HORIZON ACQUISITION FOR ATTITUDE DETERMINATION USING IMAGE PROCESSING ALGORITHMS – HORACE ON REXUS 16 – AN EDUCATIONAL PROJECT

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ABSTRACT

HORACE is a student project of the University of Würzburg that took part in the REXUS/BEXUS programme. The aim of HORACE, the Horizon Acquisition Experiment, as payload on the REXUS 16 was to prove the concept of a horizon sensor based on image processing algorithms that extract one-axis attitude information from ordinary camera pictures in the visible spectrum. Due to its high robustness we envision the field of application of this sensor to be in the area of attitude determination for satellites in emergency cases such as uncontrolled tumbling or spinning. In addition, we aim the sensor to be applicable for rough attitude determination of small satellites. This paper provides an overview about the overall approach and layout of the experiment and describes the outcome of the project. Furthermore, the project is discussed from an educational point of view. Special attention is paid to the project challenges and achievements as well as to the interconnection between theoretical know-how and its practical application in this particular project. The lessons learned while facing the challenges and applying theoretical knowledge are described in detail.

Key words: HORACE; Horizon Acquisition Experiment; Horizon Sensor; Attitude Sensor; REXUS 16; Hands-On Project; Educational Project; University of Würzburg; Aerospace Information Technology; Space Master .

1. INTRODUCTION

The emerging sector of space technologies and their decreasing costs, due to the commercialisation of space flight, leads to more and more sophisticated technologies used in spacecraft. One of the most essential subsystems of a spacecraft is the Attitude Determination and Control System (ADCS) which is crucial for the viability of a satellite and thus has to be fail-safe and be able to work in unforeseen situations, such as uncontrolled tumbling or spinning. Besides conventional sensors like star trackers, sun sensors etc. new technologies and concepts may be used to determine the spacecrafts attitude thanks to the increasing processing power and miniaturisation of spacecraft systems.

Such a relatively new concept, using ordinary optical sensors sensitive to the visible spectrum of light instead of infrared sensors for sensing the horizon of earth, was evaluated and implemented by a technology demonstration mission, HORACE (Horizon Acquisition Experiment). By using the visible spectrum of light, we envision a future sensor that relies mostly on image processing techniques. Such a sensor might be able to use existing onboard cameras on a spacecraft and thus is weight, volume and cost efficient.

The scope of the REXUS/BEXUS programme, a bilateral agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB), enabled us to develop an appropriate test platform and image processing algorithms for such a horizon acquisition. In order to validate the concept of such a horizon sensor under space-like conditions, HORACE was launched on board of REXUS 16 on May 28 2014 13:30 (UTC+2) from Esrange Space Center, Sweden. The unguided parabolic flight of the rocket provided conditions to simulate the intended operational environment.

However, even if the technology demonstration was the main objective of HORACE, the educational part of this particular mission played a significant role in the overall project life cycle, especially because it took part within the frame of the REXUS/BEXUS programme. The further sections describe not only the HORACE project itself, but also the challenges, achievements and lessons learned during the project life cycle with emphasis on the educational aspects and the interconnection between theoretical knowledge and practical realisation.

2. EXPERIMENT DETAILS

The flight segment of the experimental setup consists of five main components, further called subsystems:

the *camera*, the *core system*, the *power distribution unit*, the *measurement unit* and the *mechanical structure* (cf. Fig. 1). The following section provides only a rough experiment overview, a detailed description may be found in Barf et al. (2015).

2.1. Mechanical & Electrical Setup

All components used in the flight segment are off-the-shelf-components to reduce costs and time needed for development.

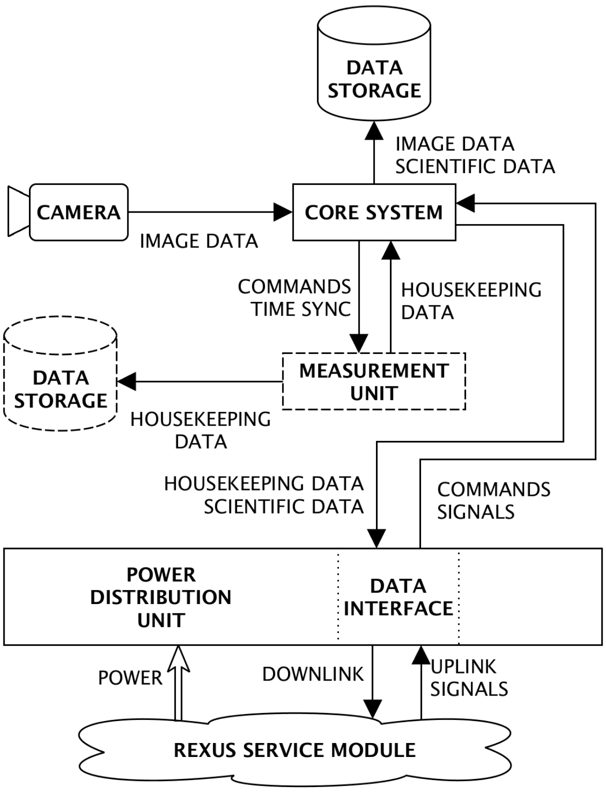


Figure 1: Block diagram of the flight segment. The measurement unit & its data storage (both dashed) are implemented by the master system only. (Barf et al. 2015, Fig. 1)

The camera, mvBlueCOUGAR-X102b, an industrial camera manufactured by Matrix-Vision, is faced perpendicular to the rocket's roll axis, to observe the outer environment. The captured image frames are then fetched by the core system, a industrial single-board computer (MIO-2260) through a GigE-Vision interface using a standard Ethernet cable. The core system then applies the horizon acquisition algorithm on the captured image frames and stores the image frames as well as the calculation data on the SSD attached via an SATA-II connection. In addition, the core system interprets the signals from the REXUS Service Module (RXSM) as well as manages the up- and downlink. For later evaluation a global timestamp is provided as well, which is linked to all data saved to the SSD.

To be able to downlink and save health and telemetry data as current consumption, temperature etc., the core system is connected to the measurement unit via an RS232 connection. The measurement unit itself collects current and temperature sensor readings and forwards them to the core system for downlink. Additionally, the data are saved to a separate SD card with the timestamp provided by the core system. During flight, the data is only stored on the SD card to save downlink bandwidth.

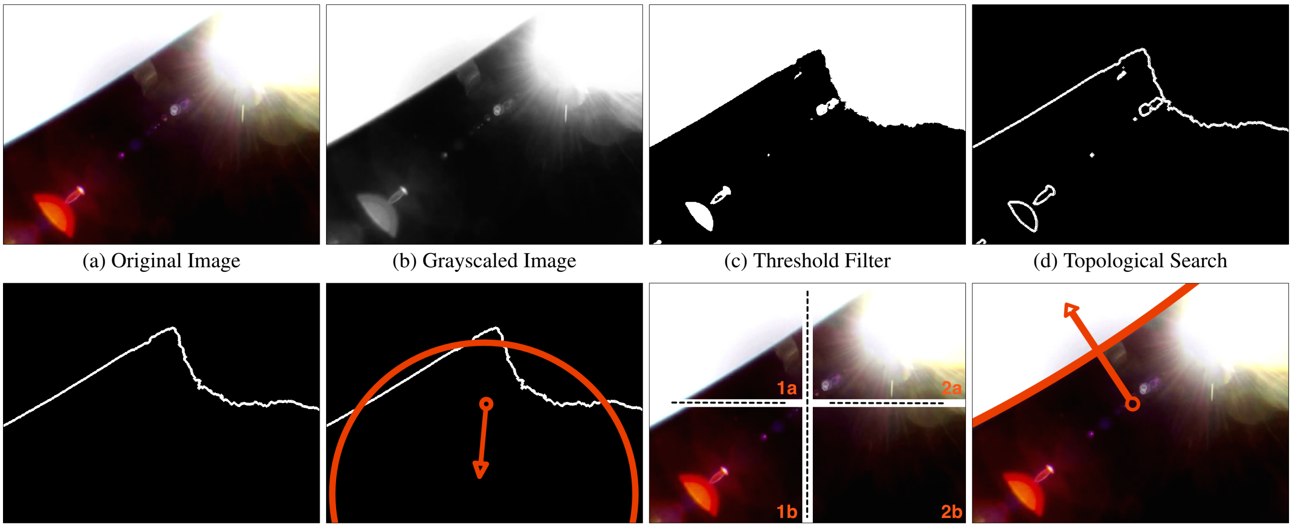
In order to be able to power the systems mentioned above, the power distribution unit is connected to the 28V unregulated power source of the REXUS rocket and takes care of regulating the power using DC/DC converters. All those components are placed in aluminium boxes to protect the electronic circuits from the outer environment and simplifies the replacement of subsystems. For redundancy reasons and to collect more scientific data, two independent, identical flight systems are placed within the same REXUS module (cf. Barf et al. 2015, Sec. 3).

2.2. Software Design

In order to operate the experiment, the core system runs *Arch Linux* (Griffin 2015), a minimal Linux operating system, on which the flight software runs on top. Using an operating system as a basis for the flight software was a specific decision to reduce development time compared to a bare metal implementation. On top of that the groundstation used a Linux derivate as well, which made it possible to use the same communication framework implementation on the groundstation and on the core system. Furthermore, this decision allowed testing in early stages of the software development, but introduced a higher risk of unwanted behaviour of the operating system. By using Arch Linux it was possible to combine the best of both worlds, since the minimal Linux distribution required explicit configuration of every operating system component.

To control the experiment, the flight software implements three different modes, the *standby* mode, the *flight* mode and the *shutdown* mode. The standby mode is executed while the rocket is still on ground. Here the flight system downlinks telemetry consisting of experiment health data to the groundstation and performs several self-checks, for example data storage access and camera connection.

After receiving the lift-off signal the flight software switches to the flight mode, where no housekeeping data but only some basic scientific data are downlinked, since the radio link bandwidth is limited. The detailed algorithm results and measurement unit data, as well as the captured images are stored on the data storages onboard. Ten seconds before being shut off by the RXSM at T+600s the flight software switches to the shutdown mode in order to finish writing data to the data storages and to prevent data corruption during the power cutoff (cf. Mawn et al. 2014; Barf et al. 2015).



(a) Original Image (b) Grayscaled Image (c) Threshold Filter (d) Topological Search

(e) Line Detection (f) Failed Vector Calcuation (g) 3 Divisions (h) Successful Processing of Partial Image 1a

Figure 2: States of Image data during Processing (Barf et al. 2015, Fig. 2)

2.3. Algorithm Design

In order to be able to find the horizon line, the software of the flight system runs a horizon acquisition algorithm which is fed with images in the visible spectrum captured by the camera. The main concept in finding the horizon is using the contrast between deep space and the central body. To cope with disturbances like lens flares, the sun etc. some additional logic is used.
This approach obviously requires the central body to be within the field of view of the camera, which sets some additional constraints for the optical system one may use. In case of HORACE, which was predicted to reach an apogee of approx. 80km, a lens with a field of view of about 18° and a very low maximum distortion of -1.6% (LENSATION 2014) was chosen. This ensured the earth horizon to be visible for at least one camera during the whole flight.

The first step of the algorithm, the *Preprocessing*, is scaling down the image while preserving its proportions to reduce computation time for the further steps and converts the coloured image to a grayscale image (Fig. 2b). If the image exceeds a certain value, e.g. is too dark or too bright, the image gets rejected and is not further processed (cf. Barf 2014, Sec. 2.2.1).
The second step applies a dynamic *Threshold Filter* to the greyscaled image, which means assigning a 1 to bright pixels and a 0 to dark pixels using an experimentally determined threshold factor and the overall brightness of the image.
In the *Line Detection* step, a topological search using an algorithm presented by Suzuki & Abe (1983) is applied to find continuous lines of border pixels and select the longest one (Fig. 2e, note: image was enhanced).
Having found the longest continuous line, the *Vector Calculation* is applied by fitting the line to a circle using the least square method. Thus, the radius of the circle can be checked for validity, since the expected radius range may be calculated if the properties of the optical system are known. Nevertheless, other factors like the atmosphere, the earth's albedo etc. have to be taken into account for tuning the parameters of the radius range calculation to avoid false positives or false negatives (Barf 2014, cf.).
If the calculated radius is valid, the vector from the center of the image to the center of the circle is calculated, giving the nadir vector of the 2D projection of the central body.
In case the calculated radius is not valid, e.g. due to image disturbances (Fig. 2f shows a failed vector calculation, note: image was enhanced), a Divide-and-Conquer approach is applied in the *Division* step to divide the image in the middle of the longer side. This is done until the partial images are too small to process and get rejected by the *Preprocessing* or return a valid result. The valid result of a partial image is then extrapolated and the circle may be calculated (Fig. 2h). Therefore this approach can be used even if the primary image is severely disturbed (cf. Barf et al. 2015, Sec. 4).

3. SCIENTIFIC RESULTS

Since the scientific data collected by the experiment during the flight were severely degraded due to a failure of the camera which led to a complete overexposure of most image frames, it was not possible to prove nor to disprove the overall concept of a software-based horizon sensor in space-like conditions (cf. Rapp 2014, Sec. 2.4).

Still, from an operational point of view, the experiment is seen as a success, since all operations went flawlessly during the Launch Campaign. Amongst other things, the developed communication framework as well as the software concept was proven to work nominally during all

critical phases. In addition, the algorithm worked as intended by discarding all unusable image frames, means it processed all the captured frames in a correct manner. Even though no useful footage was captured during flight, it was still possible to test the algorithm and its accuracy using simulations which were created by using a model of the camera and its properties within Cinema4D, a 3D-Simulation Software. Since using simulations made it possible to know the exact relative position to the earth, a comparison between the simulation data and the algorithm output could be done, which showed that the algorithm works with an accuracy of $\pm 0.6°$ in the simulated environment. During the whole simulation not a single false positive was reported and only 10.29% false negatives (cf. Rapp 2014, Sec. 3.5.4).
The disadvantage of using simulations to verify the accuracy is the inaccurate representation of reality, for instance in the simulated environment the atmosphere of the earth could only be modelled roughly.

In addition to the scientific results, some valuable technical insights were gained. During one of the last tests at the Launch Campaign only few days before the launch, it was unveiled that HORACE was disturbing the GPS antenna of the REXUS rocket when the experiment was powered on. Due to the very late discovery, it was not possible to detect the exact cause of this issue prior to launch, and counter-measures like putting ferrite beads around the cables in the HORACE setup did not solve the problem. This led to the decision to fly the REXUS rocket without a GPS signal in-between T-600s and T+600s, since the GPS signal was not vital for other experiments or the rocket itself during the period of time HORACE was powered. This issue was discovered late, because in the system tests before the Launch Campaign, especially during the bench test, the test configurations were different from the real flight configuration. Mainly, the nosecone of the rocket, where the GPS receiver was located, was not mounted as in the real flight configuration during the tests. Later on, during the post-flight analysis the cause of this issue was narrowed down to three components - the core system, the SSD and the cable connecting those two components. It was not possible to detect the exact component which caused the issue, so the only viable counter-measure would have been to shield all three components (cf. Rapp et al. 2014, Sec. 7.4).

Another anomaly, first detected during the integration week, was an issue concerning the grounding of the experiment. Even though the grounding of the experiment was done compliant to the REXUS user manual, this seemed to cause uncontrolled and indeterministic stray currents which led to occasional, unpredictable crashes of the software on the core system. Since it was not possible to fully understand the cause for the shifted ground potential, the issue could not be resolved properly. Workarounds like replacing the core system and a software solution for restarting the flight software only reduced the probability and severity of the issue to an acceptable level. So far, the only solution to this problem would have been a complete electric isolation from the REXUS rocket (cf. Barf et al. 2015).

4. PROJECT CHALLENGES

During the lifecycle of the project we faced many different challenges, some were more general and could have been encountered at any project and some were very project specific. Since all of the team members were in their second undergraduate year when HORACE was started we had trouble keeping up with the workload of the project in parallel to classes. Especially the review preparation phases (PDR, CDR, etc.) which often coincided with the exam phases forcing us to retake some exams. Also the project management of a team of six people and its resources over a two-year period turned out to be a nontrivial task, especially since we were short on experience concerning teamwork.
Although we studied "Aerospace Information Technology", the knowledge gained during the course of studies had less than expected overlap with the needed knowledge to complete HORACE. That meant that even though we still could apply much of actual class content, we had to acquire a lot of additional knowledge in parallel to the classes. Since we were the first team from our university participating in the REXUS programme we could not rely on previous experience gained in that area. All of us were computer scientists, so we had no mechanical, optical or electrical engineering knowledge which were necessary for the design of the experiment. Especially the formulation of the requirements presented a serious challenge to us.
Of course the software part of HORACE proved to be challenging as well. Besides the classical debugging of software the algorithm had to be designed in a way that it is resistant against disturbances like reflections or the sun in the camera's field of view (cf. Barf 2014). Additionally, since we do not have courses in mechanical engineering at our university we had trouble finding adequate testing facilities. For example to test the reliability at temperatures below -40°C (cf. Rapp et al. 2014, Sec. 5.2) an external company with a cooling chamber had to be contacted, since the thermal-vacuum chamber being available at the chair only allowed temperatures down to -20°C.
Another challenge was the funding of travel expenses and materials. Most materials were sponsored by the manufacturers themselves or paid by the REXUS programme and the university, but travel expenses were only fully covered for four team members.

5. CONNECTION TO ACADEMIC EDUCATION

Regarding the connection between the HORACE project and the participating students' academic education we could identify two main factors: firstly, the aspects of hands-on projects in the field of aerospace in general, which can be found at the University of Würzburg not only in the HORACE project, and secondly, the direct connection of HORACE to specific concepts and methods previously being taught in specific courses at least some of the participating students had attended. Both factors are discussed in detail in the following.

5.1. Hands-On Projects at University of Würzburg

One experience, which can probably be confirmed by any student who leaves the University and starts to work on concrete technical or scientific projects will be that there is still a lot to learn. In todays world, the education at the university will never be able to give a student all the knowledge, which is needed for a specific task. So the actual aim of a university can not be to just give a complete set of knowledge on every possible problem. It is rather to give students a fundament of specific knowledge but also and more importantly to help students to learn how to systematically develop systems , solve problems and apply appropriate methods, where necessary auto-didactically. This can all be done theoretically. But a better way is to give them the opportunity to be involved in a "real" project before they start working on projects outside the university. Although such an involvement of students is by far not obvious at every university, it is an extremely useful way to inspire and especially motivate young students.

Students at the university of Würzburg, studying in the field of Aerospace (either Bachelor of Aerospace Information Technology or SpaceMaster or Master of Informatics with a focus on Aerospace) have several such opportunities. They can for example work as student co-workers in the frame of real space related projects (e.g. star sensors, autonomous imaging systems, lunar satellites, communications systems), take part in practical work in rocketry or even work in real world problems in the frame of the international space station (ISS). In some cases, they are even allowed to do so in a relative early stage of their studies, namely within the first few semesters of their bachelor studies.

One of the examples of practical work opportunities are the REXUS/BEXUS experiments, which are a very valuable contribution of DLR/SNSB to University education. At the University of Würzburg, we have decided in 2012 to initiate and support such experiments in order to improve education and research by many different means. As described in detail in this paper, the student team worked very hard to achieve their goals and learned a lot by own experience. Even if some of the aspects had been taught beforehand by lecturers, the own experience will be much more unforgettable. As a simple example, students who are involved in space systems design projects learn how to formulate requirements, learn the organisation and management of a space project and design a space system. But to be confronted with the same contents in the frame of an external environment like REXUS, is a different experience. The pressure and willingness of being successful is much higher, than just the need of passing a regular exercise.

This increases the level of maturity of the involved students to a much higher level, which means that the institutions they will work in after the education will benefit from this fact as they will save time on job training. The specific experience described further in this paper just confirms all of these positive impacts to education. For us, the lesson learned from this is, that the universities should support much more such activities by means of more resources, which are usually very limited.

5.2. Connection to Specific Course Contents

Although, as outlined above, the gain in experience and abstract competences like problem solving in general undoubtedly had the greatest impact regarding the educational aspects of the HORACE project, we succeeded to directly link many contents of theoretical classes to the project challenges (cf. 4). Thus, we could not only face those challenges appropriately, but also gain deeper insight in those topics than it was possible during each and every of the courses.

Besides the basic architecture and the content of *telemetry and telecommand packages* which were taught in space related courses, concepts regarding reliable end-to-end transmission, i.e. error detection and correction, like the *Hamming distance* between code words or *cyclic redundancy check* were part of the "Information Transmission" lecture. Furthermore, especially the concept of *Divide and Conquer*, which was taught during "Algorithms and Data Structures" by the example of sorting algorithms, turned out to be the most important part of the HORACE algorithm to cope with heavy image distortions (cf. 2). In the lecture "Central Avionics", the advantages of common *coding directives* and a simplified example of those broadly used in the aerospace sector were presented and motivated to adapt them to improve the quality of the software. Standardised concepts of abstract modelling of software, like the *Unified Modeling Language*, standard processes and design patterns of software development were taught in the lecture "Software Technology". Applying those standards increased the collaborative productivity within the team and ensured comprehensibility of the abstract models of the software architecture for external partners. Many mathematical concepts and methods were helpful for the development of the HORACE algorithm, the later evaluation as well as to estimate the overall accuracy of the algorithm. This was not only the case for contents of the freshman course "Mathematics for Engineering Students", but also the lecture "Error Analysis" which, for example, introduced the *Least Square Method* applied for the circle fit step of the horizon (cf. 2).

As it can be seen from those various examples, the HORACE project offered the invaluable opportunity to apply the knowledge gained in the scope of our University studies. In many cases this was the very first time to do so out of the pure educational context where the concepts are often studied as isolated problems or by means of very simple examples. This raised the difficulty that, unlike in exercises of University classes, we were not told which set of tools and concepts should be applied, but we had to select, adapt and modify ones, suitable for the "real world's" problems, from our total set of theoretical knowledge. However, this way we were able to directly link our theoretical knowledge to personal experience and hence learn even more because - as one says - "knowledge gained through experience is far superior and many times more useful than bookish knowledge."

6. PROFESSIONAL SKILLS ACQUIRED

Of course, the theoretical knowledge from university classes mentioned in the previous section was not enough to overcome all challenges and to successfully complete the HORACE project. Hence, several professional skills had to be acquired mostly in an autodidactic manner. Besides the so called "soft skills", i.e. conducting proper team work or preparing good presentations, this includes skills regarding the usage of several professional tools and software-frameworks.

As the HORACE algorithm is based on image processing techniques and as it was neither reasonable nor possible to implement all needed algorithms from scratch, the *OpenCV* library was extensively used. Therefore, the team member charged with the algorithmic development had to acquire deep knowledge not only about its usage but also the underlying algorithms, limitations and disadvantages. Another essential part of the experiment was to implement a proper communication link between the core system and the camera to reliably gather images. Hence, the software developers had to study both the proprietary camera API of MatrixVision and the open and standardised one called *GenICam*. The core system ran with *ArchLinux* (cf. 2). That had the benefits of fast development of the actual HORACE flight software and a very stable and controlled operating system, but required a broad understanding of Linux itself, its configuration from scratch and how to implement applications on top of the operating system. This required of course advanced *C++* and *bash* programming skills. The measurement unit was based on the *Arduino* platform. The beginner friendly platform was easy to use in the beginning. But as the application grew more complex we had to get a deeper insight, especially regarding the restrictions and limitations of the simplified programming language as we were used to more advanced software development and hence also restricted in our thinking and way of problem solving. To test and verify the algorithms, simulations were created with *Cinema4D*. But unlike for some hobby movie project, one could not apply "trial and error" to render the simulations as they had to be as realistic as possible and as internal concepts of the tool, e.g. the internally used coordinate frames, had to be understood in order to numerically verify the HORACE algorithm (cf. 3). Although the emphasis of the project was on software components, of course some hardware was needed to run the software. While electronic components were bought as COTS to a large extend, the mechanical assembly was customised in most parts. Designing the mechanical structure using CAD-Software (*Autodesk Inventor*) was new to all team members as we all had a computer science background (cf. 4). To keep track of the project and ensure proper teamwork especially regarding software development with multiple contributors, several tools like *SVN*, *doxygen*, *Microsoft Project* or *TeamWorkPM* were applied, which of course were not covered by the theoretical university classes. For documentation and publications LaTeXwas used by some team members for the first time in an advanced and productive manner.

Already by now, several of the acquired professional skills helped to get placements for internships, student jobs or master projects and will surely be valuable for our professional careers.

7. PROJECT ACHIEVEMENTS

Even though the ultimate goal of full performance under real-life conditions was missed (cf. 3) the project delivered several valuable partial achievements besides the just mentioned education of students.

First of all, despite the competition of the project schedule with study and exam periods all SED submission, manufacturing, software completion and verification deadlines were met. This enabled us to launch a fully operational experiment. Beforehand, in order to test and verify the function of the algorithm special test videos were rendered. The short clips of a few minutes simulate the view of the experiment's camera as mounted on the tumbling rocket. In these simulations, all parameters of the optical system, the sun, clouds and the movement of the rocket were included although reality can only be approximated. Successive projects might also take advantage of the work done.

With these simulations in addition to real video footage from a previous REXUS experiment (EXPLORE) the performance of the algorithm could be analysed and verified. We managed to develop the mathematical concept and an implementation in *C++* of a horizon sensing algorithm with image processing techniques. This is another valuable outcome for successive projects.

8. LESSONS LEARNED

By facing the project's challenges and dealing with unforeseen events and difficulties, we learned a few lessons. The most unpleasant of them was learned when we missed to perform a late *End-To-End* test at the Launch Campaign. Due to that, we did not discover the overexposure of the camera pictures and as a consequence, let the scientific data become unusable. This would have easily been noticed if the experiment was fully tested outside the laboratory shortly before the mounting onto the vehicle. It would have also been possible to implement a function that allows the operator to take a quick view on the camera pictures even when the vehicle is already mounted on the launcher. This function could then have also been used at many occasions before the assembly and would have revealed the camera failure but was not

considered in the design phase (cf. Rapp et al. 2014, Sec. 7.4.1.4).
Another lesson learned could be named "*Test What you Fly - Fly What You Test*". During Bench Test an error was discovered, causing the core system software to crash completely. In previous testing this error did not occur. In later analysis it turned out that it was caused by a ground shift in connection with the grounding of the experiment structure to the RXSM structure (cf. 3). The ground connection was established the first time at Integration Week and identified as cause of malfunction during Bench Test, so the malfunction was discovered too late in the project cycle and could therefore not be fully eliminated (cf. Rapp et al. 2014, Sec. 7.4.1.2). The same lesson was learned at the Launch Campaign itself when HORACE interfered with the GPS antenna of the RXSM (cf. 3). Again, the cold countdown test was the first time the exact flight configuration was applied, meaning the "GPS antenna mounted inside the mounted nosecone and the cable harness fed through the experiments." (Rapp et al. 2014, Sec. 7.4.1.3).
Here we also had to learn that, while working on urgent problems, one should not neglect the actual important issues. While we were busy trying to install a workaround for the grounding issue in order to prevent software crashes we omitted further End-To-End tests of the whole experiment and thus allowed the camera failure to remain undiscovered as described above.
We also had to learn not to trust the manufacturer naively. The camera software provided by the camera manufacturer MatrixVision was not as flawless as it was assumed. A bug that was corrected in a later version is partially accountable for the overexposure of the camera. Had we validated the functionality of the provided software instead of trusting the manufacturer the error might have shown up before launch.

Besides these technical experiences a lot of lessons in the area of project and team management were learned. Since the University of Würzburg does not offer mechanical or electrical engineering degrees, the team consisted only of students of Aerospace Information Technology. The lack of specialised electrical and mechanical engineers was considered uncritical since no complicated electrical or mechanical components were needed. But without special knowledge in a discipline all work takes a lot more time. In addition, later in the project the need for protective windows to shield the camera from hot air inrush emerged. Especially the design of their mounting was indeed complicated and consumed a lot of time. Furthermore, the communication with the glas manufacturer was challenging and time consuming due to the lack of knowledge in available materials.

Without having a fully equipped laboratory or workshop available, all tools and materials had to be purchased or used from the personal portfolio. The costs for these purchases were completely underestimated in the early periods of the project. Another management variable that was underestimated was the time consumed by outreach activities. Creating websites and preparing presentations was assumed to be done incidentally. It eventually turned out that a proper outreach for a project like HORACE is a one-man full-time job. But outreach was also very rewarding, since it rose awareness and interest in the project. That and the SED preparations also made us practice our abilities to explain complex concepts to outsiders comprehensively. The communication inside the team was quite easy-going, since everybody studied the same subject in the same year and thus was at about the same level of knowledge. In addition, the stable team structure was very beneficial, making everyone available in the whole lifecycle. Although there were rough periods, a project of the complexity of HORACE with its team structure is manageable in parallel to the studies. Not only regular meetings but also a team management software, internal deadlines before the actual deadlines and the distribution of small tasks with short time schedules helped to keep track of all tasks. In this scope it is also advantageous to have supervisors who support the team with resources and knowledge where necessary but do not interfere with the design, manufacturing and verification process.

Writing requirements at the very early phase in the project is very tedious and time consuming. But this work is highly beneficial since every team member has time to make up his mind about the project and to discuss his perception. Furthermore, in the verification phase this work makes it possible to verify every single requirement and thus ensures that all functionalities are available. Another very tedious work is the preparation of procedures, that might never be used. But if they are needed they are extremely helpful. We experienced this when a SD card stopped working after the payload stack of the vehicle was already fully assembled. A procedure to replace the SD card was written beforehand and gave the Payload Manager a complete insight in the work to be done. It also helped us to avoid mistakes in this time crucial phase. A rather important lesson that the we learned is to start software development early, even if the design is not finalised yet. The time for software development is often hard to estimate and can easily exceed expected boundaries. Especially debugging is often very time consuming. Thus, early testing is crucial and can even affect the design. (cf. Rapp et al. 2014, Sec. 7.4)

9. FURTHER WORK & OUTLOOK

After the project HORACE was completed, a Bachelor Thesis (Barf 2014) took the algorithm to the next level by creating a version in *C++* that uses only standard libraries and implements all necessary functions previously used from *OpenCV*. This implementation is currently used by the REXUS Team PATHOS which is the followup project of HORACE. Key objectives of PATHOS are the "miniaturisation of HORACE so it could be part of a satellite, and the enhancement of the efficiency of the horizon-detection and vector-calculation algorithm" (Wagner et al. 2015). Hopefully that team can achieve what HORACE missed: a successful test under space-like conditions.

Furthermore, a setup to evaluate the accuracy and performance in a real application with a reference sensor system as proposed by Rapp (2014, Sec. 5) is a possibility for further development. Rapp also suggests the porting to already existing hardware and the upgrade of the system to provide full attitude information instead of only roll and yaw information. A Master Thesis on this topic is planned for 2016. In the scope of that work a horizon sensor based on the idea of HORACE shall be implemented to improve attitude information from heavily drifting relative attitude sensors on a sounding rocket with sensor fusion.

Thanks to the close cooperation with many space related organisations we got insights into their work and could already make contact with their staff. This already proved advantageous - and will presumably be in future - when searching for internships, thesis works and work places.

10. CONCLUSION

Although the major objective - the demonstration of the horizon detection in space-like conditions - was missed due to the overexposure of all image data, HORACE is still considered a success. This is not only because of valuable engineering outcome but also because of the great experience gained by the participating students.

Regarding the engineering conclusion, we could show that the horizon detection for attitude determination in the visible spectrum is basically possible and works with an accuracy of 0.6° in simulations. The algorithm itself proved to be working on simulated data and on real footage with a reasonable rate of false positives and false negatives. The project did not reveal any reasons why this idea can not be implemented as rough attitude determination system for safe-mode or as attitude determination sensor for small satellites. But there is still some way to go, especially regarding mass, power consumption and sampling time.

In the REXUS/BEXUS programme education plays a huge role throughout the project. In this manner it is save to say that HORACE was a full success. We now have a deep understanding of all phases of a project life-cycle and know how they affect each other, especially how design and verification insufficiencies can lead to what kind of failures. Of course, we faced challenges, made mistakes and even failed but we learned the lessons and are able to apply this experience in all further projects. Apart from the huge amount of technical skills and knowledge we also gained a fair amount of soft-skills especially regarding teamwork. We were also granted a brief insight into the space business and were already able to make first contact with possible future employers. To conclude, we suggest every space engineer to take the opportunity if it is available to take part in the REXUS/BEXUS programme and make all those experiences - good and bad - it is worth the effort.

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