Preparative demonstration of optical link establishment by using Small Optical Transponder

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Abstract— **Preparative demonstrations of optical link establishment conducted by using the small optical transponder are introduced. The first demonstration employs the engineering model to connect the distance about 8km. The second demonstration is carried out by the proto-flight model in the distance about 1.2km to measure the tracking accuracy under the influence of atmosphere. The third one is performed to observe the effect of an error correction coding, where an optical terminal that is almost the copy of the proto-flight model is used as the simulator. Through those demonstrations, the designed specifications are confirmed.**

Keywords—small optical transponder; SOTA; small satellite; free space laser communications

I. INTRODUCTION

Small satellites have interesting features for satellite applications. The short development period of a small satellite provides possibilities to bring the latest technologies to the orbit. A high resolution imaging and a wideband measurement could be typical examples that obtain the benefits. The use of such latest instruments for observation intends to raise the amount of acquired data. Thus, the communication data rate is required to be increased as well to transmit the measured data from the satellite. Generally the amount of resources such as the volume, the mass and the power consumption given to mission equipment is limited. Therefore, the balance of resources between measurement instruments and communication functions is an issue to be considered.

Recently laser communication technologies attract attentions because of the large capacity in data transmission and a potential to make the size and the mass of a terminal smaller than a RF terminal. Since restriction of satellite resources is strict in small satellites, the combination of optical communications and small satellites could be suitable for applications of generating large amount of data.

NICT initiated a research and development of the Small Optical TrAnsponder (SOTA) for micro-satellites to demonstrate optical technologies in the frame of the Space Optical Communication Research Advanced Technology Satellite (SOCRATES) project [1]. The main objective of this project is to provide optical down link from a small satellite, where the data rate is more than 1Mbps and the mass of the satellite is about 50kg [2].

The development of SOTA is completed and the specifications are confirmed with the results of tests and investigations [3]. In those tests, most of the functions can be tested in a laboratory. However for some functions, experiments under the influence of atmosphere are helpful to estimate the characteristics prior to the satellite-ground laser communications.

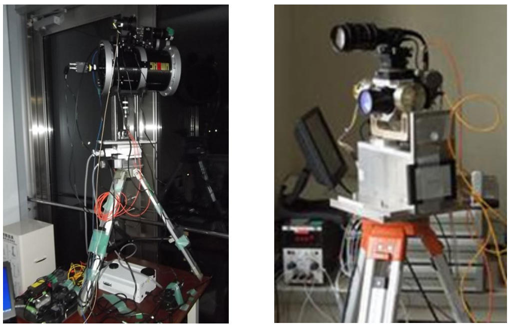
During the development process, demonstrations to form optical links by using the SOTA engineering model (SOTA-EM), the proto-flight model (SOTA-PFM) and the simulator (SOTA-SIM) are conducted, respectively. In this work, we introduce these preparative demonstrations, where the tracking performance under the influence of atmosphere is estimated and the effect of error correction coding is observed.

II. OPTICAL LINK

The first demonstration of SOTA under the atmospheric influence is performed by using the engineering model (SOTA-EM). It was carried out in November 2011 to observe establishment of the optical link in almost horizontal with the distance about 8km.

The terminals for the demonstration are shown in Fig. 1(a) and 1(b), where the counter terminal is given in Fig. 1(a) and the SOTA-EM is in Fig. 1 (b). The counter terminal is set in a building of NICT and the SOTA-EM is placed in about 8km away from NICT. The counter terminal has a telescope of the aperture diameter of 20cm. The optical axis for beam transmission and the one for reception are designed as the same. In Fig. 1(b) two similar lenses are found. The bottom one is the SOTA's main telescope. The top one is a camera lens used to take images of light emitted by the counter terminal.

As found in Fig. 1(a), the counter terminal is put on a tripod. Therefore when the beam emitted by the counter terminal is observed at the SOTA-EM, change in the arrival angle of the beam is so small that the use of the fine tracking mechanism is enough to track the beam.



(a) (b)

Fig. 1. Optical link experiment, where (a) the counter terminal set in a building of NICT and (b) SOTA engineering model located in about 8km away from NICT.

III. TRACKING PERFORMANCE

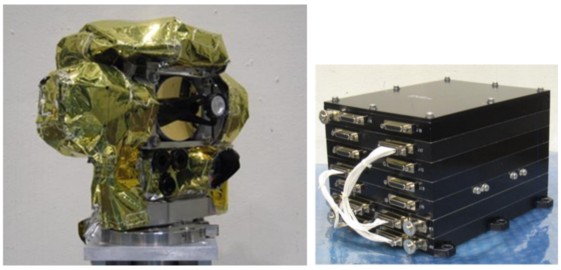
The optical part of the proto-flight model of SOTA (SOTA-PFM) including gimbals is shown in Fig. 2(a) and the electric part is shown in Fig. 2(b), respectively. SOTA-PFM has 4 laser sources. One of the sources is named as Tx1 that transmits the wavelength of 976nm, two laser sources labelled as Tx2 and Tx3 emit the wavelength of 0.8µm, and the source of Tx4 for the wavelength of 1550nm. SOTA-PFM selects the data rates of 1Mbps or 10Mbps for modulation. The transmission power is 217mW for Tx1, and 35mW for Tx4, respectively. The signal beam of Tx1 and Tx4 are modulated with a pseudo noise code or image data of camera installed in the satellite. Besides, the error correction codes such as the Reed-Solomon and LDGM can be superimposed by giving a set of parameters to SOTA-PFM.

The diameter of the aperture for acquisition and coarse tracking senor is 23mm and the diameter of the reflection type telescope is 50mm. The transmission of the wavelength of 1550nm, Tx4, and the reception of the wavelength of 1064nm for fine tracking use this telescope. The total mass including the optical and the electrical parts are 6.2kg. The dimensions of the optical part including the fork mount gimbals are (W)178mm, (D)114mm, and (H)268mm, respectively.

The experimental investigation of the tracking performance of the SOTA-PFM under the influence of atmosphere was conducted in 2012. The distance between the SOTA-PFM and the counter terminal was about 1.2km. During the experiment, the SOTA-PFM is put in a dust protection box as shown in Fig. 3(a) and 3(b). The laser transmission and the reception are carried out through the optical windows. The upper optical window passes through the both wavelengths of 1550nm and 1064nm corresponding to the transmission and the reception wavelengths for the telescope. The bottom optical window is designed for the wavelengths of 1064nm, 0.8µm and 980nm for acquisition and coarse tracking, and for transmission. A monitor camera and a photo detector are attached on the dust protection box. The counter terminal is shown in Fig. 4. The optical setup is put behind a screen which has holes in front of apertures of the receiver lens and the transmitter lens.

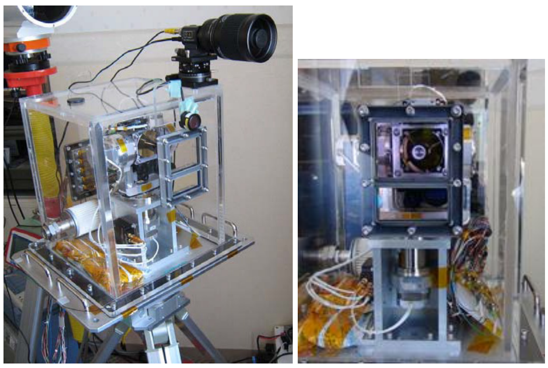
The function diagram of the experiment system is indicated in Fig. 5, where SOTA OPT and SOTA CONT mean the optical part and the electric part of the SOTA-PFM. PD is a photo detector which is attached on the dust protection box with the monitor camera as shown in Fig. 3(a). In the counter terminal, the transmitter of the beacon laser has a diameter of 10mm and the receiver has a diameter of 80mm. The screen has holes for the transmitter and the receiver. A camera is prepared to monitor the surface of the screen illuminated by the laser emitted from the SOTA-PFM. Situations during the experiment are mutually observed by using network cameras.

The SOTA-PFM acquires the beam emitted by the counter terminal and tracks it with the fine tracking mechanism. The angular error measured as a function of the power received at a quadrant detector (QD) of the fine tracking mechanism is shown in Fig. 6. In the figure, the line with a label "in a lab." indicates the angular error measure in a laboratory prior to the experiment. The line "through atmosphere" is the measured error in this experiment. Due to atmospheric influence, the angular error in the experiment is much increased comparing with the one in a laboratory. The divergence angles of transmission beams are plotted in Fig. 7, where Tx1 indicates the wavelength of 980nm and Tx4 is the wavelength of 1550nm. According to the plots of Fig. 7, the fine tracking angular error shown in Fig. 6 is confirmed to be less than the divergence angles of the transmission beams when the power detected by the QD is between -54dBm and -35dBm.



(a) (b)

Fig. 2. SOTA proto-flight model (a) the optical part and (b) the electric part.



(a) (b)

Fig. 3. SOTA proto-fight model (SOTA-PFM) in a dust protection box. (a) the side view and (b) the front view, where optical windows are installed for laser transmission and reception.

Fig. 4. Setup of the counter terminal for the SOTA-PFM.

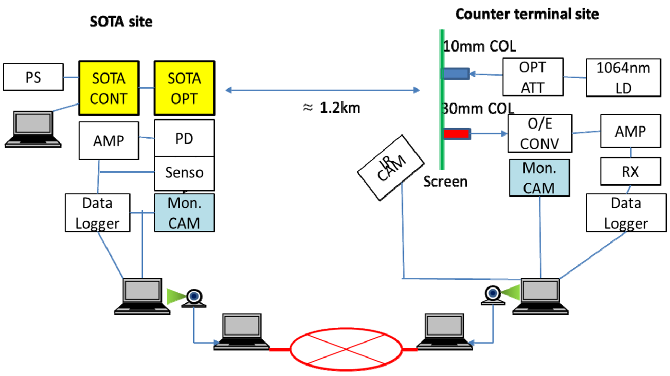


Fig. 5. Function diagram for the experiment.

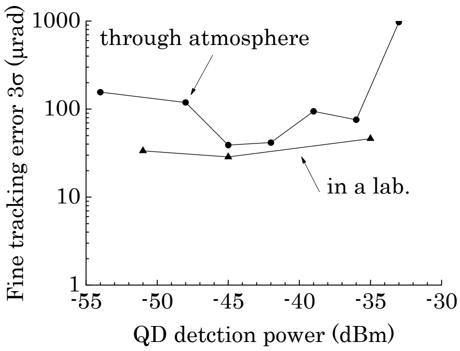


Fig. 6. Fine tracking error as a function of detected power.

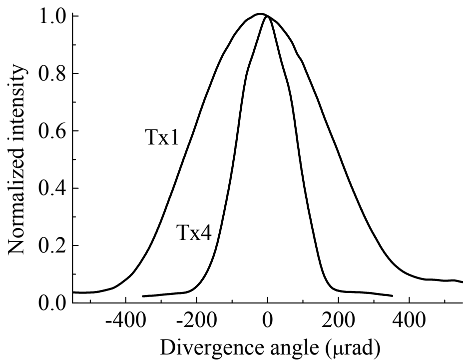


Fig. 7. Divergence angle of transmission beams.

IV. DATA TRANSMISSION AND CODING

As a part of development processes of SOTA-PFM, we also manufactured an additional optical terminal as a simulator of SOTA proto-flight model (SOTA-SIM) that has almost the same functions and specifications as the ones of SOTA-PFM. The SOTA-SIM is put in the dust protection box as shown in Fig. 8.

The demonstration using SOTA-SIM is conducted in December 2013. The optical setup shown in Fig. 9 is used as the counter terminal and is placed in about 8km distance away from SOTA-SIM. In the demonstration, we use the wavelength of 1550nm, Tx4, with intensity modulation by the pseudo random binary sequence of 15 bits to count the bit errors. The measured bit error count is used to estimate the parameters to generate coded data.

Since the distance of 8km is much shorter than the assumed distance for the satellite-ground laser communication demonstration, the data transmission results in almost error-free. To observe the error correction effect of the coding, optical neutral density filters are installed in the counter terminal to degrade the bit error count. The densities of the filters are selected to have the bit error count less than 10^{-3}.

For the bit error rate less than 10^{-3}, the set of parameters for LDGM coding is designed to impose on the transmission data. The figure 10(a) is an image constructed from the received data with no error correction and 10(b) is the one with error correction. Those figures show the effect of the properly designed set of parameters.

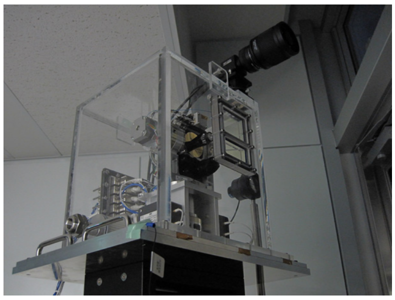


Fig. 8. The SOTA simulator (SOTA-SIM) in a dust protection box.

Fig. 9. The counter terminal for the SOTA-SIM.

(a) (b)

Fig. 10. The received data (a) with no error correction and (b) with error correction.

V. CONCLUSIONS

In this work, we have introduced preparative demonstrations of SOTA by using SOTA-EM, SOTA-EFM and SOTA-SIM, respectively. The tracking performance under the atmospheric influences has been confirmed that the angular error in the fine tracking can be covered by the divergence angle of the transmitted beam. The error correction coding has been designed according to the measured bit error count and adopted to send image data. The demonstration result showed that the data transmission errors caused by atmospheric influence are well compensated.

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