SSC04-IX-3
BILSAT-1: First Year in Orbit-
Operations and Lessons Learned

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BILSAT-1 is an enhanced small satellite platform for earth observations; designed, built and launched in the framework of a project by TUBITAK-BILTEN and SSTL through years 2001-2003.
Introduction

- Wet mass: 129 kg
- Orbit: 686 km, circular, SSO
- Control: 3-axis
- Orbit alignment: Cold gas thruster propulsion system
- Life time: (5+10) years
- Imaging systems:
  - MSI system (red, green, blue and NIR bands) with 27.3 meters ground sampling distance
  - One Panchromatic imaging system with ground sampling distance of 12.6 meters
- Store and forward communication
- R&D payloads
• After successful integration to the launch vehicle COSMOS-3M, the satellite was launched on September 27\textsuperscript{th}, 2003 @ 06:11:42 UTC

• Along with BILSAT-1, there were other payloads on the launch vehicle
  - UK-DMC (DMC satellite)
  - NigeriaSAT-1 (DMC satellite)
  - KaistSAT-4
  - Larets
  - RUBIN 4/SL-8
  - Mozhayets-4

• The launch took place at the Plesetsk Cosmodrome in Russia
On the launch vehicle:
- BILSAT was “asleep”!

All the sub systems of BILSAT-1 were “off”, as a “safety requirement” for the launch vehicle - while the satellite was on the launch vehicle

After separation:
- BILSAT started to listen only

As the satellite was injected into orbit from the launch vehicle, only the VHF receivers came on automatically

Initial acquisition:
- Ground command to awake vital systems

Thus in order to turn on the subsystems one by one, ground command was required
According to the orbital calculations, BILSAT-1 was to be in the communication cone of BILTEN ground station at 07:37:20 UTC after the launch.

The initial commands were transmitted during this predicted pass for about two minutes continuously.

As the UHF Tx was on, the first TM frames were received. The communication was then a two-way communication...

Since UHF Tx was on, the satellite started to respond back by means of acks and TMs transmitted.
Initial telemetry had taken granted the health of the satellite with good power generation capability.

- **Temperature**
  
  Whole orbit data surveys revealed that the temperatures of the running modules were cycling between 6 and 14°C. This temperature range was close to the expected range for this low power configuration.

- **Battery**
  
  The battery was healthy, supplying 400 mA in eclipse, meaning approximately 6% depth of discharge.

- **ADCS**
  
  Once the ADCS module was powered up and the ADCS software was running on flight computer, it was revealed that spacecraft was spinning about an axis that illuminates two of the arrays (array 1 & 2) in turn with about a 20 minute period.
Nadir pointing and first tests

- **Initial attitude**: High spin rate about an arbitrary axis
- **Reduced spin rate**: The spin rate of BILSAT-1 was reduced to <3°/s by means of torque rods
- **Y-Thompson mode**: Once the spin rate was reduced, the satellite was put into Y-Thompson mode on September 30th, 2003
- **Nadir pointing**: Following the Y-Thomson orientation, BILSAT-1 was successfully placed to nadir pointing attitude, which completes the attitude acquisition phase of the commissioning
- **Nominal operations mode**
Following the first phase, all the core modules, including ADCS systems (sun sensors, magnetometers, magnetorquers), RF systems (UHF Tx, VHF Rx, S-band Tx, S-band Rx), on board computers (OBC 186, OBC 386-0, OBC 386-1) and SSDR PowerPC, commissioning was undertaken in a regular fashion.

All the mentioned modules were working properly, within the expected temperature limits, drawing designed current values.

Following core module tests, all other sub systems including payloads, were tested.
DMC (Disaster Monitoring Constellation) is an international consortium that aims to help monitor disasters by imaging the disaster zone rapidly.

BILSAT-1 was launched by two other DMC satellites, namely UK-DMC (UK) and NigeriaSAT-1 (Nigeria).

By the time these three satellites were released to orbit by COSMOS 3M, the first DMC satellite ALSAT-1 had already been launched on November 28th, 2002.

All four satellites had to be phased evenly on the same orbit.
The Operations

- Once BILSAT was located into the correct location with correct attitude, the operations started
- The main mission was (and is) obviously “earth imaging”
- Various test images were taken to adjust the correct exposure values for the cameras.
- BILSAT has 5 different cameras on the earth facing facet for main mission

BILSAT has two imaging systems:
- PAN imaging system
- MSI imaging system

PAN imaging system has one camera. MSI imaging system has four different cameras imaging in BLUE, GREEN, RED and NIR regions of the spectrum
- Imaging with PAN was easy- single camera
- Imaging with MSI- not as easy as PAN- why?
Due to physical reasons and manufacturing reasons, CCDs of all four cameras are not perfectly aligned:

- A certain offset in terms of translations in both axes in plane
- A certain offset in terms of translations in axes out of plane
- A certain offset in terms of angle exist.

Which requires:

- **Translational corrections** (due to shift in plane)
- **Rotational corrections** (due to rotation in plane)
- **Scaling corrections** (due to shift out of plane)

Once these corrections have been performed, the images obtained in three bands (red, green and blue) may be merged together to produce a colourful image.
A number of images were taken to calculate these factors - a few trial and error revealed these parameters.

A reference image was to be chosen - so that other frames could be translated, rotated and scaled according to this reference frame.

“Red” frame was chosen to be the reference frame.

Thus, blue and green channels were aligned with respect to red frame according to:

\[
P_{\text{green}} = s_{\text{green}} R_{\text{green}} P_{\text{red}} + T_{\text{green}}
\]

\[
P_{\text{blue}} = s_{\text{blue}} R_{\text{blue}} P_{\text{red}} + T_{\text{blue}}
\]

where

\( P_{\text{green}}, P_{\text{blue}} \): The locations of the pixels on the green and blue images

\( P_{\text{red}} \): The location of the reference pixel from the red image

\( s, R, T \): scale, rotation and translation values respectively which were calculated for once – i.e. constant

<table>
<thead>
<tr>
<th>Channel</th>
<th>Scale</th>
<th>Rotation(°)</th>
<th>Shift(pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>0.9872</td>
<td>-0.36</td>
<td>[16,-143]</td>
</tr>
<tr>
<td>Blue</td>
<td>0.9898</td>
<td>0.09</td>
<td>[29,-103]</td>
</tr>
<tr>
<td>NIR</td>
<td>0.9896</td>
<td>0.05</td>
<td>[-65,11]</td>
</tr>
</tbody>
</table>
Example

Software, which calculates all necessary translations, rotations and scalings and then merges images so as to form a colourful image.

red channel

green channel

blue channel

Corrected image
Playing with 3-D models

- Some of the images obtained by BILSAT imaging system were also merged with 3-D maps of the area to improve the image “quality”

İskenderun Bay, 30 Oct 2003, 9:14 (GMT+2)
image after back projection + 3-d model of the same area
Strips of images

- One of the missions was to image the whole of Turkey.

- Since BILSAT was launched in September (i.e., Start of winter)- most of the pictures taken during winter season were cloudy- BILSAT team did not get much chance to get clear pictures of Turkey.

- By the summer season, we started to get clear images- so we started to take strips of images during passes over Turkey.

- We are trying to take as many images as we can until October 2004.

- By combining these images we can produce the image of Turkey.
• As the satellite flies over Turkey in the south-north direction, it starts to capture successive images with a defined overlap ratio.

• These images are then coloured and combined together to produce a strip of images.
• As a DMC member, BILSAT imaged the flooded region in Jimani
• By this image, BILSAT was credited as the first DMC satellite to take a disaster image in the constellation
As a 3-axis controlled agile satellite, BILSAT is capable of pointing its payloads (i.e. Cameras) by spinning about any defined axis.

In order to demonstrate this capability, while flying over Atlantic Ocean, BILSAT was given a roll angle to image the horizon of earth.
As a research and development satellite, BILSAT also accommodated some additional payloads to be experimented with. GEZGiN is one of these payloads.

GEZGiN: Real time image compression hardware in JPEG2000 format

MSI system can send the captured images to SSDR either directly and/or via GEZGiN

An MSI image of the target region may be captured:
- MSI image only
- Compressed with GEZGiN only
- MSI image + compressed by GEZGiN
Why would one need to compress images?

- One frame of MSI channel is around 4 MB
- One frame of image with 4 channels is around 16 MB
- Taking a strip of 5 successive frames for instance, gives a image file size of around 80 MB – GEZGiN may compress the image upto few MBs or even some hundreds of kilobytes!
- Downlink rate is 2 Mbps (mega bits per second)- best conditions
- 80 MB of image requires around 5 to 7 minutes to download
- An average pass is around 4 minutes -> requires at least two passes! The greater the size of image, the more passes are required.
- Contact time with the ground station is limited.
- Large MSI images may take a number of passes to download
- GEZGiN compressed images may save time to download
- In the case of MSI+GEZGiN imaging, first GEZGiN image can be investigated and then the original image may be discarded if necessary (cloudy images for example are not required- discarded directly)
Experimenting with the payloads

- Compression ratio can be adjusted via ground control
- Many MSI+GEZGiN images have been captured with various compression rates etc...

An MSI images of a specific target area

Image of the same area compressed by GEZGiN 120 times
At the ground station

• Due to the nature of the climate, ground station antennae are exposed to harsh conditions
• The temperature; in winter goes down to around −30 or −35 celcius and in summer goes up to +40 celcius
• The snow stays for weeks sometimes
• After long cold nights, the joints of dish antenna could get stuck due to ice and/or snow.
• This sometimes makes is impossible to track the satellite.
At the ground station

- As a solution to overcome the freezing, from time to time, we decided to track some dummy satellites, or satellites other than BILSAT – which would move the antenna at least once in about two hours...

- For hot summer days- in order to overcome the extreme temperature in the control box, we fit a cooling unit on top of the control electronics box of the dish.
There is still a lot to do

- Imaging
  - Finish imaging Turkey, combine the strips
  - Start taking stereo images for DEM (digital elevation map) model of Turkey
  - Finish calibration campaign
- Experimenting with the payloads
  - Carry on with the tests of some other sub systems
    - Gezgin
    - SA1100 ssdr
    - Star cameras
    - CMG
    - Gyros
    - ADCS system as a whole- software upgrades to improve accuracy etc.
- Ground station software
Thank you

http://www.bilten.metu.edu.tr/bilsat/