

Vision-based Guidance and Navigation for Autonomous MAV in Indoor Environment

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Abstract— The paper presents an autonomous vision-based guidance and mapping algorithm for navigation of drones in a GPS-denied environment. We propose a novel algorithm that accurately uses OpenCV ArUco markers as a reference for path detection and guidance using a stereo camera. It enables the drone to navigate and map an environment using vision-based path planning. Special attention has been given towards the robustness of guidance and controlling strategy, accuracy in the vehicle pose estimation and real-time operation. The proposed algorithm is evaluated in a 3D simulated environment using ROS and Gazebo. The results have been presented for drone navigation in a maze pattern indoor scenario. Evaluation of the given guidance system in the simulated environment suggests that the proposed system can be used for generating a 2D/3D occupancy grid map autonomously without the use of high-level algorithms and expensive sensors such as lidars.

Keywords—ROS, Gazebo, Pose estimation, Quadcopter, Vision Guidance, SLAM.

I. INTRODUCTION

Micro Aerial Vehicles (MAVs) commonly known as drones playing an important role in achieving various tasks in both civilian and military areas because of their autonomy, high versatility, low cost, extreme agility, easy to deploy, and the capability for performing complex manoeuvres in both structured and unstructured environment [1]. However, a lot of work has been progressed during the past recent years, research on their deployment and control efforts are still focused on achieving fully autonomous drones that can perform high-level missions particularly in GPS denied environment [2]. Estimating and mapping of the surrounding 3D environment is one of the key challenging tasks for fully autonomous MAVs to navigate safely and operate high-level tasks [3].

The proposed research work aims at developing an algorithm for vision-based path following and navigation approach in indoor application. In this paper, we have deployed an online ArUco based OpenCV tracker, which helps the MAV to autonomously track, detect and find its position with reference to the ArUco marker for the online navigation application. Whenever an ArUco tracker is detected, the controller flag is set to high which results in the position controller module to receive the sensor feedback data in order to generate (x- y) relative positions of the MAV with respect to the tracker (shown in Fig. 1). The reference value r which is relative distance to the marker of controller is set to

zero. In order to achieve the proposed task, the localization relies on the drone vision-based technique using ArUco markers. Finally, the simultaneous localization and mapping (SLAM) based model using cartographer ROS has been implemented for mapping 2D/3D surrounding. The test is performed in a virtual environment created by gazebo and Rviz by placing different dynamic ArUco markers for different destinations on the map.

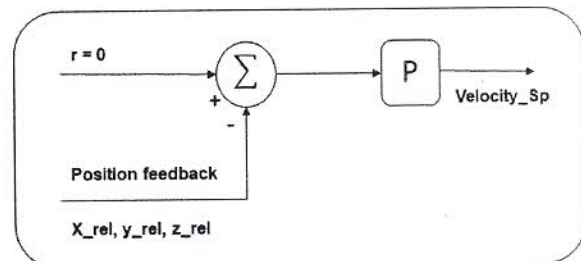
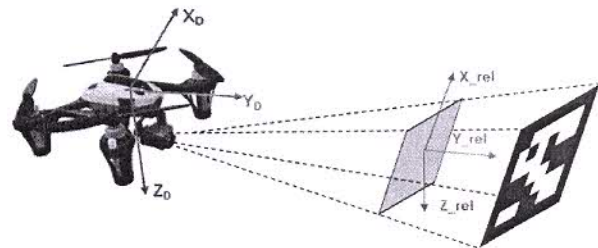


Figure 1. A vision-based navigation control law

This research aims to contribute to the emerging field of research of MAVs in a wide range of different applications by introducing a low-cost vision-based intelligent indoor pathfinding and mapping technique. The novelty of the developed algorithm relies on its simple yet accurate autonomous real-time online navigation and mapping with no prior information from external infrastructure.

II. RELATED WORK

The real-time vision-based navigation and mapping approach is the research of interest in many areas from augmented reality to intelligent robotics and autonomous aerial vehicle application. It collects the visual information from vehicles using path trackers like ArUco [4], [5]. The other type works without using such markers but considers the 3D surrounding information [5], [6]. There are many techniques that are already implemented to control the MAV

attitude/altitude and position [7], which includes PID [8], LQR [9], H_∞ [10], and model predictive [11] controllers. The ideal purpose of such a controller is to maintain a suitable accurate position of the vehicle, however, the position control is used to drive the drone to navigate a predefined indoor tracking path. To enhance the performance of the controller, vehicle pose feedback is an important parameter. GPS signals are widely used for outdoor in the robotics control tasks because inertial measurement unit (IMU) sensors have accumulated errors. Furthermore, in an indoor environment, GPS signals are undetectable many times, which leads to new research scope to the design of autonomous MAV controllers [9, 12].

The traditional monocular camera is used because of its low-cost solution to determine the vehicle pose estimation in GPS denied environment. As resulted in vision loss depth qualities as compared to binocular camera vision and some additional features required to estimate the vehicle pose [13,14,15]. Simultaneous localization and map (SLAM) algorithm use depth information for MAV pose estimation [16], however this method require a larger memory system and high computation resources. An OpenCV ArUco library initially developed for augmented reality but later it uses in different robotics applications [17]. It also used as intelligent markers for MAV pose estimation [18, 19]. Google cartographers are used for mapping purposes. SLAM provides autonomous vision-based guidance and mapping work [20].

In this paper, we present a high-level comprehensive vision-based position control algorithm in a complex indoor 3D environment. This results in robust autonomous navigation in GNSS denied environment. An iris camera equipped in the gazebo model-based quadcopter to observe ArUco trackers which are placed on the wall, and estimate the pose of the MAV. To improve the accuracy and eliminate the error of pose estimation, an intelligence PID controller [21] is implemented for position control of the vehicle. A 3D ROS based Gazebo simulation platform has been created to verify the proposed control algorithm. Different navigation trials have been performed and obtained simulated results are able to provide an accurate vision-based algorithm for real-time MAV pose calculation while mapping the surrounding seen at the same time.

III. VISION-BASED GUIDANCE ALGORITHM

The proposed research work consists of three main segments. Firstly, an OpenCV library ArUco marker-based technology for indoor navigation purposes. Second, a stochastic method to track and generate a path to a goal location, taking into account for safe navigation. This method is efficient because it only uses simple ArUco markers to find its position for autonomous pre-defined path tracking and does not require any high-level optimized method and sensors. Lastly, a computationally efficient algorithm for creating the map of its surrounding while navigating. All the above tasks can be achieved using a single RGB-D fixed non-tilting frontal camera interfaced with the onboard processor. The proposed vision-based guidance algorithm consists of several segments of ROS compatible packages namely, ArUco_ROS package and MAV pose estimation method to determine the MAV pose, design of intelligent PID controller for safe position control of the vehicle and SLAM based mapping algorithm using ROS_cartographer.

A. ArUco_ROS Trackers

For autonomous target detection, pose estimation, and path tracking purposes, we have used ArUco_ROS package from OpenCV library, which is commonly used in robotics, augmented reality and camera calibration applications [22].

The ArUco tracker consists of several binary bits having five bits in each row, while the second and fourth bits are known as information bits and the rest three bits act as error control bits. There are different types of ArUco markers as shown in Fig.2. Each ArUco markers has its unique ID and each marker ID's are recognized by the information present in bits. It consists of a total of 1024 different patterns. The proposed system uses 7x7 dictionary-based markers (7x7 bits) for better detection, resulting in reduced false-positive identification of the markers.

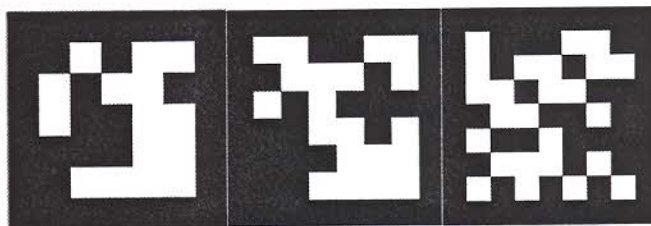


Figure 2. ArUco square markers of 5x5, 6x6 and 7x7 dictionary size respectively.

B. MAV pose estimation

The vehicle pose can be estimated by using any calibrated camera which calculate minimum of four co-planer and non-co-linear elements by the obtained image. Let us assume that $P(A, B, C)$ be the location of the camera in space. The camera coordinates can be projected with 3D point in a condition such that translation, (t) and rotation, (R) values should be known already. Given coordinate location of the point $P(X, Y, Z)$ by the r200 camera can be determine using the obtained eqn. (1) and (2)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = R \begin{bmatrix} A \\ B \\ C \end{bmatrix} + t \quad \dots\dots\dots (1)$$

After expanding equation (1), we will get

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} r_{00} & r_{01} & r_{02} & t_x \\ r_{10} & r_{11} & r_{12} & t_y \\ r_{20} & r_{21} & r_{22} & t_z \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ 1 \end{bmatrix} \quad \dots\dots\dots (2)$$

Now, the value of real world coordinates ($A B C$) are obtained and points ($X Y Z$) are unknown. The (X, Y) point can be calculated from eqn. (2).

$$\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = s \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad \dots\dots\dots (3)$$

From the above obtained equation (3), f_x and f_y are known as focal length of drone camera in x and y direction respectively, whereas, 's' considered as unknown factor and c_x and c_y are known as optical centers of drone camera.

