Landmark-Based Localization for Unmanned Aerial Vehicles

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***Abstract*—Localization is an aspect of robotics that is of fundamental importance in the deployment of autonomous vehicles. Robots need to know where they are relative to a global frame of reference, or other robots. Robot odometry is a trivial way of acquiring distance travelled by an autonomous vehicle. However, odometry has inherent flaws such as errors caused by wheel slippage on ground based vehicles. Other platforms like Unmanned Aerial Vehicles (UAVs) have built-in odometry capabilities that can be affected by drift. Further, the Global Positioning System (GPS) has a 10 foot error, which contributes a significant error to the robots location as discussed in [10]. Landmark-based localization is an ideal supplement to odometry and GPS. Recognition of landmarks such as tags or terrain using cameras can provide localization data. The Parrot AR drone was the platform for the landmark-based localization experiments. The real-time camera feeds from the drone along with ROS' (Robot Operating System) AR tag node provided the parameters: roll, pitch, yaw, x-metric, y-metric, z-metric. Utilizing a mathematical algorithm and the camera feed, the relative position of the drone to a point of origin was calculated. The error associated with the position was an acceptable 100mm-150mm, which was a significant improvement compared to other localization methods. Landmark-based localization is proving to be an effective way to attain position information when other sources such as GPS are unavailable as described in [11]. Despite its advantages, certain limitations and challenges need addressing. Dealing with limitations in camera image quality, lighting and locale restrictions would require further exploration.**

Keywords—landmark-based localization; unmanned aerial vehicles

I. INTRODUCTION

Localization is an aspect of robotics that is of fundamental importance in the deployment of autonomous vehicles. To operate autonomously in their workspace, mobile robots must include localization or positioning system in order to estimate the robot pose, i.e. the position and the heading angle of a robot as accurately as possible [1].

Localization methods can be classified into relative localization and absolute localization. The relative localization method that uses internal sensors such as odometry and inertial measurement unit is robust against environment changes, but the accumulated error caused by wheel slippage on ground based vehicles becomes quite large for a long operation time [2][3][4][5]. The absolute localization method that uses external beacons or landmarks can identify a pose of the robot even after abrupt movement from the current location and the accumulated error does not exist [6]–[11]. The fusion of these methods is widely used to reduce the localization error by employing Kalman filter or particle filter [12][13][14], which gives more accurate and robust outcome than each single method alone.

Recently a new localization method referred as landmark-based localization, has been used widely for relocation because it enables localization without preliminary information on the environment [1][15][16]. Landmark-based localization is one of the methods for relocation also referred as first localization, global localization, or kidnapped robot problem. Relocation is the problem in which a mobile robot has to estimate its pose only with a map of environment and measurements taken by sensors without using any information of the initial pose [17]. Commercial localization modules in outdoor environment use this method because of the cost and robustness. The robot can identify its location by measuring the distance between the robot and landmarks [6], the displacement to landmarks [7][8], or the bearing angle between the robot and landmarks [9][10].

Unlike mobile robot, Unmanned Aerial Vehicles (UAVs) have built-in odometry capabilities. Robot odometry needs to be supported by utilizing other methods of localization such as Global Positioning System (GPS). Unfortunately, GPS also has its limitations: cannot work indoors, GPS fix easily lost by weather conditions [18][19][20], at least 10 foot error in localization. An additional method is required to compensate and minimize error.

To resolve the above problems, it is extremely important to find a potential solution to the indoor localization problem of unmanned aerial vehicles. Due to the limitations of GPS indoors, i.e. the GPS signal is unavailable, landmark-based localization based on object or tag recognition would provide an ideal solution for determining the location of a drone.

The rest of the paper is organized as follows. In Section II, the algorithm and method are presented. In Section III, the Parrot AR drone quadcopter, which is the platform for the landmark-based localization experiments, is briefly introduced. In addition, the Willow Garage's Robot Operating System (ROS), which was utilized for the processing of the tag

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data acquired by the cameras will be illustrated. In Section IV, experimental results were demonstrated. In Section V, the conclusions are given. Challenges are also briefly described.

II. Algorithm and Method

A. Algorithm

The AR toolkit algorithm is used to calculate the real camera position and orientation relative to marked cards, allowing the programmer to overlay virtual objects onto these cards [21]. The algorithm is based on a basic corner detection approach with a fast pose estimation algorithm, as shown in Fig. 1.

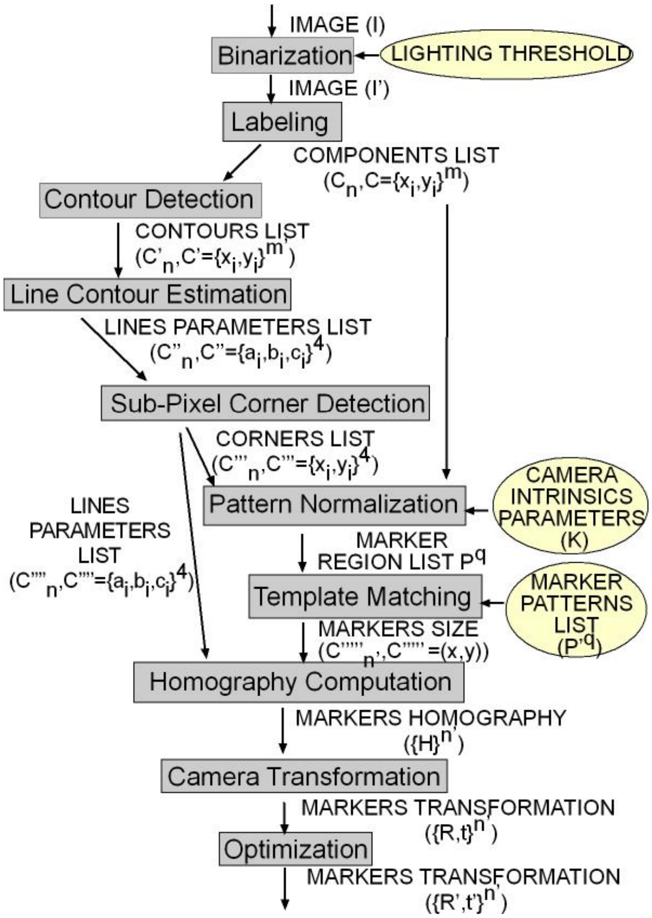

Fig. 1 Corner detection algorithm.

B. Visual Odometer Tracking Algorithm

A tracking algorithm is adopted to update drone position by locking onto objects that initially appear at the main camera image center and tracking them in subsequent images [22]. For simplicity, the tracked objects will be referred to as “the target” hereafter. To calculate the relative position of the drone, let us examine a situation where the helicopter moving from ground frame position P0 to P1, as depicted in Fig. 2.

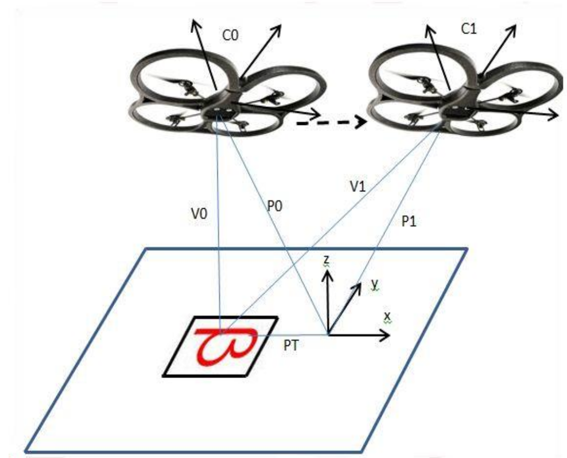

Fig 2. Position Estimation method.

Looking at the scenario where the drone moved from C0 to C1. To calculate the new position, the ground target position PT must be localized along with the target view vectors V0, V1 and camera vectors C0 and C1 in the ground coordinate frame. The algorithm estimates the new position, P1, by first localizing the ground target position, PT , and sensing the target view vectors V0 and V1, and camera vectors C0 and C, in the ground coordinate frame. By vector arithmetic the new position is computed from Eq. (1). The superscripts represent the ground and drone coordinate frames.

$$P1^{G} = PT^{G} - V1^{G} - C1^{G} \tag{1}$$

where:

$$PT^{G} = V0^{G} + C0^{G} + P0^{G} \tag{2}$$

$$V1^{G} = RD^{G}\, RC^{D}\, V1^{C} \tag{3}$$

$$C1 = RD^{G}\, C^{D} \tag{4}$$

and:

$$V0^{G} = RD^{G}\, RC^{D}\, V0^{C} \tag{5}$$

$$C0^{G} = RD^{G}\, C^{D} \tag{6}$$

RD^{G} are the drone to ground rotation matrices at the two positions, RC^{D} is the constant camera to drone rotation matrix and C^{D} is the constant main camera translation vector in the drone frame.

C. Method

Utilization of the AR toolkit along with Brown University’s ar_recog Robot Operating System (ROS) package provided the basis of the localization information for the drone in flight [23]. The preloaded library of AR tags was recognized by the ar_recog node, and the tag identified. Since the positions of the tags were predetermined and inserted into the mathematical equations, they can be used for localization.

The following parameters were extracted from the AR tags: xRotation, yRotation, zRotation, xMetric, yMetric, zMetric, as shown in Fig. 3. All these parameters are the drone's downward facing camera relative to the AR tag in the camera field of view.

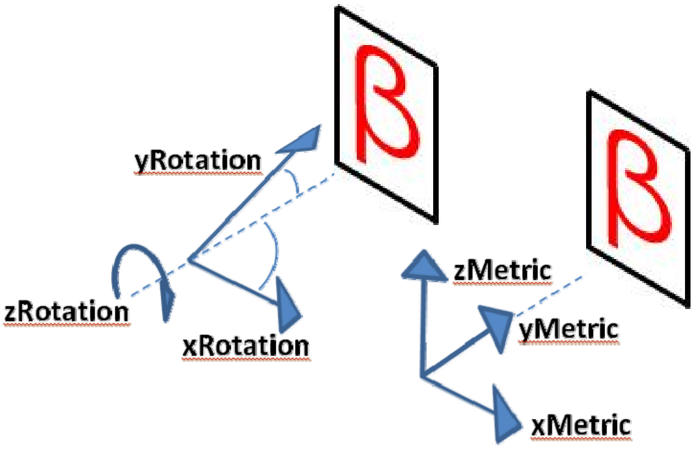

Fig. 3. The xMetric, yMetric, zMetric, xRotation, yRotation, and zRotation parameters relative to the AR tag.

III. Experimental Results

The goal of the experiment was to determine the approximate position of the drone without the aid of GPS information. The position was estimated using the AR tag that is in the field of view of the camera. The ar_recog node ascertained the necessary x, y and z distances and rotations of the AR tag relative to the drone camera. The drone camera had to be calibrated prior to being used.

A. Hardware

Usually, a camera is used to obtain environmental information like landmarks in robotics research. A general-purpose camera has little distortion and has a narrow field of view which provides less information about the environment. On the other hand, an omnidirectional camera has a wide field of view with radial distortion to obtain enough information about the surrounding environment at a time, but it needs expensive omnidirectional vision system. A fish-eye lens camera, however, has a relatively wide field of view with radial and tangential distortion and it needs a cheap lens. Thus, it can be an alternative for a robot vision system except for a distortion problem.

The hardware used for experimentation was the Parrot AR drone quadcopter, as shown in Fig. 4. The drone had a downward facing 64 degree lens, and a forward facing camera with a 93 degree wide-angle lens with a resolution of 640 x 480 pixels. The drone was controlled via wifi using a computer running Ubuntu Linux. The live camera feeds from the drone were relayed to the computer along with the tag parameters. All the tag processing intelligence was handled by the computer. The drone's on-board computer was responsible for maintaining a constant hover.

Fig 4. Hardware setup for testing.

B. Software

Willow Garage's ROS was utilized for the processing of the tag data acquired by the cameras. The AR tag recognition node was Brown University's ar_recog ROS package. The package provided the xMetric, yMetric, zMetric, xRotation, yRotation, and zRotation parameters relative to the AR tag, as shown in Fig. 5. A ROS node was written in C to process these parameters and calculate the position of the drone relative to a point of origin.

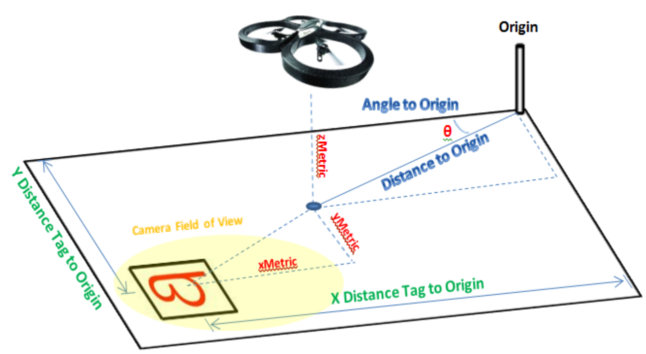

Fig 5. Experimental setup.

For experimentation purposes, the origin was a pre-determined place in the room of a known elevation, as shown in Fig. 5. The position of the drone would be calculated relative to this point of origin. The drone camera field of view would detect the tags, and was able to calculate the position of the drone. This was possible since the AR tags were placed on the ground at known locations throughout the room. The xMetric, yMetric, zMetric, xRotation, yRotation, and zRotation parameters relative to the AR tag are shown in Fig. 6.

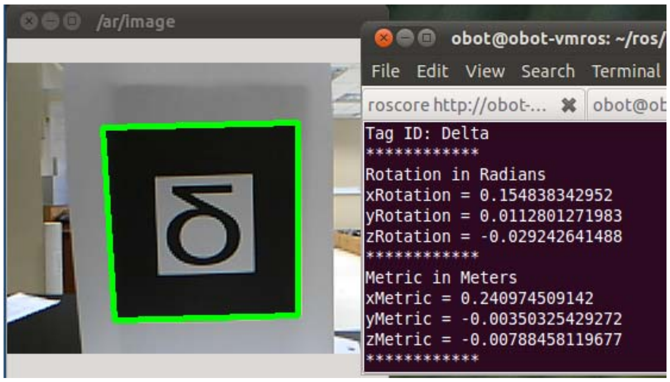

Fig. 6. The extracted parameters: xMetric, yMetric, zMetric, xRotation, yRotation, and zRotation relative to the AR tag.

IV. CONCLUSIONS

This paper provides an excellent method of localization without the presence of GPS data. Landmark-based localization is proving to be an effective way to attain position information when other sources such as GPS are unavailable.

Challenges. Despite its advantages, certain limitations and challenges have to be addressed, as follows. All of which can be improved with more research. Position estimates can also be better improved by the utilization of filtering techniques as described in [24] and [25].

- Camera image quality – The resolution of the camera feed will have an impact on the accuracy of the metric data.
- Lighting – Inadequate lighting can impede the recognition of tags and consequently the metric data that is required for localization.
- Locale Restrictions – Areas that do not have tags or landmarks that are recognizable by the robot cannot be used. Therefore, the coverage area is restricted.

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