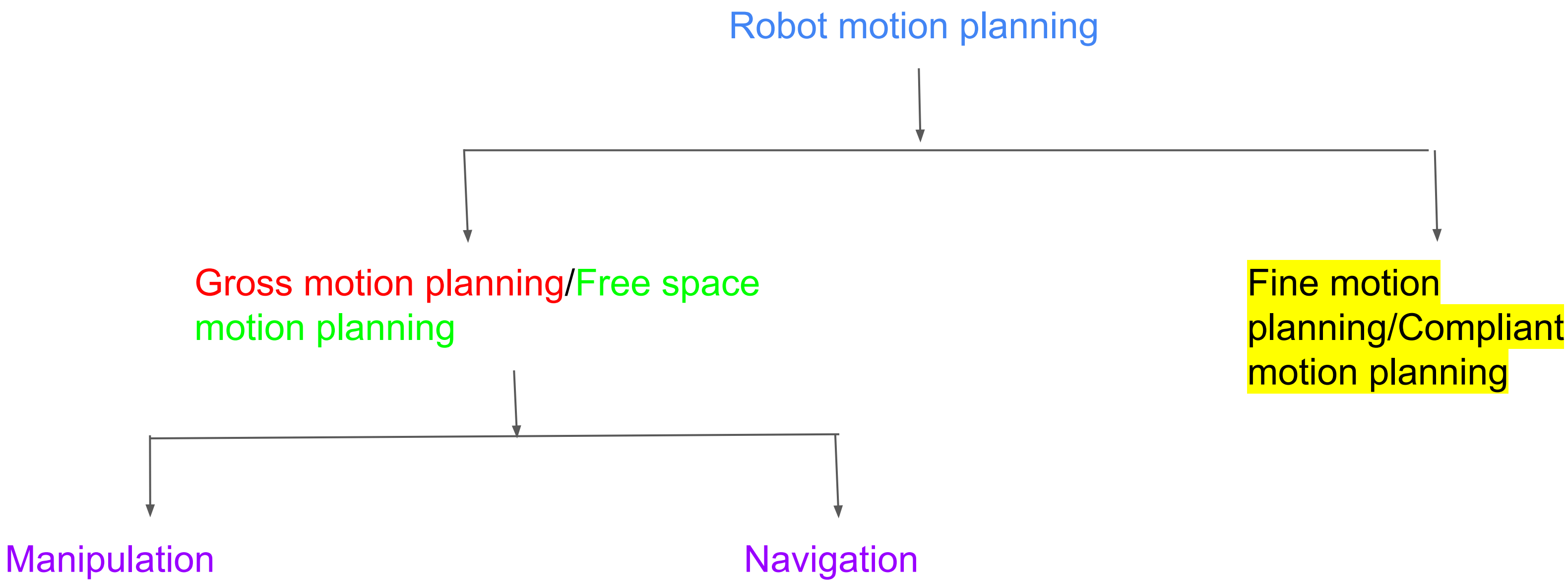
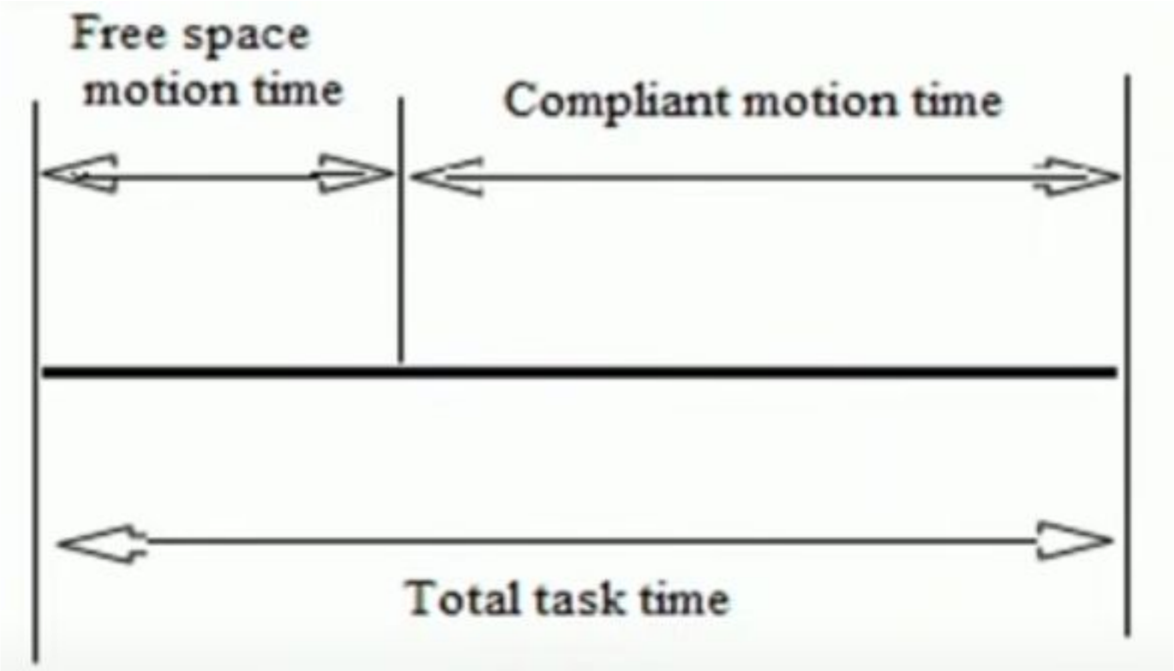
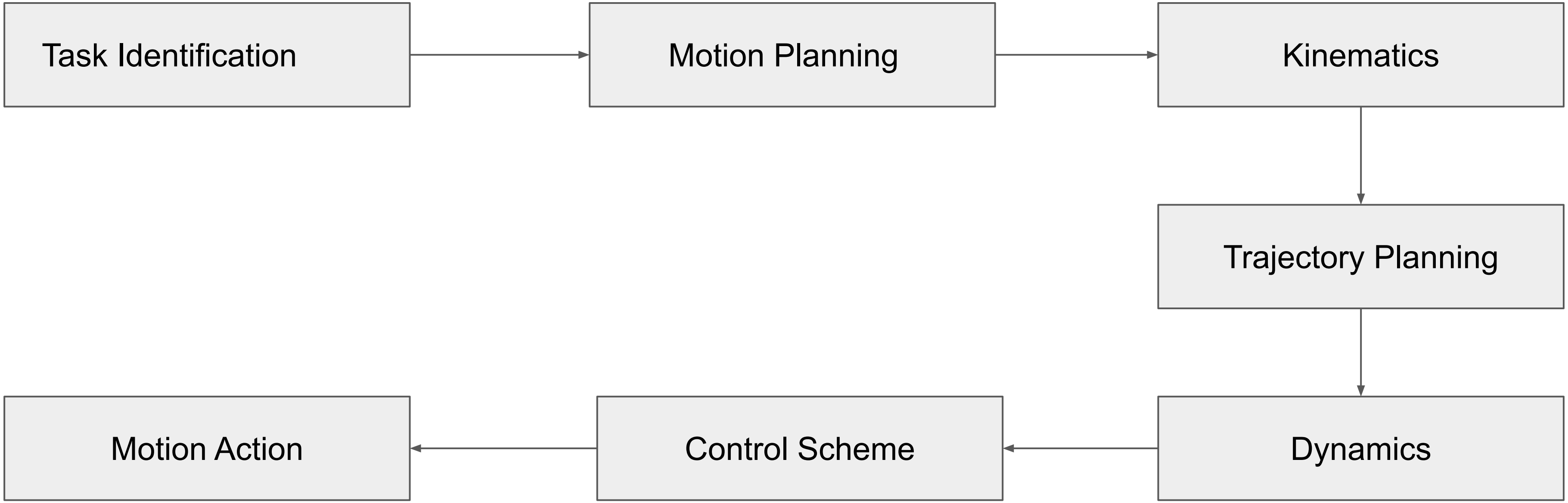
Robot Motion Planning

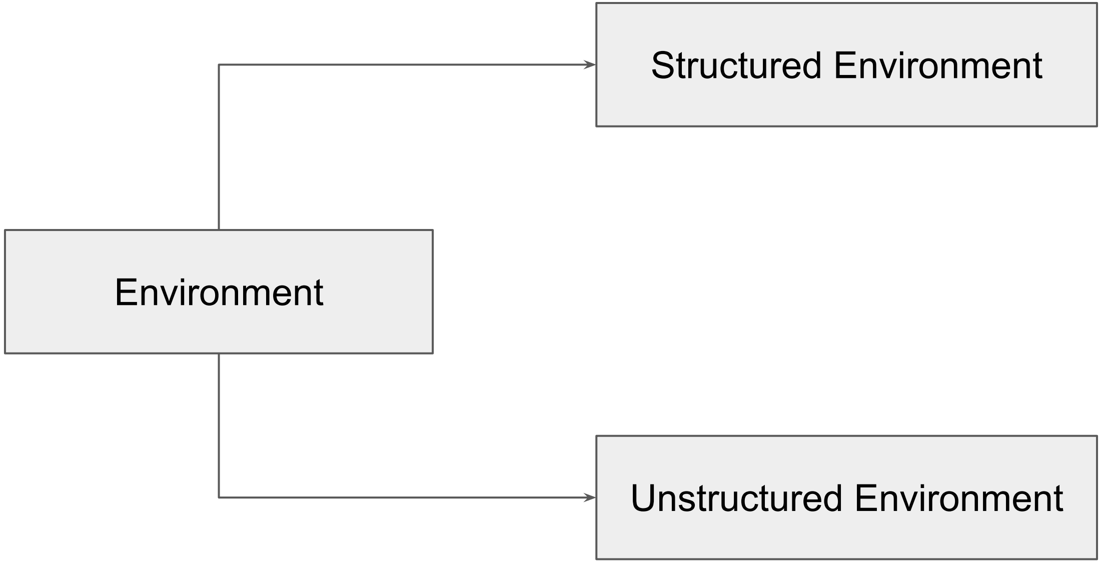

Robot motion planning
Gross motion planning/Free space motion planning
Fine motion planning/Compliant motion planning
Manipulation
Navigation


Free space
motion time
Compliant motion time
Total task time

Sequence of Robotics Action



Find path problem



Dynamic motion planning

Motion Planning Approaches

Global Approach/ Act-After-Thinking process/ Off-line planning (Motion planning with complete information)

Local approach/Act-While-Thinking process/ On-line planning (motion planning with incomplete information)

Motion planning algorithms

Traditional schemes/ Algorithmic approaches

Graph-based methods

1. Visibility graph
2. Voronoi diagram
3. Cell decomposition
4. Tangent graph
5. Accessibility graph

Analytical approaches

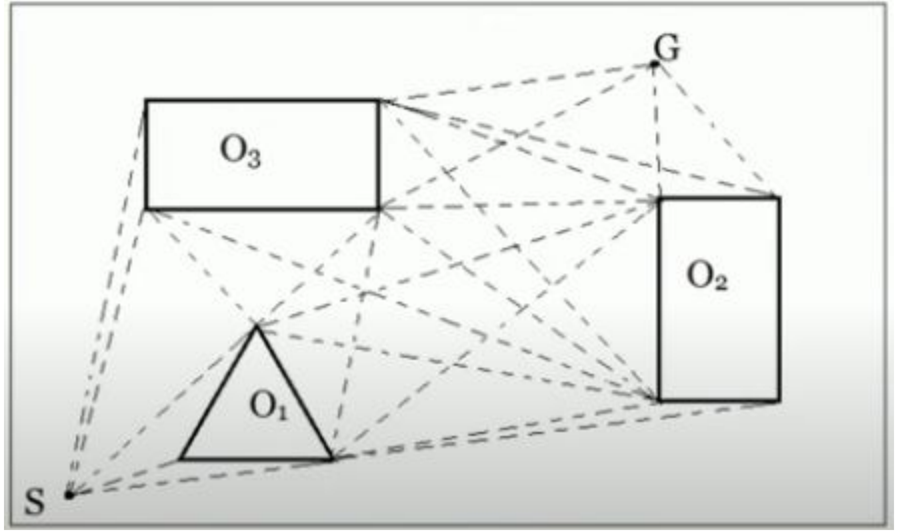
1. Potential Field approach
2. Path velocity Decomposition
3. Incremental Planning
4. Probabilistic Approach
5. Relative Velocity Approach
6. Reactive Control Strategies (Behavior based Robotics)

Non-Traditional scheme (Using soft computing)

1. Fuzzy logic-based
2. Neural networks-based approaches

Visibility Graph(Nilsson 1969)

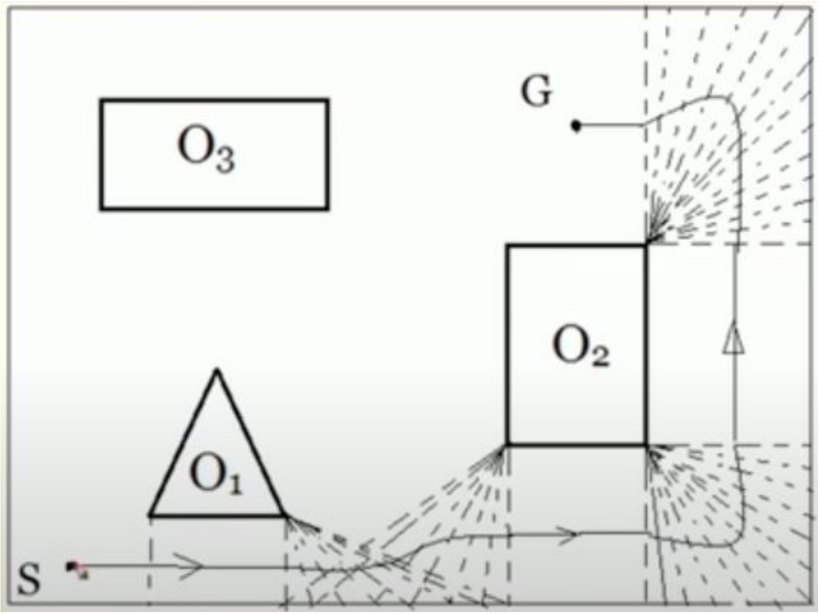
It connects those vertices of obstacles, which are visible from one another.



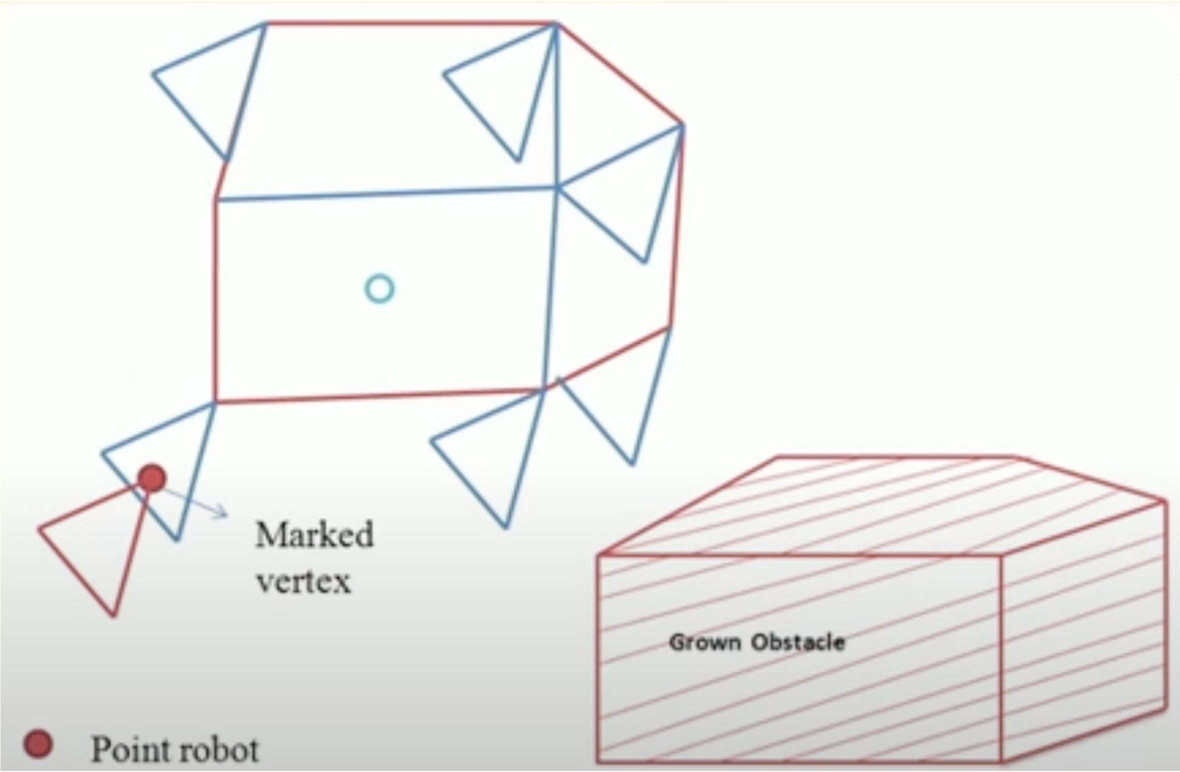
- Point robots
- Obstacles fixed find-path problem

Voronoi Diagram (Dunlaing et al. 1986)

Represents the locus of points those are equidistant from at least two of the boundaries (obstacle).

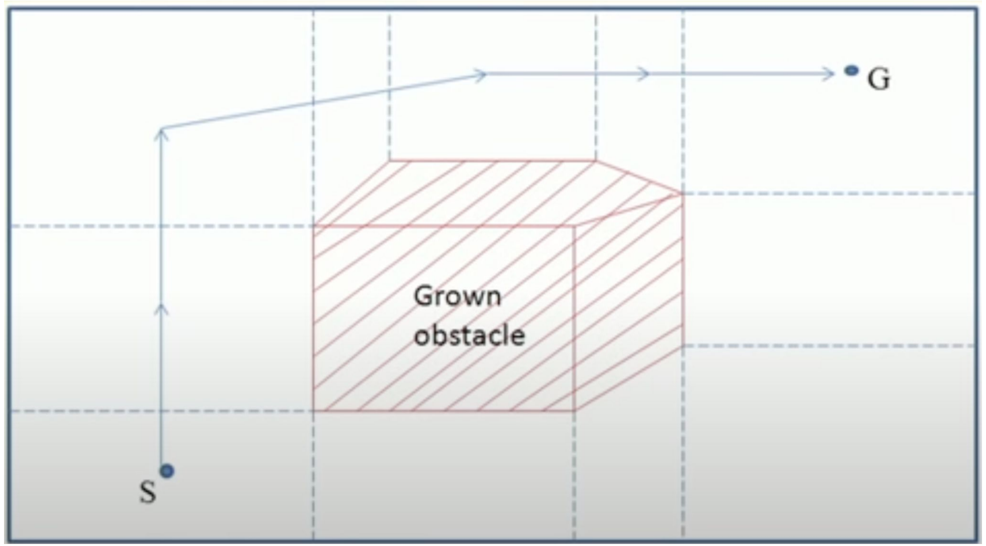


Cell Decomposition(Lozano Perez, 1983)
Configuration space (C-space)



Cell Decomposition (contd.)

Robot’s free area is divided into a number of small regions called cells. A connectivity graph is then constructed and searched

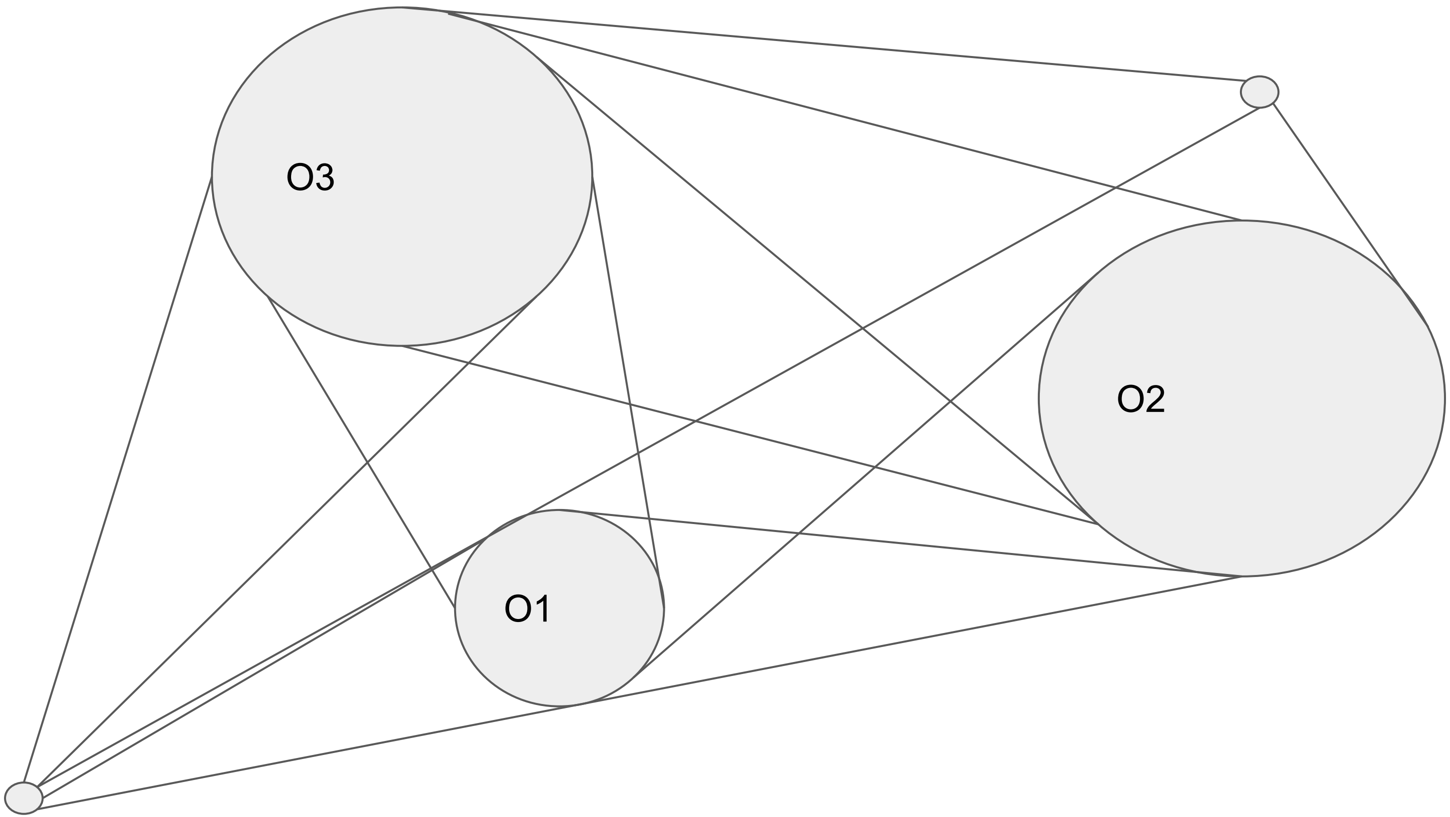


Tangent Graph(Liu & Arimoto 1991)

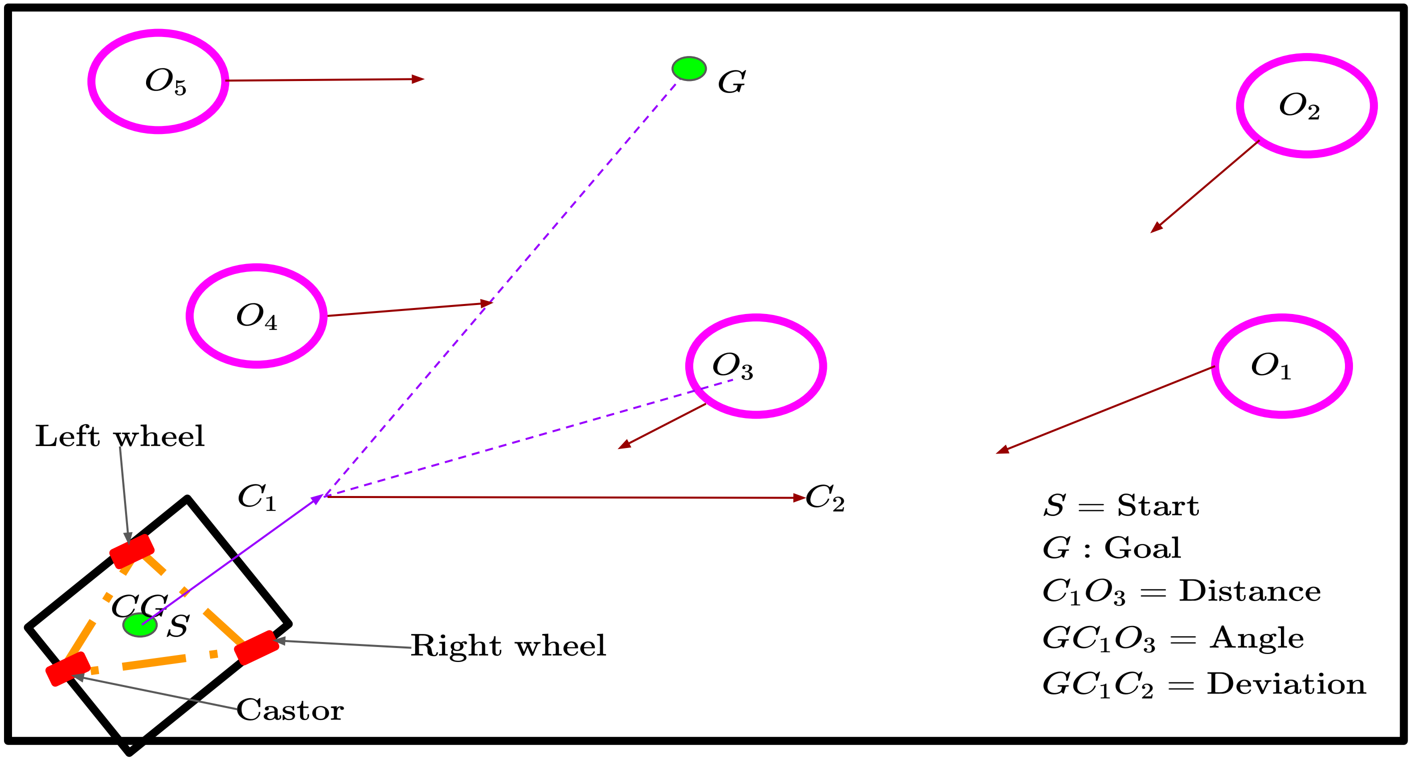
Tangent are drawn from the starting point to the visible obstacle and then from one obstacle to another

A path comprises of tangents and circular arcs

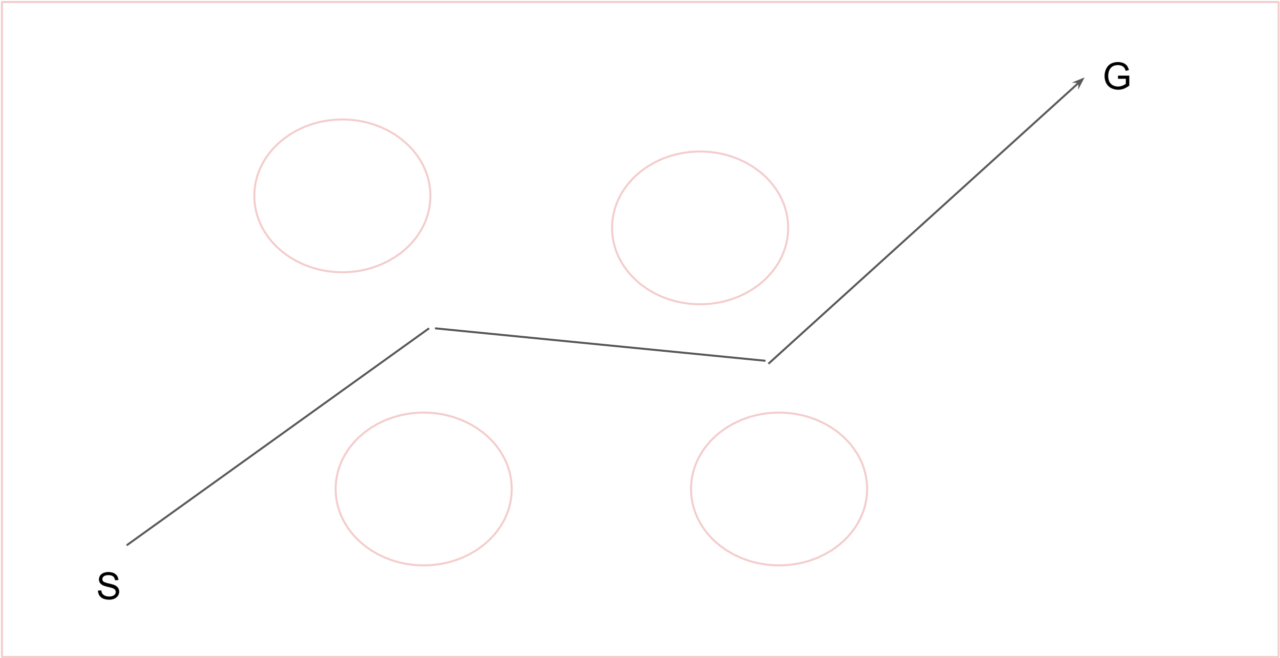
Complexity :O(N^2), where N is the number of control points


O3
O2
O1

Dynamic motion planning problem



Dynamic motion planning problem



$t = t_1$

Approaches to solve Moving Obstacle problems

Path Velocity Decomposition (Kant and Zucker, 1984)

This problem is decomposed into two subproblems as follows:

1. Path planning problem (PPP)-to plan a path to avoid collision with static obstacles
2. Velocity planning problem (VPP)- to plan the velocity of the robot along the above planned path to avoid collision with moving obstacles

Drawbacks

- The path may not be always good, particularly when there are many obstacles
- As there is a sudden change of velocity of the robot, it will have jerky motion, which is not desirable

Accessibility Graph (Fujimura and samet, 1988)

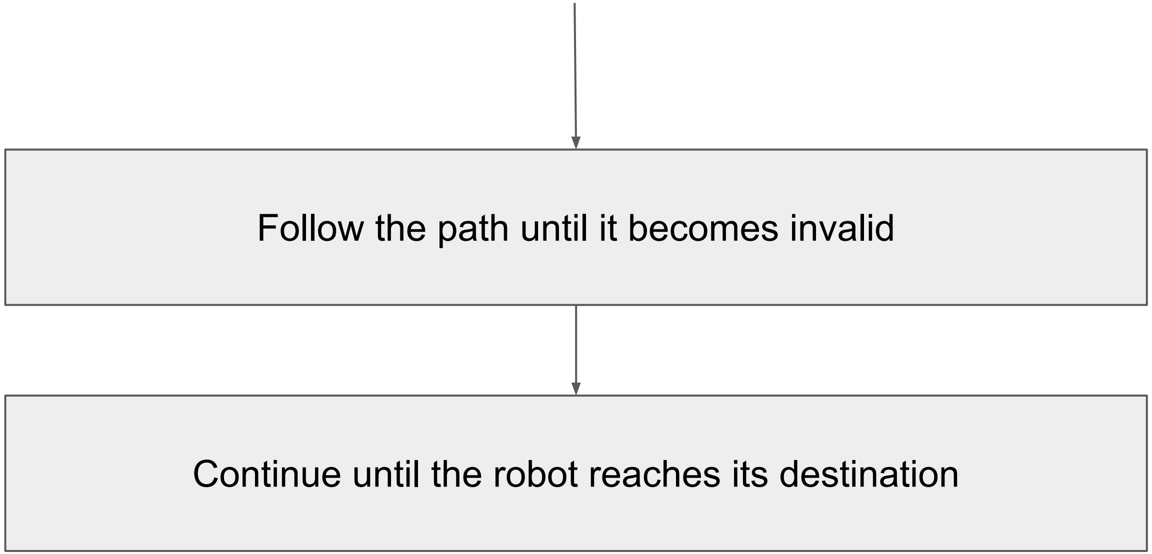
- Generalization of the visibility graph
- At a particular instant of time, motion planning problem in dynamic environment is converted into find-path problem, which is solved using visibility graph
- In dynamic environment, visibility graph will go on changing.
- Computationally expensive and may not be used online

Incremental Planning scheme(slack & Miller, 1987)

Plan a collision-free path based on predicted position of obstacles

Follow the path until it becomes invalid (validity is checked based on the data collected using sensors(s). camera(s))

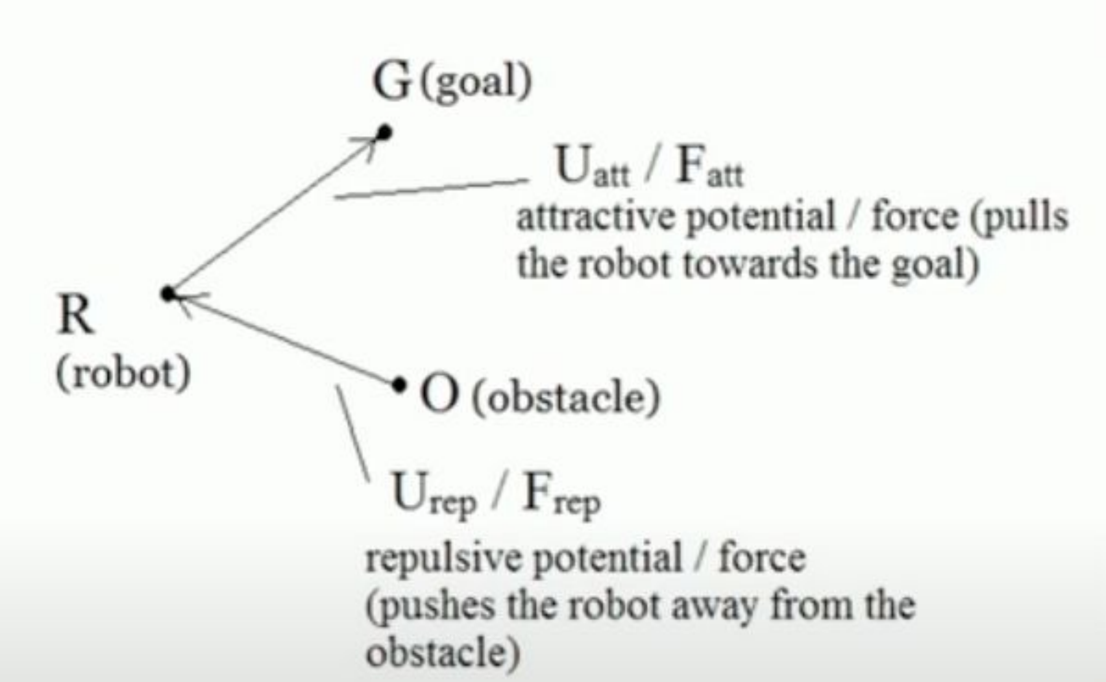
Adjust the predictions and plan a new collision-free path


Follow the path until it becomes invalid
Continue until the robot reaches its destination

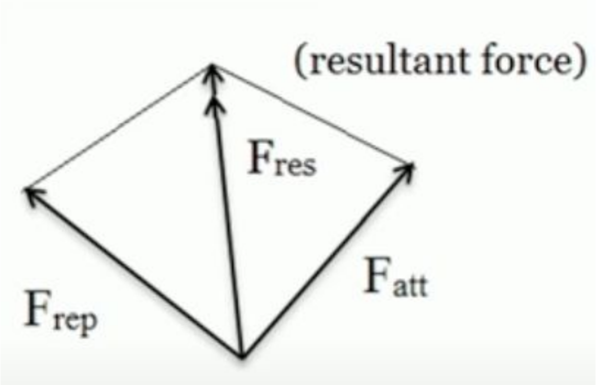
Relative velocity scheme

- Consider relative velocity of the robot with respect to obstacles
- Dynamic motion planning problem is converted into several static problems.
- Several static problems are then converted into a single problem by means of a vector transformation
- Set of velocity vectors are then computed, so that the robot avoids collision with all the moving obstacles.

Potential field approach (Khatib, 1986)



$$F_{att.} = \frac{d\,U_{att.}}{d\,d_{goal_R}}$$



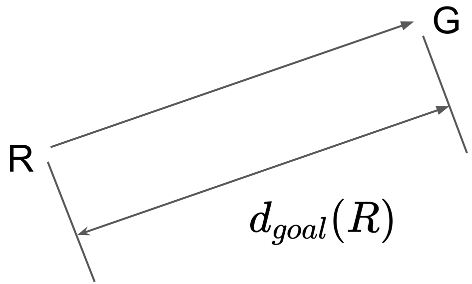
$$F_{rep.} = \frac{d\,U_{rep.}}{d\,d_{obs._R}}$$

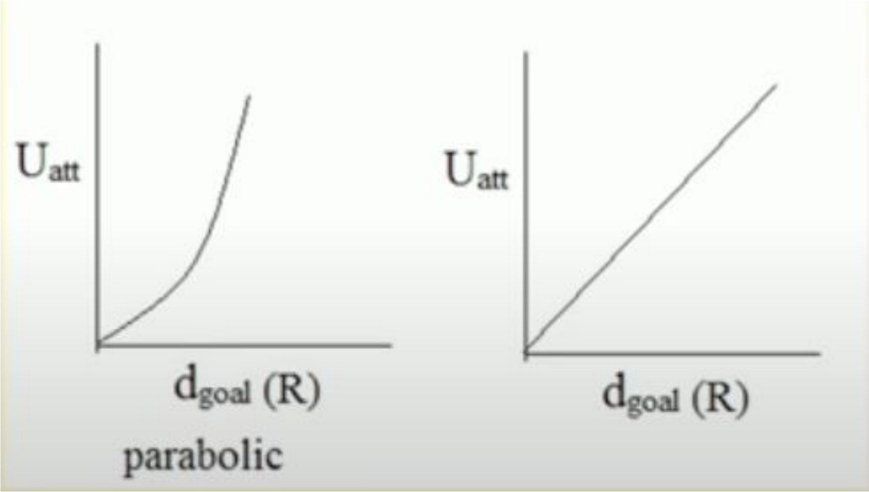
$Speed \propto F_{res.}$

- Speed of the robot $\propto F_{res.}$
- Direction of movement of the robot is along the direction of resultant force

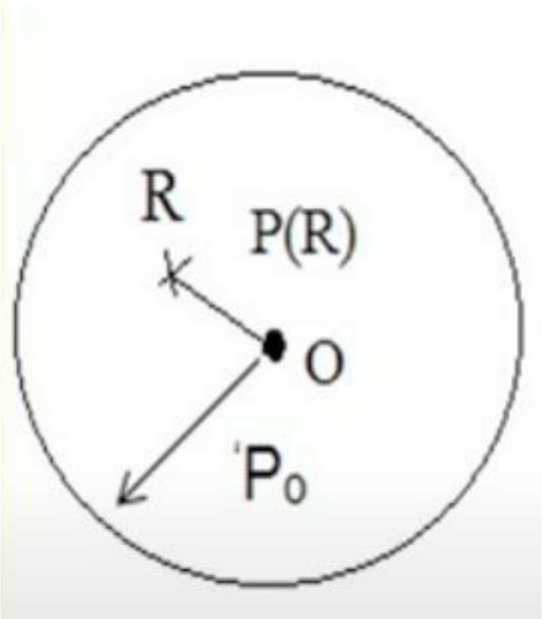
Attractive potential

$$U_{att.}(R) = \frac{1}{2}\zeta d^2_{goal}(R), \text{ if parabolic}$$
$$= \zeta d_{goal}(R), \text{ if conic-well}$$

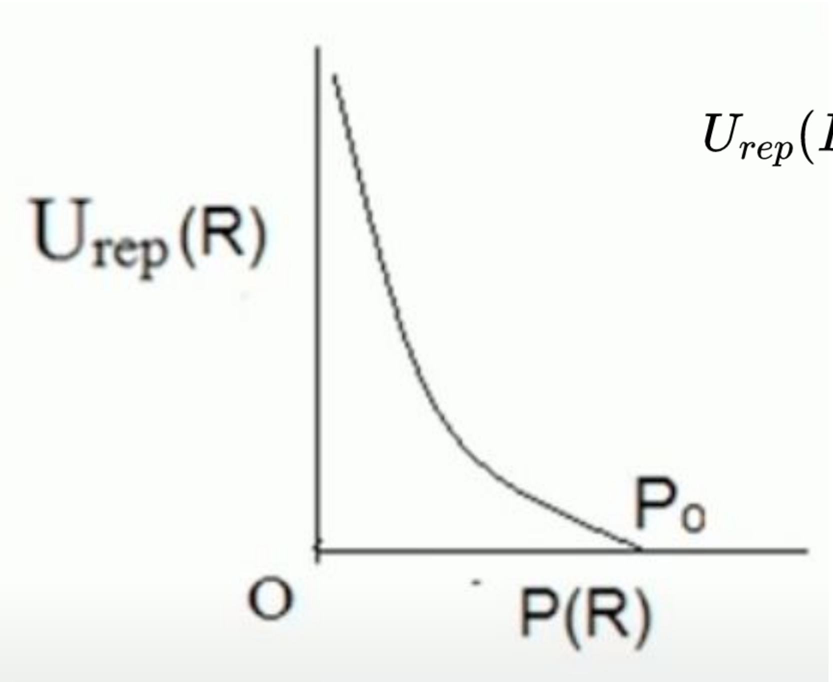




Repulsive Potential



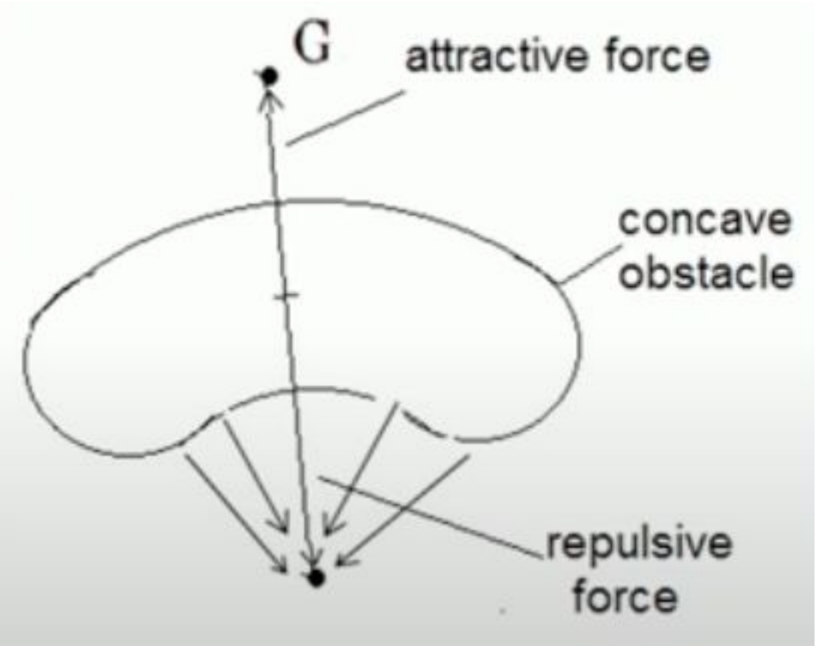
$$U_{rep}(R) = 0$$



$$U_{rep}(R) = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{P(R)} - \frac{1}{P_o}\right)^2, & \text{if } P(R) < P_o \\ 0, & \text{if } P(R) \geq P_o \end{cases}$$

Drawbacks

- Solution depends on the chosen potential function
- Chance of local minima problem-when the attractive force is balanced by the repulsive force



- When the robot travels in a narrow corridor, it experiences repulsive forces simultaneously from the opposite sides, and consequently the motion becomes unstable
- Unable to find a path among closely spaced obstacles

Reactive control strategy (Brooks, 1986)

- Robotic action is decomposed into some independent primitive behaviours like move-to-goal, avoid-obstacles, etc.
- Basic behaviours are controlled at different layers of control architecture
- Basic behaviours are coordinated by a central mechanism (Behaviour-based Robotics)

Computational Complexity

- Canny and Reif (1987)
- Motion planning for a point robot among moving obstacles in 2D plane with bounded velocity is NP-hard

Reif and sharir(1985)

a. Motion planning among moving obstacles in 3-D space without velocity bound is NP-hard
b. Motion planning among moving obstacles in 3-D space with velocity bound is PSPACE-hard

Drawbacks of the Traditional Methods of Motion planning

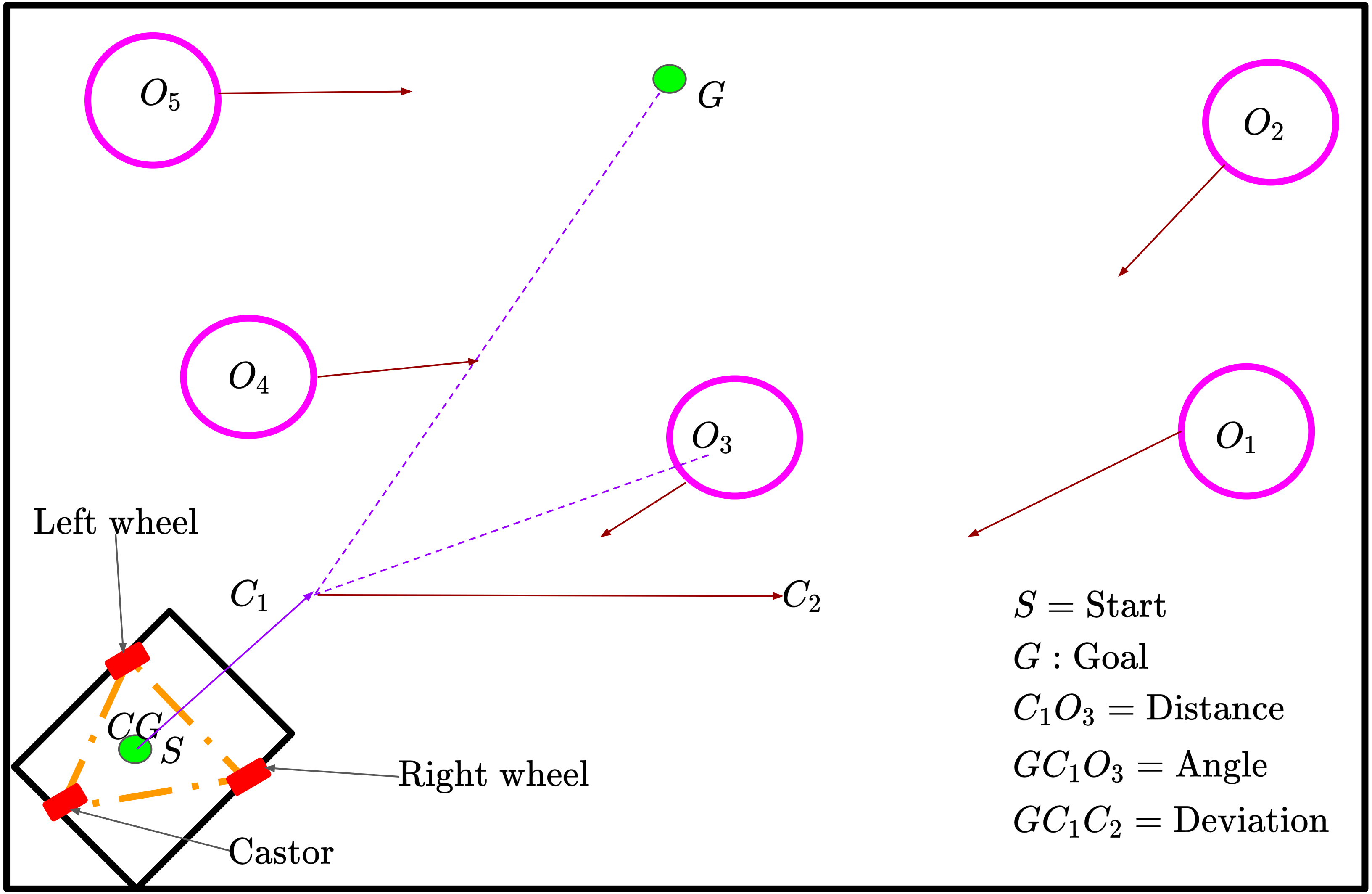
- Traditional methods are computationally expensive even for a simple problem
- No versatile algorithm, which is applicable to all the problems
- As most of the algorithms do not have an optimization module, the generated path may not be optimal in any sense

Intelligent Robot

Introduction

- Intelligent Robot: Adaptive Motion planner & Controller (AI to be merged with Robotics);Ex. Robot soccer
- Ultimate Goal of the RoboCup: “By the mid-21st” century, a team of autonomous humanoid robots shall beat the human world cup champion team under the official regulations of FIFA

In 1997, deeper blue (expert system) defeated gary kasparov (word chase champion) using the principle of AI,



O_5
G
O_2
O_4
O_3
O_1
Left wheel
C_1
C_2
CG
S
Right wheel
Castor
S = Start
G : Goal
C_1O_3 = Distance
GC_1O_3 = Angle
GC_1C_2 = Deviation

Optimization

Minimize

Traveling time

Subject to

Path is collision free

Kinematic and Dynamic constraints are satisfied

Potential field method

Attractive potential generated by the target /goal

$$U_{att}(X) = \frac{1}{2}\zeta_{att} d^2_{goal}(X)$$

Where ζ_{att} is a scaling factor and

$d_{goal}(X)$ is Euclidean distance between the goal and CG of the robot

Repulsive potential provided by obstacles

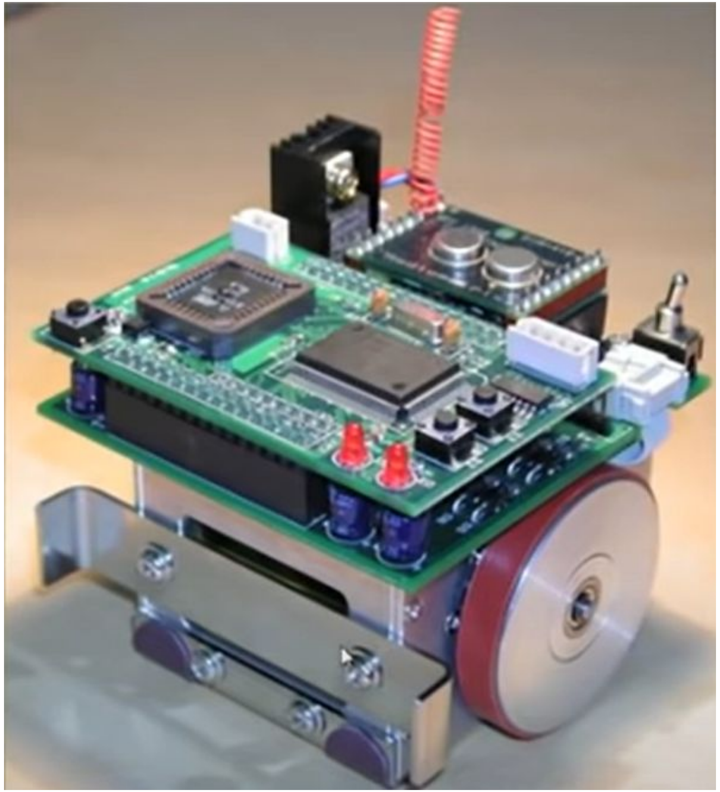
$$U_{rep}(X) = \frac{1}{2}\zeta_{rep}\left[\frac{1}{d_{obs}(X)} - \frac{1}{d_{obs}(0)}\right]^2$$

where ζ_{rep} – scaling factor

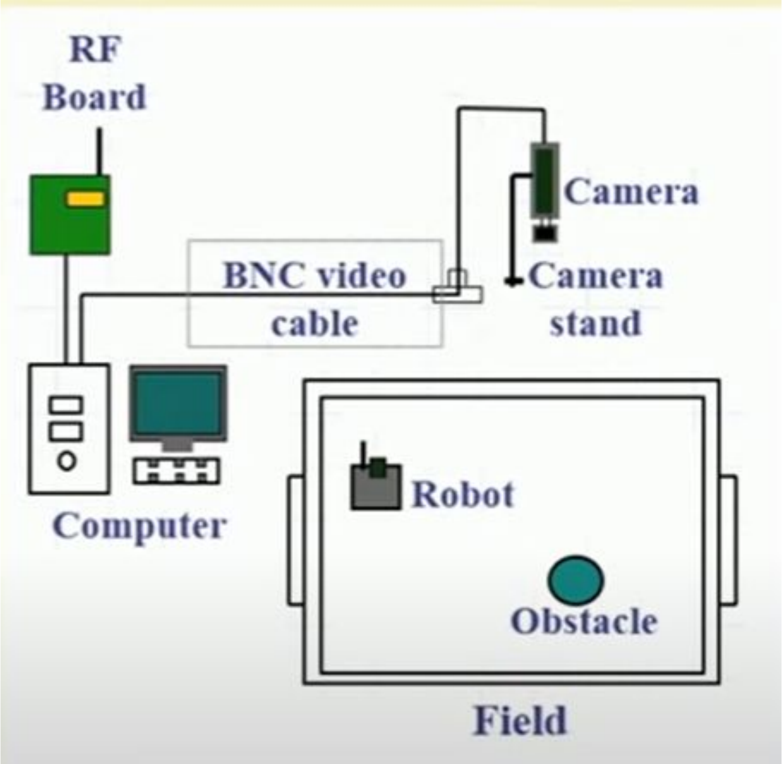
$d_{obs}(X)$ – distance of the obstacle from the robot

$d_{obs}(0)$ – distance of influence of the obstacle

Robot and its accessories



Experiments on Real Robot



Methods of Conducting Experiments

Camera Calibration

On-line image processing

Activation of the motion planning approach

Wireless communication through RF board

Actuation of the robots through motors

Video