DELMAS Sarah

Robotics Internship Report

Study of box particle filtering and trajectory tracking

Institut de Robótica
i Informática Industrial

2018

Abstract

During this 12 weeks internship at the Institut de Robótica i Informática Industrial, in Spain, I worked on simulating a four-wheeled omnidirectional robot in Matlab and on its state estimation using particle filtering and box particle filtering. The goal was to evaluate which of these methods were the more accurate.

I choose this internship, because I wished first to work in a foreign country, to confront myself to a different culture. My choice was easily made for a Hispanic country to improve my Spanish.

The subject of the internship was also a source of interest for me. State estimation methods, trajectory tracking, and interval analysis are things we had begin to learn this past year and getting practice and a different point of view on their uses sounded interesting.

This report explains first my internship's context and objectives, before going into the work I did and finishing by analyzes of the both economic side of the Institut and of how the internship impacted my professional project.

Résumé

Ceci est le rapport de mon stage de 12 semaines à Barcelone. Lors de ce stage, encadré par le Dr. Joaquim BLESA, j'ai travaillé sur l'étude et la simulation sous Matlab d'un robot à 4 roues omnidirectionnelles, ainsi que sur 2 méthodes d'estimation d'état : le « particle filter » et le « box particle filter ». Mon but était d'évaluer laquelle de ces méthodes était le plus efficace.

En premier sont présentés l'institut où j'ai fait mon stage ainsi que les objectifs, réalisés ou non, de celui-ci. Ensuite, je parle des simulations que j'ai effectuées, puis du côté économique de l'institut. Enfin, je termine sur ce que ce stage m'a apporté, autant en connaissances techniques que personnelles.

Content Table

Chapter 1:

Internship context

1.1 The Institut de Robótica i Informática Industrial

The Institut de Robótica i Informática Industrial (IRI), located in Barcelona, is a joint research centre of the Spanish National Research Council (SNRC) and the Universitat Politécnica de Catalunya (UPC). The UPC is a public university which focuses on the fields of architecture, engineering, sciences, and technology and IRI is one of the Spanish leaders in robotics, computer vision and automatic control.

The Institute has three main objectives:

- To promote fundamental research in Robotics and Applied Informatics
- To cooperate with the community in industrial technological projects
- To offer scientific education through graduate courses.

Its activities are organized under four research lines, three of them on various aspects of robotics research, and the fourth aimed at energy efficiency research. The most important research angles of these lines are:

- Automatic control: developing research in automatic control, emphasising on modelling, control and supervision of non-linear, complex and/or large-scale systems.
- Kinematic and robot design: research on design, construction, and motion analysis of complex mechanisms, such as multi-fingered hands.
- Mobile robotics and intelligent systems: aiming to endow robots with perceptual skills (tracking, recognition, situation awareness) and motion skills (localization, mapping, autonomous navigation, path planning, and exploration).
- Perception and manipulation: enhancing the perception, learning, and planning capabilities of robots for higher degrees of autonomy and user-friendliness.

1.2 Internship’s context in IRI

My 12 weeks internship, supervised by Dr. Joaquim BLESA, was under the IRI’s automatic research line presented in the preceding part. Dr. BLESA is currently working on developing state and parameter estimation methods, which mix bounded and statistical approaches with the application of robust and fault tolerant control. My internship was thus directly linked to his work.

Chapter 2:

Objectives

2.1 Initial objectives

With the possibility of implementing the codes on a real omnidirectional robot, the objectives of my internship were at the beginning:

- Study of realistic models of four-wheeled omnidirectional mobile robot
- Study and understanding of box particle filtering for state estimation
- Study of trajectory tracking strategies and implementation to minimize the probability of shocks

2.2 Changed objectives

Instead of going directly for box particle filtering after finishing the first objective, I first began working on simple particle filtering, to see if there was a distinct difference in accuracy and efficiency between the two filter methods.

Understanding those methods, and creating and refining the simulations took more time than initially planned. Because of this, it was estimated than continuing to work on tracking strategies and implementing them would be impossible, and that objective was abandoned.

The planned borrowing of a real robot from a nearby city lab also ended up infeasible, due to availability constrains.

2.3 Challenges

The most difficult part was the understanding of particle filters and box particles filters, due to the complexity of publications. This was resolved with help from D. BLESA who had previously worked with them, both directly and with other internshipping students in past years.

It was also made clear that interval analysis wasn’t a well-known field at the IRI lab, which allowed both for new ideas to be explored, but also communication difficulties on both part.

Chapter 3:

Work

3.1 Robot simulation

3.1.1 Type simulation

Joaquim BLESA and I chose to simulate a robot doing clockwise circles around a landmark. To get a good accuracy, the robot could perceive 2 others landmarks, so as to be able to triangulate itself with its 8 sonars. The robot would initially be placed at 10m of left of the center landmark. The placement of the landmarks and the robot are shown in the figure below.

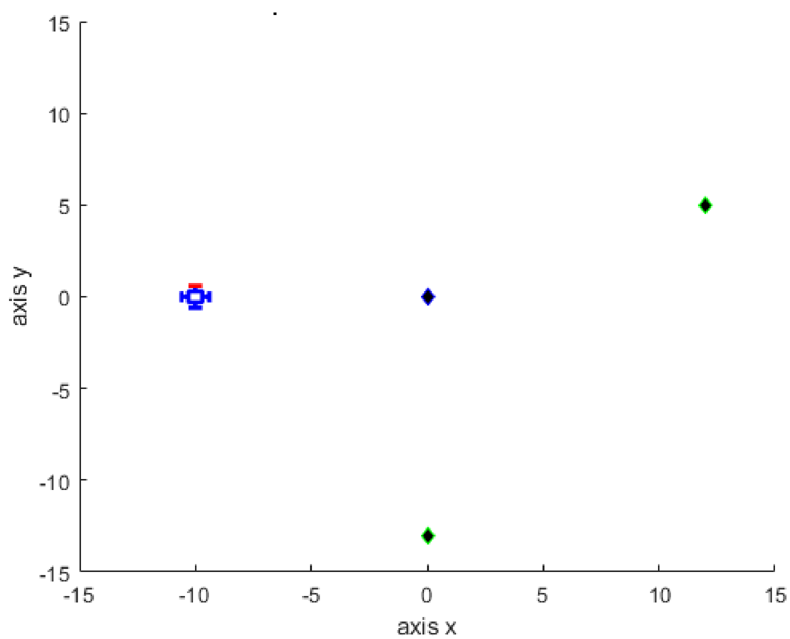

Fig 1: landmarks and initial robot position

3.1.2 Angle trajectory

The first thing I did was to study how to simulate the robot. Beside a simple display function, I wanted the robot to be able to take full advantage of the omniwheels. Omniwheels are wheels with smaller wheels integrated in their circumference. As such, they can roll forward/backward as well as laterally.

Because of this, I created a function which takes the robots' current orientation and the next orientation, and computes the smallest rotation necessary. As such, the robot never has to turn by more than 45° to change trajectory.

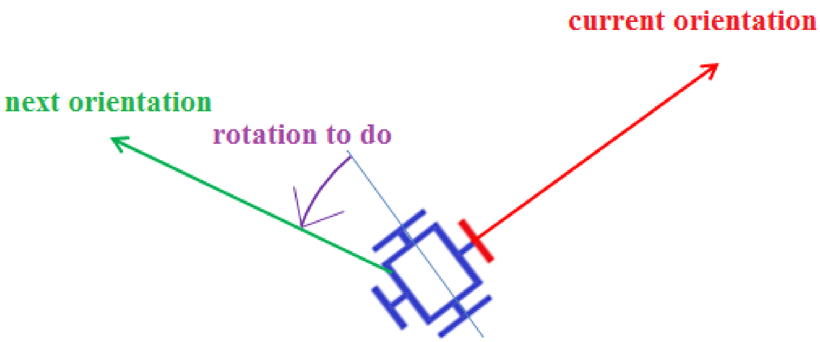

Fig 2: example of trajectory change

3.1.3 Equations of motion

The robot's equations of motion, presented under this, came from "*Estudio y diseño de un sistema de control anticipativo para un robot móvil*" by Bernat ROCA GARCIA. To simulate the motions of the robot, I used an Euler method.

```
dc_PF = distance(x_cPF, m1);
Ps_PF = planeSpeeds(t, dc_PF, dci_PF);
Ws_PF = planeSpeeds_To_WheelSpeeds(Ps_PF, dist);
Wse_PF = addErrors(Ws_PF, std_dev);
Pse_PF = wheelSpeeds_To_PlaneSpeeds(Wse_PF, Ps_PF(3), dist);

x_cPF = x_cPF + dt*Pse_PF;
```

Fig 3: equations of motion

This figure shows the functions used for the common Particle Filter. The variables are:

- x_cPF is the present estimated position of the robot
- m1 is the landmark the robot is circling
- dci_PF is the wanted radius of the circle
- dci_PF is the wanted radius of the circle
- dist is the distance between the center of the robot and a wheel.
- Ps are plane speeds: $[\dot{x}, \dot{y}, \dot{\theta}]$

- Ws are a wheel speeds: $[\ front\ \ left\ \ back\ \ right\ ]^T$

The first function, “distance”, computes the current distance between the robot and the circled landmark.

“planeSPeeds” computes the plane speeds and the orientation needed $[\dot{x}, \dot{y}, \dot{\theta}]$ to move by the angle t, and corrects the orientation if there is a significant difference between the preceding computed distance and the distance wanted, so that the robot stay as much as possible on a true circle trajectory.

“planeSpeeds_To_WheelSpeeds” takes the computed speeds on the plane referential and transposes them into the wheels referential with those equations:

$$A = [\begin{matrix} -sin\,\theta & cos\,\theta & dist \\ -cos\,\theta & -sin\,\theta & dist \\ sin\ \theta & -cos\,\theta & dist \\ cos\ \theta & sin\ \theta & dist \end{matrix}]$$

$$WheedSpeeds = A * PlaneSpeeds^T$$

The function “addErrors” is here to simulate the errors made by the robot and its odometers when given its wheel speeds in instruction. The function adds random errors to the wheel speeds, depending on the standard deviation chosen.

Finally, the function “wheelSpeeds_To_PlaneSpeeds” computes the plane speeds $[\dot{x}, \dot{y}, \dot{\theta}]$ from the sensed wheel speeds with the following equations:

$$A = [\begin{matrix} -sin\,\theta & -cos\,\theta & \sin\ \theta & cos\ \ \theta \\ -cos\,\theta & -sin\,\theta & -cos\,\theta & sin\ \ \theta \\ \frac{1}{dist^2} & \frac{1}{dist^2} & \frac{1}{dist^2} & \frac{1}{dist^2} \end{matrix}]$$

$$PlaneSpeeds = \frac{A}{2} * WheelSpeeds^T$$

The only difference between the equations for the Particle Filter and those for the Box Particle Filter is that those for the BPF were made to take an interval vector and of a common vector:

$$x_{BPF} = [\, interval_x \quad interval_y \quad interval_\theta \,]$$

3.2 Particle Filtering

Once the equations of motions were done, I concentrated on understanding Particle Filtering and Box Particle Filtering, with the goal of implementing the first before the second to compare their capacities.

3.2.1 Particle filtering principle

Particle filtering is a method used to pinpoint the possible position of an object, here a robot, into a limited zone. For this, the robot must be able to detect its distance to landmarks, in our case, the robot being equipped with sonars.

A multitude of particles are randomly placed into the robot's plane, all with the exact same uniform weight attributed, so that the weight sum is of 1. In the following examples, from "*State estimation and fault detection using box particle filtering with stochastic measurements*", the plane is capable of measuring its elevation to the sea and its distance to the ground.

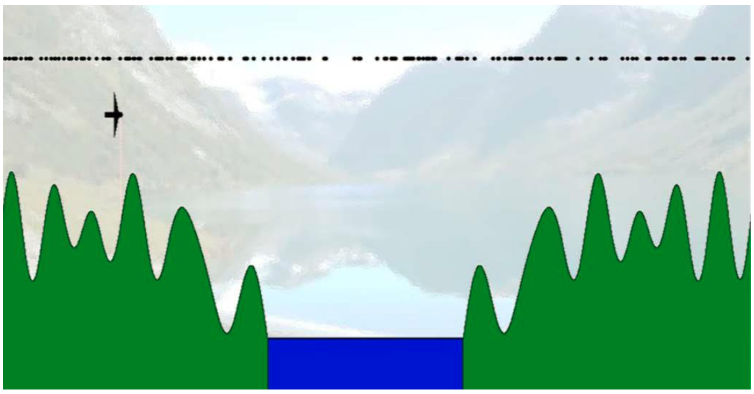

Fig 4: randomly distributed particles

Then, by using the difference in distance between the landmarks to the particles, and the landmarks to the robot, a number of particles can be declared as the most likely positions of the robot. The less difference there is, the more weighted the particles get; the more difference there is, the less weighted they get.

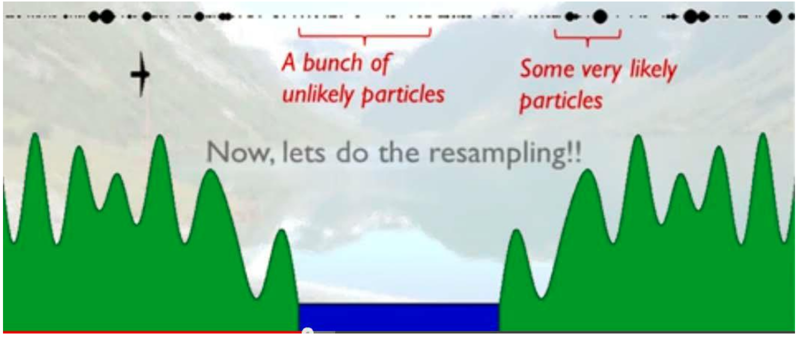

Fig 5: likely particles by weight

Only the most weighted of the particles are then kept. They are replicated so that the end number of particles is the same as that of the beginning, with a bigger probability of replication given by weight. All the particles' weights are regenerated to be uniform. Finally, the mean of the particles' position is computed to find the estimated position of the robot. Once this is done, the system loops to the next movement.

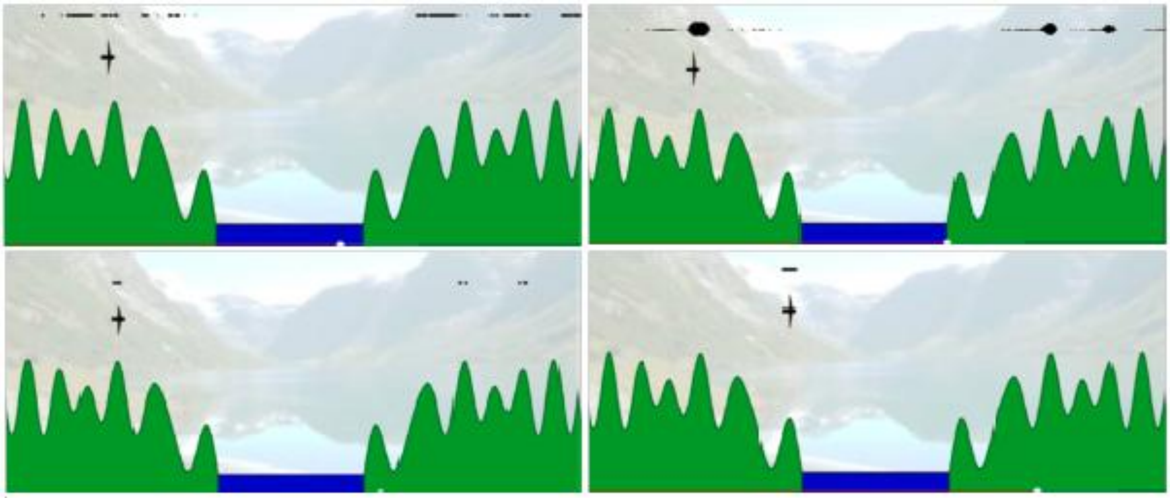
Fig 6: next movements

3.2.1 Bounded particle filtering

Because randomly distributing particles in a large zone leaves empty sections, and thus, decreases the accuracy of the method, I began to distribute the particles in a bounded box around the estimated position of the robot. This also decreased the time necessary for the simulation to run, as, for obtaining the same accuracy, the simulation can now use 500 particles instead of 5000.

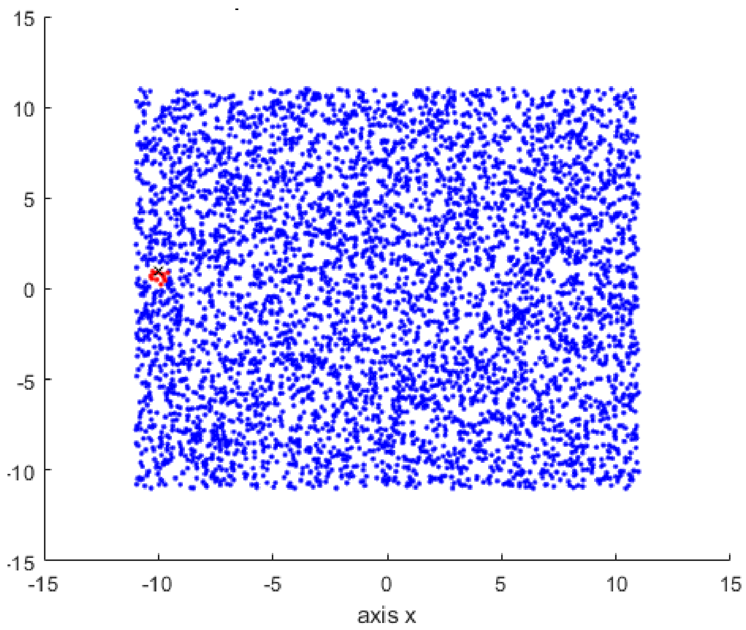

Fig 7: randomly distributed 5000 particles showing empty sections

Here, in blue, are the initial randomly distributed particles and, in red, the kept and replicated particles. The black cross is the true position of the robot.

3.3 Box Particle Filtering

Box Particle Filtering is an equivalent to the particle filter, using boxes instead of particles. The first step is the creation of a box enclosing the position of the robot. This box is then divided in sub-boxes of a predetermined size and uniform weights, which are then given to the movement equations.

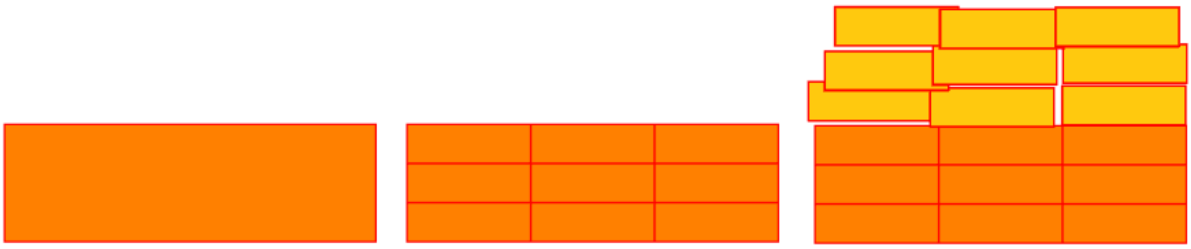

Fig 8: 3 first steps of BPF

After this a new box is created, it is the union of the preceding sub-boxes, so as to be the smallest box possible containing all the sub-boxes. This new box is by turn also divided in sub-boxes.

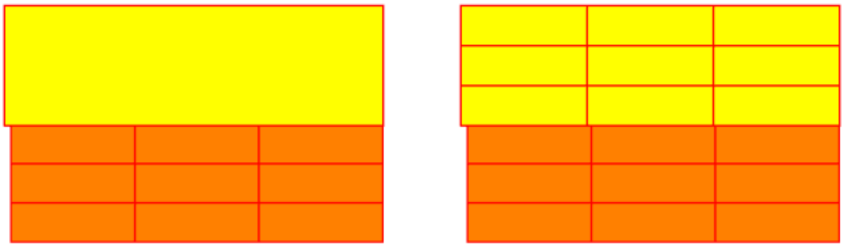

Fig 9: fourth and fifth steps of BPF

For each of the latest sub-boxes (in yellow) is computed the area of intersection with the preceding sub-boxes (in ligth orange). The weights of the preceding sub-boxes are then modified depending on those intersections. The more intersections a sub-box has, and the bigger their area, the higher its weight becomes.

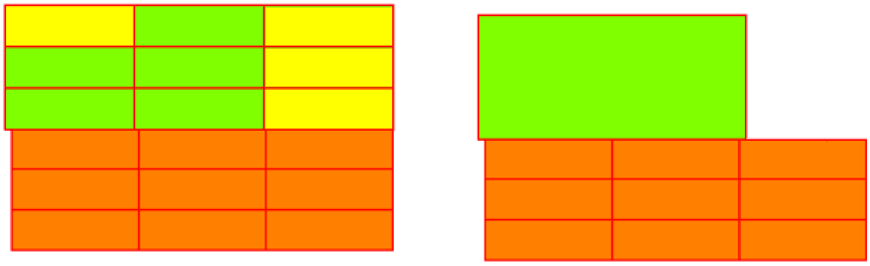

Fig 10: sixth and seventh steps of BPF

As with the Particle Filtering, only the highest weighted sub-boxes are then kept to estimate the new box enclosing the robot after a movement. The higher weighted sub-boxes are here in green. Once the moved box is found, the system continues to the next movement.

3.4 The simulations

For both the PF and the BPF, three simultaneous simulations were made, with three landmarks for the robot to orient itself with. The first simulation always computes the exact movement of the robot.

For the PF, the second simulation was of a traditional PF, and the third one was one with the positioning of the particles bounded around the estimated robot's position. The goal was to show which method was the most accurate, and the grow rate of positioning errors.

3.4.1 PF simulations

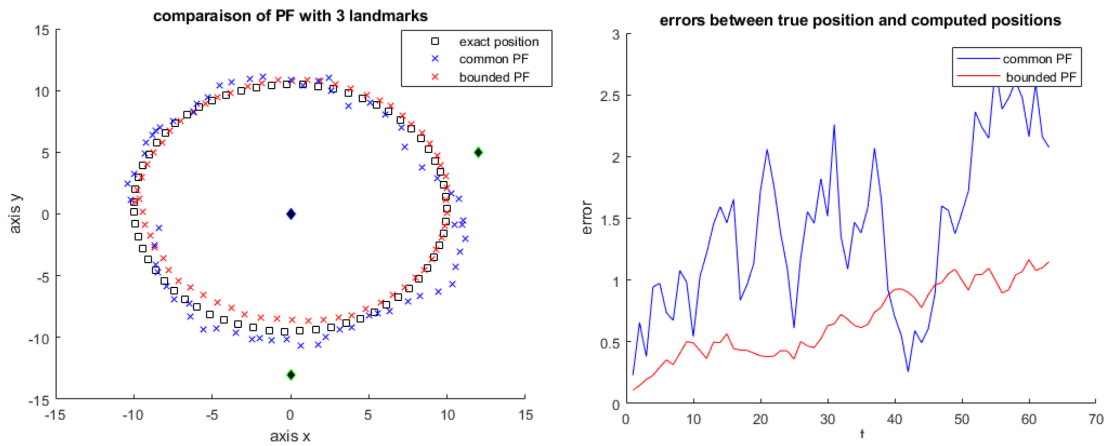

Fig 11: PF simulation and errors for 1 circle

As seen there, with the robot doing one circle, the bounded PF is more accurate than the common one, due to the existence of sections empty of particles for the common PF.

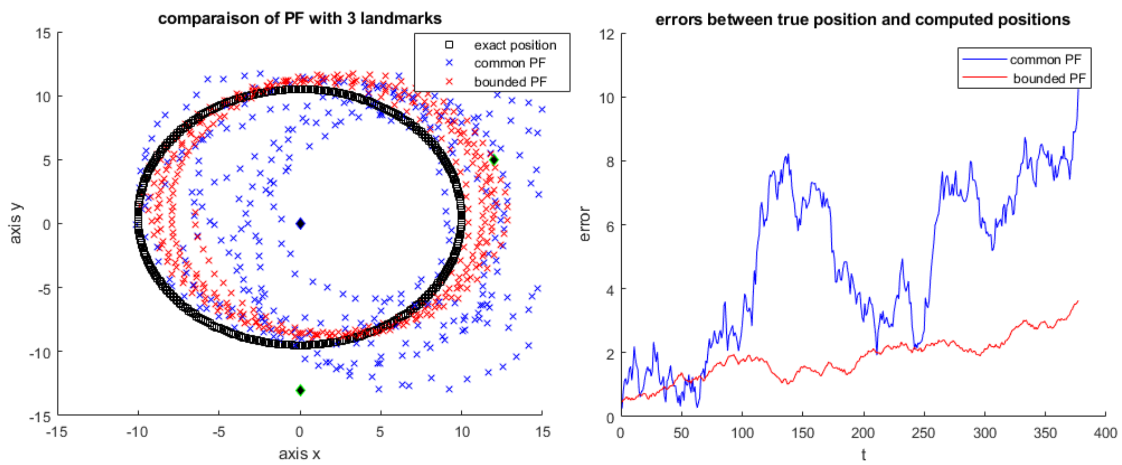

Fig 12: PF simulation and errors for 6 circles

With more circles done (here 6), both errors grow, with the common PF accumulating errors more easily.

3.4.2 BPF simulations

For the BPF, the second simulation takes the last exact box-position of the robot, while the third takes its own last estimated box-position, thus being completely estimated from beginning to end.

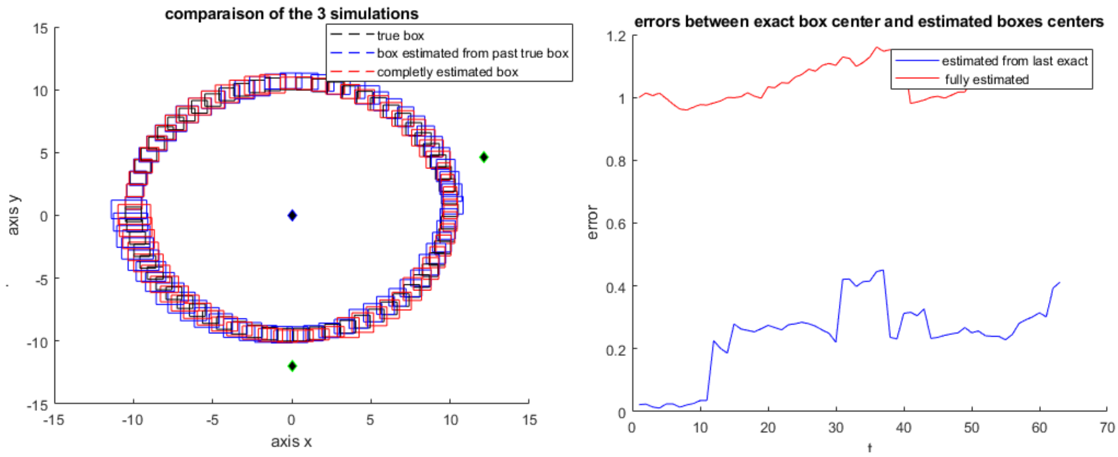

Fig 13: BPF simulation and errors for 1 circle

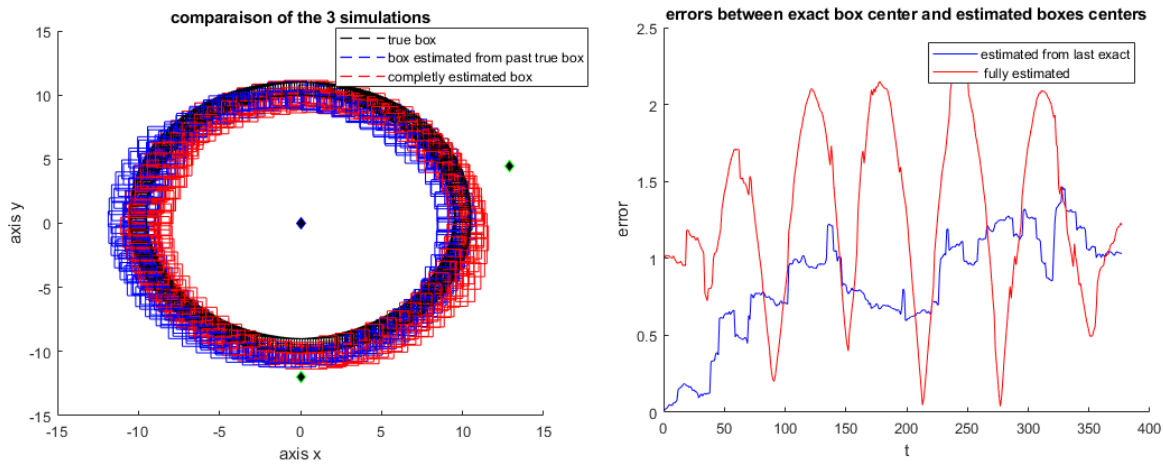

Fig 14: BPF simulation and errors for 6 circles

The fully estimated BPF simulation has more positioning errors than the one based on the last true position-box, but the difference stay relatively low and it tends to regularly found a more accurate position, thus limiting the error growth.

3.4.3 PF versus BPF

The BPF proved itself more accurate than the common PF, with an oscillating error generally under 2.5m, while the common PF's error kept growing. It is more similar to the bounded PF, though still more accurate.

Chapter 4:

Economic analysis

Contrary to some of my colleagues, I worked on a pure research project, not destined to produce an economic benefit. As such, it was difficult for me to see an economic impact of my internship.

On the other hand, in a public setting most of the research done has the goal of being published. Publication is a way of gaining reputation, and through this, the attention of other researchers and sometime founds.

For example, IRI is currently working on a 4 year strategic research program, with the help of the María de Maeztu scientific excellence seal. The program is focused on:

- Empathic natural human robot interaction
- Robust localisation and mapping
- Dexterous textile manipulation
- Robot learning using natural communication
- Energy supply and optimization
- Advanced supervision and control of complex systems
- Ethical, regulatory and philosophical aspects of social robotics

Researchers at IRI also frequently work in other labs and other cities, which allows for more professional contacts and once again can boost IRI's reputation.

In a public lab, the work is determined by grants, and the possibility of getting them. As such, while there is a weight given to obtaining results, it is a very different system than the one for enterprises. Instead of trying to deliver a product, research labs try to show to investors that their research is worth it. This causes a different work mentality.

Chapter 5:

Personal project

5.1 University versus business

I am interested in research and development, and while this wasn't my first internship in a public lab, it was one of the most interesting, as a learning experience and in the subject matter. I am curious, having done only one internship in a non-university but still public structure, what are the differences with working in a private one.

As such, I am planning to do my next internship in a private structure, to be able to decide if there is one sector I prefer. As I am still thinking about doing a PhD, it will also allow me not only to see if pure R&D is what I want, but if I wish to do it in a, as it looks like, more structured environment.

5.2 Skills learned during the internship

During this internship, I obtained and furthered different technical skills:

- Particle filtering and box particle filtering methods and how to use them for state estimation
- An understanding of how omniwheeled robots function
- A more complex understanding of Matlab

Furthermore, by speaking with my colleagues, all of which worked in different projects, I expanded my general knowledge and understanding, which allowed me to participate in discussions out of my field.

But the majority of what I learned during this internship wasn't in the realm of technical skills but in the social ones and my sense of responsibility. This internship was the first time I worked in another country, and while I had gone on holidays out of France, it was at least 6 years ago and, beside two weeks in London with a friend, always with my family. It was the first time I had to be responsible for myself for such a long period, which taught me a lot and made me more confident in myself.

This internship also gave me the opportunity to practice my Spanish out of a codified environment and to fluidify the way I spoke. Finally, evolving in a very different culture, more open and easily social, was challenging but extremely rewarding. Without doubt, it allowed me to improve my social skills.

Chapter 6 :

Conclusion

This internship at IRI has given me many opportunities and taught me many things, both technical and more personal. Overcoming the challenges that they posed before me, whether by the work itself, by the different country and its culture, or by the autonomy I had to assume, has helped me grow.

It reinforced the importance I see in intercultural and global relationships, because we may learn the same skills but we see and use them differently.

List of abbreviations

IRI: Institut de Robótica i Informática Industrial

UPC: Universitat Politècnica de Catalunya

PF : Particle Filter

BPF: Box Particle Filter

List of figures

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Evandro Bernardes "*State Estimation by Interval Analysis and Probabilistic Approaches Box Particle Filtering and Localisation Applications*".

Raphaël Abellan-Romita "*Obstacle Avoidance with Robust Path Generation*".

Annex

ENSTA Bretagne

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 :* *Institut de Robòtica i Informàtica Industrial (CSIC-UPC)*

Adresse / *Address* *C/ Llorens i Artigas 4-6 08028 Barcelona (SPAIN)*

Tél / *Phone (including country and area code)* *+34 93 4015751*

Fax / *Fax (including country and area code)* *+34 93 4015750*

Nom du superviseur / *Name of placement supervisor* *Joaquim Blesa Izquierdo*

Fonction / *Function* *PhD Lecturer/Researcher*

Adresse e-mail / *E-mail address* *joaquim.blesa@upc.edu*

Nom du stagiaire accueilli / *Name of trainee* Sarah Delmas

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 ? *Was the initial contract carried out to your satisfaction?* — (A) B C D E F
- Manquait-il au stagiaire des connaissances ? *Was the trainee 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 trainee 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* ________

1

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 ?
(Proposition de solutions aux problèmes rencontrés, autonomie dans le travail, etc.)

(A) B C D E F

Did the trainee adapt well to new situations?
(eg. suggested solutions to problems encountered, demonstrated autonomy in his/her job, etc.)

(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* ______

CULTUREL – COMMUNICATION / *CULTURAL – COMMUNICATION*

Le stagiaire était-il ouvert, d'une manière générale, à la communication ?
Was the trainee open to listening and expressing himself /herself?

(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* ______

OPINION GLOBALE / *OVERALL ASSESSMENT*

❖ La valeur technique du stagiaire était :
Evaluate the technical skills of the trainee:

(A) B C D E F

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? ☒ oui/*yes* ☐ non/*no*

Fait à / In Barcelona, le / on 27/9/18

Signature Entreprise / *Company stamp* ______ Signature stagiaire / *Trainee's signature*

INSTITUT DE ROBÒTICA I INFORMÀTICA INDUSTRIAL
C/ Llorens i Artigas, 4 - 6
08028 Barcelona Tel. 93.401.57.51
Mail: admin-[illegible].upc.edu
CSIC

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

2

Version du 03/05/2017