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On-Orbital Experiment on Target Motion Estimation and Tracking Using Micro-LABSAT

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Abstract

On a NASDA's microsatellite named "μ-LABSAT," which was launched by H-IIA on December 14, 2002, Communications Research Laboratory (CRL), National Aerospace Laboratory (NAL) and University of Tokyo (UT) are jointly performing several orbital experiments as technology demonstration towards the future orbital servicing missions. UT plans to release a small object named "target," and its rotational motion is estimated by the images captured continually using a camera developed by CRL. Then satellite attitude control will be performed by visual feedbacks of the target image position on the camera frame so that the target image may come to a certain point on the camera frame. This is a pre-experiment of so-called LOS (Line Of Sight) control during rendezvous and docking to the satellite to be serviced. In this paper, the objectives and procedure of these experiments will be described.

1. Introduction

Capture of tumbling object in space will be one of important on-orbit service missions. Tumbling objects may be satellites who have lost attitude control function, debris or manned vehicles, in each case of which it would be desirable to retrieve the objects to repair or insert into the atmosphere. Sometimes, such operation should be made very quickly and safely, especially when the tumbling object have important data, expensive systems or human crew.

In order to safely capture the tumbling objects, the first step will be to obtain relative location of the object and perform rendezvous, and the next step will be to estimate the target rotational motion. For these steps, images obtained by some camera-type device will provide effective information. In our previous research [1], we showed that a chaser satellite can estimate the target rotational velocity and moment of inertia ratio in real time fashion using the images of the target obtained by even one camera implemented on the chaser. In [2], we also showed that a certain control algorithm based on visual information can make the chaser's manipulator arm reach a certain point of the target even if the point is moving. Besides, [3] showed that once such rotational information of the target is obtained, a novel control algorithm can very quickly and efficiently synchronize the chaser's motion with the target's one so that the relative velocity between the chaser manipulator arm and the point on the target to be grasped can be reduced.

Based on this theoretical and simulation-based research, we have been preparing on-orbit experiment of these technologies using a micro satellite named "μ-LABSAT (Fig.1)." μ-LABSAT is the first NASDA in-house satellite, aiming for the in-house development of micro satellite technologies as well as hands-on training of young engineers in NASDA. The flight model has already been fabricated and launched successfully on H-IIA on December 14, 2002. The initial check-outs have been completed and now μ-LABSAT is working very well and obtaining various good experiment results such as camera image capture and processings, three axis stabilization and attitude sensor processings, etc.

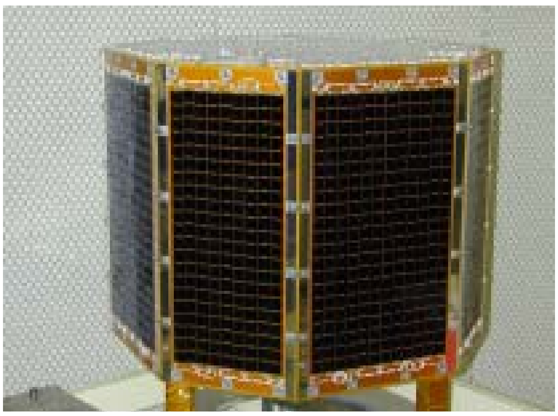

Fig. 1 μ-LABSAT launched in December 2002

2. UT's Experiments on μ-LABSAT

CRL has developed high performance MCM (Multi-Chip-Module) onboard computer (MOBC) and C-MOS camera (CMR) [4]. Using these devices, University of Tokyo will conduct as a PI (Primary Investigator) target motion estimation and tracking experiment, in the following way.

1) A target, 10 cm diameter small object with some visual markers on the surface (Fig.2) will be released from the bottom of the μ-LABSAT.

Fig.2 "Target" to be released from μ-LABSAT

2) When it comes into the view the CMR, the target image is obtained with about two-second interval.

3) Motions of visual markers on the surface are tracked with a certain image processing algorithm, and using the position information of these markers in the visual frame, the target attitude and attitude rate as well as moment of inertia ratio will be estimated using Kalman Filter.

4) When the target goes far away from CMR, the target tracking experiment is initiated, in which the chaser control its orientation so that the target image comes to the center of the CMR visual frames.

3. Target Motion Estimation Using Images

In the target motion estimation experiment, lighting condition on orbit will be difficult to predict, and the experiment will focus on how the invented image processing algorithm can successfully track the visual markers (Black points on yellow as shown in Fig.2) on the target surface under real lighting condition.

For detecting the target position in images, the color information of each pixel is to be utilized to discriminate the area of the target image from the black background and the image of the Earth. Especially, the image of the Earth, whose color distribution cannot be predicted because of the ambiguity of how the clouds cover the Earth, should be discriminated from the target image. In order to deal with this ambiguity, the thresholds for this image processing can be uplinked during the experimental operations, seeing the real images of the target and the Earth. We call this function "QL (Quick Look)". A special network system to process the downlinked data and software to view the images in quasi-real time fashion have been developed.

For Kalman filter processing, we should consider the special condition that the characteristic points may appear and disappear irregularly. At those occasions, the states and covariance matrix are to be appropriately modified to follow the changes of the number of observed points. The algorithm is implemented with this function and has been verified by computer simulations.

4. Visual Feedback Attitude Control Experiment

In the attitude control experiment, the special feature of μ-LABSAT that the attitude should be controlled using only two wheels (x-axis reaction wheel and z-axis momentum wheel), requires not-straightforward type control algorithms. For this objective, UT and NAL invented two novel control algorithms, one based on optimal control theory and the other based on sliding mode controller, as described below. In the current plan, these two algorithms will be applied sequentially, with different target goal positions. In this visual feedback, the observed state variables to be input to the control algorithm are the position (x,y) of the target image on the visual screen of the camera, body angular rates provided by the FOG (Fiber Optic Gyros), and the angular momentums of the two wheels.

(1) Switching Time Search Controller (SWSC)

This algorithm mimics an optimal control profile in real time fashion. The optimal profile which minimizes the time to reach a certain target position can be obtained using optimal control algorithms such as SCGRA. Such off-line type algorithms are, however, usually very computational intensive, and so cannot be employed on onboard computer in real time fashion. But the time profile of the control input has a certain common feature and if it can be mimicked in some way, the optimality of the control will be approximately restored.

Left figure of Fig.3 shows a typical example of a control input profile obtained by SCGRA. It shows a certain bang-bang type profile, and this feature is always observed in the obtained solutions. SWSC mimics this profile in the following way:

(a) The final angular momentums of the x and z-axis wheel can be predicted using the angular difference between the initial body attitude and the final one.

(b) The time required to reach the final angular momentum of the wheels can be obtained by the difference between the initial and final momentums of the x-axis wheel divided by the maximum torque of x-axis wheel. This time is called T_f hereafter.

(c) The x-axis wheel keeps the maximum or minimum torque during 0 to T_f. Whether it keeps maximum torque or minimum torque is to be decided using the required momentum change direction for x-axis wheel.

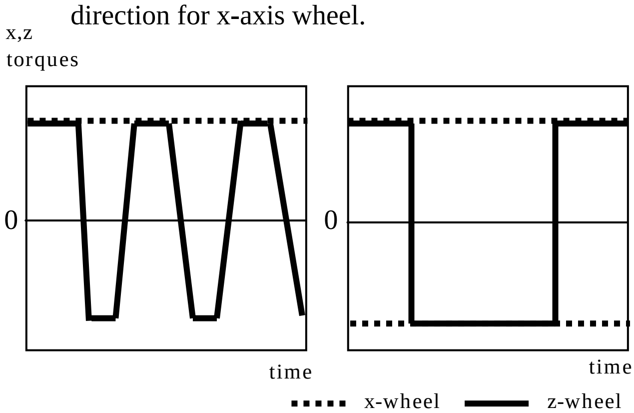

Fig. 3 Optimal Control Profile (left) and Mimicked One (right)

(d) The z-axis wheel is to change its sign twice as in the right figure in Fig.3. There are two degree of freedoms (DOF), that is, two switching times, should be specified. One of the DOF is utilized to make the total integrated torque, which equals to the momentum change of z-axis wheel, to be the required momentum change of z-axis wheel calculated in (a). The other DOF can be utilized to make the final target position as near to the goal point as possible. So one dimensional search using an attitude motion simulator is performed before actual control.

(e) After T_f, the residual target position error and the satellite angular velocity is to be diminished by a simple feedback controller which feedbacks the difference between the current and desired values of the observed state variables.

(2) Sliding Mode Controller

Sliding mode control is a well-known robust controller design algorithm that could be applied for both linear and nonlinear plant. This control is performed in two consecutive modes such as reaching mode and sliding mode. In reaching mode, the state of the plant is forced from any initial point to the designed sliding surface by the switched control input between two spaces divided by the sliding surface. In sliding mode, the state is constrained to the sliding surface and is moved to the origin naturally by the characteristics of the sliding surface.

The sliding surface for this particular attitude control problem is defined as a linear combination of Rodriguez parameter and its time derivative. Rodriguez parameter that represents relative attitude error for the target tracking is calculated using error Euler angles obtained from the target image position in the camera image frame. The time derivative of it is calculated using itself and attitude angular velocity of the satellite that is measured by FOG. By using Rodriguez parameter, it becomes possible to formulate the relation between attitude rate along the axis without wheel (y-axis) and those along the axes with wheel (x-axis and z-axis). This formula and the distance from the state (Rodriguez parameter and its time derivative) to the sliding surface is used to calculate the control input to force the state to go to the sliding surface (reaching mode) and then constrain it to the sliding surface (sliding mode). The angular velocity command of each wheel is given from this controller and each wheel command torque is approximately calculated from them.

5. Conclusions

On-orbital experiment of real time target attitude motion estimation and the autonomous visual feedback attitude control will be very unique experiments and the results will provide us with a new insights into the required systems for on-orbit servicing system. The experiments are planned in early May, whose first results will be shown at the symposium.

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