Title:	Smart Control Strategies for Autonomous Navigation of Multi-robot Systems
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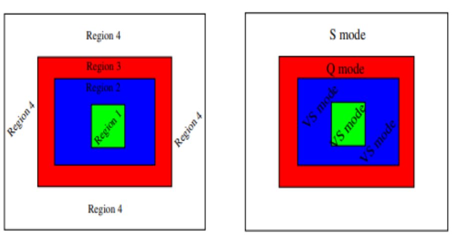
Abstract:

Some of the key challenges in the field of autonomous navigation of robotic systems are: (1) visibility of features; (2) finite-time convergence; (3) robot control and estimation in a single loop; (4) adaptive trajectory tracking without reusing the trajectory planner; (5) collision-free trajectory tracking in formation in the presence of disturbances. In this thesis, we provide some innovative solutions to some of these challenges. A unique design of a hybrid approach to robust visual servoing has been developed which enables an autonomous ground vehicle to reach the home location even when the visual marker momentarily disappears from the camera field of view due to external disturbances. A vision integrated model for non-holonomic mobile robots is derived to directly relate feature motion to the vehicle motion. A fractional order sliding mode controller has been designed where the parameters of the sliding surface are adapted in real time. These adaptive laws are derived to ensure finite time convergence. An optical flow based heading restoration law is combined with the reinforcement learning to solve the visibility problem. The challenge of controlling the mobile robot while simultaneously estimating the camera to mobile robot transformation is solved. This is achieved using Gradient Descent based estimation and the sliding mode approach. Estimation of robot-to-camera parameters in a single experiment, robustness with respect to accidental camera displacement, performance in the presence of noise and inaccuracies are the highlights of this work. Dynamic Movement Primitive (DMP) which is a popular form of motion planning of a robot manipulator, has been adapted for a nonholonomic mobile robot, in order to track the desired trajectory. Two Radial Basis Function Networks (RBFNs) have been used to learn the forcing function associated with the DMP model. Steering angle dynamics is proposed to handle the asymmetric nature of an obstacle. The proposed scheme is capable of generating a smooth trajectory in the presence of an obstacle even when start and goal positions are altered, without losing the spatial information embedded while training. The approach has been extended to multiple static and dynamic obstacles for the successful convergence of the robot at the goal position. The proposed scheme offers the online goal adaptation, adaptation to different initial points, conservation of shape, and obstacle avoidance, without the need to reuse the trajectory planner for a new path, thus reducing the computational cost and providing much flexibility. The proposed approach addresses issues that are found in warehouse automation and elderly health care. The displacement based formation control problem for perturbed multi-robot systems, with practical issues like collision avoidance and connectivity assurance, is a challenging problem. We present and implement a two-step design process consisting of both holonomic and non-holonomic frameworks. Human demonstrations have been used to obtain the parameters of the desired trajectory. In the holonomic framework, each virtual robot

is described as a double integrator system. This framework generates a set of reference trajectories. The idea is to feed these generated reference points for the mobile robots to track under a non-holonomic framework. This work formulates control laws under which multiple mobile robots simply connected are stable while ensuring collision avoidance and connectivity. Both holonomic and non-holonomic models are subjected to external disturbances. In the holonomic framework, the proposed controller ensures collision avoidance and connectivity while maintaining the desired formation. The proposed controller in the non-holonomic framework tracks the reference trajectories while guaranteeing Lyapunov stability. Demonstrated path tracking in formation by a set of nonholonomic mobile robots, with practical issues like collision avoidance and connectivity assurance, is a challenging problem. This problem becomes more challenging when there is a need to change the formation pattern during the task. We present and implement an integrated approach along with a smooth switching mechanism to solve this problem. A process of demonstration is used to obtain the parameters of the desired path of interest. A novel transition mechanism is designed to ensure the smooth transition in finite time, from a current formation to the next required formation. We demonstrate that the proposed approach enables a group of non holonomic mobile robots to navigate along the demonstrated path of interest while acquiring, maintaining, and switching the formation without collision under limited sensing range. The implementation issues of the proposed approaches have been tested through rigorous perturbation studies conducted based on real-time experimentation. Various dynamic environment scenarios are evaluated to verify the capability of the proposed methods. It has been shown that the proposed strategies are versatile enough to solve some of the real world practical problems from industrial point of view.

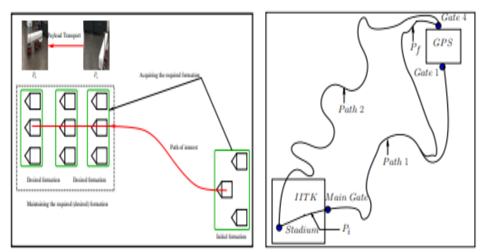


Regions | Modes

Figure 2.3: Various regions and modes to implement hybrid approach

Robot with onboard camera and laptop

Marker



(a) (b)

Figure 1.1: (a) Payload transport by a group of mobile robots; (b) Map

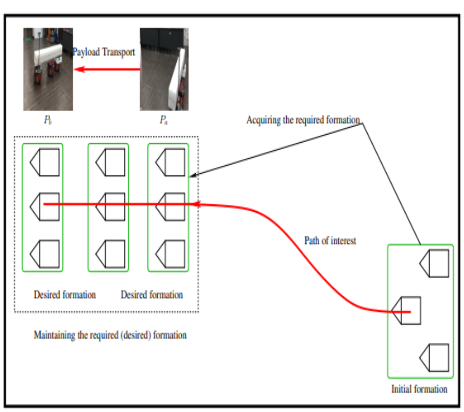


Figure 5.1: Payload transport by a group of mobile robots

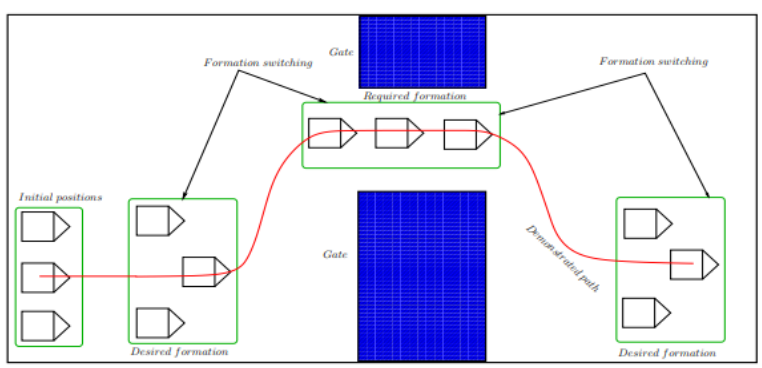


Figure 6.1: Pictorial representation of a practical problem and necessity to change the formation for multi-robot systems.