論 文 の 内 容 の 要 旨

論文題目　Study on Localization Assistance for Mobile Robot Navigation using Probabilistic Pose Estimation Techniques
(確率的ポーズ推定法を用いた移動ロボットの位置同定支援手法に関する研究)

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This thesis puts forward the notion of assistance for autonomous mobile robot navigation. The conventional approach to autonomous navigation is to make the robots as intelligent as possible to tackle with the environment. Such a strategy can often run into pitfalls as there is no way to program the robots for all scenarios that can arise. Humans tend to depend on some assistance, sometimes unintentionally, to save both the effort and time spent on navigation. This human behavior can be imitated in autonomous navigation for mobile robots, which motivates us to come up with a robot assistance scheme. Such an assistance system can act as the missing building block to provide fully autonomous capabilities for mobile robots to navigate in real, complex environments.

The main concepts of the proposed localization assistance scheme are as follows: i) The mobile robots that need assistance are detected, tracked and managed by an agent acting as the “assistant”. ii) Tracked data are transformed into localization information and are relayed back to the mobile robots as “localization assistance” using communication devices. iii) The assistant can either be stationary or mobile, depending on the size of the environment. iv) The mobile assistant refines its self-localization with the help of other mobile robots. v) To deal with uncertainties in sensing, actuating, and system modeling etc., probabilistic methods have been employed.

In the first stage, a stationary assistant is proposed for real, populated indoor environments. The stationary assistant senses the environment using a laser range finder (LRF) and a camera based sensor unit while the environment modification is kept at minimum. Using Rao-Blackwellized particle filter (RBPF) technique, localizations of the robots that need assistance are estimated. RBPF makes sure the data association problem is handled robustly. A novel method to track only the mobile robots in crowded environments by changing the LRF placement and by making a modification at the robot platform is proposed. The proposed method can detect mobile robots even in complex environments. Two mobile robots were simultaneously navigated in given trajectories successfully using real-time assistance data, which shows the validity of the proposed scheme for simultaneous localization assistance for multiple mobile robots.

In the second stage, a new mobile assistance scheme is proposed for large environments, since the coverage of a stationary assistant is limited. A planetary environment is considered for the implementation. Due to the cost factor and success of deployment, the number of rovers is restricted to two; a mobile assistant (master) plus a general rover (scout). Master rover has LiDAR, IMU and wheel encoder sensors while the scout has IMU and LiDAR sensors. Mobile assistant should be able to maintain accurate self-localization to assist other mobile robots. In order to do so, two strategies are employed. First, the rovers use a leap-frog motion strategy. That is, as long as the scout rover is moving inside the masters coverage area, master remains stationary. When the scout goes outside the coverage region, the scout is stopped and the master follows the scout. Second, the scout rover observes the environment while it is moving, and relays this information back to the master to be used in future when master rover is moving.

For rough and uneven terrains, the scout relays terrain point clouds to the master. A novel state variable extension (SVE) method is proposed by combining the relayed terrain point cloud with rover kinematics to improve the self-localization of the master. SVE establishes a connection between state variables of full 6-DOF pose of an outdoor rover. With this approach, the number of effective state variables to be estimated has been reduced from six to three. This reduction allows a particle filter to maintain a lesser number of particles. The results show that when the 2D state variables (x, y, yaw) are known, the 2D state can be extended to its 3D state (x, y, z, roll, pitch, yaw) successfully. Finally, the proposed SVE method is employed in a particle filter to determine the 2D state variables, which in turn results in achieving the full 6-DOF position tracking of the rover. The proposed method also assures the validity of the estimated 6-DOF poses on a given terrain through SVE method. Once the master (assistant) maintains improved self-localization accuracy while moving on rough terrain, the scout receives accurate localization assistance from the master.

SVE works well in rough, uneven terrains, but yields poor results on even, flat terrains. Thus, in the proposed scheme, instead of relaying terrain point cloud data, scout relays rock landmark information to master when the terrain is flat and even. With these landmarks (tethered landmark initialization), master performs EKF SLAM to estimate its pose when it moves. In tethered landmark initialization, scout rover observes and initializes landmarks that are outside the observable region of the master. Virtual loop closing occurs when the master observes those landmarks directly. This new inverse observation model, together with EKF SLAM and leap-frog motion, which is named as "Cooperative Positioning SLAM (CPSLAM)," minimizes the localization error for the master, which in turn results in improved localization accuracy for scout through localization assistance. The results show that when the motion model is weaker than the observation model, which usually the case in rough outdoor environments, the proposed method yields superior results when compared to the conventional SLAM method.