Sheffield University Solar Balloon Lifted Telescope (SunbYte - BEXUS 25)

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***Abstract*— Solar observations from the ground is often difficult due to the turbulent atmosphere distorting incoming light. Learning about the Sun is critical in modern society as solar flares have the potential to cripple telecommunication and global navigation systems. Project SunbYte (Sheffield University Nova Balloon Lifted Telescope) aims to revolutionise the industry by using a high-altitude balloon to lift a solar telescope to an altitude of 25-35km, where it has the potential to capture images of much better quality. As existing ground and space telescopes are large, complex and expensive, SunbYte will provide a new technique for scientists to collect low cost, high quality data. The experiment was launched on BEXUS 25 from ESRANGE, Sweden in Oct 2017 as part of the German-Swedish student programme REXUS/BEXUS. This paper will discuss the educational impact of the project and the science and engineering developed by students. It will assess the lessons learnt from a management and technical perspective.**

Keywords*— *Solar astronomy; Sun tracking; University of Sheffield; telescope; Balloon;

I. Introduction

In the UK alone, €22 million was invested in the Space Situational Awareness program emphasising the need to better understand and predict solar events [1] [2]. Even though experimental studies using high altitude balloon telescopes have been previously conducted, these are, in terms of cost, inaccessible to many mainstream research institutions across the world.

SunbYte is a University of Sheffield student led project with academic and industry partners - Northumbria University, Queen's University of Belfast, University of Hull, Andor Ltd, Astrograph Ltd and Alternative Photonics. Combining the latest practices in manufacturing, astrophysics science and engineering, the team aims to deliver a low cost, high quality method of imaging the Sun.

The team includes members from first years undergraduate studies to PhDs, from aerospace, civil, electrical, mechanical, materials, chemical and Automatic Controls and Systems departments within the Faculty of Engineering, to Physics, Astronomy and School of Mathematics and Statistics within the Faculty of Science. All working together to develop an integrated, accurate and stabilised system.

The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through the collaboration with the European Space Agency (ESA). Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. EuroLaunch, the cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles.

II. Design

A. Mechanical

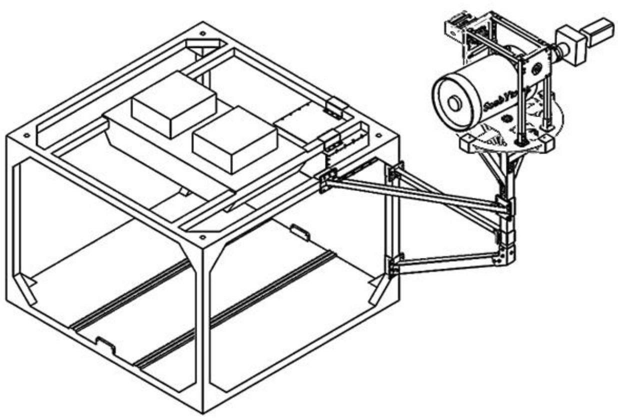

Fig. 1. Mechanical Overview

The experiment positioning on the gondola can be seen in Figure 1. This set-up provides height to the telescope to offer maximum field of view. It also moves the experiment away from the gondola's connections to the balloon. This support system has been designed to ensure the stability of the whole mechanical structure. By implementing a third horizontal metallic strut, transverse (side- to-side) low frequency vibrations caused by wind or gondola rotation can be minimised.

A mixture of aluminium square tubing and steel sheets was used to connect the supporting structure together. At areas of high stresses, additional bolts and steel plates were used to increase the local strength. Wire Electrical Discharge Machined (WEDM) parts were used where precise 90 degree bends were required (e.g. gondola clamps).

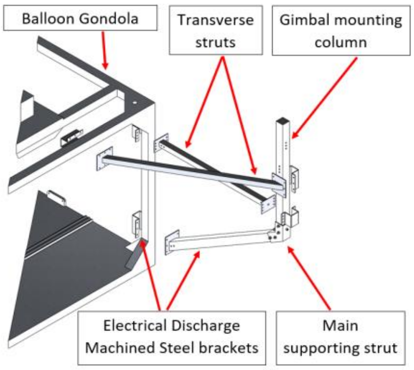

Fig. 2. Exploded view of supporting structure

Above the supporting structure is the two-axis gimbal which aims the telescope at the Sun. The gimbal is split into a fixed square platform and a rotating circular platform. The square platform also provides a mounting position for the yaw motor housing and C-clamps which secure the rotating platform. The rotating platform consists of a circular plate on which the telescope support sits.

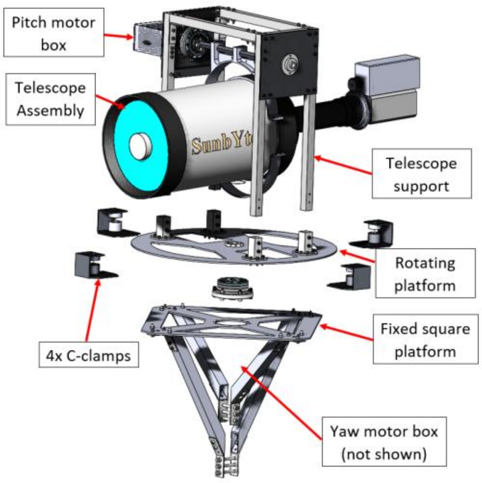

Fig. 3. Exploded view of gimbal

Within each motor housing, is a stepper motor and the motor driver. The team was able to learn from real industrial Engineers to select a harmonic drive which would meet torque, speed and power requirements, suitable for use with the motor. Due to the complex geometry necessary to adapt the motor shaft to the harmonic drive input, the team worked with the university's materials research group to design and manufacture a custom 3D printed titanium part.

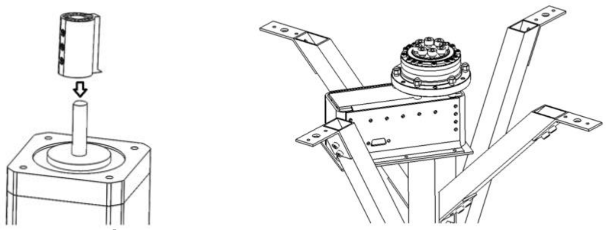

Fig. 4. Harmonic drive to motor interface

Students learned that the final design sometimes needs modifying even during final assembly. To ensure tight clamping, some clamps were initially designed to be 2mm shorter than the width of the strut. However, upon assembly, it was found that this caused the plates to significantly deform resulting in less contact area with the terminal surface of the strut. Here, the team utilised good judgement to deliver suitable modifications within the time constraint.

B. Optics

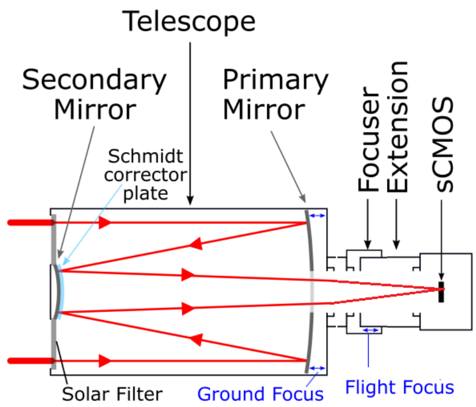

Fig. 5. Optics System

Fig 5 shows the optical design, a solar energy rejection filter reduces the energy entering the aperture of the telescope. This prevents overheating in a near vacuum environment. A Schmidt Cassegrains derivation of the Cassegrain telescope design was chosen because it is less susceptible to spherical aberration. It also has a long focal length with a compact length and volume. A focuser adjusts the distance between the camera and the telescope to account for thermal contraction during flight. The team learned the painful lesson that manufacturer deliveries can be late (often by months). The short project cycle was a surprise to manufacturers who were more accustomed to longer space missions. The H-alpha filter scheduled for arrival in summer 2017 did not arrive even by Oct 2017 so the experiment was finally launched without the intended h-alpha filter.

C. Electronics and its Modification

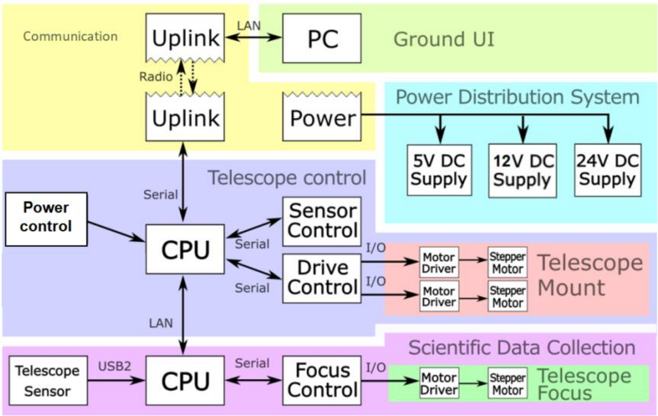

Fig. 6. Electronics system overview

The main goal of the electronic components is to provide a platform for the software that allows effective tracking and adjustment. Power distribution alters the voltage supplied (30V) and transfers this to the various devices (5V/12V/24V).

Telescope control gives commands for scientific data collection and controls the movement of gimbal. A Raspberry Pi (RPI) was used as main controller. Using sensor inputs, it calculates the motor movement required in order to position the Sun at the center of the telescope. In the scientific data collection system, a high resolution sCMOS camera capture pictures. The electronic layout, selection of programming language and components were conducted according to the design specification.

During final assembly, the team discovered that the power relay delivered a pulse to all connected devices on battery connection. The PC was supposed be in off mode by default to conserve power, however the relay accidentally turns this on with the pulse. The team identified this issue through a series of careful and logical tests to trace the error from the power supply to the user end.

During testing, the main RPI controller was accidentally destroyed. Current sensors between the battery to DC/DC converters and the RPI were supposed to monitor this. However, because the current sensors were connected together via data line, when the address pins were mistakenly connected to the 5V supply, the current sensor between the battery and the DC/DC converter was overpowered and 30V from the battery bypassed DC/DC converter via the data line of the sensors into the RPI.

D. Software Design

The aim of the tracking software was to center the sun in the sCMOS camera. This was done by capturing a feedback image from the RPI camera. Then, comparing the current position with the reference point. The required movement was calculated and output to the controller of stepper motor. There are three steps to the process: the high-speed tracking, fine adjustment tracking and the focusing system. There are many possible methods to accomplish tracking, the team conduced research and discussed the most appropriate approach. This was different from the typical classes where the teacher provides a system diagram and the students write code.

E. Summary

Despite the issues which arose during assembly, the team worked together and the experiment flew with basic functionality and a limited power management system without sensors or a focusing mechanism.

III. DATA EVALUATION

During the flight, the Raspbery Pi Camera was able to consistently take images of the sky for the tracking. The Sun clearly visible as a circle with a diameter of approximately 11 pixels against a black sky. Due to the strong solar filter used, the lack of glare and other visible light sources shows the solar filter film was operating as desired, but also far better than during ground-based tests. Pre-processing software filters mistook the Sun to be noise/dust particles and removed it prior to the tracking algorithm, see Figure 7. This led to the experiment being unable to acquire scientific data from the telescope camera.

Fig. 7. Image processing steps for the Pi *(Camera images with solar filter installed and modified filters.(a) original, (b) gaussian blurred (3x3), (c) threshold removal (240 to 255), (d) erode filter, (e) dilate filter.)*

Ground-based tests showed more glare/coma of the sun than in-flight tests and there was no way to have reasonably anticipated this. Changes to the image pre-processing parameters have been made and show proper functional tracking.

IV. OUTREACH

Public Engagement

Throughout the project, the team has worked with university societies such as “Women in Engineering” and the Sheffield Space Society to promote Engineering. They have participated in the UK Space Missions Forum, Sheffield Festival of Science and Engineering, Pint of Science, and the UK National Astronomy Meeting. The team has developed a website (http://sunbyte.group.shef.ac.uk/) with different social media channels (e.g. Facebook (facebook.com/Project-SunbYte) and Twitter (@Project_SunbYte). These allow interested parties to watch the team’s progress as they manufactured, tested and launched the payload. Viewers were able to see the team live at the launch campaign and learn more about the conditions near Space. Outreach into schools inspired younger students and gave them a broader idea of the Engineering involved to survive in these harsh conditions. Giving team members the opportunity to talk about their work also boosts morale and makes them proud of their achievements representing their university.

V. TEAM WORKING STYLES

As part of an investigation into the compatibility of team members, a Belbin working styles test was conducted on each team member at the beginning of the project. This was later repeated in the later stages of the project to see if team members adapted their style to work together. The Belbin test is used to identify behaviour preferences of an individual and has been developed over the last 9 years [3].

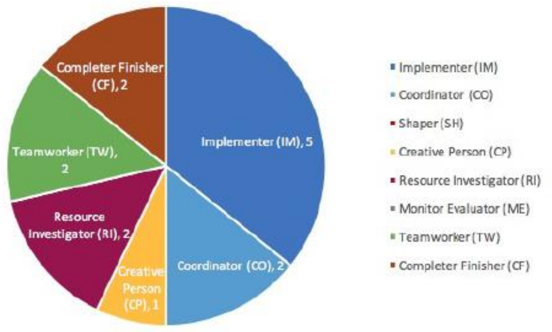

Fig. 8. Belbin test result

From fig 8, it can be seen that the highest occurring personality trait is "Implementer". Looking at the combined primary and secondary traits, "Implementer" appears in almost all the team members. This trait is prominent in people who like to turn ideas into reality and could be a reflection of the type of student Engineers who wish to join the project. However, those with this trait also tend to be slow to accept new ideas. This makes working within a dynamic design environment challenging, especially when combined with the lack of "Monitor Evaluators". The lack of "Monitor Evaluators" means a decrease in ability to objectively assess different the options. A second Belbin test later in the project showed that team members changed working styles in order to fit the needs of the team. Previously lacking roles like the "Monitor Evaluator" mentioned above were more prominent and the team was much more balanced. It is therefore important that teams effectively analyse the way team members prefer to work and distribute tasks accordingly.

VI. IMPROVEMENT AND RECOMMENDATIONS

A. Time Management

Although it was envisioned that that each team member would only spend around 3-5 hours per week on the project, this was vastly underestimated. Successful members often need to spend closer to 10 hours per week. As conflicts of priorities arise, emotional management of the team is important to maintain morale and working efficiency.

This effect is exacerbated in the managers of the team. For example, a task requires 10 hours of work. If delegated to an unacquainted team member, it would take an additional 5 hours of the manager's time to prepare a clear explanation of the task, how to approach the task and check up on the individual. Hence, there is often a trade off between the manager taking on task themselves or delegating the task. Until this effect was realised, the team often underestimated the time required to complete tasks and did not leave enough contingency time.

B. Leadership

As a consequence of the above, some sub-team leaders had a tendency to take on all the work instead of assigning tasks to team members. This led to students without sufficient training and experience. During critical periods or when the sub-team leaders were busy, the team struggled to meet the targets set. Therefore, it is recommended that no matter the circumstance, time is invested in training new members who are able to takeover more work during critical periods.

Contrary to expectation, the most senior student is not necessarily the most ideal to lead a sub-team. Team members have a variety of reasons for joining the project, for example, a high performing senior mechanical engineering student may join to learn new electrical knowledge. A proper recruitment process is needed to ensure that the individual actually wants to take on the role the team wishes them to do.

C. Project Management

Segregation of teams by disciplines is a terrible idea, projects are interdisciplinary so internal teams should be formed around functionality (e.g. gimbal mechanism, telescope system, etc.). This forces students from different disciplines (e.g. electrical and mechanical) to sit together and design mutually compatible systems. If this is not achieved, proper integration of systems is much more difficult and work often needs to be repeated.

D. Project scope

In the early stages, the team lacked student expertise in astrophysics. Instead, they relied on academics who had much a better understanding of the field. However, academics may not have a good understanding of what students can achieve within a year. The lack of understanding on both sides led to project creep with the team leader unaware of the impact of a high accuracy telescope pointing requirement until later in the project when it led to specification of very strong motors, very strong structure and excessive power consumption. Thus, emphasis on achieving secondary objective (proving the scientific value) affected the primary objective (demonstrating the tracking). Realistically, the team should have recognised their limitations and opted to deliver an achievable goal successfully rather than risk aiming for an amazing but unlikely result. However, as this was an educational program, the challenge was an opportunity for the students to gain massive technical experience and recognise their own limitations.

As the team of students matured, they learned the key areas to focus on and the areas to forget. The requirements document and risk assessment (created with guidance from the REXUS/BEXUS organisers) were a core aspect of the decision process. One critical area which was covered well was spare parts. During final assembly, anything which could possibly malfunction somehow broke. The team was only able to deliver the flight experiment (with limited functionality) because they had the foresight to bring enough parts and tools (including a 3D printer) which could be cannibalised for stepper motors and spare parts. In post flight evaluation, a smaller scale model could have been used to decrease structural requirements and reduce the need for high torque motors. The scientific camera used required a very high performance computer to receive all of the images. This was not provided due to the budget and as a result, some of the experiment's better components were underutilized. An internal post flight review by team members showed that a smaller telescope with increased emphasis on refining the software Sun tracking would be ideal. Once this is achieved, it is a matter of cost to put more expensive components on-board for higher quality images.

VI. CONCLUSION

Nowadays research led teaching is extremely important in giving an opportunity for STEM students to work together, gain actual real life experience of the aerospace industry, apply their scientific and engineering knowledge and network with students and companies from all over Europe. During the course of the project SunbYte student team members attended a number of events organised by ESA in Netherlands, Germany and Sweden. Every three months 4-5 of students participated in review meetings organised by REXUS/BEXUS team to assess progress. All of this was very similar to preparation of real space missions and participating STEM students took their tasks very seriously. The success of the SunbYte mission inspired many of the students to continue in space engineering and science related projects. Also, STEM students who were not involved in SunbYte now wanted to be! Due to popular demand this led to the formation of the Sheffield Space Initiative (SSI) at the end of 2017. Working with the world’s largest professional Engineering Institution (IET) and the University of Sheffield Space Society, SSI started to inspire the next generation of space engineers and scientists for a variety of exciting new projects. Our research led teaching project has now engaged more than 50 students from first year undergraduates to PhD students from the engineering and science faculties. The different engineering departments involved are Automatic Control & Systems, Aerospace, Civil, Electrical, Material, Chemical and Mechanical and the science departments are Physics & Astronomy and the School of Mathematics and Statistics. Through a lot of feedback from the students, it is clear that these projects definitely helped them become the best, open up their full potential and develop their knowledge. All of which will stand them in good stead to inspire life long learning and to achieve a fulfilled and rewarding professional life.

Now, the team successfully applied to NASA's High Altitude Student Platform to fly a smaller scale experiment. This time, using a 90mm aperture telescope with a smaller scientific computer and science camera. The experiment mass was greatly reduced. The motor specification was also relaxed leading to power savings. The experiment has now been preliminary accepted and the team is working hard to continue making the most of the opportunity that the REXUS/BEXUS program first provided. Old code which proved to work is being combined with new sensors to bring more data into the experiment and allows better diagnostics. In addition, new methods of Sun tracking are used as back-up systems to ensure that the Sun can be tracked. Finally, improved trial and error algorithms which adjust the on-board imaging filter parameters are being developed so that the experiment can automatically change key variables to prevent itself from accidentally erasing the Sun again.

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