper, we introduce the outline and performance of the COTS-based intelligent camera system for space debris mitigation.

1 INTRODUCTION

Space debris is becoming a serious problem owing to the increasing utilization of outer space. Further, collisions between space debris produce an even greater amount of fragments, and therefore, the debris must be removed from orbit. Toward this end, the client space debris must be reliably and efficiently accessible. However, space debris is a so-called "uncooperative" client because its state cannot be controlled and position cannot be determined precisely. Therefore, a highly intelligent visual guidance navigation system that can autonomously identify the client space debris and realize a controlled rendezvous maneuver with it is urgently required. Further, the space debris mitigation system must have low cost because of its subsidiary function. However, these problems are quite difficult to solve.

We developed a highly intelligent camera system that combined autonomous control software technologies and COTS devices. Through the use of a high-resolution COTS imager and a field-programmable gate array (FPGA) system, high-resolution images and very fast image processing could be achieved at a very low cost. We improved the hardware; further, we used a free software scheme and improved the software performance and reliability by sharing software resources among university satellite development communities. We successfully utilized the intelligent camera system in various missions such as IKAROS, Hayabusa-2, and Hodoyoshi.

Now, we plan to utilize the intelligent camera system for visual guidance and navigation for space debris mitigation in combination with orbit estimation and autonomous homing and rendezvous control technologies.

This visual guidance and navigation system for space debris mitigation is expected to play two important roles: (1) autonomous client tracking and calculation of relative position and orientation and (2) real-time monitoring.

To home and rendezvous with the uncooperative client debris safely and reliably, the servicer satellite needs information on the relative motion and orbit of the client debris. Visual images are one of the most effective solutions for obtaining such information. We realize such a function by expanding the image processing capability of an intelligent camera by using both image processing software and FPGA processing.

Homing to and rendezvous with the client debris are risky operations, thereby making situation monitoring crucial. Toward this end, we achieve real-time image transmission by using the same image processing unit by reconfiguring the FPGA. The images acquired during the mission are automatically packetized and directly transferred through the communication system

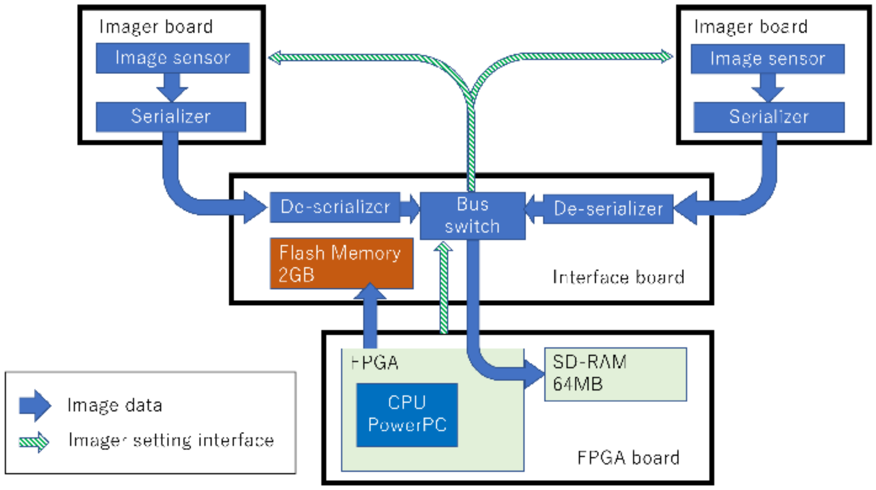

Figure 1: System Architecture of the Intelligent Camera System for Space Debris Mitigation

and transmitted to the ground station with minimum latency. Further, these functions are achieved using the same COTS-based image processing unit, thereby reducing costs.

We plan to demonstrate the orbital performance of the COTS-based intelligent camera system on the upcoming ELSA-d, a technical demonstration mission for satellite end-of-life services. For this mission, Astroscale has been collaborating with Tokyo University of Science to develop a visual guidance and navigation system for space debris mitigation.

In this paper, we introduce the outline and performance of the COTS-based intelligent camera system for space debris mitigation.

2 COTS-BASED INTELLIGENT CAMERA SYSTEM FOR SPACE DEBRIS MITIGATION

2.1 Architecture

The guidance and navigation camera system consists of camera head units and a processing unit. Because the camera head units are independent of the image processing unit, they can be made as small as possible to make them easy to equip in a miniaturized satellite system. In particular, the camera heads are equipped inside a small capturing mechanism; therefore, the camera system can acquire images of the entire process.

These units are interconnected using a high-speed serial interface that was space qualified during the KITE mission. Therefore, a full frame image can be transmitted using one pair of harnesses. The interconnection between the camera heads and the processing unit can be extended to a length of up to 1 m; therefore, the camera head units can be equipped freely.

2.2 Camera Head Units

The camera head units are used to acquire visual images and convert them into a differential serialized signal. The visual image sensor and serializer are installed in a 28mm by 28mm image sensor board (Figure 3).

We utilize a 1/2.5 inch 5M pixel CMOS color image sensor as a high-resolution imager. Region of interest image capture is also supported to increase the frame rate.

Through serial connections, we can change the registers to control image capture settings such as the shutter speed and image sensor gain. Such settings must be easily adjustable to deal with the widely and rapidly changing luminance conditions in orbit.

A lens with a proper focal length with the same lens attachment is chosen depending on the field of view requirement. In addition, a multispectral image can be obtained by installing a bandpass filter at the end of the lens.

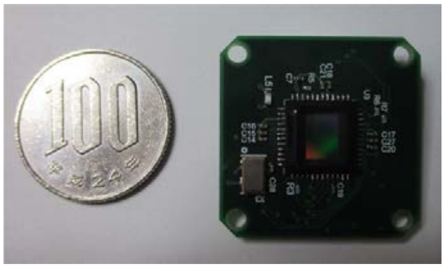

Figure 3: Camera Head Board

Size	30mm by 30mm by 34mm (minimum)
Weight	35g (minimum)
Resolution	2592 x 1944 (5M pixel)
ADC Resolution	12 bit
Sensitivity	1.4 V/lux-sec (550 nm)
Power Consumption	335mW

Table 1: Specifications of the Camera Head Unit

2.3 Image Processing Unit

The image processing unit consists of the FPGA board and the interface board.

The FPGA board uses Vertex-II Pro as the main processor in the same architecture as that of the intelligent cameras used previously in the IKAROS and Hayabusa-2 missions. To support high-speed processing for real-time image transmission and client recognition, the working clock is upgraded, and the processing capability is improved by more than 50%. The FPGA board has a 64 MB SDRAM for image processing and 512 MB Flash memory for the operating system and software.

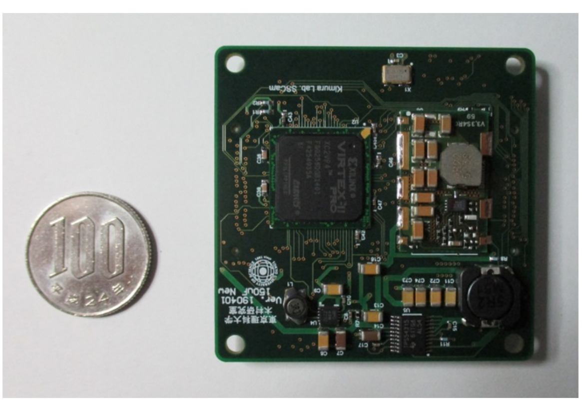

Figure 4: FPGA Board

The interface board supports image storage and various interface capabilities of the processing unit. The interface board has 2 GB NAND nonvolatile flash memory; this is adequate for storing more than 2000 frames of 1 megapixel images. The interface board supports two channels of a deserializer interface for the camera head units, RS-422 command and telemetry serial interface, and LVDS bit stream output interface for real-time image transmission through the direct connection to the transmitter. For real-time image transmission, a high-precision oscillator is also implemented.

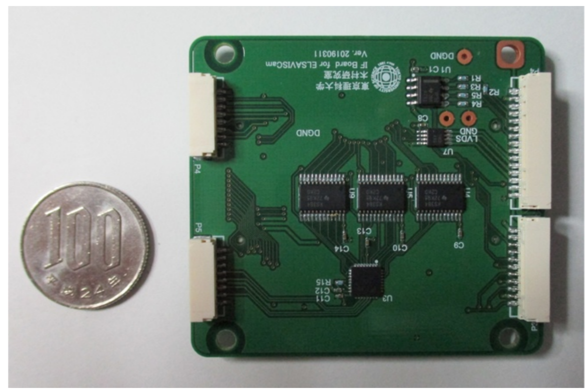

Figure 5: Interface Board

The processing unit can perform two main functions.

First, it can perform real-time client recognition and tracking. In the ELSA-d mission, camera-A is installed for this purpose. Client recognition is performed by the FPGA core through the image capture process. The image processing software receives rough information of the client's position along with image data that are automatically and intermittently transmitted into the SDRAM memory through a direct memory access function. Because the image transfer process evokes an interrupt cue, the application software can work synchronously with the image capture process. This software architecture is quite effective for achieving real-time control of processes based on the visual information.

Second, the processing unit can perform real-time image transmission to monitor the homing and rendezvous processes. In the ELSA-d mission, camera-B is installed for this purpose. This camera can generate CCSDS packets from image data and transmit them as a bitstream output directly to satellites. This enables uncompressed image data with minimum latency to be obtained.

Interface	Serial Image Data: 2ch RS422: 1ch LVDS for CCSDS bit stream:1ch
Non-volatile memory	2G bytes
Operating system	LINUX
Calculation Capability	675MIPS
Power Consumption	915mW

Table 2: Specifications of the Processing Unit

3 CONCLUSION

This paper presents an outline and discusses the performance of the COTS-based intelligent camera system for space debris mitigation. This camera system is currently awaiting launch with the ELSA-d satellite. We hope to present successful in-orbit results in the near future with the aim of opening up new possibilities for space debris mitigation.

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