# Visual fiducial-based precision landing system

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## Introduction

This project presents the development of a visual fiducial-based precision landing system for Unmanned Aerial Vehicles (UAV) with limited computing resources. Apriltags, a visual fiducial system was used to estimate the pose of the landing target from the image stream, captured by a single downward-facing camera. A specialized algorithm was designed to output control commands to perform a smooth, precision landing based on the pose estimation. This enhance drone's landing ability where GPS is unreliable or unavailable, such as indoor environment or outdoors environment where tall buildings block signal.

## Methods

The UAV has two computing platforms.

**1. Flight controller unit (FCU) and PX4**

The FCU runs the PX4 firmware on a real-time operating system (RTOS) to process essential sensor data from the IMU, GPS, and barometer. PX4 handles state estimation, flight control, and generates low-level control commands (e.g., motor outputs) in real-time to ensure stable and responsive flight operations.

**2. Companion computer and ROS2**

A Raspberry Pi 4 serves as a companion computer to the FCU. It runs ROS2 nodes to handle more complicated senor and processes a more complex algorithm to provide a higher-level command to the FCU. Micro XRCE-DDS bridge is the middleware for communication between FCU and companion computers. It was proven to have lower latency and significantly lower memory and CPU usage compared to MAVROS/MAVLink, the traditional way of communication.

Figure 1: System architecture

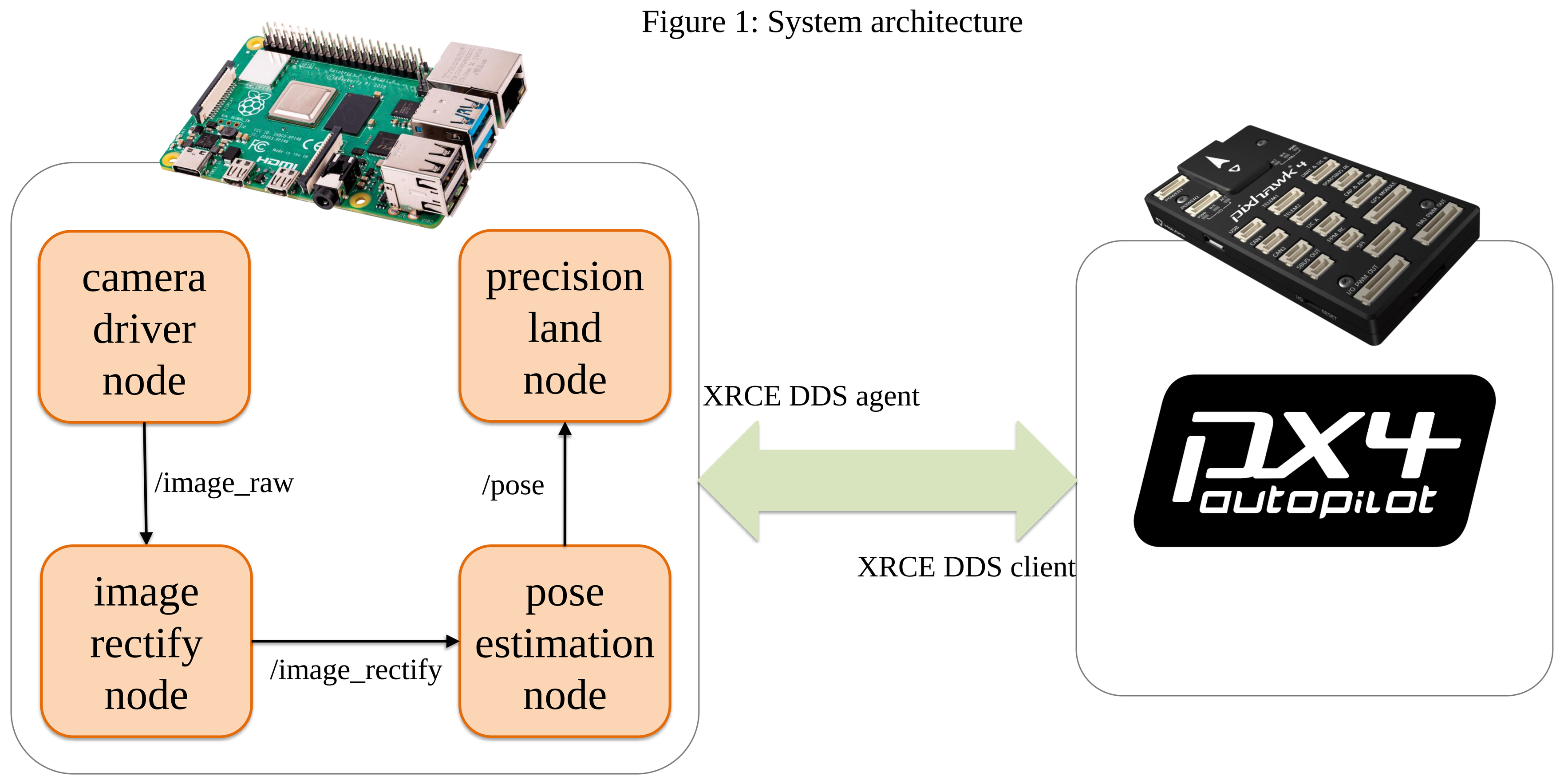
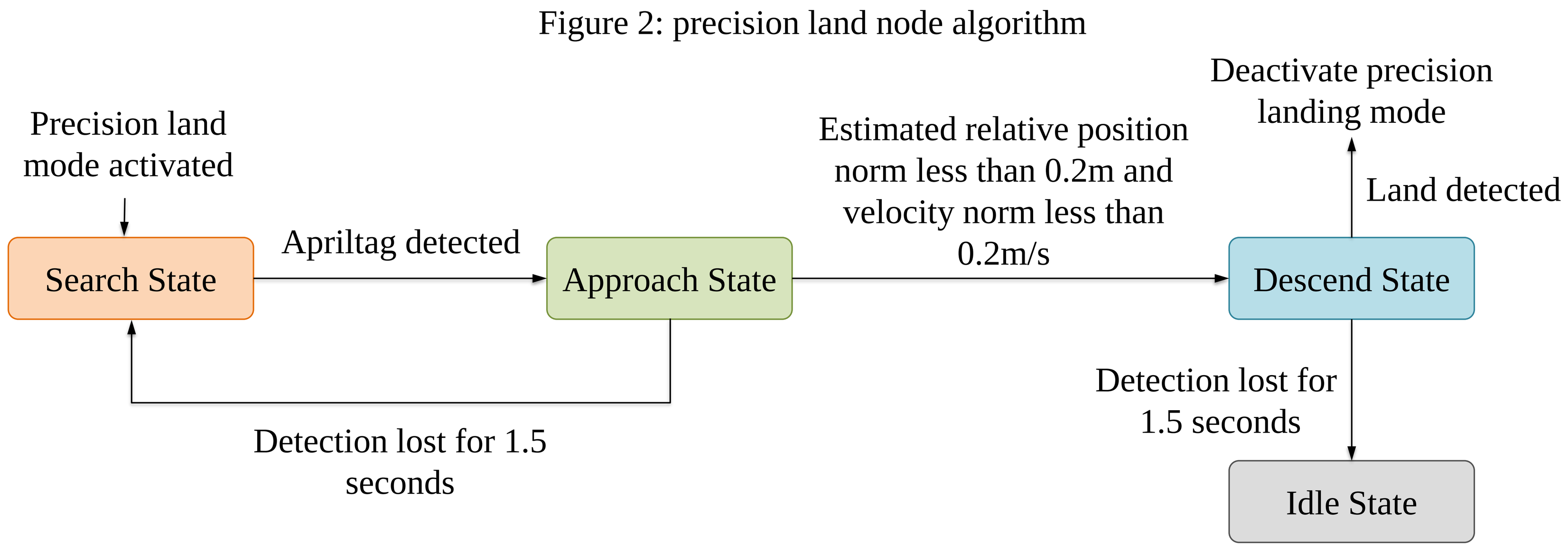



Figure 2: precision land node algorithm




In descend state, a PID controller was implemented to generate smooth control over the horizontal velocity.

## Experiments

The experiment was conducted in a Software-in-the-Loop (SITL) simulation environment within Gazebo.

1. fiducial marker for landing: Apriltag tagStandard41h12 no.0
2. marker size: 17cm by 17cm
3. camera resolution: 640×480
4. camera FOV: 0.866 rad (≈49.6 degree)
5. camera FPS: 30hz

Figure 3: tagStandard41h12 no.0

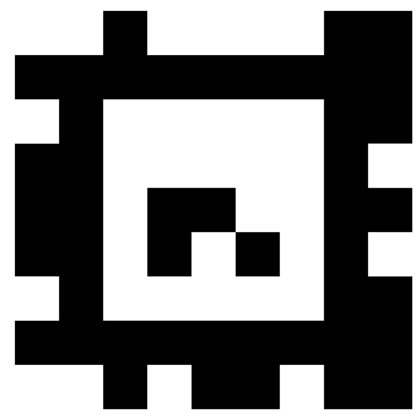


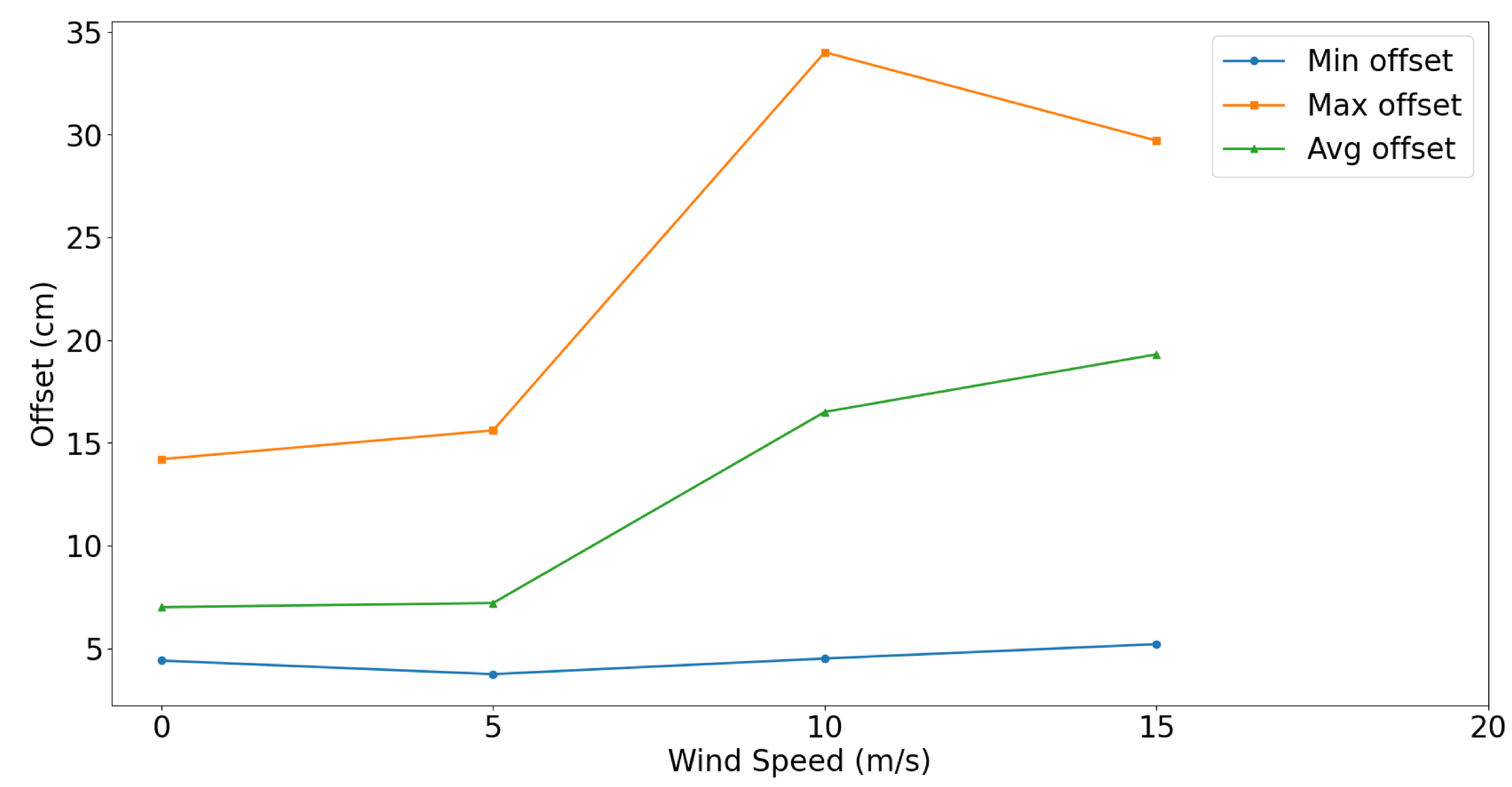
Figure 4: drone in the Gazebo simulation environment

## Result

Table 1: Metrices measured in no-wind environment
(offset was measured from the center of the tag)

| AVG_OFFSET | MIN_OFFSET | MAX_OFFSET | AVG_LAND_TIME | NUM_TESTS |
|---|---|---|---|---|
| 7.0 cm | 4.4 cm | 14.2 cm | 6.7 sec | 20 |

Figure 5: Comparison between environments with different wind speed (each conducted 10 times)




The system is capable of consistent precision landing where there is no wind and with the presence of mild wind (around five m/s). The maximum offset is only around 15 cm. When the wind speed exceeds ten m/s, it was observed that it maintains its horizontal position quite well during the approach state and most of the time in the descending state until the camera gets too close to the marker and loses track of it. Lastly, although we could not assess the system under real-world scenarios due to a lack of compatible FCU, verifying that the system works is crucial.

## Conclusion

Overall, this project provides a robust solution to precision landing for drones with limited computing resources and basic sensors and demonstrates the potential of ROS 2 integrated into a UAV system. With the clean and easily extendable architecture ROS2 offers, as well as low latency and computation-efficient communication provided by Micro XRCE DDS, Some more advanced algorithms could be performed to achieve even more complex tasks in the future.