KOÇ UNIVERSITY

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DEPARTMENT OF MECHANICAL ENGINEERING

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MECH 444/544 PROJECT #2

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Contents

Introduction and Abstract

Motion planning is very crucial for the robotics. The robot has to be able to move while avoiding obstacles or decide not to move if no collusion free path can be found to avoid harm. Motion planning has many applications in the industry (e.g., Autonomous driving). The motivation is to go from start position to end position without touching any obstacle.

One of the methods of deterministic motion planning is called the potential field method. In this method, goal position is said to have an attractive potential, and obstacles are said to have a repulsive potential. This is analogous to potential of electrical charges. The pros of this method can be summarized as follows: Spatial paths are not preplanned and can be generated in real time; planning and control are merged into one function; smooth paths are generated; planning can be coupled directly to a control algorithm. The con is that the robot can get stuck in a local minima, and there would be no way for the robot to continue heading towards the goal position without applying other methods to solve this problem.

In this project, we are asked to implement the potential field method for a 2-link robot arm. As a bonus, we have decided to implement a wave-front planner to avoid getting stuck in a local minima. This approach is explained later in this paper. The position of the 2-link robot arm in the cartesian coordinate system is given in the figure below:

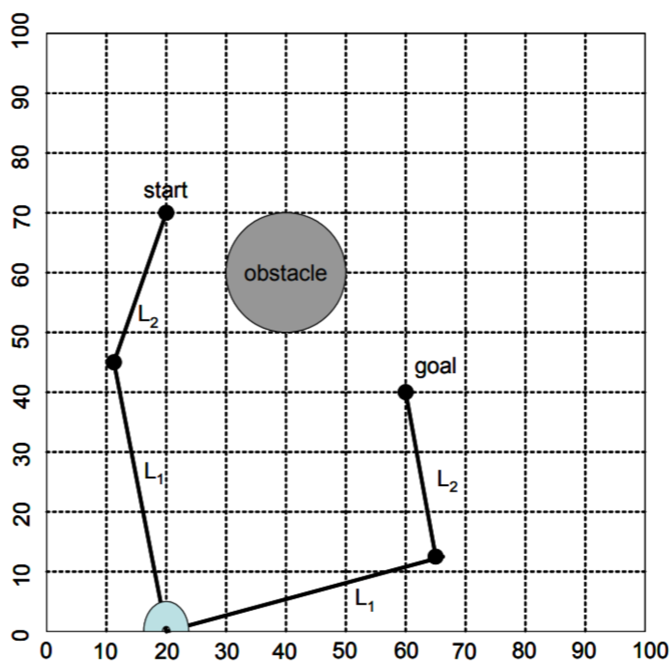

Figure 1 Cartesian coordinate location of the 2-link robot arm

Discussion & Results

Configuration Space

To be able to calculate a collision-free path for the robot one has to transform the cartesian space into configuration space. In the configuration space, the robot is treated as a point and the movement constraints (such as obstacles or working zone boundaries) are treated as obstacles. Construction of the configuration spaces requires checking the collision of the robot's links for every possible α, β pairs. Discretization of the continuous range of α, β pairs should be fine enough such that it does not cause any collision. However, the density of the discretized space immensely affects the computational cost of both space and trajectory generation. In that sense, selecting the discretization rate is crucial. We have picked 1 as our discretization value for the α, β pairs. Resulting configuration space is given in the figure below:

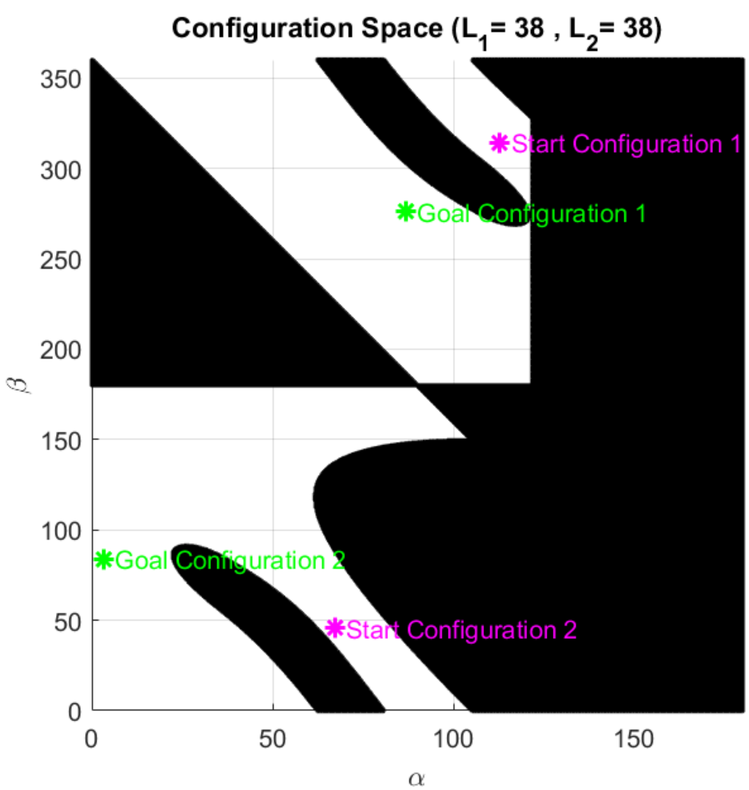

Figure 2 Configuration Space

In this figure elbow-up and elbow-down solutions of the given cartesian coordinates are also marked.

The potential value of a single point in the configuration space is the sum of attractive and repulsive potentials at that point. Attractive potential solely depends on the distance between the goal and the current configurations. The attractive potential is calculated using the following formula:

$$U_{goal}(q) = \frac{1}{2}\zeta\left\|q - q_{goal}\right\|^2 \quad , \qquad \boldsymbol{\zeta}: attraction\ gain$$

Repulsive potential, on the other hand, is affected by the distance between the current configuration and the closest obstacle to that configuration. The repulsive potential of a point is calculated using the following formula:

$$U_{rep} = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho(q)} - \frac{1}{\rho_0}\right)^2 if\ \rho(q) \leq \rho_0 \\ 0 \qquad\qquad\qquad\quad if\ \rho(q) > \rho_0 \end{cases} \quad , \qquad \begin{array}{c} \boldsymbol{\eta}: Repulsion\ gain \\ \boldsymbol{\rho_0}: Distance\ of\ influence \end{array}$$

where,

$$\rho(q) = \min_{q\prime = CB}\|q - q'\|$$

Potential Field Implementation

In our implementation, the collision-free trajectory calculation of the robot can be made with both the potential field and the wavefront approaches. To calculate the trajectory using the potential field method, potential values on a small 3-by-3 point grid is calculated. In this small square grid, the point in the middle is taken as the current location on the trajectory. Then, the point with the smallest potential value in this small 3-by-3 point grid is selected as the next point of the trajectory. This selection process is repeated until the current point (The point in the middle of the grid) has the smallest potential value among these 9 points. Potential values of all the points in the discretized configuration space are shown in the figure below:

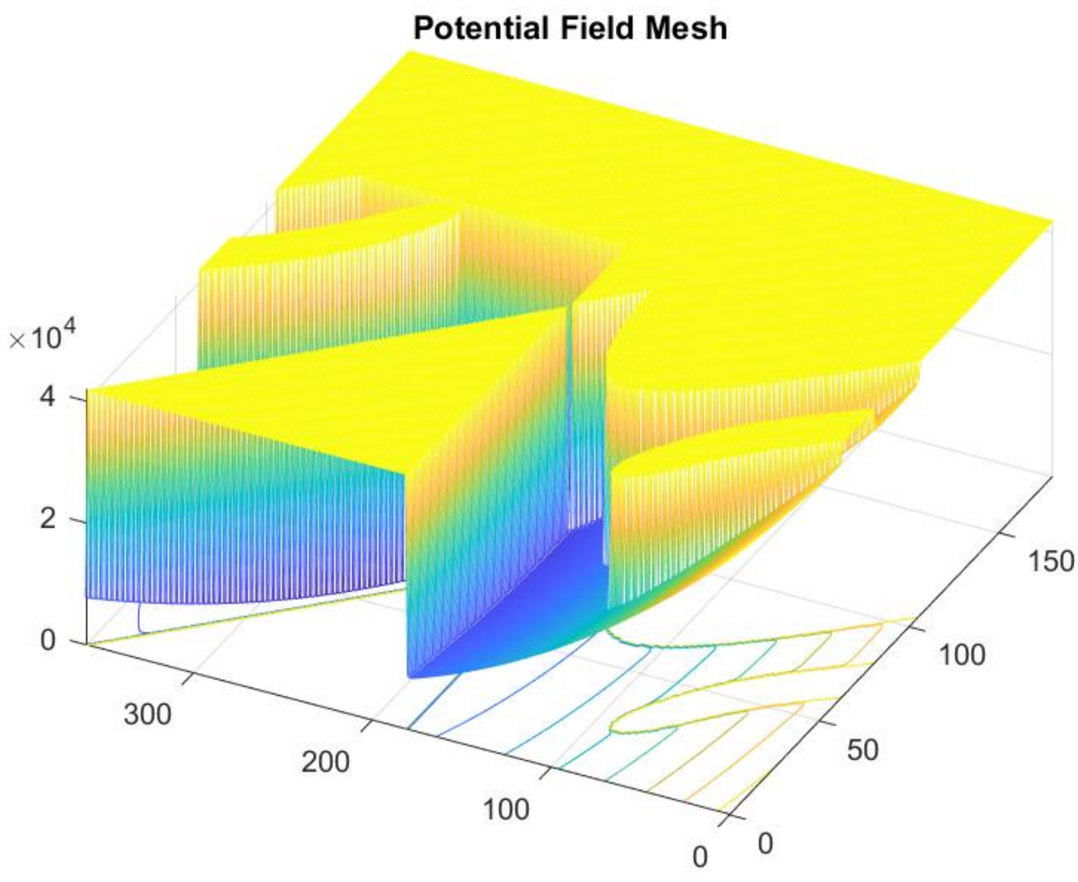

Figure 3 3D potential field mesh

2D contours of the potential field are given in the figure below:

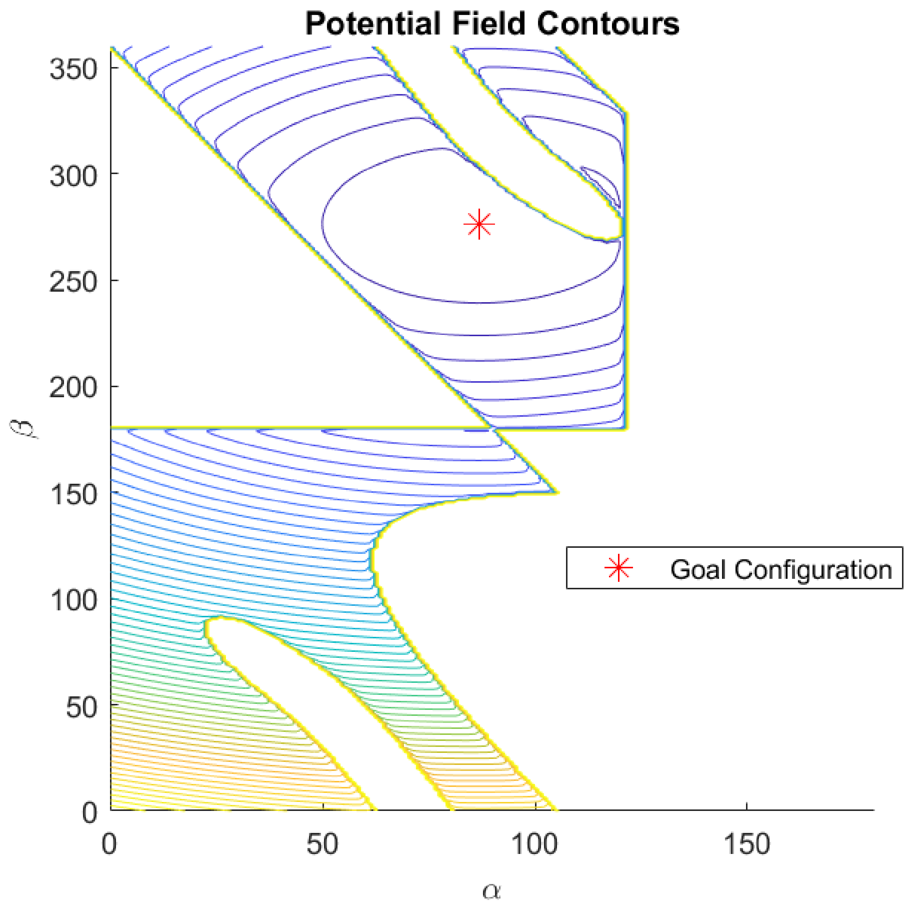

Figure 4 2D Potential Field Contours

Wave-Front Planner

One problem with the potential field implementation is that there might be a local minima other than the goal configuration. Wave-front planner is an alternative to the potential field approach to tackle the local minima problem. This method only works with configuration spaces that are represented in grids. In this mesh map, obstacles are labeled as 1 and the empty spaces as 0. Next step is to mark the target configuration as 2. After that, we label the zero-valued neighboring pixels with 3. Then zero-valued pixels adjacent to 3 are marked as 4. This process continues until all the zero-valued pixels are labeled. From this "cost-map" points on the trajectory are calculated using gradient descent method. Due to the nature of the wave propagation, it is guaranteed that there will be a neighboring pixel with a smaller value than the current point.

Conclusion

In conclusion, we were able to implement 2 different approaches to calculate a collision-free trajectory for a 2-link robot arm. For the cases where potential field implementation fails to generate a path, wavefront implementation should be preferred as it is guaranteed to generate a trajectory. One drawback of the wavefront approach is that the path is generated at the cost of robot coming too close to the obstacle. An example of a case where potential field implementation fails to generate a path is given in the figure below:

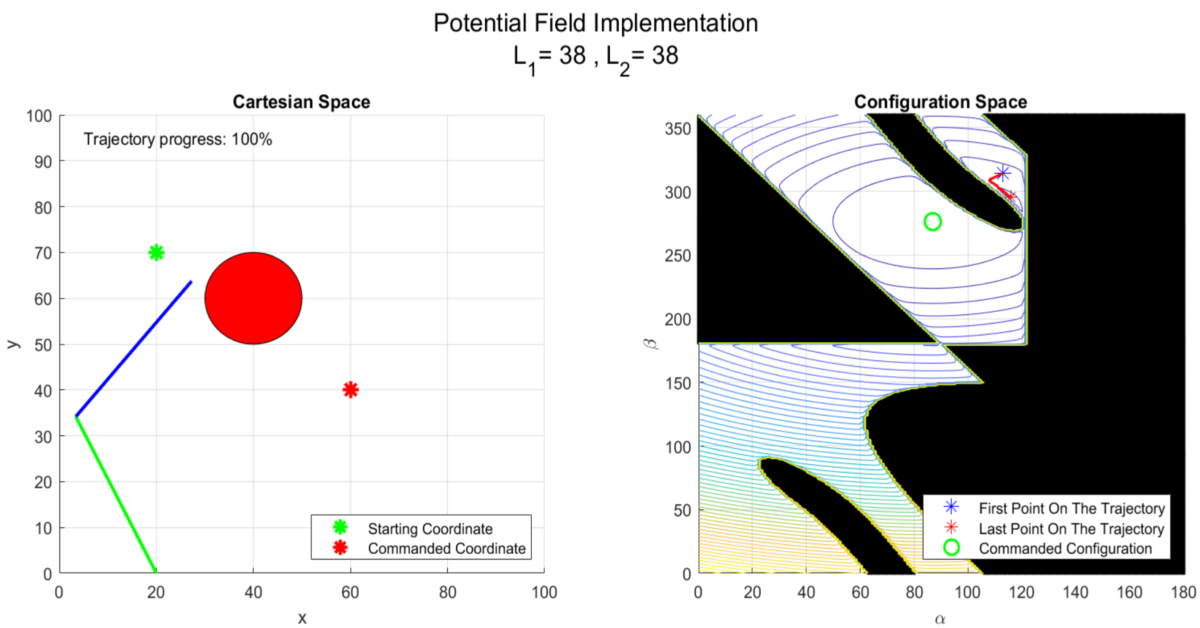

Figure 5 Potential field implementation stuck in a local minima

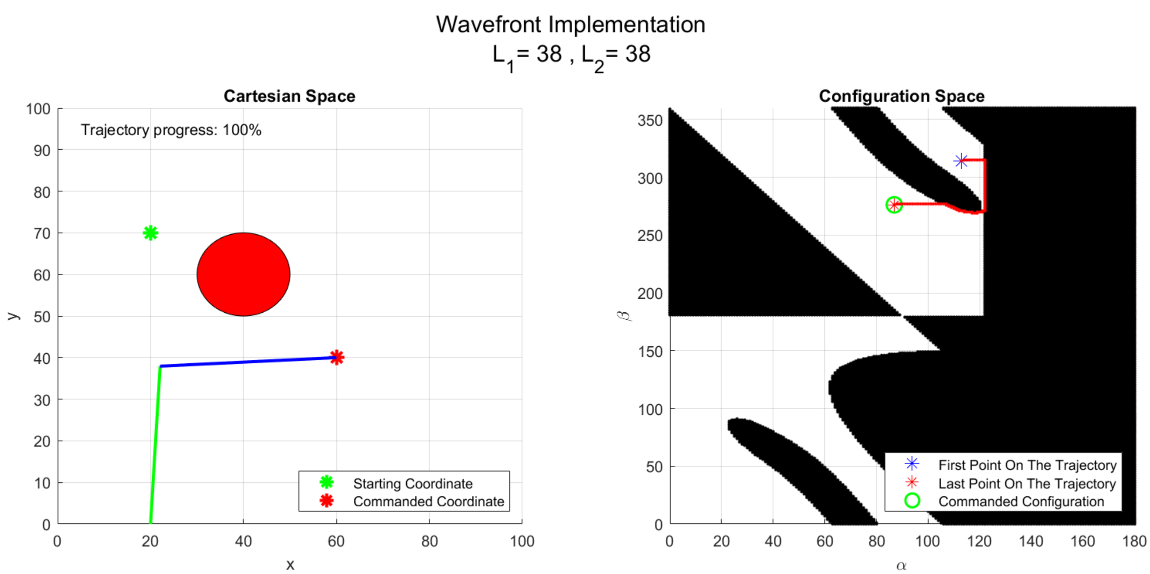

Figure 6 Wavefront approach does not fail to generate a path

As one can see in figure 6, wavefront approach is capable of generating a path. However generated path is very close to the obstacles. Virtually increasing the size of these obstacles (Rubber banding) can create a bigger clearance between the robot and the obstacles.

A readme file is included with the MATLAB files. Further instructions to run the animation can be found in that file. Also, animation recordings are included with the files. There are 8 animation files in total. Half of these animations are for the potential field implementations; other half is the wavefront implementations of the same coordinates.