Adaptive control for a post-capture system of non-cooperative targets by a dual-arm space robot

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EXTENDED ABSTRACT

1 Introduction

Space robotics plays an increasingly important role in on-orbit servicing missions. Compared with single-arm space robots, dual-arm space robots present more flexibility and dexterity in performing complicated on-orbit servicing tasks. However, due to the dynamic coupling between the robotic arms and the movable base, the dual-arm space robots are complex multibody systems and their trajectory control is more difficult than that of ground-based robotic systems or single-arm space robots. On the other hand, the malfunctioned satellites to be served are often assumed to be non-cooperative targets with unknown inertial parameters (mass, inertia and center of mass) [1-2], making the task by a space robot more arduous.

A lot of research focused on the coordinated control of single-arm space robots where the inertial parameters of the capture target are known have been performed [3-4]. For the situation where a dual-arm space robot is utilized for capturing and stabilizing the rotating non-cooperative targets, fewer studies are discussed. In terms of control of dual-arm space robots, the motion planning and control of open-loop systems stand as the mainstay.

In this paper, after capturing a rotating target, coordinated control of base attitude and movement of manipulators in inertial space for a dual-arm space robot is studied. Combined with geometric constraints of the closed-loop system, dynamic equations of the post-capture system are established. On this basis, a self-adaptive control algorithm is designed to deal with the unknown inertial parameters of non-cooperative targets, namely Radial basis function (RBF) network adaptive controller, to achieve tracking of a desired path and to stabilize the entire system. Such a controller will enable the dual-arm space robot to adapt to various non-cooperative targets with different initial rotation speeds and can be generalized for multi-arm space robots in undertaking different on-orbit tasks.

2 Methodology

On the basis of RBF, the controller takes the real-time state feedback of robot joints and the planned expected trajectory as the network inputs. The adjustment of adaptive weights is combined to achieve coordinated control of the entire closed-loop system. Figure 1 shows the simulation model framework for the RBF adaptive control strategy.

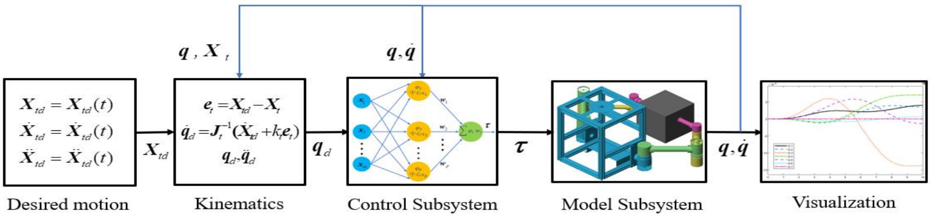


Figure 1: Simulation flow chart

The error function in the joint space is defined as

$$\mathbf{e}_s = (\dot{\mathbf{q}}_d - \dot{\mathbf{q}}) + \Lambda\ (\mathbf{q}_d - \mathbf{q}) = \dot{\mathbf{e}}_q + \Lambda \mathbf{e}_q \tag{1}$$

By substituting the dynamic equations of the closed-loop system, the uncertain term in the system $\mathbf{f}$ is obtained, and $\mathbf{f} = \overline{\mathbf{A}}(\ddot{\mathbf{q}}_d + \Lambda \dot{\mathbf{e}}_q) + \overline{\mathbf{B}}(\dot{\mathbf{q}}_d + \Lambda \mathbf{e}_q)$. The input of the RBF network is $\mathbf{x} = \left[\mathbf{e}_1{}^T, \mathbf{e}_2{}^T, \mathbf{q}_d, \dot{\mathbf{q}}_d, \ddot{\mathbf{q}}_d\right]$, and the neural network output is $\hat{\mathbf{f}}(\mathbf{x}) = \hat{\mathbf{W}}^T \boldsymbol{\varphi}(\mathbf{x})$.

Therefore, the control law is designed as follows

$$\boldsymbol{\tau} = \hat{\mathbf{W}}^T \boldsymbol{\varphi}(\mathbf{x}) + K_v \mathbf{e}_s - \mathbf{v} \tag{2}$$

with the adaptive weights

$$\dot{\hat{\mathbf{W}}} = F \boldsymbol{\varphi} \mathbf{e}_s{}^T \tag{3}$$

where $\mathrm{K_v}$ and F are the positive-definite matrices, v is a robust term for overcoming neural network approximation errors $\boldsymbol{\varepsilon}$, $\mathbf{W}$ is the weight value of the RBF network, $\hat{\mathbf{W}}$ is an estimate of the RBF network weight, $\boldsymbol{\varphi}(\mathbf{x}) = \left[\phi_1, \phi_2, \cdots, \phi_j\right]$ is a radial basis function of RBF networks.

Considering the adaptive control of robotic arm based on RBF network approximation, which consists of the robot control law of Eq.(2) and the adaptive law of the neural network of Eq.(3), the trajectory tracking error of non-cooperative targets can converge to zero even with unknown dynamic parameters.

3 Results

To verify the dynamic model of the space robot and the developed control law, Simscape Multibody which provides a multibody simulation environment is used. Figure 2 shows the stabilizing courses for the captured system with an initial angular velocity of the target. Figure 3 (a) presents the angular velocity, angular velocity error and angular error of the target. Figure 3(b) indicates the tracking error when the base is subjected to external disturbance torques. The results demonstrate that the proposed algorithm can finally stabilize the rotating target. At the same time, it can also realize its position-level angle trajectory tracking.

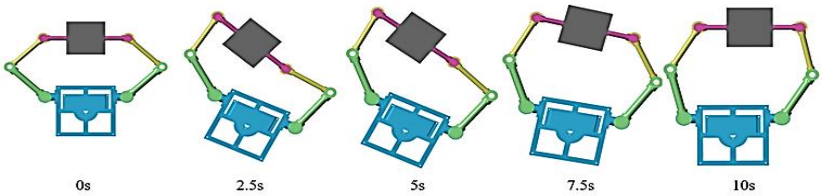
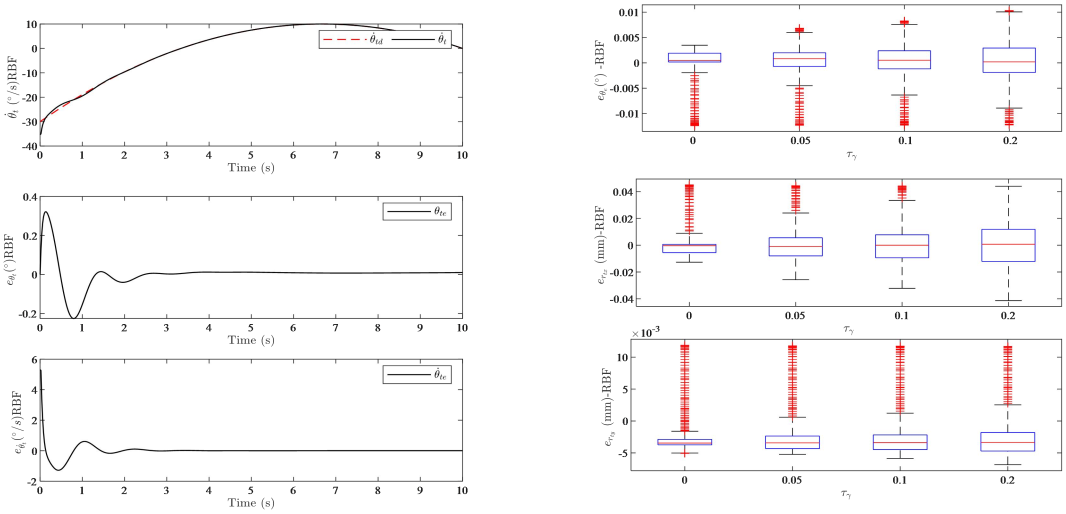


Figure 2: Post-capture course



(a) The angular velocity and error of the target

(b) Tracking error with Gaussian interference torque

Figure 3: Trajectory tracking results

4 Conclusions

The simulation results prove the feasibility of stabilizing the entire system where a rotating target is captured by a dual-arm space robot with the developed controller. The adaptive control algorithm can maintain high trajectory control accuracy under the condition of unknown system inertial parameters, and shows a certain robustness in the presence of external interference. Such a controller can be generalized for multi-arm space robots in implementing more orbit servicing tasks.

References

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