MAPPING AND LOCATION FOR NASA SAMPLE RETURN ROBOT CHALLENGE

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Abstract: A simultaneous location and mapping solution is proposed and developed for the NASA Sample Return Robot Challenge. The solution uses an Extended Kalman Filter to initialize scan matching using Iterative Closest Point to obtain pose estimates in real time. These pose estimates are further refined in a background thread using GraphSLAM. The solution offers improved accuracy in pose estimation within a simulation environment.

1. INTRODUCTION

The NASA Sample Return Robot Challenge (NSRRC) requires the design of an autonomous robot to explore a large area of outdoor terrain, collect a number of samples of interest, and then return to its starting location. The competition is intended to simulate an extra-terrestrial mission so sensors that would not operate on such a mission (eg. GPS and compass) cannot be used.

A key part of any autonomous robot is a localization system that allows the robot to determine where it has travelled within its environment. This system is especially important for the NSRRC as time is limited and planning an efficient exploration path requires accurate knowledge of the robot's previous positions.

The design team's goal for this project was to develop a simultaneous location and mapping (SLAM) algorithm that could use information from wheel odometry, an Inertial Measurement Unit (IMU), and a 360^{o} laser range scanner (LiDAR).

2. BACKGROUND

A study of the current state of the art found that very few techniques exist for estimating the location and orientation (together called the pose) of a robot in a 3-dimensional environment in real-time. Most real-time solutions to the SLAM problem were developed for indoor environments with a level ground plane and simple obstacles, where 2 dimensions (3 degrees of freedom (DOF)) are sufficient to represent the environment. Most 3-D (6 DOF) SLAM solutions are used to reconstruct a map of the robot's path in post processing.

Three general techniques have been used with the allowable sensors for the competition. The first technique is the use of a Kalman Filter to integrate the separate measurements from the IMU and wheel odometry to obtain a better estimate of the pose than could be obtained from either source independently. A Kalman Filter works by estimating an update to the pose based on the motion model of the robot and applying a correction to that estimate based on a measurement from a sensor [1]. Kalman filters accrue error over time, as each estimate is based on the previous estimate only.

The second general technique used is called scan matching. This is the process of estimating the relative locations at which two scans of the environment were taken. Using this information the change in the position of the robot can be estimated. Iterative Closest Point (ICP) is a well-known scan-matching algorithm [2]. It determines the rotation and translation between two pose scans by iteratively determining the rotation and translation that will minimize the difference between corresponding points in the scans. Corresponding points are assumed to be the nearest points. Scan matching also accrues error over time as the last position is used to calculate the next.

The final general technique uses the entire history of scans and pose estimates to create a linear constraint graph and then minimize the error in the constraints. This technique, known as GraphSLAM, uses observations common to multiple scans to refine previous estimates of the robot pose. 6-DOF GraphSLAM has not traditionally been used in real-time SLAM solution due to its high computational complexity [3]. GraphSLAM recalculates the entire pose graph each time it is used, and redistributes the error across the entire graph.

The proposed solution combines these three techniques in a novel and effective way.

3. PROPOSED SOLUTION

Building within the Robot Operating System (ROS) environment, the proposed solution incorporates all three localization techniques. A

Kalman Filter is used to integrate wheel odometry and IMU measurements and the pose estimate from the filter are used to initialize ICP. ICP is then run on a reduced set of points from the last two laser scans to obtain a better estimate of the robot's motion.

Simultaneously, a background thread is initialized for running GraphSLAM on the refined poses outputted from ICP. After enough poses have been collected, GraphSLAM outputs a further improved path estimate for the robot. Since it takes significant time to relax the pose graph, the output of GraphSLAM is used to update all of the poses that have been calculated using ICP since GraphSLAM began, improving any future estimate of the pose. The block diagram of the solution is shown in Figure 1.

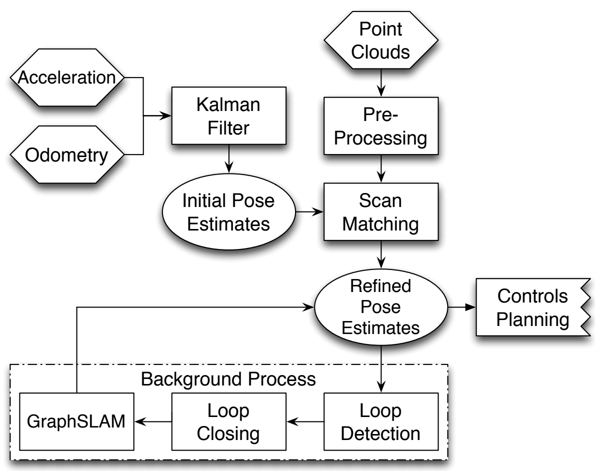

Figure 1: Block Diagram of Proposed Solution

4. Implementation

The proposed solution was implemented using a multi-threaded ROS Node which was available both for testing in simulation and can be used directly on the final robot. The node uses implementations of ICP and GraphSLAM from 3D-Toolkit developed by Nüchter et al [4]. The completed node will be run on a single powerful laptop for the competition and was tested in the same way.

5. Testing and Results

The completed solution was tested within a simulation environment created by the design team. The environment includes rolling terrain as expected for the competition along with features such as rocks and trees. Several data sets were collected from the environment and used for testing the localization.

During testing it was found that the proposed solution is a viable method of calculating the robot's pose in real-time. The error in the pose estimates for one particular data set is shown in Figure 2. The proposed solution is an improvement over using the results from the EKF directly (magnitude of error shown in blue) or using just ICP (magnitude of error shown in green).

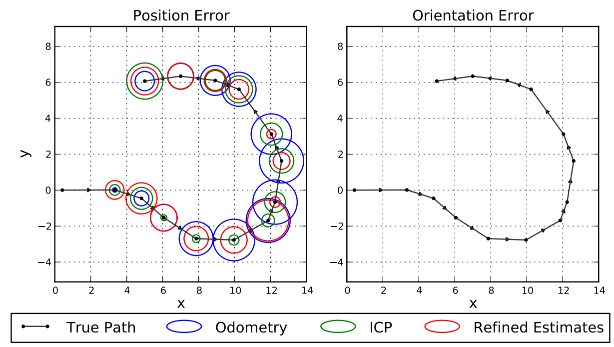

Figure 2: Error Results

There remain instabilities that need to be investigated in the final ROS node. Occasionally, when running on longer data sets, the node encounters numerical issues inverting and calculating matrices. These issues will be investigated using real-world data when the solution is integrated onto the competition robot.

6. Conclusion

A real-time 3D SLAM algorithm was proposed and built that uses scan matching in the foreground along with graph relaxation in the background to obtain accurate estimates of robot pose from 3D laser scans for the NSRRC. The results obtained demonstrate an improvement over several of the traditional real time 6-DOF location and mapping techniques, including Kalman Filtering and ICP Scan matching in isolation.

References

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