Photogrammetrie • Fernerkundung • Geoinformation 1/2002, S. 15–19, 2 figs.

Flight Experiences with DLR-TUBSAT

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Abstract: DLR-TUBSAT is a microsatellite joint project of the Institute of Aerospace at the Technical University of Berlin (TUB) and the German Aerospace Centre (DLR). It was launched on 26 March 1999 with the Indian Polar Spacecraft Launch Vehicle (PSLV) as secondary payload. DLR-TUBSAT was designed for interactive earth observation where the target is not identified in advance, a search action is involved or a target has to be visually followed. Whereas classical earth observation uses nadir pointing satellites the design of DLR-TUBSAT was made for using interactive control strategies. Since the start of the operation many different strategies for different acquisition and operation modes are developed and tested. New software programs on satellite and ground segment and new ground control procedures are a result of this development. Possible applications of the produced earth observation data could be defined and were integrated in the new control strategies. DLR-TUBSAT showed that it can serve new market areas of earth observation and new customers, which cannot use or do not want to use classic earth observation satellites. The main advantages are the interactive search abilities, very high repeat cycles (1 day) and the low mass and low costs of the satellite system.

Zusammenfassung: *Flugerfahrungen mit dem DLR-TUBSAT.* Der DLR-TUBSAT ist ein gemeinsames Mikrosatelliten-Projekt des Instituts für Luft- und Raumfahrt der Technischen Universität Berlin (TUB) und des Deutschen Zentrums für Luft- und Raumfahrt (DLR). Er wurde am 26. März 1999 mit dem indischen Polar Spacecraft Launch Vehicle (PSLV) als Sekundärnutzlast gestartet. Der DLR-TUBSAT wurde zur interaktiven Erdbeobachtung entwickelt, bei der das Ziel vorher noch nicht klar identifiziert ist, eine Suchaktion durchgeführt werden muss oder ein Ziel visuell verfolgt werden soll. Während die klassische Erdbeobachtung Nadir-blickende Satelliten nutzt, wurde der DLR-TUBSAT für interaktive Kontrollstrategien entwickelt. Seit Beginn des Betriebes wurden viele verschiedene Strategien für verschiedene Lageregelungs- und Betriebsmodi entwickelt und getestet, woraus neue Softwareprogramme für das Satelliten- und Bodensegment sowie neue Bodenkontrollprozeduren abgeleitet wurden. Mögliche Anwendungen der erhaltenen Erderkundungsdaten konnten definiert und in die neuen Kontrollstrategien integriert werden. DLR-TUBSAT zeigte, dass seine Daten neue Segmente des Erdbeobachtungsmarktes abdecken können sowie für neue Kunden interessant sind, die nicht die klassischen Erdbeobachtungssatelliten nutzen können oder wollen. Seine grundlegenden Vorteile sind, neben geringer Masse und niedrigen Kosten des Satellitensystems, die Fähigkeit zu interaktiven Such- und Beobachtungsoperationen und seine sehr hohen Wiederholrate der Beobachtung eines Zielgebietes (1 Tag).

1 Introduction

Satellite remote sensing is going to be a commercial market in the last years, but most of the systems are still governmental projects. With IKONOS a high resolution earth observation system is available for commercial users. With the panchromatic resolution of 1 m and a multispectral resolution of 4 m IKONOS can serve new commercial users of earth observation. But nearly all these systems have some identical characteristics:

1. They use nadir pointing.
2. They have repeat cycle rates from 3 to 26 days.
3. They are not interactively controlled. Targets must be exactly defined.

1432-8364/02/2002/0015 $ 1.25

4. They only deliver photos, not moved pictures. Most of the pictures must be processed before they can be used.
5. They are heavy systems with huge development and start costs.

The main design idea of DLR-TUBSAT was to go new ways in earth observation. As a microsatellite the system is smaller, cheaper and lighter than classic earth observation systems. This has two important effects: On the one hand the system can be offered to customers who are not able to pay several millions for a satellite. Normal commercial systems have many users and sometimes there are conflicts between the different needs of the users. Microsatellites offer the possibility to create a payload for the special needs of the user and to fly the wanted orbit without rising costs. The optimisation of the orbit is possible because there are many new small launchers (e.g. SHTIL) on the commercial market in the last years, most of them converted military ICBMs. For nearly the same price a user can have his own satellite and can use it the whole time by himself. The disadvantages of using a microsatellite are the small payload volume and mass and the small power supply. Because of that it is not possible to make radar observation with microsatellites but it is possible to use the visible and near infrared spectrum with resolutions of 3 to 6 m by flying in LEO.

On the other hand the low mass of microsatellites makes it possible to control the satellite interactively and to use smaller and cheaper launchers. In this case interactive earth observation means that the user in the ground station receives video images from the satellite and is able to steer the pointing direction of the camera platform (by moving the satellite) interactively via keyboard, mouse or joystick control to the interesting event (see Fig. 1). Interactive earth observation makes earth observation possible where the target is not identified in advance, a search action is involved or a target has to be visually followed. This and the real time video pictures of such a microsatellite open the earth observation market for many new users.

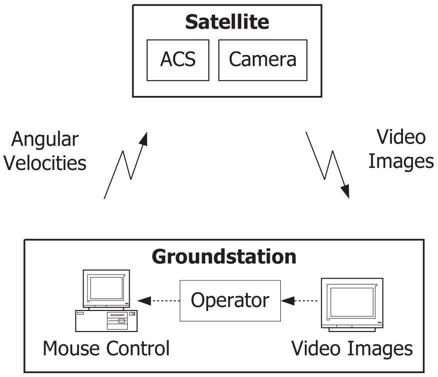

Fig. 1: Interactive earth observation.

The last two years of operations with the DLR-TUBSAT show that possible applications are for instance:
1. Monitoring of areas with repeat cycle rates of 1 day.
2. Observation of boarders, ship and air traffic, pollution, vegetation etc. by searching around without knowing where the target is located.

This second point is the most important for operating DLR-TUBSAT. We can supervise a great area by using small resolution and can switch to high resolution if we see an interesting object. There is no difference if this object is stationary or moves with high velocity.

2 The DLR-TUBSAT System

DLR-TUBSAT is a microsatellite joint project of the Institute of Aerospace at the Technical University of Berlin (TUB) and the German Aerospace Center (DLR). TUB was responsible for the satellite bus and DLR for the payload. It was launched on 26 March 1999 with the Indian Polar Spacecraft Launch Vehicle (PSLV) as secondary payload. In the frame of operation the TUB has a co-operation with the German Remote Sensing Data Center (DFD) in Neustrelitz. The TUB Satellite Control Center is responsible for health monitoring and telecommanding and the DFD for receiving the S-band video signal.

2.1 *Space Segment*

The cube shaped satellite measures 32 cm × 32 cm × 32 cm and weights 44.81 kg. DLR-TUBSAT is subdivided into a Payload, a Housekeeping and an Attitude control module. Telemetrie and telecommand are transmitted via VHF (2 m) band or UHF (70 cm) band with FFSK modulation and a data rate of 1200 baud. Both antennas are omnidirectional dipol antennas. The analogue video signal is transmitted via S-band with a bandwidth of 8 MHz. The beam width of the helix antenna is 70°. The payload module contains two fore field cameras (16 mm and 50 mm focal length) and a high resolution telescope (1m focal length) with a ground pixel resolution of 6 m. The power supply is done by 4 duplex NiH2 battery cells which are charged by 4 solar panels, each containing a single string of 34 silicon cells. A single string of solar cells is attached at the surface in the z-axis and is used for sun acquisition manoeuvre. The attitude control system contains 3 reaction wheels, 3 optical gyros and two different magnet torquers. For interactive attitude control of the satellite we use the reaction wheels, the gyros, the analogue video signal and the solar cell telemetry (solar cell current). The magnet torquers are only used to reduce or to increase the angular momentum.

2.2 *Ground Segment*

The primary ground segment contains the TUB Satellite Control Center and the DFD S-band receiving station. The satellite is controlled by the TUB VHF/UHF ground station. TUB is not able to receive the wideband video signal in Berlin because the S-band antenna is not great enough to get a good signal to noise ratio. That is why the S-band video signal is received by the DFD Neustrelitz. A reduced video signal is send to the TUB via internet. With this reduction of the video signal it is possible to send the picture information to Berlin in real time, what is important for the interactive satellite control. The original video signal is recorded on SVHS video tapes in Neustrelitz.

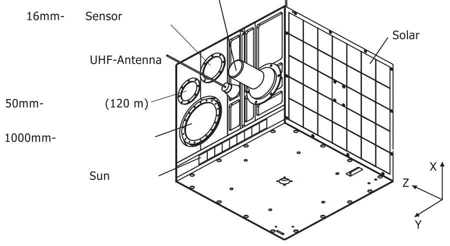

Fig. 2: DLR-TUBSAT.

In course of the satellite operation phase a complete satellite control station in Tromsö (Norway) was build up and a cooperation with a satellite control station in Rabat (Morocco) was started. This two stations can control the satellite and receive the wide band video signal.

3 Acquisition and operating strategies

The main advantage of the DLR-TUBSAT system is the interactive attitude control. One design requirement was to keep the system as simple as possible and to build a cheap system. Because of that no star sensor or GPS system was used. That is the reason why other acquisition strategies than in the classical earth observation systems must be used. Since the start of the operation many different strategies for different acquisition and operation modes are developed and tested.

3.1 *Acquisition strategies*

In normal case the satellite power system is shut off and the satellite is in free rotation. The first step is to stabilise the satellite and to orientate the camera axis to the earth. Without that we would have no S-band connection and no video signal could be received (S-band antenna is located in the camera axis – see Fig. 2). Different possibilities were tested. Which strategy is to be used depends on the season and the geographical position of the ground station.

In the early beginning of operation we use sun pointing modes. For this acquisition mode we do not need any video signal, only the electrical telemetry of the solar cells is used. At first we start the Attitude Control System (ACS) and send the ACS damping command to the satellite. ACS damping means that the rotation in each axis is stopped by the reaction wheels. Sensor signals are delivered by the laser gyros. After stopping the rotation we use the electrical telemetry of solar cells to rotate the satellite till all sunlight is shining on the $-z$ solar panel. The satellite is orientated when $-z$ solar cell has more than 910 mA current in summer and more than 980 mA in winter. Then the camera axis ($+z$) is pointing to earth, S-band signal can be received (after switching on the Camera System) and interactive attitude control can start. With this procedure we reach an orientation accuracy of 5°.

The main problem of this procedure was, that in winter the sun is standing too far in the south. By using this sun pointing mode the satellite looks too far to the north or, if Tromsö station is used, the cameras look into the space. For stations in the nearness of the equator it is not a problem. To solve this problem we tested a new sun pointing mode. Instead of orientate the $-z$ axis into sun, we use the $+x$ axis for that. After putting the $+x$ axis to the sun we start a rotation around the x-axis and wait for the S-band signal from DFD. Disadvantage of this procedure is that we do not know in which direction we are looking. The orientation by the earth surface must be done by looking for the geographical characteristics of the earth surface.

The big advantage of both sun pointing modes is, that no signal from the cameras is needed. So it was possible to write boot software for the satellite to make this acquisition automatically. This boot program can be started by a timer clock and the satellite could be orientated to the earth before we get the first contact. The whole acquisition procedure needs 100 sec.

But we are not satisfied with the accuracy of the orientation. An accuracy of ±5° is not good enough for a good predestination what we will see in the video pictures. It could be compensated by the interactive control (searching around and orientation by geographical characteristics) but it could not be the development's end.

That is why we decided to use the video pictures for acquisition. At first we start with stopping the satellite rotation. Then we switch on the camera system and make a 6°/sec rotation around the x-axis. If the earth horizon is reached, we stop the rotation and rotate around the z axis till the earth horizon is vertically shown in the video picture. Then we make a 64° rotation around x-axis to the earth centre. Now we are nadir pointing with an accuracy of ±1°. It could be that we do not see the earth horizon by rotation around the x-axis, because we are scanning pass by the earth. With 6°/sec rotation we make one round in one minute and if we do not see the horizon in 60 sec then we will stop the rotation and start a rotation around the y-axis and then we will get the horizon. The advantage is that we reach a very good accuracy of orientation and for day overflights the procedure is working in every season for the ground stations in Germany and Morocco. At night it is a little bit more difficult to find the horizon because only a little part of the horizon is visible as an enlightened crescent. The Tromsö station has the same problem in polar night. In this case it takes more time to find the horizon but the rest of the procedure is the same. The disadvantage is the long time of up to 4 min we need for this operation if we do not find the horizon by rotating around x-axis. Another disadvantage is that we require the video signal in real time. The internet is too slow for transfer of the whole video information and so we can only use a reduced video picture in Berlin. The stations in Rabat and Tromsö do not have this problem.

A solution of this problem is an addition of sun pointing to earth horizon orientation. At first we use the automatic sun pointing mode and then we start the acquisition with the video pictures. With this procedure we can be sure that we will get the horizon by the first rotation around the x-axis. Because of the good orientation accuracy and the acceptable acquisition time this is at the moment our preferred procedure.

3.2 *Interactive earth observation*

After the acquisition phase the earth observation can start. The first step is the north-south orientation of the video picture to get a picture as known from the atlas. If we use the sun pointing mode with all sunlight on the x-axis the picture is orientated to the south, that means south is on the upper boarder of the monitor. In every other case we must make the orientation by hand. To make the north-south orientation we use the temporal changing of the video picture. We know that the footprint of the satellite is moving from the north to the south (at day) or from the south to the north (at night). By rotating the satellite around the z-axis we can make the picture move from the lower to the upper side of the monitor (at day; at night reverse). Now north is at the upper boarder of the monitor.

The real interactive earth observation starts with searching around with the 50 mm telescope to find the target area. The camera axis is controlled via keyboard, joystick or mouse control commands. We have learned that the control via keyboard is too difficult and it is too susceptible to mistakes (finger trouble). Because of that we developed the joystick and mouse control. In this case the user can control the camera as known from other computer applications without looking to the keyboard. The user can look the whole time to the monitor picture and can change between the 50 mm and 1 m cameras. At this point we must say that we have a light problem with the 16 mm and 50 mm cameras. If it is cloudy the cameras are overexposed because it was planned to do earth and star observation with this cameras. Only the 1 m camera does not have this problem.

The target pointing could be made by joystick or mouse control or by using keyboard commands for rotation around the y-axis. The reason for the north-south orientation of the video picture was not only the better orientation on a map. The precise orientation makes it possible to compensate the moving of the satellite footprint by rotating the satellite only around the y-axis. The rotation speed for starting target pointing at nadir pointing position is 0.55°/sec. It goes down to 0.1°/sec depending from the deviation to nadir pointing. If the orientation is not precise the picture breaks out to the left or right. It must be compensated by rotating a specific angle around the z-axis. If the rotation speed around the y-axis is not correct the picture breaks out to the upper or lower boarder. If the target moves to the lower border the rotation speed must be reduced, if it moves to the upper border it must be increased.

Our experiences show that a target search and target pointing with keyboard commands is possible but too jerky and too susceptible to mistakes. Joystick and mouse control work better but the rotation speed about the axis can be better controlled by mouse. Only the north-south orientation corrections should be done by keyboard, because these are angle and not angle velocity commands.

In the near future we want to update the software. The goal is to made the acquisition and the north-south orientation automatically. This should be done by detecting the earth horizon (black to white transition) and the temporal changing of the horizon.

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