

Mobile robot path planning using exact cell decomposition and potential field methods

Dusan Glavaski, Mario Volf, Mirjana Bonkovic

Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture

University of Split, Ruđera Boškovića bb

dusan.glavask@fesb.hr, mario.volf@fesb.hr, mirjana.bonkovic@fesb.hr

Abstract: - In this paper two classic path planning procedures have been explained and adopted to reduce computational time. When studying mobile robotics and robot motion planning, there is always a gap which exists between theoretical achievements and practical considerations of the described methods. This paper clearly overrides the mentioned problem describing minutely the procedures necessary for practical implementations and simulation in the Matlab and MobileSim environment. The algorithms have been presented together with their pseudo codes. The simulation results clearly show the advantages and drawbacks of each of the method.

Key-Words: - path planning, mobile robot, exact cell decomposition, potential field

1. Introduction

The research in the field of robotics is focused on the algorithms used to accomplish fundamental tasks. The typical task is path planning for which exist numerous software [1], [2], [5], [6], [7], [8] as well as hardware [2], [3], [4] implementations for problem solving. In this paper we compare the efficacy through advantages and drawbacks of two methods for basic robot motion problem solutions, together with a practical implementations using Aria programming library, adopted for Amigo Bot mobile robot, produced by Active Media Robotics Ltd. The solutions are based on the classic path planning algorithms, namely exact cell decomposition and potential field methods. Therefore, the introduction follows with the basic motion problem and configuration space specifications. In Section 3, the path planning algorithms are presented together with the pseudo code of the concrete implementations. Section 4 presents the simulation results whereas Section 5 concludes the paper.

2. Basic motion problem and configuration space specifications

In the basic problem, it is assumed that the robot is the only moving object in the workspace and

the dynamic properties of the robot are ignored, thus avoiding temporal issues. The motions are restricted to non-contact motions, so that the issue related to the mechanical interaction between two physical objects in contact can be ignored. These assumptions essential transform the "physical" motion planning problem into a purely geometrical path planning problem. The geometrical issues are simplified even further by assuming that the robot is a single rigid object. The motions of this object are only constrained by the obstacles.

The basic motion planning problem resulting from these simplifications is the following:

- Let A be a single rigid object (the robot) moving in Euclidean space W , called workspace, represented as R^N , with $N=2$ or 3 .
- Let β_1, \dots, β_q be fixed rigid object distributed in W . These objects are called obstacles.
- Assume that both the geometry of A , β_1, \dots, β_q and the locations of the β_i in W are accurately known. Assume further that no kinematic constrains limit the motions of A (we say that A is a free-flying object).

The problem is: Given an initial position and orientation and a goal position and orientation

of A in W , generate a path τ specifying a continuous sequence of positions and orientations of A avoiding contact with β_i , starting at an initial position and orientation, and terminating at the goal position and orientation. Report failure if no such path exists.

The underlying idea of the configuration space is to represent the robot as a point in an appropriate space (the robot's configuration space) and to map the obstacles in this space. This mapping transforms the problem of planning the motion of a dimensioned object into the problem of planning the motion of a point.

Let the robot A (at a certain position and orientation) be described as a compact subset of $W = R^N$, $N=2$ or 3 , and the obstacles β_1, \dots, β_q be closed subsets of W . In addition let F_A and F_W be Cartesian frames embedded in A and W , respectively. F_A is a moving frame, while F_W is a fixed one. By definition, since A is rigid, every point a of A has a fixed position with respect to F_A . But as position W depends on the position and orientation of F_A relative in F_W . Since the β_i 's are both rigid and fixed in W , every point of β_i , for all $i \in [1, q]$, has a fixed position with respect to F_W .

A configuration of an arbitrary object is a specification of the position of every point of this object relative to a fixed reference frame. Therefore, a configuration q of A is a specification of the position τ and orientation θ of F_A with respect to F_W . The configuration space of A is the space C of all the configuration of A .

The path of A from the configuration q_{init} to the configuration q_{goal} is a continuous map:

$$\tau: [0,1] \rightarrow C$$

with:

$$\tau(0) = q_{init}, \text{ and } \tau(1) = q_{goal}.$$

q_{init} and q_{goal} are the initial and goal configurations of the path, respectively. Saying that A is a "free-flying" object means that, in the absence of obstacles, any path defined as above is feasible.

The above definition of a path does not take obstacles into consideration. The set of paths which are solutions to the basic problem when there are obstacles in the workspace will be characterized.

Every obstacle β_i , $i = 1$ to q , in the work space W maps in C to a region:

$$C\beta_i = \{q \in C / A(q) \cap \beta_i \neq \emptyset\}$$

which is called a $C - obstacle$. The union of all the $C - obstacles$:

$$\bigcup_{(i=1)}^{(q)} C\beta_i$$

is called the $C - obstacle$ region, and the set:

$$C_{free} = C \setminus \bigcup_{(i=1)}^q \{q \in C / A(q) \cap (\bigcup_{(i=1)}^q \beta_i) \neq \emptyset\}$$

is called the free space.

Any configuration in C_{free} is called a free configuration.

A free path between two free configurations q_{init} and q_{goal} is a continuous map formula.

Two configurations belong to the same connected component of C_{free} if and only if they are connected by a free path.

Given an initial and a goal configuration, the basic motion planning problem is to generate a free path between the two configurations, if they belong to the same connected component of C_{free} , and to report failure otherwise.

A semi-free path is a continuous map formula, where formula denotes the closure of C_{free} . Hence, as it moves along such a path, the robot may touch obstacles.

More details and formal notations have been taken from [1].

3. Planning methods

There exist a large number of methods for solving the basic motion planning problem. Not all of them solve the problem in its full generality. Despite many external differences, the methods are based on few different general approaches which are roadmap, cell decomposition and potential field. These approaches will be briefly introduced bellow. The first type of motion planning algorithm is referred to as roadmap method. There are several different methods for developing the roadmap such as visibility graph and Voronoi diagrams. The roadmap method vs. cell decomposition has been deeply studied in [2]. In this paper we study more deeply cell decomposition method and path planning algorithms. In the next section these two methods have been described more deeply, together with the basic idea of the roadmap method.

3.1 Roadmap

The roadmap approach to path generation consists of reducing the environmental information to a network of one-dimensional curves, called the roadmap. Once the roadmap has been constructed, a path can be calculated by connection the initial and final configurations to the network and finding a path in the roadmap. Examples of roadmap methods are the visibility graph, Voronoi diagram, free way net and silhouette graphs.

In general roadmap methods are fast and most of them are easy to implement, but they do not provide an intrinsic way of describing the environmental information [1].

3.2 Cell decomposition

The basic idea behind this method is that a path between the initial configuration and the goal configuration can be determined by subdividing the free space of the robot's configuration into

smaller regions called cells. After this decomposition, a connectivity graph, as shown below, is constructed according to the adjacency relationships between the cells, where the nodes represent the cells in the free space, and the links between the nodes show that the corresponding cells are adjacent to each other. From this connectivity graph, a continuous path, or channel, can be determined by simply following adjacent free cells from the initial point to the goal point. Cell decomposition can be used in path planning in the following way:

1. The free space of the polygonal two-dimensional configuration space is determined.
2. The free space is partitioned into a collection of cells.
3. A connectivity graph is constructed by connecting the cells that share a common boundary (a hole in the bounding polygon corresponds to a cycle in the connectivity graph).

In the on-line phase:

1. A sequence of cells, a channel, which the robot must traverse in order to go from the initial position to the goal position, is obtained from the connectivity graph.
2. A free path is constructed from the channel. [9]

If the robot is not a point and can turn in any direction then computing the free space is a major part of the calculation. Most methods assume a point-sized robot or a convex polygonal robot with fixed orientation and increase the thickness of the wall by the width of the robot. The resulting free space is taken as an input. The triangular robot has a fixed orientation and a reference point p . Given the workspace defined by the interior of the bold polygon, the free space of the robot, with respect to the point p , is the white area with the bold line. However, it now becomes more difficult to describe the actual environment around a cell and most robots do not have a fixed orientation.

3.3 Potential field

Potential field method treats the robot represented as a point in configuration space as a particle under the influence of an artificial potential field U whose local variations are expected to reflect the "structure" of the free space [1].

The potential fields can be imagined either as a charged particle navigating through a magnetic field or a marble rolling down a hill. The basic idea is that behavior exhibited by the particle/marble will depend on the combination of the shape of the field/hill [10]. Unlike fields/hills where the topology is externally specified by environmental conditions, the topology of the potential fields that a robot experiences are determined by the designer. More specifically, the designer creates multiple behaviors, each assigned a particular task or function, represents each of these behaviors as a potential field, and combines all of the behaviors to produce the robot's motion by combining the potential fields. The potential function is typically defined over free space as the sum of an attractive potential pulling the robot toward the goal configuration and a repulsive potential pushing the robot away from the obstacles. At each iteration an artificial force $\vec{F}(q) = -\nabla U(q)$ introduced by the potential function at the current configuration is regarded as the most promising direction of motion, and path generation proceeds along this direction by some increment.

The potential is calculated as the sum of two or more elementary potential functions:

$$U(q) = U_{att}(q) + U_{rep}(q)$$

The attractive potential field can be simply defined as a parabolic well:

$$U_{att}(q) = \frac{1}{2} e(p_{goal}(q))^2$$

where e is a positive scaling factor and denotes the Euclidean distance. The function is positive or null, and attains its minimum at q_{goal} , where U_{att} is singular.

The main idea underlying the definition of the repulsive potential is to create a potential barrier around the C -obstacle area that cannot be traversed by the robots configuration. In addition, it is usually desirable that the repulsive potential does not affect the motion of the robot when it is sufficiently far away from C -obstacle. Formula for the repulsive potential:

$$U_{rep}(q) = \begin{cases} \frac{1}{2} \eta \left(\frac{1}{\rho}(q) - \frac{1}{\rho_0} \right), & \text{if } \rho(q) \leq \rho_0 \\ 0 & \text{if } \rho(q) > \rho_0 \end{cases}$$

where η is a positive scaling factor, ρ_0 denotes the distance from to the C -obstacle region, and is a positive constant called the distance of influence of the C -obstacle.

4. Exact cell decomposition algorithm

In this section, the exact cell decomposition method which was used for the software implementation of the algorithm is introduced. Polygonal configuration space method is the simple case of exact cell decomposition where $C = \mathbb{R}^2$ and the C -obstacle region $C\beta$ (the union of the C -obstacles) forms a polygonal region in C . For simplifying the presentation, we assume that the robot's free space $C_{free} = C / C\beta$ is bounded. Figure 1 depicts such a configuration space.

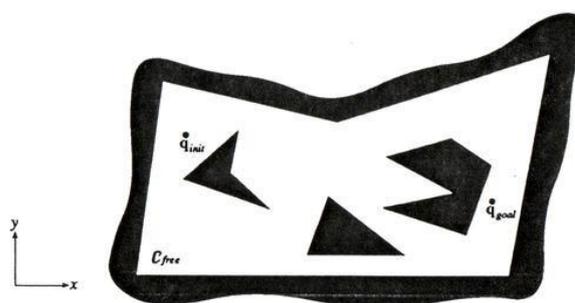


Figure 1: Two-dimensional configuration space (image taken from [1])

The decomposition of C_{free} and the associated connectivity graph is defined as follows:

- **A convex polygonal decomposition** K of C_{free} is a finite collection of convex polygons, called cells, such that the interior of any two cells do not intersect and the union of all the cells is equal to C_{free} . Two cells κ and κ' in K are adjacent if only if $\kappa \cup \kappa'$ is a line segment of non-zero length.
- **The connectivity graph** G associated with a convex polygonal decomposition K of C_{free} is the non-directed graph specified as follows:
 - G 's nodes are the cells in K .
 - Two nodes in G are connected by a link if and only if the corresponding cells are adjacent.

Consider an initial configuration q_{init} and a goal configuration q_{goal} in C_{free} . The exact cell decomposition algorithm for planning a free path connecting the two configurations is the following:

1. Generate a convex polygonal decomposition K of C_{free} .
2. Construct the connectivity graph G associated with K .
3. Search G for a sequence of adjacent cells between q_{init} and q_{goal} .
4. If the search terminates successfully, return the generated sequence of cells; otherwise, return failure.

The output of the algorithm is a sequence $\kappa_1, \dots, \kappa_p$ of cells such that $q_{init} \in \kappa_1$, $q_{goal} \in \kappa_p$ and for every $j \in [j, p-1]$, κ_j and κ_{j+1} are adjacent. This sequence is called a **channel**.

One simple way to generate a free path contained in the interior of the channel produced by the search of G is to consider the midpoint Q_j of every segment β_j and to connect q_{init} to q_{goal} by a polygonal line whose successive vertices are $Q_1, \dots, Q_{(p-1)}$.

The optimal convex decomposition of a polygon is computable in polynomial time. The degree

of a polynomial is proportional to the number of vertices n . Unfortunately, the presence of holes in the polygon makes this problem NP-hard.

A non-optimal convex polygonal decomposition of C_{free} is generated by sweeping a line L parallel to the y -axis across C_{free} . The sweep process is interrupted whenever L encounters a vertex X of $C\beta$. A maximum of two vertical line segments are created, connecting X to the edges of $C\beta$ that are immediately above and immediately below X , as shown in Figure 2. The boundary of $C\beta$ and the erected vertical line segments determine a **trapezoidal decomposition** of C_{free} . Each cell of the decomposition is either a trapezoid or a triangle. Two cells are adjacent if and only if their boundaries share a vertical segment. When such a segment is crossed the vertical structure of the constraints imposed by $C\beta$ on the motion of A (*robot*) changes discontinuously.

Notice that the same algorithm also applies when $C\beta$ is not bounded; the generated decomposition then includes cells that extend infinitely in the y -axis direction.

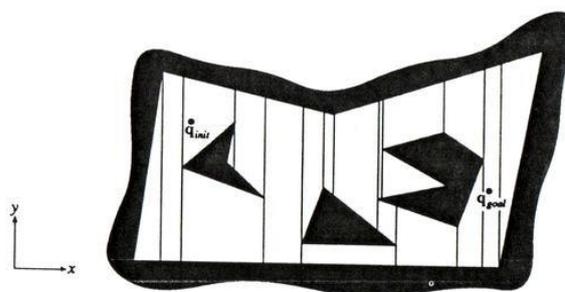


Figure 2: Trapezoidal decomposition of free space (image taken from [1])

The search of G can be done in various ways. A simple breadth-first search takes $O(n)$ time. But the produced channel may be far from optimal with respect to the Euclidean lengths of the paths it contains. One possible alternative is to use the A^* search algorithm, with a different search graph G' specified as follows:

- The nodes of G' are q_{init} , q_{goal} , and the midpoints Q_j of all the portions of boundary shared by adjacent cells.
- Two nodes are connected by a link if and only if they belong to the same cell (they can be joined by a straight line segment in the cell).

Each link is weighted by the Euclidean length of the straight line segment joining the two nodes.

If a free path exists, the search produces the shortest free path contained in G' . It also determines a sequence of cells from which another path can be extracted. The search takes $O(n \log n)$ time.

5. Potential field algorithm

The algorithm that is used in the implementation is called best-first planning. It consists of throwing a fine regular grid of configurations across C . The grid is denoted by GC . GC can be defined by considering a single chart over C and discretizing each of the m corresponding coordinate axes. Given a configuration q in the m -dimensional grid GC , its p -neighbors are defined as all the configurations in GC having at most p coordinates differing from those of q , the amount of the difference being exactly one increment in absolute value. In addition, for simplifying the presentation, we make the following assumptions:

- Both q_{init} and q_{goal} are configurations in GC .
- If two neighbors in GC are in free space, the straight line segment connecting them in R also lies in free space.
- The grid GC is bounded and forms a rectangle.

Best-first planning consists of iteratively constructing a tree T whose nodes are configurations in GC .

The root of T is q_{init} . At every iteration, the algorithm examines the neighbors of the leaf of T that has the smallest potential value, retains the neighbors not already in T at which the potential function is less than some large threshold M , and installs the retained neighbors in T as successors of the currently considered

leaf. The algorithm terminates when the goal configuration q_{goal} has been attained or when the free subset of GC accessible from q_{init} has been fully explored. Each node in T has a pointer toward its parent. If q_{goal} is attained, a path is generated by racing the pointers from q_j to q_{j+1} . The pseudo code will now be explained.

The procedure BFP given below (Table 1.) is a formal expression of the best-first planning algorithm. In addition to the tree T , BFP uses a list $OPEN$ that contains the leaves of T sorted by increasing values of the potential function. $OPEN$ supports the following three operations: $FIRST(OPEN)$, which removes the configuration of $OPEN$ having the smallest potential value and returns it; $INSERT(q, OPEN)$, which inserts the configuration q in $OPEN$; and $EMPTY(OPEN)$, which returns true if the list $OPEN$ is empty.

```

Procedure BFP;
begin;
install  $q_{init}$  in  $T$ ;
[initially,  $T$  is an empty tree]
INSERT( $q_{init}$ ,  $OPEN$ ); mark  $q_{init}$  visited;
[initially, all the configurations in  $GC$  are marked "unvisited"]
SUCCESS <- false;
while !EMPTY( $OPEN$ ) and !SUCCESS do
begin
 $q$  <- FIRST( $OPEN$ );
for every neighbour  $q_c$  of  $q$  in  $GC$  do
if  $U(q_c) < M$  and  $q_c$  is not visited then
begin
install  $q_c$  in  $T$  with a pointer toward  $q$ ;
INSERT( $q_c$ ,  $OPEN$ ); mark  $q_c$  visited;
if  $q_c = q_{goal}$  then SUCCESS <- true;
end;
end;
if SUCCESS then
return the constructed path by tracing the pointers in  $T$  from
 $q_{goal}$  to  $q_{init}$ ;
else return failure;
end;

```

Table 1: Pseudo code of the BFP procedure

This procedure follows a discrete approximation of the negated gradient of the potential function until it reaches a local minimum. The algorithm is guaranteed to return a free path whenever there exists one in the free subset of the grid GC and to report failure otherwise.

6. Implementation

Implementation was done using ARIA programming library, MATLAB, C++, Mapper and MobileSim robot simulator. A short description for the above (less known) programming packages will be given:

1. **ARIA** - is an object-oriented, robot control applications-programming interface for MobileRobots (and ActivMedia) intelligent mobile robots. Written in the C++ language, ARIA is client-side software for easy, high-performance access to and management of the robot, as well as to the many accessory robot sensors and effectors. ARIA includes many useful utilities for general robot programming and cross-platform (Linux and Windows) programming as well. ARIA can be run multi- or single-threaded, using its own wrapper around Linux threads or Win32 threads. You can access ARIA at different levels, from simply sending commands to the robot through ArRobot to development of higher-level intelligent behaviour using Actions.[11]

2. **Mapper** – Mapper is application from ActivMedia Robotics company which provides the tools needed to construct a map of robot's real operating space.[11]

3. **MobileSim** - is software for simulating MobileRobots/ActivMedia platforms and their environments, for debugging and experimentation with ARIA . It replaces SRIsim previously distributed with ARIA. MobileSim builds upon the Stage simulator, created by Richard Vaughan, Andrew Howard, and others as part of the Player/Stage project, with some modifications by MobileRobots. [12]

6.1 Best-first path

The algorithm is implemented using MATLAB and ARIA. The source code can be found in [3]. The BFP algorithm includes a tree structure. In the implementation a tree structure was not used because of its complexity. Instead, a so called checking function was designed and used. Consequently, for every iteration starting at the initial point q_{init} it looks up its p -neighbors. Then, it returns the neighbor configuration that has the lowest potential value. This returned configuration is marked as $a1$ and $b1$. The

current configuration is marked simply as a and b . After the configuration with the minimal potential value is returned, it is checked if that value corresponds to the goal configuration. If it does then the path from initial to the goal configuration can be constructed. Otherwise, a and b become $a1$ and $b1$ and the iteration process continues.

Also the **GC** space is represented as a 100x100 grid. Every point is accessed through two counters I and J representing x and y of the configuration. In the example two obstacles are introduced: a rectangle and a square. The first iteration calculates the repulsive potential from every point of C-obstacles to the current point (note that the Euclidean distance between every point in C-obstacle and the current point must first be calculated). Then the attractive potential between the current point and the goal configuration is calculated. At the end these two potentials are added and the value of the potential in the current point attained. The checking function will now be explained in more detail. It takes the matrix of all potential values in a 100x100 space, current position (a,b) and the maximal configuration in 100x100 which is naturally (100,100) or (X,Y). Then it examines the following conditions:

1. if ($a \geq 2$) & ($b \geq 2$) & ($a < X$) & ($b < Y$)
2. elseif ($a \geq 2$) & ($b \geq 2$) & ($a < X$) % eliminates $b+1$
3. elseif ($a \geq 2$) & ($a < X$) & ($b < Y$) % eliminates $b-1$
4. elseif ($a \geq 2$) & ($b \geq 2$) & ($b < Y$) % eliminates $a+1$
5. elseif ($b \geq 2$) & ($a < X$) & ($b < Y$) % eliminates $a-1$
6. elseif ($a == 1$) & ($b == 1$)
7. elseif ($a == X$) & ($b == 1$)
8. elseif ($a == 1$) & ($b == Y$)
9. elseif ($a == X$) & ($b == Y$)
10. elseif ($a == 1$)
11. elseif ($a == X$)
12. elseif ($b == 1$)
13. elseif ($b == Y$)

These conditions are used to see where the current configuration is in the map and to generate the p -neighbours $A11, A12, A13, A21, A23, A31, A32, A33$. As you can see $A22$ is the current location. Now the algorithm must return the value of the neighbour that has the lowest potential value. Before this step is performed several conditions must be examined:

```

% A13 A23 A33
% A12 X A32
% A11 A21 A31
if      (A11<A21)&(A11<A31)&(A11<A12)&
        (A11<A32)&(A11<A13)&(A11<A23)&(A11<A33)
x=a-1;
y=b-1;
elseif (A21<A31)&(A21<A12)&(A21<A32)&
        (A21<A13)&(A21<A23)&(A21<A33)
x=a;
y=b-1;
elseif (A31<A12)&(A31<A32)&(A31<A13)&
        (A31<A23)&(A31<A33)
x=a+1;
y=b-1;
elseif (A12<A32)&(A12<A13)&(A12<A23)&
        (A12<A33)
x=a-1;
y=b;
elseif (A32<A13)&(A32<A23)&(A32<A33)
x=a+1;
y=b;
elseif (A13<A23)&(A13<A33)
x=a-1;
y=b+1;
elseif (A23<A33)
x=a;
y=b+1;
else
x=a+1;
y=b+1;
end

```

6.1 Polygonal configuration space

The algorithm is implemented using ARIA library and C++ programming language. The maps for the simulation are made with the Mapper application. Implementation of exact cell decomposition algorithm has two separate parts:

1. Graphical analysis and processing of the map.
2. Robot movement through coordinates of the shortest path for the given map.

In this paper the focus is on the second step of the implementation. It is up to the user of the application to calculate the coordinates of all possible paths for the given map.

For input, the application uses file created by the user which contains coordinates of all possible paths. The file must be formatted in a way that one line represents one path and each point is divided by a space character from another. Each path must contain robots initial configuration for purposes of calculating

Euclidean distance for them. The sample of such file can be seen in Table 2.

```

1.01 1.01 2 1.5 3 1 4 1.5 5 1 6 0.5 6.51 1.52 7.5 4
1.01 1.01 2 1.5 3 1 4 1.5 5 3.5 6 4.5 6.31 4.02 7.5 4
1.01 1.01 2 4 4 4 5 3.5 6 4.5 6.31 4.02 7.5 4
1.01 1.01 2 4 4 4 5 1 6 0.5 6.31 1.52 7.5 4

```

Table 2: Sample of map configuration file
Class *Coord* (Table 3.) is created for purposes of storing x and y points for single coordinate:

```

class Coord {
public:
    Double xt;
    Double yt;
    Coord();
    Coord(double x, double y) : xt(x), yt(y) {};
};

```

Table 3: Class *Coord*

The application reads the contents of file and stores data in vector of classes *Coord*; the collection of all paths is stored in vector of vectors *Paths* (Table 4.):

```

typedef vector<Coord>Dots
typedef vector<Dots>Paths

```

Table 4: Vectors used for storing paths

When all the data has been stored the Euclidean distance is calculated for each path and these values are used to determine the shortest path:

```

double distance (Dots d) {
double dist, tmp;
for (Dots::size_type i=0; i < d.size();i++) {
for (Dots::size_type j=i+1; j<=i+1; j++)
tmp += pow((d[i].xt - d[j].xt),2) + pow((d[i].yt -
d[j].yt),2);
}
dist = sqrt(tmp);
return dist;
}

```

Table 5: Function for calculating Euclidean distance of paths

Once the shortest path has been chosen it is stored in a file called *shortest*. The initial configuration of robot isn't stored in this file (it is only used for the calculation of distance from initial to goal configuration of the robot). While creating the map user can position the robot anywhere in the free space. When the simulation

is started MobileSim uses robots initial configuration as the beginning of the coordinate system (0,0). To solve this problem offset has to be subtracted from each point in the coordinates before moving of the robot occurs. Notice that the initial configuration of the robot (coordinates of robots starting point) represents the offset. ARIA with needed classes and methods is initialized for purposes of controlling robot movement (Table 6.).

```
Aria::init()
ArArgumentParser
parser(&argc, argv)
parser.loadDefaultArguments()
ArSimpleConnector
simpleConnector(&parser)
ArRobot robot
ArSonarDevice sonar
ArAnalogGyro gyro(&robot)
robot.addRangeDevice(&sonar)
```

Table 6: Initialization of ARIA classes and method

The method *gotoPoseAction.setGoal(ArPose(x, y))* is used for the movement of the robot. The *setGoal(ArPosegoal)* method sets a new goal of the robot and sets the action to go to the given goal. This action goes to a given *ArPose* coordinate very naively. The action drives straight towards a given *ArPose* and it stops when it gets close enough to the goal. *setGoal* method is used for giving a new goal to the robot, while *haveAchievedGoal* is used to check if the robot has achieved the given goal. *ArPose* takes coordinates in millimetres. For this reason the coordinates of the paths given in a file should be multiplied by 1000, because the values in the file are given in metres (Mapper application uses metres as coordinate values). The whole procedure can be seen in Table 7.

7. Simulation results

7.1. Best-first path

The algorithm is simulated in Matlab and on MobileSim as well. For the purpose of the simulation a map with two rectangle obstacles is used. In the example which follows, the goal point is (8,8). Figure 3 illustrates only the repulsive potential.

It can be easily seen that the repulsive potential does not depend on the position of the goal configuration. Figure 4 represents only the attractive potential. The difference between these two graphs is that the attractive potential depends on the position of the goal configuration.

```
if (gotoPoseAction.haveAchievedGoal()) {
shortest >> x;
shortest >> y;
if(shortest.eof())
break;
x=x-x_offset; //offset rescission
y=y-y_offset;
x=x*1000; //conversion of coordinates to millimetres
y=y*1000;
gotoPoseAction.setGoal(ArPose(x, y)); //sending robot to
the next calculated goal
}
```

Table 7: Procedure of robot movement

Adding up repulsive (negative) and attractive (positive) potential fields, a graph which can be seen in the Figure 5, is attained. Similarly, as in previous example, Figure 6 shows how the algorithm works when it is embedded in MobileSim. The movement of the robot depends on the potential function. It determines the value of the potential in each point of space. Also the C-obstacle region is controlled with the distance of influence. If it has a large value than the C-obstacle space spreads out in space creating a potential barrier that can not be traversed by the robot. If a goal configuration is inside the radius of the distance of radius than the algorithm would run for infinity. This is one problem that we must pay a close attention to. Another problem is the local minima. The local minima is a point in which the value of the potential equals zero but it is not a goal point.

Aside from obvious problems potential field method is the simplest and wittiest technique for robot motion planning. Its main attribute is its simplicity.

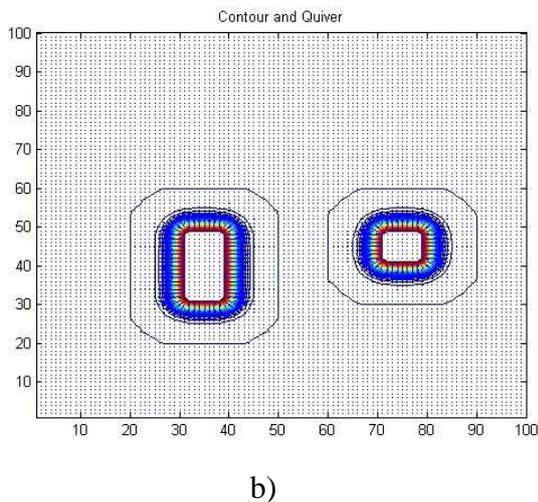
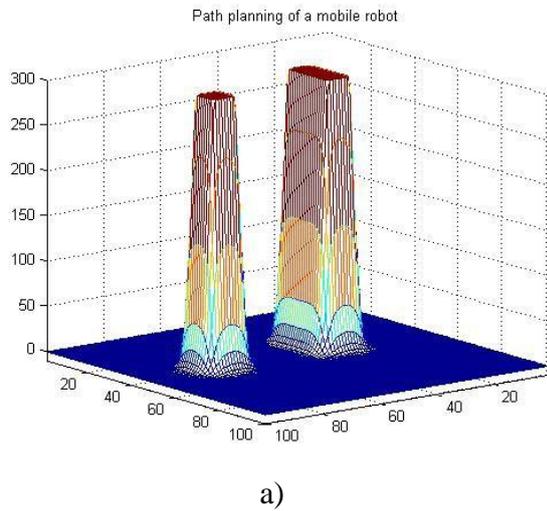


Figure 3: Potential field in case where there are two obstacles: a) perspective representation; b) plane view

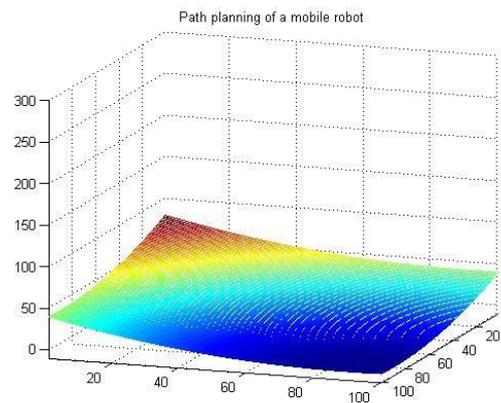
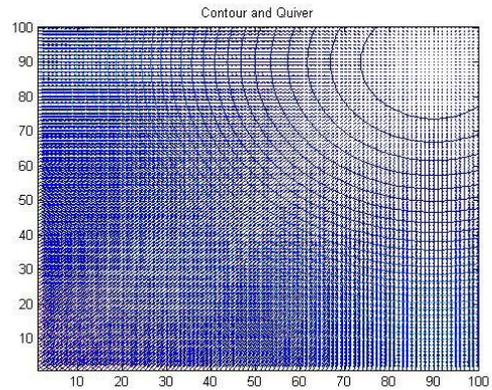


Figure 4: The map represents the attractive potential

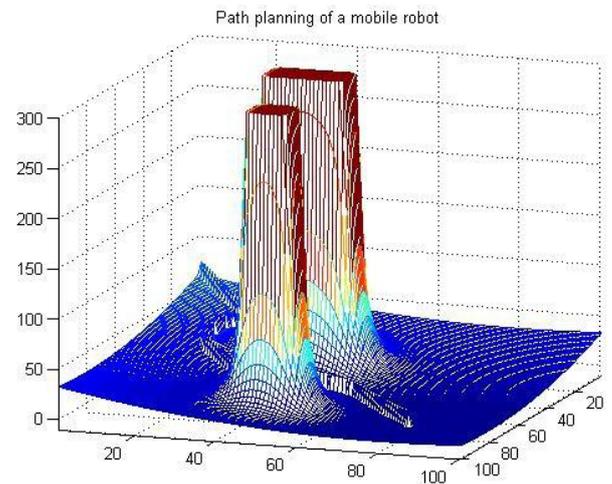


Figure 5: Attractive+repulsive potential field+free path

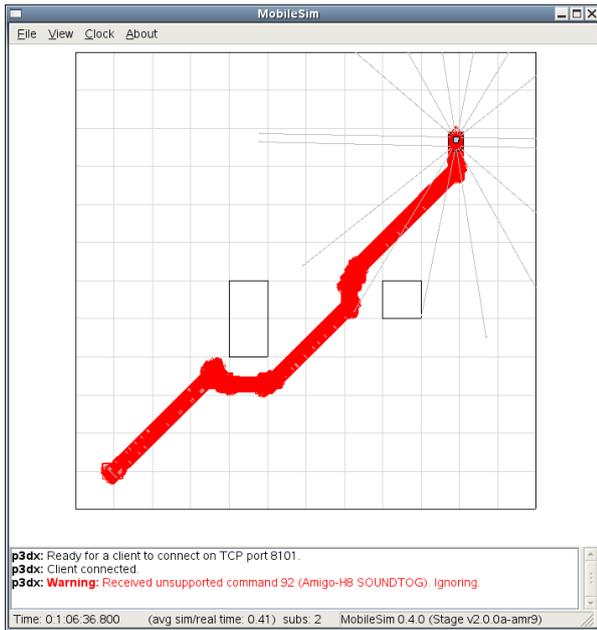


Figure 6: Trace of the path generated in MobileSim

7.2 Polygonal configuration space

MobileSim application was used for the simulation of the algorithm. The application works from a command line. A user must pass three arguments to application:

- Name of the file with coordinates of all possible paths for a certain map
- Wanted speed of the robot (mm/s)
- Close distance (used to set the distance which is close enough to the goal (mm)).

The program prints out values of all possible paths, values of Euclidean distances and the coordinates of the shortest path. The motion and path of the robot can be seen in the MobileSim application. It is easily noticed that the robots path is determined by the midpoints Q_j of segments β_j . The path of the robot is highly influenced by the layout of the obstacles in free space. The distance between obstacles and the edge of robots free space determines how widely

the robot avoid an obstacle (Figure 7). During the simulation problems occurred with higher speed values on certain maps. The robot would rotate too fast and miss its next goal, resulting in a random circular movement of the robot around

the missed coordinate (Figure 8). Similar problems occurred when the robot would come too close to the obstacle during the rotation. The possible solutions to this problem are lowering robots speed or increasing close distance through application arguments.

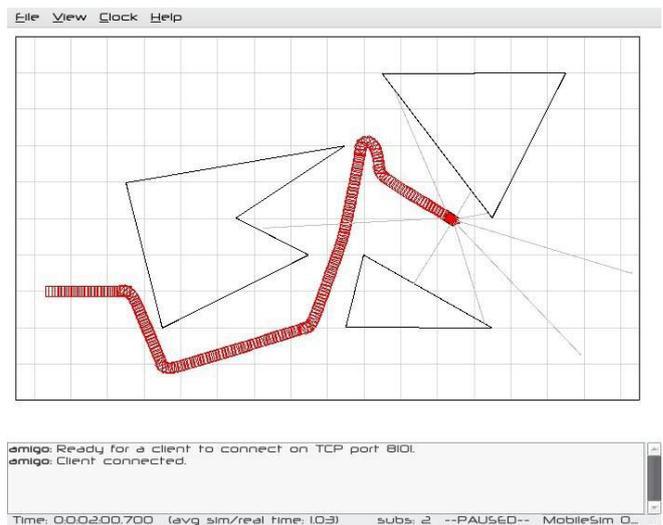


Figure 7: Path generated by the application (simulation in MobileSim)

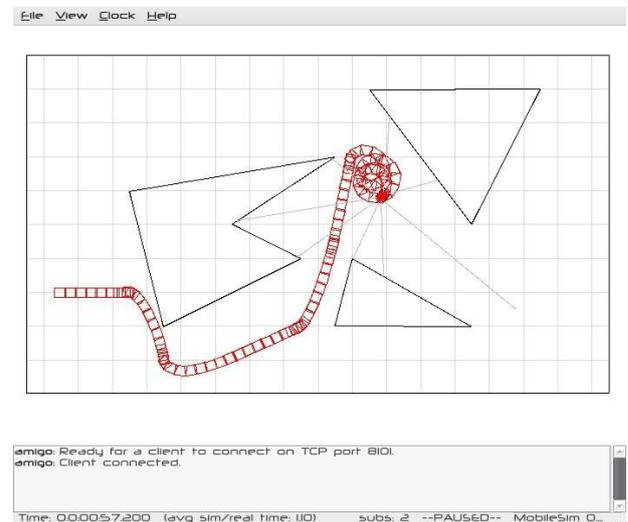


Figure 8: Robot movement problem as a high speed result

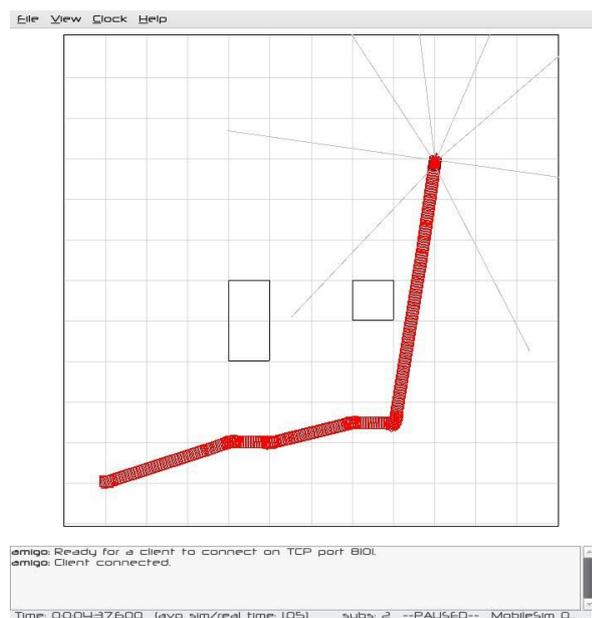


Figure 9: Path generated by polygonal configuration space method

This method, in most cases, avoids obstacles more widely than other methods, while the paths not being significantly longer. The paths generated by this method are usually significantly better than those generated using the visibility graph method. The simulation on the same map as shown in the best-first path chapter can be seen in Figure 9.

The main disadvantage of this method is hard implementation of map analysis and processing. On the other hand, it is very logical and easy to understand.

8. Conclusion

Two typical methods used in robot motion planning were shown. Potential field method was originally developed as an on-line collision avoidance approach, applicable when the robot does not have prior knowledge of the obstacles, but senses them during motion execution. Emphasis was put on real-time efficiency, rather than on guaranteeing the attainment of the goal. It may get stuck at a local minimum of the potential function other than the goal configuration. However, the idea underlying potential field can be combined with graph searching techniques. Then, using a prior model

of the workspace, it can be turned into systematic motion planning approach and this was done in the previous examples. In contrast to potential field method the exact cell decomposition method is not meant for real time path planning. It is a graphical method used when a prior model of the workspace is known. The method guarantees finding a free path if one exists and if it is attainable by the robot.

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