Acoustic Camera-Based Pose Graph SLAM for Dense 3-D Mapping in Underwater Environments

SEMINAR

Abhishek Jayachandran

College of Engineering Trivandrum, Electrical and Electronics Engineering

Based on the work by Yusheng Wang, Yonghoon Ji Hanwool Woo, Yusuke Tamura, Hiroshi Tsuchiya, Atsushi Yamashita, and Hajime Asama

CONTENTS

Objectives

- Generate 3D local maps of underwater environment using an acoustic camera mounted on a rotator
- To generate a robust and accurate dense global map of an underwater environment using pose graph SLAM

Introduction

- Many underwater missions require robots equipped with a 3-D imaging system for reconstructing the underwater environment
- Because of limited field of vision due to turbidity and lack of illumination, sonars are considered the most effective means for underwater environment sensing
- Sonars are classified into passive and active sonars. Active sonars are further divided into ranging and imaging sonars
- Side scan sonars (SSSs) and synthetic aperture sonars (SASs) are effective tools to create large-scale seafloor images based on backscattered acoustic signals and along-track motion

Introduction
(Continued...)

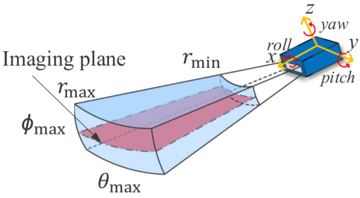
- Mechanical scanning sonars (MSSs) are another type of imaging sonar, generating 2-D images by scanning the environment with a 2-D beam
- Acoustic cameras, also known as forward-looking imaging sonar, such as the dual frequency identification sonar (DIDSON) and adaptive resolution imaging sonar (ARIS) have made it possible to generate high resolution and wide-range images
- This type of sensor is relatively small and can be easily mounted on an underwater robot

Process Overview

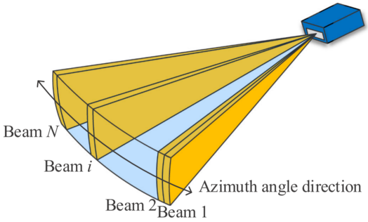
- A volumetric 3-D model consisting of voxels is used for 3-D mapping
- An inverse sensor model for the acoustic camera is built to effectively update the probability of each voxel
- Each of the 3-D local maps is generated from each viewpoint of the acoustic camera
- Odometry is estimated from the transform matrices of consecutive local maps without requiring internal sensor data
- A graph optimization process is performed to realize the accurate pose estimation of each viewpoint and generate a 3-D global map simultaneously

Principle of Acoustic Camera

Acoustic cameras are active sonars that insonifies a wide range of 3D fan-shaped ultrasonic waves and receives a reflection when an object is hit



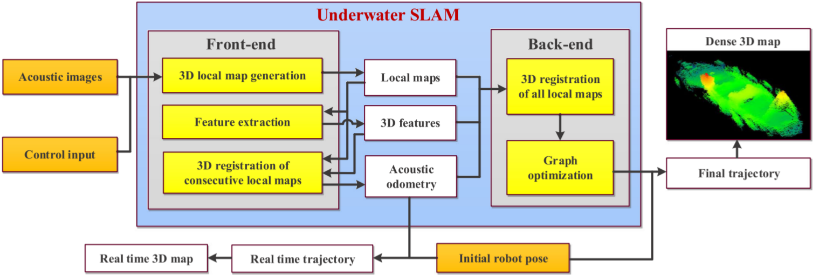
(a)



(b)

System Overview

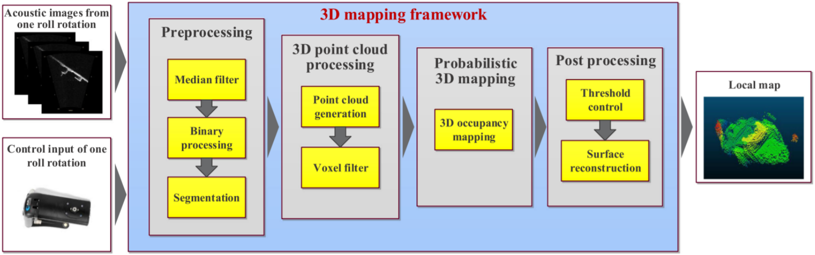
Figure: Overview of an underwater SLAM framework using graph optimization



3D mapping

The 3D mapping framework consists of pre processing, 3D point cloud processing, probabilistic 3D mapping and post processing

Figure: Overview of local map generation based on a 3-D occupancy mapping framework



The preprocessing consists of:

- Obtain raw image
- Binarization on the raw image
- Binarization after passing median filter
- Segmentation of each pixel where green, red, and blue refer to free, occupied, and unknown, respectively

After the image segmentation process, pixel data are converted to input point clouds by generating candidate elevation angles

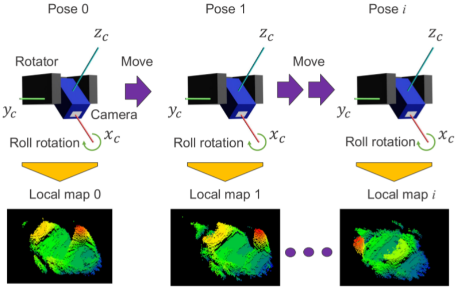
- Initially, each pixel in a raw acoustic image is represented by (r, θ)
- The candidate elevation angles ϕ are generated as: $\phi_k = \frac{\phi_{max}}{2} - \frac{\phi_{max} k}{K}$
- Three-dimensional points are generated by extending (r, θ) to (r, θ, ϕ)
- The generated points are converted from the camera spherical coordinates (r, θ, ϕ) to the camera Cartesian coordinates (x_c, y_c, z_c)

To narrow the candidate elevation angles, a typical occupancy mapping algorithm was implemented. To perform 3-D occupancy mapping, the OctoMap library is used to produce an Octree structure-based 3-D model angles. The point cloud data is defined from discrete time step as $C_1, C_2, ..., C_T$ where the time step is the same as the index of the image used. A 3-D environment map is denoted by M and each voxel is denoted by m_i.

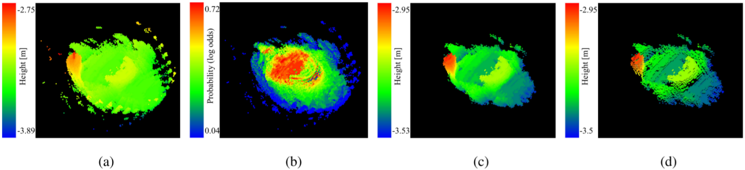
Then: $L(m_i|C_{1:t}) = L(m_i|C_{1:t-1}) + L(m_i|C_t)$ where $L(m_i|C_t)$ is the inverse sensor model.

The authors of the article have proposed a novel scan mechanism for generating the local maps of the environment.

- Perform roll rotation in one position
- Camera moves to another position
- Perform roll rotation again
- Repeat till mapping process is complete



- Threshold control: Used as a means of filtering out the noise in the measurements. Outliers and distortions, commonly occuring in the edges of the local maps, can be filtered by increasing the probability threshold.
- Surface reconstruction: The map is downsampled by leaving the voxels on the top surface. This process leaves fewer points, which can decrease the computation cost for further processes, such as 3-D registration.



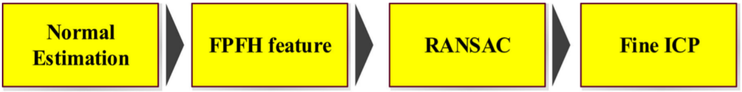
Graph Slam

- The state-of-the-art SLAM architecture can be separated into the front-end and back-end stages
- In the front end stage, odometry is calculated from the 3-D registration between consecutive local maps
- In the back-end stage, by optimizing the best configuration of the local maps, a final global map and accurate robot trajectory are produced

Graph Slam

Front end stage

- 3D registration - Global registration is performed to obtain an initialized alignment, and then local refinement is performed to obtain a tight registration result.



- Acoustic odometry - Similar to the concept of visual odometry for optical cameras or light detection and ranging (LiDAR) odometry for LiDAR. Odometry is calculated directly from images or point clouds. AO is acquired from the 3-D registration of two adjacent local maps.

Graph Slam

Back end stage

- Graph Optimization - Local maps and FPFH features are passed to the back-end stage and the graph optimization scheme is applied for refinement. This method relies on loop closures to acquire the alignment of the local maps. Graph optimization is calculated in this case by using Open3D Library.
- Map Integration - To integrate the rearranged local maps after graph optimization into a global map. Two methods for the same are
  (i) by overlaying all the local maps together
  (ii)integrating the maps by retaining probability information of the voxels and using Bayesian inference during map fusion.

EXPERIMENT

Simulation and real world experiments are conducted to verify the results of the underwater slam framework.

- Simulation - A simulation experiment was conducted using the simulator that the researchers developed. Realistic virtual images were generated from the simulator based on sonar propagation and acoustic camera projection theory.
- Real Experiment - A real experiment was also conducted to verify the feasibility of the method in a real environment.

SIMULATION

Simulation setting:

- Environment consisting of 6 basic shapes for easy evaluation
- Point cloud environment built using PhotoScan software, then converted to OctoMap model
- Acoustic camera with a rotator, mounted on a 3-DOF arm of a mobile robot to simulate a crawler-type underwater robot

SIMULATION

Figure: Simulation Environment and Results

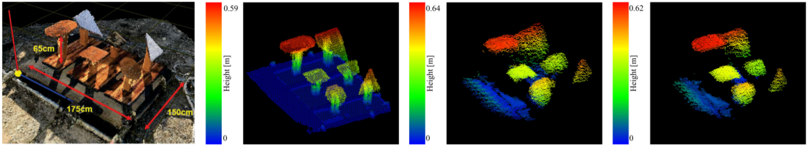
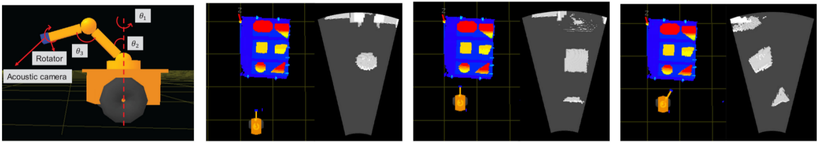
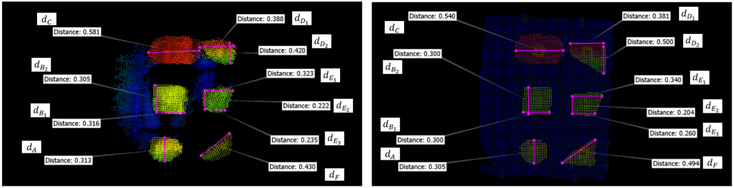


Figure: Simulation Environment



Evaluation of Shapes

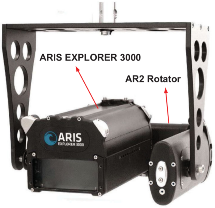


Proposed method [m]	d_A	d_{B1}	d_{B2}	d_C	d_{D1}
	0.313	0.316	0.305	0.581	0.388
	d_{D2}	d_{E1}	d_{E2}	d_{E3}	d_F
	0.420	0.323	0.222	0.235	0.430
Ground truth [m]	d_A	d_{B1}	d_{B2}	d_C	d_{D1}
	0.305	0.300	0.280	0.540	0.381
	d_{D2}	d_{E1}	d_{E2}	d_{E3}	d_F
	0.500	0.340	0.204	0.260	0.494
Absolute error [m]	d_A	d_{B1}	d_{B2}	d_C	d_{D1}
	0.008	0.016	0.025	0.041	0.007
	d_{D2}	d_{E1}	d_{E2}	d_{E3}	d_F
	0.080	0.017	0.018	0.025	0.064

REAL EXPERIMENT

Experiment Setting:

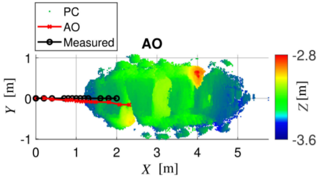
- ARIS EXPLORER 3000
- AR2 2-DOF Rotator



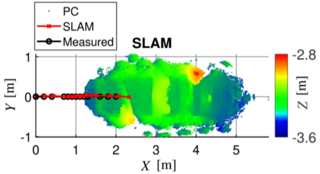
REAL EXPERIMENT

Experiment Result: Generated map with trajectory

Figure: (a) Map generated from AO with the estimated AO trajectory (b) Map generated from SLAM framework with the estimated SLAM trajectory



(a)



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Thank you for listening!

Abhishek Jayachandran

abhishekjay@cet.ac.in