

MULTI ROBOT OPTIMAL TRAJECTORY GENERATION

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ABSTRACT. Abstract.

KEYWORDS: multi robot path planning, mobile robot.

1. INTRODUCTION

The command and control of mobile robots is a long-standing subject of research in the iterative robotics domain. As many modern companies started to adopt mobile robot systems such as fleets of autonomous forklift trucks to improve their commercial performance, this subject becomes increasingly important and complex. Especially when those robots are executing their tasks in human-occupied environment.

One basic requirement for such robotic systems is the capacity of generating a trajectory that connects two arbitrary configurations. For that, different constraints must be taken into account, in particular:

- kinematic and dynamic constraints;
- geometric constraints;
- and constraints associated with the uncertainties in the robot's "belief" in the world state.

The first constraints derive directly from the mobile robot architecture implying in nonholonomic constraints for many types of mobile robots. Geometric constraints come from an impossibility for the robots to assume some particular configuration due to the presence of obstacles or bounds in the habited environment. Uncertainties constraints come from the impossibility for the robot to have an absolutely perfect perception of the world (including its own state).

In recent years, a great amount of work towards collision-free trajectory planning has been done. TODO STATE OF ART.

In this paper, we focus on the development of a trajectory planning algorithm. This algorithm finds collision-free trajectories for a multi robot system in presence of static obstacles which are perceived by the robots as they evolve in the environment. The dynamic trajectories found are near optimal with respect to the total time spend going from the initial configuration to the final one. Besides, this algorithm uses a decentralized approach making the system more robust to communication outages and individual robot failure than compared to a centralized approach. Another advantage of this method is its real-time performance. Identified drawbacks are the dependence

on several parameters for achieving real-time performance and good solution quality and not being able to handle dynamic obstacles as it is. This algorithm is based on the work done in ?? and we propose some changes especially for reaching the final configuration and about how to set some parameters for solving NLP (nonlinear problem).

2. MONO-ROBOT SLIDING WINDOW PLANNING ALGORITHM

TODO present method or make reference to Defoort introducing T_c , T_p etc.

However, two aspects of the implementation of this algorithm are neglected in [1]: the initial values for the control points and the procedure for reaching a desired final state.

2.1. INITIALIZATION

The initialization of the solution paths used for each NLP solving is important for two reasons:

A good initialization allows the optimization solver to find a better solution for a given timespan.

When using a local optimization method the initialization can drag the final solution to one or other local minima.

The simplest of initializations was performed in our studies. Linear spacing from current flat output value to the estimate final flat output. The estimate final output is simply the flat output computed from the estimate final states and inputs. The estimate final states and inputs are computed assuming a displacement from the current position of the maximum linear speed of the robot times the planning horizon, and assuming that the direction of the movement is equal to (final position - current pos) vector.

TODO talk about the too close obstacles problem and the dumb solution.

2.2. STOP CONDITION AND LAST NLP

As the robot evolves its state approximates to the final state. At some point the constraints associated to the final state shall be integrated into the NLP and the timespan for performing this last step shall not be fixed and must be one of the values calculated.

The criterion used to pass from the NLP used during for the initial and intermediates steps to the last step NLP is define below in the equation ??:

$$d_{rem} \geq d_{min} + T_c \cdot v_{max} \quad (1)$$

This way we insure that the last planning section will be done for at least a d_{min} distance from the robot's final position. This minimal distance is assumed to be sufficient for the robot to reach the final state.

After stopping the sliding window algorithm we calculate new parameters for the solution representation and computation taking into account the estimate remaining distance.

The following pseudo code summarizes the algorithm:

Algorithm 1 Sliding window planning algorithm

```

1: procedure PLAN
2:    $knots \leftarrow \text{GENKNOTS}(t_p, d_{spl}, n_{knots})$ 
3:    $time \leftarrow \text{LINESPACING}(0, t_p, n_s)$ 
4:    $q_{latest} \leftarrow q_{initial}$ 
5:    $d_{rem} \leftarrow |\text{POS}(q_{final}) - \text{POS}(q_{latest})|$ 
6:   while  $d_{rem} \geq d_{min} + T_c \cdot v_{max}$  do
7:      $q_{latest} \leftarrow \text{PLANSEC}$ 
8:      $d_{rem} \leftarrow |\text{POS}(q_{final}) - \text{POS}(q_{latest})|$ 
9:   end while
10:   $s \leftarrow \text{MIN}(\frac{d_{rem}}{v_{max} \cdot t_p}, 1.0)$ 
11:   $n_{knots} \leftarrow \text{MAX}(\text{ROUND}(s \cdot n_{knots}), d_{spl})$ 
12:   $n_s \leftarrow \text{MAX}(\text{ROUND}(s \cdot n_s), n_{knots} + d_{spl})$ 
13:   $\Delta t \leftarrow \text{PLANLASTSEC}$ 
14: end procedure

```

3. DECENTRALIZED MULTI ROBOT SLIDING WINDOW PLANNING ALGORITHM

A straight forward extension of the previous algorithm can be done in order to support a multi robot system. The sliding window algorithm presented before remains virtually the same. The changes are done within the PLANSEC PLANLASTSEC routine.

After solving the NLP stated before each robot will have generated an intended trajectory that would be valid if we were dealing with a mono robot system. For the multi robot system some exchange of information among the robots and possibly some replanning has to be done.

Right after solving the standalone NLP a given robot represented by the index i computes a conflict list that is based on all robots' positions as of when they started planning their intended trajectories (solving the latest standalone NLP). This conflict list contains the indexes of the robots in the fleet that can possibly cause some conflict. The word conflict here is understood as a collision or a loss of communication between robots in the fleet.

Notice that the i robot can compute its conflict list as soon as it finishes its planning even though other robots may still be doing so.

For the next step of replanning all robots involved in a conflict have to be done computing the first standalone planning. This is needed simply because all intended trajectories will be taken into account on the replanning part.

Using the intended trajectory as the initialization of the optimization parameters a new NLP is solved where collision avoidance between robots and keeping communication are translated into constraints.

After solving this second NLP, the trajectories are updated and the planning goes on to the next section.

In Figures 1 and 2 the results of the decentralized multi robot algorithm can be seen. In Figure 1 no conflict handling is done and two collisions zones can be identified. For trajectory showed in the Figure 2 the robots optimize their trajectories using the multi robot adaptation of the algorithm. No conflict occurs and we can observe a change in the robots velocities and total execution time.

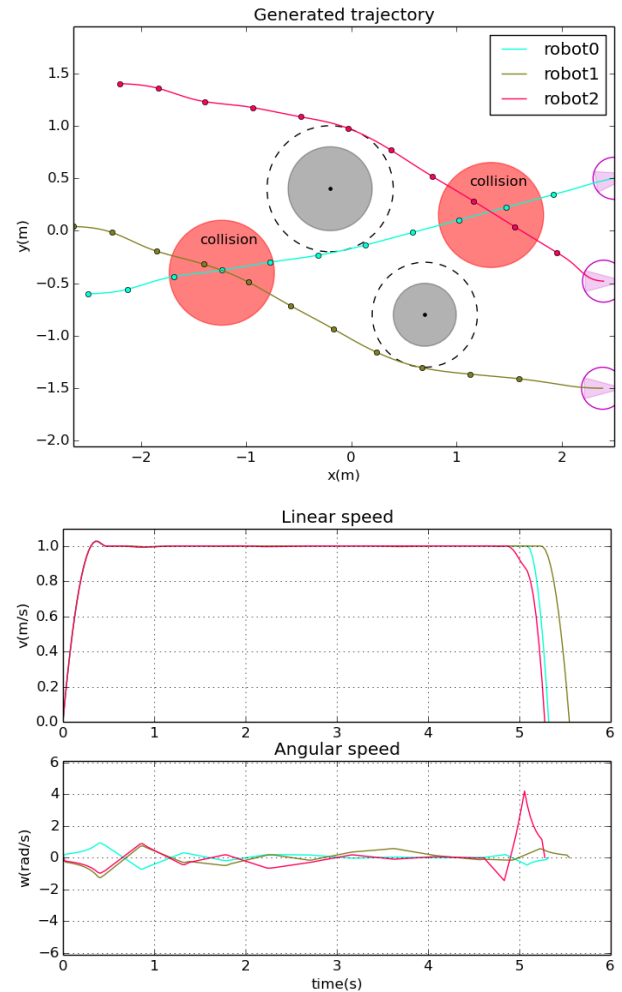


FIGURE 1. Our results: black box (top) and black box (bottom).

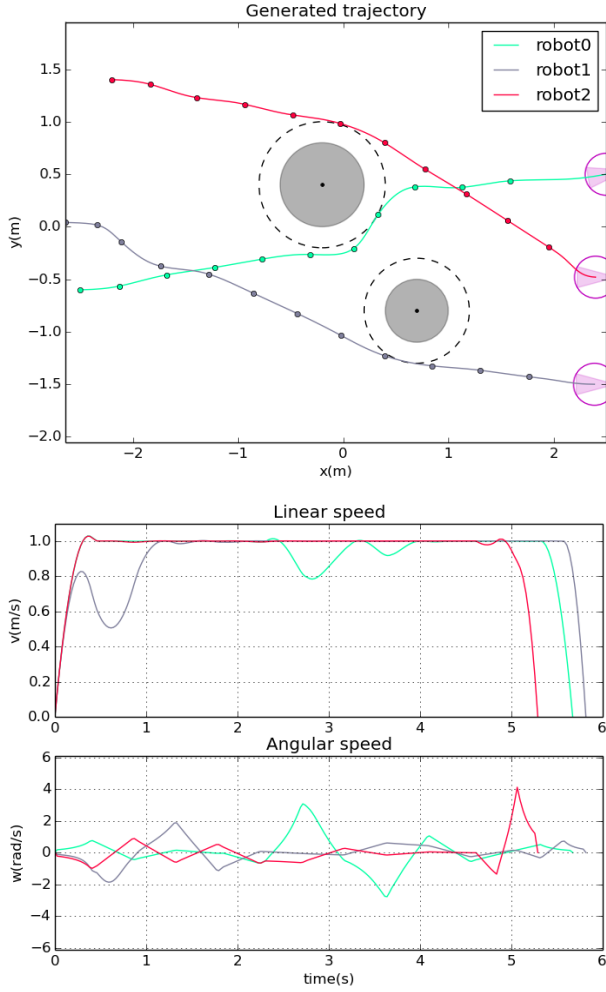


FIGURE 2. Our results: black box (top) and black box (bottom).

3.1. CONFLICT DETECTION

Conflict detection is computed TODO

3.2. ADDITIONAL CONSTRAINTS

The additional constraints associated to the multi robot system TODO

4. PARAMETERS' IMPACT ANALYSES

Four criteria considered important for the validation of this method were studied. We tested different parameters configuration and scenario in order to understand how they influence those criteria. The four criteria were:

- *Maximum computation time* over the computation horizon (MCT/T_c ratio);
- Obstacle penetration area (P).
- The total execution time (T_{tot});
- Additional time for conflict handling???

4.1. MAXIMUM COMPUTATION TIME OVER COMPUTATION HORIZON MCT/T_c

The significance of this criterion lays in the need of quarantining the real-time property of this algorithm. In a real implementation of this approach the computation horizon would have always to be superior than the maximum time took for computing a planning section (robot-to-robot conflict taken into account).

Based on several simulations with different scenarios we were able to TODO

- SLSPQ method request $O(n^3)$ time, n being the number of knots;

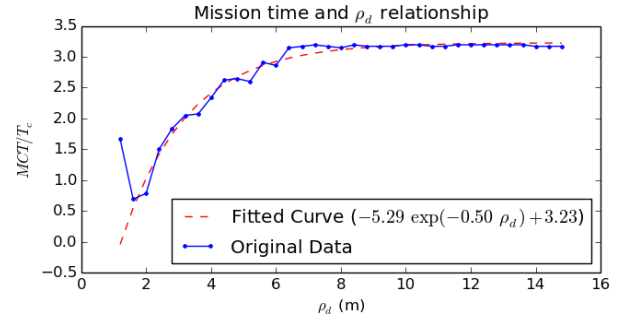


FIGURE 3. Increasing of detection radius and impact on a MCT/T_c ratio

4.2. OBSTACLE PENETRATION P

4 TODO rescale images

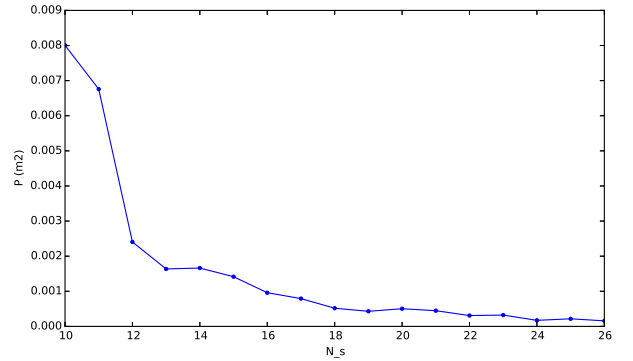


FIGURE 4. Obstacle penetration decreasing as sampling increases

4.3. TOTAL EXECUTION TIME T_{tot}

4.4. ADDITIONAL TIME FOR CONFLICT HANDLING P

TODO Comparison with the other method;

TODO Before concluding do comparison with other approach and make sure to have multi-robot stuff

5. CONCLUSIONS

TODO perspectives

Analise influence of dynamics of system, sensors, communication latency;

REFERENCES

[1] M. Defoort. Contributions à la planification et à la commande pour les robots mobiles coopératifs. *Ecole Centrale de Lille* 2007.