COPPE
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**Instituto Alberto Luiz Coimbra de
Pós-Graduação e Pesquisa de Engenharia**

MASTER THESIS PROPOSAL

UNDERWATER MAPPING USING IMAGING SONARS

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Proposta de tema de tese a ser desenvolvido no LEAD/COPPE/UFRJ para o Mestrado do Programa de Engenharia Elétrica da COPPE/UFRJ

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Chapter 1

Introduction

This proposal refers to a system for 3D underwater mapping. It consists of a hardware plus a software that is the main objective of the research. The chosen hardware will constrain the software options and decisions on the underling algorithm.

A mapping system usually comes together with a localization algorithm in what is called a SLAM (*Simultaneous Localization and Mapping*). SLAM is an active topic of research and has remarkable solutions using laser scanners, but most of the underwater SLAM is focused on 2D maps treating the environment as a floor plant or as 2.5D maps of the seafloor.

The reason for the problematic of underwater mapping, and thus SLAM, in contrast with laser based systems used outside water is mainly its sensor. While lasers are precise low-noise sensors, sonars, which are the standard sensor for underwater SLAM, are the opposite.

Sonars measures the sound on the water, its main parts are the hydrophones. They can emit and receive sound waves just like microphones and headphones do in the air. They can be specialized to listen the environment and interpret its sounds, usually by their spectrum, which is the case for passive sonars. Or they can emit a beam of sound and wait for the reception of the echo.

When talking about active sonars, the ones that measures sound echo emitted by itself, there are two important classes based on its beam directional gain: Profiling and Imaging.

Profiling have a narrow pencil shaped beam, with an aperture of about 1.7 degrees, i.e. the half power point. It is meant to have a similar response of what is expected from a laser scanner, but working with sound waves. At the end of the day, they does not correlate much because they differ greatly on noise, response time and spatial resolution.

Imaging sonars will be the focus of this work, they make use of a much wider than Profiling sonar fan shaped beam. It use to have around 3 degrees angle of aperture in

the vertical direction, but keeping same angular resolution on the horizontal plane. It does not have to precisely aim to provide a localized information about the target, but rather a more general information, being able to infer some information about the presence of objects below or above its horizontal plane. From this point of view, each beam gives a concentrated information about the region it ensonifies, so fusing the information of multiple beams from different directions and angles is expected to give a better outline of the environment than just using isolated sonar responses.

Besides classification based on beam shape, there are others as multi- or single beam. Firing multiple beams at once gives a faster rate, as one does not need to wait for the response to arrive before redirecting the beam to the next angular position. But the least expensive still single beam and is the one that is going to be considered.

Chapter 2

Motivation

The mapping of underwater environments is not just a part of a SLAM system. It might have importance on its own, it can be used for humans to visualize things that could not be seeing otherwise.

In the ROSA (*Robô para Operações de Stoplogs Alagados*) project, developed by LEAD/COPPETEC to ESBR, one of the goals is to make a reconstruction of the hydroelectric power plant turbine entrance to spot any underwater debris that could block the lowering of stoplogs, used to block the water flow, and then cause delays and setbacks. When it happens for a stoplock to stuck the need for a diver also incur in further human risk, so even then it is important to know the surroundings.

On a developing perspective, besides the importance for the ROSA project, it has characteristics that makes it appropriate for mapping. It has a lifting beam for inserting the stoplogs into the water that can act as stable fixation point for any sonar structure. So reducing the impact of poor a localization system on the mapping. It also has a known and not-so-complex ground truth environment (besides possible debris). Thus data collected there is suitable for testing the mapping algorithm in a real world environment, as opposed to lab testing. Although the noise environment might impair greatly the mapping, and subsequent visual reconstruction.

It is also a integral part ROV's, where it gives feedback to the operator for him to know where it is or/and what he is doing, especially because cameras do not have a very useful range. And glaringly its automated counterpart (AUV's) as a requisite for SLAM.

Chapter 3

Objectives

The general objective is to map an underwater environment. But to get there it is important to describe some facts first.

As stated before, profiling sonar try to mimic laser scanner, but using sound. So most of the approaches on 3D underwater SLAM focus on applying laser scanner techniques to profiling sonars, e.g. point cloud reconstruction. On the other hand, imaging sonars are usually cheaper and gives more information per sound beam. So having the possibility of using imaging sonar and benefiting from its extra information is a win-win strategy.

Besides the definition of the sonar, one should carefully look into the meaning of mapping, because, it can be interpreted in different ways, depending on the context. Taking what they all have in common, it is possible to generically define mapping as being the processing of received environmental data to characterize the surroundings. In the understanding of characterization is where the difference lays, how the environs are going to be represented is dependent on the application.

On a SLAM system there is no intrinsic need for a human readable map. In such a system, it may be more interesting to store the map information, the "characterization", only through its most representative features, if that is what matters for the localization procedure.

Still, if the map is to be seen by a human it should store more information about the environment, so that it can be displayed as a usual map, 3D or 2D depending on the case. This representation also guides how the data could be stored, e.g. if it wants to show a surface, it can be stored as a elevation map, or if one wants to see a 3D object it can be stored as a point cloud.

Using de aforementioned ideas, the main goal of the thesis reported here is to implement state of the art techniques for mapping, using binary bayesian filters. Fuse all the data on a octree structure using a robotic framework, named ROCK, and implement a visualization for the reconstruct underwater map. The data source shall be a imaging sonar mounted on a pan-tilt unit, so to provide the sonar extra

degrees of freedom.

Optimization of the visible surface for based on the expected response of a sonar beam in a given direction will also be attempted. It might supply information about the surface material, specifically its reflectance. A technique based on previously articles.

Chapter 4

Metodology and Expected Results

The work is divided into tree main branches. Each having a theoretical research followed by implementation and testing.

The sonar model definition starts with a compilation on the description of sound waves on the water, reflection, sonar directional gain and noise sources. Then tests are realised on known environments so to fit and validate the proposed model. The test results are finally used create the full sonar model, including metric conventions by the sonar protocol.

The second branch deal with the map filling, basically the Binary Bayesian Filter implementation. A review on Bayesian Filtering is scheduled before the coding writing to be done on the robotics framework, ROCK. The implementation will make use of the Octotree data structure, through the Octomap library, to store the map.

The integration of the sonar model with the Bayesian Filter give the means to process sonar data. So data acquired on the LNDC/UFRJ tank (LaboratÃşrio de Ensaios NÃčo Destrutivos, CorrosÃčo e Soldagem), which loosely translated means Non-Destructive Testing, Corrosion and Welding Laboratory, and on the Jirau Power Plant, by means of the ROSA/COPPETEC project, will be processed and compared to the tank and power plant entry layout, respectively.

In a more complex endeavor, which is the third branch, a theoretical derivation for the optimization of 2D surfaces embed on 3D environments will take place. It uses sonar response as expectation, and must take into account the probabilistic nature of the map grid. The objective is, instead of having a fixed sonar model, be able to better infer the underlying geometry of a sonar responde, and also recover some information about the surrounding materials reflectivity properties. This optimization algorithm will then be implemented on ROCK so it can also be integrated to the Bayesian Filter, instead of the sonar model. The same data processed by the combination "Filter + Sonar Model" shall now be processed by "Filter + Optimization".

Based on the literature, even with not much similar works, the reconstruction with *a priori* sonar model will probably experience problems when reconstructing corners, shallow angle surfaces, very complex (intense multipath) or on highly noise environments. For the optimization, it shall encounter similar issues, but a less accentuated shallow angle quality degradation and an overall less blurry reconstruction.

Chapter 5

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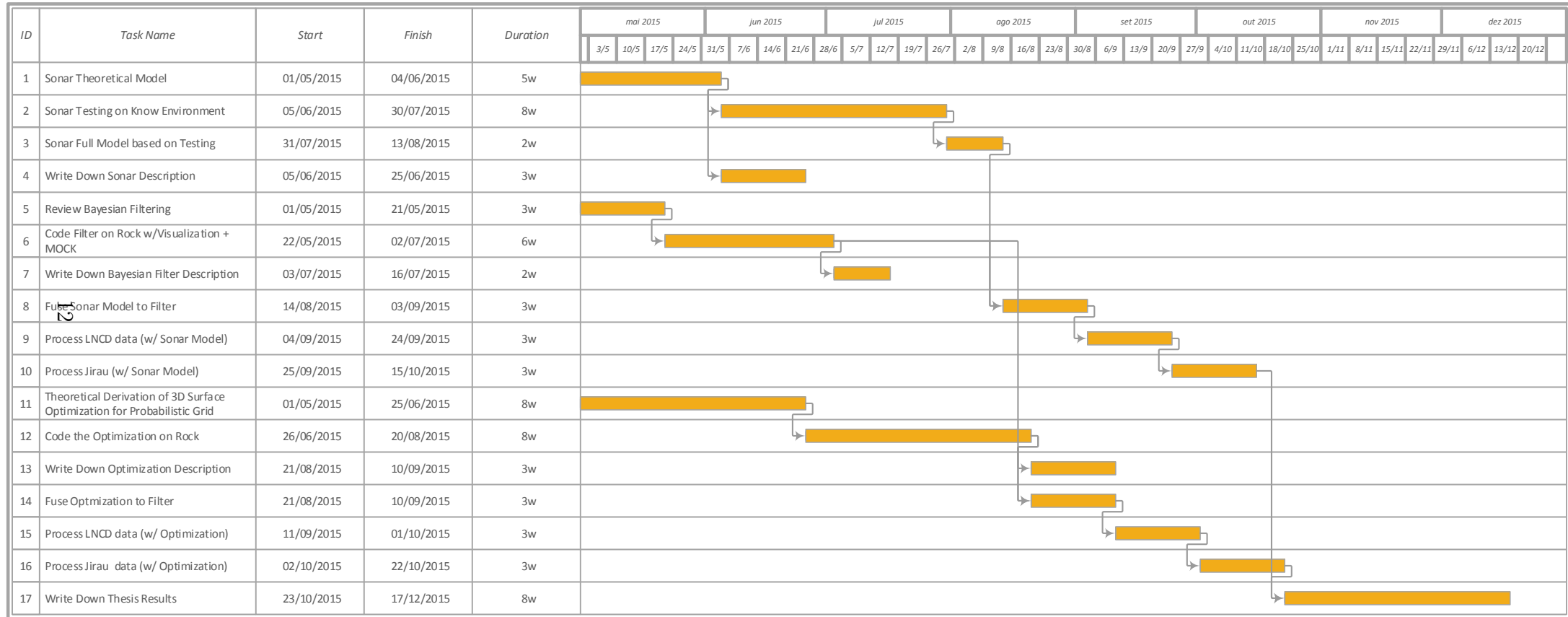
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5.1 Timetable and milestones

ID	Task Name	Start	Finish	Duration
1	Sonar Theoretical Model	01/05/2015	04/06/2015	5w
2	Sonar Testing on Know Environment	05/06/2015	30/07/2015	8w
3	Sonar Full Model based on Testing	31/07/2015	13/08/2015	2w
4	Write Down Sonar Description	05/06/2015	25/06/2015	3w
5	Review Bayesian Filtering	01/05/2015	21/05/2015	3w
6	Code Filter on Rock w/Visualization + MOCK	22/05/2015	02/07/2015	6w
7	Write Down Bayesian Filter Description	03/07/2015	16/07/2015	2w
8	Fuse Sonar Model to Filter	14/08/2015	03/09/2015	3w
9	Process LNCD data (w/ Sonar Model)	04/09/2015	24/09/2015	3w
10	Process Jirau (w/ Sonar Model)	25/09/2015	15/10/2015	3w
11	Theoretical Derivation of 3D Surface Optimization for Probabilistic Grid	01/05/2015	25/06/2015	8w
12	Code the Optimization on Rock	26/06/2015	20/08/2015	8w
13	Write Down Optimization Description	21/08/2015	10/09/2015	3w
14	Fuse Optmization to Filter	21/08/2015	10/09/2015	3w
15	Process LNCD data (w/ Optimization)	11/09/2015	01/10/2015	3w
16	Process Jirau data (w/ Optimization)	02/10/2015	22/10/2015	3w
17	Write Down Thesis Results	23/10/2015	17/12/2015	8w

Chapter 6

Conclusion

This master thesis proposal has described a less than a year full-time plan for study and implementation of a underwater mapping system. So to be able to scrutinize state of the art technologies to apply on a poorly explored condition, that is the full 3D environment. And even, based on these technologies, tailor a new algorithm to enhance the outcome. Besides the theoretical realizations, it is committed to provide results based on real-world data from UHE Jirau (the Jirau power plant).