Coordination in Multi Robot Systems

Motion Planning

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Outline

1. Motivation
2. Motion Planning
3. Centralized Approach
4. Decentralized Approach
5. Conclusion

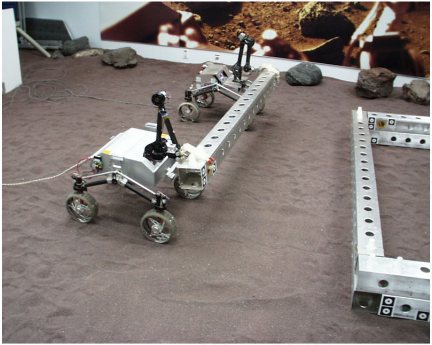
Motivation

[1]

[1] <https://www.popsci.com/these-new-motivational-posters-will-get-your-robot-out-its-slump>

Why do we need coordination in multi-robot systems?

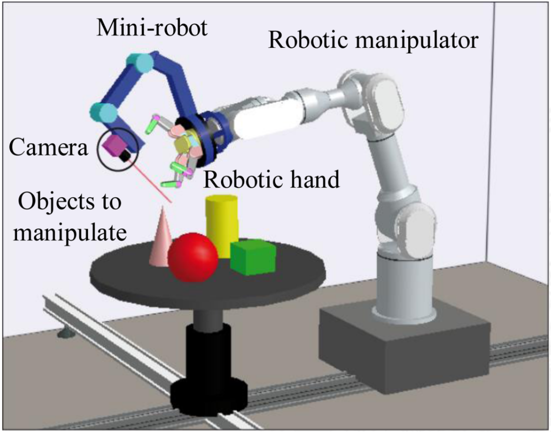
- Force multiplication



(PRL-based research in multi-rover coordination for conceptual lunar-surface assembly operations. [2])

[2] <https://www-robotics.jpl.nasa.gov/facilities/facility.cfm?Facility=4>

- Simultaneous presence

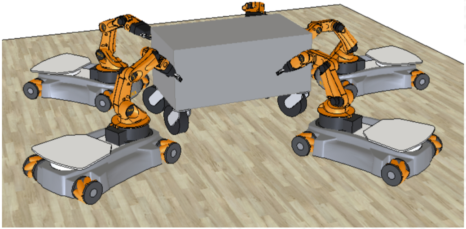


(Multi-robot system in an eye-in-hand configuration. [3])

[3] <http://www.mdpi.com/1424-8220/11/10/9839/htm>

Motivation

- Faster execution
- Redundancy, fault tolerance
- Greater efficiency
- Larger range of task domains - cooperative manipulation



(Cooperative manipulation [4])

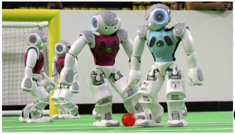
[4] <https://homepages.laas.fr/afranchi/robotics/?q=node/251>

Applications

- Warehouse management
- Competitions - Robot Soccer
- Product assembly
- Digital entertainment

[5]

(a) Kiva Systems/Amazon


[6]

(b) Robot Soccer

[7]

(c) Clash of Clans

Example Applications

[5] <https://www.youtube.com/watch?v=lTJ1slqBoro>

[6] <https://tams.informatik.uni-hamburg.de/lehre/2016ws/seminar/ir/doc/slides/JuliusMayer-Genetic_Algorithms_in_Robotics.pdf>

[7] <https://www.youtube.com/watch?v=Bzc7P99be9E>

Research

- Multi-robot motion planning
- Traffic control
- Multi-robot docking
- Foraging
- Multi-robot soccer
- Exploration and localization

Research

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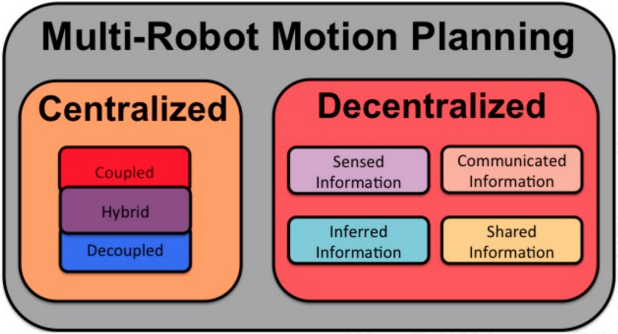
Objective

Enable robots to navigate collaboratively to achieve spatial positioning goals. [6]

Motion planning in dynamic environment with moving obstacles is NP-hard

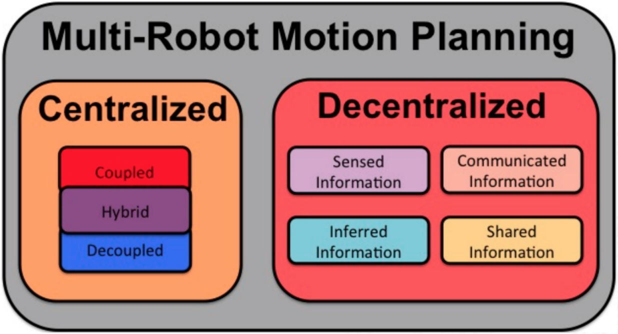
Approaches



(Motion planning in Multi-robot systems [8])

- What information does an approach access?
  - Global = Centralized
  - Local = Decentralized

[8] http://multirobotsystems.org/sites/default/files/slides/2015_RSS_MRS_Bekris.pdf



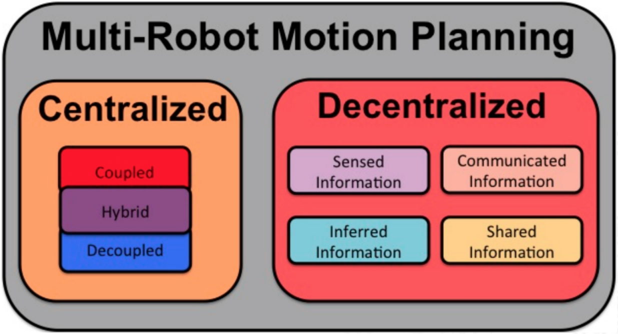
(Motion planning in Multi-robot systems [9])

Key question for Centralized Approaches

- What space does the approach search over?
  - Composite space of all robots = Coupled approach
  - Individual robot space and co-ordination = Decoupled approach

[9] http://multirobotsystems.org/sites/default/files/slides/2015_RSS_MRS_Bekris.pdf

Approaches



(Motion planning in Multi-robot systems [10])

Key question for Decentralized Approaches

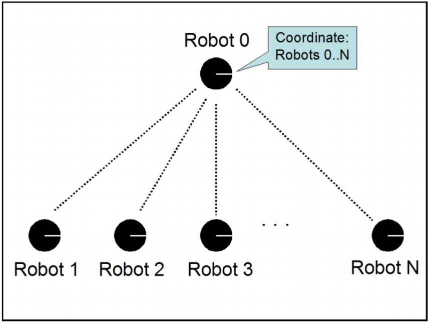
- How does a local method access information from robots?
  - Sensing or communication
  - Inference or shared information

[10] http://multirobotsystems.org/sites/default/files/slides/2015_RSS_MRS_Bekris.pdf

Centralized Approach - Coupled

Treat multiple robot as just one robot
Single agent "leader" plans for the entire team

- Plan path in configuration space Q = Q1 x Q2 x . . . QN



(Centralized approach[11])

[11] <http://www.robotmotionplanning.org/teaching/LecRoboMultiRobots.pdf>

Centralized Approach - Coupled

Treat multiple robot as just one robot

Click!

[12]

[12] <https://www.cs.rutgers.edu/ kb572/pubs/scalable_asympt_opt_multi_robot.pdf>

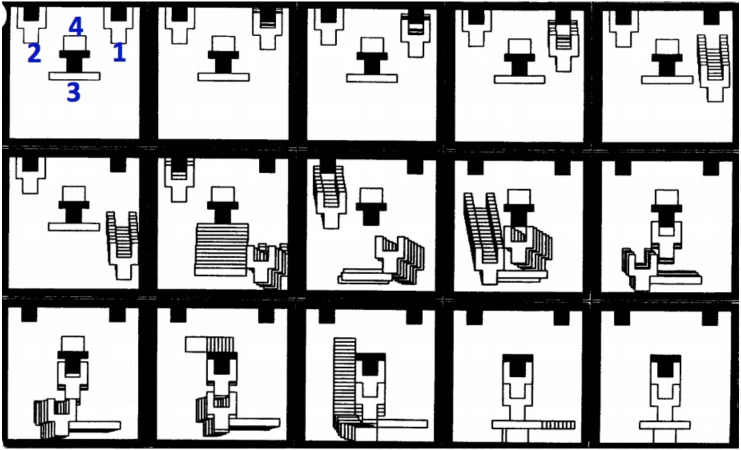
Centralized Approach - Decoupled

- First compute individual path for each robot for their corresponding space Qi
- The consider path interaction to produce a solution in composite space
- When successful, they solve problems faster than coupled approach

Various methods for Decoupled approach are:

- Prioritized planning
- Velocity tuning

Centralized Approach - Decoupled



(Decoupled approach[13])

[13] <http://www.robotmotionplanning.org/teaching/LecRoboMultiRobots.pdf>

Centralized Approach

Advantages:

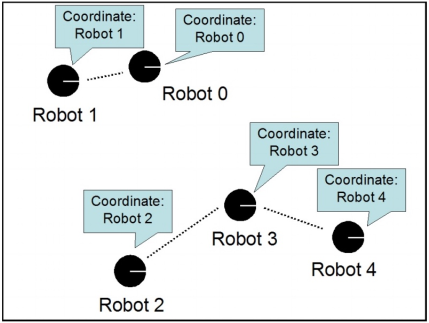
- Single robot motion planning algorithms can be directly applied
- Leader can take all information into account
- In theory, co-ordination can be perfect
- Guarantees probabilistic completeness

Disadvantages:

- Computationally hard
- Vulnerable to malfunction of leader
- Heavy communication load

Decentralized Approach

- Control processing is distributed among agents
- Each robot basically independent
- Robots use locally observable information to make plans



(Decentralized approach[14])

[14] <http://www.robotmotionplanning.org/teaching/LecRoboMultiRobots.pdf>

Decentralized Approach

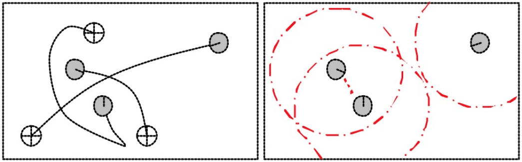
Why do need decentralized approach?

Decentralized Approach

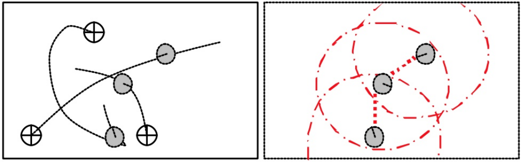
Why do need decentralized approach?

Robust to limits on or loss of communication

Decentralized Approach



a) All three robots are following their initial trajectories. The two left robots are in communication range and have formed a network to create collision-free trajectories.

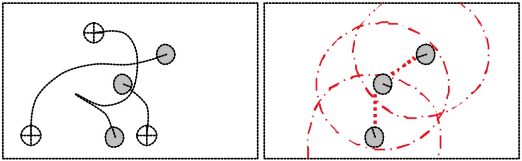


b) As the robots move along their trajectories, the middle robot enters communication range with the robot on the right and forms a larger network.

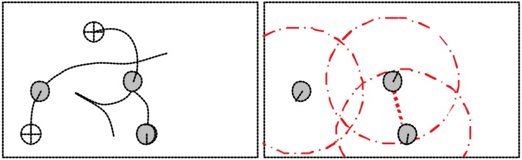
(Multiple robot systems using Dynamic Networks [15])

[15] http://multirobotsystems.org/sites/default/files/slides/2015_RSS_MRS_Bekris.pdf

Decentralized Approach



c) A new plan is made for all three robots in the network. The plan consists of collision-free trajectories for all three robots.



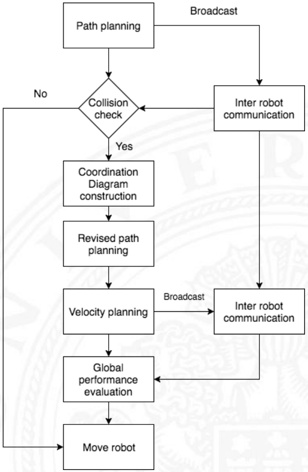
d) As robots continue along their new trajectories, they leave communication range of each other and some network connections are broken.

(Multiple robot systems using Dynamic Networks [16])

[16] http://multirobotsystems.org/sites/default/files/slides/2015_RSS_MRS_Bekris.pdf

Decentralized Approach

- Every time a new network is formed, data is exchanged.
- Each robot uses its own centralized motion planner to construct trajectories
- After each robot has received a plan from all other robots, it will implement the best plan.



Objective of communication

Inter-robot communication

Objective of communication

Enable robots to exchange state and environmental information with a minimum bandwidth requirement [4]

Decentralized Approach

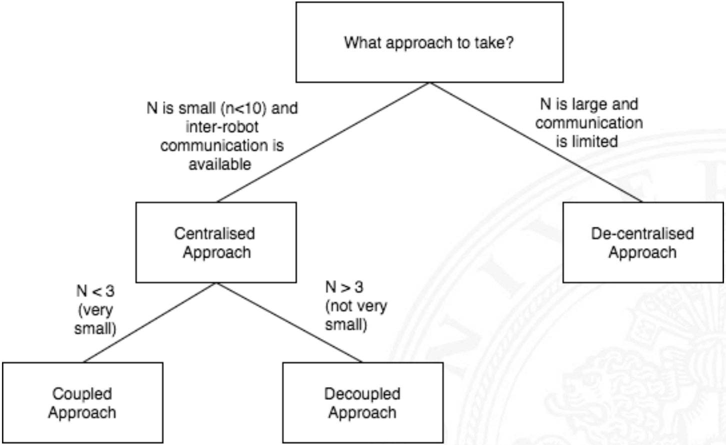
Advantages:

- Dimensionality of configuration space does not increase
- Faster response to dynamic conditions
- Little computation required
- Very robust

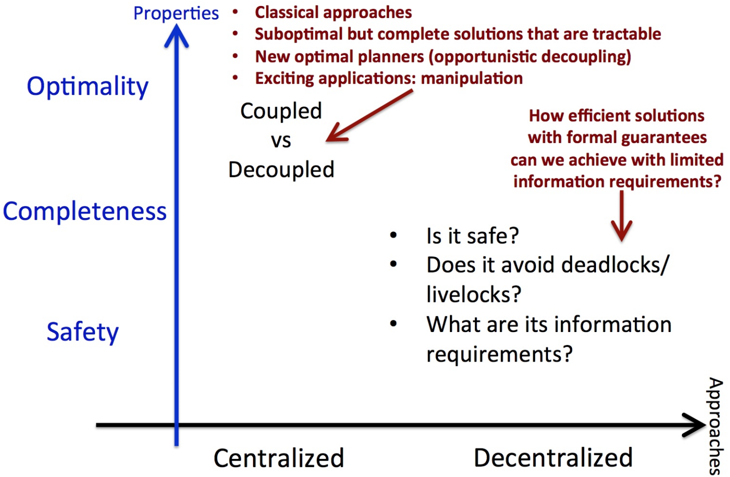
Disadvantages:

- Plans based only on local information
- The solutions are often highly sub optimal

Conclusion


What approach to take?
N is small (n<10) and inter-robot communication is available
N is large and communication is limited
Centralised Approach
De-centralised Approach
N < 3 (very small)
N > 3 (not very small)
Coupled Approach
Decoupled Approach

Conclusion



([17])

[17] http://multirobotsystems.org/sites/default/files/slides/2015_RSS_MRS_Bekris.pdf

Any Question?

Sources

[1] Bekris, K. (2015). Motion Planning in Multi-Robot Systems.

[2] Guo, Y. and Parker, L. (2014). Distributed and optimal motion planning for multiple mobile robots.

[3] Likhachev, M. (2017). Planning Techniques for Robotics.

[4] Plaku, E. (n.d.). Path Planning for Multiple Robots.

[5] Black, J. (2015). Multi-Robot Systems.

[6] Tang, D. (2016). Multi-Robot Path Planning.

[7] C. M. Clark, S. M. Rock and J. C. Latombe, "Motion planning for multiple mobile robots using dynamic networks," 2003 IEEE International Conference on Robotics and Automation (Cat. No.03CH37422), 2003, pp. 4222-4227 vol.3.