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An Active Stereo Vision-Based Learning Approach for Robotic Tracking, Fixating and Grasping Control

Nan-Feng Xiao & Saeid Nahavandi

1. Introduction

Vision-based robotic tracking, fixating and grasping control depends on many environmental factors in an unknown environment. The robot control systems lack robustness, and the calibration of the CCD cameras is very slow and tedious in the existing methods.

Although the binocular cameras can solve some of these problems, it is necessary to rely on the time consuming and complicated 3-D reconstruction algorithms (8)-(9). Therefore, it is necessary to develop a more effective vision-based robotic tracking, fixating and grasping method, and use the robotic learning ability to improve the tracking, fixating and grasping in the unknown environment.

This chapter presents an active stereo vision-based learning approach for robotic tracking, fixating and grasping. First, the many-to-one functional mapping relationships are derived to describe the spatial representations of the object in the workspace frame. Then, ART_NN and FF_NN are used to learn the mapping relationships, so that the active stereo vision system guides the end-effector to track, fixate and grasp the object without the complicated coordinate transformation and calibration. Finally, the present approach is verified by simulation.

2. Visual Tracking, Fixating and Grasping

Active vision can easily realize selective attention and prevent an object to go out of the view fields of the cameras, therefore the active stereo vision-based robotic tracking, fixating and grasping can achieve greater flexibility in an unknown environment.

Figure 1 shows an active stereo vision-based robotic system for the tracking, fixating and grasping. The CCD cameras have 5 DOF, the robot has 6 DOF, which constitute an 11 DOF tracking, fixating and grasping system.

Because the active CCD cameras and the robot can move independently or together, the active CCD cameras can observe freely an object in Σ_o .

According to the visual feed back information, the robot can track, fixate and grasp the object autonomously.

where ψ is a nonlinear many-to-one mapping function, which denotes that the combinations of Q_i and V_i correspond to P_i . On the other hand, it is known from Fig.2 that any combination of Q_i and V_i should map to the same P_i , because p_i is stationary feature.

Figure 2. Projection and fixation relationships

4. Active Vision-Based Robot Control

4.1 Tracking and Fixating Control

It is known from Fig. 2 that when the active stereo vision system tracks p_i , V_i is obtained for p_i and Q_i , we have from Equation (2),

$$P_i = \psi(V_i, Q_i), \quad (3)$$

where the active stereo vision system tracks p_i . When the active stereo vision system fixates p_i and the coordinate vector V_{O_i} of p_i corresponds to the centers (o_l , o_r) of the image planes, then the desired joint angle vector Q_{O_i} which is necessary to bring V_{O_i} to V_{O_i} can be computed as follows:

$$P_i = \psi(V_{O_i}, Q_{O_i}), \quad (4.a)$$

$$\text{or } Q_{O_i} = \psi^{-1}(V_{O_i}, P_i), \quad (4.b)$$

where ψ and ψ^{-1} are invertible functions which can be used to control the fixation on p_i , respectively. Because P_i has invariance, Q_{O_i} can be computed by combining Equation (3) with Equation (4),

$$Q_{O_i} = \psi^{-1}[V_{O_i}, \psi(V_i, Q_i)], \quad (5)$$

therefore, Q_{O_i} is used to control the active vision system to fixate p_i .

4.2 Grasping Control

Figure 3 shows the configuration parameters of the active stereo vision system. Let d, s, l be the distance, height of the CCD cameras and diameter of the sphere coordinate system. Let $\theta_{i\alpha}, \theta_{i\beta}, \theta_{i\gamma}$ be the configuration angles of the active stereo vision system and the spatial coordinates of p_i in Σ_C be ${}^C P_i = [x_{ci}, y_{ci}, z_{ci}]^T$, respectively. When the active stereo vision system fixates p_i , ${}^C P_i$ can be computed by the triangular geometry relationships in Fig. 3

$$x_{ci} = l \cos(\theta_{i\gamma}) \sin(\theta_{i\beta}), \tag{6.a}$$

$$y_{ci} = l \cos(\theta_{i\gamma}) \cos(\theta_{i\beta}), \tag{6.b}$$

$$z_{ci} = l \sin(\theta_{i\gamma}). \tag{6.c}$$

Figure 3. Configuration of the vision system

Figure 4. Frames of the active vision system

Figure 4 gives the joint coordinate frames of the robot joint system. In Fig. 4, let $\Sigma_j(j=1,2,\dots,6)$, Σ_B , Σ_H , Σ_C be a coordinate frame of i th robotic joint, base frame, coordinate frame of the end-effector, camera frame, ${}^B P_i = [x_{bi}, y_{bi}, z_{bi}]^T$, ${}^H P_i = [x_{hi}, y_{hi}, z_{hi}]^T$, $P_i = [x_{oi}, y_{oi}, z_{oi}]^T$ be an Euclidian coordinate vector of p_i in Σ_B , Σ_H , Σ_O , respectively.

By homogeneous transformation relationship, ${}^B p_i$ can be specified by

$${}^H P_i = {}^H H_C \bullet {}^C P_i, \quad (7.a)$$

$${}^B P_i = {}^B H_6 \bullet {}^6 H_H \bullet {}^H P_i, \quad (7.b)$$

$${}^O P_i = {}^O H_B \bullet {}^B P_i. \quad (7.c)$$

where ${}^H H_C$, ${}^6 H_H$, ${}^B H_6$, ${}^O H_B$ are the homogeneous matrixes from Σ_C to Σ_H , Σ_H to Σ_6 , Σ_6 to Σ_B , Σ_B to Σ_O , respectively.

According to the robotic forward kinematics $A[\theta_r(t)] \ R^{6 \times 1}$, we obtain

$${}^O P_{Hi} = A[\theta_r(t)], \quad (8)$$

$$J[\theta_r(t)] = \partial A[\theta_r(t)] / \partial \theta_r(t), \quad (9)$$

$${}^O \dot{P}_{Hi} = J[\theta_r(t)] \dot{\theta}_r(t), \quad (10)$$

where ${}^O P_{Hi}$ is the original coordinates of Σ_H in Σ_O , $J[\theta_r(t)] \ R^{6 \times 1}$ is a Jacobian matrix of the end-effector, $\theta_r(t) \ R^{6 \times 1}$ is a reference joint angle vector of the end-effector. Therefore, we have

$$\dot{\theta}_r(t) = J^{-1}[\theta_r(t)] \bullet {}^O \dot{P}_{Hi}. \quad (11)$$

When the sampling period of the robot joint control system T is every minute, it is suitable that using $\dot{\theta}_r(k) = [\theta_r(k+1) - \theta_r(k)]/T$ to replace $\dot{\theta}_r(k)$ at time $t = kT$. Therefore, Equation (11) is discretized by

$$[\theta_r(k+1) - \theta_r(k)]/T = J^{-1}[\theta_r(k)] \bullet {}^O \dot{P}_{Hi}, \quad (12.a)$$

$$\text{or } \theta_r(k+1) = \theta_r(k) + T J^{-1}[\theta_r(k)] \bullet {}^O \dot{P}_{Hi}, \quad (12.b)$$

where ${}^O \dot{P}_{Hi}(k) = [{}^O P_{Hi}(k) - {}^O P_{Hi}(k-1)]/T$, $\theta_r(k+1)$ can be used to control the robot joint angles. When ${}^O P_{Hi} = {}^O P_i$, the end-effector can grasp the object.

5. Visual Robot Learning Control System

5.1 Visual Learning Control System

In order to obtain the nonlinear many-to-one mapping function, ART_NN are combined with FF_NN to learn ψ defined in Equation (3). The architecture of ART_NN, FF_NN and the vision-based robot control system based on ART_NN and FF_NN are showed in Figs. 5 and 6, respectively.

Figure 5. Architectures of ART_NN and FF_NN

5.2 Learning of ART_NN and FF_NN

In Fig. 5, T_{ij} , B_{ij} , w_{gl}^{AB} , w_{lj}^{BC} and w_{ji}^{CD} are weights. The self-adaptive resonance algorithms for ART_NN and the learning algorithms for FF_NN are omitted. In Fig. 6, the ART_NN require two types of inputs V_i and Q_i , where V_i corresponds to the image coordinates of p_i on the image planes of the CCD cameras, and Q_i is the joint angle coordinates corresponding to the CCD cameras tracking p_i . The ART_NN clusters V_i into classes within

(3) The present approach was evaluated by simulation using the models of an 11 DOF active stereo vision system and the simulation confirms that the present approach has high robustness and stability.

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9. References

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This book is the result of inspirations and contributions from many researchers worldwide. It presents a collection of wide range research results of robotics scientific community. Various aspects of current research in robotics area are explored and discussed. The book begins with researches in robot modelling & design, in which different approaches in kinematical, dynamical and other design issues of mobile robots are discussed. Second chapter deals with various sensor systems, but the major part of the chapter is devoted to robotic vision systems. Chapter III is devoted to robot navigation and presents different navigation architectures. The chapter IV is devoted to research on adaptive and learning systems in mobile robots area. The chapter V speaks about different application areas of multi-robot systems. Other emerging field is discussed in chapter VI - the human- robot interaction. Chapter VII gives a great tutorial on legged robot systems and one research overview on design of a humanoid robot. The different examples of service robots are showed in chapter VIII. Chapter IX is oriented to industrial robots, i.e. robot manipulators. Different mechatronic systems oriented on robotics are explored in the last chapter of the book.

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