MEAM520, University of Pennsylvania

Pre-Lab 5

Potential Field Planning

Sheil Sarda

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Write a mathematical description of a potential field controller for the Lynx robot (i.e., what does your controller look like in equation form?) Explain your choices

(Using some screenshots from the textbook to avoid having to retype equations)

We know that the Artificial Potential Field U is constructed as an additive field and a second component that repels the robot from the boundary of the feasible configuration space. Once we have formulated the artificial potential fields, we can solve the resulting optimization problem of starting from q_start and reaching q_goal using gradient descent algorithms.

To specific attractive and repulsive fields, we can use Conic well or parabolic well potentials. The downside of only using parabolic well potential for the attractive force is that the discontinuity near the goal position (from unit force to zero force) can lead to stability problems. Hence, for the attractive force, we plan to use a combination of parabolic and conic well potential to result in a continuous and monotonic potential.

$$U_{\text{att}}(q) = \begin{cases} \frac{1}{2}\zeta||q - q_{\text{f}}||^2 & : \ ||q - q_{\text{f}}|| \le d \\ d\zeta||q - q_{\text{f}}|| - \frac{1}{2}\zeta d^2 & : \ ||q - q_{\text{f}}|| > d \end{cases}$$

The resulting attractive force:

$$F_{\text{att}}(q) = \begin{cases} -\zeta(q - q_{\text{f}}) & : \ ||q - q_{\text{f}}|| \le d \\ -d\zeta\frac{(q - q_{\text{f}})}{||q - q_{\text{f}}||} & : \ ||q - q_{\text{f}}|| > d \end{cases}$$

For the repulsive force, we want the force to repel the robot from obstacles, but when the robot is far away from the obstacle, the repulsive force to be nonexistent to not influence the robot's trajectory. We can get this behavior by specifying a threshold distance such that an obstacle will not repel the robot if the distance from q to the obstacle is greater than the threshold rho_0.

A Potential function and force equation which meets this criterion:

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

$$F_{\text{rep}}(q) = \eta\left(\frac{1}{\rho(q)} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q)}\nabla\rho(q)$$

The performance of your potential field will change depending on what you choose for your specific parameters. For 1 parameter in your controller, predict what affect increasing/decreasing this parameter will have on your planner performance. Explain

For our Lynx robot, we will define a potential for each of the origins of the DH frames. These workspace potential fields will attract the origins of the DH frames to their goal locations while repelling them from obstacles. We will use these fields to define motions in the configuration space using the manipulator Jacobian matrix.

By defining repulsive potentials only for the origins of the DH frames, we cannot ensure that collisions never occur, since the middle of a long link might still collide with the obstacle even if the joints do not. To circumvent this problem, we can define additional potential fields at these collision-prone points on the robot body.

Parameters for attractive fields

- Zeta_i is a parameter used to scale the effects of the attractive potential.

  We plan to use a "follow the leader" type of motion by assigning a larger weight to the origin of the end effector, quickly attracting it to the final position and letting the robot reorient itself so that the other origins also reach their final positions.

  In general, varying this parameter will ensure how quickly the origins reach their goal positions by increasing the magnitude of the attractive force drawing them towards the goal.
- Eta_i is a constant controlling the influence of the repulsive potential for each joint.

  We plan to set the value of eta to be much smaller for obstacles that are near the goal position of the robot to avoid having these obstacles repel the robot from the goal.
- Rho_0 defines the distance of influence for obstacles.

  We will assign distinct values of rho_0 to each obstacle to avoid the possibility of overlapping regions of influence for distinct obstacles, since we want to design the regions of influence to not include goal positions of any repulsive control point.

Design and describe a (set of) evaluation tests to check whether your prediction is correct. What environment will you use. What will you measure?

- **Evaluation Test 1**: The obstacle region is defined by two rectangular obstacles. For all configurations to the left of the dashed line the force vector points to the right, while for all configurations to the right of the dashed line the force vector points to the left. Thus, when q crosses the dashed line, a discontinuity in the force occurs.

  The case will ensure that regions of influence of distinct obstacles do not overlap.

  We will run this test in the ROS simulation environment, and measure the trajectory generated by the planner in this case to ensure it is smooth and accurate.

- **Evaluation Test 2:** A configuration which is the local minimum for the potential fields where the attractive force exactly cancels the repulsive force, and the planner fails to make further progress. In this case, the planner should use a random walk to escape the local minimum.

  This case will test the planner's ability to determine when it is stuck in the local minimum, and determining a random walk that puts the planner back on track to finding the global minimum inside gradient descent.

  The environment for running the test, and the measurements taken will be similar to the first evaluation.

- **Evaluation Test 3:** Two forces applied around a joint of equal magnitude in opposite directions.

  A vector addition of these two forces produces zero net force, but there is a net torque induced by these forces.

  This case will test the planner's ability to aggregate forces on a joint-level and determine the net artificial torque acting upon the joint using Jacobians.

  The environment for running the test will be the same as above, but in this case we would also like to measure the individual magnitudes of the repulsive and attractive forces.