Unmanned Solar Powered Airship Concept Evaluation

Preliminary Design Report

imaging subsystem

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Authors

Bastian Hacker
Oliver Porges
Ivan Šinkarenko
Jan Sommer

Supervisors

Kjell Lundin
Alf Wikström

Project Manager

Dries Agten

Quality Manager

Morten Olsen

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Luleå University of Technology
Rymdcampus, Kiruna, Sweden

Acronyms

APR Array Power Regulator

B2R Buck-Boost Regulator

BCR Battery Charge Regulator

BDR Battery Discharge Regulator

BJT Bipolar Junction Transistor

BoIBB Boost Interleaved By Buck

BoSBB Boost Superimposed By Buck

BuCBB Buck Cascaded By Boost

CCM Continuous Conduction Mode

CM Current Mode

DCM Discontinuous Conduction Mode

DET Direct Energy Transfer

ECSS European Cooperation for Space Standardization

EMI Electromagnetic Interference

EOL End Of Lifetime

EPS Electrical Power Subsystem

ESA European Space Agency

ESR Equivalent Series Resistor

GaAs Gallium Arsenide

IC Integrated Circuit

IRF International Rectifiers

LEO Low Earth Orbit

LT Linear Technology

MDC Mode Detection Circuit

MEA Main Error Amplifier

MPP Maximum Power Point

MPPT Maximum Power Point Tracking

MPPTU Maximum Power Point Tracking Unit

OpAmp Operational Amplifier

PCB Printed Circuit Board

PCU Power Conditioning Unit

PWM Pulse Width Modulated

PFC Power Factor Corrector

PI Proportional-Integral

PV Photo Voltaic

RHPZ Right Half Plane Zero

S3R Sequential Switch Shunt Regulator

SA Solar Array

SEE Single Event Effect

SSA State Space Averaging

TI Texas Instruments

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1 Subsystem Introduction

The Imaging and Tracking Payload Unit (ITPU) is the scientific payload of the airship, and will be independent of the airship project to a large extent. The purpose of IPS is to take aerial images from different positions, acquire accurate position and attitude data and use those combined information to create aerial image maps and extract further information from the images such as terrain height, 3D object recognition and possibly image-aided attitude control and path planning. This could be used as a learning platform to simulation environment for Low Earth Orbit imaging.

The system is further divided into the following parts:

- Attitude determination: Usage of advanced data fusion method to facilitate GPS, Gyro, Accelerometer and Magnetometer information, to extract accurate position and attitude information together with reasonable error estimates.
- Imaging system: A megapixel resolution webcam will provide images in regular timesteps in the order of a second. The image data will be saved on a SD memory card together with attitude information for offline processing.
- Communication system: Attitude data and spacecraft telemetry will be transmitted to ground. We try to achieve high bandwidth transmission that could even allow for image downlink.
- Image processing software: Image matching and evaluation will be done on a standard PC after payload recovery or in realtime if the transmission rate can be made sufficient. There will also be a groundstation that communicates with the spacecraft during flight.

2 Technical and functional requirements

2.1 Functional requirements

- Measure absolute and accurate position and pointing angles.
- Take images in regular steps and save them together with attitude data.
- Receive and execute basic telecommands such as image capture start/stop.
- Send basic telemetry data such as position.
- Combine single image captures to a large area map.

2.2 Technical requirements

- Operate in open air environment up to 500 m over ground.
- Operate at 5 V unstabilized input voltage at a maximum power consumption of 2.5 W.
- Store at least 1000 medium-resolution images.

2.3 Expected performance

- Operate in image capture mode for at least 15 minutes.
- Create aerial images with 10cm horizontal resoultion (pixel size).
- Optional: Extract height information with 0.5m relative and 7m absolute resulution.

3 Preliminary Design

3.1 Electronic components

In this section an overview about the requirements and the planned electronic components is given. In order to achieve the functional requirements mentioned in 2.1 following components are needed:

- Board computer
- Accelerometer
- Magnetometer
- Gyroscope
- GPS-receiver
- Transmitter/Receiver
- Camera

Board computer

For controlling the sensors and the camera as well as communicating with the ground station first a standard microcontroller was considered, but as the requirements in 2.1 state, it is necessary to get a picture around every second. Also the resolution of the pictures should be in the range of some megapixels. Taken this into account, a standard microcontroller would not be able to process these amounts of data fast as well as it normally does not come with a USB-interface necessary for connecting most cameras.

Instead it was decided to use a BeagleBone embedded computer [**BeagleBone:SRM**]. It is populated with an ARM Cortex-A8 microprocessor running at 500 – 700 MHz and provides an USB-port, several I^2C and serial interfaces. It is capable of running an embedded Linux operating system and therefore able to support a large varity of devices (plugged to the USB-port) and to provide the possibility for sophisticated onboard calculations from a large set of libraries.

Sensors

For sensors it is planned to use the LSM303 [**LSM303:datasheet**] combined magnetometer and accelerometer and the ITG-3200 triple-axis gyroscope [**ITG-3200:datasheet**] both from sparkfun. Both sensors have been used during the CanSat-project in Würzburg, hence the group is familiar with working with these sensors. They communicate via an I^2C interface with the main board. For receiving GPS information a LS20031 5 Hz GPS receiver [**LS20031:datasheet**] can be used. It is connected via a serial line interface with the main board.

Transmitter/Receiver

For the communication during the flight mission a trasmitter/receiver module is necessary. To download not only telemetry and housekeeping data but also images taken by the camera, it has to provide a preferably long range, low power consumption and a hight bandwidth. Therefore a small WiFi-module could be consiered sending in around 2.4 GHz frequency. If it is only considered to send telemetry and housekeeping data and receive commands, then a RF-module with lower bandwidth would be sufficient.

Camera

As high quality embedded industrial cameras are very high priced, it is planned to connect a consumer webcam with a resolution of several megapixels to the USB-port of the main board. It is intended to buy a camera which is supported by the Linux operating system running on the main board. To save weight, the case of the webcam will be stripped as much as possible leaving only the bare camera and electronics. An example of a compatible camera would be the Logitech HD Webcam C525[1].

[1] `http://www.logitech.com/de-de/webcam-communications/webcams/devices/7794`

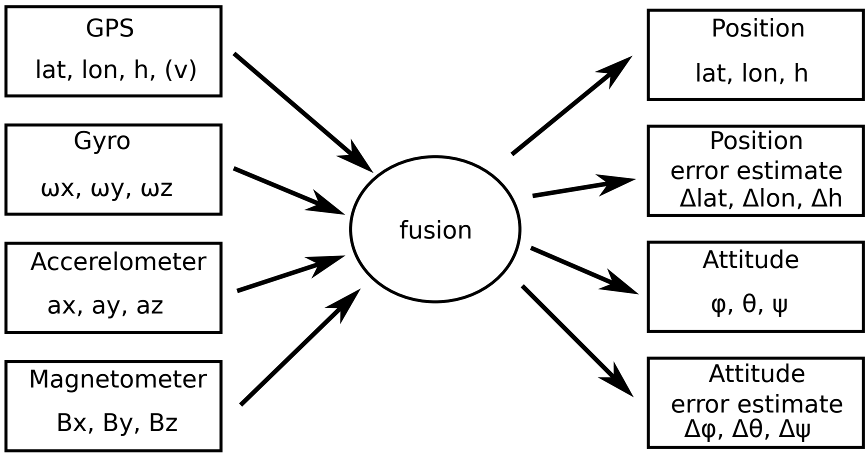

Figure 1 – *Attitude Determination System overview*

3.2 Attitude Determination System

The Attitude Determination System (ADS) measures and estimates position and pointing direction of the payload system. This is crucial for the further use of recordet images, as it provides the reference system and relative alignment of the taken images towards each other.

In order to produce high-accuracy attitude estimates and compensate for disadvantages of certain sensor types such as drift and noise, we chose to use a variety of sensors and fuse their information to a combined information. The facilitated sensors will be (see figure 1):

- GPS receiver: Provides absolute position values, but has much high-frequency noise
- Gyroscope: Provides accurate relative pointing direction, but has drift.
- Accerelometer: Provides absoulte pointing relative to the horizon (gravity) and linear acceleration.
- Magnetometer: Provides absolute pointing relative to the earth's magnetic field.

Combined all together, these sensors provide complete information about the module's attitude. As a fusion method we will use well-understood algorithms, such as the extended Kalman filter.

The fused information will be updated in real-time and stored together with each image snapshot.

For development of the software, a simulation module will be written that feeds simulated measurement data into the fusion algorithm. By this the performance can be quantified and development gets much faster than with waiting for actual measurement data.

3.3 Software environment

Since a Linux operating system is run as a basic software layer, it is planned to deploy the Robot Operating System (ROS) as a middle-ware. This system is a modern framework for mobile robotic applications. Its main advantage is the interoperability of modules and inter-use of underlying layers. This increases the flexibility of future research and overall system robustness. Since ROS is an open-source system along with its packages it is used for knowledge exchange and achievement demonstration in terms of modern algorithms. These algorithms include Simultaneous Localization And Mapping (SLAM), Navigation and position control, Image processing and many more. This way the IPS could also easily be mounted to different carrier systems and, if desired, be responsible for flight control.

3.4 Image processing

The main goal is to take numerous aerial images and combine them into one usable map. This system should then be able to automatically collect images over a given area and produce an aerial map. A proposed solution for image matching is described in section 3.4

Image matching

The proposed solution should be very robust to different illumination conditions and overall image quality, namely sharpness.

1. Step
   It is needed to extract common and significant points from all the images in question. Since the images will be taken in sequence it can be assumed that there will be a high correlation in the neighboring pictures. Having this assumption an algorithm proposed in can be implemented for finding Points of Interest (POI) based on histogram leveling.

2. Step
   Having a reliable set of POI another technique to match the points together can be used. This part is computationally intensive. In order to be able to use it in real-time it is recommended to use the Iterative Closest Point algorithm already implemented and optimized in the Point Cloud Library.

3. Step
   By knowing the difference between two set of points in two consecutive images it is possible to calculate a very precise transformation matrix. The transformation

will be determined by how many points could be found in the previous step. The expectation in a general scenery and medium resolution picture is about a 100 points. This would be enough even to compensate for camera deformation.

4. Step
   As a last step the transformation matrix obtained before has to be applied to the images before combining them into one large array.

4 Test and Verification of Design

4.1 Design Models and Verification Methods

- A Development Model (DM) will be built, using a breadboard to connect the electronic components together. System stability will be monitored by sequence of tests. Modifications of the software will be done if needed.
- If time allows, a Flight Model (FM) will be build, using a custom designed PCB schematic layout. This design would minimize circuit mass, size and internal losses.
- Image processing and stitching algorithms can be tested with a set of example pictures on the ground before using pictures taken by the payload. The performance of example and taken pictures can then be compared.

5 Resources and Scheduling

5.1 Main Tasks

Table 1 – *Main tasks*

Task	Duration [days]	Dependence (finish-to-start)
1. Electronic components assembly	2	
2. Operating system installation	5	
3. Software development	20	1,2
4. Testing	5	1,2,3
5. Build PCB and test the subsystem	10	1,2,3,4

5.2 Parts List and Costs

- BeagleBone microcontroller board: 73€ + 13€ shipping

- Camera: Logitech Webcam: 319 SEK
- Accelerometer + Magnetometer: 30$ + 5$ shipping
- Gyroscope: 50$
- GPS receiver: GPS-08975 from Sparkfun: 60$
- Radio transmiter: 40€
- Radio transmitter groundstation: 40€
- SD card 8GB: 100 SEK

Total budget: 3000 SEK

5.3 Electronics Ground Support Equipment (EGSE)

- Laboratory equipment: Digital oscilloscope, power supplies, solder iron, multimeter
- PC for programming and maintaining the operating system on the microcontroller
- Ground segment receiver to receive housekeeping and scientific data

5.4 Mechanical Ground Support Equipment (MGSE)

- PCB manufacturing facilities - UV light sources, etching facilities, punch-through hole machine etc.