SPACEMASTER

Attitude Sensing and Determination System (ASDS) for the MPEG platform

Proposal

for an experiment on BEXUS 5

by

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A ABSTRACT

This proposal aims to introduce an attitude determination system for the student balloon project BEXUS. Currently the orientation of the BEXUS platform throughout the flight is not precisely known. Providing information about the orientation will enlarge the scope for future experiments and will bring knowledge about the way forces act upon the gondola during the flight period. The proposal presents a detailed approach to designing and building such an attitude sensing and determination system.

Preliminary studies showed that the most effective way is to use the magnetic field of the Earth along with the direction of the Gravity force as references for the system. The physical concept of the approach and its technical implementation are also presented. In order to build the experiment inexpensive standard commercial components are to be used. They give sufficient accuracy and come in line with the limitations of a low-cost student budget. Furthermore the current project has another goal which is to test the basic system structure that if performing successfully may be modified and implemented in a future nanosatellite mission designed within the IRV department in line with e.g. the CubSat mission requirements.

The proposal also reveals a new concept of ground station visualization of the balloon flight. Its goal is to create a 3D model of the position and the orientation of the platform within the coordinate system North-East-Up which is also used for GPS. The ground station program will convert the incoming data stream into real time video thus allowing better perception for the observers. It will also facilitate the succeeding analysis of the mission data.

The performance of the system will be analyzed and evaluated with the help of other experiments flying on BEXUS 5. There might be another team sensing the orientation of the gondola with the help of photodiodes and a team taking video sequences of the flight. Both and especially the video sequences can be taken for validating the 3-D model after the flight.

The project will be done by a team consisting of four members who have different technical and cultural background. Participating in such a group gives a unique chance to develop the personal skills one needs to be part of a multinational team where the sharing of knowledge is a must for increasing the overall success of the work.

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1. STATEMENT OF PROBLEM

BEXUS is a project that enables students to create and put their experiments on a stratospheric balloon mission. Thereby the MPEG platform greatly facilitates the integrating of the projects for the balloon mission. It accommodates the experiments and supplies them with power and communication interfaces. The BEXUS mission is also equipped with GPS thus making it possible to track the position of the balloon in real time. However, the orientation of the box in each moment has not been known yet. During the flight the platform is swung by the wind depending on the winds current direction and strength, both of them varying in time. The platform is also rotating around its z-axis in both directions limited by the ropes connecting it to the balloon. There may also exist other types of movement caused by the interaction of the forces due to the initial acceleration of the balloon, its floating and descend and the natural forces of the environment. The platform orientation then could be represented by a dynamic system, which elements are not exactly known. Sensing those unknowns during the flight will provide important information for creating a dynamic model of the platform orientation and direction of pointing.

2. FEASIBILITY STUDIES

MPEG platform attitude sensing and determination is to be performed in a dynamic environment due to the accelerations caused by the wind. The accelerations change the gondolas orientation with respect to the geographical North Pole and tilt it with respect to the horizontal plane [Figure 1].

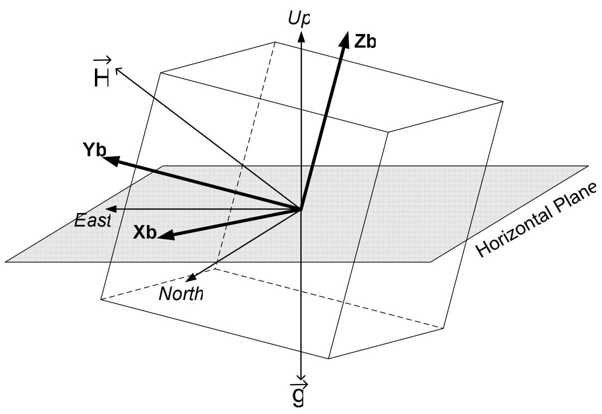


Figure 1: Definiton of body fixed and NEU coordinate system

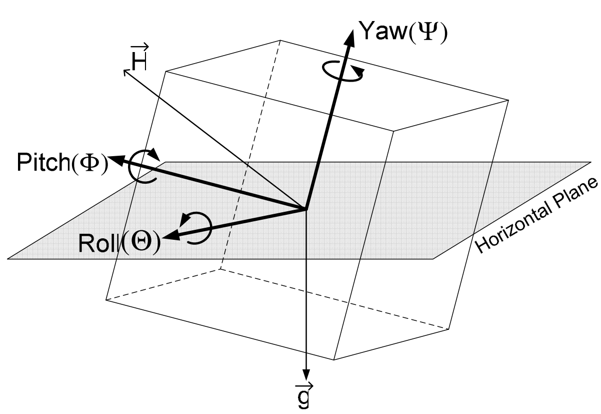


Figure 2: Definition of Roll, Pitch and Yaw with rotation angles

In Figure 1 the horizontal plane corresponds to the North-East plane in the North-East-Up (NEU) coordinate system. The NEU is defined by the pointing of one axis towards the geographical North Pole, one towards East and one in the opposite direction of the gravity force vector g. The tilting is illustrated in Figure 2 by a rotation in the body fixed frame of the gondola – indexed with b – around the Roll-Axis equal to x_b with the angle Θ and the Pitch-Axis equal to y_b with the angle Φ.

The stratospheric balloon mission ascends up to about 30 km and floats at that altitude before descending to the ground. Using optical sensors to obtain the attitude of the platform is not possible during the ascending phase due to the possibility of clouds. Another solution may be the application of the GPS signal for determining the acceleration vector orientation, its strength and using that information for the attitude determination. There may be two methods of doing that, both are not applicable to the current project. Using differential GPS will not give the needed accuracy due to the small dimension of the MPEG platform. The other method which uses the change in phase of the L1 carrier of the GPS signal involves a more complex receiver which costs exceed the budget restrictions.

An inertial navigation system (INS) has also been studied. However, using only accelerometers and angular rate sensors (gyros) will give poor accuracy of the system due to the lack of the reference to calibrate the sensors in real time. The platform is swinging and rotating and it cannot be determined in which moment its orientation may be used for self calibration. Introducing a magnetometer will supply the attitude determination system with a reference vector pointing towards the magnetic North Pole. A combination of a magnetometer, accelerometers and gyros results to be the optimum trade-off between accuracy and cost. In this configuration the attitude sensing and determination system (ASDS) may be thought of as a compass for a dynamic system.

In order for the magnetometer to determine the North direction its orientation should be known in terms of the tilting angles Θ and Φ. This is necessary because the magnetometer will detect a different pointing direction of the earth's magnetic field vector by being in the tilted plane instead of the horizontal plane. The INS could provide those tilting angles.

The accelerometers in the INS can detect the orientation of the gravity vector with respect to the horizontal plane. That makes them eligible for low varying dynamic systems. In high varying dynamic systems however, they cannot be used due to the presence of other acceleration vectors which sum up with the gravity vector and give a resultant vector with different properties. That vector is sensed by the accelerometers. The problem is solved by using gyros giving the rate of change around the axes in the body fixed frame [Figure 2]. The difficulty of using angular rate sensors is that they give information relative to an initial position. This introduces a constant drift due to the required integration which transforms the angular rate into the angular velocity and finally in the angle of tilt. In order to produce sufficient accuracy, the gyros need to be updated with the correct orientation which is used as reference.

Applying the just described method the INS provides the tilting angles Θ and Φ. These angles are essential to transform the detected magnetic field vector from the body fixed frame into the NEU. This can be performed by with the Euler Angle Rotation around the Roll and Pitch axis. Once the magnetic field vector is transformed in the NEU its pointing angle Ψ around the Yaw-axis (z_b) [Figure 2] can be determined via simple trigonometry.

When this is achieved certain influences have to be considered. First of all the magnetic North Pole has an declination with respect to the geographical North Pole and the magnetic field of the earth is not an homogeneous dipole field. Moreover magnetic fields initiated by other experiments on the gondola and such caused by ferrous material close to the sensor have to be considered.

Another set of crucial factors will influence the structure of the system. The high temperature range has to be considered as much as the accelerations stressing the system. According to the BEXUS Campaign Requirement Plan temperatures down to -80°C are possible and acceleration up to 10g are possible in the descend phase of the balloon flight.

The angle of orientation with respect to the magnetic North Pole Ψ, the tilting angles of the platform Θ and Φ, the acceleration vector in three dimensions, GPS and the consideration of all factors influencing the system will provide the parameters for a three dimensional dynamical model of the MPEG platform movement in the horizontal frame.

Commercial systems providing these parameters are very expensive and not suitable for the rough environment. Consequently the decision was made to develop an own system with standard commercial components which fulfils the requirements.

3. PROJECT DEFINITION

3.1. OBJECTIVES

The proposed project main goal is to allow its team members to gain experience in handling a project from its planning and realization to the point of testing and evaluation. Thus all the team members gain far-ranging experience in different technical areas and organizational areas like project management.

Up till now only a few of the student projects performed had the intention of improving the mission itself and thus providing greater opportunities for future student projects. The proposed project will realize a new idea and also hold the line between the past and the current work done in BEXUS.

The MPEG platform is one example where a project was done for enhancing future BEXUS missions. That's were the proposed project will join in. The ASDS will be a subsystem integrated on the MPEG platform to provide other experiments with attitude information. The information will consist of the platform's orientation in the North-East-Up coordinate system

(NEU), the tilting angles with respect to the horizontal plane [Figure 2] and the acceleration vector in the NEU which acts upon the Gondola. That information combined with the trajectory position of the GPS will provide the possibility to determine the absolute position of the gondola in certain time intervals, which have to be defined. The information will be send to the ground station, stored on the system's memory and – if possible in the timeline – provided via a standard serial interface to the other experiments.

The accuracy of the system concerning the pointing angle towards the North Pole will be around 1°- 5° according to similar systems applied in cars. A more precise value can not be given since it will highly depend on the actual forces acting on the balloon during the flight. They are not known yet and can just be estimated which makes a prediction of preciseness difficult. Moreover it will highly depend on the tolerances which can be achieved in the mechanical manufacturing and assembly.

The ground station will demonstrate the behavior of the balloon in real time as if somebody was filming from a plane which follows the balloon. In the ground station, the operating program will be able to recreate the real-time attitude of the balloon. Instead of reading data on a screen, it will convert these data into 3-D images. Thus a dynamic model of the gondola illustrated on a screen will be seen.

3.2. METHODOLOGY

The complexity of the physical realities requires a structured approach to the problem. Consequently a work phase plan is introduced which clearly defines every phase of the project. The different work phases and their results are illustrated in Figure 3.

At the current state feasibility studies were performed and showed that the objectives set in this project can be met. The results obtained in the feasibility studies were applied to design a concept for the ASDS.

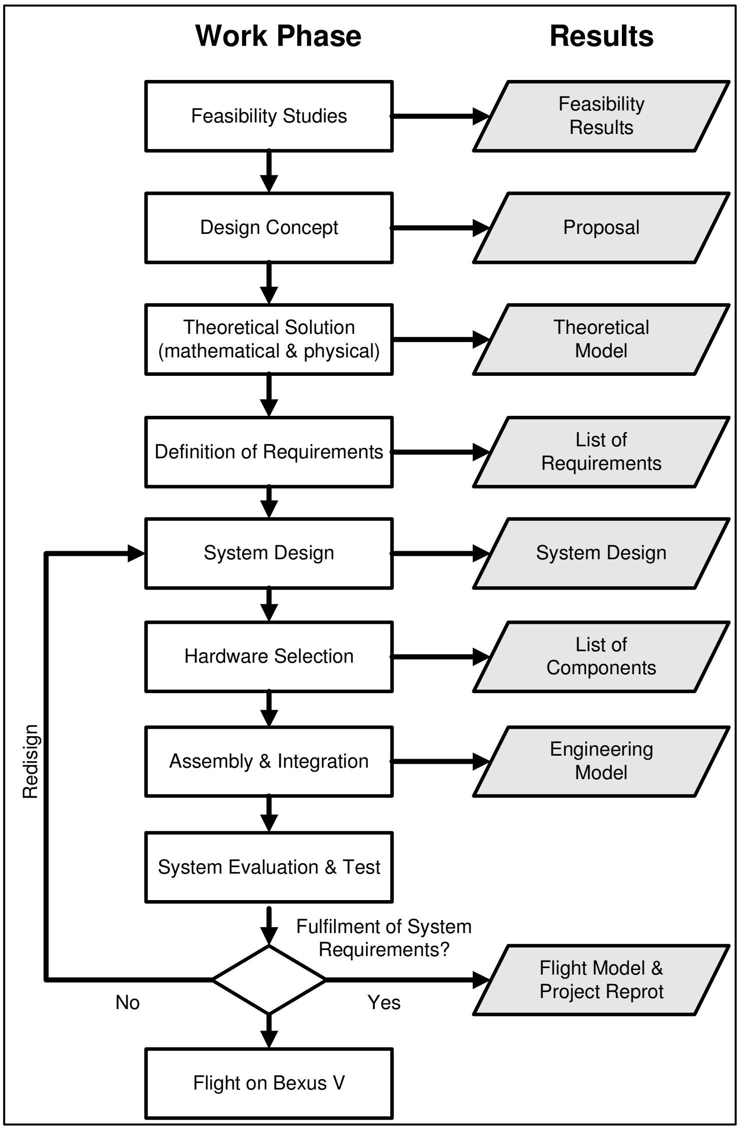


Figure 3: Methodology Flow Chart

Building on top of the design concept detailed calculations can be made to define the requirements which form a basis for the System Design. With a detailed system and subsystem design the process of selecting the all the hardware can be done. At that phase a realization of the system design is possible. Once all Subsystems are integrated the Engineering model will be ready for test and evaluation. In this phase the requirements ASDS has to meet will be verified and evaluated. Should the system violate crucial requirements a redesign of the system will be necessary. If the engineering model of ASDS fulfils all the requirements it will be qualified for changing its status to flight model. Thus the ASDS will be ready to fly on BEXUS 5.

The project does not end here, but two of the team members might leave the team after the flight model is qualified. Therefore a project report will be provided along with a personal knowledge transfer to the other team members.

3.3. Compass Design Concept

The design of the ASDS will be divided in the compass system which will be mounted on BEXUS 5 to sense the physical parameters and the ground station segment to process and illustrate a dynamic model of the balloon platform.

3.3.1. Physical Concept

Orientation in the North-East-Up frame

The indicator for the gondola's orientation in the North-East-Up (NEU) coordinate system [Figure 1] is the magnetic field vector $\vec{H}$ sensed by the 3-axis magnetometer. If the gondola is tilted with respect to the horizontal plane the magnetometer is not sensing the correct orientation of $\vec{H}$. Therefore $\vec{H}$ has to be transformed in the NEU frame like already mentioned in the feasibility studies. The method of the Euler Angle Rotation is used for that operation which consists of successive rotations in the same direction around the body axes. The angles of rotations Θ and Φ are the tilting angles sensed by the INS which is explained in the next paragraph.

Applying the Euler Angle Rotation $\vec{H}$ is transformed into the NEU frame with two successive rotations in clockwise direction. The first rotation around the Roll-Axis operates with the following matrix:

$$\overline{A}_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Phi & \sin\Phi \\ 0 & -\sin\Phi & \cos\Phi \end{bmatrix}$$

The second rotation around the Pitch-Axis with:

$$\overline{A}_y = \begin{bmatrix} \cos\Theta & 0 & -\sin\Theta \\ 0 & 1 & 0 \\ \sin\Theta & 0 & \cos\Theta \end{bmatrix}$$

This results by matrix multiplication in a rotation matrix:

$$\overline{A}_{xy} = \begin{bmatrix} \cos\Theta & 0 & -\sin\Theta \\ \sin\Phi\sin\Theta & \cos\Phi & \sin\Phi\cos\Theta \\ \sin\Theta\cos\Phi & -\sin\Phi & \cos\Phi \end{bmatrix}$$

With the matrix A_{xy} the transformation of $\vec{H}$ from the body fixed frame into $\vec{H}_h$ in the horizontal NEU frame can be achieved in the following way:

$$\vec{H}_h = \overline{A}_{xy} \cdot \vec{H} \quad \text{with} \quad \vec{H}_h = \begin{pmatrix} x_h \\ y_h \\ z_h \end{pmatrix} \quad \text{and} \quad \vec{H} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

Figure 4 shows that the angle Ψ between $\vec{H}_h$ projected in the horizontal plane and the Roll-Axis represents the pointing deviation of the Roll-Axis with respect to the magnetic North pole. The angle is calculated in the following way regarding the arctan limits:

For $x_h<0$: $\Psi = 180° - \arctan(y_h/x_h)$

For $x_h>0$, $y_h<0$: $\Psi = -\arctan(y_h/x_h)$

For $x_h>0$, $y_h>0$: $\Psi = 360° - \arctan(y_h/x_h)$

For $x_h=0$, $y_h<0$: $\Psi = 90°$

For $x_h=0$, $y_h>0$: $\Psi = 270°$

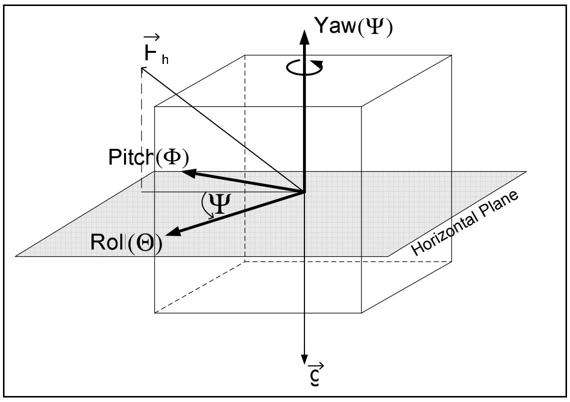


Figure 4: Rotated body fixed frame

The calculated angle Ψ corresponds to the actual compass position of the Gondola. However the North-East-Up coordinate system is defined via the geographical North Pole consequently the measured parameters have to be corrected by the declination angle β_D which represents the angle between the axis of the earth's magnetic dipol field and the geographical axis of rotation. Moreover it has to be corrected by a further factor β_A which represents pointing anomalies of the earth's magnetic field with respect to the magnetic North Pole. This will be done with the International Geomagnetic Reference Field (IGRF) which is a mathematical model of the earth's magnetic field released by the International Association of Geomagnetism and Aeronomy (IAGA). Thus the corrected angle:

$$\Psi_c = \Psi - \beta_A - \beta_D$$

The corrected angle Ψ_c corresponds now to the actual angular orientation of the gondola's Roll-Axis with respect to the geographical North Pole.

Tilting with respect to horizontal plane

In order to provide the magnetometer with the correct orientation with respect to the horizontal plane [Figure 1] an inertial navigation system is used. The principle is to use one accelerometer and one angular rate sensor for each axis to define the orientation. That makes two one-axis accelerometers and two one-axis gyros aligned with the X and Y axis of the body frame. The accelerometers will provide the orientation according to the gravity vector when there is no other acceleration present – that information will be used also for calibration of the gyros. The gyros will give the angle of rotation along each of the axis when there are other acceleration vectors present. The reason why the gyros are not used in low dynamic environment is that they accumulate an error in time and do not provide as accurate measurements as the accelerometers when sensing orientation only. However, their use is inevitable in case of highly dynamic systems and for error correction and periodic calibration accelerometers are implemented.

Let the initial calibration of the INS be done before the flight. The criterion for calibration is that the axis *Up* and the axis z_b are congruent like depicted in Figure 5. Thus the gondola is in the horizontal plane and its orientation in the North-East-Up coordinate system can be determined like mentioned. Moreover the magnetometer can be calibrated so that x_b is congruent with *North*.

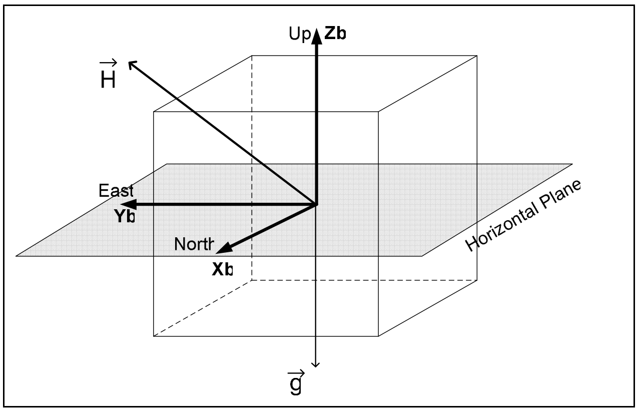


Figure 5: Calibration configuration of the gondola

During the flight, rotations around all the three axes are present. The aim of the INS is to give the tilting of the gondola with respect to the horizontal plane. This is illustrated in Figure 6.

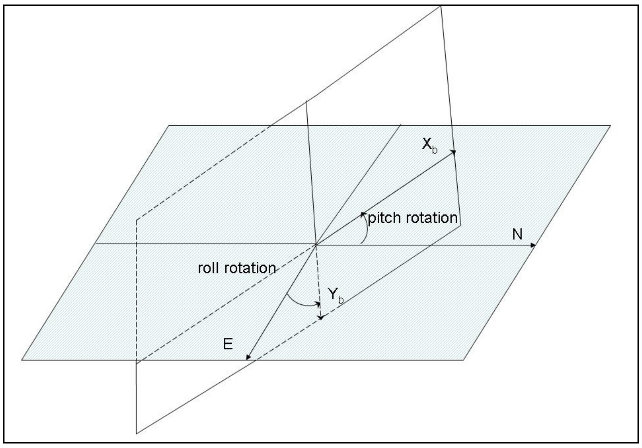


Figure 6: x_b – y_b plane tilted towards the horizontal plane

For that reason it is sufficient to find the rotations along two axes only – here the Roll- and Pitch-Axis. Each of these axes has an accelerometer and a gyro aligned with it.

In absence of other accelerations the accelerometer gives the orientation towards the gravity vector with good accuracy [Figure 7].

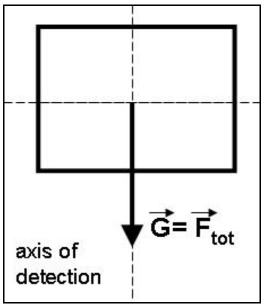


Figure 7: Absence of external forces

If there are other forces which cause the platform to accelerate then the acceleration vector will have its direction aligned with the resultant total forces vector [Figure 8] and the accelerometer will give orientation according to that one, not according to the gravity. If the external forces also change their strength then the acceleration will also change. In such case a gyro can be used by which the rate of angular change can be sensed. Afterwards that rate is integrated in order to find the angle of rotation itself. Using gyros will introduce continuous error if there is no way of periodically providing them with an accurate reference. In order to do that, the movement of the gondola shall be used. In highly varying dynamic system, the gondola will be swinging back and forth with the strength of the swinging depending on the unknown forces that act on it.

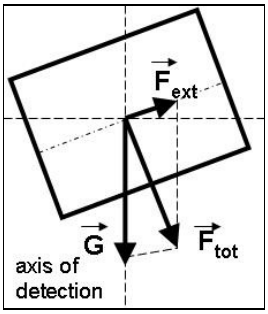


Figure 8: Presence of external forces

Let the wind blow in one direction (to the right in Figure 9) with sufficient strength to move the box. As consequence of the wind acting, the gondola will have more kinetic energy and will swing to the right. When its kinetic energy levels its potential energy, the gondola swinging will stop (position (3)). If the wind changes its strength the gondola may keep on swinging to the right (stronger wind) or go back to position (2) (lighter wind) and then reach position (1) when the two energies are again in equilibrium. Positions (1) and (3) and also position (2) – when the horizontal plane is perpendicular to the gravity vector – are candidates for using them as reference positions for the gyros since the accelerometers may give accurate sensing towards the gravity vector then. Further studies will be conducted to find the best algorithm to provide accurate reference for the gyros.

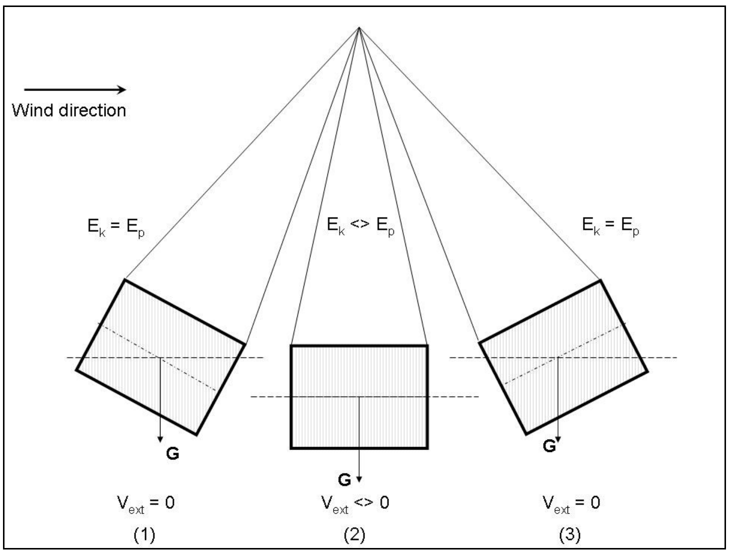


Figure 9: The gondola representing a pendulum movement

3.3.2. TECHNICAL CONCEPT

Electronics

According to the physical concept the sensors depicted in Figure 10 are needed to detect the required input parameters for calculating the attitude of the gondola. The microcontroller will be used for data processing and controlling the compass. The Serial Interface I will be responsible for the communication with the ground station via the MPEG. The GPS receiver and the Serial interface II for communication with other experiments will be optional features already regarded in the design for future enhancements. The power system will convert the 12V input voltage according to the required input voltages of each component.
According to the pre-selection of the components the maximum power consumption will not exceed 2 Watt. Moreover the components are chosen to fulfil at least the industrial standard and to withstand at least 10g of acceleration.

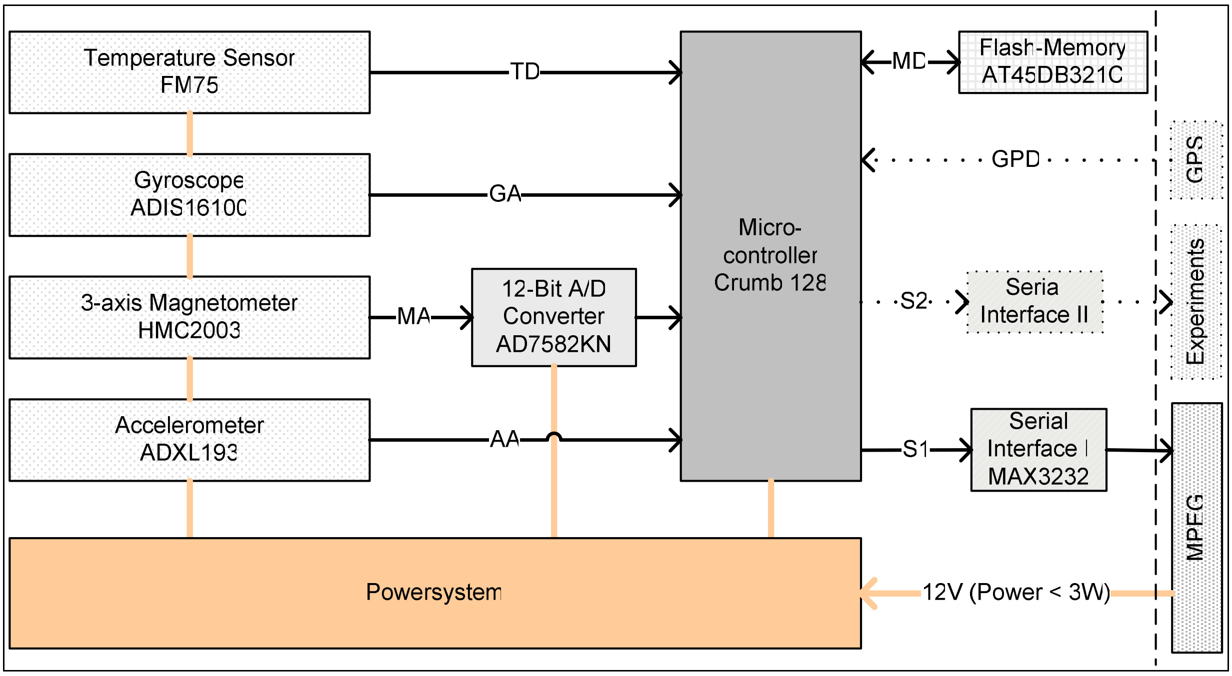


Figure 10: Electronic Design Concept

Compass Software

The microcontroller is the brain of the ASDS. It collects, processes, stores and sends the data received from the sensors. The data flow diagram is represented in Figure 11.

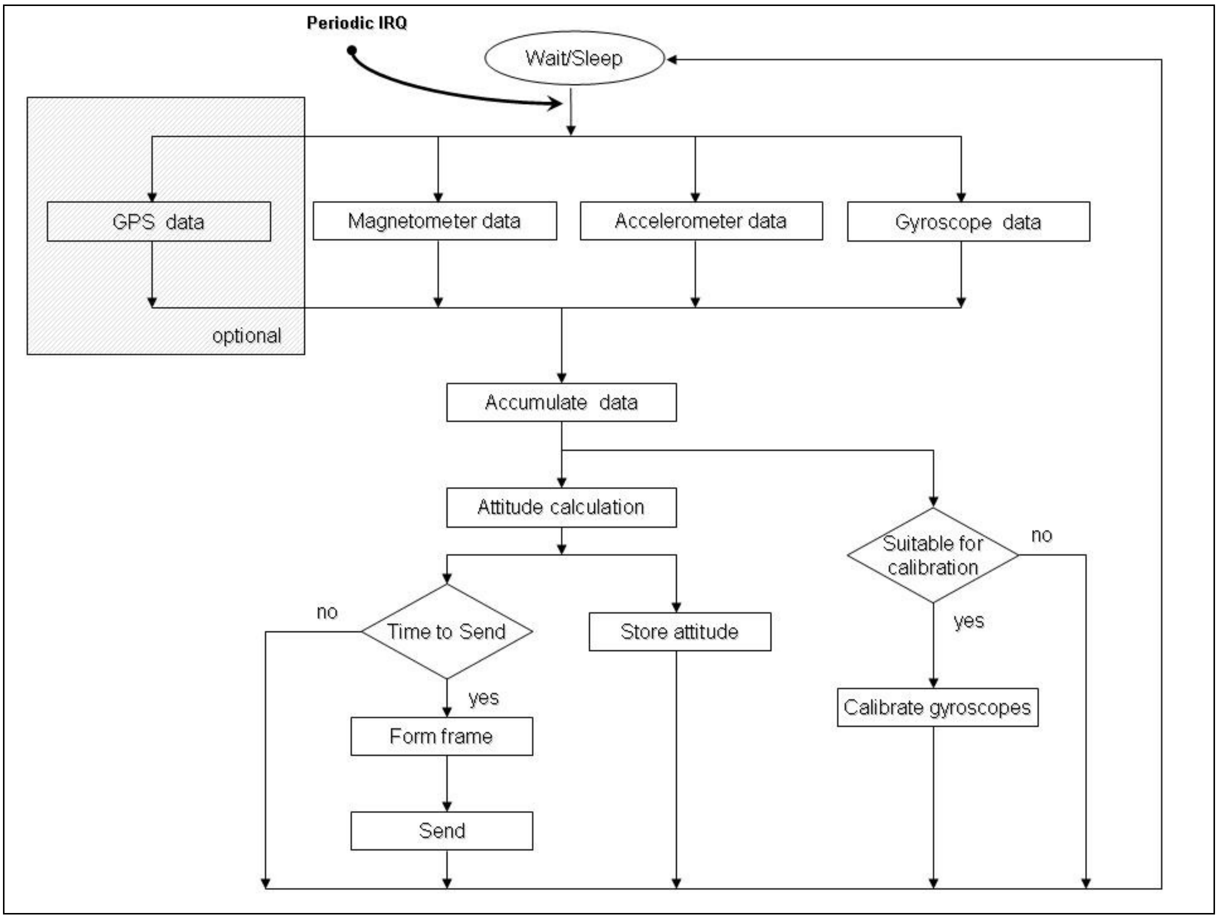


Figure 11: Data flow on ASDS Compass

The process is relatively straightforward. After a given period, the timer issues an interrupt request and the IRQ handler starts the program handler. It basically gathers the data from the sensors – the magnetometer, accelerometers and the gyros. It processes it if needed – like analog to digital conversion, integration, etc., and provides it to the attitude determination algorithm. The result of the algorithm is the absolute orientation of the platform in the NEU coordinate system. Then the orientation is stored in a memory and also sent if it is time to do that. Given the limited bandwidth for communication, most of the data is stored in an on-board chip, while few of the calculated attitude data are sent down to the ground station. If the accelerometer data shows that it is suitable for calibration of the gyros – then that action is also performed.

Mechanics

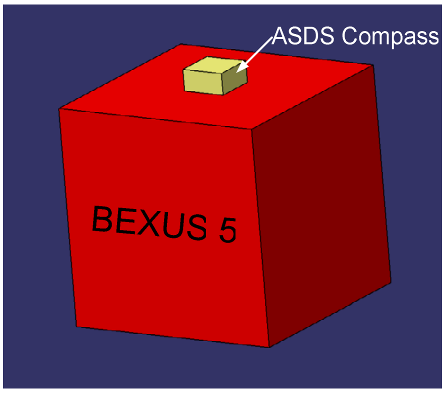


Figure 12: Mounting of ASDS Compass

It is planed to mount the ASDS Compass right in the centre on top of the BEXUS gondola parallel aligned to the edges like shown in figure 5. This is the best position for the gyroscopes to detect the angular rate of change and to exactly determine the orientation of the gondola. Additionally this will be a position the farthest away from all possible disturbances in terms of magnetic fields produced by the experiments or the power supply of the MPEG. Should magnetic fields produced by the other experiments interfere with the measurements of the magnetic field a new design with a placement of the magnetometer on a boom needs to be considered. Moreover in this position the thermal insulated box will be heated by the radiation of the sun and a higher temperature inside can be achieved. Rough calculations will be performed and temperature data of former missions will be evaluated to estimate if additional heating will be required. Concerning the mass and weight first estimations show that the ASDS compass will not exceed a mass of 1.5 kg and a size of 250mm length, 150mm height and 200mm width.

3.4. GROUND STATION DESIGN CONCEPT

The data analysis is divided into two steps. There will be a first analysis during the flight and then, after the flight, the realization of the flight movie with all the data stored inside the balloon.

For the first step, the data will be analyzed in real time. When the ground station receives them, data will be stored in a file. The file is made up of GPS data (longitude, latitude and altitude) and angles (roll, pitch, and yaw). The operating program will read the data inside the file as soon as the data is received. It converts the GPS data (longitude, latitude, altitude) into the NEU coordinate system. Then, these data are combined to create the real position of the balloon in three dimensions. The block diagram in figure 13 shows the structure of the data flow.

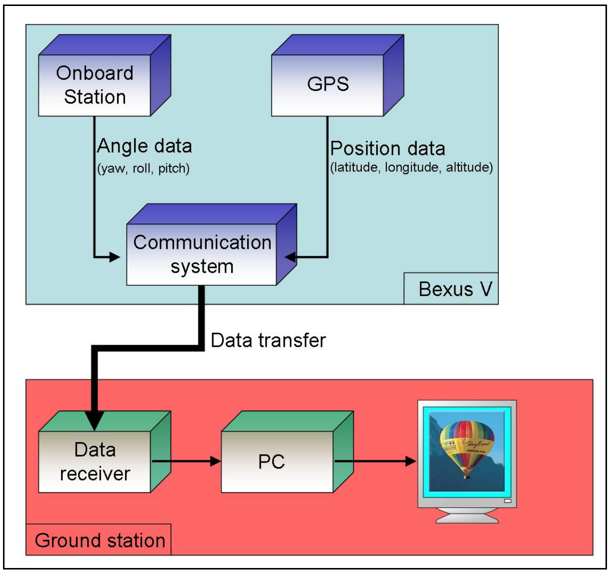


Figure 13: Ground station design concept

The balloon - represented by a box - will have its own coordinate system (the body fixed frame) which moves compared with the Earth coordinate system (the NEU), considered as fixed during the experiment. The coordinate systems are the same as those used onboard to calculate the angles. After computing, the operating program displays an image with the real position of the balloon in space.

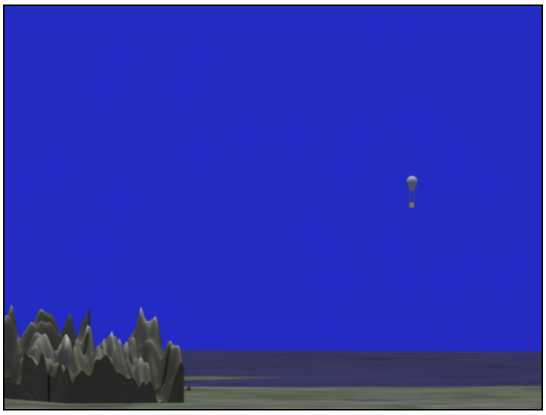


Figure 14: Visualization with GPS data

During the flight, we have different opportunities to display the images. On the one hand, if we have access to GPS data, the displayed images will be made up with the balloon over a 3-D map [Figure 14]. In that case, the map has to be created. The balloon motion has twelve degrees of freedom in total:

- Moving left and right (x-direction): 2 degrees of freedom;
- Moving forward and back (y-direction): 2 degrees of freedom;
- Moving up and down (z-direction): 2 degrees of freedom;
- Rotating around the Up-axis: 2 degrees of freedom;
- Rotating around the East-axis: 2 degrees of freedom;
- Rotating around the North-axis: 2 degrees of freedom.

On the other hand, if we can not have access to GPS data, the displayed image will be made up of a box which does not move along a trajectory but moves only in accordance with the three angles (roll, pitch and yaw) sent by the onboard station [Figure 15]. Thus, the balloon motion has six degrees of freedom (the three rotations around the three axes Up, East, North).

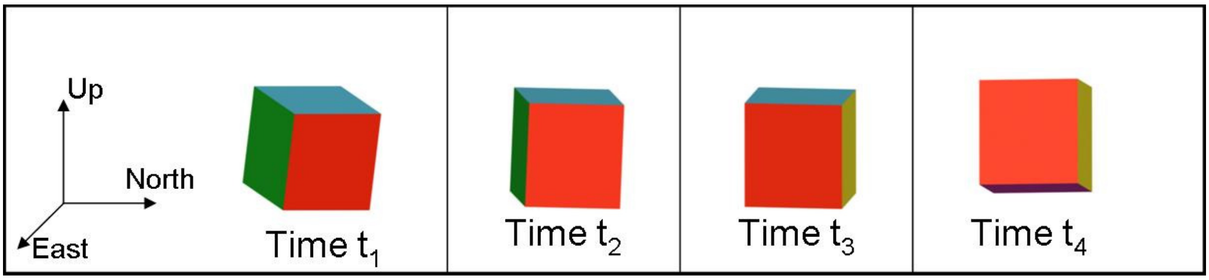


Figure 15: Visualization without GPS data

In those two cases, the camera positions itself in such a way that the balloon stands always in the center of the image. Thus the coordinate system of the image is according to the NEU

frame. The user is free to move around the balloon (with the keyboard or the mouse) to change the angle of vision.
Making a real time video depends on the number of positions we could send to the ground station. If we get enough data, we will be able to make a real time movie. If we do not have enough data, we will be able to make only single images at time t. In this last case, the operating program will be able to interpolate the missing images between two successive single images. Estimating the number of data we need is tricky because such experiment has never been made.
The second step is the data analysis after the flight. Indeed, all the data will be stored in the balloon. Thus it is possible to make a video of the balloon motion a posteriori. This movie could be compared with the video recorded during the flight. The programming language will be C++ with the OpenGL library.

3.5. SUMMARY OF CRUCIAL FACTS

In the following a summary of crucial facts set by the balloon operator Esrange is given:

Size:	*< 250mm length, 150mm height and 200mm width placed on centre top of BEXUS V gondola*
Mass:	*< 1.5 KG*
Power consumption:	*< 2 Watts*
Environmental influence	*No influences since only passive elements are used!*

Table 1: Crucial facts/ requirements set by Esrange

4. TECHNICAL IMPACT

The Attitude Sensing and Determination System will provide the future BEXUS users with valuable data of the platform's orientation changing during the flight period helping them to more accurately plan their own missions. Even if just a rough accuracy can be achieved the information that will be collected may also help to enhance the knowledge about the dynamics of the system in flight and provide the parameters for a model.
Given that the line of continuity between the annual missions is preserved, the proposed project may serve as a basis for future development work like introducing motion control unit for the platform. The attitude determination then may be processed and the swinging and rotation of the box controlled at least for some part of the flight. Such project may involve the installation of actuators and turn the platform into an active system. The control will assure stable orientation towards given direction. Stable orientation is a necessity for number of

missions that cannot be performed now on the student balloon missions like using a telescope above the clouds for example and much more.

The ground station will provide an extra feature. It will be able to demonstrate the real position of the balloon. These data could be useful for other experiments. For example, if one wants to take some pictures, one knows exactly where the cameras are pointing. In long terms this technique could be used to model 3-D radar for air traffic. The air-traffic controllers could estimate the position of aircrafts in a better way. Finally, by improving the program, it is possible to model a spacecraft with the slightest detail. Thanks to sensors, engineers could locate and visualize any failure inside from the Earth.

Apart from the impacts on the BEXUS mission, the ASDS project could be the first step towards developing an attitude determination and control system for a future nanosatellite mission. The CubeSat project guidelines can be used to develop such a mission. Its heaviest restrictions are that the mass has to be below 1 kg and the dimensions are 10x10x10 cm. A modified unit of the ASDS then may be used as the basis of the sensing part since the current state of the art allows small, light and also inexpensive components to be used for it. Thus the first test of gyros, accelerometer and magnetometer will have been already performed on the balloon and their results evaluated in order to contribute to the needed knowledge for the attitude control system.

5. PROJECT PLANNING

5.1. RESOURCE ESTIMATION

5.1.1. FACILITIES

The following facilities will be used:

- Most of the design work is to be performed in the IRV computer labs or on private computers along with searching for references in the IRF library and in the internet
- Electronics assembly and initial testing is to be done in the electronics lab at the IRV
- Mechanics work is to be performed in the IRV workshop
- Microcontroller programming and Ground station 3D model programming are to be done in the IRV computer rooms and private computers. C compilers are to be used for the microcontroller. 3D programming languages and libraries are studied for the modeling
- The need for further testing of the assembled boards is to be examined
- Magnetometer calibration may also need special facility. Still under consideration

5.1.2. Budget

Initial Budget calculations:

TYPE	NUMBER	COST (KR.)
Electronics – hardware		
Magnetometer, HMC2003, Honeywell	1	0
Gyroscopes, ADIS16100, Analog Devices (samples requested)	2	1000*
Accelerometers, ADXL193, Analog Devices (samples requested)	2	200*
Microcontroller on a board, Crumb128, chip45.com	1	0
External flash memory- AT45DB321C, Atmel	2	0
Analog-to-Digital Converter, AD7582KN, Analog Devices (sample requested)	1	566*
Additional components (available in the lab)	-	0
		1766*
Electronics – software		
Free C compilers are to be used	-	0
		0
Mechanics – hardware		
Materials	-	TBD**
		0
TOTAL		***1766****

**For each specific components samples have been requested. However, here budgetary prices are given in a worst-case scenario*
*** To Be Defined*

Table 2: Initial Budget Calculations

5.1.3. RESPONSIBILITIES

Thomas Ott

- Compass design
- Magnetometer, calculations for the magnetometer
- Electronics design
- Mechanics design, implementation and test
- Attitude determination design - rotation matrix

Christo Grigorov

- Compass design
- INS, calculations for the INS
- Data handling design, implementation and test
- Attitude determination design - algorithm implementation

Laurent Aupin

- Ground station software design and implementation
- 3D modeling
- Real time model and interpolation
- Overall data final model
- Flight Data Evaluation and Supervision

Jimmy Loven:

- Electronics design
- Electronics implementation
- Electronics test
- Flight Integration and Supervision

5.2. Time and Task Planning

In Figure 17 the overall time planning for the ASDS project is shown. The project is mainly divided into two parts, the compass and the ground station. At the beginning the work on the ground station and compass will be more or less separately apart from the definition of interfaces. Once the ground station provides the basic functions the different subsystems of the compass will be tested in interaction with the ground station according to the graphic in Figure 16. Once a subsystem is assembled it will enter the loop shown in the graphic. Thus a overall integration can be achieved and the team can work parallel in the assemble and test phase.

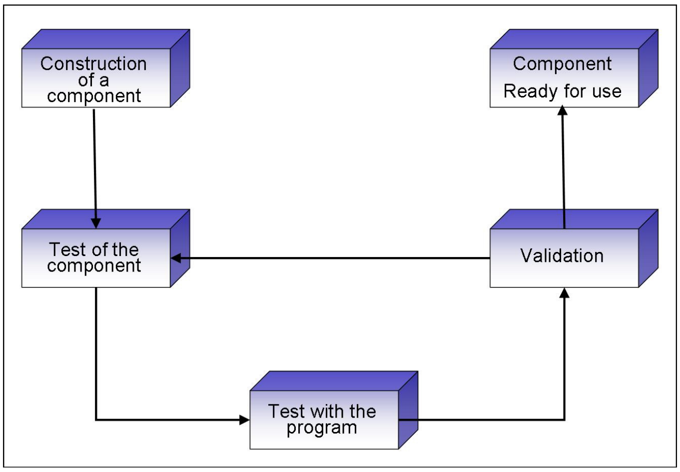


Figure 16: Test loop for subsystems

An additional timetable in more detail concerning the tasks and timeslots can be found in the appendix.

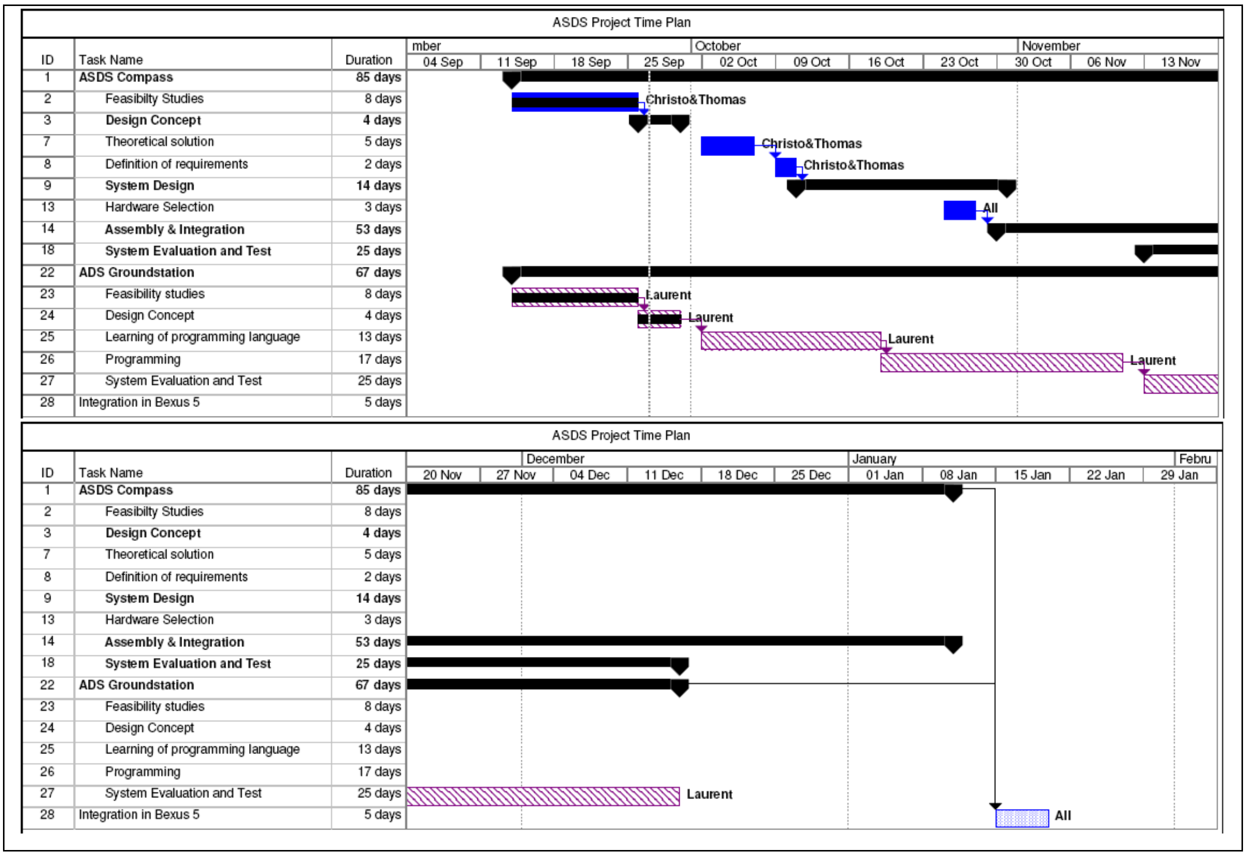


Figure 17: Overall timetable

6. TEAM EXPERTISE

Christo Grigorov is currently in his second year in the Space Science and Technology (SpaceMaster) program specializing in Space Technology and Instrumentation. He holds Masters Degree in Computer Science from Technical University – Sofia, Bulgaria, with major in Computer Systems and Technologies. During his studies there he used to participate in a project group working on optimizing the scheduling in Distributed Real-Time Embedded Systems. He was involved in design of buffer memories on fast FPGA chips too. He was also part-time and later full-time employed by Stara Planina Hold Plc as an IT Responsible and Data Analyzer. His duties covered the corporate site and network management and developing tools for data processing and analysis.

Jimmy Lovén was born the 23rd of July 1981 in Sweden. After high school, where he was graduated as an electronics technician, he moved from Malmö to Kiruna to study Space Engineering. For two years he's been learning electronics and now during his third year he's going to use that knowledge in different projects including BEXUS 5.

Laurent Aupin was born the first of August in 1982 in France. He is a student from a French engineering school "Télécom INT". He has spent two years learning telecommunication engineering and computer programming (C, Java, Actionscript). During the last year, he was trained as three-D animator. He developed short movies with the software 3D Studio Max and realized the prototype of a new communication simulator to train pilots and air-traffic controllers. This project was the fruit of the collaboration with a French company, Thales, and French students from "Télécom INT". During the summer 2006, he made the video clip to sell this simulator. The particularity of this simulator lies in three-D radar of air traffic. This project could be the first step to understand how such radar works. Then, he will have all the skills to realize one life-size.

Thomas Ott was born on the 13th of October in 1981 in Germany. He holds an Engineering degree in Mechatronics of the University of Cooperative Education in Stuttgart, Germany. At the current state he is a student in the second year of the Erasmus Mundus Master of Space Science and Technology program. Therefore his expertise is in designing mechatronic systems and spacecraft system engineering also including attitude determination and control. The University studies in Germany were accompanied by a trainee program at EADS Space including special seminars in project management, soft skills and two major projects in the department of solar arrays involving the design and realization of test benches for the solar array's components/subsystems. This makes him eligible for designing the ASDS compass with the main responsibilities in mechanics and electronics.

7. List of Figures

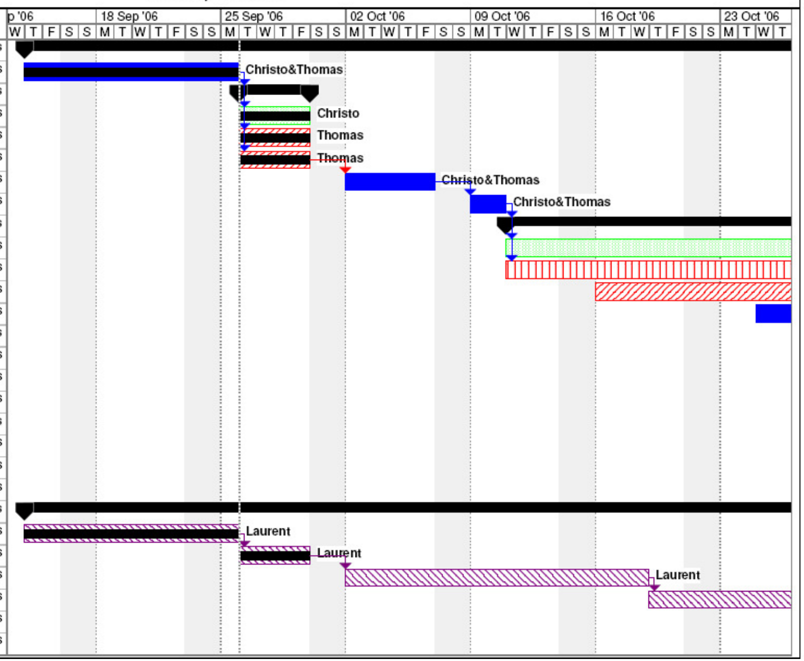
8. List of Tables

9. APPENDIX

Detailed timetable:

ASDS Project Time Plan

ID	Task Name	Duration
1	**ASDS Compass**	**67 days**
2	Feasibilty Studies	8 days
3	**Design Concept**	**4 days**
4	Software	4 days
5	Electronics	4 days
6	Mechanics	4 days
7	Theoretical solution	5 days
8	Definition of requirements	2 days
9	**System Design**	**14 days**
10	Software	14 days
11	Electronics	14 days
12	Mechanics	11 days
13	Hardware Selection	3 days
14	**Assembly & Integration**	**19 days**
15	Software	19 days
16	Electronics	19 days
17	Mechanics	19 days
18	**System Evaluation and Test**	**25 days**
19	Subsystem Test	10 days
20	System as a whole	10 days
21	System Calibration	5 days
22	**ADS Groundstation**	**67 days**
23	Feasibility studies	8 days
24	Design Concept	4 days
25	Learning of programming language	13 days
26	Programming	17 days
27	System Evaluation and Test	25 days
28	Integration in Bexus 5	5 days



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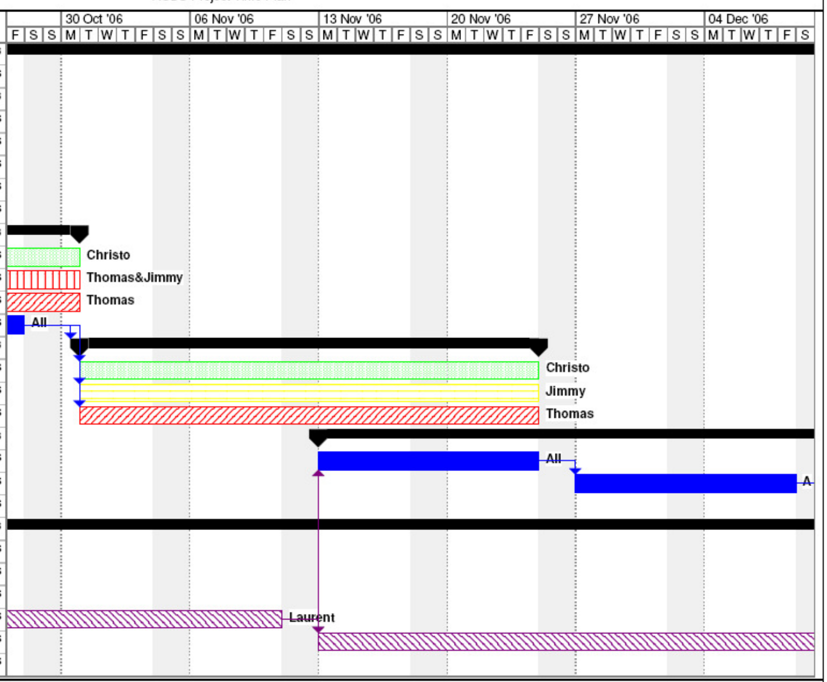

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