Coursework 3

Trajectory planning

Ting QIAO - 16 February 2017

Question 1

Question a

Note: The total simulation time is 12s. Since the Vrep is simulating 0.05s each trajectory configuration, the total sampling is 12 * 1/0.05 = 240. So in the code, the camping rate is 240.

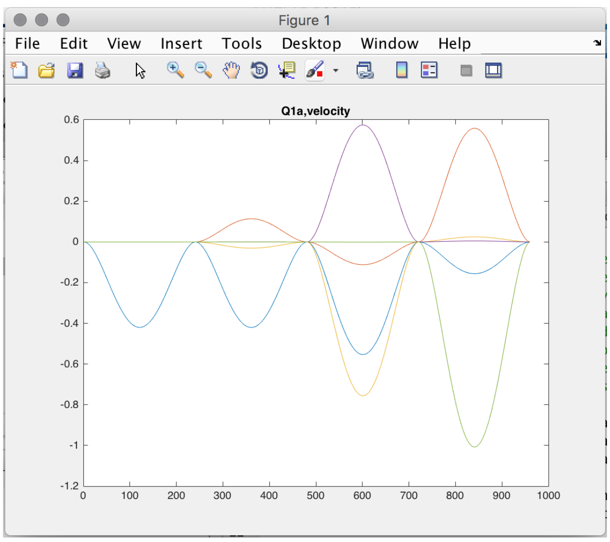
Method:
The idea of cubic trajectory planning is based on the linear equation below.

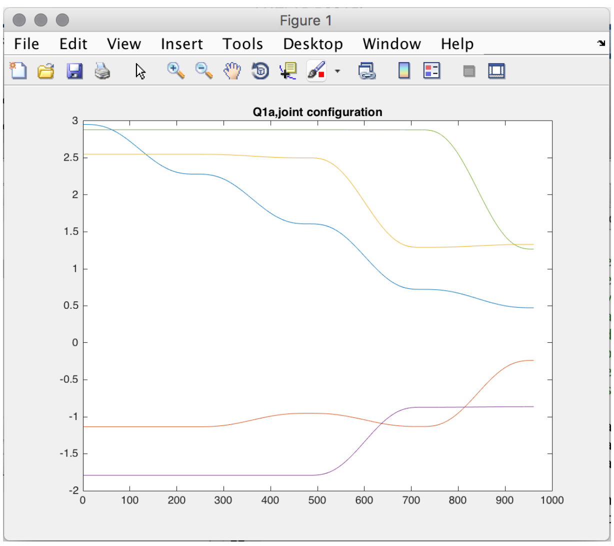
$$q(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5$$

$$\begin{bmatrix} 0 & 1 & 2t_i & 3t_i^2 & 4t_i^3 & 5t_i^4 \\ 0 & 0 & 2 & 6t_i & 12t_i^2 & 20t_i^3 \\ 1 & t_f & t_f^2 & t_f^3 & t_f^4 & t_f^5 \\ 0 & 1 & 2t_f & 3t_f^2 & 4t_f^3 & 5t_f^4 \\ 0 & 0 & 2 & 6t_f & 12t_f^2 & 20t_f^3 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} = \begin{bmatrix} v_i \\ \alpha_i \\ q_f \\ v_f \\ \alpha_f \end{bmatrix}$$

Assume that the 'q' is the 1 joint space configuration. It is satisfying a linear equation. However, the parameters for each item in the linear equation is unknown. In order to calculate the coefficients, the linear equation system was built based on given configuration, configuration(joint space) speed, configuration(joint space) acceleration. For each joint, there will be a 'q' function and coefficient.

Figures: The Q1A velocity figures was shown below:





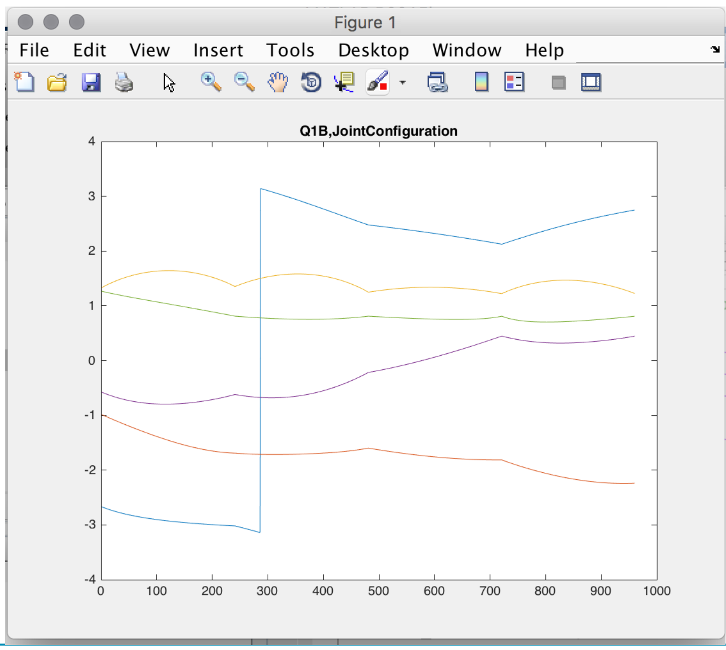
Question b

Method:
The interpolation method used in the Question b is linear interpolation. Since we didn't define any via points or special points that influence the trajectory, so the B-spline interpolation is not suitable for this problem.

The core idea of question b is using inverse kinematics to convert the coordinates from cartesian space to joint space and then create the trajectory. I have two ideas in this question. The first idea is after converting one sampled cartesian space coordinate to joint configuration space, we have one more equation about 'q' and time 't'. So we can rebuild the cubic equation to more degrees. As the degree increase, the cubic(more than three now) equation will be more accurate to describe the trajectory. However, this idea was proven useless. The reason is time consuming. The another reason is that we can simply increase the accuracy by adding more sampling via points. So it is better to add more sampling points directly to planning a more accurate trajectory. The velocity in the question b is useless. The reason is that the calculation of velocity are largely depends on the sampling rate rather than actual velocity.

The cartesian coordinates can be easily calculated by sampling. In each axis, the coordinate is the starting point coordinate add the whole distance between two points divided by sampling rate. However, the pose of at each via points should be calculated. The pose calculation method is called 'Slerp(spherical linear interpolation)'. The 'Slerp' is building a constant-speed motion along with the circle arc. The pseudo-code implementation of 'Slerp' can be found on the wikipedia. Before running the 'Slerp', the starting and ending pose must be converted to Quaternion representation. After finding the pose and coordinates for all the via points. The trajectory can be built.

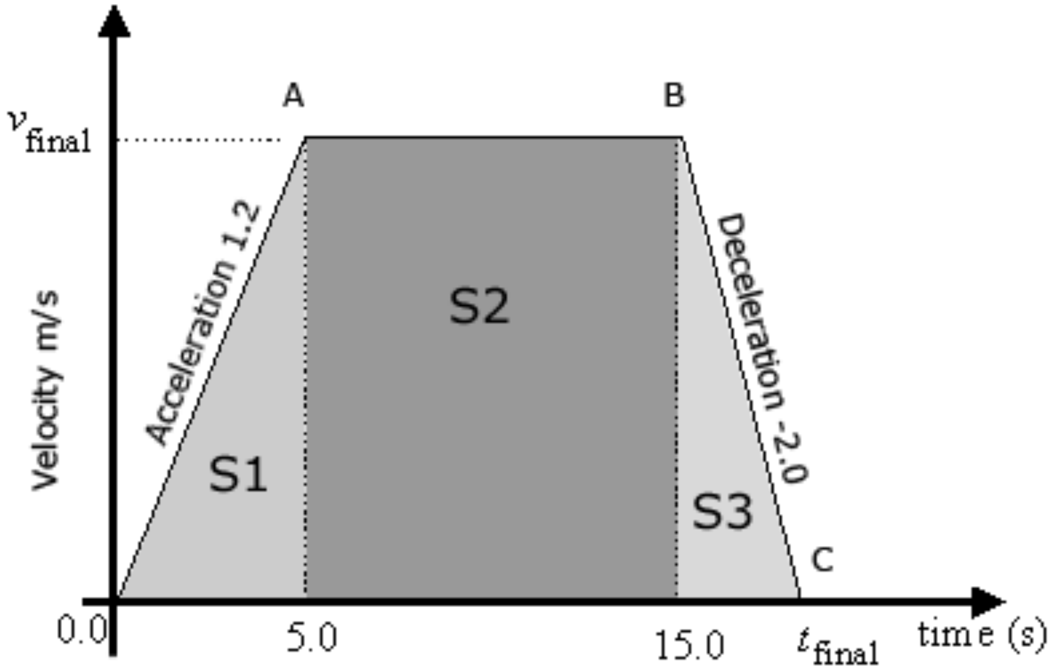
Figures:



Conclusion:
There is a outlier in the figure. The blue line jumped around 300's via point which is between the second and the third target. The reason could be the singularity in the inverse kinematics happened. So the joint configuration changed dramatically. But the cartesian space doesn't change much.

Question c

Method:
The main constraint of question c is the velocity in the joint configuration space must be in trapezoidal shape. It involves the Linear Segments with Parabolic Blends. We can draw the time-velocity figure for each joint between each two target destination. The absolute area is changed joint configuration.



The image is from the Internet. The time and velocity are not the same as the time and velocity in our coursework. However, the idea is similar. The whole process can be divided into three phases. The acceleration phase, the constant speed phase, and the deceleration phase.

Before calculating the trajectory, we have to calculate the maximum constant speed. As we mentioned before, the change(delta) between two target destination is the area of the trapezoidal shape. Since we already known that the [whole time = 3s] and the [constant speed time = 1s], we can easily calculate the maximum speed by solving the equation [delta = 1/2 * (1 + 3) * v_max]. In which, the delta is the area of the trapezoidal shape, the '1' is the length of upper bound, the '3' is the length of the lower bound, the v_max is the height of the trapezoidal shape.

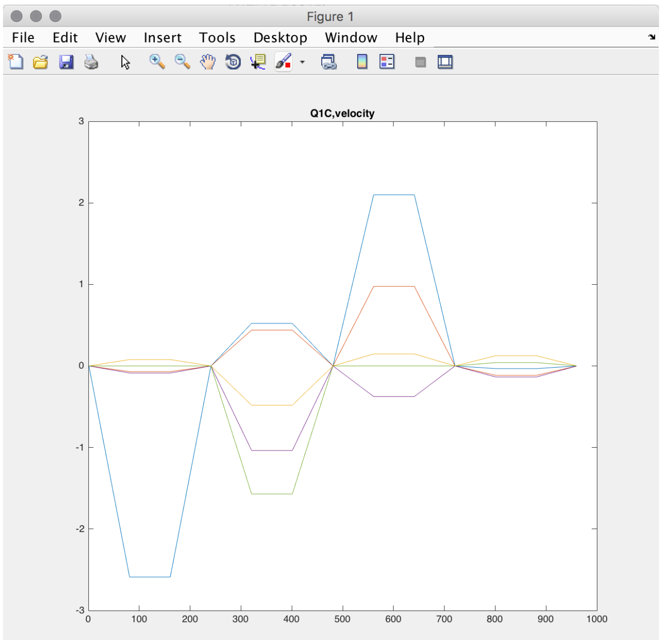
In the acceleration phase, as the time going larger, the area of the graph is the triangle area which equals to [1/2 * time * speed]. The speed equals to [time * acceleration]. So the [delta_joint = 1/2 * acceleration * time^2]. With the delta_joint and starting point, we can easily calculate the joint configuration by adding them together.

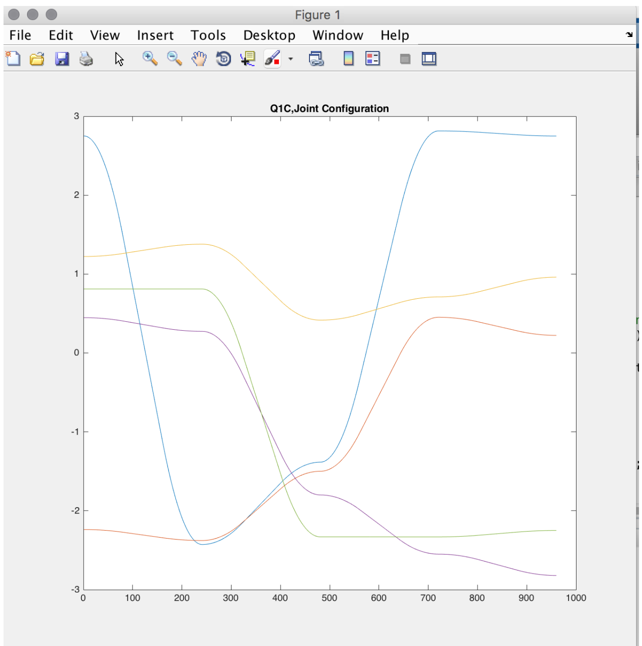
In the constant speed phase, the area is consist of two parts. The first parts are the area from acceleration phase. The second is the rectangle area. The rectangle area is equals to [v_max * (time - 1)]. The reason [time - 1] is that the '1' is belongs to the acceleration area.

In the decelerate speed phase, the total area is consist of three parts. The first part is the area of acceleration part(triangle). The second part is the area of constant speed part(rectangle). The third part is the deceleration part. One thing needs to be noticed is that the area in the deceleration is in the trapezoidal shape. The upper bound is the [v_max + (time - 2) * deceleration]. The lower bound is [v_max]. The height is [time - 2].

So based on the relationship shown above, we can calculate the change(shapes' area in velocity-time graph) between the starting point and the current time. So we can calculate the current joint configuration at any time. The result of question b is shown below.

Figures:





Question 2

Overall

The Question 2 is picking up and drop rectangles. This problem is consist of two parts. The first part is finding the suitable joint configuration to move the Youbot arm to the right place. the second part is planning the trajectory to complete the task. For each scene, the Rectangle 15 was picked up first and put upon the Rectangle 13. Then is the Rectangle 14 was picked up and put upon the Rectangle 13. For processing each rectangle, there are 7 phases. The first phase is moving the arm to the interim pose which is all theta is equaled to zero. The second phase is rotation the Joint0 to the desired theta1. It will make the robot facing to the Rectangle. The third phase is moving the arm to the rectangle. It is completed by moving each joint to the desired configuration. Now the robot can grab the rectangle.

The fourth phase is moving the arm to the interim pose again to avoid collision with other items. The fifth phase is moving the robot facing the Rectangle 13 pile. The sixth phase is moving the arm to the position a little bit upper than the pile. The robot will drop the rectangle in the 'hand' upon the Rectangle pile. The reason why we need the interim pose is that the arm can be moved to the desired position from the top of the item. It can avoid the collision.

Usage

1. Run the 'first' to add the paths and connect to rvctool
2. Run the 'CW3Setup' and 'CW3Setup2'
3. Set the stop point at 21 line at 'pick_all' file.
4. Run the 'pick_all' file.
5. Wait until the planning complete
6. Start the simulation
7. Continue

Scene Influence

In the situation, the planning will take a relatively long time. It can be solved by set the robot arm to the previous steady pose every time. Or it can be complete by planning a trajectory from current pose to the previous steady pose. However, get the updated current pose is time-consuming.

The Link 1's length is different between given DH table and the scene. So I changed the Youbot's Link1's length.

As the time going, the robot vehicle will move along with y-axis. And due to the inertia, the robot will move a lot when we want to pick the second Rectangle. My solution is re-planning the joint configuration after putting the first rectangle.