Wireless Avionics for a Solar Sailer (GOSSAMER-1)

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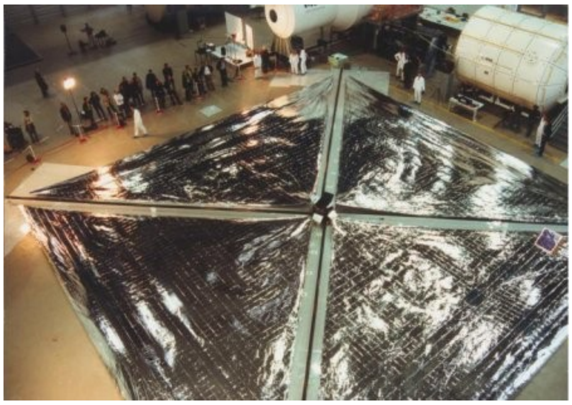
1. Abstract / Motivation

This abstract is about a new system design concept for a solar sail mission, taking place in 2014. Thereby the idea of travelling through space by using the solar light pressure is not new. But for that very special conditions have to be met. The solar light pressure is very low and therefore forces and the delta-V is very low too. The huge advantage of this methode is the fact, that this pressure it 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 gengerate very intensive but limited acceleration.



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.
In the GOSAMER-1 project we have other threads handling structure, sail deployment, energy and so on, but our part is the contribution development of the avionic system to reach the sailing vision. In order to reduce the weight to a minimum we decided to use wireless communication in our avionics system. 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. And for our surprise, it makes the board computer more simple and universal!

The next step to reduce weight is to separate (discard) all components which are not required any more. For example after deployment we separate as much as possible from the deployment mechanism. This is another reason why we may not have any wires between deployment mechanism and the rest of the space craft. To operate the deployment mechanism we have to provide energy to many motors. This energy unit means extra weight and is required only as long as we have motors, therefore it is mounted together with the motors and when de motors are discarded, the power unit will be discarded too.

The same holds for some avionic components. Computing power, storage, sensors and actuators, which are required only for the deployment, will be discarded together with the deployment mechanism, too. Therefore the communication between these avionic components and others have to be implemented as wireless, too.

In order to avoid power lines, the power will be produced, stored and conditioned in the same place where it is required. So we have a distributed power unit, which may be separated. For the cruise phase we have less power demand, therefore we will discard excessive weight due to excessive power, so it will not be a dead freight for the rest of the mission.

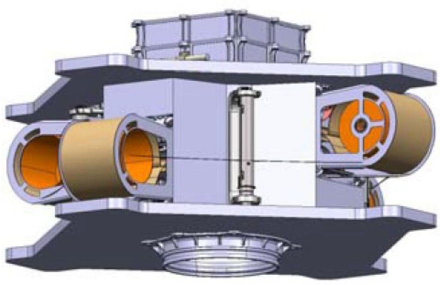
The deployment will be monitored and recorded by eight high resolution cameras mounted on different parts of the space craft. After deployment the cameras will transmit their pictures to the central unit using wireless links and after the transmission is completed the cameras will be discarded together with the deployment units. After separation the dead deployment units have still power and the controllers, sensors (gyros and accelerometers), cameras and wireless links are still operable. So it will be possible to get some more data from the moving away components as long as they are in radio range.

We can consider each of the 4 deployment mechanism to be a complete autonomous, self-sufficient pico satellite (ca. 1kg each) and the central unit to be a nano satellite (ca. 10 kg). As long as they are in radio range (ca. 100 m) we have a communicating swarm with five members, but we have something special: Normally one would have one communication link per member and from outside it is not possible to access internal devices. In our case, even inside of each member we use radio links, so each unit may access not only other members, but also internal units (controllers and cameras) in other members.

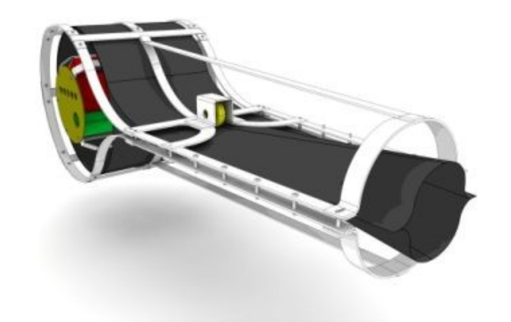
So, while some groups are performing research on solar sails, we (avionic group) will perform research on radio communications inside of a space craft (at the beginning all units are attached together as a single space craft) before separation - and swarm control after separation.

2. Components of Gossamer-1

The deployment mechanism is a distributed system. It consist of a central component and four boom deployments. Each has its own controller, power unit and payload.



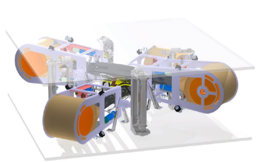
Central Unit



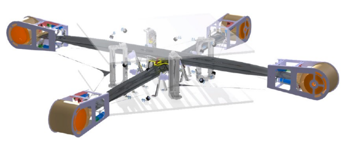
Distributed Deployment (to be separated)

Figure 1: Mechanical Structure

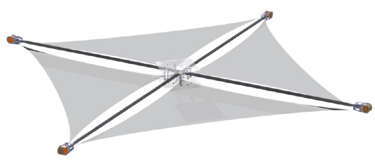
In this experimental mission payloads are just cameras, which will be used to record the deployment. But each camera can be considered to be a payload unit since it comes with its own control computer and communicates with the rest of the system using high level protocols.



Stowed configuration



Deployment initiated



Deployment concluded.
next step: Separate boom heads

Figure 2: Deployment configurations

The control is a distributed system. Each boom deployment unit and the central unit has its own controller, only the central controller is implemented as redundant. Each controller consist of a:
1. Cortex-CPU as control unit, running our RODOS building blocks execution platform

2. Gyro and accelerometer 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, etc of the whole system.

3. SD-Cards (flash memory) as mass memory to store pictures and telemetry

4. Radio communication links: Zigbee and Bluetooth.

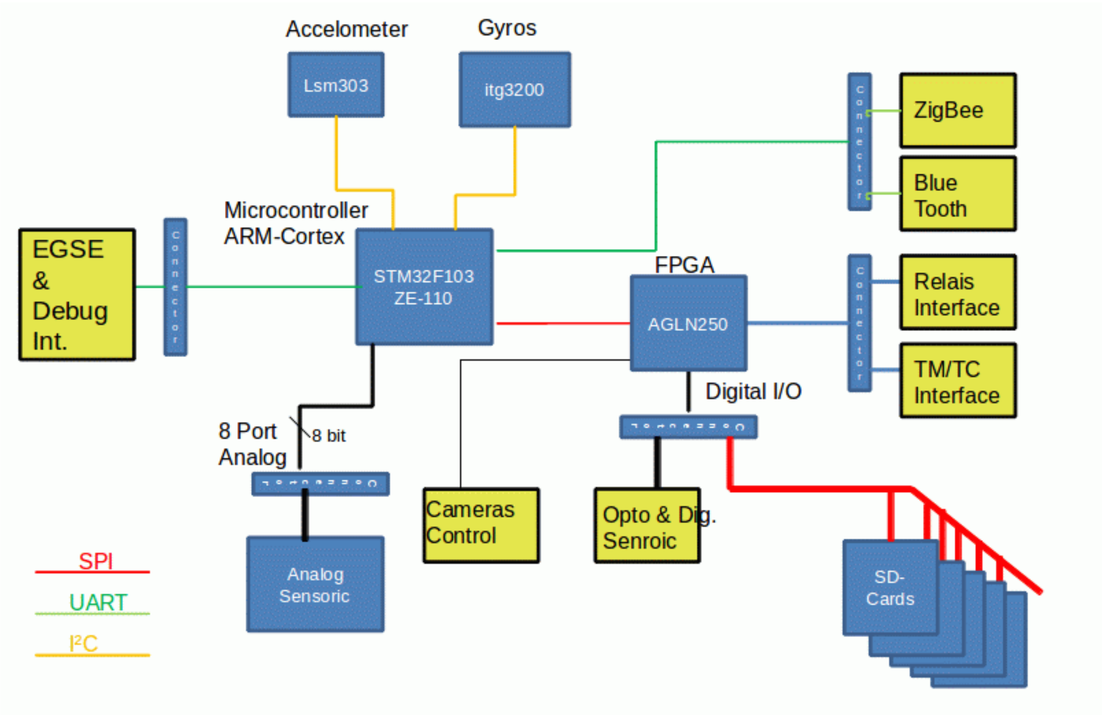


Figure 3: Controller for each deployment unit and for the central unit (Redundant)

3. Wireless communication

Figure 4 shows the radio links in the whole spacecraft. We use Zigbee for low data rates and real time messages to coordinate the deployment and to command the units. Further on we use Bluetooth for high data rate, to get non real time data, for example telemetry and camera pictures.
The reason for using two different wireless systems comes with the characteristics of each protocol. Zigbee is a braodcast system, that can reach all network members in realtime. So it is perfectly suited for sending commands. But for sending huge data amounts like pictures, the datarate of aproximatly 20kBit/s is too low. Due to that we decided to make additionally use of Bluetooth. Here the datarate is in the range of 1MBit/s. The disadvantage of Bluetooth for our use is the fact, that it can only be used in a peer to peer connection and changing the network partner takes about 1 second. In order to synchronise the deployment of all booms we need to interchange positions and speeds of all of them twice per second. With Bluethooth we got one cycle every 4 seconds (Since there are 4 booms).

Using radio communication was a simplification for the controller hardware. Normally one would need a link (eg. UART) to each camera and to each other controller. This would mean about 10 UARTs per controller and complex interrupt management in order to handle all of them at the same time. Using radio communications we had to implement only one link (UART) to a radio unit (eg. 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 crafts with radio links. Normally you have to design a new controller if you have another IO structure. In our case adding or removing IO devices is just a matter of software to reconfigure the radio links.

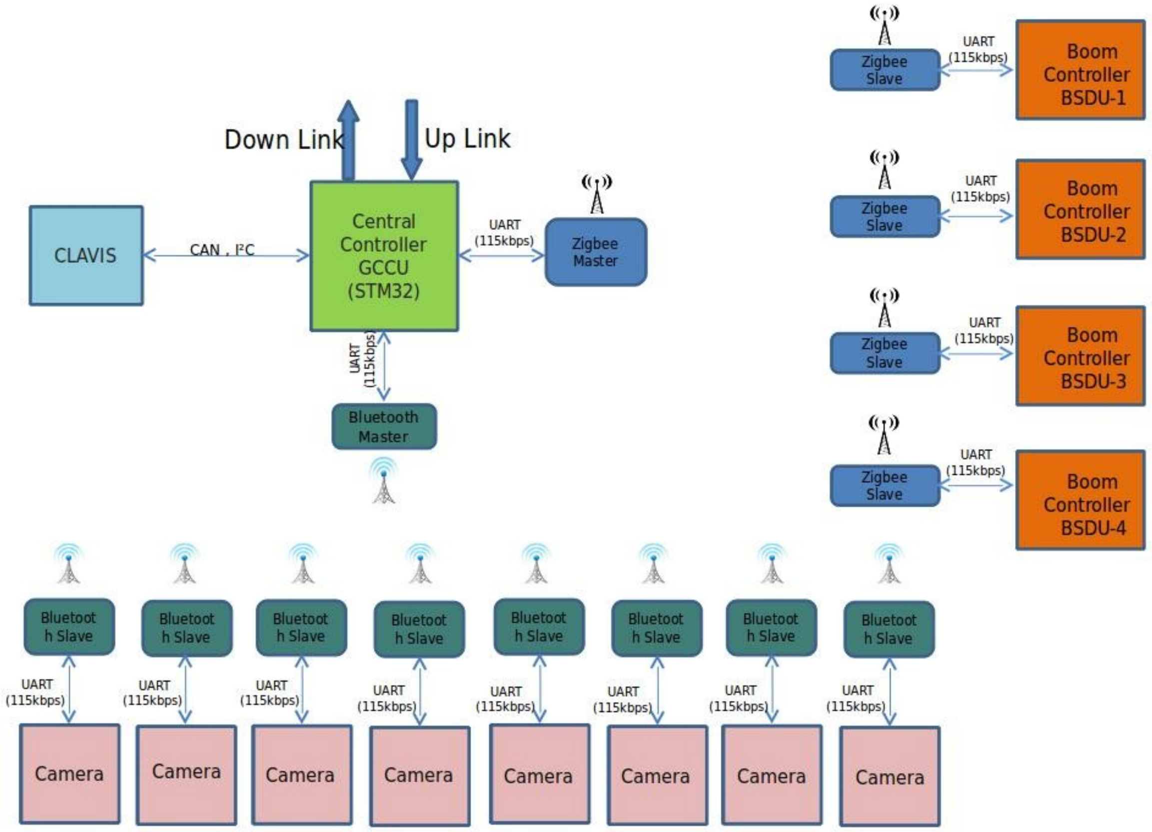
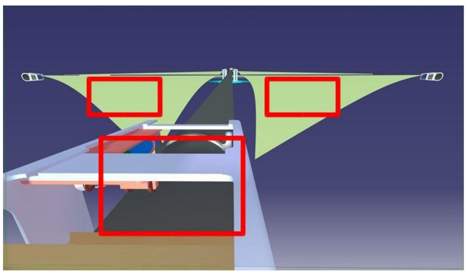


Figure 4: Radio links

4. Cameras

The cameras for GOSSAMER-1 are equipped with a DaVinci processor (300 MHz ARM9) running the Linux operating system and a 600 MHz DSP with 4800 MIPs that is entirely available for image processing tasks. With a standard Debian Linux operating system, the intelligent camera provides developers a convenient platform for programming their own applications and transferring them to the camera by means of cross-compilers. The components are equipped with 128 MB RAM and a 512 MB flash module – both can be extended. A high level of data security is guaranteed by a stable and fast file system (UBIFS).



On GOSSAMER-1 we have nine such Cameras, each executing a time controlled program to monitor the deployment of each boom and each sail segment.
Four cameras are placed on the end of the booms, another four are cater-cornered in the satellite and the last one is a fish-eye Camera to have a global view.
Each Camera is an autonomous subsystem, programmed to take about 120 pictures with different resolutions from 1024 x 768 pixel to 2056 x 1544 pixels. The program in each camera will make three ROI (Region of Interest) measurements to compute best exposure time for each picture. We expect to have extreme contrast conditions. In total we will have about 1080 pictures from the deployment. That is more than what we can download, therefore each camera is able to accept and executed commands from earth to send pictures selectively.