Motion Planning

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9. May 2019

Outline

Motivation

Motion planning [...] is a term used in robotics for the process of breaking down a desired movement task into discrete motions that satisfy movement constraints and possibly optimize some aspect of the movement.

https://en.wikipedia.org/wiki/Motion_planning

Applications

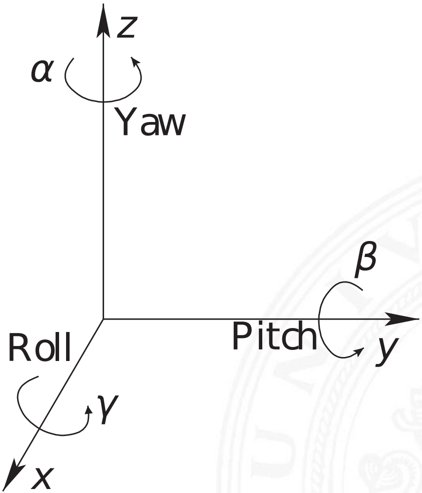
- Robotic Manipulators
  - Robotic arms
  - CNC machines
- Path planning and execution
  - Mobile robots
  - Autonomous cars
- Computer animation

Kinematics

Kinematics pertains to the motion of bodies in a robotic mechanism without regard to the forces/torques that cause the motion.

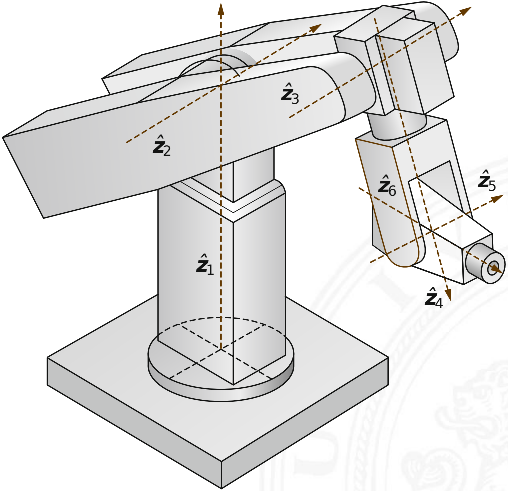
[1, p. 11]

Cartesian Coordinates



[2, p. 80]

Kinematics



[1, p. 26]

Configuration Space

- n dimensional space where n is the number degrees of freedom in the robot
- limited by joint limits
- transforming from configuration space to Cartesian space: Forward Kinematics
- transforming from Cartesian space to configuration space: Inverse Kinematics

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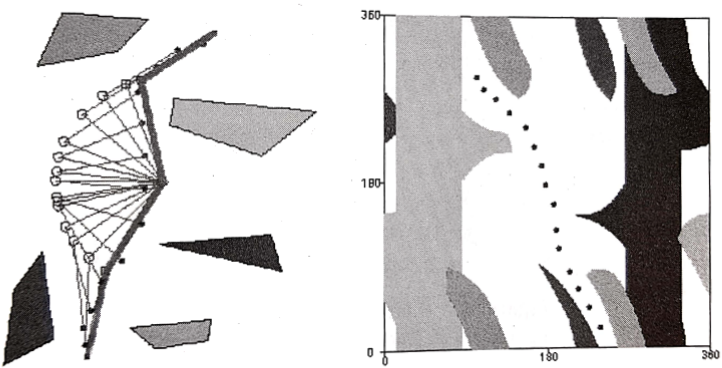
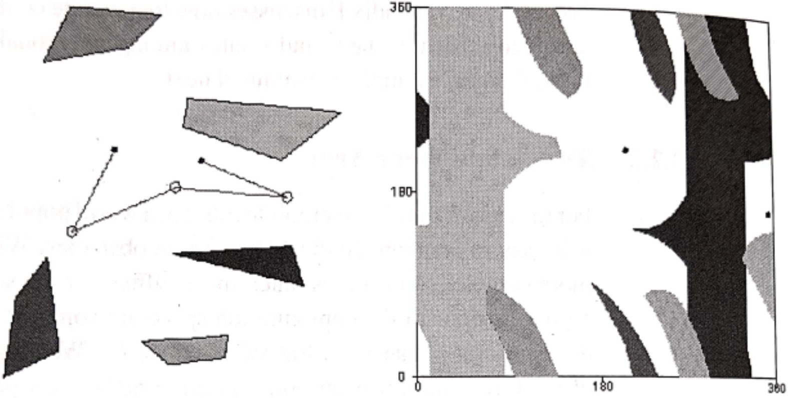
- live demo `http://demonstrations.wolfram.com/RobotMotionWithObstacles/`

Configuration Space



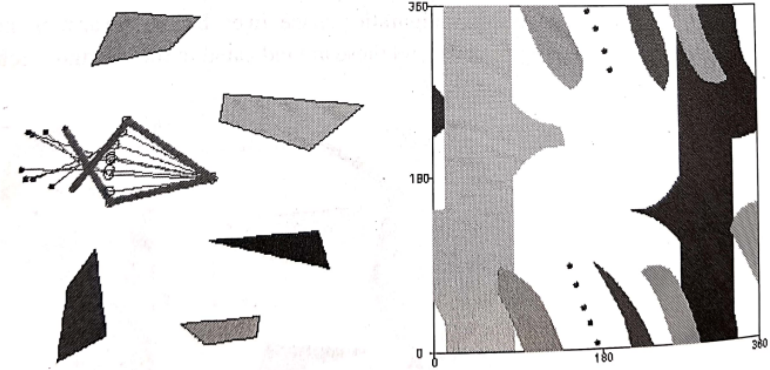
[3, p. 45]

Configuration Space



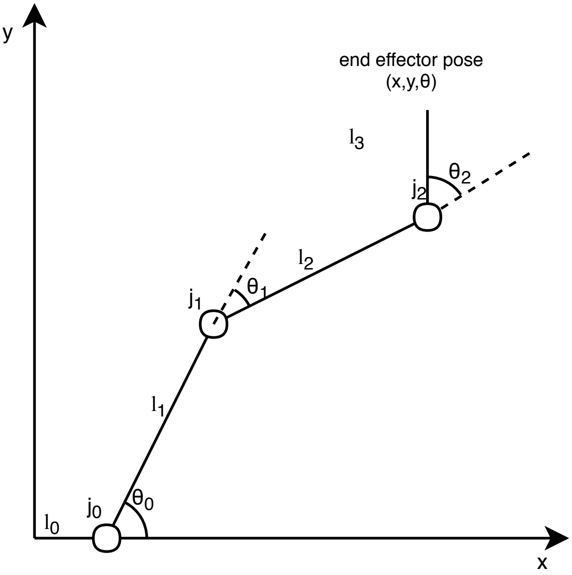
[3, p. 46]

Configuration Space



[3, p. 46]

Forward kinematics

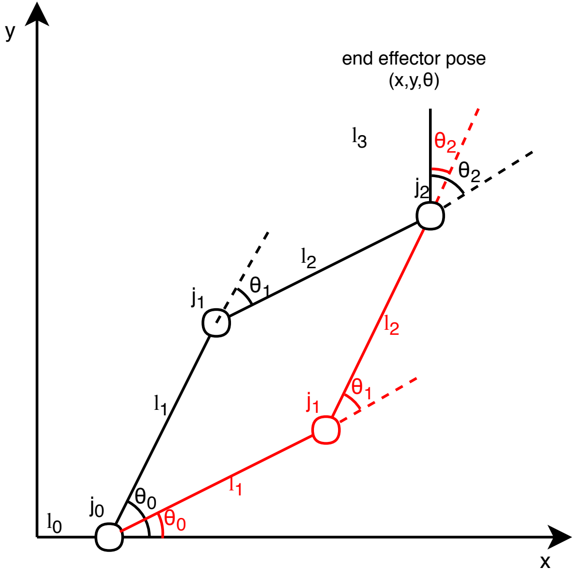


Forward kinematics

- can be calculated using transformation matrices (geometry)
- unambiguous
- fast
- DH-Parameters [4]
- URDF[1] + `robot_state_publisher`[2] + `tf/tf2`[3]

[1] `http://wiki.ros.org/urdf/`
[2] `http://wiki.ros.org/robot_state_publisher`
[3] `http://wiki.ros.org/tf` | `http://wiki.ros.org/tf2`

Inverse kinematics



Inverse Kinematics

- not necessarily unambiguous
- much harder than Forward Kinematics
- analytic robot specific solution
- generic numeric solution

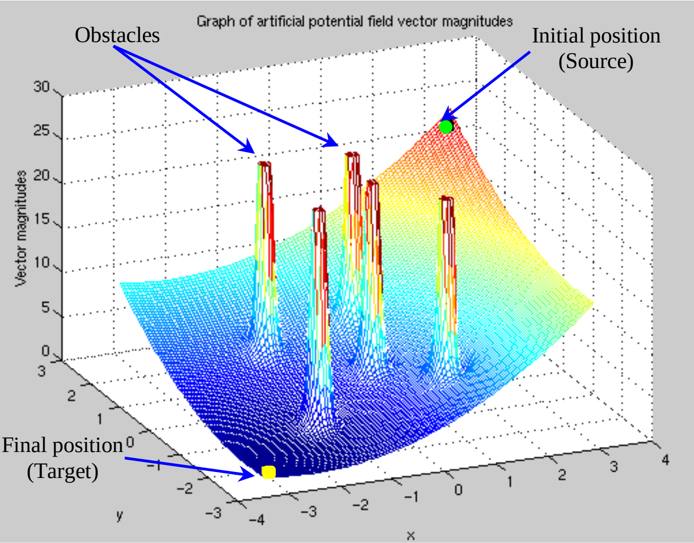
Inverse Kinematics

Analytic	Numeric
fast	comparably slow
robot specific	generic
guarantees correctness	does not guarantee correctness
	optimization for secondary goals

Examples of Inverse Kinematics engines

- OpenRave [5] (analytic)
- TracIK [6] (numeric)
- BioIK [7] (numeric)

Potential Functions



[8]

Potential Functions

- attractive potential field for goal
- repulsive potential field for obstacles

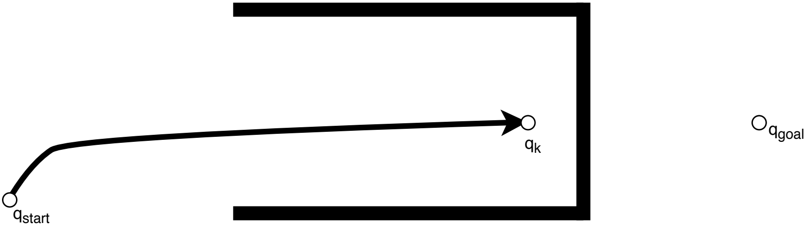
Gradient Descent

Data: A means to compute the gradient $\nabla U(q)$ at a point q
Result: A sequence of points $q(0), q(1), ..., q(n)$

$q(0) = q_{start}$;
$i = 0$;
while $\nabla U(q(i)) \neq 0$ **do**
  $q(i+1) = q(i) + \alpha(i) \nabla U(q(i))$;
  $i = i + 1$
end

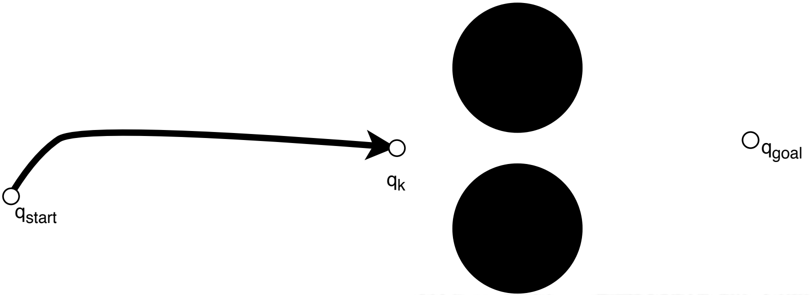
[3, p. 85]

Problem: local minima



inspired by [3, p. 85]

Problem: local minima



inspired by [3, p. 86]

Discrete Planning

- discretization of configuration space
- collision check for each explored state
- variety of graph creation algorithms
  - evenly spaced grid
  - Probabilistic Roadmaps [9]
  - Rapidly-Exploring Random Trees (RRT) [10]
  - RRT-Connect [11]

Probabilistic Roadmaps

Data: A means to check for collision of a configuration c
Result: Graph in the configuration space
repeat n **times**
    generate random configuration c;
    if c *is collision free* **then**
        find k closest points ;
        try to connect c to closest points using local planner
    end
end

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local planner can be achieved using a set of interpolated vertices between the points to be connected

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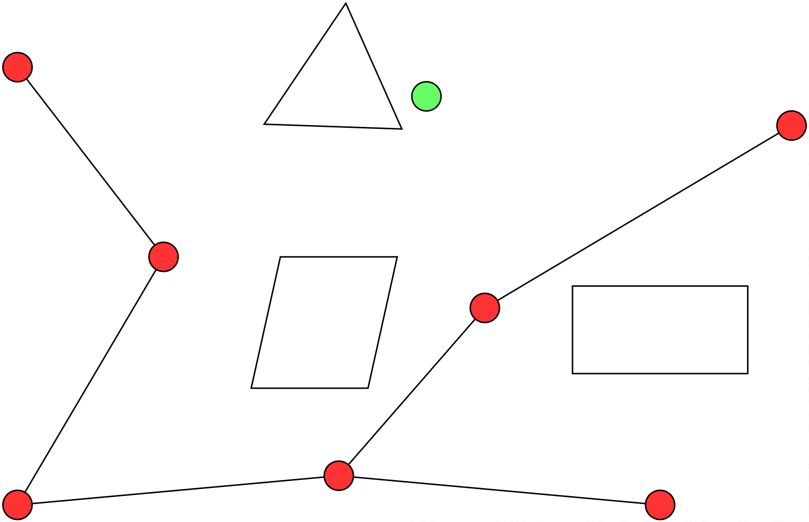
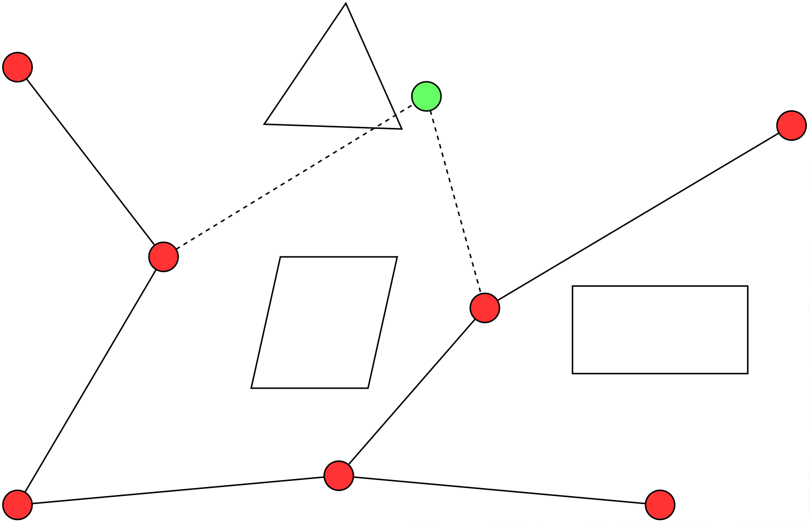
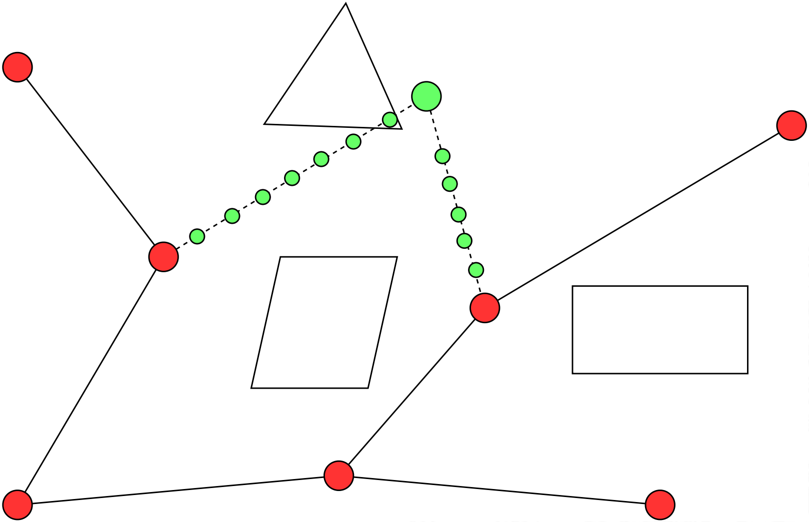


Probabilistic Roadmaps



Probabilistic Roadmaps



Probabilistic Roadmaps

- single roadmap construction
- costly for changing environment
- fast path planning once roadmap has been constructed
- no guarantee for optimal path

Rapidly-Exploring Random Trees (RRT)

- instead of trying to connect a random configuration x directly to the graph, a configuration y between the closest and the new random state x is connected
- more states are connected while the tree still rapidly expands
- motion constraints of the robot can be added to the selection function of y

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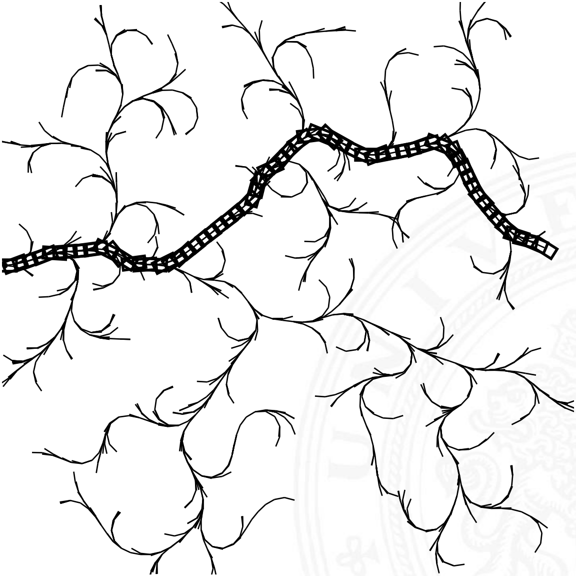

RRT-Connect

- Bidirectional search from start and goal configuration
- usually outperforms classical RRT algorithm
- goal and/or start configuration is often cluttered (i.e., close to obstacles for example for grasping)

Conclusion and Outlook

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- dynamic environment needs recalculation, therefore we need fast algorithms
- trade-off: optimal solution / computation time
- motion prediction not modeled
- additional constraints (e.g. keeping bottle upright/mostly upright) may be required for motion task

References

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