Camera Assisted Autonomous UAV Landing*

Mainak Mondal [0000-0002-4671-0070], Stanislav Shidlovskiy[0000-0002-7541-9637], and Dmitriy Shashev [0000-0002-9533-4577]

National Research Tomsk State University, Tomsk, Russia
`mainakme2140@gmail.com, shidlovskiysv@mail.ru, dshashev@mail.ru.`

Abstract. This article describes the use of a monocular camera attached to a multirotor perpendicular to the horizon, to recognize visual cues or artefacts (AprilTag) and use it as an anchor for aerial alignment to finally land on it, thus attempting to make autonomous flights safer and usable in slightly hard-to-reach locations. A Hexacopter frame with the DJI N3 flight controller was used for prototyping and realizing the desired algorithm. Factors like wind speed and gusts were taken into account as well as the center of gravity of the multirotor and the position of the molecular camera attached to the copter facing downwards or at a 90-degree angle. The results of the experiments conducted were verified against existing methods like the GPS (Global Positioning System) waypoint mission provided by major commercial Unmanned Aerial Vehicle(UAV) or Flight Controller manufacturers and were also compared to experimental methods presented in related research articles, fairing excellent results

Keywords: Multirotor · Unmanned Aerial Vehicles · Autonomous Navigation · Guided Landing

1 Introduction

Multirotor unmanned aerial vehicles have come a long way since its inception when auto stabilization was a dream. Today most off-the-shelf consumer multirotors are equipped with features like autonomous flight, GPS waypoint-mission, optical-flow stabilization and a lot more. An important aspect of autonomous flight is GPS or Global Positioning System. It uses GNSS to triangulate a position approximate to 5 meters [1]. Using this, UAVs have achieved great feats in the past decade by using this to navigate faraway territories without human intervention.

These features enable multirotors to navigate through the skies with ease, and in recent years the industry of multirotors has grown due to the consumer interest in these devices. Manual control of these multirotors are as safe as the pilots but autonomous

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fights depend on the flight controller as well as the onboard computer on the UAV itself.

Since it is already established that GPS is approximately accurate to 5 meters and which is in the best of conditions, landing autonomously in tight or dangerously small spots is fairly risky. Camera Assisted landing makes autonomous flights in these UAVs more reliable

The main objective of this research is to use a monocular camera in a UAV to detect visual cues, and use it as an anchor to align itself while landing at the spot, to avoid unnecessary hitches or movement due to wind or other susceptible causes like COG.

2 Concept

Assisted landing has existed for a while in open-source flight controllers like the pixhawk, using an infrared emitter beacon and receiver [2]. The controller is connected to an IR-LOCK sensor which is a slightly modified camera to detect IR light. The sensor spits out the position of the detected IR light and the controller uses this data to align itself and land at approximately 1 m/s. This mode of landing can be difficult to use on sunny days as the IR Sensor might recognize the sunlight as a landing beacon. In the tests conducted, on a fairly sunny day, it was observed that 3 out of 4 times the sensor mistook the spot formed by crepuscular rays under a tree as a landing beacon.

Although this system is fairly accurate most of the time, it's reasonable to find alternatives. One can suggest the use of specialized colors and landing markers to use for this process but it might also be mistaken by the camera in many situations. This method uses an AprilTag detector system developed by the team of APRIL Robotics Laboratory at the University of Michigan, to get the coordinates of a marker in 3d space.

AprilTag is a visual fiducial system, useful for a wide variety of tasks including augmented reality, robotics, and camera calibration. Targets can be created from an ordinary printer, and the AprilTag detection software computes the precise 3D position, orientation, and identity of the tags relative to the camera. The AprilTag library is implemented in C with no external dependencies. It is designed to be easily included in other applications, as well as be portable to embedded devices. Real-time performance can be achieved even on cell-phone grade processors [3].

It is theorized that using a monocular camera and the April tag library to recognize and localize an artefact (printed April tag) as a marker will provide ample guidance for a multirotor to land at a designated location

2.1 Platform

Fig. 1. Hexacopter Platform

Figure 1 shows the drone we assembled for our testing purposes. This drone comprises of Nvidia Jetson TX2 as our field computer and DJI N3 as our flight controller, which is connected to the ground station for all simulations. A similar UAV is used in [6].

Hardware:

1. Ground Station - A Basic Computer, preferably with Linux.
2. NVIDIA Jetson TX2 - A Single Board Computer, compact enough to be mounted on a drone. The NVIDIA Jetson TX2 is a full-featured development platform for visual computing. It comes with a Linux environment, which includes support for many common APIs, and is supported by NVIDIA's complete development toolchain.
3. Monocular Camera - Camera pointed downwards.
4. Flight Controller – A flight controller that will follow a path set by the assisting field computer and perform various switching tasks. The DJI N3 flight controller is made by DJI for industrial applications. Its robust flight control algorithm is ideal for controlling a broad range of industrial and DIY multirotor aircraft, providing professional stability

Software:

1. ROS- ROS or Robot Operating System [4], provides services designed for multiple computers such as hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management.

2. Flight Controller SDK – A Software Development Kit which provides all the application programming interfaces to the flight controller used.
3. Open CV - OpenCV is a library of programming functions mainly aimed at real-time computer vision.

Please note- An additional software- 'DJI Assistant' was used since the aforementioned platform used the DJI N3 Controller. (For ease of operation, running simulations and using additional features provided by the controller).

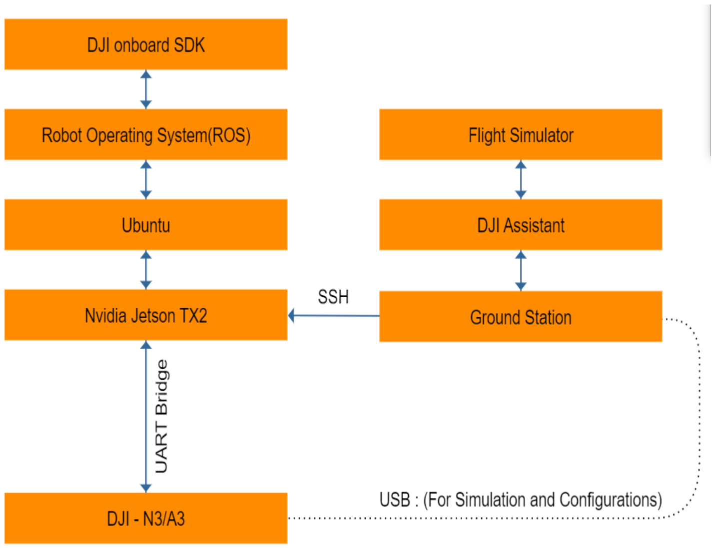

Fig. 2. Architecture

Figure 2, shows the basic groundwork done for the project to work. The Left side of the diagram shows the structure from the drone and the Right side shows the Ground Station

Left Side(Drone). The DJI onboard SDK for Robot Operating System is the software heart of this system, which controls the Flight Controller: DJI – N3. It is the flight controller SDK which has a lot of services, subscribed and published topics which we can use as inputs for algorithms and actuator controls which be used for movement. The UAV should also have a Camera pointing downward at the ground to look for the artefact.

Right Side (Ground Station). The Right Side of figure 2, contains the Ground Station i.e. the computer we use to connect to the field computer or the computer mounted in the drone to view back box data in real-time. It is also used to start all the scripts for sending autonomous flight commands to the controller.

3 Method

Airports have used high-intensity runway lights(HIRL) on the landing strips or runways to guide a pilot to a safe landing. Airports also have Pilot Controlled Lighting, or PCL, where pilots can adjust the lighting themselves by keying a microphone button a certain number of times.

High-intensity lights would be very useful as guidance markers for an Autonomous Unmanned Aerial Vehicle. The use of HIRL is an aid to the human pilots and thus need to be on the visible spectrum of lights. Although, HIRL is not used for assistance here, an attempt to realise the same concept with High-Intensity Lights can be made in future.

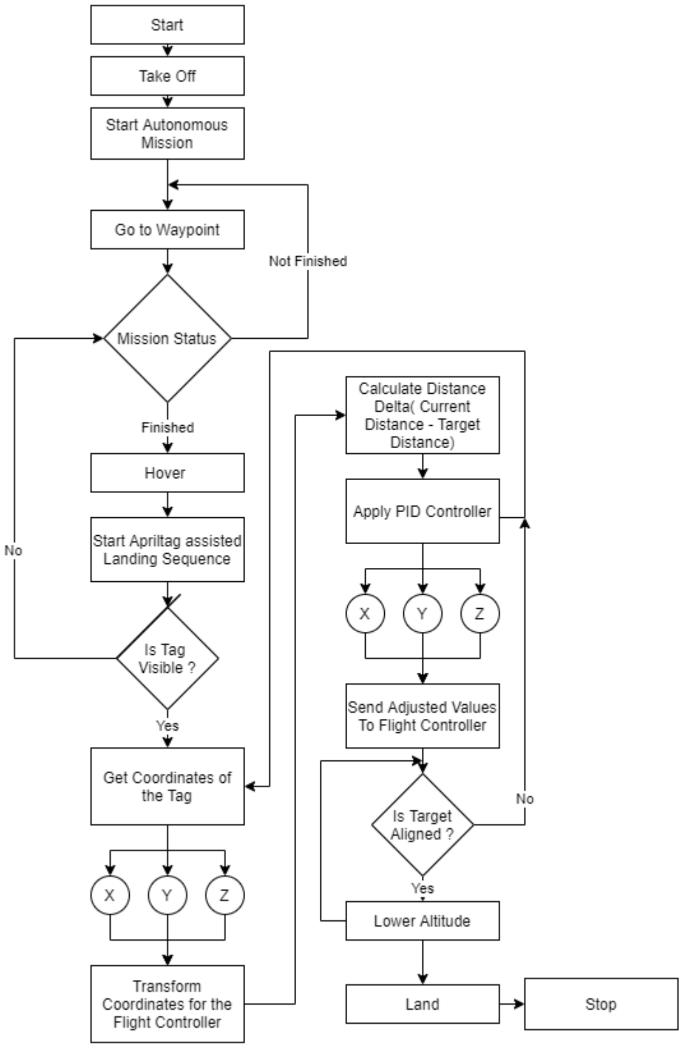

Fig. 3. Flowchart

Figure 3 outlines the process of assisted autonomous landing. This landing sequence can be initiated in the air, which will wait for the UAV to navigate to the final waypoint in its mission parameters. Once the final waypoint is reached, it will look for the April tag in the ground using the monocular camera pointed downwards.

Once the tag is located, the Apriltag library will broadcast(publish) the detected location in the ROS interface. This data is read by another subscriber which does the necessary adjustments and transformations required and publishes delta values to the flight controller.

A PID controller is also applied for accurate reaction to the changes in the position of the UAV and to account for external factors. The delta distance values will be sent to the flight controller, so the UAV aligns itself over the marker and lowers altitude, while locked on the marker. Eventually, the altitude will be 0 and the UAV will land.

4 Execution

To realise the aforementioned algorithm [5], the following services, subscribers and publishers were used, as shown in table 1, 2 and 3.

Table 1. Subscribed Topics

Name	Type/Structure	Function
/flight_control_setpoint_generic	/sensor_msgs/Joy	General setpoint where axes[0] to axes[3] (X, Y and Z Axes) stores setpoint data for the 2 horizontal channels, the vertical channel, and the yaw channel, respectively.
/tag_detections	/apriltags_ros /AprilTagDetectionArray	Array containing the x,y and z coordinates of the detected April tag.

Table 2. Published Topics

Name	Type /Structure	Function
/local_position	/geometry_msgs/PointStamped	Local position in Cartesian ENU frame, of which the origin is set by the user by calling the /set_local_pos_ref service.

Table 3. Services

Name	Type/Structure	Function
/activation	/dji_sdk/Activation	The service to activate the drone with app ID and key pair.
/mfio_config	/dji_sdk/MFIOConfig	Configuration for Multi-function IO.
/drone_task_control	/dji_sdk/DroneTaskControl	Execute takeoff and landing.
/set_local_pos_ref	/dji_sdk/SetLocalPosRef	Set the origin of the local position to be the current GPS coordinate.
/sdk_control_authority	/dji_sdk/sdk_control_authority	This service is used to hand over control of the drone to the SDK installed in the on-board computer.

According to the flowchart (fig. 3) in the previous section, the landing sequence initializer takes over control after the GPS/Visual waypoint mission is finished. At this stage the UAV is at Z altitude, hovering near the landing area. The hover point may have an error radius of 5-10 meters depending on the GPS signal or the visual odometry setup used.

When the landing sequence is initialized, the onboard camera on the UAV looks for pre-configured AprilTag artefact in the ground. The apriltag_ros publishes the detected tags, in the /tag_detections topic as approximate x,y and z coordinates in 3d space (in meters). The accuracy of the detections depends on the camera calibration, and even with the best calibration, it can have discrepancies.

The x,y and z coordinates are then transformed as required by the flight controller. The transformation is defined in equations (1), (2) and (3):

$$\text{AT } x \rightarrow \text{FC } x, \tag{1}$$

$$\text{AT } y \rightarrow \text{FC } y, \tag{2}$$

$$\text{AT } z \rightarrow \text{FC } z. \tag{3}$$

Where,
AT – AprilTag and FC – Flight Controller.

The transformation will vary depending on the coordinate system used by the flight controller. Using the new coordinates, we need to calculate the delta distances or the difference in distances:

$$\Delta x = Px - \text{FC } x, \tag{4}$$

$$\Delta y = Py - FC\ y, \tag{5}$$

$$\Delta z = (Pz - FC\ z) * -1. \tag{6}$$

where, Px, Py and Pz are the alignment coordinates or the ideal position the UAV needs to reach. (Δz is negated, as negative values sent to the flight controller to reduces the altitude)

The ideal coordinates for the UAV used in this experiment are as follows: Px – 0, Py – 0.3 and Pz – 0. The adjusted delta coordinates are sent to the flight controller by publishing to the /flight_control_setpoint_generic topic after applying a PID controller, to for smoother movements. Once the ideal position is achieved, the motors can be turned off as the UAV has landed.

5 Results

Fig. 4. Alignment

Figure 4 shows the UAV aligning itself to the AprilTag marker. An AprilTag marker was pasted to the orange Landing pad.

Similar research [7] has been done by the Robotics Institute of Carnegie Melon University in Pittsburg with an average accuracy of 0.44 meters in the grass. Table 4 shows a comparison of landing methods.

Table 4. Comparison of landing methods

Method	Wind Speed*	Gusts	Number of Trials	Average Accuracy
GPS Mission***	4 m/s	8 m/s	15	3.9 meters
Precision Landing– RI, Carnegie Melon University**	3 m/s	5 m/s	17	0.44 meters
Apriltag assisted Landing***	3 m/s	4 m/s	15	0.15 meters

*The approximate wind data was taken live from windy [8] for the GPS mission tests and the AprilTag assisted landing system.

**The precision landing used by Robotic Institute at Carnegie Melon University is better at landing in un-even landing environments, whereas, under perfect conditions, AprilTag based landing is superior.

*** The same copter was used for doing the tests.

Fig. 5. Assisted landing position

Figure 5 shows the position of the UAV after the autonomous landing sequence is completed. Since the UAV landed on the marker accurately with a negligible error of 0.15 meters, this test can be considered a successful one. On the other hand, if only GPS was used, a 5-meter radius of error can be expected.

6 Conclusion

An attempt to make autonomous flights safer and more useable was made by using a monocular camera pointed downwards, in the UAV multirotor. This monocular camera, in turn, recognises artefacts or markers(AprilTag) and publishes an estimated location. The location of the tag is used as an anchor to align the UAV in flight. While in flight, the UAV lowers the altitude while maintaining position lock with the marker. Once the altitude reaches 0 the UAV has safely landed. This approach had an error of 0.15 meters and thus effectively a tight and small landing zone as small as 0.30 - 0.40 meters can be used.

Light-based markers are used in airports to guide pilots while taking off and landing.

Since a computer controls movements in an Autonomous UAV, any kind of markers can be used. If light-based markers are used, they need not be in the visible spectrum and thus Infrared Light Markers can be used to mark a landing area for a UAV. A control system for precision landing using infrared markers can be made for a future project

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