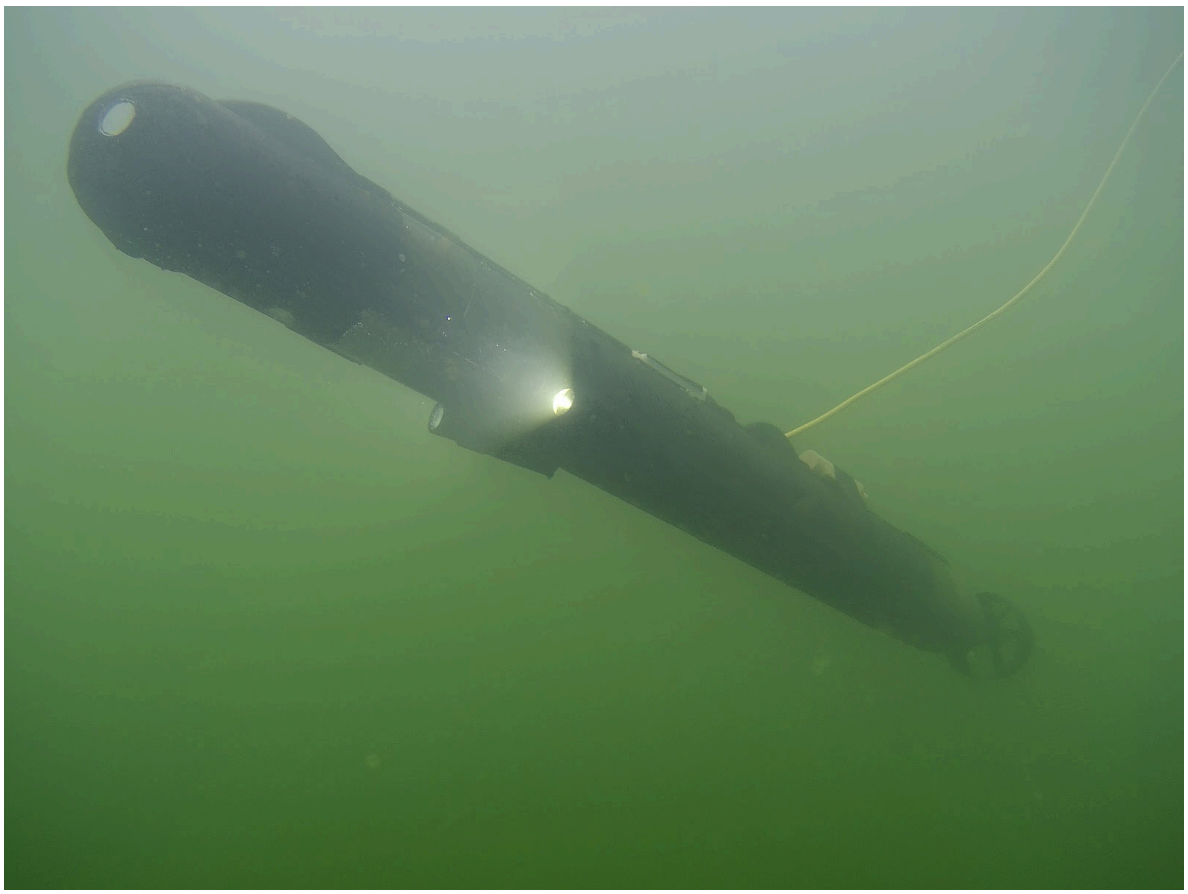
Underwater Robot Projects in SMaRC

We typically have 4-8 Master students projects running that can be thesis projects or for course credit in for example DD2411 or DD2414.



Background

Within the Swedish Maritime Robotics Center, SMaRC, we have developed both a small AUV, SAM, and a larger AUV, LOLO, with unique capabilities and sensors. One of the partners researches around cultivation of algae, SEAFARM. Those algae farms are one of the testbeds for our AUV technology. If inspection of the algae cultivation could be automated it would allow much larger and more efficient production. There are also surface and ROV vehicles.

The SAM AUV is currently equipped with Doppler Velocity Log (DVL), three cameras, sonar, depth and attitude sensors. The dead-reckoning and waypoint following system has been tested in field tests and demos. A model predictive controller has been developed. The vehicle has several innovative actuation features. For example, it can vary its buoyancy and center of gravity to adjust pitch roll and depth. Lolo is much larger and can carry a variety of sensors such as cameras and sonar.

Besides the AUVs themselves we have much data collected from More advanced AUVs such as the Kongsberg Hugin, as well as underwater data from industrial survey ships/ROVs. All this data can be used for testing of perception and navigation algorithms.

Simulators are an important tool for testing and evaluation. We have recently focused on the unity simulation environment but have used others each with strengths targeting a specific research area, such as modeling dynamics, cameras or sonars. We can load environments based on real bathymetric data and simulate collection of new data with our AUVs.

In early 2025 we will begin using a new test tank on campus equipped with a motion capture system. This will facilitate ground truth for such things as reinforcement learning of controllers, and pose estimation from vision systems.

We also have access to a dry dock in Stockholm where we have built a detailed 3D model of it when dry and then gone in when flooded to test out mapping and control algorithms.

In addition we carry out testing and demos in the seas around Sweden when weather permits.

Industrial partners include Ocean Infinity, Deep Vision, SAAB Dynamics and SAAB Kokums.

Possible Projects

1. **Pose estimation of an AUV team**: Using one way travel time modems one can estimate the distance from one or two lead surface vehicles to a team of AUVs doing a one pass survey of an area with sonar or cameras. THis could be done using Bayesian optimization. There is some need to do this real time in a good enough way to hold the formation but then post processing in an as good as possible way for data fusion such as in https://arxiv.org/pdf/2302.11614 . This could aso focus more on the control of the formation. Applications include high resolution ocean surveys and search.
2. **AUV launch and recovery from Drones:** Part of an ongoing project with Purdue and SAAB, ALARS, where we are developing a system to recover the SAM AUV with a drone. This work would tend to be more hands on with close simulation followed by actual trials on the vehicle. Parts of the system include, control of the drone, planning of the mission, detection and estimation of the AUV and recovery mechanism from the drone. simulation of high winds and sea state.

3. **Localization in the drydock:** Could use [UFOMap]() or other map representation to localize the AUV within the drydock using sonar or cameras. Alternatively do SLAM in the dry dock. The main results will be obtained in our Unity simulation with verification in the dry dock. This could be done using a combination of ICP and factor graphs or a particle filter. Unsupervised semantic segmentation would also be an excellent project used to build higher level map and or change detection.
4. **Neural representations of the sea floor:** Using neural rendering framework for self supervised learning of a bathymetric map, investigate adding more channels to the representation for such things as albedo, reflection 'law', or in some way estimating sound velocity profiles or pose using such an approach. Can we incorporate uncertainty estimates and correct updates to such models?
5. **Sim to Real:** Within our unity simulator we have developed a universal sonar module that can produce some of the basic characteristics of our sonars using ray casting. In this project we would like to train a neural net to learn the difference from simulated to real data in a way that would allow even more realistic simulations.
6. **System Identification**
   https://www.kth.se/profile/torroba/page/master-thesis-proposals

7. **Sampling Based Informative Path Planning – FLIPP (see below)**
8. **Sampling-Based Safe Return (see below)**
9. **More underwater projects with sonar, control, planning, ... Talk to us**
10. **More projects if you page all the way down.**

Merits for these projects include an interest in robotics, control and estimation. Proficiency in programming and deep learning can be beneficial. The student will be part of a dynamic team at SMaRC, and will receive support in the form of regular meetings with supervisors and colleagues.

Some key people in the group are:

Contact: johnf@kth.se John Folkesson, Faculty at RPL

Ivan Stenius, Leader of SMaRC at TekMek

Petter Ögren, Faculty at RPL

Nils Bore, Sonar Expert Ocean Infinity

Carl Ljung Research Engineer at TekMek,

Ignacio Torroba, Post-doc RPL/TekMek

Özer Özkahraman, Post-doc RPL

Li Ling, PhD student at RPL,

Aldo Teran, PhD student at TekMek,

FLIPP: Fast Lightweight Informative Path Planning

This Could Be You, Matti Vahs, Chelsea Sidrane, Ignacio Torroba

I. INTRODUCTION

Informative path planning is the task of intelligently choosing waypoints online during planning to maximize information gain and other objectives. Typically, a distribution over an unknown field such as a Gaussian process is maintained and updated in a Bayesian fashion using measurements taken along the chosen path. The most difficult part of informative path planning is accurately accounting for the value of future information. As each data point is collected, it changes the value of information that future observations can provide. While some approaches use greedy/myopic planning to select the next waypoint [1], state of the art approaches tend to use multi step planning horizons [2]. When using a long planning horizon, one must then condition the value of information gain for each potential new observation in the trajectory on the information gained by previous potential measurements in the planned trajectory. While there are many methods to approximate the Bayesian update [3], most still involve costly computation, limiting the length of the planning horizon.

II. GOAL

We propose combining a lightweight Gaussian process posterior approximation that we have developed with a fast sampling-based online planning algorithm, RT-RRT*, to perform fast, online, long-horizon conditional planning for information gathering. We compare our algorithm to other recent multistep conditional planners on the task of bathymetric mapping for AUVs and drones navigating an obstacle course. We hypothesize that our algorithm will gather information more quickly leading to accurate surrogate models of the unknown field in less time/distance traveled. We also expect our algorithm will enable longer planning horizons and/or have faster execution time than more computationally heavy methods. We will evaluate the algorithm both in simulation and on real hardware. If there is time, the project may explore extending from 2D to 3D planning.

III. PREREQUISITES

Prerequisites include an interest in robotic planning and information gathering, knowledge of differential equations, dynamical systems, strong programming skills in any high-level language (Python, Julia, C++, etc.), and basic knowledge of statistics. Desirable skills include knowledge of / experience with robotic planning algorithms, optimizing code for speed and parallelism, and experience with robotic hardware.

IV. NOTE

This is not intended as a master's thesis project but could evolve into one in future terms if the work goes well. We do expect to publish the results of this work.

V. CONTACT

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REFERENCES

[1] R. Marchant and F. Ramos, "Bayesian optimisation for informative continuous path planning," in 2014 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2014, pp. 6136–6143.

[2] P. Morere, R. Marchant, and F. Ramos, "Continuous state-action-observation pomdps for trajectory planning with bayesian optimisation," in 2018 IEEE/RSJ international conference on intelligent robots and systems (IROS). IEEE, 2018, pp. 8779–8786.

[3] I. Torroba, M. Cella, A. Ter´an, N. Rolleberg, and J. Folkesson, "Online stochastic variational gaussian process mapping for large-scale bathymetric slam in real time," IEEE Robotics and Automation Letters, vol. 8, no. 6, pp. 3150–3157, 2023.

Master's Thesis Project

Sampling-Based Safe Return for Autonomous Underwater Vehicles

This Could Be You, Chelsea Sidrane

Introduction

One of the major concerns in the operation of autonomous underwater vehicles (AUVs) is that they will get lost and run out of battery, rendering them unrecoverable. In response to this concern, this project will explore `safe return` path planning; where the vehicle always plans a path to return to its origin point within battery limits, while also pursuing other objectives. In this case, the vehicle will have an exploration objective. We propose to solve this problem using sampling-based motion planning as it is fast enough to use in real-time. If successful, we would like to test the method onboard the SAM AUV (pictured at right).

Sampling-based motion planning typically builds graphs or trees [1, 2] but the safe return problem necessitates that the first initial path is a cycle and subsequent paths return to the goal/origin point. Existing work on planning graph cycles for persistent monitoring exists [3], but needs to be adapted to the finite horizon case and combined with existing online methods [1] to construct subsequent trajectories that return to the origin [4], all while considering an exploration objective [2].

Goal

You will produce a novel algorithm, theoretical guarantees for the algorithm, a clean open-source implementation of the algorithm working in the SMARC simulator, and if time permits, demonstrate the performance on the SAM hardware platform (pictured above).

Prerequisites

Prerequisites include an interest in robotic motion planning and information gathering, strong programming skills in any high-level language (Python, Julia, C++, etc.), basic graph theory, basic knowledge of statistics, some exposure to formal proofs, basic knowledge of ROS[1]. Desirable skills include knowledge of differential equations or dynamical systems, knowledge of / experience with robotic planning algorithms, optimizing code for speed and parallelism, and experience with robotic hardware.

Contact

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References

[1] Some missing prerequisites can be fulfilled through completion of provided reading material or coursework in the semester preceding the project.

[1] Naderi, Kourosh, Joose Rajamäki, and Perttu Hämäläinen. "RT-RRT* a real-time path planning algorithm based on RRT." In *Proceedings of the 8th ACM SIGGRAPH Conference on Motion in Games*, pp. 113-118. 2015.
[2] Hollinger, Geoffrey A., and Gaurav S. Sukhatme. "Sampling-based robotic information gathering algorithms." *The International Journal of Robotics Research* 33, no. 9 (2014): 1271-1287.
[3] Lan, Xiaodong, and Mac Schwager. "Planning periodic persistent monitoring trajectories for sensing robots in gaussian random fields." In *2013 IEEE international conference on robotics and automation*, pp. 2415-2420. IEEE, 2013.
[4] Xin, Peng, Xiaomin Wang, Xiaoli Liu, Yanhui Wang, Zhibo Zhai, and Xiqing Ma. "Improved bidirectional RRT* algorithm for robot path planning." *Sensors* 23, no. 2 (2023): 1041.

Perception and Collision Avoidance for an Autonomous Hydrofoiling Craft

Are you interested in cutting-edge research in autonomous systems and hydrofoiling technology? Meet Evolo, an unmanned hydrofoiling craft developed at KTH. Evolo serves as a versatile research tool, enabling us to explore control concepts, sensor integration, and real-world usability for both civilian applications and defense. Right now, Evolo performs well in both remote control and autonomous waypoint missions. But we're aiming higher.

What's next?

We're enhancing Evolo's perception capabilities to enable collision avoidance and potentially SLAM (Simultaneous Localization and Mapping). We're experimenting with onboard cameras, FPV (First Person View) systems, head-tracking, and soon, a 360° LiDAR (currently being procured) to improve decision-making for safe and effective path planning.

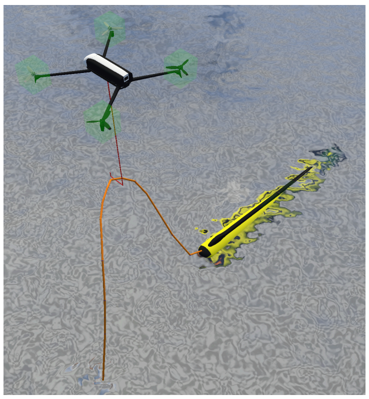
Where do you fit in?

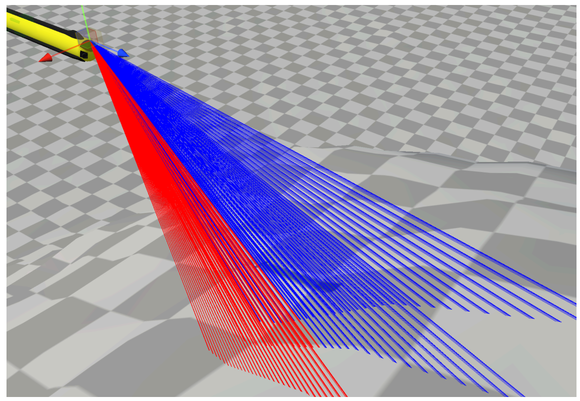
We need creative minds to help develop methodologies for onboard analysis, perception, and decision-making. If you're interested in autonomous systems, sensors, and maybe AI-driven decision-making, this is your chance to work on a real-world project that makes an impact.

Join us!

This is a unique opportunity to contribute to thrilling research and make your mark in the field of autonomous systems.

Contact: Jakob Kuttenkeuler: jakob@kth.se, 070-3464240





Simulating All the Things Underwater

All of the above things need to be tested and verified in a safe environment before they can be put on precious real robots. We have been working on an **open source simulator** based on Unity for a while for this purpose. It has *most* things already implemented, at least at the "it works" level. There are quite a few improvements that can be made to many aspects!

Some examples of things we would like simulated

- Realistic underwater currents
  - Produced by winds, propellers, moving bodies. A large sub will push things away just by moving.
- Water column effects on sonars
  - Ray bending -> refractions, reflections around other objects
  - Speed changes
- Seabottom "stuff"
  - Grass, grows all over and sways around
  - Rocks, scattered around with interactable geometry
  - Sand/Clay/Mud, things can leave a mark on the bottom!
  - Floating particles affected by currents
- Sea surface "stuff"
  - Foam: Floating, forming, dispersing
  - Algae: Swaying around in the currents~~
  - Fish: Swimming around with *some* behaviors
  - Traffic: Surface vehicles that are on "auto-pilot"
- Sub-bottom profiler sonar
- Accurate buoyancy for arbitrary shapes
- More accurate side-scan sonar imaging
- And so on…

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