DE LA RECHERCHE À L'INDUSTRIE

Interactive Robotics Laboratory

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DEMUR 2015
Workshop on On-line decision-making in multi-robot coordination

MULTI-ROBOT MOTION PLANNING: A MODIFIED RECEDING HORIZON APPROACH FOR REACHING GOAL STATES

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CONTEXT

- Indoor environment with static obstacles
- Multi-robot system composed by nonhonolomic mobile robots
- Robots’ limited perception of the environment
- Robots’ limited communication range

OBJECTIVES

Development of a real-time motion planning algorithm for a multi-robot system

- Real-time generation of collision-free trajectories
- Precise reaching of goal configuration
- Minimization of travel time

CHOICES & REFERENCES

- Distributed approach over centralized approach
  - Drawbacks: less optimal
  - Advantages: computation time, security, communication

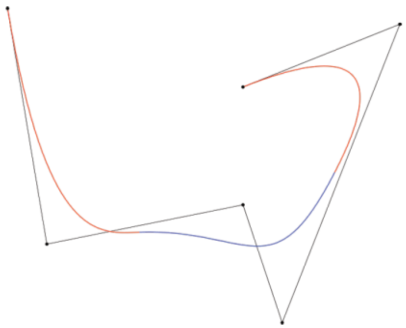
- Local planning over global planning

- Base algorithm:

  M. Defoort, A. Kokosy, T. Floquet, et al. Motion planning for cooperative unicycle-type mobile robots with limited sensing ranges: A distributed receding horizon approach. Robotics and Autonomous Systems 57(11):1094–1106, 2009. doi:10.1016/j.robot.2009.07.004.

MOTION PLANNING DESCRIPITON

- Constrained optimization problems numerically solved
- Local planning computation by using a receding horizon approach
- Distributed planning performed by postponing the consideration of coupling constraints, meaning inter-robot communication and collision avoidance
- Planning in the flat space rather than state space. The solution is denoted $z^*(t)$ where $z(t)$ is the flatoutput
- Solution represented by B-splines (minimal support)



CONSTRAINED OPTIMIZATION PROBLEM

Constraints

- Kinematic model
- Initial state
- Goal state
- Bounded input (control) vector
- Obstacle avoidance
- Inter-robot collision
- Lost of communication

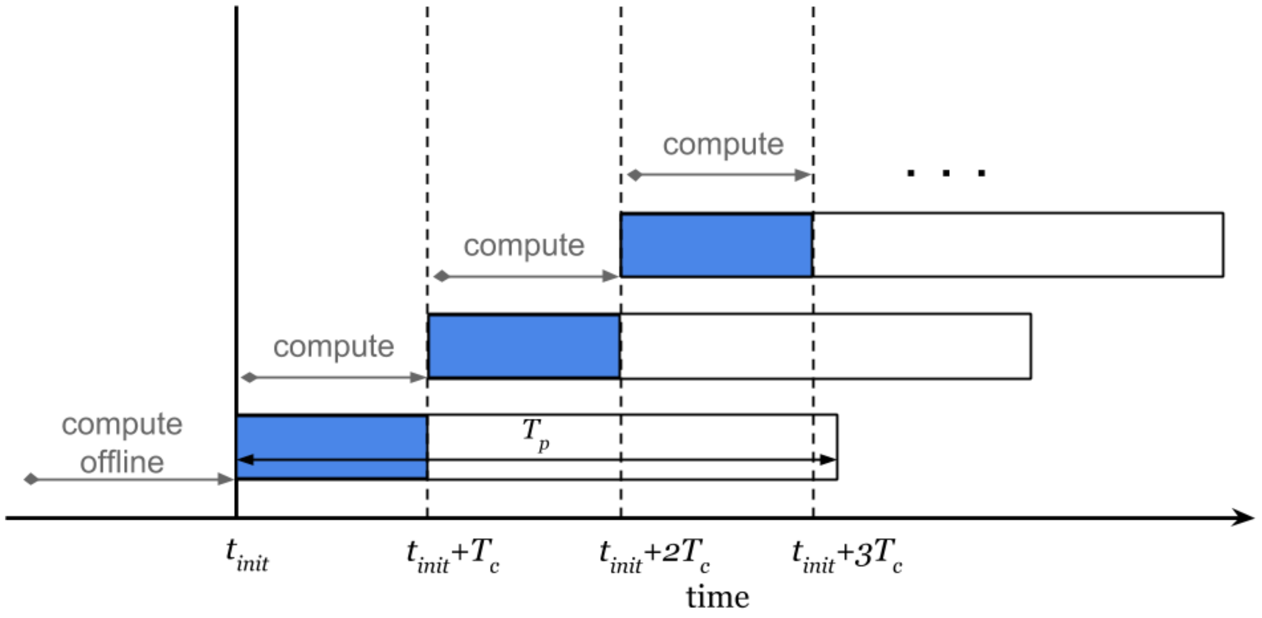
} Coupling constraints

Objective function to be minimized

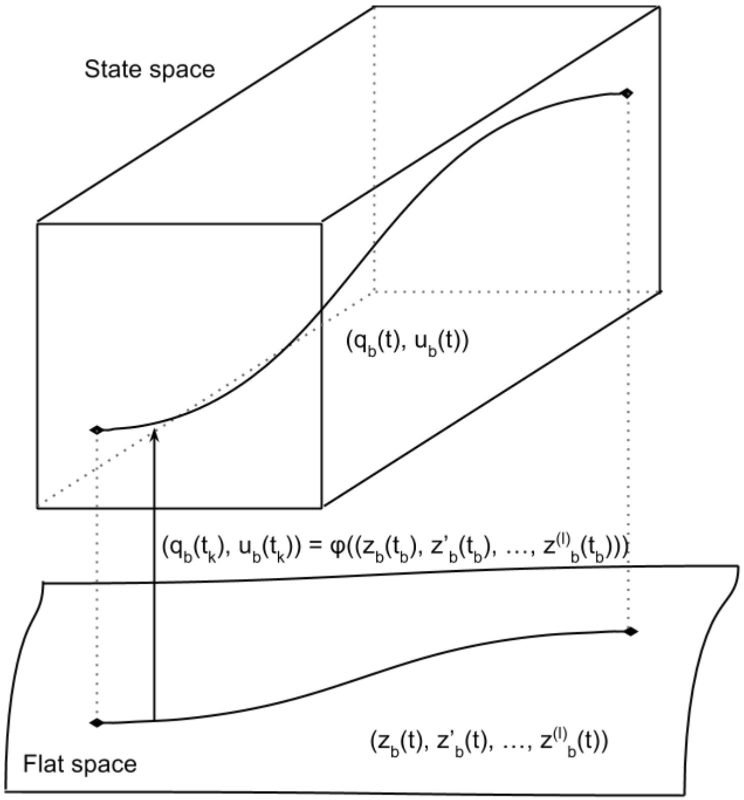
- Travel time

RECEDING HORIZON APPROACH

- Planning horizon (T_p)
- Computation horizon (T_c)



Complete description of the system behavior using the flat output and its derivatives



POSTPONING COUPLING CONSTRAINTS ($NLP_{b,1,1}$)

Constraints

- Kinematic model
- Initial state
- Goal state
- Bounded input (control) vector
- Obstacle avoidance
- Inter-robot collision
- Lost of communication

} Coupling constraints

Objective function to be minimized

- Geodesic distance from planned configuration at T_p to the goal configuration

TAKING THEM INTO ACCOUNT ($NLP_{b,1,2}$)

Constraints

- Kinematic model
- Initial state
- Goal state
- Bounded input (control) vector
- Obstacle avoidance
- Inter-robot collision
- Lost of communication
- Deviation from $\hat{z}_{\mathrm{b},\tau_k}(t)$

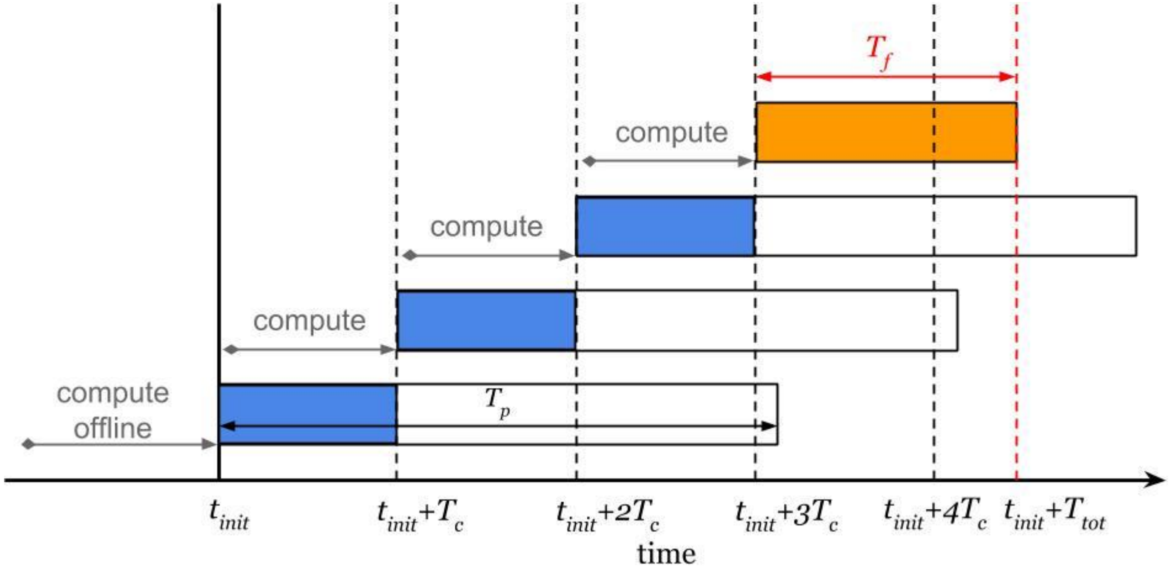
} Coupling constraints (Inter-robot collision, Lost of communication)

Objective function to be minimized

- Geodesic distance from planned configuration at T_p to the goal configuration

TERMINATION PLANNING

- Stop receding planning when close to the goal configuration
- Compute new time sampling and b-spline parameters
- Change NPLs to consider goal state



Constraints

- Kinematic model
- Initial state
- Goal state
- Bounded input (control) vector
- Obstacle avoidance
- Inter-robot collision
- Lost of communication

} Coupling constraints

Objective function to be minimized

- Time to reach the goal state

$NLP_{b,\mathbf{1},1} \Rightarrow NLP_{b,\mathbf{2},\mathbf{2}}$

Constraints

- Kinematic model
- Initial state
- Goal state
- Bounded input (control) vector
- Obstacle avoidance
- Inter-robot collision
- Lost of communication
- Deviation from $\hat{z}_{\mathrm{b},\tau_k}(t)$

} Coupling constraints (Inter-robot collision, Lost of communication)

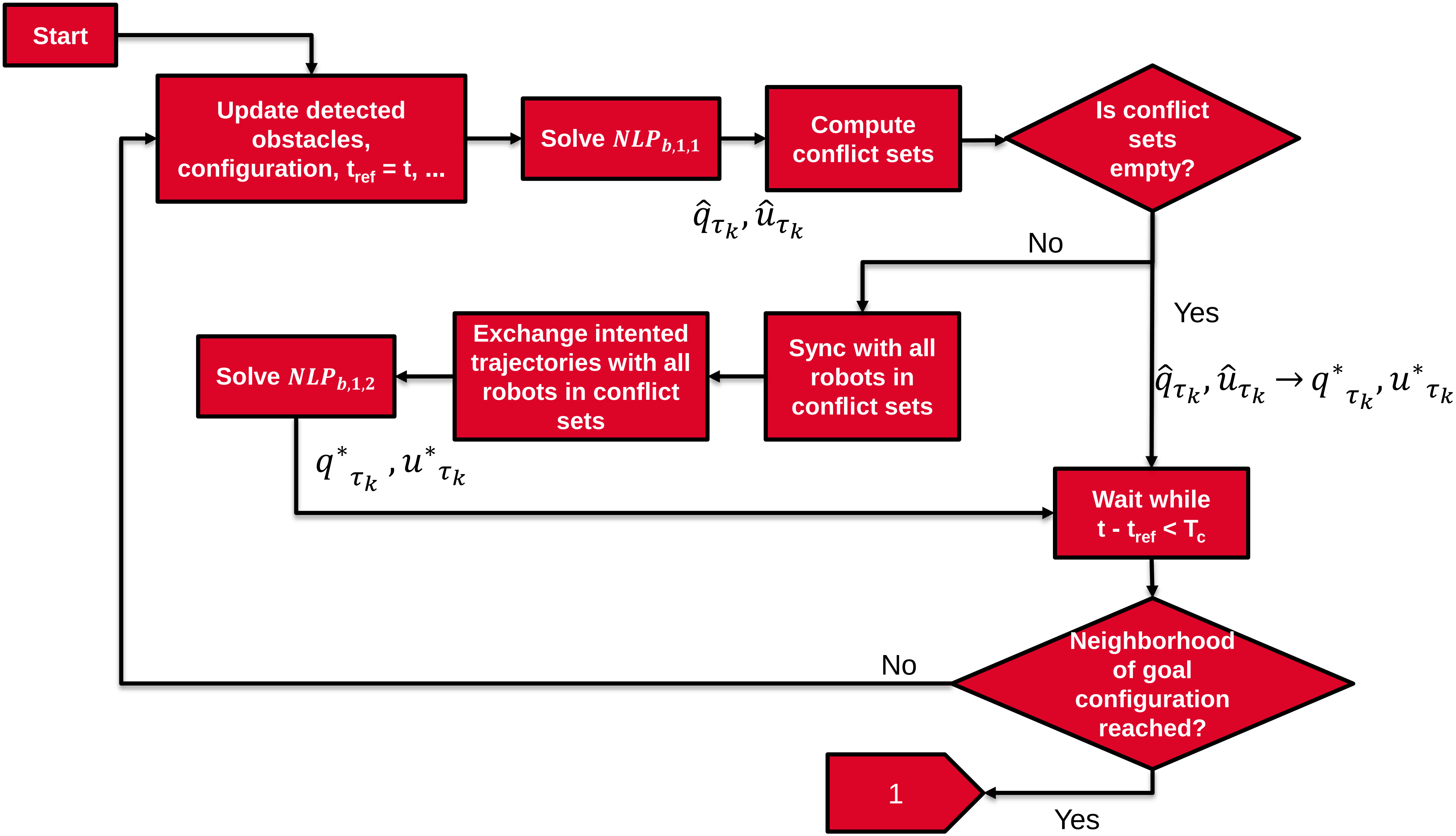
Objective function to be minimized

- Time to reach the goal state

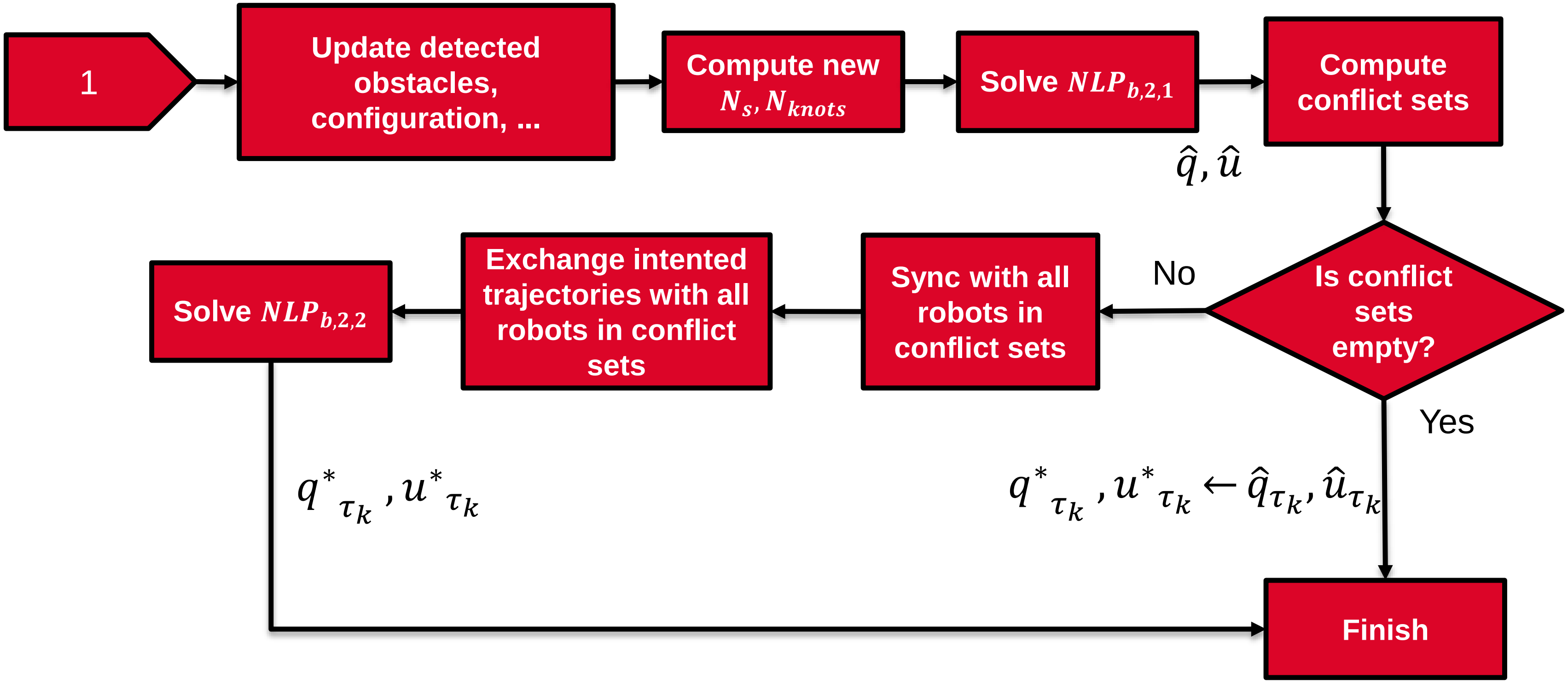
SUMMARIZING

NLP	Goal constraints	Coupling constraints
$NLP_{b,1,1}$		
$NLP_{b,1,2}$		X
$NLP_{b,2,1}$	X	
$NLP_{b,2,2}$	X	X

MOTION PLANNING DIAGRAM



MOTION PLANNING DIAGRAM

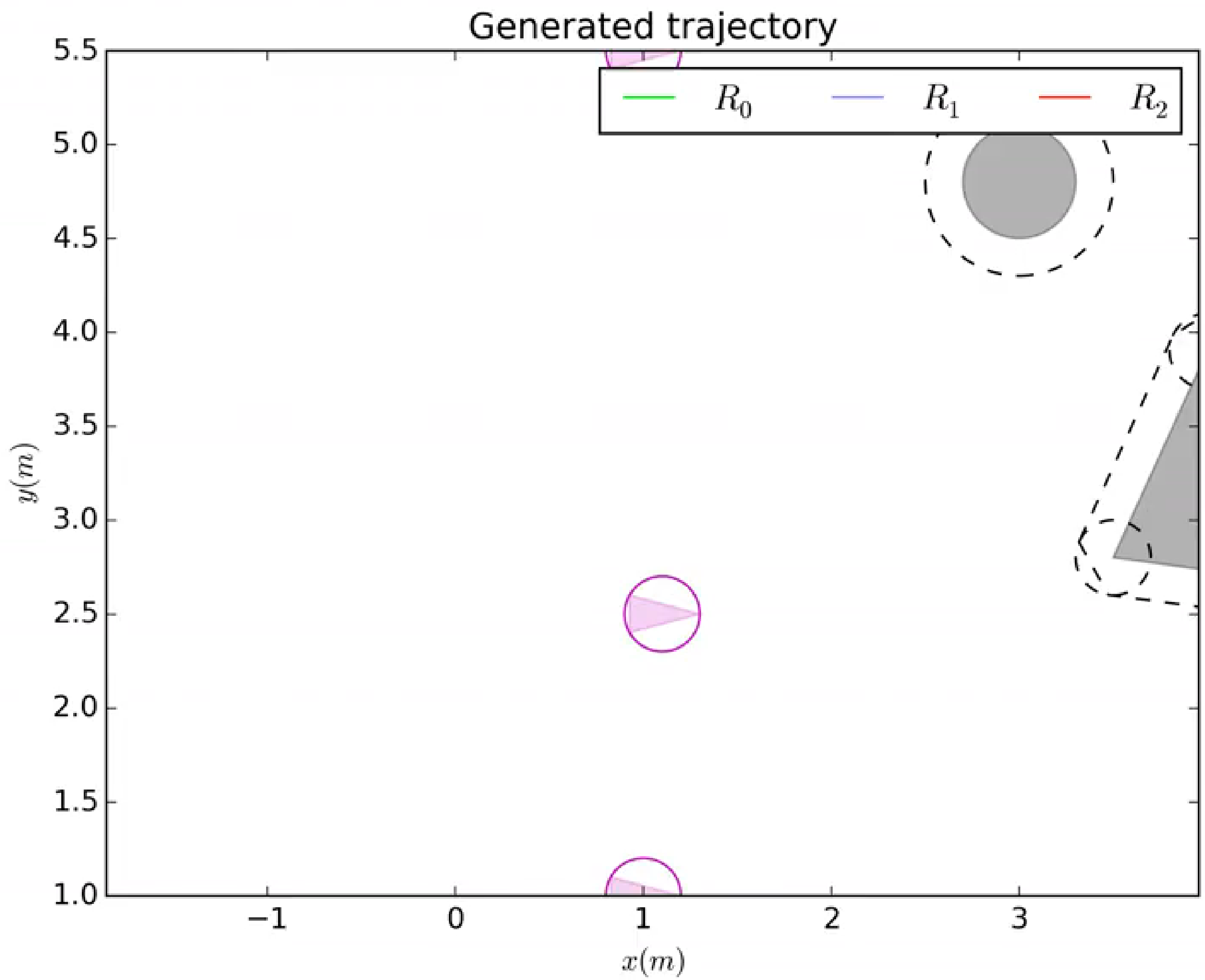


SIMULATIONS

- Kinematic simulation example
  - Planning horizon: 2.0 s;
  - Planning horizon: 0.5 s;
  - Time samples for numerically solving the NLPs: 14 s;
  - Number of internal knots for B-spline representation: 4;
  - 3 robots;
  - 3 obstacles;
  - Max velocities $[1.0m/s,\ 5.0rad/s]^T$;

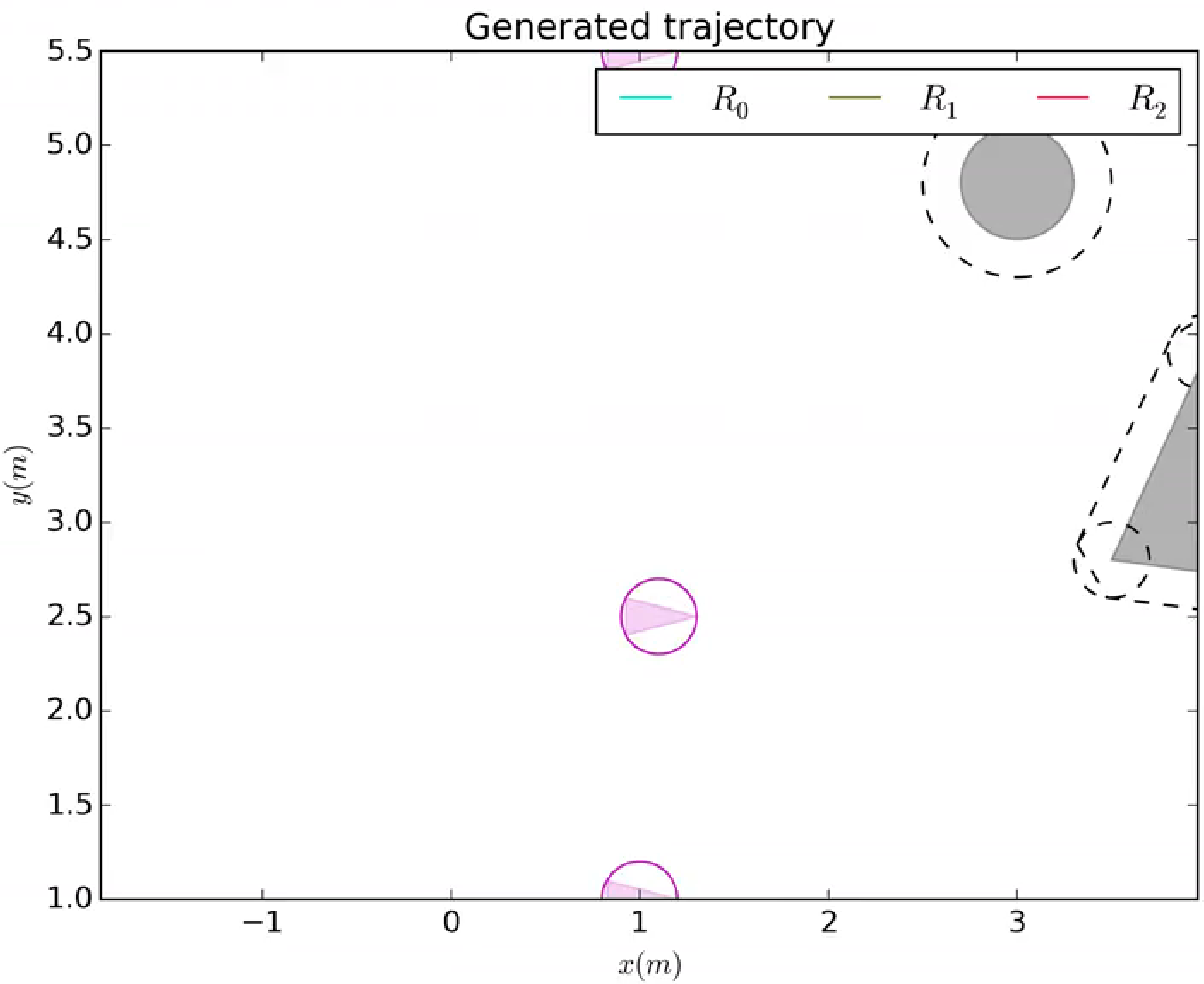
SIMULATIONS

Without coupling constraints ($NLP_{b,2,1}$)



SIMULATIONS

With coupling constraints ($NLP_{b,2,2}$)



SIMULATIONS

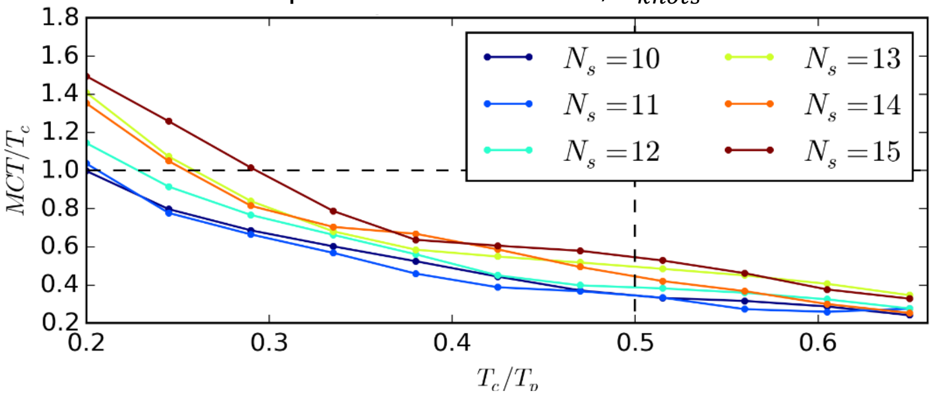
Algorithm parameters analysis

- Number of time samples (N_s)
- Number of internal knots for B-splines (N_{knots})
- Planning horizon (T_p)
- Computation horizon (T_c)
- Detection radius of the robots

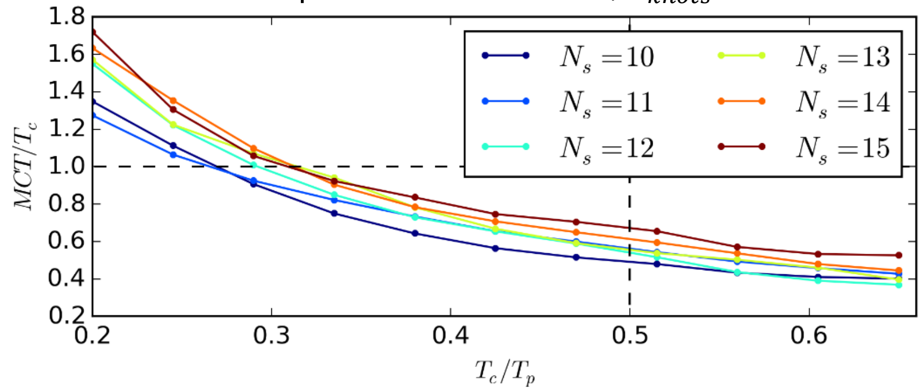
SIMULATIONS

- "Maximum Computation Time"/ Tc (real-time hypothesis)
  - An increasing number of N_s increases MCT/Tc at $O(N_s)$ with SLSQP
  - An increasing number of N_{knots} increases MCT/Tc at $O(N^3_{knots})$ with SLSQP

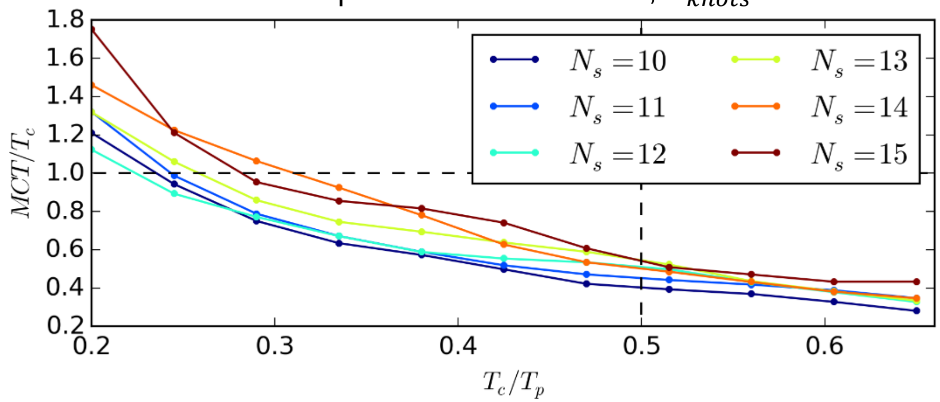
Computation cost behavior, N_{knots} = 4



Computation cost behavior, N_{knots} = 6

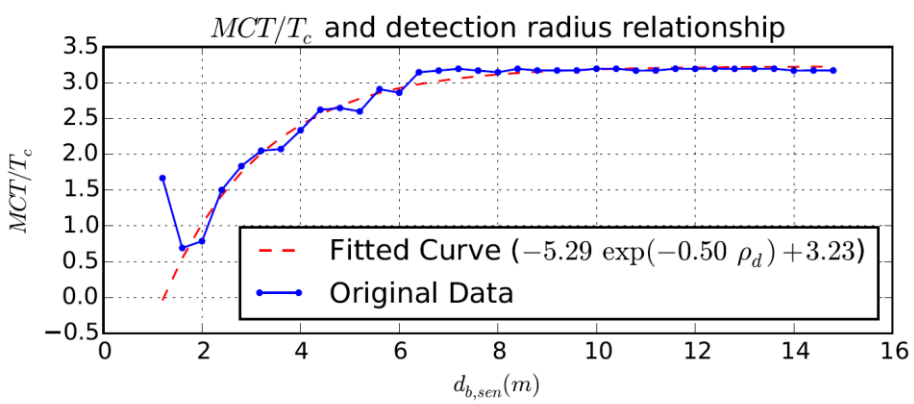


Computation cost behavior, N_{knots} = 5



SIMULATIONS

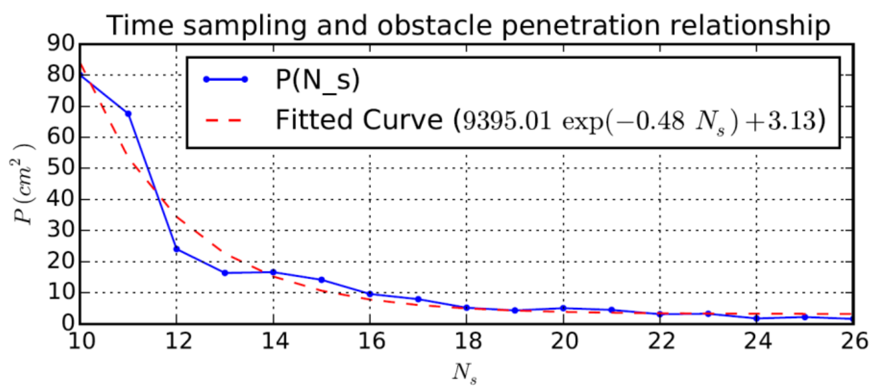
- "Maximum Computation Time"/ Tc (real-time hypothesis)
  - An increasing number of N_s increases MCT/Tc at $O(N_s)$ with SLSQP
  - An increasing number of N_{knots} increases MCT/Tc at $O(N^3_{knots})$ with SLSQP
  - An increasing of the obstacles detection radius d_{sen} increases MCT/Tc



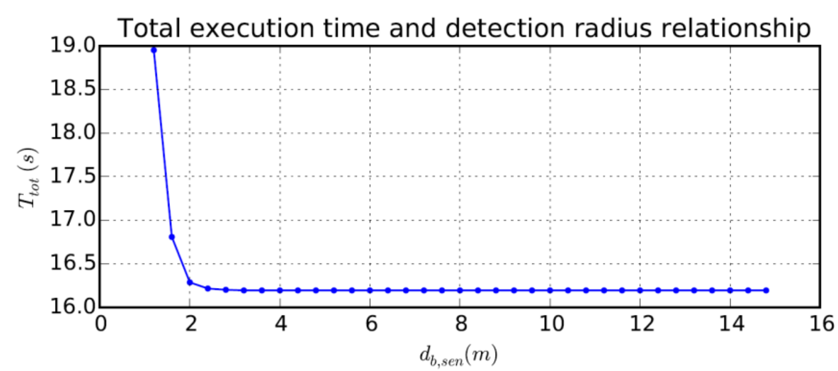
Simulations run on an Intel Xeon CPU 2.53GHz processor

SIMULATIONS

- Obstacle penetration area P (obstacle avoidance $P = 0$)
  - Penetration area P decreasing as the number of samples N_s increases



- Travel time (optimization)
  - Travel time decreases with the planning horizon T_p
  - Travel time decreases with the number of samples N_s
  - No high influence of the obstacles detection radius d_{sen}



CONCLUSIONS & PERSPECTIVES

- Motion planner based on:
  - system flatness property,
  - B-spline parameterization of the flat output
  - SLSQP optimizer

- Enhancement of this cooperative multi-robot systems motion planner, with:
  - termination constraints consideration
  - circle and convex polygon representation of obstacles

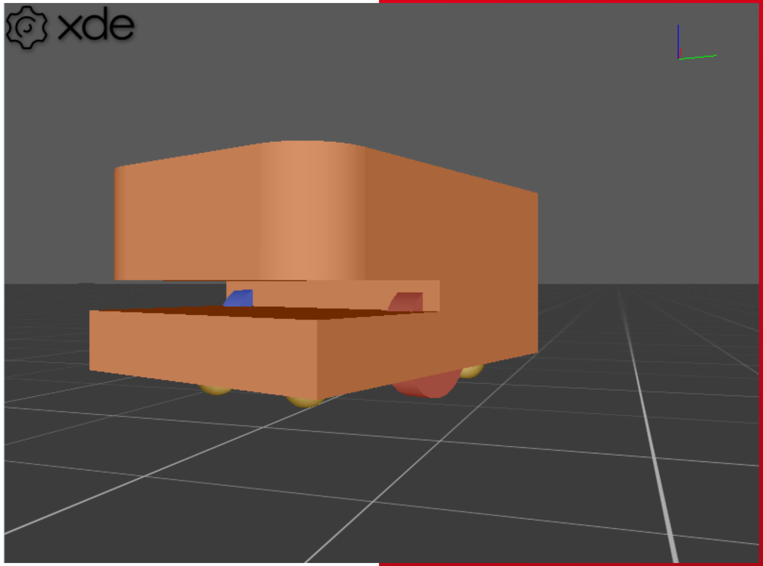
- Kinematic simulation with 3 mobile robots in presence of obstacles

- Analyze of Impact of different parameters, to guarantee
  - Real time implementation
  - Obstacles avoidance
  - Travel time optimality

- Work in progress in physics simulation environment, taking into account:
  - vehicle dynamics
  - sensors models
  - communication latency

- Future tests in real conditions with monocycle robots

Thank you!



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