Wireless Avionics for a Solar Sailer (GOSSAMER-1)

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ABSTARCT

GOSSAMER-1 is a demonstrator for a solar sailer, and it shall conduct an in-orbit deployment of versatile ultra-lightweight deployable sail hardware as a feasibility demonstration and it shall provide evidence of the successfully accomplished deployment by means of suitable visual and technical observational data to be downlinked to ground.

The sail structure shall be suited for different use cases, as there are:

- Solar sailing
- Ultra-lightweight solar photovoltaic generators
- The deorbiting of a space craft from LEO

Reflective foils and photovoltaic foils are prerequisites for the future use of a solar sails as a new propulsion technology for space exploration. The latter especially includes the combination of this different foil types within one sail segment.

The mission objective is the demonstration of a successful a reliable deployment, not yet the use a solar sail. [3]

1. INTRODUCTION

The solar light pressure is very low and therefore forces and the delta-V is very low too. The huge advantage of this method is the fact that this pressure is permanently available and may be used continuously for months and years.

After months of very small acceleration we may get higher speeds than possible using current chemical propulsion systems, which may be used only for a few minutes to generate very intensive but limited acceleration.

The solar radiation flux at Earth is S_0 = 1368 W/m^2 and divided by the speed of light, gives the solar radiation pressure at 1AU distance 4,563 μN/m^2. Assuming an ideally reflecting sail surface, the pressure on the sail surface is larger by a factor of 2 p_{Sail} is 9.126 μN/m^2. [1] (The momentum of a photon before the reflection is p, afterwards it is –p, therefore Δp = 2|p|). Maximum propulsive force exerted on the sail craft at 1AU distance is 20,75 mN (Eq 1).

$$F_{max} = p_{sail} \cdot \eta \cdot A \qquad (1)$$

η = Sail efficiency (Al η = 0,88), A = Sail area (50 m x 50 m)

$$\sigma = \frac{m}{A} \qquad (2)$$

If the mass is 70 kg, then the sail assembly loading gives 28 g/m^2 (Eq. 2). [1]

Therefore in order to get the highest possible acceleration from very low light pressure we have to achieve two properties: reduce the space craft weight to the minimum and have sails as large as possible. To reduce the weight to a minimum we decided to use wireless communication in our avionics system.

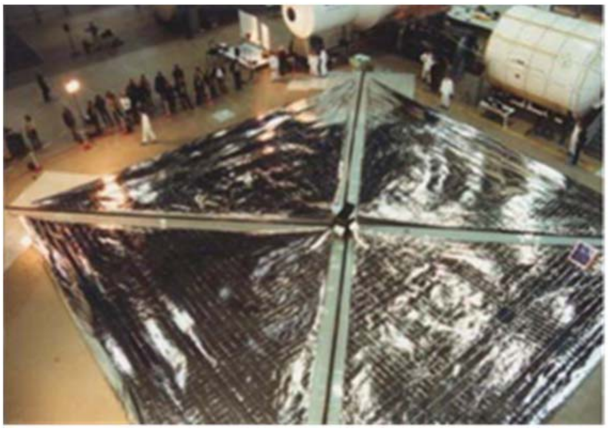

Figure 1. On-ground deployment demonstration of a 20m x 20m solar sail (ESA contract, DLR delivered booms and sails)

We employ no wires neither for data transfer nor for power distribution. This not only reduces the weight but also simplifies the harness and assembly of the space craft, too.

2. COMPONENTS OF GOSSAMER-1

Figure 2 summaries the GOSSAMER-1 demonstrator into smaller units and sub-units.

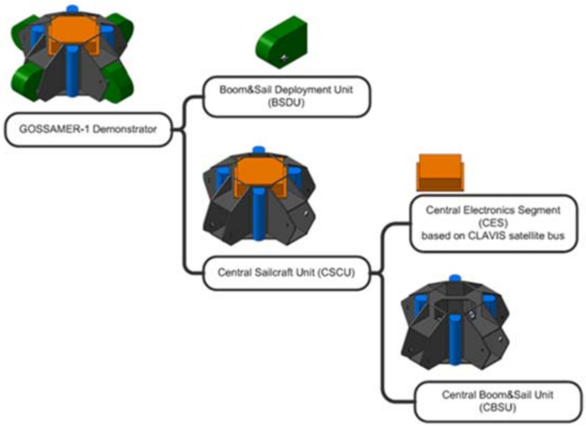

Figure 2. Hierarchy according to accommodation/location

The CBSU (Central Boom and Sail Unit) contains all sail assemblies, which are the sail spool mechanisms and all sail specific hardware's. [4] CES (Central Electronics Segment) accommodates all auxiliary electronics subsystems, like power conditioning, TM/TC, OBC, etc…, it is essentially the CLAVIS satellite bus, which on the GOSSAMER-1 satellite bus based. [4] BSDU (BOOM and Sail Deployment Unit) perform the deployment of the booms and the first step of unfolding the sails and which, after successful deployment, will be jettisoned. [4] The CSCU (Central Sail Craft Unit) is the main unit without the four BSDUs, no matter whether the deployment has actually occurred or not, stowed as well as deployed configuration. [4] This is the sail craft as such, as the BSDUs are not part of the sail craft, which actually meant to sail. [4] Then the CSCU is the CES, CBSU and the Sail Spool Mechanism (SSM) together.

2.1. Booms and Boom Deployment Mechanism

The BSDUs contain the boom deployment mechanism as such the mechanism for extracting the sail and fixing it in the end position.
The rollable boom has been developed by DLR within the ESA funded solar sail study in the late 1990s. [6]
On GOSSAMER-1 we have four of these mechanisms, which will be jettisoned after the deployment.

The basic concept of the boom consists of a so called double OMEGA shape of the cross section. It enables the boom to be attended without material damages.
The necessary flexibility of the material is generated by the thin small material thickness of about 0.1 mm which leads to outer fiber strains that can be carried by the used carbon fiber laminate. [6]
The upper sketch of Figure 3 shows the cross section in

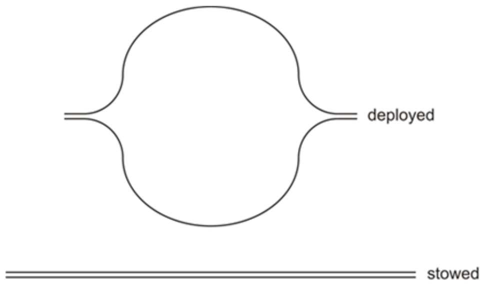

Figure 3. Deployed and stowed state

its deployed state and the lower sketch in its stowed configuration.

2.2. BSDU (BOOM and Sail Deployment Unit)

The deployment mechanism is a distributed system. It consists of a central component and four boom deployments. Each has its own controller, power unit and payload.
In this experimental mission payloads are just cameras, which will be used to record the deployment.
Each boom deployment unit and the central unit have its own controller, only the central controller is implemented as redundant.
Each controller consists of a:

- CORTEX M3 CPU as control unit, running our RODOS building blocks execution platform.
- Gyro, accelerometer and magnetometer sensors to protocol physical movements of the central unit and of each sail arm. All this measurements will be sent as telemetry to earth in order to compute forces, rotations, vibrations of the whole system.
- Radio communication link.
- Camera for the documentation.
- Motor and motor driver.

In the deployment of the BOOMs the sails are simultaneously deployed.
The motors of the BOOMs have to synchronization in order to the kapton foils without damages deployed.
We have therefore a measurement sensoric and a regulation circle. GOSSAMER-1 is able to operate without synchronization, the distance is only circa three and half meters, but after GOSSAMER-1, which sail is 5 m x 5m, we want to build GOSSAMER-2 and GOSSAMER-3, and they are as big as GOSSAMER-1 and the synchronization for them is necessary.

GOSSAMER-2 is 20 m x 20 m and has a limited orbit and attitude control. The limited orbit control is caused by the too small acceleration gained by the only 400 m^2 sail and the still relatively large atmospheric drag. The attitude control will enable a very precise measurement of orbital parameters for different sail attitudes. [7] GOSSAMER-3 will launch in 2016, if GOSSAMER-1 successful accomplished. The sail of GOSSAMER-3 is 50 m x 50 m and >10.000 km Earth orbit. An additional narrow angle camera on board the sail craft may provide images of the Earth once it leaves the Earth orbit and of the Moon once it is approached. An acceleration >0.1 mm/s^2 together with the sufficiently high initial orbital altitudes will enable the sail craft to leave the Earth gravitational field after ~100 days. It is planned to perform a lunar swing-by after about 600 days. [7]

In view of scalability GOSSAMER-1 FM will have an active synchronization. The distance will be measurement via motor rotation or maybe via RFIDs or barcodes which will be to stick successive on the BOOMs.

Each of four BDSU controller will have a complete autonomous. The controllers are waiting the commands from the CSCU, and then making the function of the command.

Therefore the OBC have not to do with the BSDU controller, it send only commands for the controller and monitor they work. The OBC will be more simple and universal.

The BSDU controllers are running our RODOS operating system.

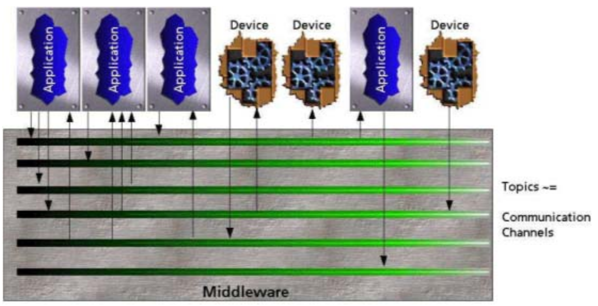

Figure 4. Topics in the Middleware

RODOS is a real-time embedded operating system (OS) designed for applications demanding high dependability. Simplicity is our main strategy for achieving dependability, as complexity is the cause of most development faults. The system was developed in C++, using an object-oriented framework simple enough to be understood and applied in several application domains. Although targeting minimal complexity, no fundamental functionality is missing, as its microkernel provides support for resource management, thread synchronization and communication, input/output and interrupts management. The system is fully pre-emptive and uses priority-based scheduling and round robin for same priority threads. [5]

And on the BSDUs are the fixations and release mechanisms, which hold the BSDUs in stowed configuration during launch and which release them prior to the start of the deployment.

2.3. Sail Spool Mechanism (SSM)

These four mechanisms required for the safe and reliable stowing and fixation of the sails during launch plus the functionality for controlled release of the sails in the course of the deployment. [4] They contain the sail spool, on which the sail on folded configuration is rolled up and those parts required for tensioning the inner corner of the sail triangle. [4]

2.4. Clavis

The GOSSAMER-1 satellite bus is based on the CLAVIS bus system.

The project CLAVIS aims at the design and manufacturing of nano satellites, which allow for a low cost operation of payloads in an earthy orbit and the realization of technology demonstration tests within very short response times.

From mechanical point of view, the CLAVIS concept focuses on a modular structural composition and from electrical point of view, on the realisation of plug&play features. CLAVIS is ideal for the use of standard payloads which can be operated in the NanoSat-class and it is suitable for technologies demonstration purposes. [2] The on-board computer is based on Atmel AT91SAM7A1 MCU. The board is manufactured by external vendor which provides the basic software library for the development and implementation of system level applications. OBC contains two 2 MB external flashes and a 2MB external RAM to load the software and run from RAM.

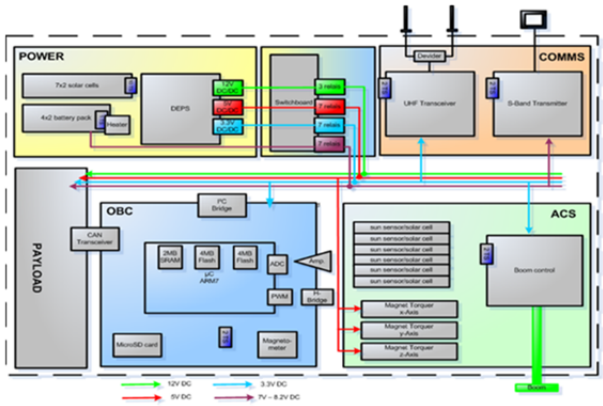

Figure 5. Clavis block diagram

Standard communications peripherals (I^2C, SPI, PWM, USART etc) are available for communicating with the external hardware subsystems. [2]
Switchboard supports the switching mechanism of different components and provides additional interfaces to enables the communication with the serial devices. The board is based on PC/104 standard, which behaves like a translator of the I^2C and Serial interfaces. Different analogue inputs can also be directed to the switchboard for ADC conversions. [2]
CLAVIS hardware contains all the basic components needed to exist for normal operation of the satellite. By keeping the I^2C as a standard satellite communication bus, different external devices connect to the main computer by this interface.
The real time operating system is FreeRTOS which contains mini kernel to control the system processes and its resources. The nominal operations of the satellites rely continuously on frequent accesses of the computer to the other hardware subsystems. [2]

4. WIRELESS SYSTEM

The BOOMs will be jettisoned, after the successful deployment in order to reduce the weight to a minimum.
With this we can achieve one property, to have the highest possible acceleration from the very low light pressure: we reduce the weight.
After the successful deployment GOSSAMER-1 has lot of units which are not required any more.
This are:

- The motors.
- BSDU electronic; Computing power, storage, sensors and actuators, cameras which are required only for the deployment.
- Batteries; to operate the deployment mechanism we have to provide energy to any motors. This energy unit means extra weight and is required only as long as we have motors.
- And itself the BOOM mechanism, because the sails are already fixed.

Therefore the communications between these avionic components and others have to be implemented as wireless too.
Another reason is; whereat we will separate the BSDUs, we may not have any wires between deployment mechanism and the rest of the space craft. This reduces the weight, simplifies the harness and assembly of the space craft too.
For the wireless communication we will use BlueTooth. On the central and on the BOOMs are the BlueTooth Module as redundant implemented.

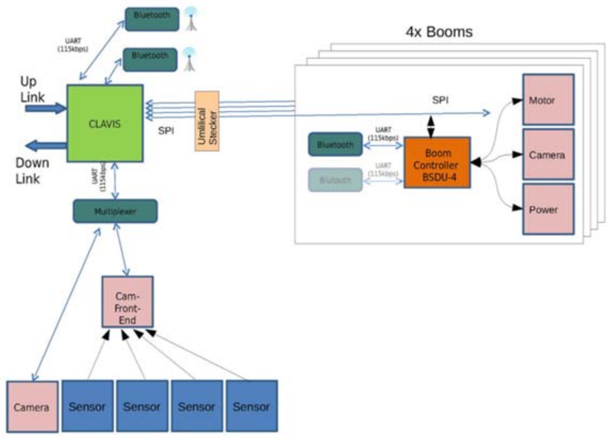

Figure 6. Radio links in the whole space craft

The conditions were for the wireless system:

- It must able to send broadcast messages from master (CSCU) to slaves (BSDU), in order to sync the BSDUs together.
- To provide real time messages to coordinate the deployment and the command the units.
- The range of the radio link must be enough, for GOSSAMER-3 we have circa 50 meters.
- The energy consumption must be very low, the life of the BOMMs batteries are strong limited. The mission will take five days.
- The speed of the transfer must be as fast as possible, each BOOMs we have 120 pictures with jpeg compression and they are circa 30-40 MB. Earlier we wanted to use ZigBee, which is a super viable system, but the speed of radio link is not so fast. It is circa 9600 bps, and with this speed we would have been circa 20-30 minutes. Therefore we decided to use BlueTooth, though it needs a little bit more energy.

With BlueTooth we can build a PICONET, which consist of 1 master and 7 slaves. In the PICONET the master make the connection to the slaves and in the PICONET can be only one master, but slave can be master in other PICONET too. The slaves are able to communication only with the master.
Using radio communication was a simplification for the controller hardware. Normally one would a link to each controller. This would mean about 15 UARTs per controller and complex interrupt management in order to handle all of them at the same time. Using radio communication we had to implement only one link, UART, to a radio unit, BlueTooth, and there we can attach many units without increasing the hardware overhead.
Another nice by-product is, that our controller is easy to reuse in other space craft's with radio links. Normally you have to design a new controller if you have another IO structure. In our case adding or

removing devices is just a matter of software to configure the radio links.

5. CAMERA SYSTEM

We will use 9 same cameras for documentation. We would like to see in action the Boom and Sail deployment unit and the sail spool mechanism.
4 are placed on the BOOMs, another 4 are cater-cornered in the satellite, and the last one is a fish-eye camera to have a global view.

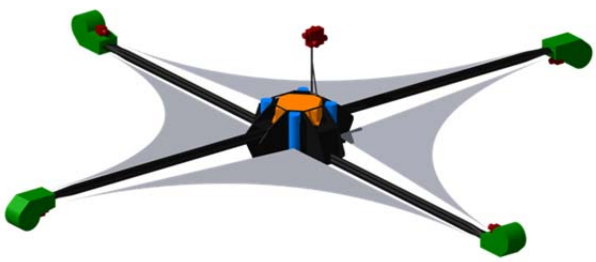

Figure 7. Cameras on GOSSAMER-1

The cameras for Gossamer-1 are equipped with a DaVinchi processor, which a 300 MHz ARM9 processor is, running the Linux operating system and a 600 MHz DSP that is entirely for image processing tasks.
Each cameras executing a time controlled program to monitor the deployment of each boom and each sail segment.
All cameras are an autonomous subsystem, programmed to take about 120 pictures with different resolutions.
All fifth pictures will be making with the resolution 2048 x 1536 pixels. The rest will be with 1024 x 768 pixels.

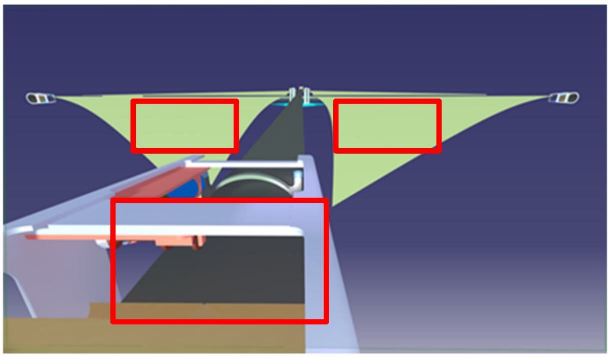

Figure 8. ROIs

We expect to have extreme contrast conditions. It can be on account of sun the one side of the space craft is full hell and another side is in shadow.
If we have only one ROI, then on account of the sun and shadows the recorded pictures cannot be used. The pictures will be to hell or to dark and it is nothing to see.
Therefore the program in each camera will make three ROI measurements to compute best exposure time for each picture.

6. REFERENCES

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