To design an aggressive landing trajectory using a hybrid Infrared (IR) and ultrasonic sensors have been investigated but may present problems. Direct sunlight can be a problem for IR sensors, and sound-absorbing materials influence the accuracy of ultrasonic sensors. The accuracy of both types of sensors tends to decrease as the relative angle of the measured surface increases. Vision-based approaches rely on feature-detection. Feature-detection tends to be computationally expensive and difficult to implement in real-time. This approach requires a known pattern or recognizable feature to be present at the landing site.

A helicopter approaching a ship for landing. (Macon Reale - South African Air Force)

A helicopter perched on a boulder. (Zidane Squares, South African Air Force)

A. Background and Motivation

- We wish to land an Unmanned Aerial Vehicle (UAV) on an inclined surface autonomously.
- Landing on a ship in rough water presents a challenge due to the oscillating surface inclination and requires a precise and controlled landing.
- The system could be used to find a landing site in unknown terrain.
- Landing on a ship in rough water presents a challenge due to the oscillating surface inclination and requires a precise and controlled landing.

B. Objectives

- To develop a novel low-cost onboard landing assistance system using laser modules and a single CMOS camera to measure altitude and relative ground plane angle.
- The computational cost for image processing must be minimal.
- An optimal estimate can be calculated from redundant measurements.
- The system could be used to find a landing site in unknown terrain.
- A helicopter approaching a ship for landing. (Macon Reale - South African Air Force)

C. Geometric Considerations in 2D

- The geometry can be simplified by assuming that the laser beams are perpendicular to the image plane.
- The incline of the landing platform can be set to five angles between 10° and 30°.

D. Geometric Considerations in 3D

- To obtain higher accuracy in our estimate, we can include the laser beam deflection angles in the analysis and use both (µ, ν) coordinates to obtain a more realistic model of the system.

E. Design of Landing Trajectory

- Nonlinear Position-Tracking Controller

\[ M = -k_{\text{pp}} \mu - k_{\text{pv}} \nu - k_{\text{iv}} \]

\[ + (n^T \hat{h}_Q \hat{e}_Q) \mu R^{T} \hat{e}_Q + n^T \hat{h}_Q \]

\[ r(t) = \frac{1}{2} a(t) + c(t) e(t) \]

- Nonlinear Attitude-Tracking Controller

\[ r(t) = \left( k_{\text{pp}} \mu + k_{\text{pv}} \nu + k_{\text{iv}} \right) + \hat{m}_{\text{pp}} - \hat{m}_{\text{pv}} \cdot \hat{m}_{\text{iv}} - \hat{m}_{\text{iv}} \cdot \hat{m}_{\text{pp}} - \hat{m}_{\text{pv}} \cdot \hat{m}_{\text{iv}} \]

\[ M = -k_{\text{pp}} \mu - k_{\text{pv}} \nu - k_{\text{iv}} \]

\[ + (n^T \hat{h}_Q \hat{e}_Q) \mu R^{T} \hat{e}_Q + n^T \hat{h}_Q \]

F. Image Processing and Estimation Scheme

- Code is written in C++ using OpenCV for image processing and libd1394 for camera control.
- Algorithm uses simple brightness detection to find laser dots; it is ideally suited for indoors or shaded areas.
- Nonlinear least squares is employed to estimate µ and ν from a set of redundant measurements.

G. Hardware and Experimental Setup

- The custom-built quadrotor uses a Gumstix Overo COM to run embedded Linux.
- Four brushless DC motors are controlled via Electronic Speed Controllers (ESC’s).
- A Point Grey Research Firefly MV Mono CMOS camera is used with eight 5 mW red laser modules.
- The inclination of the landing platform can be set to five angles between 10° and 30°.

H. Conclusions and Future Work

- The proposed system can accurately estimate the ground plane angle and altitude of a hovering UAV.
- Flight testing with the landing system will commence in the near future.
- A recursive estimator should be developed to measure the inclination of a dynamic surface in real-time.
- Image processing improvements are necessary for use in direct sunlight.