Appendix

Q2_C

(i) Simulation of the robot for 6 seconds when initially θ2 = 90 degs and θ1 = 0 deg and all the torques are set to zero.

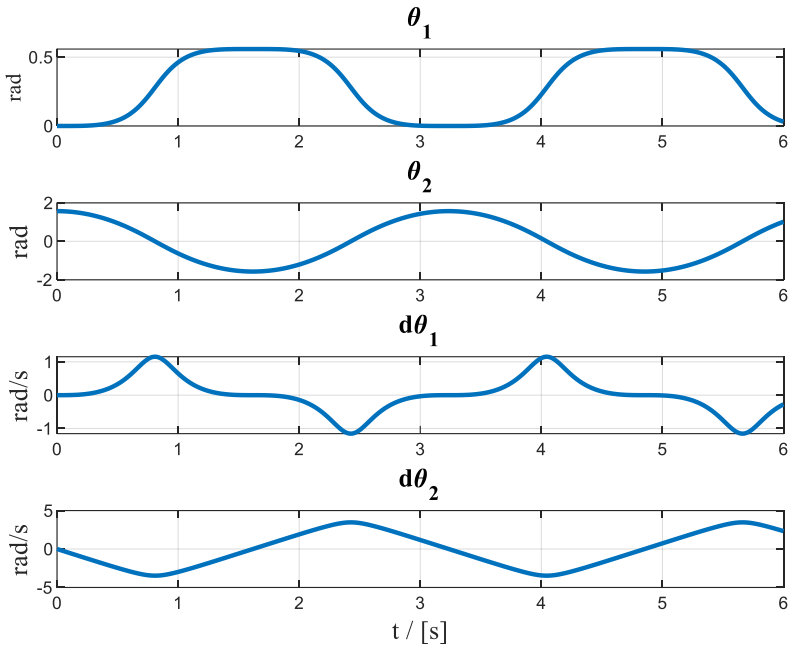

Fig. 1. ODE45 simulation result

(ii) Standard Euler integration approaches (with step size δt = 0.01 second).

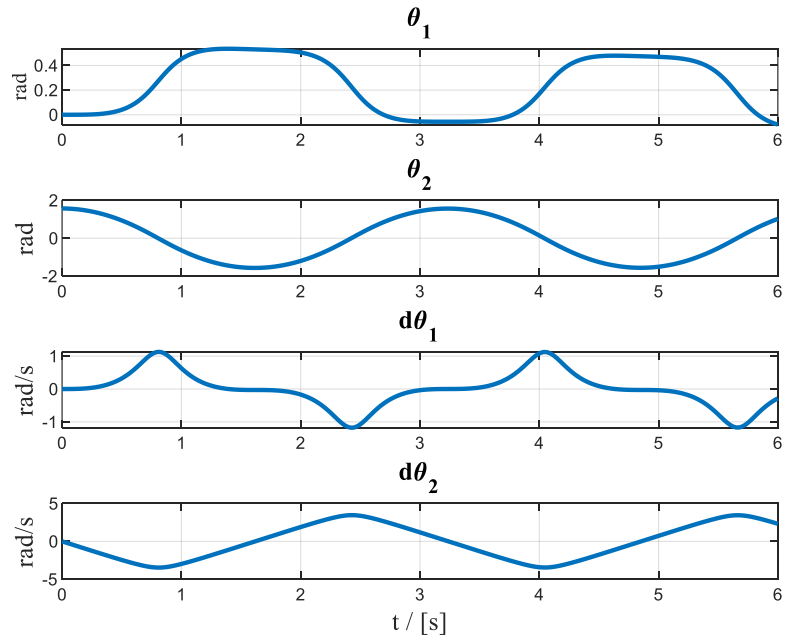

Fig. 2. Standard Euler integration simulation result

Comparison of the simulation results between the Runge-Kutta (ODE 45) and standard Euler integration approaches (with step size $\delta t = 0.01$ second). (Using ODE45 result minus Euler result).

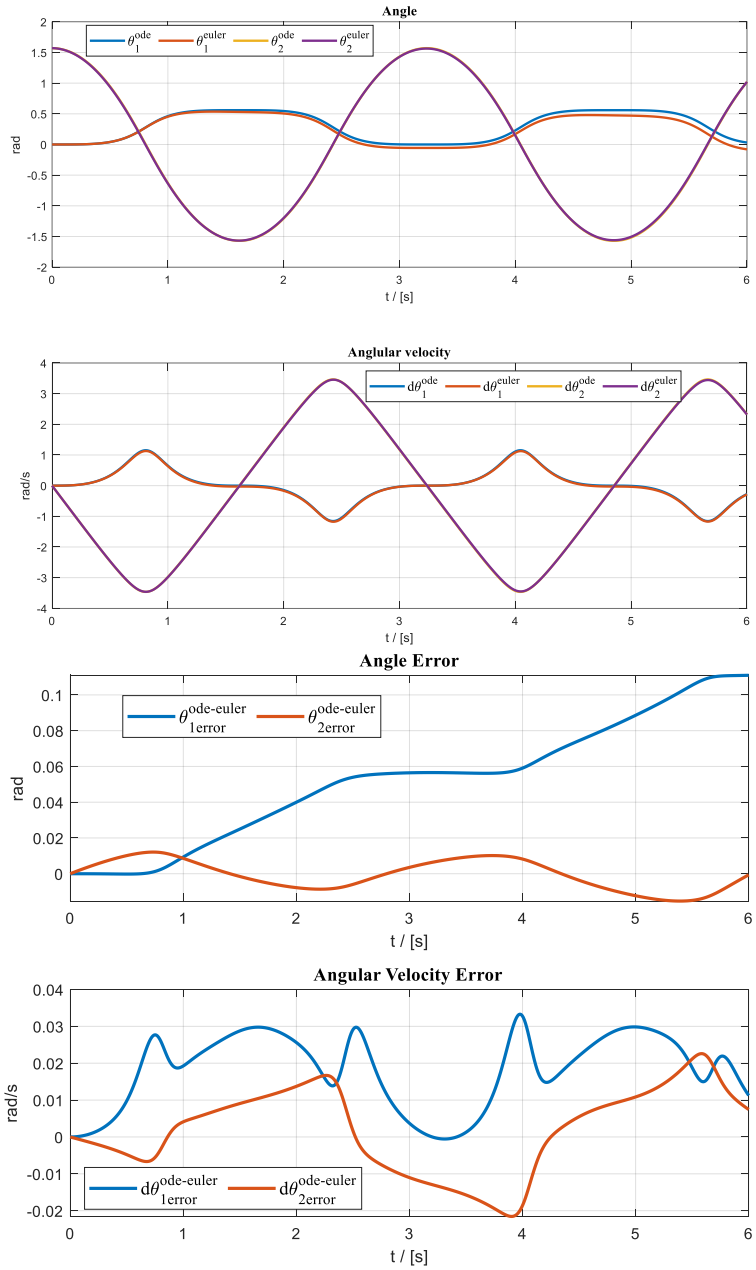

Fig.3. Comparison of the simulation results

(iii) Repeat the simulation for 300 seconds with the ODE 45 integration approach。

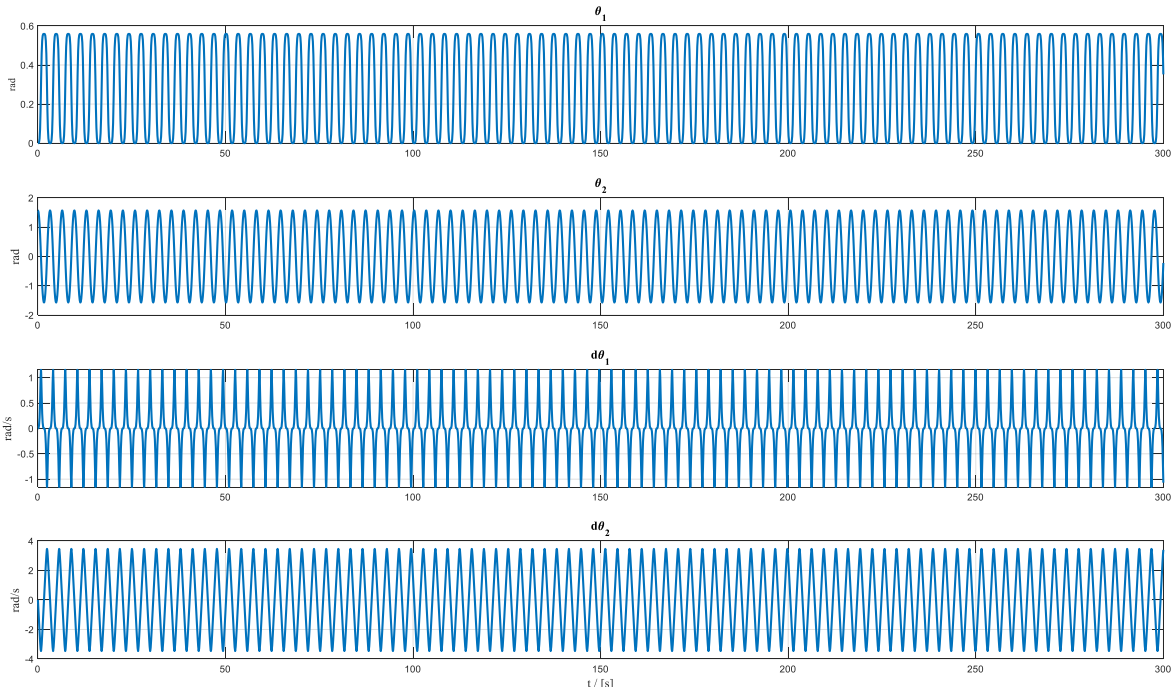

Fig.4. simulation for 300 seconds with the ODE 45

Q2_e. Draw the ellipsoid when θ1 = θ2 = π/2 and joint velocities are all zero

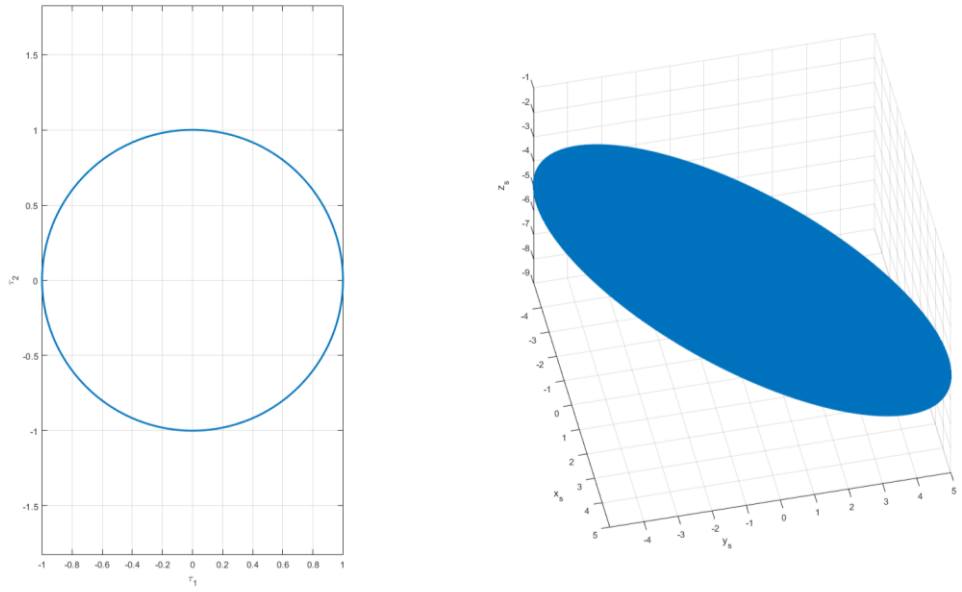

Fig.5. Left: $\tau^T\tau = 1$
Right: the dynamic manipulability ellipsoid

Q5_c. The necessary torque for each joint in order to create the suggested movement during 5 seconds.

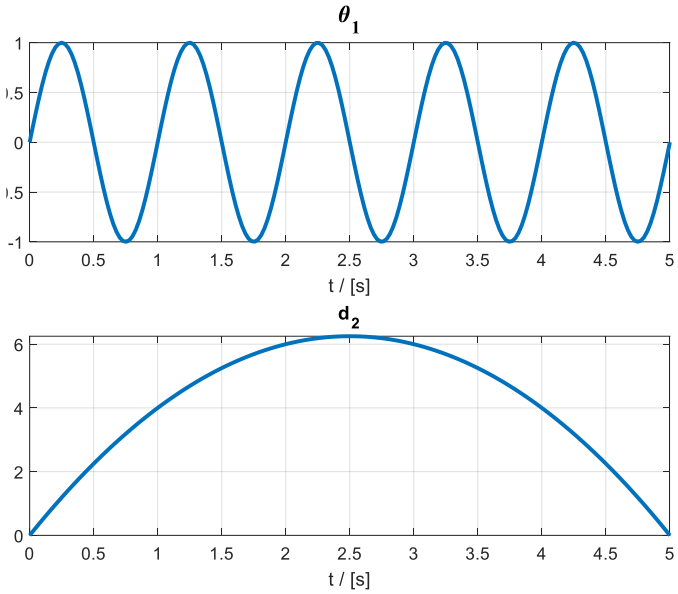

Fig.5. Joint variable

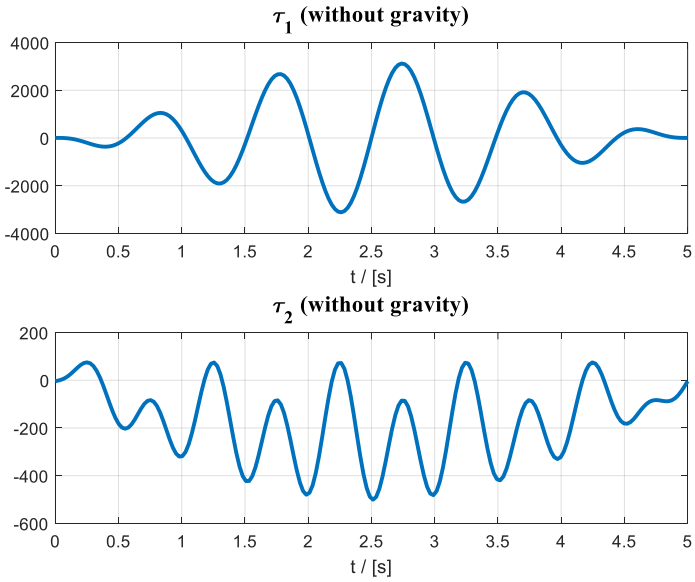

Fig.6. Joint torque

Q5_d. If only joint 2 will move in accordance with the function d(t) = −t*t+5t and joint 1 is free, the movement of Joint 1.

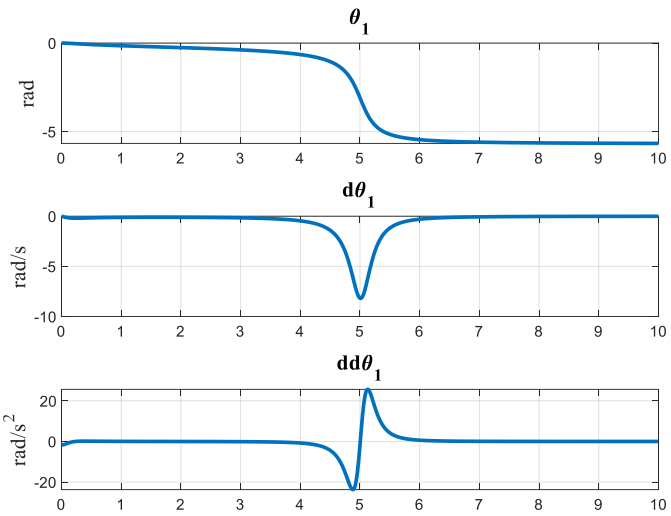

Fig.7. Joint 1

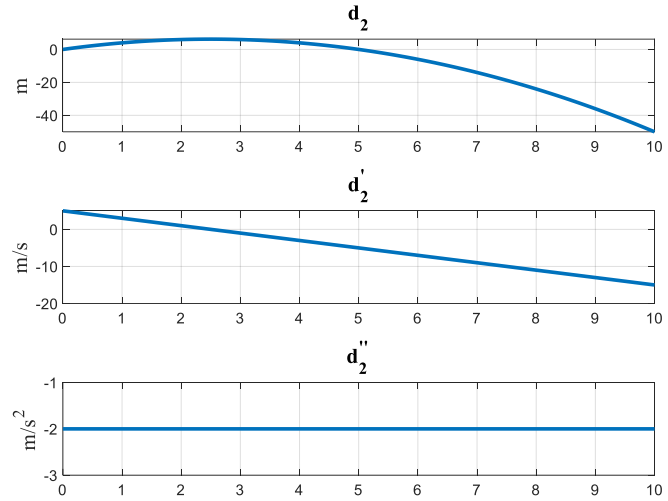

Fig.8. Joint 2

Q5_e. Consider the viscous friction, if only joint 2 will move in accordance with the function d(t) = −t2+5t and joint 1 is free, the movement of Joint 1.

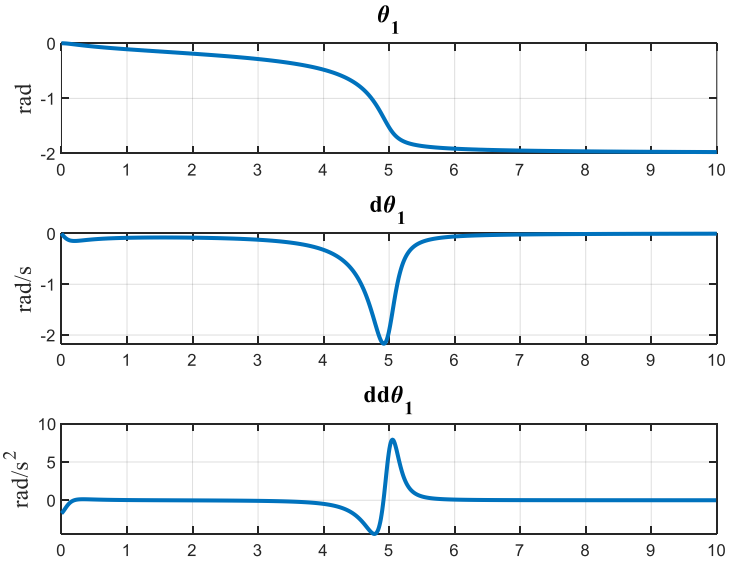

Fig.9. Joint 1 with friction

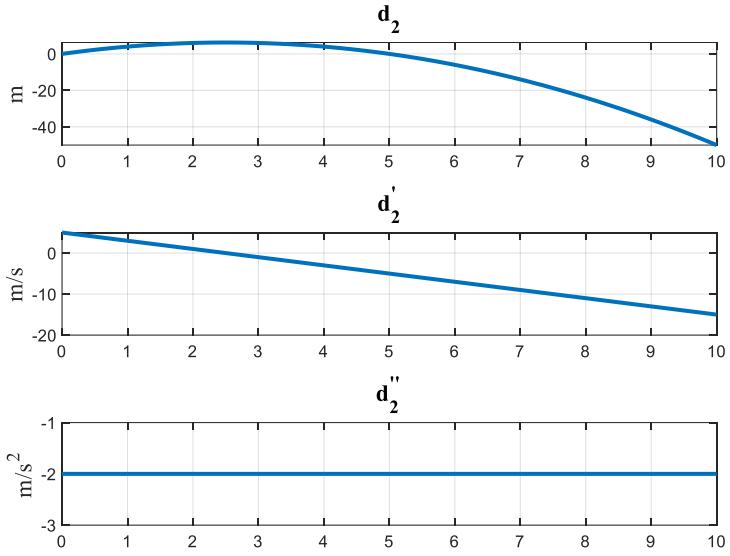

Fig.10. Joint 2

Compare the changes in the joint variables against the non friction case, we can see that the maximum acceleration and velocity of joint 1 are much smaller than non-friction case. This is because that the friction in joint1 would dissipate energy transferred from the motion of joint 2.