ABSTRACT

The micro satellite mission BIRD demonstrates the technical and programmatic feasibility of the combination of ambitious science and new, not yet space-proven advanced technologies under fixed budget constraints. The demonstration of new micro satellite technologies is one key point of the BIRD mission. The technology experiments demonstrate the limits and the advantages of the new developed components and technologies. The micro satellite BIRD (mass = 92kg) was launched with the Indian PSLV-C3 from Shar on 22 October, 2001 into an Sun-synchronous circular orbit at an altitude of about 568km. The paper describes the new developed technologies and the results of the space demonstration.

1. INTRODUCTION

The BIRD mission demonstrates a new solution for the detection and evaluation of vegetation fires and other hot spots from space by means of a new generation of cooled infrared array sensors implemented on an advanced micro satellite bus. Some basic features of the BIRD spacecraft bus are

- compact micro satellite structure with high mechanical stability and stiffness
- envelope qualification for several launchers
- cubic shape in launch configuration with dimensions of about 620x620x550mm³
- mass ratio bus : payload = 62kg : 30kg
- high peak power of 200W @ 10…20min, and av. power 60W
- thermal control system with radiators, heat pipes, MLI, sensors and heaters
- new developed high-performance spacecraft bus computer with integrated latch-up protection and error detection and correction system
- three-axis stabilization by an attitude control system in state space representation
- on-board determination of the spacecraft position and velocity
- S-band communication with high bit rate (2.2 Mbps) and low bit rate.
3. TECHNOLOGY EXPERIMENTS AND TECHNOLOGY DEMONSTRATION

Low-Cost Star Sensor

An autonomous star sensor is necessary for the high precision attitude information. The BIRD star sensor was developed in close cooperation between Jena-Optronik and DLR. The sensor has a robust and compact design with a total mass of 1.2 kg and consists of a CCD matrix camera in combination with an internal star catalogue and an image analysis software for star identification and search. The sensor delivers the attitude information in quaternions.

Results

Different tests in orbit showed that both star cameras determine their orientation reliably and with the right sign. They even will remain logged in if the slewing rate reaches up to 0.5 °/s.

High Precision Reaction Wheel

For BIRD a reaction wheel system with 4 wheels in combination with 2 x 3 magnetic coils are applied. Basing on the reaction wheel development of the Technical University of Berlin (Prof. Renner) a new reaction wheel for micro-satellites was developed for BIRD in close cooperation between Astro- und Feinwerktechnik Adlershof GmbH, TU Berlin and DLR. These reaction wheel is characterized by high control precision by means of smart control electronics, low level emitted vibrations and robustness of assembly. Inputs of the reaction wheels are rate acceleration (torque) or revolutions per minute or their variations.

Results

Already on ground there was shown that the torques with a medium error rate of $10^{-7}$Nm and with a variance of $< 0.0016$ Nm are effected. Therefore, the pointing errors for BIRD range lower than 22 arcsec. Because of the precise internal control the occurring errors are almost independent on the speed and the commanded torque when the determined by the wheel itself acceleration reserve is kept.

Autonomous Attitude Control

The Attitude Control System (ACS) of BIRD consists of two star sensors, a gyroscope, a magnetometer, 2 sets of Sun sensors, 4 reaction wheels, a low-mass magnetic coil system, an attitude control system with a high degree of autonomy basing on a state-space representation of the attitude estimation, prediction and control, a real-time operational system embedding the attitude control software and a combination of the attitude control with an on-board navigation system. Dependent on the results of the on-board failure detection system an autonomous decision on-board about the used sensor/actuator combination and the required attitude mode is tested in orbit, if enabled from ground.
Results

The first acquisition from an initial revolution with about 5 °/s up to the stable sun-pointing was perfectly performed, the mean damping acceleration was 0.1 °/s². The magnetic torquer system minimized the angular momentum very well. The remaining jitter movement is lower than 6 arcmin/s. Commanded turns are effected with high precision. The autonomous configuration of the ACS was tested and turned out to be very reliable. Even, when the gyro-system shortly failed the satellite remained in an acceptable sun-pointing position although in this case its slewing rate could be derived only from the sun-sensor and the magnetometer.

Spacecraft Bus Computer

The Spacecraft Bus Computer (SBC) controls all activities of the satellite bus. The SBC receives, stores and processes the commands, gathers and evaluates the housekeeping data of all subsystems and partially of the payload and controls the telemetry and science data formatting and transmission activities on-board. Furthermore it is also the attitude control computer of BIRD. To assure a high system reliability and robustness several measures were done: latch-up detection and protection, redundant processing and memory structures, implementation of a special redundant structure (2x2) of the 4 SBC boards and watchdog circuits for failure detection and recovery.

Results

The board computers are functioning from the very beginning without problems, as it does the implemented new developed operating system BOSS. Some bursts of high-energy radiation and extremely high particle density caused a switch to the redundancy structure or into the safe mode. The functioning of the redundancy structure was demonstrated.

On-Board Navigation System

Making use of a low-cost GPS receiver, an advanced orbit determination and orbit prediction system assures, that precise position and velocity data are available on-board, even in the absence of GPS measurements. The system is also capable to estimate mean orbital elements in the form of standard Two Line Elements. This enables a novel concept for combined ground-space autonomy. Furthermore, shadow transit times and ground station contact times are computed autonomously onboard and thus demonstrate the high potential of increased autonomy for satellite operations.

Results

Following a smooth initialization some days after launch it was possible to determine the current orbit position on board of the satellite with an accuracy of 10 m in any direction. The comparison of the orbit positions given by the satellite and the ones retrieved at GSOC by means of an independent orbit determination and a highly precise orbit modeling served as a proof of this capacity. Currently a position accuracy of 5 m is ob-
tained in all axes. The BIRD On-Board Navigation System is currently used for routine on-board orbit determination and generation of Two Line Elements.

On-Board Classification Experiment

For a group of remote sensing tasks, like disaster warning and hazard detection a quick classification and a short response time is required. Therefore a high level data processing chain on-board the satellite would be very useful. Today’s powerful processing technologies allow to implement the processes of data pre-processing, calibration, correction of distortions, feature extraction and classification on-board of the satellite. Additionally a learning system is implemented on-board of the BIRD satellite. The thematic data reduction on board of BIRD are made by a multi-spectral supervised classification basing on the neural network processor NI1000. This neuronal network is able to "learn" on-board BIRD by an upload of learning vectors.

Results

June 14 2002 for the first time on board of the BIRD satellite a scene was classified by means of the neural network classification experiment. For this the classes water, warm clouds, cold clouds, fire, land surface, and non-classifiable were defined. The classifier was “taught and trained” from ground. In follow-up experiments the working method of the neural network classifier was investigated and demonstrated.

Experimental Ground Station

The basic idea of the Experimental Ground Station consists in the philosophy to give the user only regionally limited data, for which a high performance ground station is not necessary. A common PC with a Pentium class CPU is used for data reception and processing as well as for commanding. Most of the base-band-hardware is built into the PC. The software for the downlink is intended to receive, display and store payload and housekeeping data. Payload data can be processed with a separate software developed by DLR. In case of detected anomalies, alarm messages can be forwarded. Automatic update of two line elements directly from the BIRD satellite will be possible.

First results

The ground station receives and processes BIRD data. The housekeeping data are visible on-line when being received. The received payload-data (image data) can be decommutated, pre-processed, and displayed in a quick-look mode almost in real time.

SUMMARY

Seven new micro-satellite technologies were tested successfully in space. The BIRD spacecraft bus is a new adaptive platform for further science or Earth watch missions supplementing already planned missions. The ground station demonstrates the advanced conception for a user oriented data reception and processing system without any delay.