

CALU: Collision Avoidance with Localization Uncertainty (Demonstration)

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ABSTRACT

CALU is a multi-robot collision avoidance system based on the velocity obstacle paradigm. In contrast to previous approaches, we alleviate the strong requirement for perfect sensing (i.e. global positioning) using Adaptive Monte-Carlo Localization on a per-agent level.

Categories and Subject Descriptors

I.2.9 [Artificial Intelligence]: Robotics

General Terms

Algorithms, Experimentation

Keywords

multi-robot systems, optimal reciprocal collision avoidance, adaptive monte-carlo localization

1. INTRODUCTION

Local collision avoidance is the task of steering free of collisions with static and dynamic obstacles, while following a global plan to navigate towards a goal location. Local collision avoidance differs from motion planning, global path planning and local path planning. In motion planning the environment of the robot is assumed to be deterministic and known in advance, thus allowing to plan a complete path to the goal. Global path planners usually operate on a static map and find either the minimum cost plan (e.g. using A* or Dijkstra's algorithm) or any valid plan (e.g. sample based planners). Local path planners, such as Trajectory Rollout and Dynamic Window Approaches (DWA), perform forward simulations for a set of velocity commands; each resulting trajectory is scored based on proximity to the goal location and a cost map built from current sensor data. In principle this allows to stay clear of dynamical obstacles; however, in multi-robot settings two problems arise:

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1. Robots are not merely dynamic obstacles; each robot itself is a pro-active agent taking actions to avoid collisions. Neglecting this might lead to oscillations and thus highly inefficient trajectories or even collisions.
2. The sensor source (e.g. laser range finder) is usually mounted on top of the robot's base to allow for a maximal unoccluded viewing angle. In a system with homogenous robots this implies that there is very little surface area that can be picked up by the sensors of other robots and thus prevents the robots from observing each other.

Local collision avoidance addresses these challenges and is an important building block in any robot navigation system targeted at multi-robot systems. Although robot localization is a requirement for collision avoidance, most approaches assume perfect sensing and positioning and avoid local methods by using global positioning via an overhead tracking camera - or are purely simulation based. Nevertheless, to be able to correctly perform local collision avoidance in a realistic environment, a robot needs a reliable position estimation without the help of external tools.

Our approach, Collision Avoidance with Localization Uncertainty (CALU) builds on two techniques: Optimal Reciprocal Collision Avoidance (ORCA) [3] in combination with Adaptive Monte-Carlo Localization (AMCL) [1]. Thus effectively alleviating the need for global positioning by decentralized localization on a per-agent level. We provide a solution that is situated in between centralized motion planning for multi-robot systems and communication-free individual navigation. While actions remain to be computed independently for each robot, information about position and velocity is shared using local inter-robot communication. This keeps the communication overhead limited while avoiding problems like robot-robot detection. CALU bounds the error introduced by localization [2] and combines the computation for collision-free motion with localization uncertainty.

2. PROBLEM DESCRIPTION

ORCA (and all its variants) does not require any inter-robot negotiation to find optimal collision free motion trajectories and is hence in principal fully distributed. However, all methods require perfect information about the positions, velocities and shapes of all other robots. In order to preserve the distributed nature of this approach, robots need to

be able to accurately identify other robots using on-board sensors; furthermore, positions and velocities have to be deduced from the same data. The list of typical sensors for mobile robots includes stereo cameras, laser range finders and lately 3D image sensors (e.g. Microsoft Kinect). These sensors deliver large data-streams that require considerably computational power to process even for the detection and classification of static obstacles.

The computational requirement is not the only problem when considering robot-robot detection. As low-end laser range finders (e.g. Hokuyo URG-04LX) become widely available even for mobile robotic projects on a small budget, they are the preferred sensor choice due to their high accuracy, resolution and field of view. However, robot-robot detection based on laser range finders remains challenging.

Previous approaches have worked around these problems by providing global positioning to all robots based on an overhead tracking camera. Such a system is not distributed since a host computer connected to the camera needs to process the sensor data and communicate with all robots to provide position and velocity data.

3. APPROACH

We propose to utilize agent-based localization and inter-robot communication to provide a system that is more realistic in real-world scenarios (i.e. without the need for external positioning data) and also more robust (i.e. single component failure does not lead to system failure). Our approach, called Collision Avoidance with Localization Uncertainty (CALU), results in a fully decentralized system that uses local communication to share robot state information in order to ensure smooth collision free motion. Below we describe the four key components of this approach.

Platform: The robots are assumed to be differential drive robots. Required sensors are a laser range finder and wheel odometry. For simplicity we assume a circular footprint; other shapes can be approximated by the circumscribed radius. In order to connect the different subsystems, including device drivers and software modules, we use ROS¹.

Sensor processing and localization: Each robot integrates wheel odometry data which is in turn used to drive the motion model of AMCL, hence tracking the pose of the robot. Laser range finder scans are used in the update phase of AMCL. The uncertainty of the current localization, i.e. the spread and weight of the particles, is taken into account for the calculation of collision free velocities. We assume a prior static map that is used for localization and available to all robots, thus providing a consistent global coordinate frame.

Inter-robot communication: Each robot broadcasts its position and velocity information in the global coordinate frame on a common ROS topic. Each robot also subscribes to the same topic and caches position and velocity data of all other robots. Message delays are taken into account and positions are forward integrated in time according to the motion model of robots using the last known position and velocity information.

Collision avoidance: ORCA is used to compute optimal collision free velocities according to the aggregated position

¹For more information see: <http://www.ros.org>

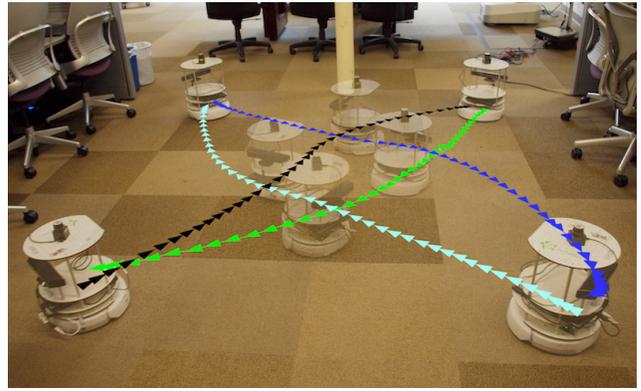


Figure 1: Real-world collision avoidance with four differential drive robots using CALU.

and velocity data of all surrounding robots. As a last step we incorporate localization uncertainty in the ORCA computation.

4. DEMONSTRATION

We will demonstrate our approach in simulation and a real-world setting. In simulation, robots are positioned on a circle and the goals located on the antipodal positions, i.e. each robot's shortest path is through the center of the circle. For experiments and detailed results of the proposed system, we refer to [2].

In addition to simulation runs, we present our approach on up to four differential drive Turtlebots². The robots are based on the iRobots Create platform and have a diameter of 33.5 cm. In addition to the usual sensors, they are equipped with a Hokuyo URG laser-range finder to enable better localization in large spaces. All computation is performed on-board on a Intel Atom D525 1.8GHz dual core CPU netbook. Communication between the robots is realized via a 2.4 GHz WiFi link.

Figure 1 shows the trajectories of an example run of the four robots using CALU. The initial positions are approximately 3.5 meters apart; the goal location are set to the diagonally opposing start locations. The system successfully avoids collision and produces smooth paths; except for a small jump in the localization that can be observed in the path of robot starting in the upper right corner.

A demonstration video is available at:
<http://swarmlab.unimaas.nl/papers/aamas-2012-calu/>.

5. REFERENCES

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²For more information see: <http://turtlebot.com>