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on

DEVELOPMENT OF A NOVEL GUIDANCE LAW FOR ACCURATE AUTONOMOUS DRONE TAKE-OFF AND LANDING

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

MARRI LAXMAN REDDY

INSTITUTE OF TECHNOLOGY & MANAGEMENT

(AN AUTONOMOUS INSTITUTION)

(Approved by AICTE, New Delhi & Affiliated to JNTUH, Hyderabad)

NAAC Accredited Institution with 'A' Grade & Recognized Under Section2(f) & 12(B)of the UGC act,1956

October, 2021

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

Date: 29-October-2021

CERTIFICATE

This is to certify that the project work entitled "**DEVELOPMENT OF A NOVEL GUIDANCE LAW FOR ACCURATE AUTONOMOUS DRONE TAKE-OFF AND LANDING**" work done by **VISHAL BAKSHI (187Y1A0455) AND P. VAMSHI KRISHNA (187Y1A0451)** students of Department of Electronics and Communication Engineering, is a record of bonafide work carried out by the members during a period from June, 2021 to October, 2021 under the supervision of **Dr. G. AMARNATH, Associate Professor**. This project is done as a fulfilment of obtaining Bachelor of Technology Degree to be awarded by Jawaharlal Nehru Technological University Hyderabad, Hyderabad.

The matter embodied in this project report has not been submitted by us to any other university for the award of any other degree.

VISHAL BAKSHI **P. VAMSHI KRISHA**

This is to certify that the above statement made by the candidates is correct to the best of my knowledge.

Date: (**Dr. G. AMARNATH**)

The Viva-Voce Examination of above students, has been held on………………………

Head of the Department External Examiner

Principal

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LIST OF ABBREVIATIONS

UAV	Unmanned aerial vehicle
EKF	Extended Kalman filter
ROS	Robot operating system
IMU	Inertial measurement unit
SLAM	Simultaneous localization and mapping
GUI	Graphical user interface
FCU	Flight controller unit
OBC	On-board computer
GPS	Global positioning system
VTOL	Vertical take-off and landing
QC	Quadcopter
ESC	Electronic speed controller
ANN	Artificial neural networks
OS	Operating system
QGC	Qground Controller
UART	Universal Asynchronous Receiver/Transmitter
SPI	Serial Peripheral Interface
GPU	Graphic processing unit
Kp	Proportional gain
KI	Integral gain
KD	Differential gain
χ	Vehicle course angle
ψ	Yaw angle
KrR	Tuning parameters with color Red
KgG	Tuning parameters with color Green
KbB	Tuning parameters with color Blue
Cr, Cb	Different colors formed by subtracting luma from RCB

ABSTRACT

Rotary vehicles like quadrotors, have become an essential part of many applications like mapping, object delivery, tracking, patrolling, and communication relay, etc. A key requirement for these applications is that the vehicle needs to perform these tasks autonomously from takeoff to landing. Landing is the most crucial task in the mission, which has a direct impact on the physical safety of the vehicle. Further, in mapping and object delivery applications, the vehicle landing area is constrained, and hence requires precision landing capability. Additionally, external disturbances like winds and visibility add another dimension to challenges in actual landing scenarios. This thesis focuses on the development of vision-assisted guidance techniques for landing of a quadrotor. The primary concern of a guidance strategy is to enable persistent tracking of the landing pad (referred to as target) which could be either stationary or moving and accurately land on the target.

Additionally, for a moving target, the velocity of the UAV and the target must be the same to achieve zero closing velocity at the time of landing. Besides this, it is desired that the convergence profile of the UAV velocity to the target velocity is slower in the beginning and faster towards the end for achieving time efficient landing. To this end, we have developed a novel log polynomial guidance for accurately landing the vehicle on the target, while meeting the required velocity characteristics. The target is persistently detected and the distance to the target is estimated using an onboard camera vision algorithm. Based on the estimated distance, the log polynomial guidance law drives the vehicle towards the target and ensures landing with zero closing velocity. We theoretically prove the convergence of the proposed guidance law. The guidance law is applicable to both stationary and moving targets. We have performed simulations and carried out field experiments to demonstrate the efficacy of the guidance law.

Chapter 1

Autonomous UAV landing techniques

1.1 Introduction

Unmanned aerial vehicles (UAVs) are highly effective in remote operations. These vehicles have been used in several types of applications like surveillance, search, agriculture border patrol, scientific experiments, and mapping. Communication, sensor and control techniques have evolved over the past few decades that has led to the development of a wide range of UAVs varying in shape, size, configuration, and characteristics. The common types of UAVs are fixed wing UAVs, quadrotors and helicopters at different scales (large UAVs or miniature vehicles or micro aerial vehicle). Fixed wing UAVs have a simple structure, fly at high speeds, and for a longer duration as compared to rotary wing UAVs. However, some of the fixed wing UAVs may require a runway for takeoff and landing, while those that can be either hand launched or through a catapult mechanism can be landed on their belly. On the other hand, rotary wing UAVs have an advantage of hovering, which is useful for monitoring some regions of interest. Rotary wing UAVs have agile maneuvering capability but at the same time they have high mechanical complexity, low speed and short flight range. UAV flight consists of different phases, namely, take-off, climb, cruise, descent and finally landing. Most of the UAV autopilots have autonomous take-off (catapult and hand launched) and cruise but limited autonomous landing capabilities due to high risks and reliability issues. The accuracy of the landing must be high otherwise the aircraft may crash.

Autonomous landing is one of the most challenging part of the flight. Landing must be done in a limited amount of time and space. Hence precise sensing techniques and accurate control is required during this maneuver. There are two aspects to the design of a landing controller namely sensing and control. The choice and design of these aspects must take into consideration a number of factors like: the type of landing (indoor or outdoor), visibility, type of terrain, wind disturbances, etc. The sensing techniques used can be either active or passive. Although radar, LIDAR, ultrasonic, and other time-of-flight active sensors can provide accurate range estimates, they are subject to several disadvantages. For example, surfaces and environmental factors can affect the ultrasonic range finder measurements. Most types of radars especially microwave radar which has a low frequency band does not provide sufficient angular resolution but it is insensitive to weather environment. On the other hand millimeter wave radar is smaller, provides fine angular resolution but it is limited to detection range and is sensitive to weather conditions. Also, by their nature, active sensors rely on self-emitted RF, laser or ultrasonic signals, which can be used to detect, or be used to localize by triangulation. Furthermore, active sensing modalities have relatively high rates of power consumption. Visible-light or IR cameras, on the other hand are passive and rely solely on the reflected ambient light or heat, thereby lowering the probability of detection as well as reduced power consumption. Factors that make vision-in-the-loop difficult are: achieving the accuracy of active sensors without time-of-flight measurements; high bandwidth and computation subject to operation in real-time; and inherent photogrammetric ambiguities making some computations ill-conditioned. Therefore, selection on the type and the number of sensors to be used is a trade-off between accuracy, system complexity, power consumption and application scenario. These sensing techniques are used to estimate the POSE (position and orientation) of the UAV which is then used by the controllers. The type of controllers can range from simple linear control to complex techniques involving intelligent and hybrid control systems. A general block diagram of the landing control system is shown in Figure 1.1.

The system consists of four blocks namely sensors/navigation system, guidance controller, flight controller and type of the UAV. The sensors/navigation system determines the POSE of the vehicle. This information is used for the flight and guidance controllers. The guidance controller generates guidance commands like change in velocity, acceleration and rotation to follow a desired trajectory. The flight controller takes the guidance command to generate the appropriate actuation commands according to the type of the UAV (VTOL or fixed wing). In this chapter, we review the existing work on landing technique for UAVs. We broadly classify the literature based on the type of sensors and controllers used for landing. These are vision-based, control-based, guidance-based and net recovery-based landing techniques and we also provide a detail comparison of these landing techniques.

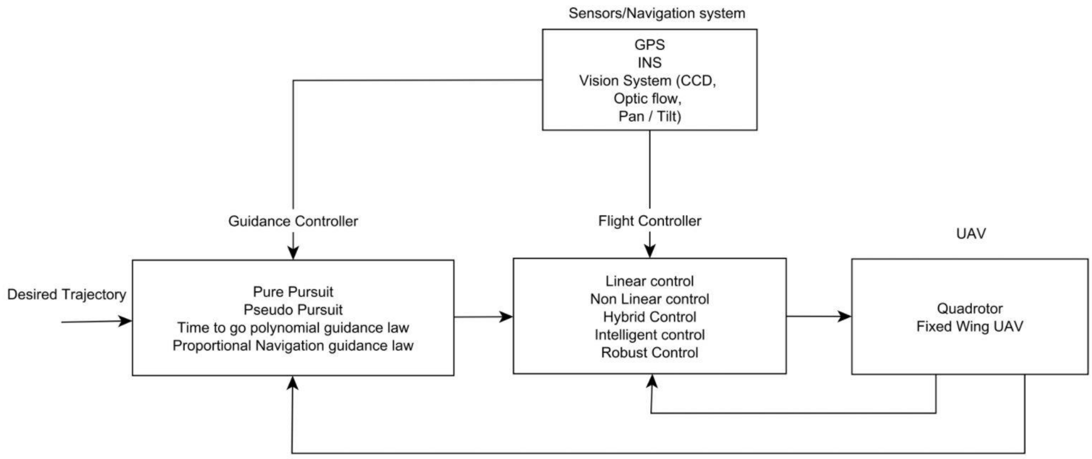

Figure 1.1: A generic landing control system consisting of Sensor/Navigation system, Guidance and Flight controllers along with the type of the UAV

1.2 Landing Site Selection

Emerging applications of unmanned aerial vehicles demand more autonomous capabilities to guarantee safe operation. Emergency landing situations due to power, actuation, or sensing failures may not include special navigation markers for landing. In such scenarios, it is essential to find a suitable landing site taking UAV flying characteristics, application scenario, and safety into account. Therefore, there is need to develop efficient algorithms that can detect flat zones , and select a landing site quickly.

1.2.1 Site selection search

There are three steps in the site selection process: search, detection and determination of the best landing site. Park et al. used a stereo vision system to detect primary landing sites and also store information about secondary candidate landing sites for a quadrotor. The system consisted of two cameras pointing downwards.Most appropriate landing site was decided by a decision map which was a weighted combination of three maps: evaluated depth map, flatness map and energy consumption map. Highest scoring sites were made as primarywhere as the others were stored as candidate landing sites. The weights of the parameters could be adjusted depending on the type and situation of landing to be performed. Three types of topographies were considered in the testing scenario: rough sinusoidal, mountain and urban. Brockers et al. used a single camera for visual detection and reconstruction of the position of navigation targets but used a motion capture system forscale information and closed loop control. Homography estimation was derived from matched feature points with the assumption of a planar surface which can be used for ego motion estimation. The navigation system operated in three sequential phases with three distinct behaviors, in order to first detect the target (detection phase), then determine an accurate estimate of the target location (refinement phase), and finally to perform an autonomous maneuver based on the final target estimate (descent and landing phase). In the detection phase, imagery data was collected for landing platform detection while the vehicle followed a predefined path. Once the first landing spot waypoint was generated, the control system transitioned to refinement phase whereadditional measurements were taken to increase the estimated waypoint's accuracy. This included collection of additional 3D waypoints in the vicinity of the current estimate.

1.2.2 Planning for site selection

UAV needs to plan and perform a sequence of flight operations to select a landing site that minimizes the expected cost of flight, to the desired goal location. This requires planning under uncertain environments. Kushleyev et al. proposed to solve the problem of computing this sequence using a probabilistic planning framework, called PPCP (Probabilistic planning with clear preferences) . The PPCP algorithm decomposes into a series of deterministic graph searches that are fast-to-solve and require little memory. Theoretical guarantees on the optimality of the returned policies are also described. Griffith et al. presented a system that plans nominal paths for a miniature aerial vehicle (MAV) through a terrain. A rapidly exploring random tree (RRT) algorithm was used to build a tree of traversable paths through an environment modeled using apriori data. Branches in the tree were then checked to ensure that they satisfy turn radius and climb rate constraints and are also collision free. While on course, the MAV avoided frontal threats via data from a forward-pointing laser, and used flow field information from three optic flow cameras to negotiate rough terrain. A hybrid path planner capable of both single-mission path planning in known environments, as well as path re-planning in uncertain and dynamic environments was presented by Ping et al. . Initially, the planner uses Dijkstra's algorithm to find a minimum cost path inside a 2-D grid representation of the environment. By using a grid map, sampling the C-space can be avoided, which in turn reduces the computational complexity. In the roadmap grid, UAV constraints, such as minimum flying altitude, as well as landing time were represented as cost functions that penalized the cost of the path to prevent the UAV from traversing an undesirable flight path.

1.2.3 Approach trajectory:

The selection of a landing site and the trajectory followed to reach the site are application dependent. For example, in perch and stare application, the MAV should land close to the edge of the elevated surface, for emergency or fast landing tasks, a safer location is preferable . For VTOL most of the work presented in the literature assumes that the selected landing site can be reached by using two waypoints. The first waypoint is a point directly above the landing zone and the second waypoint is the landing spot itself. For a fixed wing UAV, to accomplish a successful landing, there are three main factors which must be under control . First of them is the lateral position of the UAV with reference to the runway since the goal is to touchdown on the lateral middle point of the runway. The second attribute is the vertical position, which is the AGL (above ground level) altitude of the UAV. It is a dynamic value for a fixed wing UAV, since it changes according to the distance to the runway. The last main attribute is the speed. The speed value is a static value and it depends on the aircraft characteristics. The main aim is to keep the desired speed value during the period of final approach.

1.3 Landing controllers :

A typical landing system uses GPS (Global positioning system) and INS (inertial navigation system) along with range sensors like radar altimeter, or barometric pressure sensor, since the altitude measurement from the GPS in inaccurate. Using the fused information of the GPS, INS and the altitude, one can design efficient landing controllers for different types of aircrafts. We now present a review of landing controllers for quadrotors and fixed-wing aircrafts.

1.3.1 PID control:

The proportional-integral-derivative (PID) controller is the most widely used feedback design. The control u(t) is determines as

u(t) = Kpe(t) + KI Z t 0 e(t)dt + KD de(t)

where KP is the proportional gain, KI is the integral gain and KD is the differential gain. Most of the aircrafts use the PID as a low-level control technique. The other control techniques including the vision-based control are high level techniques that provide signals to the PID controller. Erginer and Altug presented a PD controller design for a quadrotor vehicle that has different PD control loops for controlling quad-rotor altitude, pitch angle, yaw and its motion. Quadrotor control using vision was also presented where the POSE was estimated using feature extraction technique. Lippiello et al. proposed a PID based landing controller for a quadrotor for emergency landing. Ha and Kim proposed an adaptive gain PID control technique using genetic algorithms for landing under harsh weather conditions.

1.3.2 Nonlinear control techniques:

An aircraft model can be either a linearized or nonlinear aircraft model. In a linearized model, the longitudinal and lateral dynamics of the aircraft are decoupled which eases the design by developing separate controllers for longitudinal and lateral controllers. Nonlinear control techniques such as feedback linearization, sliding mode control and back stepping control designs are often used for nonlinear aircraft model .

1.3.3 Feedback linearization

Feedback linearization is a technique used for controlling nonlinear systems. It attempts to introduce auxiliary nonlinear feedback in such a way that the system can be treated as linear for the purpose of control design. Prasad and Pradeep used this technique for landing control of a fighter aircraft. Voos and Nourghassemi proposed a stabilized flight and landing strategy for quadrotor UAVs where they use the nonlinear feedback linearization technique to linearize and decouple three out of the six degrees of freedom. Burchett applied feedback linearization to vehicle point mass dynamics to control the approach and landing of a reusable launch vehicle. This resulted in a linear system with inputs that were combinations of lift, drag and bank angle. By applying a simple aerodynamic model, lift and drag were mapped to negative z axis acceleration and speedbrake commands. Direct application of feedback linearization requires second and third order derivatives of uncertain aerodynamic systems which does not guarantee stability. To overcome this, flight dynamics can be separated into slow and fast dynamics with sufficient timescale separation.

1.3.4 Sliding mode control

Sliding mode control technique is a nonlinear control technique that changes the nonlinear dynamics by application of a discontinuous control signal. In this technique, trajectories are forced to reach a sliding manifold in a finite amount of time and remain at that manifold for all future time. These trajectories in sliding mode control are defined as solutions to a set of sliding functions where the number of variables to track the trajectory should be equal to the number of available control inputs . The main issue with sliding mode control is chattering and high control demand. Therefore, appropriate selection of sliding functions and reaching laws needs to be designed. Lee et al. designed an adaptive sliding mode control to take into consideration the effect of sensor noise, uncertainty in the estimates and ground effect. Huang et al. developed an integral sliding mode control to ensure the tracking is minimized to zero and the controller is robust to parameter uncertainties and external disturbances.

1.3.5 Backstepping control

Backstepping control is another nonlinear technique which can be used for designing a landing controller. The backstepping approach provides a recursive method for stabilizing the origin of a system in a strict-feedback form. In this system, the designer can start at a basic known stable system and "back out" new controllers that progressively stabilize each outer subsystem. For autonomous landing of a UAV the subsystems can be rotation and linear translation subsystem . Using the backstepping approach one can synthesize the control law by forcing a system to follow a desired trajectory. Ahmed and Pota presented an application of backstepping controller for landing of a quadrotor using a tether. This approach was extended in where the backstepping-based controller takes advantage of the “decoupling" of the translation and rotation dynamics of the rigid body, resulting in a two-step procedure to obtain the vehicle control inputs. Lee and Kim proposed a flight and landing control using backstepping along with neural networks where the backstepping controller tracked the angle of attack, side slip angle and roll commands assuming that aerodynamic model is completely known. Yoon et al. proposed an adaptive backstepping controller design for aircraft landing with wind disturbance and actuator failures by the use of hedging techniques. Nonlinear six degree of freedom aircraft model was considered for the design of the backstepping controller that tracked a desired glide slope towards the runway. In order to estimate the modeling errors of aerodynamic coefficients in the nonlinear model, the adaptive parameter estimation of the nonlinear function was adopted.

1.3.6 Neural network-based control:

Neural network-based control basically involves two steps: system identification and control. Neural networks have the ability to learn. Given a specific task to solve, and a class of functions F, learning means using a set of observations to find $f \in F$ which solves the task in some optimal sense. Malaek et al. addressed the problem of designing an intelligent auto-landing controller in the presence of different wind patterns to expand the flight safety envelope. Four different types of controllers were designed namely, PID, neuro, hybrid neuro PID, and ANFIS-PID . Neuro controller was designed to control the aircraft in glide and flare modes. Hybrid neuro controller was designed to handle the aircraft in very strong wind pattern. A controller based on vision and neural network was proposed in where the pilot action was modeled using neural network. The constraint with most of the neural networks is that they are reliable when landing conditions fall within the range of trained data set, thus a significant amount of training data is required for sufficient reliability.

1.3 Vision-based Landing

The localization with GPS involves errors in meters (3-5 meters). Therefore, for precision landing in confined areas, it is essential to have additional information about the target position for accurate landing. One such sensor is camera, where we can use computer vision algorithms to acquire the target information which in turn can be for autonomous landing. There are a number of vision-based control techniques for heli-pad detection, tracking and landing (both indoor and outdoor). Classical vision-based target tracking and landing focuses on object recognition using edge detection techniques. Although vision provides a natural modality for object detection and landing, it can only sense the changes due to the applied forces not the forces themselves. Hence vision-based techniques are integrated with conventional control techniques for a robust landing design.

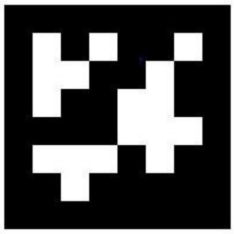

Figure 1.2: A sample ArUco marker

1.3.7 Indoor landing

Indoor landing involves landing in a controlled environment with less environmental disturbances as compared to outdoor landing. Wenzel et al. use a Wii remote infrared camera for their visual tracking approach with the control algorithm running on an onboard microcontroller. They track a pattern of infrared spots by looking downwards with a fixed camera. The integrated circuit provides the pixel position of each spot at a high frequency. The estimated pose is used in various integrated PID control loops to control the vehicle motion. Sani et al. uses ArUco markers as shown in Figure 1.2, along with inertial sensors to land on a stationary target. The markers enables the vehicle to localize accurately. Green et al. use optical flow in an indoor environment to land vertically on a landing pad.

1.3.8 Outdoor landing

Outdoor Landing is a more challenging problem due to the presence of external disturbances such as wind, visibility, etc. The key component of any vision-based landing is to detect the heli-pad (also called as “target”) using object detection or pattern recognition techniques. We will now describe some of the popular approaches to detect the target.

Chapter 2

Quadrotor landing using vision and pursuit guidance

Vision assisted quadrotor landing at a desired location involves two steps: (a) detection of the target and (b) generating control commands to the vehicle such that it lands accurately on the target. In the vehicle, fused INS and GPS information is used for localization, however, the altitude measurement from GPS is inaccurate and hence additional sensors like radar altimeter, ultrasound or barometric pressure sensor are used for altitude measurement. The GPS-based measurement has errors between 3-5 meters and the vehicle may not land at the desired location with only GPS-based navigation. In this chapter, we use camera vision to provide information about the target location in the form of a landing pad with distinct color as shown in Figure 2.1. By estimating the location of the target, a guidance command is generated to the vehicle for landing as shown in Figure 2.2.

Landing controllers can be implemented in two ways. In the first approach, a controller is desired that directly determines the control signals for the vehicle motors. In the second approach, a successive loop closure method is employed, where the low level controller uses PID controller and the guidance command is generated at a higher level. The first approach is employed for high maneuvering trajectories. In this chapter, we use the second approach, as it is flexible and offers finer control on each module of the system without interfering with the working of inner PID control loops of the UAV. Since we are using guidance loop, we need to ensure that at touch down the closing velocity of the target to the vehicle is zero. Otherwise, the vehicle may have some physical damage due to impact. Most of the landing techniques using vision that are proposed in the literature have been limited to vertical landing approach only.

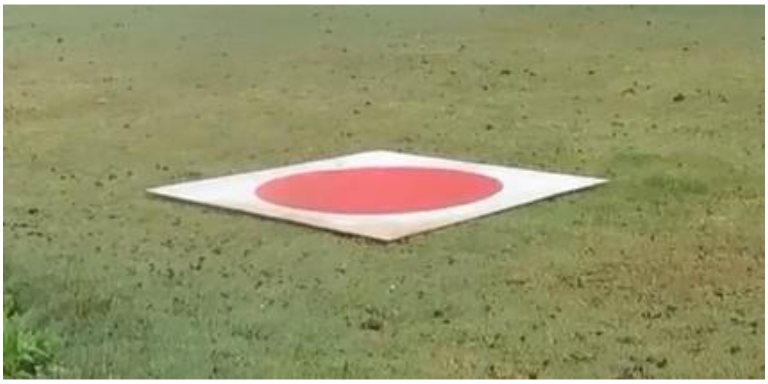

Figure 2.1: The target for landing is a red colored circle, which is drawn on a wooden sheet.

In such approaches, quadrotor tracks the target while moving along a linear path until it is above the target and then descends vertically to land as shown in Figure 2.3. Although, the approach is simple, the resultant trajectory is inefficient in terms of increased flight time during the landing process. In this chapter, we propose a pure pursuit based guidance law to land on a stationary as well as a moving target. Using the guidance commands, the quadcopter approaches the target while simultaneously descending in altitude, thus following a more efficient trajectory as compared to track and descend approach. In order to ensure zero closing velocity for landing, we develop a novel log polynomial function based velocity controller

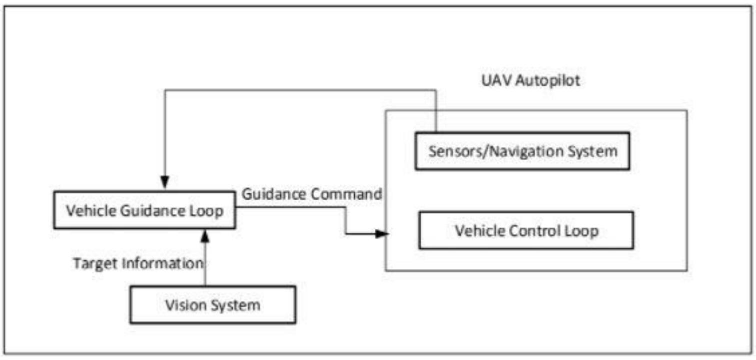

Figure 2.2: Block diagram of a guidance based landing system.

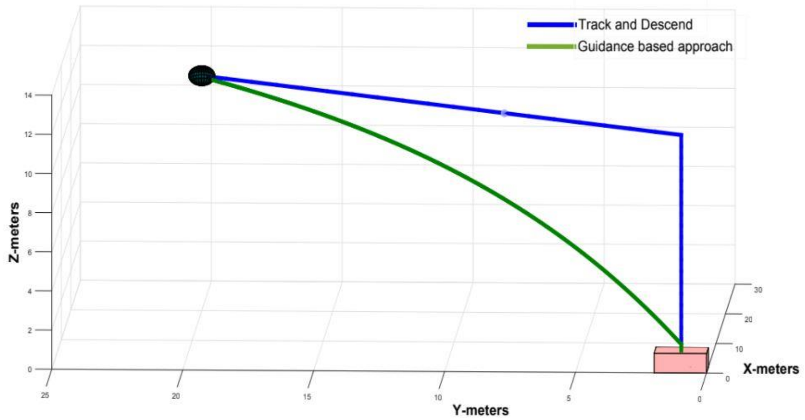

Figure 2.3: Trajectory of typical landing of a quadrotor and the proposed landing using pure pursuit guidance law.

We evaluate the efficacy of the guidance law extensively in simulation and validate the performance through outdoor field experiments on a 3DR IRIS quadrotor platform carrying a camera and an on-board computing unit. Since we are using several techniques for the landing, we will provide brief description of these approaches before using them. We will first describe basics of guidance laws, then we describe the target detection algorithm using the camera vision, followed by the novel log polynomial velocity controller and evaluation of the landing system in simulation and outdoor experiments.

2.1 Basics of Pure Pursuit (PP) guidance

In this section, we provide basics of 2D and 3D pure pursuit guidance laws for completeness and then use these guidance laws for landing in the subsequent sections.

2.1.1 2D Pure Pursuit (PP) Guidance

Consider a planar UAV-target engagement geometry as shown in Figure 2.4. The speed of the UAV and the target are Vu and Vt respectively. The notation χu, χt , ψ, and Rxy represent the UAV course angle, target course angle, line-of-sight (LOS) angle, and range separation respectively. The target is assumed to be non maneuvering, that is χt is constant. Using the engagement geometry in Figure 2.4, $\dot{R}$ xy and $\dot{\psi}$ are calculated as,

$$\dot{R}_{xy} = V_t \cos(\chi_t - \psi) - V_u \cos(\chi_u - \psi)$$

$$\dot{\psi} = (V_t \sin(\chi_t - \psi) - V_u \sin(\chi_u - \psi))/R_{xy}$$

The guidance command, denoted as a_{xy} is the lateral acceleration applied normal to the velocity vector.

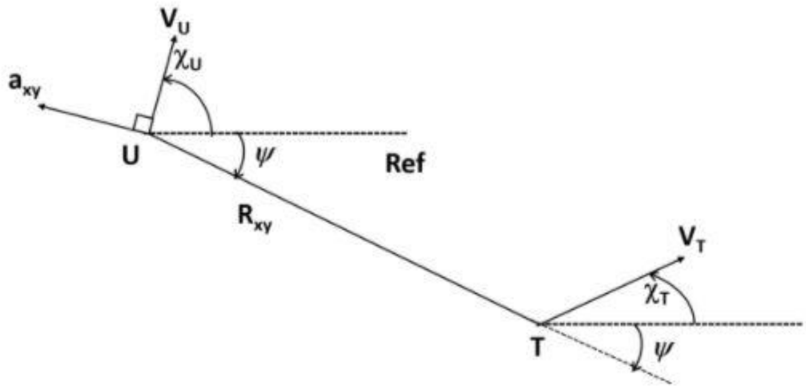

Figure 2.4: Planar engagement geometry of UAV-target

The guidance command is expressed as,

$$\dot{\chi}_u = a_{xy}/V_u.$$

Pure pursuit (PP) works on the principle, that if the tracking vehicle persistently points towards the target then it will ultimately intercept it [79]. In other words, PP aligns χ_u towards ψ. A practical implementation of the pure pursuit uses a feedback law as,

$$a_{xy} = -K_a(\chi_u - \psi),\ K_a > 0,$$

where K_a is the gain. However, for PP to be effective, it is important to maintain $\dot{\chi}_u = \dot{\psi}$, so that the vehicle can point towards the target at all times. Combining equation (2.3) and (2.4), the guidance command for simple pure pursuit is given as,

$$a_{xy} = V_u\dot{\psi} - K_a(\chi_u - \psi).$$

2.2 Landing pad detection using vision

Our focus is to design an autonomous landing controller; hence we select a target in the form of a red colored circle with known diameter. The selected landing pad pattern can be detected using blob detecting algorithm which is computationally cheap. The obtained RGB image was converted to HSV colour space due to its robustness to change in lighting conditions. Figure 2.6(a) shows the obtained image. Hue defines the dominant color of an area, saturation measures the colorfulness of an area in proportion to its brightness. The value is related to the color luminance. These parameters are calculated as follows,

$$H = \frac{\arccos(1/2((R-G)+(R-B))}{\sqrt{(R-G)^2+(R-B)(G-B)}},$$
$$S = 1 - 3\frac{\min(R,G,B)}{R+G+B},$$
$$V = \frac{R+G+B}{3}.$$

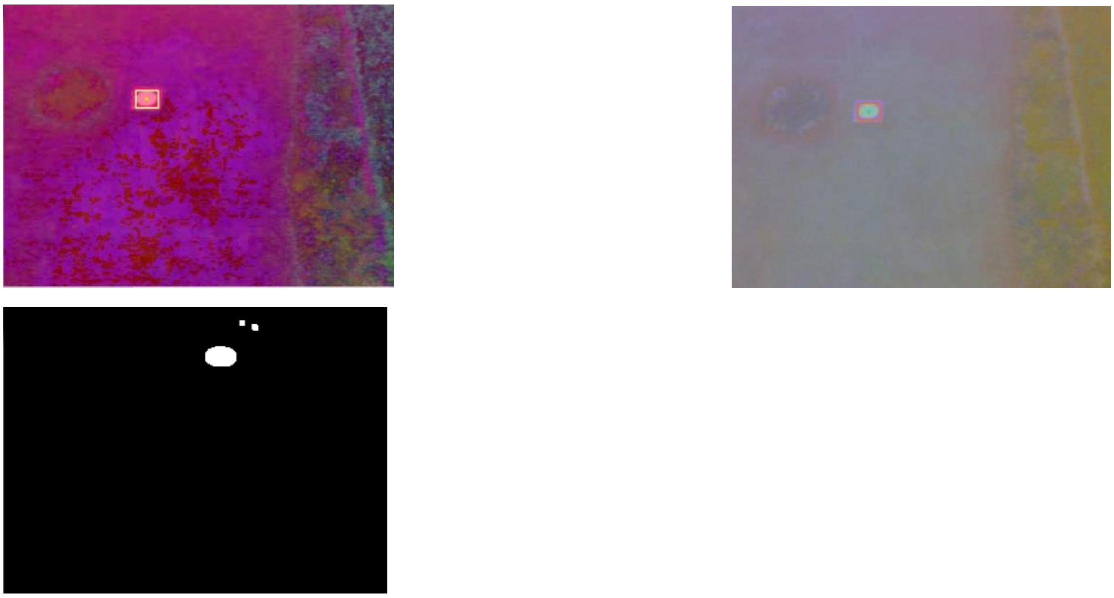

Figure 2.6: a) HSV color space mask b) YCrCb color space mask c) Combined mask after thresholding

Next, the original RGB image was converted to YCrCb color space. Figure 2.6(b) shows the obtained image. In this space, color is represented by luma, constructed as a weighted sum of RGB values, and two color difference values Cr and Cb that are formed by subtracting luma from RGB red and blue components. The conversion equations are given as,

$Y = KrR + KgG + KbB,$

$Cr = R - Y,$

$Cb = B - Y,$

where Kr, Kg, and Kb are the tuning parameters associated with the RGB colors. The union of the two color space masks was taken and morphological operations were applied to remove the noise, while preserving the mask boundaries. Erosion was performed using a 8 x 8 rectangular kernel, followed by dilation using a 3 x 3 rectangular kernel. Figure 2.6(c) shows the obtained mask with multiple contours. The target is detected by extracting the largest contour in the scene.

2.2.1 Target state estimation using Kalman Filter

During the landing process, the target may be partially or fully occluded or may move out of the field of view. Hence, we use Kalman Filter (KF) to estimate the target parameters, which is robust to environmental changes.

The detection algorithm determines the x and y centroid pixel coordinates of the target, which is given as the input to the KF. The target is modeled in discrete time as,

$X_t(n) = F_t X_t(n-1) + w(n),$

where, $w(n)$ is the random process noise and the subscript n denotes the current time and $n-1$ denotes the previous time instant. X_t is the state vector comprising of target characteristics: centroid pixel coordinates (x_t, y_t), rate of change of pixel coordinate positions ($\dot{x}_t$,$\dot{y}_t$), dimensions of the detected target contour (*width* (w_c), *height* (h_c)). F_t is the state-transition model that is applied to the previous state $X_t(n-1)$. We measure the position of the target using target detection (using vision). Measurement at time n is given by,

$Z_t(n) = H_t X_t(n) + v(n),$ (2.31)

where, H_t is the measurement model and $v(n)$ is the random measurement noise in landing pad parameter measurements. Both process and measurement noise are modeled as white, zero mean Gaussian noise with covariance matrices Q and R respectively. The formulation of the Kalman Filter is given as follows,

$$\begin{bmatrix} x_t(n) \\ y_t(n) \\ \dot{x}_t(n) \\ \dot{y}_t(n) \\ w_{c_n} \\ h_{c_n} \end{bmatrix} \begin{bmatrix} 1 & 0 & dt & 0 & 0 & 0 \\ 0 & 1 & 0 & dt & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_t(n-1) \\ y_t(n-1) \\ \dot{x}_t(n-1) \\ \dot{y}_t(n-1) \\ w_t c_{n-1} \\ h_t c_{n-1} \end{bmatrix}.$$

The prediction step of the Kalman Filter is given by, The prediction step of the Kalman Filter is given by,

$$\begin{aligned} \hat{X}_t^-(n) &= F_t \hat{X}_t(n-1), \\ P_t^-(n) &= F_t P_t(n-1) F_t' + Q, \end{aligned}$$

where Xˆ −t(n) is the predicted state estimate. The update step of the Kalman Filter is given by,

$$\begin{aligned} K_t(n) &= P_t^-(n) H_t' \left(H_t P_t^-(n) H' + R\right)^{-1}, \\ P_t(n) &= \left(I - K_t(n) H_t\right) P_t^-(n), \\ \hat{X}_t(n) &= \hat{X}_t^-(n) + K_t(n) \left(Z_t(n) - H_t \hat{X}_t^-(n)\right). \end{aligned}$$

In the above equations, superscript ^{0} denotes the matrix transpose. $K_t$is the Kalman gain, $P_t$is the predicted error covariance and Q and R are the covariance matrices for process and measurement noise respectively. The estimated parameters of the target are given as input to the guidance loop.

Chapter 3

METHODOLOGY

3.1 Introduction

A Quadcopter, also called a Quadrotor helicopter, is a multirotor helicopter that is lifted and propelled by four rotors. Unlike most helicopters, Quadcopters use 2 sets of identical fixed pitched propellers, 1st set consists of 2 clockwise and 2nd set consists of 2 counter-clockwise. These use variation of Revolutions Per Minute to control lift and torque. To maintain balance the Quadcopter must be continuously taking measurements from the sensors i.e. Gyroscope and Accelerometer, and making adjustments to the speed of each rotor to keep the body level. These adjustments are done by a sophisticated control system like Arducopter, Pixhawk on the Quadcopter in order to stay perfectly balanced. A Quadcopter has four controllable degrees of freedom: Yaw, Roll, Pitch, and Altitude. Each degree of freedom can be controlled by adjusting the thrusts of each rotor

Fig 3.1 Basic quad copter

Quadcopters are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of rotors. Quadcopter configurations were seen as possible solutions to some of the problems in vertical flight. Mostly there are two types of Quadcopter configurations. First configuration is plus '+' and the second configuration is cross. Quadcopters use an electronic control system and electronic sensors like Electronic Speed Controllers to stabilize the aircraft. With their small size, these Quadcopters can be flown indoors as well as outdoors. The use of four rotors allows each individual rotor to have a smaller diameter than the equivalent helicopter rotor. Due to this every motor has to carry 1/4th of the weight of Quadcopter as opposed to Helicopter where the single motor carries the whole weight. This increases the efficiency and life of motors. Some small-scale Quadcopters have frames that enclose the rotors, permitting flights through more challenging environments, with lower risk of damaging the vehicle or its surroundings.

COMPONENT DESCRIPTION:

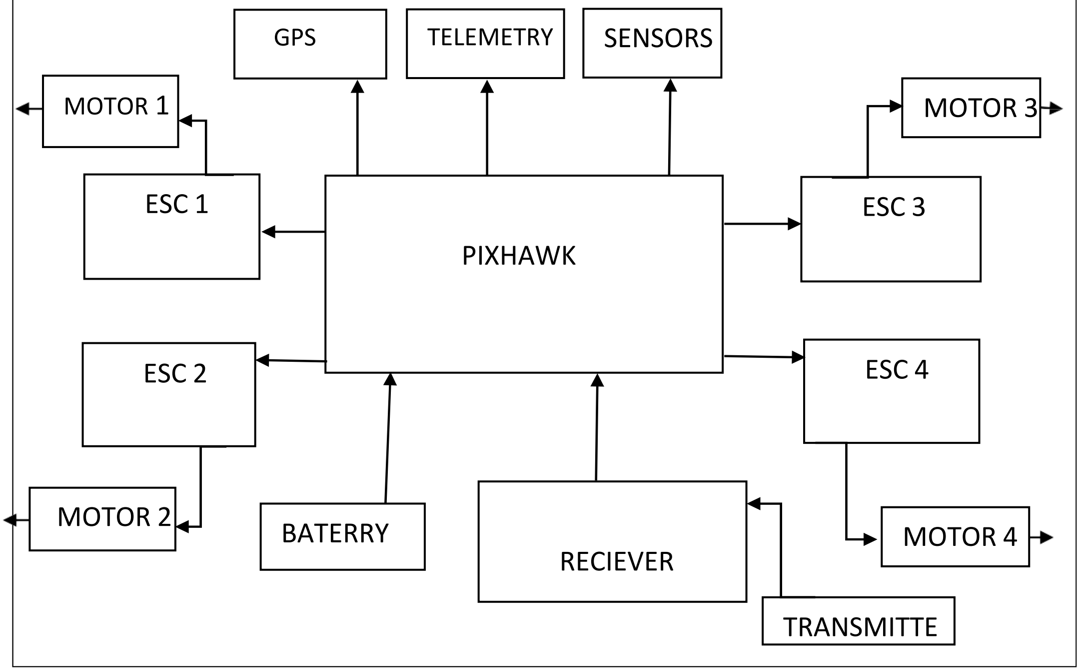

Fig 3.2 Quadcopter model block diagram

Frame: There are two possibilities when it comes to a frame for your drone. You can make it yourself or buy it in an online store, and for a wide choice of high-quality frames, we suggest checking out our article about best drone frames. If you decide to build it yourself, the project is not that difficult, but you'll need some engineering knowledge and knowledge of the materials you are going to use. For instance, you can use metal (something light), plastic, or even wood slats. If you opt for a wooden frame, you'll need a wood board which is about 2.5 cm thick.

Motor: Motors are a bit similar to normal DC motors in the way that coils and magnets are used to drive the shaft. They are two kinds of motors brushed motors and brushless motors. As the motors do not have a brush on the shaft which takes care of switching the power direction in the coils, and so it is called as brushless motors. Instead, the brushless motors have three coils on the inner of the motor, which is fixed to the mounting. For a small-scale Quadcopter, the DC Brushless motor used is of 1000 KV rating. It operates at 7.4-14.8 volts. A brushed DC motor has permanent magnets on the outside of its structure, with a spinning armature on the inside.

ESC: The brushless motors are multi-phased, normally 3 phases, so direct supply of DC power will not turn the motors on. That is where the Electronic Speed Controllers comes into play. The ESC generating three high frequency signals with different but controllable phases continually to keep the motor turning. The ESC is also able to source a lot of current as the motors can draw a lot of power.

Propellers: On each of the brushless motors there are mounted a propeller. The 4 propellers are actually not identical the motor torque of and the law of physics will make the Quadcopter spin around itself if all the propellers were rotating the same way, without any chance of stabilizing it. The larger diameter and pitch the more thrust the propeller can generate. It also requires more power to drive it, but it will be able to lift more weight.

Flight Controller: The Flight Control Board is the "commander of operations". It controls the accelerometer and gyroscopes, which control how fast each motor spins. The flight controller is Pixhawk. Pixhawk is an independent open-hardware project that aims to provide the standard for readily-available, high-quality and low-costautopilot hardware designs for the academic, hobby and developer communities. Pixhawk supports multiple flight stacks: PX4 and ArduPilot. PX4 is an open source autopilot system oriented toward inexpensive autonomous aircraft. Low cost and availability enable hobbyist use in small remotely piloted aircraft. The projectstarted in 2009 and is being further developed and used at Computer Vision and Geometry Lab of ETH Zurich and supported by the Autonomous Systems Lab and the Automatic Control Laboratory. Several vendors are currently producing PX4 autopilots and accessories. An autopilot allows a remotely piloted aircraft to be flown out of sight. All hardware and software is open source and freely available to anyone under a BSD license. Free software autopilots provide more flexible hardware and software. Users can modify the autopilot based on their own special requirements.

Fig 3.3 Flight Controller

RASPBERRY Pi: The Raspberry Pi is a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. The Raspberry Pi primarily uses Linux kernel based operating systems. It is used for providing an IDE for writing Python scripts and hence generating inputs to be fed to the Flight Controller.

It is a capable little device that enables people of all ages to explore computing, and to learn how to programin languages like Scratch and Python. It is capable of doing everything you would expect a desktop computerto do, from browsing the internet and playing high-definition video, to making spreadsheets, word-processing, and playing games. The raspberry Pi has the ability to interact with the outside world, and has been used in a wide array of digital maker projects, from music machines and parent detectors to weatherstations and tweeting birdhouses with infra-red cameras

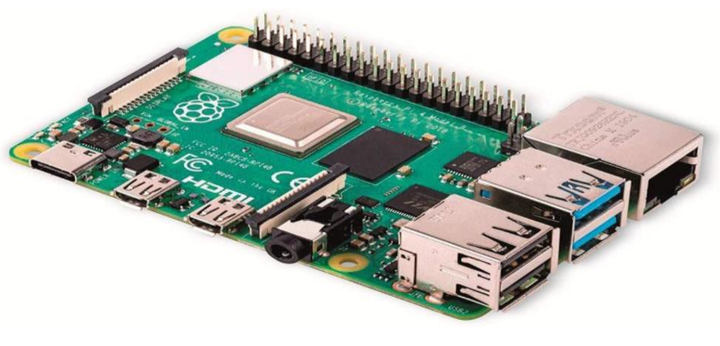

Fig 3.4 On Board Computer

Methodolgy:

3.1.1 Working of Drones:

A frame / drone chassis is built first before anything else is done. The choice of motorsand other components specify the type of frame we will use. The frame consideredhere is F450 frame of X or + shape. Motors are set first on the frame.

Vertical Motion: Drones use rotors for propulsion and control. It is same as a rotor of a fan, because they working is the same. Spinning blades push air down. Of course, allforces come in pairs, which means that as the rotor pushes down on the air, the air pushes up on the rotor. This is the basic idea behind lift, which comes down to controlling the upward and downward force. The faster the rotors spin, the greater the lift, and vice-versa.

Now, a drone can do three things in the vertical plane: hover, climb, or descend. To hover, the net thrust of the four rotors pushing the drone up must be equal to the gravitational force pulling it down. Moving up, which pilots call as climbing, isjust increasing the thrust /speed of the four rotors so that there is a non-zero upward force that is greater than the weight. After that, with decrease the thrust a little bit—butthere are now three forces on the drone: weight, thrust, and air drag. So, it still needs for the thrusters to be greater than for just a hover. Descending requires doing the exact opposite: Simply decrease the rotor thrust /speed so the net force is downward.

Turning /Rotating:

In this configuration, the red rotors are rotating counter clockwise and the green ones are rotating clockwise. With the two sets of rotors rotating in opposite directions, the total angular momentum is zero. Angular momentum is a lot like linear momentum, and is calculated by multiplying the angular velocity by the moment of inertia. The moment of inertia is similar to the mass, except it deals with rotation. The angular momentum depends on how fast the rotors spin. If there is no torque on the drone, thenthe total angular momentum must remain constant, zero in this case. The red counter clockwise rotors have a positive angular momentum and the green clockwise rotors have a negative angular momentum. Let’s assign each rotor a value of +2, +2, -2, -2, which adds up to zero.

Let's say, want to rotate the drone to the right. Suppose the decrease in angular velocity of rotor 1 such that now it has an angular momentum of -1 instead of -2. If nothing else happened, the total angular momentum of the drone would now be +1. So, the drone rotates clockwise so that the body of the drone has an angular momentum of -1. Decreasing the spin of rotor 1 indeed cause the drone to rotate, but it also decreased the thrust from rotor 1. Now the net upward force does not equal the gravitational force, and the drone descends. Thus, the thrust forces aren't balanced, so the drone tips downward in the direction of rotor 1.

To rotate the drone, decreasing the spin of rotor 1 and 3 and increasing the spin for rotors 2 and 4. The angular momentum of the rotors still doesn't add up to zero, so the drone body must rotate. But the total force remains equal to the gravitational force and the drone continues to hover. Since the lower thrust rotors are diagonally oppositefrom each other, the drone can still stay balanced.

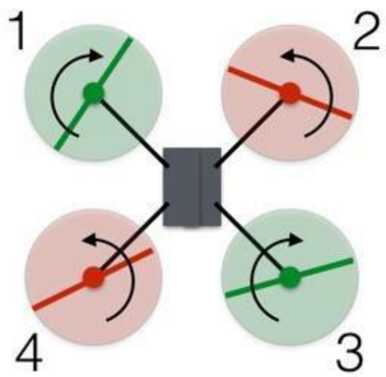

Fig 3.5 Motor Directions on Frame

Forwards and Sideways: The difference between moving forward or backward is none, because the drone is symmetrical. The same holds true for side-to-side motion. Basically, a quadcopter drone is like a car where every side is the front. This means that explaining how to move forward also explains how to move back or to either side.

There are four main quadcopter controls: Roll, Pitch, Yaw, Throttle

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter the results are discussed and analyzed. In this we discussed the method of how a quadcopter is used for delivery purpose from one point to other point. We used a simulator called gazebo to show the movement of a quadcopter for delivery from one point to other. The gazebo simulator helps in knowing the exact working of autonomous robot by creating the real time environment. This is why most of autonomous robots are tested in the simulators before testing it in real world environment so that they don't cause any damage. The gazebo environment includes many options in it like, we can add the sensors, obstacles and test the model.

4.1.1 Gazebo

Robot simulation is an essential tool in every roboticist's toolbox. A well-designed simulator makes it possible to rapidly test algorithms, design robots, perform regression testing, and train AI system using realistic scenarios. Gazebo offers the ability to accurately and efficiently simulate populations of robots in complex indoor and outdoor environments

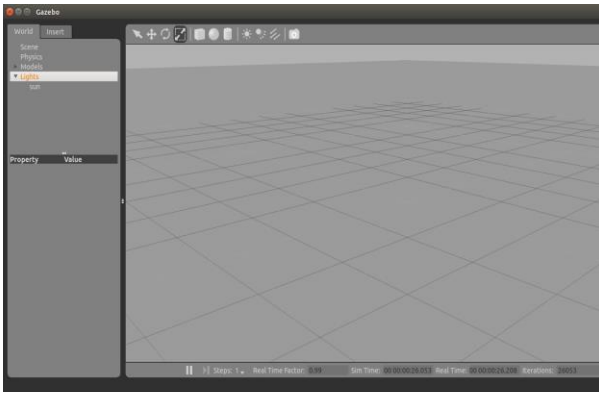

Fig 4.1 Gazebo simulator

It is an open source 3D robotics simulator. It helps in simulating the model near to the real world. It providesrealistic rendering of environments including high-quality lighting, shadows, and textures. Prototypes of theactual model are simulated in gazebo with help of ROS nodes and then the model is allowed to perform therequired action to be performed in real world using the code. Simulation output helps to understand the working process of a robot perfectly. It can model sensors that "see" the simulated environment, such as laser range finders, cameras including wide-angle, Kinect style sensors, etc. It is flexible to use different sensors with the gazebo and helps in understanding their performance.

ANALYSIS:

4.1.2 Simulator output explaination

The output is explained using a simulator which is gazebo. The environment in gazebo can set up as the real world. Here pose represents position and orientation combined. The below shown outputs are virtual outputs which works same as in real world environment.

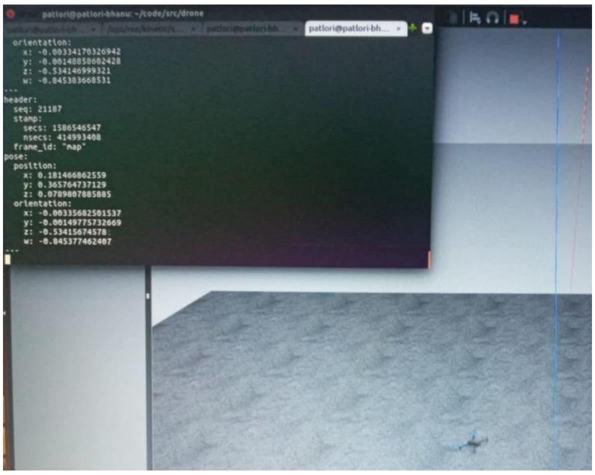

Fig. 4.2 Initial pose of Quadcopter

Initially the quadcopter is at the origin with respect to its global and local frame. From the above fig 4.3 the initial position of the quadcopter can be noted. The position is x =0, y = 0, z = 0.

Now the process of autonomous navigation starts with arming the quadcopter using RC. The connections are established between the flight controller and OBC such that the working mode of drone changes from manual to autonomous. Now the code to work as an autonomous delivery drone executes. The delivery is made to be done between a point to point. In fig.4.4, now the location of the drone after executing the code is at the starting location or at the pickup point of the delivery process. Here the object to be delivered should be manually attached to the drone.

The position of coordinates is x = 0, y = 0, z = 2. This means that the drone is at a height of altitude 2m from the ground, this can be changed as per the requirement of the customer and the developer.

At the pick-up position we can place the packet on the quadcopter which needs to be delivered. The packet which is placed can be anything based upon the requirement andthe purpose of the delivery. The amount or weight of the packet to be delivered depends upon quadcopter working specifications like battery capacity, payload etc.

delivered. The packet which is placed can be anything based upon the requirement andthe purpose of the delivery. The amount or weight of the packet to be delivered depends upon quadcopter working specifications like battery capacity, payload etc.

4.2 APPLICATION:

The major applications include in the fields of robotics etc.

- **Pick and Place:** With the help of End effector integrated in the Quadcopter, picking up of parts and components depending on the lift capacity of Quadcopter is possible.
- **Storage and Retrieval:** The Multipurpose end effector is capable of holding parts, this can be implied in Storage of components and retrieval of them in warehouses and inventories.

- **Remote Surveillance:** With the integrated FPV camera, the Quadcopter can be sent for stealth infiltration of enemy bases. Advanced versions of camera include Heat Vision, Thermal Cameras and Night Vision to carry out operations in various environmental conditions.

- **Disaster Relief and Rescue:** In natural calamities or any post disasters events, where human help cannot be quickly accessed, The Quadcopter can be sent for rescuing the victims and providing relief.

- **Dispersing Pesticides:** The Quadcopter can be mounted with a Pesticide dispersing canister which will spray it evenly across the farm fields.

- **Elevated Spray Painting:** The Quadcopter can be mounted with a miniature spray-painting device and can be used for painting High rise buildings.

- **Aerial Photography:** The Quadcopter can be commercially used for Aerial view of public events, sports, concerts, etc.

- **Code Enforcement and Inspection:** Building and bridge inspection without placing a person on a ladder or other potentially dangerous situation

- **Police Assistance:** The Quadcopter can be used to assist law enforcers in crowd control, mob management and surveillance.

- **Search and Rescue:** When a person goes missing in deserted locations like mountains, dense forests, artic regions, deserts, The Quadcopter will be able to locate them and intimate their location to the rescue team.

Chapter 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION:

This deals with a systematic process of online delivery with an autonomous Quadcopter. Quadcopter will deliver the parcel to the customer which will reduce both time and manpower using for delivery. This process will be continued to optimize the cost of delivering products through QC so that people can use these systems more easily. The project could go in a variety of directions since the platform seems to be as flexible as we initially intended. This flexibility allows changing the functions it performs and also allows integration of any technology that would prove to be useful. The project could be enhanced as per the requirements, resources and the budget. More no of Sensors could be mounted on it thus providing more unique features. The high definitions cameras could also be installed in it. This project has clearly demonstrated the goals of proving that small scale UAVs are useful across a broad range of applications.

5.2 FUTURE SCOPE:

This can be applied for surveillance integrating FPV camera, the Quadcopter can be sent for stealth infiltration of enemy bases. Advanced versions of camera include Heat Vision, Thermal Cameras and Night Vision to carry out operations in various environmental conditions.

By tracking the movement of UAV or an autonomous quad copter we can use them in remote areas for supply of any needs which cannot be done by man power. One such example is a tethered drone system, which provides secure communications with continuous flight, fit to serve any purpose and environment.

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