Samuel Prouten ENSTA BRETAGNE **October 1, 2021**

Intership Report

Commissioning and improvement of an agricultural robot
Small Robot Company

Contents

1 Acknowledgement

I would like to thank Small Robot Company for allowing me to carry out this internship during the summer 2021.

I would also like express my gratitude to Tom Burrell, robotics engineering team leader, Sarah Reade, Robin Jackson, Saul Puente and James Lawrence, members of the team, for sharing their knowledge with me and making me feel part of the team.

Finally, I would like to thank my teachers, Mr Jaulin, Zerr, Le Bars and many others for teaching me the necessary skills that made this placement a success and a valuable experience within my studies.

2 Abstract

During the summer of 2021, I took part in an internship in Small Robot Company. This company develops robots for agriculture, which is the sector I am interested in working in. For three months, I carried on various tasks, from electrical engineering to software development.

3 Résumé

Pendant l'été 2021, j'ai réalisé un stage d'assistant ingénieur au sein de Small Robot Company, une startup spécialisée dans le développement de robots pour l'agriculture. Les robots agricoles étant le domaine dans lequel je souhaiterais travailler, ce stage était idéal dans la construction de mon projet professionnel. Durant ces trois mois, j'ai réalisé de multiples tâches variées, allant de l'électronique à la programmation.

4 Introduction

4.1 Small Robot Company

Small Robot Company (SRC) is an agricultural robotics and AI company based in West Dean, UK. Their goal is to re-imagine farming to help farmers deal with the increasing challenges they are facing. Indeed, farming needs to fundamentally re-invent itself to tackle growing obstacles: yields are stagnating, machinery costs are rising, weeds are becoming more resistant to herbicides... [1]

Small Robot Company's strategy to deal with these problems is what they call "Per Plant Farming". Today, farmers deal with issues on a crop type level or on a field level. To explain this very simply, this means that to get rid of a pest that has invaded one side of a field, the whole field will be treated with pesticides. "Per Plant Farming" is the opposite, the goal is to operate at the individual plant level to deliver the minimum amount of pesticides, herbicides and treatments in general. Mobile robots are particularly suited to carry out these kinds of missions: they can operate autonomously on large areas for extended periods of time, their size enables them to get close to each plant to inspect and treat it, they can gather large amount of data that can be used to inform the farmers of the state of their crops...

The service that SRC is developing aims at empowering farmers with tools to make decisions based on large amount data gathered in their fields, to treat the problems they face on a plant based approach and to advise farmers on ways to improve their profits and sustainability.

4.2 Small Robot company's products and services

The service that SRC is developing is based on 3 main elements : data gathering, data processing and handling/treatment.

- The data gathering is accomplished by "Tom" (figure: 1), one of their most advanced robot.

Figure 1: Tom, weed detection robot

Tom is sent in a field to gather images of growing crops. It is made up of a mobile robotic platform equipped with a boom on which cameras face the ground to capture images as it surveys the field. It uses GPS to position itself in order to follow a Boustrophedon survey path and to localise the images taken.

- The data processing is done by Wilma (figure: 2), a weed detection and crop health monitoring AI. The AI will process the images taken by Tom and cross reference the image location and the weed detection to localise the weeds with a 10cm accuracy. Wilma will then plan a mission to treat the identified issue.

- Finally, the mission planned by Wilma will be executed by a weed killing robot. It will drive to the weed location and either zap the weed with a high voltage electric discharge or by spraying pesticide in a very precise and located form. This robot is still in early development.

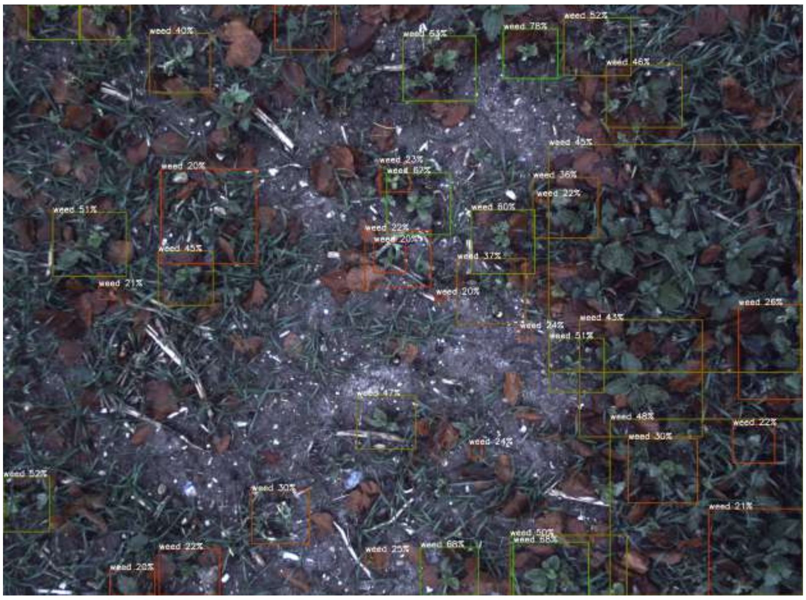

Figure 2: Wilma, weed detection and crop health AI

4.3 Context of the internship

Autumn is the season of the year where many crops are in a growing phase. This is the time where Tom is supposed to survey the fields to gather data. The summer is a calmer season the robot as the crops are fully grown, ready for harvest so it cannot perform its mission or it will destroy the plants. This means that summer is a significant research and development period for SRC employees as everything must be ready for the short period the robots need to operate in the fields.

Additionally, Small Robot Company developed the Tom V3.0 robot internally and subcontracted the build of two robots to Tharsus, a company specialised in robotic design and manufacture. For some reason, the build was not completed to its full extent and one of the robots was delivered in an unfinished state.

5 Tasks carried out during the internship

5.1 Commissioning of a Tom V3.0 agricultural robot

My first task was to get the second Tom V3.0 robot up and running to have 2 equally performing robots. This meant fully stripping down the robot from its cables, checking each cable and each connections down to individual crimps. I then had to re-crimp the loose wires, reinstall the cables in the robot and check all the connections once installed.

Figure 3: Crimps for a M12 connector

I have learned a lot about electronics during this period, improved my soldering skills and overall, learned about electrical design in robotics applications. Namely the important decisions that need to be taken when choosing the means of powering components, actuators and sensors, the way power and data are distributed and rooted in a robot and the way each choice can affect the robot's modularity and future development.

Indeed, one of the struggles I had while working on the robot was accessibility. The chassis is not designed with accessibility in mind.

This is due to several mechanical requirements, however, on a prototype that is susceptible to evolve, being able to access easily the insides of the robot is essential. This will definitely be something I will keep in mind if I ever have to design a robot.

This task took most of my time during the first half of my internship. By mid-July, the second Tom robot was able to drive manually and by the end of July, the robot was able to drive autonomously. It was then in a state ready to be improved in order to meet the business requirements.

5.2 Improving GPS accuracy

A requirement for the SRC service is being able to localise a point on an image taken by the Tom robot with a precision of at least 10cm. To understand the challenge that rose from this requirement, I will now explain how Tom localises a point on an image.

First, the attitude of Tom is acquired by GPS, using two antennas located on either end of the camera boom:

Figure 4: Tom's camera boom

One antenna acquires its position that is then converted into the robot's position using transforms. The second antenna is used to compute the robots heading using a "baseline heading".

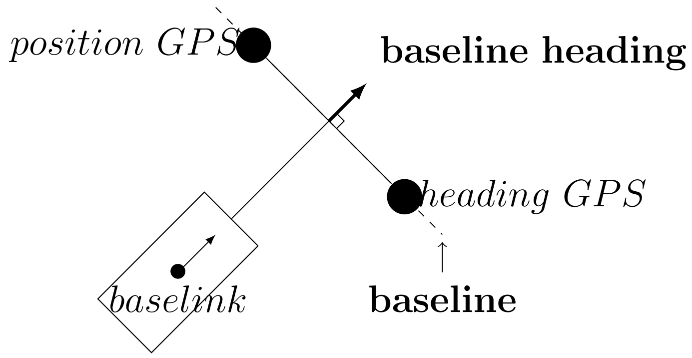

Figure 5: Baseline heading on the Tom robot

The baseline heading is a simple way to compute the heading of the robot from the position of the two antennas. It is also precise because it only uses the relative positions of the antenna between one another.

The images are saved with the robot's position and heading at the time the image was taken. Then, some post processing is applied to the image to determine the position of the weed in the image and thus, the position of the weed on the earth.

The position of both antennas are corrected using RTK. A base station is set up for every field survey. The position of this base station is determined by taking the average of the last couple of thousand measurements. This method, it turned out, wasn't very accurate. In fact, by averaging the last 1000 measurements, the location of the base station can be off by tens of centimetres. This in turn means that the robot's location and the weeds position is not accurate.

One of my tasks was to take multiple surveys of a permanent base station set up near the office. Each survey was 20min long. I then had to post-process[2] the data using Ordnance Survey measurements which is the equivalent of IGN in France. I did this using the *rtklib* library. By post-processing the surveys, we managed to position the fixed base station within a 2cm radius for all surveys. This was a great step in getting to a 10cm accuracy for the robot's survey as we could now rule out the position of the base station as a contributing error factor.

The next step to increase the GPS accuracy was to reduce the time delay between the GPS time and the CPU time. This meant increasing the CPU, which is what I will explain now.

5.3 Get 6 cameras to run on the robot

My main task by the end of the internship was to adapt the robot so that the 6 cameras on the boom (figure: 4) could work simultaneously. This was an issue for two main reasons. The first on and the most difficult to fix was because the CPU of the robot could not keep up with the amount of information transmitted by the 6 cameras. The second was the USB 3.0 cables that connect the cameras to the computer degraded the GPS signal such that the robot could not localise itself when a camera was operated near the GPS antenna.

5.3.1 GPS signal degradation by USB 3.0

This problem is known by GPS manufacturers and especially by SwiftNav, the manufacturer of the GPS system used on the robot[3]. To fix this problem, several actions can be done:

- Use better shielded USB3 cables
- Remove the USB3 devices from the system
- Use USB2 instead of USB3
- Shield the GPS antennas from the USB3 cables

In the case of Tom, the cables used were already the best quality USB3 cables on the market, so the shielding was supposed to be excellent. Removing the cameras or placing either the camera or the GPS antenna somewhere else was not an option as this would have required a complete redesign of the robot. The cameras require USB3 so using

USB2 is not possible. Therefore, the option that we went for was to shield the GPS antennas from the USB cables.

To shield the GPS antennas, we tried different materials and different sizes to find a suitable option. We ended up using an aluminium tray as a quick temporary fix:

Figure 6: Prototype shield to protect the GPS antenna from the USB3 cable

The next step was to communicate with the mechanical design team our findings so that they could design a properly integrated shield for the antenna.

5.3.2 Increasing CPU to run six cameras

The second task that needed to be implemented to run the six cameras was to increase the CPU.

Tests that I had run in the beginning of my internship showed that with only 4 cameras, the CPU load was averaging at around 95% during the survey. When running the six cameras, the CPU was at 100% constantly and some messages were dropped. Furthermore, the

GPS time was ahead of the CPU time by as much as 5 seconds on the worst occasions. This meant that when the robot arrived at the end of the row, instead of slowing down and stopping at the right place, it carried on for 5 seconds. This is obviously an issue that can even be dangerous if the robot is near the fields limit.

The processing unit was initially made up of a Nvidia Jetson TX2, which is the middle of the range computing module developed by Nvidia:

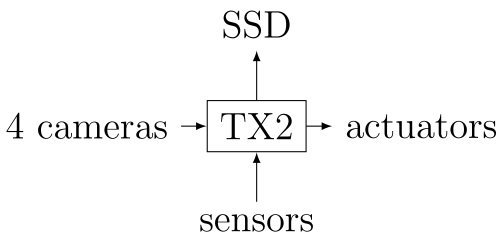

Figure 7: Diagram of the initial internal networking of Tom

At first, we tried adding a second TX2 tasked with running the cameras and saving the images. A lot of time was allocated to separating the different nodes that had to run on the different computers. Thankfully, ROS makes this process "easier". The internal networking of the robot then was as follow:

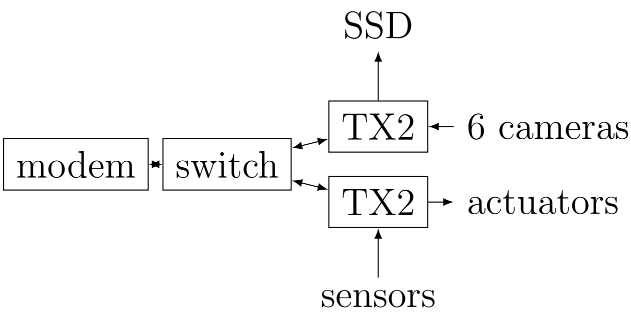

Figure 8: Diagram of the second internal networking of Tom

The Ethernet switch and the modem were responsible for dispatching the messages between the 2 computers. As we can see, one computer dealt exclusively with saving the images from the cameras while the other one took care of all the computing.

After running some tests, we concluded that the TX2 was not powerful enough to cope with the amount of data received from the cameras. The CPU load was still at 100%. So, we decided to switch it for a Nvidia Jetson AGX, which is the high-end computer in the Jetson family with an amazing 8 core CPU and 32G of RAM. We also swapped the switch and the modem for a more powerful modem with several Ethernet ports. Here is the final networking layout:

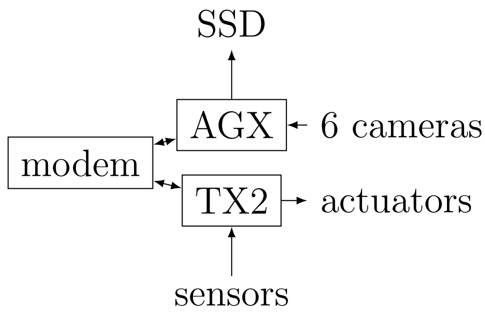

Figure 9: Diagram of the final internal networking of Tom

After these modifications the CPU could cope with the amount of data. However, the many changes we made in the networking layout and the distribution of the computing tasks between the 2 computers meant that we had broken several less important parts of the system such as the autonomous startup sequence or the connection with the web-service which allows telemetry to be sent to a tablet for the robot handler. We then had to fix these issues. The end of my internship was approaching by then, so I only mildly participated in this part of the development.

I learned a lot about networking during this period which was one of my weak points going into the internship. I feel that the distribution of computing power is an important problem in robotics, and I am thankful that I had the chance to experience it first-hand. Also, the communication between multiple machines on a ROS network is a great skill to have, as it is often necessary in robotic systems.

6 Lessons learned during the internship

This internship has been very instructive for me. I have had the chance to tackle various subjects from electrical engineering to software development and networking.

A great lesson I have learned is the importance of accessibility. The first month I spent working on the robot really made me realise the importance of being able to access components easily. This is especially true on a prototype that is prone to evolve and be equipped with different systems.

I have also made huge progress in networking, especially in ROS networks. I better understand the logic behind multiple machines networks and the way these machines interact. Although I feel I have only scratched the surface, I am now more confident working with a network. In general, I have learned a lot about ROS.

Finally, the most valuable teaching I received from this internship is a method to work efficiently in a team. The method uses at SRC based on the Agile project management method. It was the first time using such a method for me and I could really appreciate the benefit for teamwork. However, I still feel that the Agile method is extremely well suited for software development, yet it needs to be adapted for robotics development. I believe that the fact that robotics deals as much with physical components as well as software, make the method less applicable. For instance, if a component fails and a replacement needs to be delivered, then the wait time can sometime take the whole sprint, making it impossible to attain the goals. And a component failing can halt the robot, sometimes for several days, which can hinder development and, in the end, render a whole sprint worthless because other goals could not be reached. My final thought is that the Agile method is perfect for software development, but as soon as physical components come into play, the method somewhat fails. A fusion between the V-Model and Agile seems, to me, the most efficient development process for robotics application that deal with physical and software.

7 Future intentions

Having never worked in a robotics company before, nor in a startup, I was extremely pleased to experience this environment during my internship. I was excited to take part in Small Robot Company's development and discover the challenges that a small, innovative company can face. SRC really gave me a taste of what it is like to work in a startup, and I believe that it is a context that would suit me in my career. What I have learned about myself during the internship is that I prefer the research and development aspect. The first part of the internship was very technical and closer to production than R&D. Although it was very interesting and instructive, after a month I felt like I wanted to tackle more challenging issues and address real innovative problems. That is why I would like my next internship to be in R&D, perhaps in a robotics laboratory to discover the research area. I would then be able to decide what is genuinely adequate for me and my career.

References

[1] Small Robot Company. *About SRC*. URL: https://www.smallrobotcompany.com.

[2] J.M. Juan Zornoza J. Sanz Subirana and M. Hernández-Pajares. *GNSS DATA PROCESSING - Volume I: Fundamentals and Algorithms*. URL: https://gage.upc.edu/sites/default/files/TEACHING_MATERIAL/GNSS_Book/ESA_GNSS-Book_TM-23_Vol_I.pdf.

[3] SwiftNav. *USB3 interference*. URL: https://support.swiftnav.com/support/solutions/articles/44001850798-usb3-interference.

RAPPORT D'EVALUATION
ASSESSMENT REPORT

ENSTA Bretagne

Merci de retourner ce rapport par courrier ou par voie électronique en fin du stage à :
At the end of the internship, please return this report via mail or email to:

ENSTA Bretagne – *Bureau des stages - 2 rue François Verny - 29806 BREST cedex 9 – FRANCE*
☎ 00.33 (0) 2.98.34.87.70 / stages@ensta-bretagne.fr

I - ORGANISME / *HOST ORGANISATION*

NOM / *Name* Small Robot Company

Adresse / *Address* Unit C-D, The Courtyard, Dean Hill Park, Salisbury, SP5 1EZ

Tél / *Phone (including country and area code)* ____

Nom du superviseur / *Name of internship supervisor* Thomas Burrell

Fonction / *Function* Head of Robotics

Adresse e-mail / *E-mail address* tom@smallrobotcompany.com

Nom du stagiaire accueilli / *Name of intern* Samuel Prouten

II - EVALUATION / *ASSESSMENT*

Veuillez attribuer une note, en encerclant la lettre appropriée, pour chacune des caractéristiques suivantes. Cette note devra se situer entre **A (très bien)** et **F (très faible)**
Please attribute a mark from ***A (excellent)*** *to* ***F (very weak).***

MISSION / *TASK*

- La mission de départ a-t-elle été remplie ? *Was the initial contract carried out to your satisfaction?* — (A) B C D E F
- Manquait-il au stagiaire des connaissances ? *Was the intern lacking skills?* — ☐ oui/*yes* ☑ non/*no*

  Si oui, lesquelles ? / *If so, which skills?* ____

ESPRIT D'EQUIPE / *TEAM SPIRIT*

- Le stagiaire s'est-il bien intégré dans l'organisme d'accueil (disponible, sérieux, s'est adapté au travail en groupe) / *Did the intern easily integrate the host organisation? (flexible, conscientious, adapted to team work)* — (A) B C D E F

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* ____

COMPORTEMENT AU TRAVAIL / *BEHAVIOUR TOWARDS WORK*

Le comportement du stagiaire était-il conforme à vos attentes (Ponctuel, ordonné, respectueux, soucieux de participer et d'acquérir de nouvelles connaissances) ?
Did the intern live up to expectations? (Punctual, methodical, responsive to management instructions, attentive to quality, concerned with acquiring new skills)?

(A) B C D E F

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* ______________________

____

INITIATIVE – AUTONOMIE / *INITIATIVE – AUTONOMY*

Le stagiaire s'est –il rapidement adapté à de nouvelles situations ? A B C D E F
(Proposition de solutions aux problèmes rencontrés, autonomie dans le travail, etc.)

Did the intern adapt well to new situations? (A) B C D E F
(eg. suggested solutions to problems encountered, demonstrated autonomy in his/her job, etc.)

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* ______________________

____

CULTUREL – COMMUNICATION / *CULTURAL – COMMUNICATION*

Le stagiaire était-il ouvert, d'une manière générale, à la communication ? (A) B C D E F
Was the intern open to listening and expressing himself /herself?

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* ______________________

____

OPINION GLOBALE / *OVERALL ASSESSMENT*

- La valeur technique du stagiaire était : (A) B C D E F
  Please evaluate the technical skills of the intern:

III - PARTENARIAT FUTUR / *FUTURE PARTNERSHIP*

- Etes-vous prêt à accueillir un autre stagiaire l'an prochain ?
  Would you be willing to host another intern next year? ☑ oui/*yes* ☐ non/*no*

Fait à ______________________, le ______________
In ______________________, on ______________

Signature Entreprise T. Barrell ______________ Signature stagiaire
Company stamp ______________________ *Intern's signature*

Merci pour votre coopération
We thank you very much for your cooperation