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Simulation Study of UAV and Robotic Arm Cooperation Based on Orthogonal Iteration Algorithm

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ABSTRACT

Aiming at the problem of cooperation between quadrotor UAV and six-degree-of-freedom robotic arm in the warehouse environment, the goal is to achieve smooth cooperation to improve logistics efficiency as well as accurate status delivery of goods. Taking the quadrotor UAV and the six-degree-of-freedom robotic arm as the research object, the PID control algorithm is used for the control system design of the UAV, and the D-H parameter method is used to establish the coordinate system of the robotic arm, and the kinematic equations are further derived to carry out the model construction of the robotic arm model and the motion simulation using MATLAB. For the matching process, laser SLAM positioning and navigation simulation is used for the UAV trajectory simulation, monocular colour information acquisition method is used for the docking of the UAV and the robotic arm, orthogonal iteration algorithm is used to complete the positional solution before the UAV receives the goods, and finally the simulation is completed from the trajectory of the UAV approaching the robotic arm to the transfer of the goods from the robotic arm to the end of the UAV actuator. The results show that the robot arm model is correctly constructed, the UAV SLAM trajectory simulation is completed, and the monocular colour information acquisition method and the orthogonal iteration algorithm are effective, which can ensure the correct docking of the UAV end-effector and the gripper jaws of the robot arm. The mechanical arm and UAV can complete the action of transferring goods with the expected motion accuracy, which lays the foundation for the further practical application of UAV.

KEYWORDS

PID control algorithm; Denavit-Hartenberg; SLAM; Monocular color information acquisition; Orthogonal iteration algorithm

1. INTRODUCTION

UAV technology is becoming more and more popular, and as a vehicle that can be controlled remotely and fly autonomously, it is widely used in many fields such as military reconnaissance, agriculture, and security inspection. In the field of warehouse goods allocation, many scholars are gradually exploring how to use UAVs to achieve more efficient warehouse inspection and goods transfer, for which it is particularly important for the working UAVs to achieve stable cooperation with other robots and complete the target tasks through precise attitude adjustment. For example, UAVs need to fly stably and hover in time to scan the labels of goods on the shelves to ensure the accuracy of inventory, and should also be able to follow the calculated trajectory to perform the flight procedures when carrying out the cargo handling tasks. This paper focuses on the main issues in the co-operation between UAVs and robotic arms in the handling of goods.

The aim of this paper is to explore how to dock the end-effector in the process of cooperation between UAV and robotic arm, and how to transfer the goods obtained by the robotic arm to UAV under the smallest possible error, and how to carry out attitude solving is very critical due to the weak stability of UAV vehicle, which makes it easy to have a large error in these links. Solving the above problems can not only improve the efficiency of logistics operation in the warehouse, but also expand the scope of use of UAV, so that it can work in a richer and more diversified environment.

2. DOMESTIC AND FOREIGN RESEARCH STATUS

Based on the characteristics of wide application, simpler structure and better stability, this paper chooses quadcopter UAV to carry out research. In the previous research of other scholars, for the design of the control system of quadrotor UAV, Wu Junhua and others [4] designed a series control system so that the controller can effectively estimate and compensate for the perturbations of the system; Yu Yongping [7] designed a fuzzy PID control law and verified its effectiveness for the altitude control system; in the selection of the robotic arm modelling and the forward and inverse kinematics research methods, whether it is using the D-H model or the other modelling methods, or choosing numerical analysis method, geometric method, or using neural networks and genetic algorithms for the study, this paper chooses the quadrotor UAV to carry out the research. other modelling methods, or choosing numerical analysis method, geometric method, or using neural network and genetic algorithm for inverse solution, all methods have their own advantages and disadvantages. For robotic arm simulation, Cao Yi et al. [6] proposed a method of robotic arm motion planning based on deep reinforcement learning, which shortens the planning time; Zeng Bo et al. [2] used MATLAB to establish a Cartesian coordinate system, and adopted the B-spline interpolation algorithm to carry out trajectory planning, and finally proved that this method can complete the trajectory planning for the robotic arm.

The situation will be more complicated when the quadrotor UAV is loaded with a robotic arm, which already needs to maintain balance and stability in normal flight, and carrying a robotic arm will increase the complexity of the whole system, such as the mass and motion of the robotic arm will have an effect on the power as well as the balance of the UAV, and a more precise control system is needed to maintain the balance, and Xiong Jingfeng et al. [3] analysed the interaction between the rotary wing UAV and the robotic arm, and finally designed a system that can control system to keep the fuselage hovering while the robotic arm is operating. For the positioning coordination between the actuator loaded on the UAV and the end-effector of the robotic arm, Wu Qi et al. [5] designed an indoor navigation method for the UAV using the fusion of sensors such as camera, inertial measurement device, and ultrasonic range finder by adopting the fusion of optical flow and landmarks for the indoor navigation of the UAV, but it was not able to measure the z-axis velocity, and the estimation of the flight height was not sufficiently accurate.

3. KINEMATIC ANALYSIS OF A 6-DEGREE-OF-FREEDOM ROBOTIC ARM

3.1. Modelling of the Robotic Arm

The dh parametric method is used to establish the coordinate system and derive the parameters for further calculations.

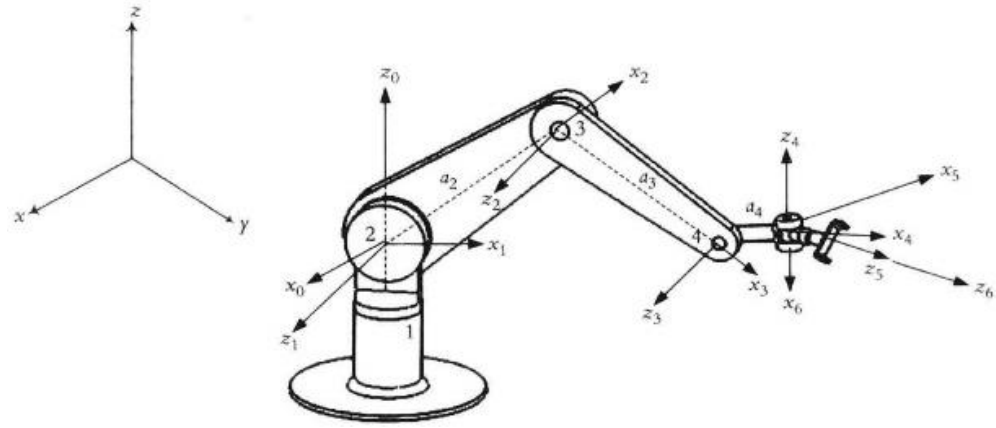

Figure 1. Reference coordinate system for a simple 6-degree-of-freedom chain robot

As an example:

When filling in the parameters according to the coordinate system, from z0-x0 to z1-x1, rotate θ1 so that x0 turns to be in the same direction as the x1 axis, and there is no need to translate along z1 and x1, and it is necessary to rotate +90 degrees so that z0 turns to be in the same direction as z1. Following the same approach we can complete the dh parameter table.

Table 1. parameter table

i	θ	d	a	α
0-1	θ1	0	0	90
1-2	θ2	0	a2	0
2-3	θ3	0	a3	0
3-4	θ4	0	a4	-90
4-5	θ5	0	a2	90
5-6	θ6	0	0	0

3.2. Mechanical Arm Kinematics Positive Solution

The end position matrix is obtained by multiplying the transformation matrix between the two link coordinate systems

Rotating θ about zi-1 so that xi is parallel to xi-1, its operator is Rot (zi-1, θi);

Translating di along the zi-1-axis so that the x-axis of both coincide, its operator is Trans (0, 0, di);

Translating ai-1 along the xi-axis so that the origin of the two coincides, its operator is Trans (ai-1, 0, 0);

Rotating αi-1 about the xi-axis so that the two coordinate systems coincide, its operator is Rot (xi, αi-1);

Transformation matrix general formula [7]:

$$
\begin{gathered}
{}^{i-1}_{i}\boldsymbol{T} = \mathrm{Rot}(z_{i-1}, \theta_i) \times \mathrm{Trans}(0, 0, d_i) \times \\
\mathrm{Trans}(a_{i-1}, 0, 0) \times \mathrm{Rot}(x_i, \alpha_{i-1}) \\
{}^{i-1}_{i}\boldsymbol{T} = \begin{pmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i\cos\alpha_{i-1} & \cos\theta_i\cos\alpha_{i-1} & -\sin\alpha_{i-1} & -d_i\sin\alpha_{i-1} \\ \sin\theta_i\sin\alpha_{i-1} & \cos\theta_i\sin\alpha_{i-1} & \cos\alpha_{i-1} & d_i\cos\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{pmatrix}
\end{gathered}
\tag{1}
$$

The positive solution of the robotic arm is obtained by multiplying the transformation matrices of each link in turn.

3.3. Inverse Kinematic Solution of Robotic Arm

Normally the robotic arm is manipulated for gripping by known target position and attitude, so the inverse solution is needed to derive the parameters to control the movement of the robotic arm.

3.4. Verify the Inverse Solution

The constraints on the parameters of the robotic arm are fully taken into account to exclude solutions that are outside the actual workspace.

4. KINEMATIC SIMULATION OF A 6-DEGREE-OF-FREEDOM ROBOTIC ARM

4.1. Establishment of Kinematic Model

Based on the parameters derived from the dh method the kinematic modelling of the robotic arm is carried out in MATLAB software using Robotics Toolbox.

4.2. Positive Kinematic Verification of the Robotic Arm

Substitute a set of joint angles into the calculation, judge whether the position matrix obtained is consistent with that obtained by MATLAB, if it is the same, then the positive kinematics verification is correct.

4.3. Inverse Kinematics Verification of Robotic Arm

Take the values and substitute them into the robot toolbox for solving, and then the end position matrix can be obtained.

Simulated scenarios as well as physical UAV simulations are built through GAZEBO and SLAM sweeps are performed in their simulated scenarios.

Warehouse environment modelling and UAV modelling with gazebo.

Launch rviz to visualise the image building process;

Open another terminal, type roslaunch azebo_my rviz. launch, find Camera, select the tick box, click Expand to select /head_camera/rgb/image_raw in the drop-down list of Image Topic to adjust the angle and layout of Gazebo, RVIZ;

Activate keyboard control;

Open another terminal and type: rosrun teleop_twist_keyboard teleop_twist_keyboard.py;

In the keyboard control terminal, follow the key instructions to drive the Fetch motion and build the map.

5. DOCKING OF UAV TO ROBOTIC ARM USING MONOCULAR COLOUR INFORMATION ACQUISITION METHOD

The image captured by the camera is first converted from RGB colour space to HSV colour space, and the specific ranges of H, S, and V are set according to the colours of the markers, so as to determine the general range of the markers from the image. After determining the general range, ellipse detection is performed to derive the feature points for positional solution.

6. ORTHOGONAL ITERATION ALGORITHM

wi=[ui vi 1]T, i=1,2,3,4 denoted as [1].

$$\boldsymbol{W}_i = \frac{\boldsymbol{w}_i \boldsymbol{w}_i^{\mathrm{T}}}{\boldsymbol{w}_i^{\mathrm{T}} \boldsymbol{w}_i} \tag{2}$$

In the OI algorithm, bit-pose solving is equivalent to solving that minimises the sum of squared errors. The sum of error squares is defined as [1].

$$\mathrm{E}(\boldsymbol{R}, \boldsymbol{t}) = \sum_{i=1}^{n} \| \boldsymbol{e}_i \|^2 = \sum_{i=1}^{n} \| (\boldsymbol{I} - \boldsymbol{W}_i)(\boldsymbol{R}\boldsymbol{p}_i + \boldsymbol{t}) \|^2 \tag{3}$$

The algorithm estimates the pose rotation matrix R and the translation vector t by continuously performing iterative computations, and the relative positional pose (R, t) can be found at the termination of the iteration.

7. EXPERIMENTAL VERIFICATION

This experiment is based on DJI M100 quadcopter UAV, which is powerful and smooth and reliable.

Table 2. Static error analysis (data from [1])

distance/m	displacement deviation		
	x	y	z
15.0	0.75	0.67	2.3
10.0	0.31	0.25	1.5
5.0	0.23	0.18	0.7
3.0	0.08	0.08	0.17

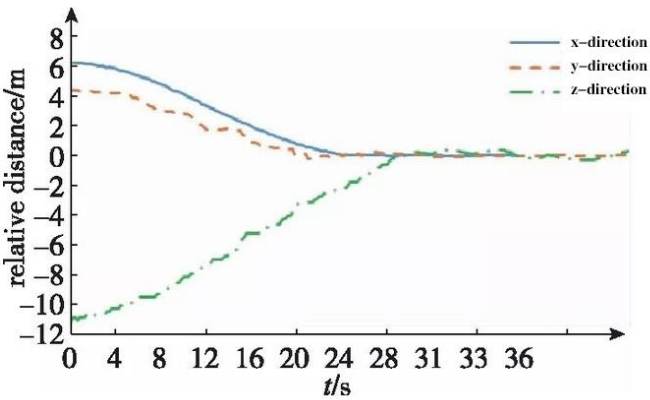

Figure 2. Relative distance curve in docking process (data from [1])

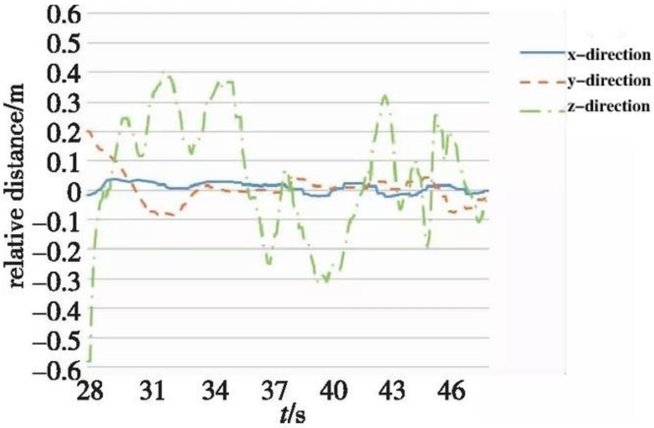

Figure 3. Terminal docking curve (data from [1])

From the above data, it can be concluded that even at high speeds, the algorithm has the ability to assist the robotic arm to dock with the end effector of the UAV.

8. CONCLUSION

Based on the orthogonal iteration algorithm, this paper researches on the UAV docking with the robotic arm after picking up the goods through the visual navigation method, and draws the following conclusions through theoretical analysis and experiments.

(1) The feasibility of using ellipse detection algorithm and orthogonal iteration algorithm to process the visual data is confirmed through the analysis of experimental data, which can meet the accuracy requirements of aerial docking between the UAV and the robotic arm, which is an important reference value for the realisation of stable cooperation between the UAV and more machines and equipments;

(2) The use of laser SLAM-based positioning navigation can increase the accuracy of UAV indoor cruising, the method effectively avoids the problem of insufficient accuracy of GPS positioning indoors, how to make the UAV tracking and aerial docking for more efficient connection will be the next step to continue research directions.

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