Marker-Based Autonomous Quadrotor Tracking for Ground Mobile Robots

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Abstract. An article usually includes an abstract, a concise summary of the work covered at length in the main body of the article. It is used for secondary publications and for information retrieval purposes.

INTRODUCTION

In recent years, the utilization of unmanned aerial vehicles, commonly known as drones or quadcopters, has surged across a wide spectrum of applications, ranging from aerial photography and surveillance to search and rescue operations. Drones have shown their potential to revolutionize various industries because of their ability to operate autonomously, collect real-time data, and navigate through challenging environments. This study explores an innovative approach to enhance the capabilities of ground robots through the implementation of an autonomous drone-following system using ArUco markers.

Quadcopters, or drones, have gained substantial prominence owing to their agility and versatility in navigating complex terrain. These aerial platforms are equipped with multirotor configurations that provide impressive stability and maneuverability. Their potential lies not only in aerial reconnaissance but also in their ability to collaborate with ground robots, creating dynamic and adaptive robotic teams. This paper presents a novel application of quadcopters in the context of ground robot interaction, enabling the seamless following of ground-based robots through the integration of ArUco markers.

Although previous research has explored aspects of both autonomous drone operation and ground robot navigation, there is a relatively limited body of work focusing on the intersection of these two domains. Existing studies have often employed GPS or vision-based techniques for tracking ground robots; however, these methods may be less reliable in GPS-denied environments or when visual obstructions are present. This study addresses the existing gap by proposing an autonomous drone-following system that leverages ArUco markers, providing a cost-effective and robust solution for enhancing the coordination between aerial and ground-based robotic platforms. By utilizing ArUco markers as visual cues, the proposed system aims to overcome the limitations of traditional tracking methods, thereby offering greater accuracy and adaptability in challenging real-world scenarios. This study strives to advance the field of autonomous robotics by introducing an innovative approach to enhancing collaborative robotics through the integration of drone technology and marker-based tracking mechanisms.

METHODOLOGY

Model of Quadrotor

A quadcopter is a popular unmanned aerial vehicle (UAV) characterized by four rotors arranged in a cross configuration. Understanding this basic model is fundamental for designing control algorithms and tracking systems. The motion of the quadcopter can be divided into six degrees of freedom: three translational and three rotational. Translational motion refers to the movement of the vehicle along the X-, Y-, and Z-axes in 3D space, whereas rotational motion represents its orientation about these axes.

In terms of the quadcopter's basic kinematics, its translational motion is governed by Newton's second law, where the thrust generated by the four rotors must balance the gravitational force and account for any desired acceleration. On the other hand, rotational motion follows the principles of angular momentum conservation, where the torque generated by the rotors creates angular acceleration. This simple yet effective model allows us to accurately analyze and control the quadcopter's movements.

The dynamics of a quadcopter involve a complex interplay of the forces and torques acting on the vehicle. These dynamics are typically described by a set of differential equations that consider the mass, geometry, and aerodynamic properties of the rotors of the vehicle. In a simplified model, the dynamics of a quadcopter can be represented by a system of equations that govern its translational and rotational motion.

For translational dynamics, we considered the forces generated by the four rotors and their effect on the vehicle's linear acceleration. These forces are determined by the throttle inputs to the individual rotors and are subject to nonlinearities, such as thrust losses owing to air resistance.

Rotational dynamics involve the torques generated by the rotors and their effect on the quadcopter's angular acceleration. The moments of inertia and geometry of the quadcopter play crucial roles in these equations. Additionally, aerodynamic effects, such as rotor-induced drag and gyroscopic precession, must be considered for an accurate model. These equations provide the foundation for developing control strategies to stabilize and maneuver a quadcopter in a controlled manner. The dynamic equation of the quadrotor is shown as follows:

$$\ddot{\phi} = \dot{\theta}\dot{\psi}\left(\frac{I_y - I_z}{I_x}\right) - \frac{J_r}{I_x}\dot{\theta}\Omega + \frac{l}{I_x}U_2 \tag{1}$$

$$\ddot{\theta} = \dot{\phi}\dot{\psi}\left(\frac{I_z - I_x}{I_y}\right) - \frac{J_r}{I_y}\dot{\phi}\Omega + \frac{l}{I_y}U_3 \tag{2}$$

$$\ddot{\psi} = \dot{\phi}\dot{\theta}\left(\frac{I_x - I_y}{I_z}\right) + \frac{l}{I_z}U_4 \tag{3}$$

$$\ddot{x} = (cos\phi sin\theta cos\psi + sin\phi sin\psi)\frac{U_1}{m} \tag{4}$$

$$\ddot{y} = (cos\phi sin\theta cos\psi - sin\phi sin\psi)\frac{U_1}{m} \tag{5}$$

$$\ddot{z} = -g(cos\phi cos\theta)\frac{U_1}{m} \tag{6}$$

ArUco Marker

In the realm of autonomous systems, marker-based tracking has emerged as a robust and efficient method for enhancing the localization and navigation capabilities of aerial vehicles like quadrotors in conjunction with ground mobile robots. One prominent marker system that has gained significant attention in recent years is the ArUco marker. ArUco markers are a type of fiducial marker characterized by their simplicity, ease of detection, and robustness. In this section, we delve into the explanation of ArUco markers and the algorithms employed for their detection, with a focus on the utilization of OpenCV for this purpose.

Aruco markers, short for Augmented Reality University of Cordoba markers, are a type of visual marker designed for computer vision applications. They consist of a grid of black squares on a white background, with a unique identifier encoded within. These markers are typically printed and affixed to objects or surfaces that need to be tracked. What makes ArUco markers particularly advantageous is their high detection accuracy, even in challenging lighting conditions and varying viewing angles. The unique identifier within each marker allows for easy differentiation, making them an ideal choice for robotics applications where precise localization and tracking are essential.

The process of detecting ArUco markers often involves computer vision libraries such as OpenCV, which provides a rich set of tools for image processing and marker recognition. OpenCV offers a specialized ArUco module that simplifies marker detection and pose estimation. The algorithm typically employed for ArUco marker detection comprises several key steps, including image preprocessing, contour detection, corner detection, and marker identification. OpenCV's ArUco module incorporates methods to estimate the marker's pose in three-dimensional space, enabling accurate localization of the robot or quadrotor relative to the markers in the environment.

PROPOSED ALGORITHM

SIMULATION ENVIRONMENT SETUP

Ground Robot

Quadrotor Robot

EXPERIMENTAL RESULT

Marker Detection

Tracking Accuracy and Reliability

CONCLUSION

REFERENCES

1. N. D. Birell and P. C. W. Davies, *Quantum Fields in Curved Space* (Cambridge University Press, 1982).