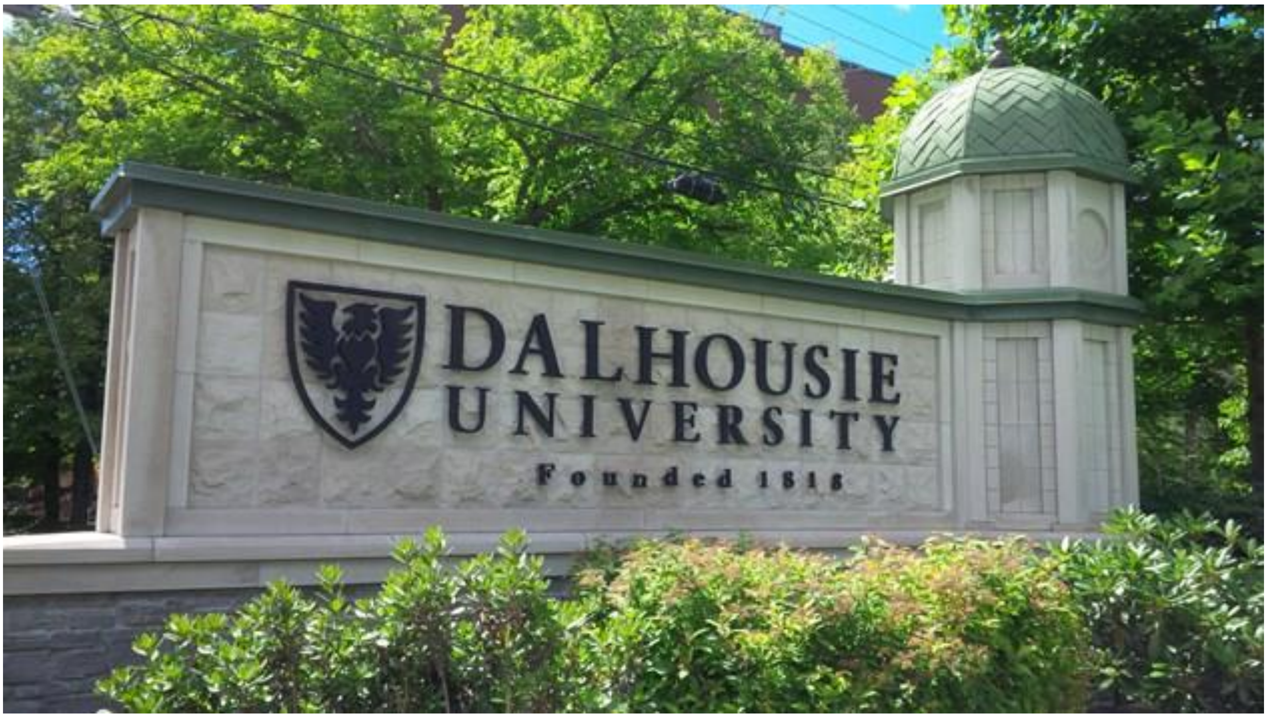

Assistant engineer internship
CI – 2019

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Special Thanks

I would like to thank Dr. Mae SETO, my internship supervisor, who offered me this great opportunity to improve my academic, technical and social abilities. She was available when I needed her to answer to my interrogations or to guide my work in the right direction.

My thanks also go to Mrs. Fonseca who assisted me with the administrative formalities. Her help was invaluable both before and during my internship. I greatly appreciated her availability and reactivity.

Finally, I would like to thank Mr. Jaulin who nominated me for this internship and for his confidence in me.

Abstract

In France, at the end of the second year of engineering school, engineering students must complete an engineering assistant internship. For my part, I worked under the supervision of Professor Mae SETO at Dalhousie University. The purpose of this document is to produce a synthesis of the work done during this internship and the personal contributions of this internship.

First, I will explain the personal motivations that led me to do my internship at Dalhousie University with Professor SETO. I will then present briefly my host university, focusing on research in the mechanical engineering department where I worked and then do a quick economic analysis of the research center. I will explain the initial objective of this internship, the different tasks carried out to achieve it and the difficulties encountered and assess the results obtained. Finally, I will highlight the technical and also cultural and sociological skills that this internship has brought me.

Résumé

En France, à la fin de la deuxième année d'école d'ingénieur, les élèves ingénieurs doivent effectuer un stage d'assistant ingénieur. Pour ma part, j'ai fait ce stage sous la supervision du Pr. Mae SETO à l'Université Dalhousie. Le but de ce document est de produire une synthèse du travail effectué pendant ce stage et des apports personnels de ce stage.

Tout d'abord, j'expliquerai les motivations personnelles qui m'ont amené à faire mon stage à l'Université de Dalhousie avec le Pr. SETO. Ensuite, une brève présentation de mon université d'accueil, plus spécifiquement du département de recherche en mécanique où j'ai travaillé, sera faite ainsi qu'une rapide analyse économique. Je me concentrerai sur le travail effectué pendant ces 3 mois. Je préciserai le mieux possible l'objectif initial de ce stage, les différentes tâches effectuées pour l'atteindre et les difficultés rencontrées. Je ferai un bilan sur les résultats obtenus. Enfin, je mettrai en lumière les compétences techniques mais aussi culturelles et sociologiques que m'a apporté ce stage.

Summary

Introduction

ENSTA Bretagne offers a complete generalist and theoretical training that is highly sought after by companies. At the end of the first year we completed a work placement of a minimum of 4 weeks allowing us to have a first approach of the industrial world. This internship aims to help us understand the operational and managerial stakes of a company through an experience of a work executor. The second-year engineering assistant internship, which must last at least 9 weeks, allows us to apply, in a concrete way, the knowledge we have acquired during our two years of engineering school. I am doing my internship in a Dalhousie University Mechanical Engineering Research Laboratory in Halifax, Canada.

Pr. Mae SETO gave me the opportunity to work on one of the following fields: land, air or underwater robotics. Because of my studies at ENSTA and my personal preference, I chose to work on an Autonomous Underwater Vehicle (AUV). My work focused on getting the AUV to fulfill a principal function which is underwater mapping. More specifically, my goal was to program the robot for autonomous behaviors, which is a crucial and interesting task.

1. The Assistant Engineer Internship

1.1. Personal motivation

After school, working in a big company does not necessarily appeal strongly to me. On the contrary, I would first like to work in a design office or in a research laboratory. I think that, in a small company, the scope of work of an engineer is wider. Indeed, in a small company the engineer must be able to manage by him/her self. He/she often takes on several jobs and must know how to "tinker". I have the impression that this allows me to work in the field of programming but also in the somewhat mechanical field of robotics. This would allow me to combine theory and practice. That is why it was important for me to discover a research environment while acquiring skills that will be useful to me. One of the objectives of engineering school internships is to discover the industrial sector. However, I will be starting a professionalization contract with Thales Group next year and I will get the opportunity to fulfill this objective. That is why, for this internship I preferred to discover the research sector.

ENSTA Bretagne has a partnership with Dalhousie University in Canada so I asked about their different robotics research centres. I consulted Professor Mae SETO's research more specifically on the autonomy of marine robots and the development of autonomous agents for autonomous vehicles. Her research was perfectly in-line with my preference for practical robotics and what was taught at ENSTA Bretagne.

Moreover, at ENSTA Bretagne, the mechanical part of robotics is much less important than the programming part. The teaching of mechanics is a little neglected in favour of electronics. Professor Mae SETO is attached to the Departments of Mechanic and Electrical Engineering at Dalhousie University. So I thought that this internship would allow me to discover new aspects of robotics.

In addition, it is necessary to spend at least 12 weeks abroad to validate the international discharge required to obtain the engineering degree. Apart from the administrative requirements to do my internship abroad, it was important for me to discover another culture while improving my English. I wanted to get out of Europe to discover a different way of living and a different way of thinking. So Canada was very much in-line with my personal objectives.

1.2. Presentation of Dalhousie University

Dalhousie University in Halifax, Nova Scotia, is one of Canada's oldest universities. Dalhousie works extensively with many other research centers in Canada and abroad. Their development projects extend across 15 different countries and the university is collaborating on research in nearly 100 countries.

DALHOUSIE UNIVERSITY

Figure 1 - Dalhousie University Logo

Dalhousie University has a large number of research centers in various and varied fields such as:

- ocean studies
- advanced materials and clean technology
- health and wellness
- governance, society and culture
- information science and communication
- agriculture and food technologies
- energy and the environment

Dalhousie University is composed of three campuses: Studley, Carleton and Sexton . I was working at the Mechanical Engineering Department based on the Sexton campus. It covers many fields of study such as land, air, sea and space transport, primary and secondary manufacturing industries, energy supply, conversion and use, environmental control and industrial management. The Department is comprised of 24 full-time faculty and 5 technical staff, with approximately 250 undergraduate and 50 graduate students.

Figure 2 - University Plan, Sexton campus in red

1.3.Economic analysis of host entity

I worked in a research laboratory so profit was not a priority, the most important being results. Prof. Mae SETO also receives funding from Dalhousie University for her research but must also find outside funding. She has several grants from the Natural Sciences and Engineering Research Council (NSERC), the Dept. of National Defense, a Chair, and industrial contracts.

The project that I worked on with Professor Mae SETO's is funded at $20k / year for 5 years by NSERC. The part allocated for the hardware-in-the-loop simulator, which was my internship work, is about $5k.

2. Work done during the internship

This part explains the work done during this 3-month internship. It is organized chronologically.

2.1.Presentation of the project

The subject of my internship is the automation of an underwater robot. My program will be implemented on the TX2-based hardware-in-the-loop simulator to test programs before implementing them on the actual robot. The robot an autonomous underwater robot (AUV) which will be used for underwater mapping or robotic collaboration.

The robot is already equipped with an original equipment manufacturer (OEM) processor which works across a control interface to communicate with a payload processor. This system makes the link between the high-level instructions received and the robot actuators. The OEM processor oversees the closed-loop control of the robot’s roll, pitch, yaw, depth/altitude, forward speed and waypoint following. The interface also allows direct access to information from the sensors on the robot. The robot is composed of an altimeter, depth (pressure) sensor and an inclinometer. An altimeter is a sensor to measure the vertical distance between a point and a reference surface (here, the seabed). A pressure sensor is a measuring instrument for determining the depth underwear that the AUV is located at.

The purpose of my internship is to create a program to control the AUV. Using the sensor data, a command must be sent to the control system already installed on the robot.

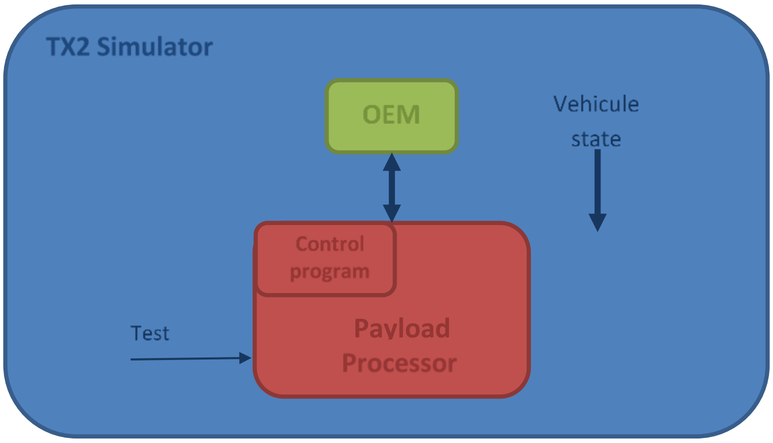

Figure 3 - General arrangement of my part of the hardware-in-the-loop simulator

2.2.Automation of an underwater robot without external constraints

2.2.1. First approach

A first stage of the work was to automate the AUV to adapt it to existing external forces in the underwater environment such as marine currents. The initial assumption was that the robot was operating in a totally calm sea without currents. The robot had to reach a waypoint autonomously. Initially, the automation allows the robot to reach a single waypoint but in practice the robot must be able to follow a defined path. The path will be defined by a list of waypoints to reach in a certain order. The proposed solution with a single waypoint must be generalized to a list of waypoints that form a path.

The problem to be solved resembles one of the problems dealt with this year in robotics class with Mr. Jaulin. Based on what I have learned, I proposed two solutions to Pr. Mae SETO: heading control or line-following control. These two solutions are generally used for 2-dimensional control in a plane but by applying it twice – to the x-y plane then, the x-z plane. This is one way to solve 3-dimensional problems.

Finally, the robot control uses a line-following method. The line-following method is adapted because it is possible to select waypoints to avoid a priori known obstacles in the robot's environment. This is, of course, not possible by just specifying a heading at the beginning. The underwater robot operates in a 3D environment which is why the method must be applied twice: first in the x-z plane to reach the desired depth and then in the x-y plane to reach the desired position (Fig. 4).

The principle of the line-following method in the x-y plane is as shown in Fig. 4. The robot heading (here in green) must become that between points A and B. In the implementation (Table x), the change in the robot heading rate as it approaches this line is proportional to its distance from it. The further the robot is from the line, the greater the change in heading rate.

By denoting $\bar{\theta}$ as the current robot heading and φ as the heading of the line, we obtain:

$$\bar{\theta} = \varphi - \operatorname{atan}(d)$$

Such that, d is the distance of the perpendicular dropped from the robot to the desired line to line to follow and $\varphi = \operatorname{atan}(b-a)^2$.

Thus one can determine a heading and pitch command to be applied to reach this angle and correctly follow the desired line.

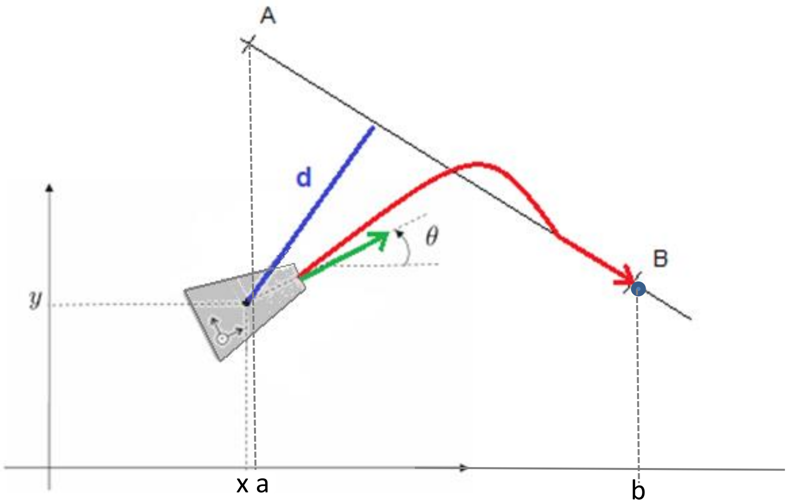

Figure 4 - Line tracking method example in x-y plane

2.2.2. Optimization

Initially, the tests were performed using python. The robot was at an initial position and then had to reach a point. Then, we had to try to optimize the code to make it execute faster without losing too much precision.

Given the line-following control, there are 3 possible solutions. If the robot approaches the line at high speeds, it will overshoot and oscillate about the line and then the oscillations damp out and the robot heading collapses on the line. At very low speeds, it takes a long time to asymptotically approach the heading of the line. In between, at a critical speed, it will approach the line efficiently and more precisely with no overshoot or prolonged period of asymptotically approaching the line. This, critical speed case is the best solution in terms of robot speed and position precision. When the robot is far from the target point, its accuracy is not important. It can therefore operate at a higher speed then. However, as it approaches the target point, the accuracy is more critical and the robot speed must decrease. In my code, the robot speed and heading are determined in a loop. With each pass through the loop, the robot moves closer to the target point. It is therefore possible to reduce the speed each time through the loop. Thus, a correct speed and better precision are obtained in this way.

	robot speed	x	y	z	Computation time
		displacement to target point			
		12	14	8	(seconds)
1	Constant speed = 1 (reference case)	13.83 15.3%	13.22 5.6%	8.17 2.1%	0.1228
2	Decreasing speed = 1 then 0.99*speed	11.97 0.3%	14.12 0.9%	8.32 4.0%	0.4118
3	Decreasing speed = 1.2 then 0.99*speed	12.1 0.8%	14.04 0.3%	8.36 4.5%	0.2006
4	Decreasing speed = 1.25 then 0.99*speed	12.21 1.8%	13.9 0.7%	8.25 3.1%	0.1671
5	Decreasing speed = 1.3 then 0.99*speed	12.31 2.6%	13.88 0.9%	8.35 4.4%	0.1232
6	Decreasing speed = 5 then 0.99*speed	21.56 79.7%	10.16 27.4%	10.22 27.8%	0.1695

Table 1 - Comparison of computation time depending on speed

As shown in Table 1, solutions 2, 3 and 6 were automatically eliminated as follows:

- **Solution 2** was eliminated because of computation time. It was too large – more than three times as long.

- **Solution 6** was eliminated due to its lack of precision. The relative uncertainty with the desired position is 79.7% along the x axis and about 27.5% along the other two axes. This lack of precision is intolerable since the computation time is not the lowest obtained.
- **Solution 3** is twice as long and does not give much more accuracy than solutions 4 and 5 which are faster.

- **Solution 5** is slightly less accurate than **solution 4**. Moreover, its computation time is better and closer to the basic one without speed processing.

In reality, the desired precision, as it approaches a waypoint, as there is a finite radius around a waypoint that the robot could be in and it would still be considered to have ‘reached’ the waypoint. Prof. Mae SETO told me that the robot should be within this radius around the waypoint. Due to marine currents and other forces, the robot cannot necessarily hit a singular point. That is why we take the faster alternative speed solution regardless of the accuracy.

Finally, the choice was made to keep a constant speed (solution 1 in Table 1). The accuracy gained did not justify the time lost so we kept the initial parameters.

2.3.Creation of a ROS Development Environment

From a programming point of view, the automation and status display of the robot was performed in python2.7. Sensor simulation and test codes were performed in C^{++}. Then, everything was implemented in the ROS middleware. The ROS (Robot Operating System) middleware is a set of open source computer tools for developing software for robotics using a publish-subscribe paradigm.

Figure 5 - ROS version used

The AUV model developed consists of components like sensors, control commands, and the control interface. The control commands must communicate across the control interface with the sensors. Within the ROS middleware, these entities are called nodes. The main command node is the AUV automation node called */control*. It must subscribe to the sensor data and it publishes the commands sent to the AUV control interface. For this project, as the sensor information is transmitted across the control interface, which is part of the AUV, we chose to integrate the sensors in the */AUV* node which is the control interface.

The automation of the AUV is achieved using commands in heading and pitch, two commands are thus sent to the control interface of the robot. I chose to publish a message by commands as shown in Fig. 6.

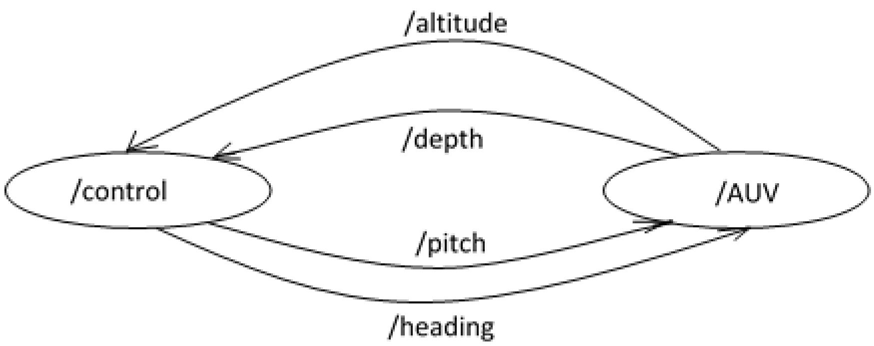

Figure 6 – Graph node for the Initial attempt at inter-node communications

The data returned by the sensors are for AUV altitude and depth as Float64 messages from the ROS std_msgs library. The topics */heading* and */pitch* are also *Float64* messages. The units used by the AUV control interface were left underfined to make this as generic as possible for later adaptation . So, here, angles are arbitrarily chosen to be in degrees but this can be easily modified to fit another unit like radians.

It would be even more useful to send heading and pitch commands as a single message / command as shown in the graph of Fig. 7.

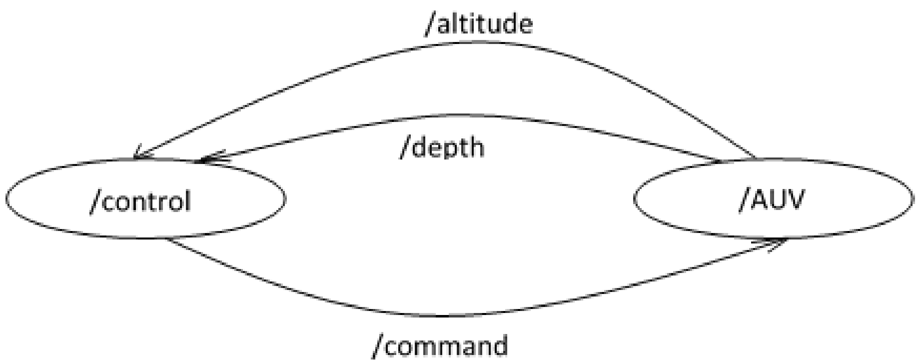

Figure 7 – Final Graph Node

The topics */altitude* and */depth* are always *Float64* messages but now the topic */command* is in the form of a *PoseStamped* message from the */goemetry_msgs* library. A *PoseStamped* message communicates a position, orientation and header which is used to communicate time-stamped data in a particular coordinate frame. One of the concerns of the *PoseStamped* message was how to communicate the orientation from quaternions and not Euler angles. In the automation program here, all calculations are performed with the AUV orientations according to Euler angles. It was therefore necessary to convert the commands received into quaternions. For that, I used an algorithm found on the internet which I reworked (Ref [5]).

2.4.Robot maintaining constant altitude or depth

For many underwater applications, the AUV must maintain a constant altitude or depth. That is why, after having succeeded in automating the robot so that it reaches a point in the horizontal plane, changes in depth and altitude were addressed next. The robot has an altimeter acoustic sensor and a pressure sensor.

For this part, the previous algorithm was useful because it was divided into two distinct parts: depth control and trajectory control along a desired depth. The control of the trajectory at a desired altitude does not change and in this case the altitude is constant. The desired altitude is determined either by a depth or altitude as defined by the user.

The x-z plane had to be followed to manage the depth of the robot. For a constant heading, we control the pitch to control the vertical position of the robot. To make this evolution mode more interactive, the operator has two choices. Choose a distance or a time with which to use the automatic depth mode. Two models have been created for seabed modelling. One of the models is a sinusoid amplitude and the other is an slope function. Then it was possible to test the robot's stability at constant altitude or depth.

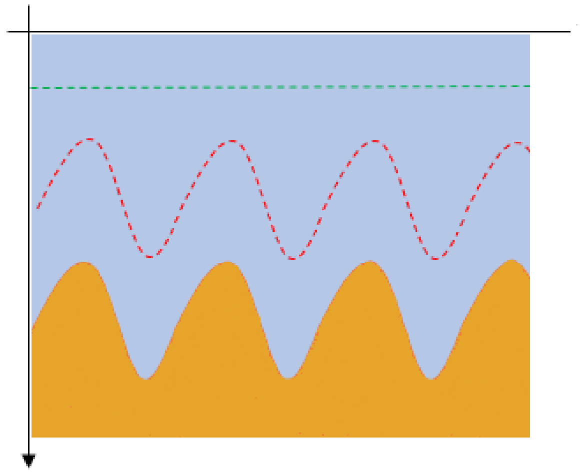

Figure 9 - Underwater sinusoïdal profile,
Constant depth (green) and constant altitude (red) control

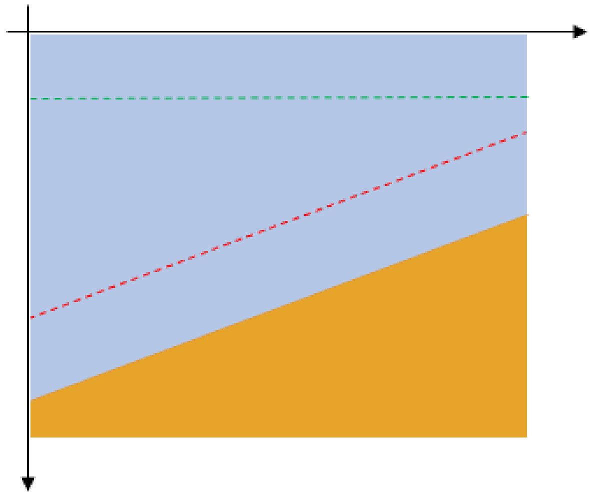

Figure 8 - Underwater affine profile,
Constant depth (green) and constant altitude (red) control

2.5.Application of externat forces

The environment and communication between the different project components was correct so I was able to progress to look at external forces. For the time being, the study did not take into account marine currents and swells. The external disturbances affecting an underwater vehicle are waves and currents. This part of the project was more difficult for me because it involves mechanical concepts that I was less familiar with. I had not previously studied dynamic modelling. For the mechanical parts, I read articles and theses that Pr. Mae SETO provided me. A thorough reading of the theses and articles allowed me to have a more global perspective on the problem. It was necessary to try to consider the external forces applied to the robot.

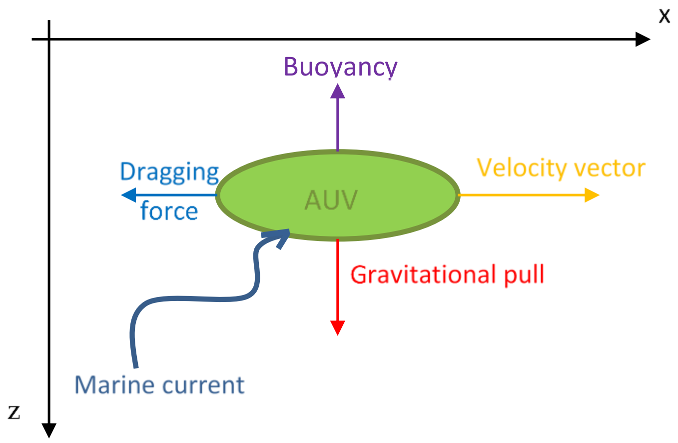

Figure 10 – Free body diagram for force balance on an AUV

3. Assessment of the internship

3.1. Work performed

The initial objective of the course was to automate an AUV operating at sea.

The automation was done without taking external forces into account. The order law is correct and meets the specifications: consistent accuracy and speed. AUV automation consists of three operating modes.

- The first is a trajectory monitoring in 3 dimensions. The AUV follows its path by line tracking between waypoints.

- The second is a constant depth x-y plane tracking. The depth is given by a pressure sensor.
- The third is a constant altitude x-y tracking. The altitude is given by an acoustic altimeter.

These last two modes also use the line tracking method but in the x-y plane.

Then, the forces applied to the AUV were carried out. However, the model could not be applied to the simulation due to time constraints. A study of external forces was made.

During my work, I encountered some difficulties. First of all, I had problems using the ROS software. Indeed, as one university teacher told me, the installation done prior to the internship was incorrect. The installed version was ROS-lunar and not ROS-kinetic so I had to change it. The change of version during the work was complicated, that is why after several attempts, I chose to uninstall everything and start again. This allowed me to make a cleaner installation with the ROS-kinetic version and choose all the proposed parameters such as dependencies that I needed. It took some time but it was necessary. Now my ROS installation allows me to do several projects in parallel without any worries which is more suitable for professional use. The internship gave me a better understanding of ROS and how it works.

Then, to consider the external forces, I did not have the mastery of certain mechanical concepts. The documents given by Prof. Mae SETO taught me a lot. It was a bit difficult to understand all the ideas but it allowed me to learn how to extract important information from a scientific document. I also like the mechanics used in robotics so it was a very rewarding and interesting job.

In conclusion, the objective of the internship was almost completely achieved. With more time, it would have been interesting to apply the external forces model and then make tests on the real robot.

3.2.Personale contribution

During this internship, I was led to work independently. It was an enriching experience on project management. Professor Mae SETO left me free in my work. We had regular meetings to review the project. First, I presented her with my progress and then she set me a new goal to achieve. There was no actual timetable but an idea of time to complete this task was estimated so I could organize my work as I saw fit. Overall the deadlines that Prof. Mae SETO indicated to me were respected. I think I managed my time well because sometimes, I could even finish faster than expected. I really liked this way of working. I think it taught me to manage my time more effectively. It also allowed me to strengthen my capacity for adaptation and autonomy. I have tried to work as autonomously as possible but it might have been beneficial and more effective for my work to ask for more progress meetings with Prof. Mae SETO.

It was also interesting to discover a different way of working from the French method. It was a good experience to discover life in the laboratory. Hours are freer than in companies. The working hours are the same but can be distributed very freely.

This internship was also extremely enriching for me from a technical point of view. This allowed me to apply concretely the theoretical knowledge acquired during these 2 years at ENSTA Bretagne.

Living in Canada for 3 months was also a great social experience. The culture and way of life are different from those in France. I was able to progress in English.

Conclusion

To conclude, this engineering assistant internship allowed me to progress in practical robotics. The only regret I could have would be to have been unable to carry out tests on the robot for lack of time. Indeed, robotics remains a field where the gap between reality and simulation can be significant. So it would have been interesting to check the validity of my code on the robot.

Finally, I would like to thank Prof. Mae SETO for this extremely interesting course and the many tips I received. And the entire laboratory for their hospitality (?). I can only recommend future roboticists to do one of their internships in the laboratory in view of the great diversity of skills that can be developed there.

Bibliographical references

[1] Dynamics and Control Simulator for the Theseus AUV, Mae L. SETO, George D. WATT, Seattle, USA 2009

[2] Dynamics and Control Simulator for the Theseus AUV, SARTI Research Group. Electronics Department. Universitat Politecnica de Catalunya

[3] Model Predictive Control for an AUV with Dynamic Path Planning, Chao SHEN, Yang SHI, Brad BUCKHAM, SICE Annual Conference Hangzhou, China, 2015

[4] Modeling and System Identification of an Autonomous Underwater Vehicle, Ali WADI, Jin-Hyuk LEE, Shayok Mukhopadhyay, Department of Mechanical Engineering American University of Sharjah

[5] Wikipedia, Conversion between quaternions and Euler angles

Table of figures

Appendix 1: Report sheet

RAPPORT D'EVALUATION
ASSESSMENT REPORT

Merci de retourner ce rapport en fin du stage à :
Please return this report at the end of the internship to :

ENSTA Bretagne – *Bureau des stages - 2 rue François Verny - 29806 BREST cedex 9 – FRANCE*
☎ 00.33 (0) 2.98.34.87.70 - Fax 00.33 (0) 2.98.38.87.90 - stages@ensta-bretagne.fr

I - ORGANISME / *HOST ORGANISATION*

NOM / *Name* Dalhousie University / Mechanical Engineering Dept.

Adresse / *Address* 1360 Barrington St., Halifax, Nova Scotia, Canada

Tél / *Phone (including country and area code)* 011-902-494-6194

Fax / *Fax (including country and area code)* ______

Nom du superviseur / *Name of placement supervisor* Mae L. Seto

Fonction / *Function* Associate Professor

Adresse e-mail / *E-mail address* mae.seto@dal.ca

Nom du stagiaire accueilli / *Name of trainee* Juliette Brugier

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 (very good)** to **F (very weak).***

MISSION / *TASK*

- La mission de départ a-t-elle été remplie ? A B C D E F (B highlighted)
  Was the initial contract carried out to your satisfaction?

- Manquait-il au stagiaire des connaissances ? ☐ oui/*yes* ☒ non/*no*
  Was the trainee lacking skills?

  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 trainee easily integrate the host organisation? (flexible, conscientious, adapted to team work)*

  A B C D E F (A highlighted)

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

9

Version du 03/05/2017

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 trainee 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 trainee 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 trainee 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
Evaluate the technical skills of the trainee:

III - PARTENARIAT FUTUR / *FUTURE PARTNERSHIP*

❖ Etes-vous prêt à accueillir un autre stagiaire l'an prochain ?
Would you be willing to host another trainee next year? [x] oui/*yes* [ ] non/*no*

Fait à ____________, le ____________
In Dalhousie University, on September 5, 2018

Signature Entreprise ____________ Signature stagiaire
Company stamp ____________ *Trainee's signature*

Mae L. Seto

Digitally signed by Mae L. Seto
DN: cn=Mae L. Seto, o=Dalhousie University, ou, email=mae.seto@dal.ca, c=CA
Date: 2018.09.05 22:18:37 -03'00'

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

10

Version du 03/05/2017