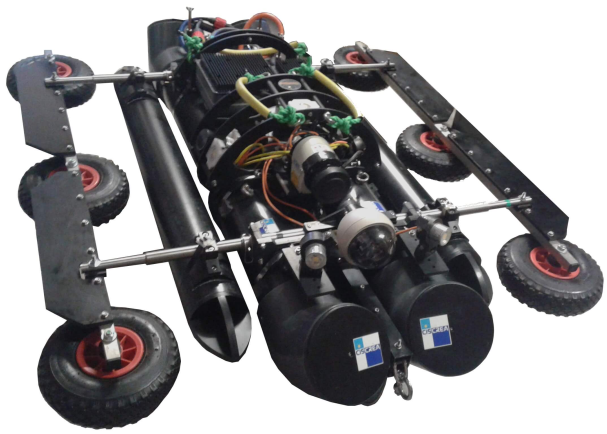

ENSTA Bretagne

Final year project

Optical Flow for SLAM

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supervised by
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Introduction

One of the hope for Robotics is to be able to replaces human with robot for hazardous task and dangerous environments. That create a need for robots to locate themselves in those environment and to be able to know what this environment is. That's why Localization is one of the major area of work in mobile robotics.

The most widespread way is to use GNSS methods which provide an absolute position in the geo-spatial reference frame. The only downside to this method is when you have a roof over your robot. And this is our case.
The project concerned by this report is a raft for the inspection of canalization, it bring us the possibility of inspect Canalization in a quicker and safer way that by fully human work. It also allow us to inspect hazardous without the need for heavy and time-consuming equipments and we have to know where we are in the canalization with our Embedded Sensors.

This is a classical SLAM situation, the drone have to find its position and at the same times build a tree dimension scan of its environment with a combination of laser sensor for emerged part and a Multi beam echo sounder for the submerged one. With several sensors able to give us some information about the position of the raft in the canalization, we have to build an information fusion system to pinpoint our exact localization.

To solve this fusion, we will use interval analysis methods. It allow the raft to use different source of data with very different precision value. It provide a safe way to find our localization in the canalization. It is especially useful against the uncertainties of the measurement and the build-up of the error, Two useful characteristics with a SLAM problem.

To carry on with our goal of exploiting our sensors to their maximum, we built an Optical Flow program with the camera already on the raft. To provide visual during the inspection, our drone is fitted with tree high definition camera, drawing an optical flow from them help us in figuring out our position in the canalization.

Chapter 1

Context

1.1 CISCREA

Ciscrea[2] is a French robotic company who design tool for hazardous and industrial environment. Created in 2008, Ciscrea mostly works with water-oriented robots for inspection and monitoring purpose. The company is based in Toulon (Provence-Alpes-Côte d'Azur) and work with European and international client.
Their most successful product is the Mini-ROV DVBot, a Multi-functions submarine ROV (remotely operated vehicle) able to dive up to 300 meter and move in any direction with 6 thrusters. It is currently used by Minesweeper, researcher and underwater raw materials survey.

Figure 1.1: The DVBot

1.2 The PLATypus Project

The current big project of Ciscrea is The PLATypus Raft. A robot built to make canalization inspection in a easier and safer way. It work with city's sewer system and industrial pipe.

The goal is to make quicker and more precise inspection with raft than a human crew could do, it can evaluate the volume of sediment in the canalization and check for leak in the pipe. For this purpose it is equipped with a large number of sensor: Sonar, Laser, HD camera and an Inertial Measurement Unit (IMU).

Those sensor allow the drone to fulfill most of the common mission : detect and evaluate the volume of sediments in a pipe, check the geometry of the pipe and audit the presence of potential hazard like gas, dangerous substance or in most of the case crack and mildew.

It is not fitted with any propulsion system. To move it use the water flow in the pipe and is restrain by a winch. The acquired Data are processed outside of the raft on a computer.

Chapter 2

Theories

2.1 Optical Flow

Optical Flow is an image processing methods to detect and evaluate the movement of objects in a video with respect to our camera. Thus this technique allows a fixed camera to detect the movement of one or more object or a mobile camera to understand its own movement towards a non-moving environments.[4]

To do that , the system have to detect point or zone of interest in a picture with Object Tracking algorithm and do so again in the next picture with knowledge of the interval of time between the two pictures. The next step is to try to match the two set of features and to compute the vector of the shift between the two pictures.

The final step is to use the calibration information of our camera to find the angle of the shift [1]. In our case we are able to find the exact movement with the distance to the object thanks to the laser sensors. Thus we have information about the speed and direction of the target with respect to our device.

Optical Flow is the technology behind the current generation of computer mouse. The optical sensor in them detect the movement of the surface with respect to the mouse.
The other major use of optical flow is in aerial robotics to find the travel of the UAV(Unmanned Aerial Vehicles). Current research focus on increasing the autonomy of UAV with obstacle detection. [11].

Figure 2.1: An Exemple of Optical Flow Detection

2.2 SLAM

SLAM is a strategic domain in robotics. It allows an Unnamed Vehicle to make its own map of his environment and find his position in this environment. This capacity is needed when you work in other environment that laboratory, which is necessary to expand robotics in more domain that pure research.

A lot of algorithm already exist and a lot of them are even marked with Open Source license [3]. Examples include FastSlam [19] or GESTALT which work with exploration rover. Their number and variety is explained by the variety of drone that can use them (Rover, UAV, Underwater Drone ...) , the variety of information provided by the sensor (laser mapping, echo-sonar, pressure plate...) and finally the number of environment (Urban, Interior, hazardous, nature).

SLAM algorithm have already pass the development stage and are currently present on commercial Drone. The most known example is the SLAM algorithm present in the first real domestic robot : The Roomba [6]. The last model , the Roomba 980 use SLAM to make a real map of his environment whereas the old drone used only machine learning to find a path. [12].

Different methods have been developed, most of them use classic Automatic control methods : Monter-Carlo and Khalman filters but in our case we will use interval analysis and set membership techniques.

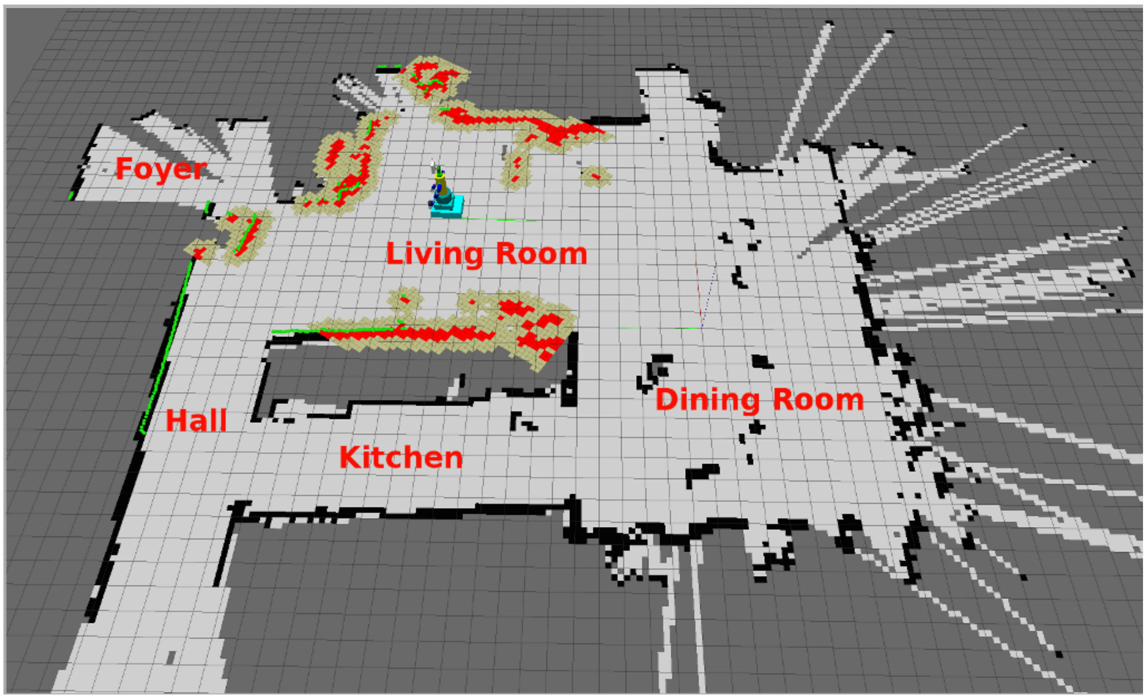

Figure 2.2: Interior mapping using SLAM

2.3 Interval Analysis

The goal of Interval Analysis is to provide a set of value that is guaranteed to contain all solution of our equation. The biggest advantage of this methods compared with traditional numerical process is the ability to compute a degraded solution in a sensible time.

This particularity is greatly welcomed in robotics and other real-time control application where we don't need the perfect solution but a fast computation.We can control the complexity of our computation with the minimal size of our boxes which is a very useful tool in engineering.

An other great advantage of interval analysis is its ability to consider the propagation of our error which allows it to assure us of the inclusion of the numerical solution in our set. This inclusion can be use to make great robust control with Interval Analysis we can foretell where the drone was a few step before and where we could be in a few step after. [10]

Interval technique are also useful to solve some instance of the egg-and-chicken problem : with Interval analysis we can, after some use of the Khalman Filter, know both the position of our landmark and the robot. This capacity make it a boon in SLAM algorithm.

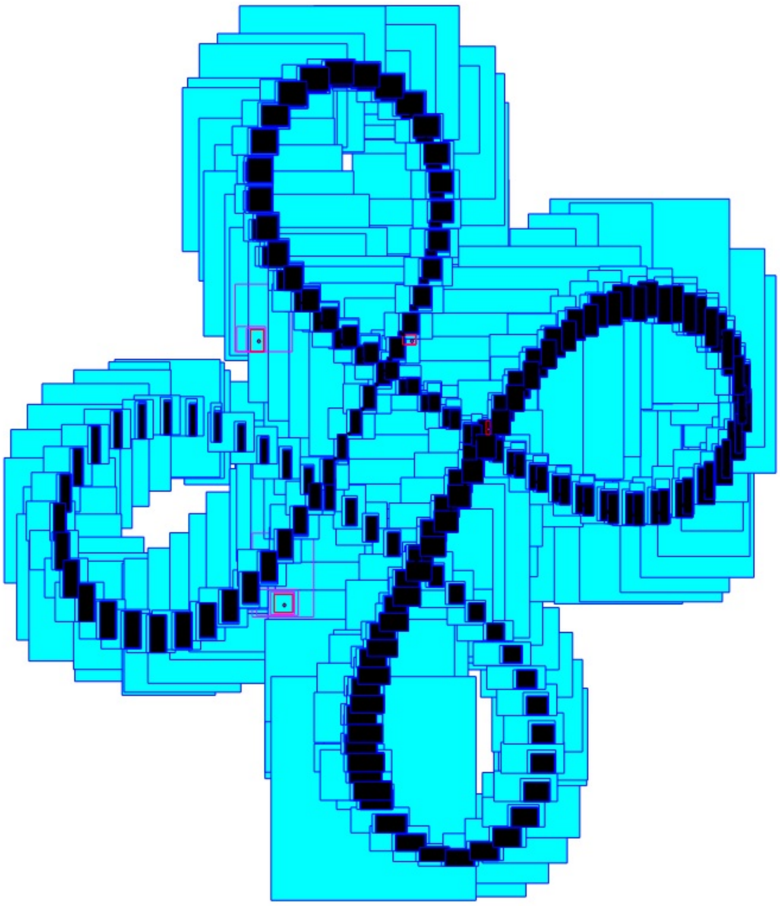

Figure 2.3: An example of Interval Analysis

Chapter 3

Implementation

3.1 ROS

Ros (Robot Operating System)[18] is a middleware created by Willow Garage, the software is OpenSource and is updated each year.It allows developer to avoid starting afresh with each project and provide a set of tool to ease the program of complex system. It also provides a way to replay the mission, a really good advantage when we try to do an inspection and a great tool for the development phase.

Ros works with a Node Architecture, a Ros system is made of a certain number of nodes and each of the node incorporate a process : Manage the Camera, compute the position, provide an HCI (Human-computer interaction). The role of Ros is to manage the flow of information between the different process, for this it use "topic". A topic is data in a ROS-standardized form, a node can subscribe itself to a topic to receive the data at a certain frequency or publish a topic and update the informations .The video taken by the camera is treated by the node managing the camera, the node publish on the relevant topic. All the node who need the video, like the display or the optical flow subscribe to this topic and receive the data streamed by ROS.

For this project we use a Node for each of the sensors use by the slam : each of the fixed camera, the length of cable between the winch and data of the LIDAR. The videos are transmitted to the optical flow process which give the computed value of the raft's travel. The localization node subscribe itself to all the sensors and the optical flow and produce a position which is published . The display node subscribe to this topic and provide the user with a view of the situation.

3.2 Optical Flow

The concept of Optical flow is born as a biological theory on the movement detection by animals. And the development of optical flow algorithm is an example of biomimetics.

Currently , the most used method to implement optical flow is The Lucas-Kanade. [17] This method is based on the fact that the neighborhood of a point is not likely to change. the algorithm try to find the maximum of correlation with the next pictures . We then compute the travel between the two pictures to find how are moving the different objects in the pictures.

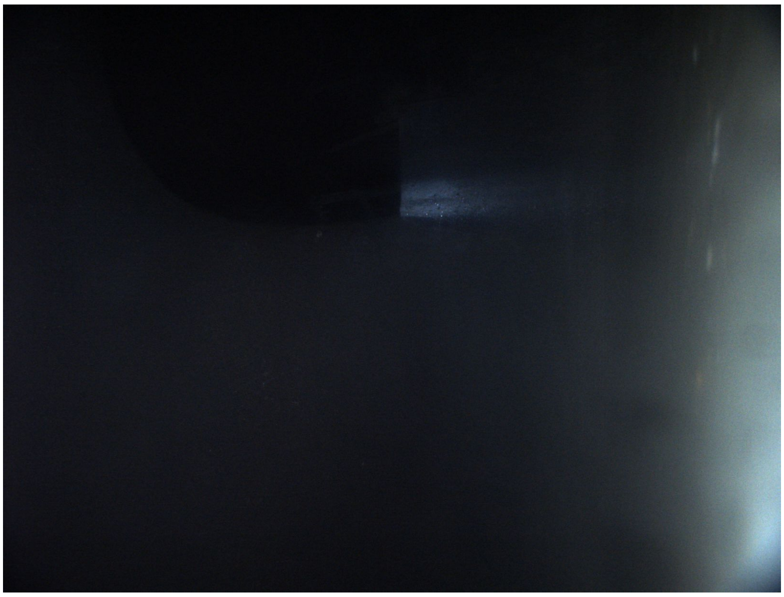

Figure 3.1: Lightning Problem

Unfortunately for us, the Lucas-Kanade method is dependent on the lighting condition and sewer are rarely the most lighted place. The drone embark its own light but the effect put the same effect on each image and it can oise a challenge This is way we had to design a new method.

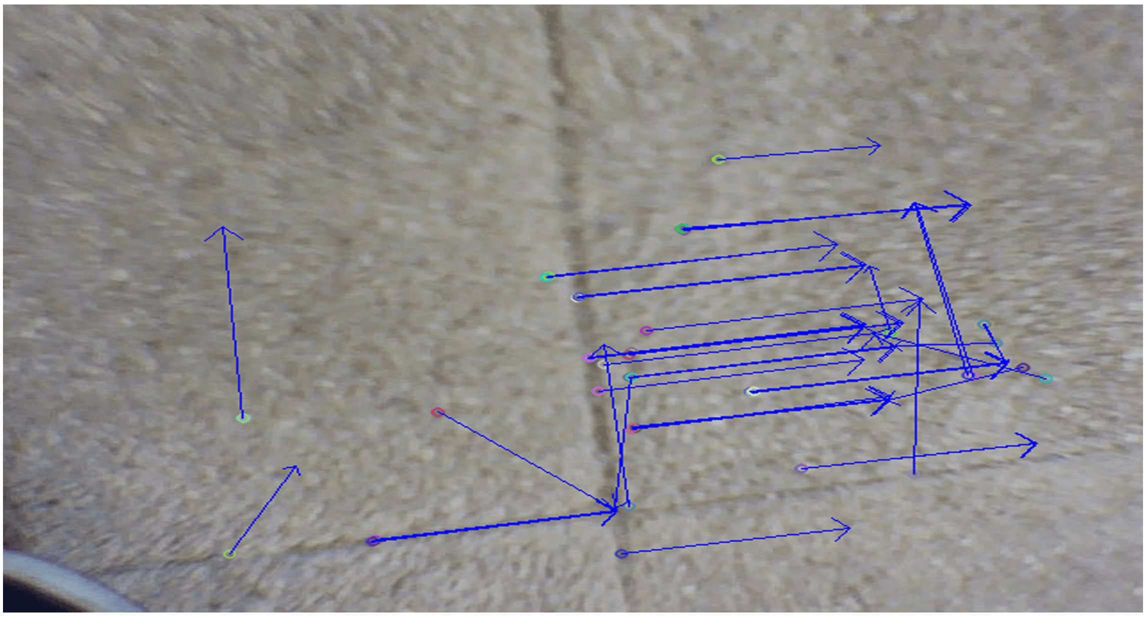

Figure 3.2: Detection of movement with Optical Flow

This new method begin by detecting point of interest in the pictures n and n+1 thanks to the ORB (Oriented FAST and Rotated BRIEF) ,[7] an algorithm developed by OpenCV Labs. It combines the best of features of the oldest feature detection algorithms : The BRIEF algorithm way of defining a key-point and the FAST algorithm way of finding those key-point. The next step is to find match between the two group of key-point, this work is done by the FLANN[16] (Fast Approximate Nearest Neighbors) algorithm. Sadly due to the poor condition of the shooting of the pictures and the few number of details in a the majority of pipe, the algorithm present a great number of false positive. We can see those false positive in the presented pictures.

Despite the false positive, we can see that our algorithm present a consensus on the movement of the different key-points so we are able to extract information on the movement of the raft. Due to the great difference of value between the real match and the outliers, we have decided to use the median value rather than the mean one because of the natural tendencies of the median to be less affected by outlier.

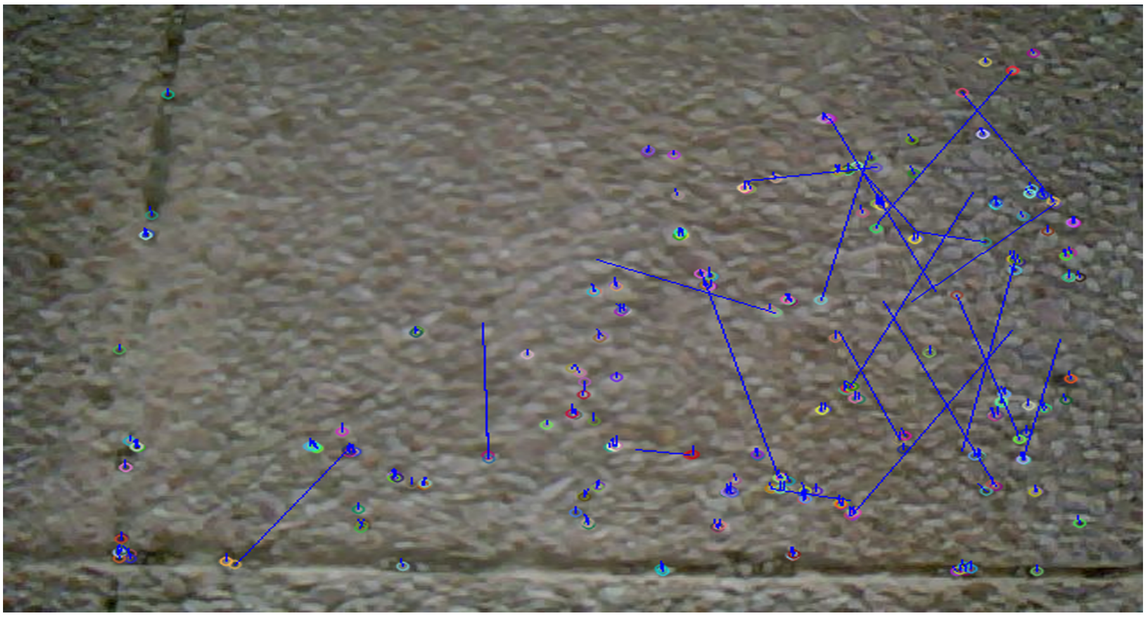

Figure 3.3: Real use of the algorithm

3.3 PyIbex

Pyibex[8] is a Python adaptation of the Ibex API (Application Programming Interface) . Ibex provide developer with built-in tool for Interface programming. It contains structure for Multi-dimensional interval and tool to create contractors and SIVIA algorithm. This allow us the program interval algorithm without having to recreate the whole algebra.

In this Localization algorithm we use the same process at every step of the journey of drone in the pipe. at first we consider the whole pipe as the possible position of our raft then we use the information of the length of our cable to reduce this space then the information of the laser sensor and to finish we use the optical flow and we save the data on the optical flow for the next step. At each of those step we use Forward-Backward Contractor to extract the maximum of information and avoid the Egg and chicken problem.

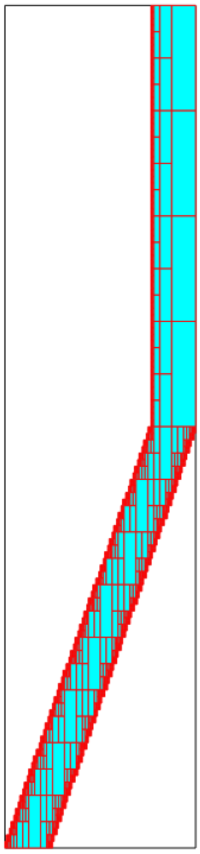

Figure 3.4: Depiction of the Canalisation with PyIbex and Vibes

With PyIbex, we use VIBes (Visualizer for Intervals and Boxes)[5]. It provides a GUI (Graphical User Interface) for Interval Programming. The Software was developed by ENSTA-Bretagne and can be used with C++ or Python on Linux or Windows. The philosophy is to stay low on the resource requirement to avoid adding to much charge on the hardware.

3.4 OpenGL

OpenGL (Open Graphics Library)[13] is the most used programming library for creating 3D (or 2D) objects . It is available in most of the mainstream computer language (Python , C++, Java) . OpenGL was created by Silicon Graphics but is now managed by the Architecture Review Board with representation from most of the computer-based corporation like Apple, IBM or Nvidia. It is frequently use into CAO-software and in Video game.

We choose OpenGL for this project because of its ease to learn thanks to the great number of books and website dedicated to teaching of the OpenGl Process. Furthermore there is a great community behind OpenGL and we can find the answer to most of the problem on the world wide web.

OpenGL naturally takes action on the 3D representation part : the goal is to provide a sight on the travel of the raft in the pipe. It is use to inform about the progression of the inspection and to helps the user deduct what part of the Pipe the cameras are seeing. It's also a commercial boon, the display of the position in 3D is more marketable than the position in meter in the main window.

To represent the pipe, we use a common approach to represent 3D form : use a lot of triangle. This is the most used way to represent complex form. Unfortunately The raft is only displayed as a cube because even if making a complete 3d representation of our robot in OpenGl could be a good project, it would have little to do with robotics.

At the current state of the project, we could have settle for a 2D display as all the inspection made were in strictly horizontal geometry. Furthermore Ciscrea ask their client to keep the flow of water constant which avoid a change of elevation in the pipe. So the need for a 3D view is mostly marketing.
It can be noted that change from 2D to 3D in OpenGL require to start anew so we judge it better to make it 3D from the start taking into account that the raft project is still at its beginning.

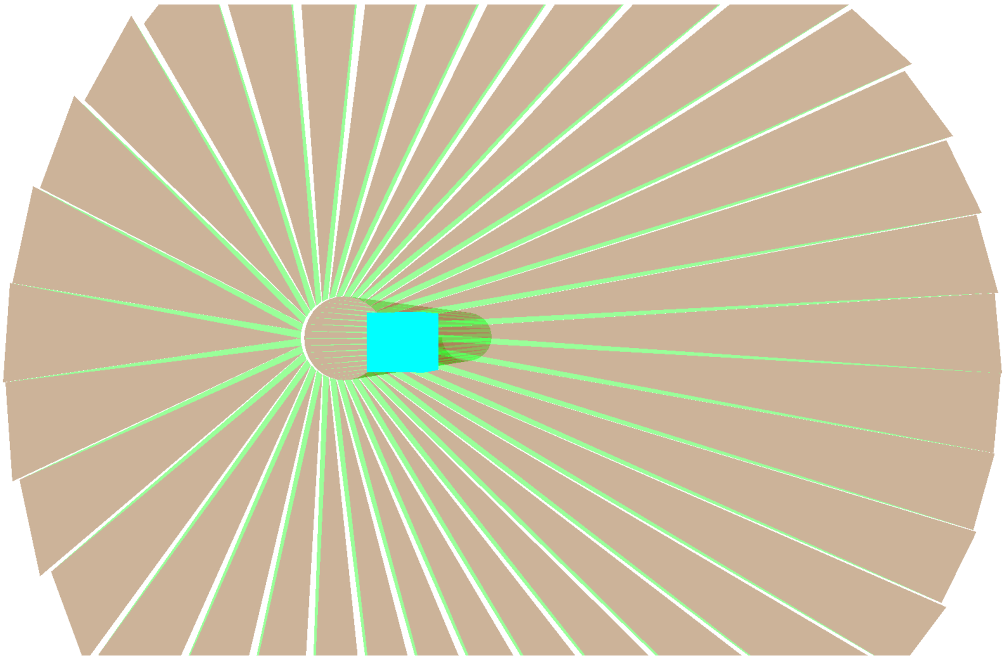

Figure 3.5: 3D Display of the raft in the pipe

Chapter 4

Results

I have to begin this part by saying that sadly, the calendar didn't allow for a test of the algorithm in a real situation. So this result come from a simulation depicting a common situation for the raft.
The simulated pipe is made of two section with a small shift in orientation between the two part. This turn's goal is to make the process of the Winch's data more complicated . The final Pipe has a total length of 103 meters. This conduit is traveled in approximately 35 minutes.

As to represent a classical scenario in our simulation we have a zone that represent a reset of the error with a sewer entrance that let us see the exact position of the raft. The goal is again to extract the maximum of information from our environment.

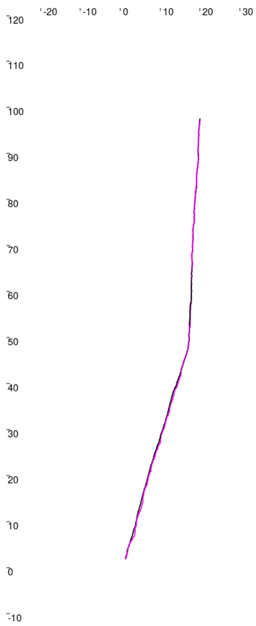

Figure 4.1: Difference between real and estimated value in the pipe

Figure 4.2: Zoom on a part of the Difference

As we can see on the picture above our estimated, travel follow closely our real trajectory. The precision is enough to see where is our raft in the canalization. It is enough for marketing purpose. An other question is to know if this is enough to locate precisely where are the problem in the pipe to make a complete unmanned inspection which is the final goal of the Raft project.

After computing the simulation we exit it with a mean error of 0.2785 m.

The Max error of our algorithm in the simulation is 1.137 m

And finally the Quartile for this simulation are 0.1141 m ; 0.2296 m ; 0.3642 m.

Those result are promising and provide a measure of security in our localization of the raft in the pipeline and allow us to ease the human work in the hazardous settings. To completely avoid human operations in the pipe there is still research to be done. There is a number of amelioration that could be develop to ameliorate the precision. The first one is to use the Principe of Interval relaxation : To test the whole pipe against each of the contractor and then to find the zone chosen by the maximum of Interval. Even if this method can be more precise than our current method it is also a lot more expensive on the processing power side.
A more obvious amelioration would be to integrate the Inertial Sensor that was incorporated in the last update of the project with a contractor on the acceleration that would be a great complement to the contractor on the speed of the optical flow.

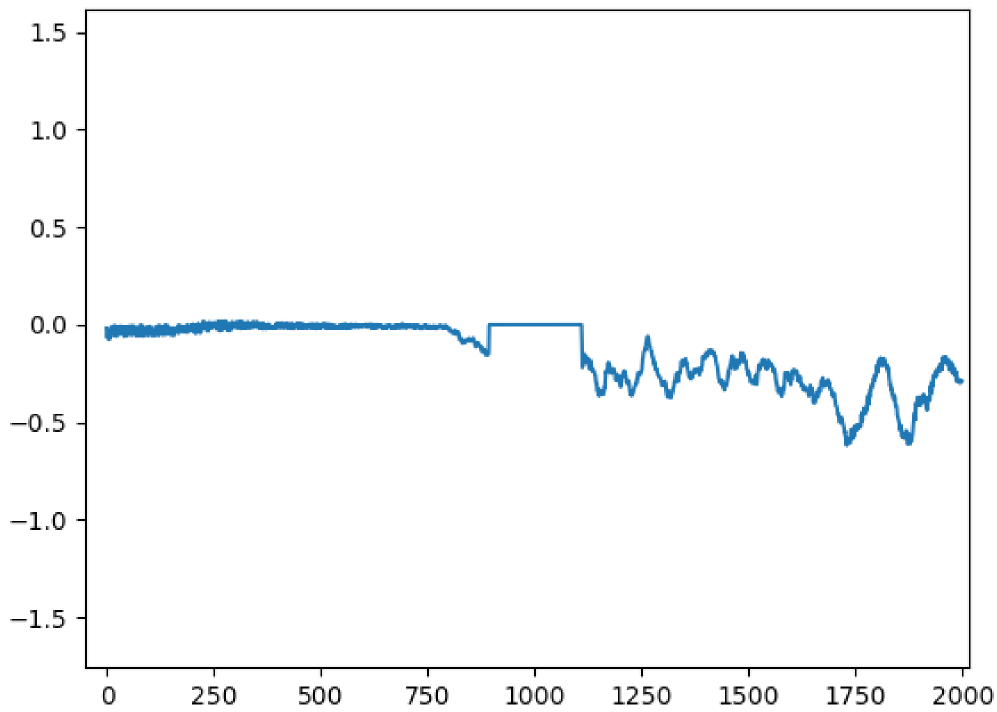

Figure 4.3: Difference between real and estimated value according to X

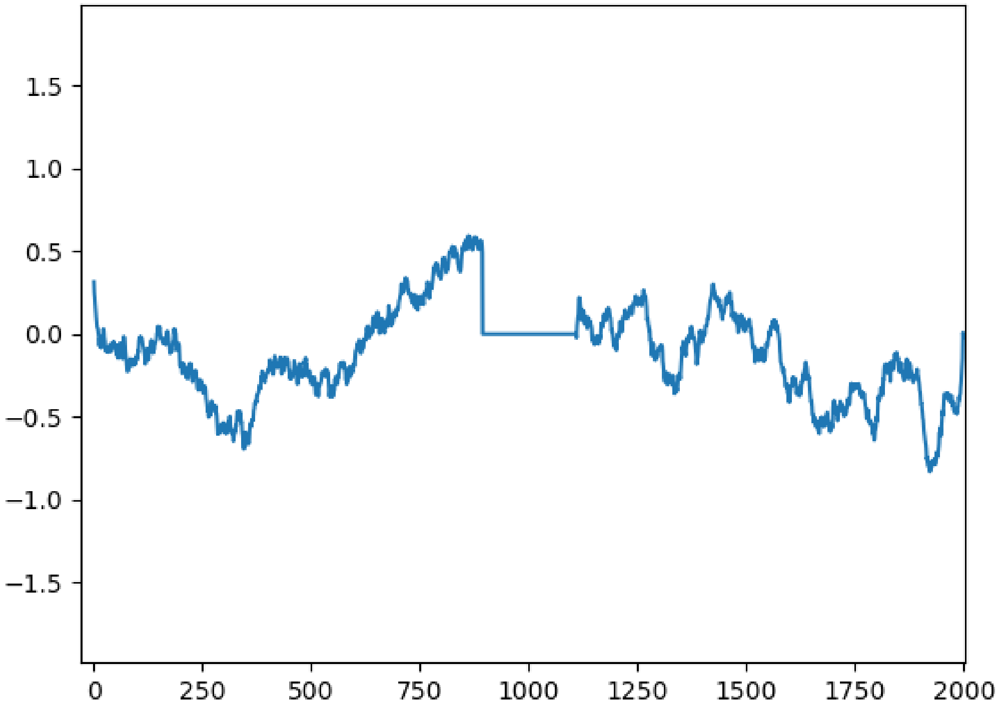

Figure 4.4: Difference between real and estimated value according to Y

Chapter 5

Conclusion

From a scientific point of view the project was interesting for the opportunity to combine the knowledge and skill acquired during my formation. Ros is one of the more powerful tool available for programming of robot and other complex system. The management of information is one of the difficulty in this sot of system and having a reliable and modular tool for this is a boon.

The development of the Optical Flow process was difficult because of the naturally poor condition of the picture inside of a pipeline but it still provide a workable result. In better condition, the process would provide a great way to avoid collision with mobile and immobile object. With the democratization of camera and the ever-expanding processor power of computer. Optical Flow algorithm will become a more common sight. computer will be able to understand more of what they are seeing.

The advantage of Interval Analysis for the position estimation was already proved in our mind but this project is one more evidence. The interest come from it's ability to combine the information of different sensors with different scale of precision. The project didn't encounter the second part of the SLAM capacity : The mapping part because we already know the geometry of the pipe explored. The capacity could be useful with a future project on exploration on a much bigger scale where we don't know the geometry of the zone.

From a professional point of view, this internship marked the end of my formation. The project was very welcomed as it allowed me to investigate part of my curriculum that I was interested in exploring like the functionality of Ros or the Optical Flow methods.

It also allows me to see for myself the working approach of a small company, with my internship with THALES in my first year and the last year one in a research center , I have seen my 3 possible professional future. The work in a small business is more intense and more difficult but you have the advantage of more flexibility in your approach and the opportunity to have more link with other domain like mechanics and electronics.

Working at Ciscrea also gave me a window on the running of a business that I didn't experience in my other internship : the working of a design brief, the different kind of worker in a company : trainee, interim, logistics. Futhermore i have seen the utility of our non-scientific class, like marketing, economics and management. Even if the students don't always see the interest they allow for a smoother transition between the formation and the industry.

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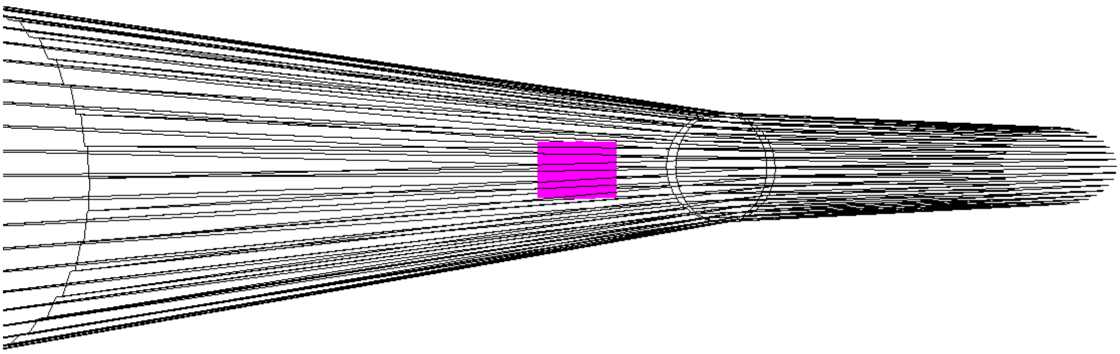
Summary

Optical Flow is a great way to gain more data from a Camera. With this process we can infer the movement of our drone or the movement of other mobile object in the immediate vicinity. Both of this option are interesting within the framework of mobile robotics : most of drones now include several camera. Every mobile Robotics system can benefit of a better knowledge of his environments.



In this Context, We tried during this project to insert Optical Flow technique in the SLAM Process of a Drone. Using Ros, OpenCV and PyIbex, we built an indoor Localization System .