Development of a Dynamic Localization Suite for Deployable Underwater Systems

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ABSTRACT

One of the biggest challenges of autonomous underwater navigation is accurate and reliable localization[1]. Without accurate estimation of localization, decisive control in the global frame, especially that of a 6 Degree of Freedom (DOF) vehicle, is not achievable. To address this problem, a suite package is developed to dynamically coalesce multiple localization methods. These include drivers for localization via apriltag fiducial markers and a triangulation localization using sonar sensors. This system allows the utilization of the specific strengths of different localization systems, such as accuracy, frequency of estimation, and applicable distance from any given Remotely Operated Vehicle (ROV) or Autonomous Underwater Vehicle (AUV). This provides an encompassing suite for localization in low-control and semi-controlled environments. In addition to the localization suite, two other drivers were created to decisively interact with the suite through either Robot Operating System 2 (ROS) or Lightweight Communications and Marshaling (LCM) communication respectively. The

localization suite and compatible communication drivers create a customizable and intuitive interface for positional and attitude estimation.

INTRODUCTION

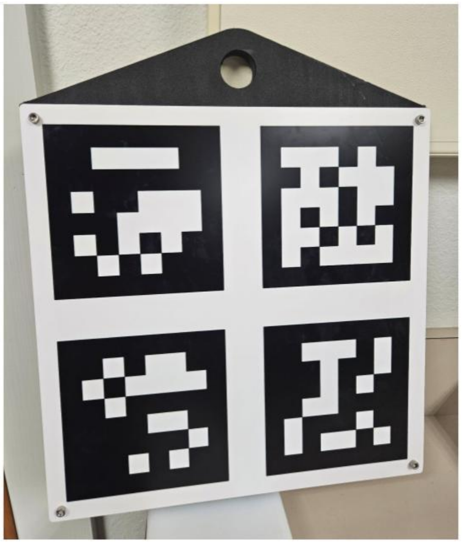

Fig. 1. Example of an Apriltag plate used in the test tank consisting of four Apriltags in a 2x2 square.

Prior to this system, the best localization estimator for our platform, the 6DOF Boxfish ROV[5], that MBARI currently offers is that from a Doppler Velocity Logger (DVL) sensor. The problem with the application of this relative sensor in testing and oceanic environments is that it incurs a natural drifting error. This error over time would eventually become too great for decisive control. To mitigate the incurred error, a global-based localization method is integral. In addition to this, With the eventual multiple sources of localization available, a parsing system is needed to derive a best position estimation from these sources.

To address these problems, two customizable global-based localization drivers were developed. The first of which uses the Fiducial Apriltag markers, onboard camera visual processing, and vector manipulation to derive an estimation in the global frame (a sub-module video driver was also created for this process). The second uses sonar and triangulation between a beacon attached to the robotic device and sonar receivers deployed in the water. The foundation for this second system is Waterlink's underwater Global Positioning System (uGPS)[2]. As mentioned, a localization parsing suite, which is able to intelligently combine multiple localization estimations over LCM communication, was also developed.

DEVELOPMENT

VIDEO/IMAGE DRIVER

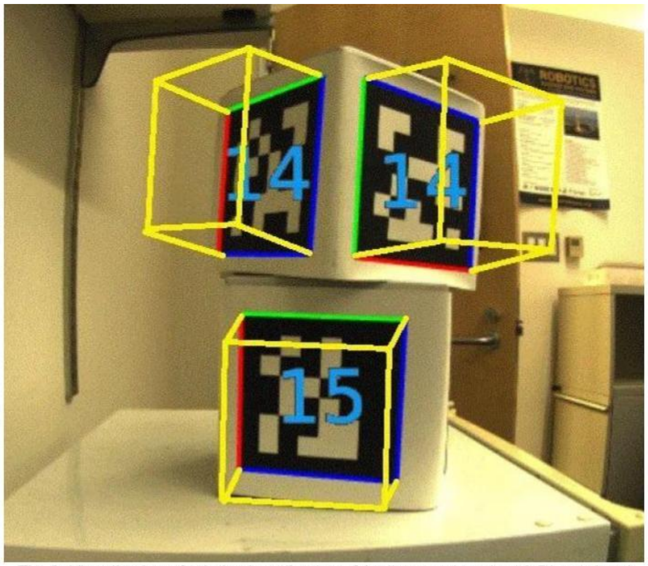

Fig. 2. Visualization of relative Localization of Apriltag markers in a 3-Dimensional space. Retrieved from https://docs.wpilib.org/en/stable/_images/homography.webp.

To first be able to process images for computer vision and localization, the images must first be collected and encapsulated. These images can come from a variety of sources: A webcam's video feed, images in a stored location, broadcasted through the network, and inserted into a directory in real-time. Each of these sources comes with its own process and challenges.

To streamline and ease this process, a python-based video driver was created that abstracts and parameterizes the variability of image source. This way, through a unified function, the image for processing can be provided without any accountancy for its source type. This driver was utilized for apriltag localization (seen below), but can have any other application where images are processed from video feed.

APRILTAG-BASED LOCALIZATION

The first localization system developed is one that utilizes Apriltag Fudicial Markers (Fig. 1). To detect and generate a vector from these Apriltags, the public python library, dt-apriltags, was used[3]. Using an ROV on-board camera, the image of the Apriltag goes through a pipeline of filters to preprocess the image. In the final preprocessed image, Apriltag markers and their unique identification integer are detected. After identification, using the distortions of the camera and known dimensions of the Apriltag, a 3-dimensional position and orientation of the tag relative to the camera can be calculated (Fig. 2.). This relative orientation and

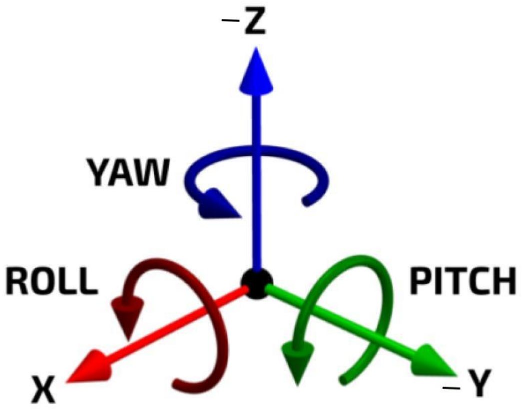

Fig. 3. Example of the 6-degrees of freedom convention used. Retreived from https://yasincapar.com/contact-types-and-behaviours-in-structural-analysis/

position is of the form of a 6-DOF vector relative to the frame of the camera, with related axis as shown in Fig. 3.

If the global position and orientation of the tag detected is known, then the relative vector can be rotated to match that of the global frame. The new relative vector in the global frame can then be added to the global positional vector of the detected apriltag to get the global position of the camera. To execute vector rotations, the Scipy Rotation module was used[4].

UGPS SONAR BASED LOCALIZATION

The second localization estimator used with our system is that of the underwater GPS sonar-based estimator from Waterlinked[2]. This system works by deploying receivers into the water that are connected to a topside base station as in Fig. 4. A remote beacon is attached to the robot which sends out sonar pings and communicates with the receivers. Using the time of signal travel, the distance from the beacon to all of the receivers can be calculated. With these distances, and a concrete depth using a pressure sensor, the position of the robot can be triangulated. This system only provides position, and not orientation estimations.

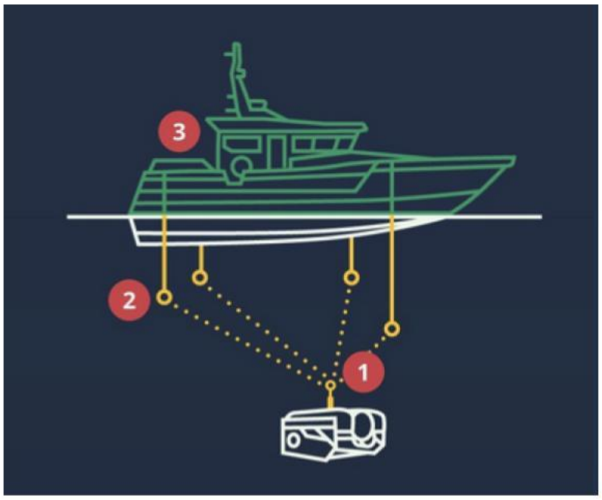

Fig. 4. Example of how the uGPS system works in deployment. Marker 3 - Base station. Marker 2 - Receivers. Marker 1 - Beacon.

After receiving the positional estimations from the topside unit, communication drivers were developed to translate the signals to ROS and LCM protocols respectively in accordance with the communication structure explained in the following section.

ROS/LCM FLEXIBLE STRUCTURE IMPLEMENTATION

The above-mentioned Apriltag and UGPS localization drivers (modules) were also developed with the capability of communication broadcast over the choice of LCM or ROS. The module and sub-module structure is depicted in Fig. 5. Essentially, the communication portion of each module is broken up into a layer in a pipeline while all of the core logic for the module runs on a separate/detached layer. This way, The appropriate communication layer can be installed and still use the original core logical code for the module without excess installation or redundancy.

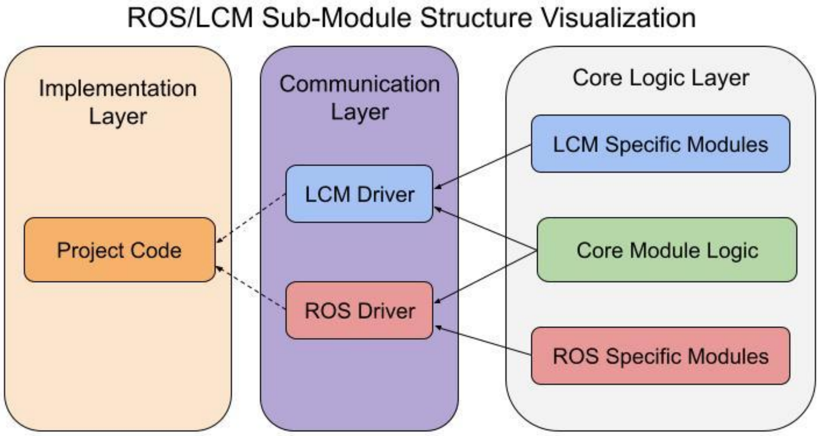

Fig. 5. Visualization of the Sub-Module structure created which separates communication and implementation into separate layers.

EXPERIMENTAL RESULTS

SIMULATION VALIDATION

Before deploying systems for experimentation and testing in a physical test-tank, the experiments are run in a simulator which can mimic the testing environment. This is to reduce equipment and/or personnel harm by ensuring that systems work correctly before

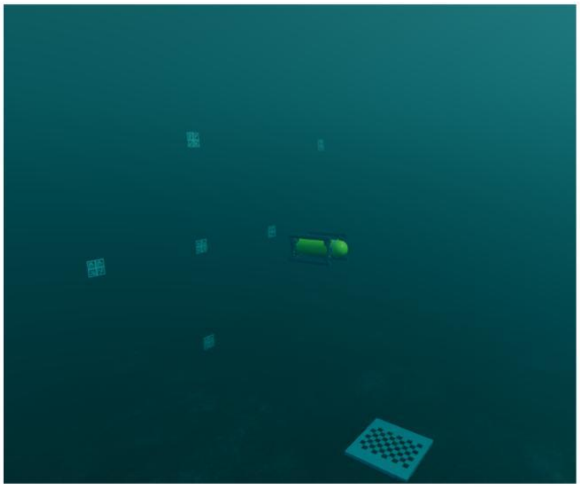

Fig. 6. Depiction of the replicated test tank Apriltag layout along with the ROV in the simulation

moving to the physical system. The simulation offers the same interface as the physical system which means that when testing is completed in the simulation, the exact logic and communication can be used for the physical experiment.

Simulation was used to validate the apriltag detection and localization system. Using a replication of the test tank environment (Fig. 6.), the estimated Apriltag position was compared to that of the ground truth localization of the simulator. The graphs and comparison provided promising results which can be viewed in Fig. 7. The data stream from these estimations were used for a control experiment where the simulated device followed a trajectory path using a past developed controller and the Apriltag estimations. The device movement was shown as smooth and controlled, which was exactly what we were looking for from the localization estimations.

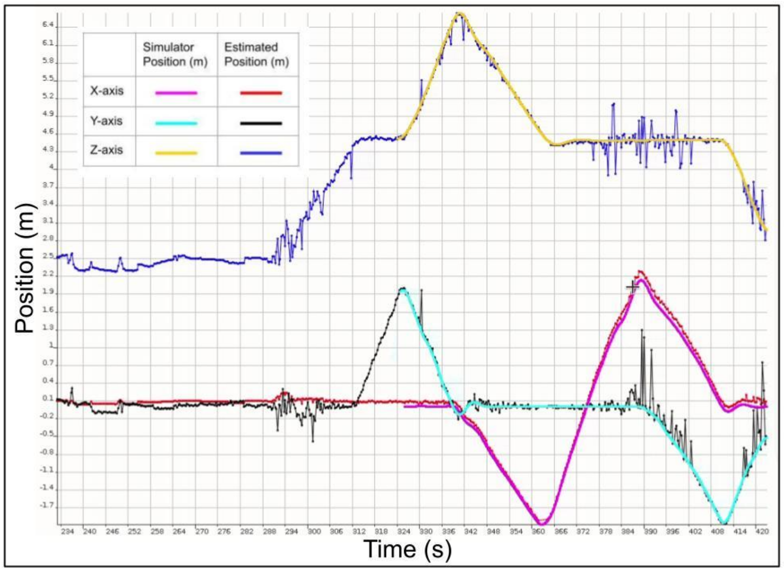

Fig. 7. Graph depicting the apriltag localization estimation (neon colors) vs the ground-truth position in the simulation experiment of the system.

TEST-TANK DEPLOYMENT

After validation in the simulator to ensure all systems were working as expected, the localization systems were deployed in the physical test tank at MBARI for further testing and comparison. The Apriltag localization system was what was tested the most thoroughly during these experiments. It was found that the raw Apriltag Localization estimation data is very noisy (Fig. 8.). This volatility was found to be from environmental factors like the lighting of the room, resolution of the camera, calibration of the camera, and ground-truth errors in the known apriltag plate locations. Unlike the simulator, this volatility in the data was too much for control of the device, and more work is needed before closed-loop control is implemented.

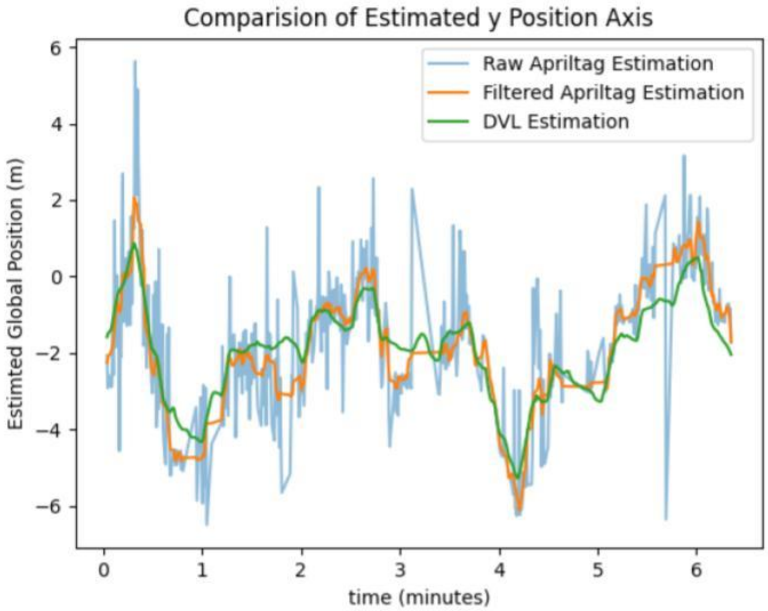

Fig. 8. Positional data comparing the DVL sensor and the Apriltag Location estimations during an experiment in the test tank.

Data from the uGPS data was received, and under a rough estimation, worked accurately and at an expected frequency. This data, though, was not collected and can not yet be validated with any other Localization systems.

CONCLUSIONS/FUTURE WORK

The tools and systems developed during this internship provide a reliable and flexible program structure with many applications outside the scope of the project. This section summarizes the tools and systems created during the course of the internship and where they can be improved upon:

UGPS/APRILTAG ESTIMATOR DRIVERS

The uGPS and apriltag localization plates and sensors are now installed and ready to be used in the MBARI test tank for experiments that can benefit from global localization as opposed to relative estimators which were used beforehand. The drivers and interfaces developed for these systems offer many customizable features to tailor the estimators to the certain application. While the localization of the Apriltag estimator was shown to be noisy in the test tank experiments, there are plans to reduce this noise by tuning a filter for the localization estimation stream from the system. Other logic can also be implemented to ignore extraneous estimations in error as well as a more intelligent combination of other estimators to validate and calibrate each other.

Until this volatility in the global localization data is alleviated, fine-tune control will not be possible. This means the docking procedure that the system was originally developed for was unable to be completed in a physical experiment in the MBARI test tank.

LOCALIZATION COALITION SUITE

The localization suite that was developed is a good way to streamline and dynamically combine multiple global localization estimates of a device. Though the suite is now able to coalesce a dynamic number of estimators with weighted importance, more improvements can be made to more intelligently combine different estimations. This can include a separate tiered system of estimators that take priority when available over other estimators. This way, when more accurate localization estimations are received, less accurate estimations can be ignored. This can be in conjunction with the current weighted system so that if two estimations are of equal accuracy, their values can be combined into a weighted average for a final estimation which incorporates all sources. Finally, the suite can be improved to be able to receive and shift relative estimators. This way, on-board estimators which only provide relative localization can then be converted to a global frame and contribute to the final estimation.

VIDEO/IMAGE DRIVER

The image driver developed offers streaming images for analysis from a variety of sources in a streamlined interface. This system can be improved upon by offering more sources to the suite for a greater range of applications. Another place of improvement can be to improve the parameterization and ussr interface for implementation. There are many parameters for this driver, and some require certain keywords that are not publicly available through the driver. Offering better explanations of the parameterization of this system can improve user experience.

ROS/LCM STRUCTURE

The ROS and LCM dynamic structure offers a system that is able to layer and abstract out communication of drivers. This way, neither ROS nor LCM is required from any given system or computer, and instead the choice can be made to use either. One Problem with this system is the slight redundancy of the actual interface using LCM and ROS. Since the two communication systems are very similar the interface between them is also very similar, causing almost identical code between the scripts on the communication interface layer. A way to mitigate this is to create a third general communication interface. This third communication type will then be converted systematically into either ROS or LCM communication. This would reduce and replace all the separate scripts involved in the communication layer and only one script will be needed for communication instead of many special case scripts as it is now.

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