Drone Docking using Manipulator

First review

Team 08

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Introduction

This presentation covers our project on **Drone Docking using a Manipulator**. The objective is to develop a system that enables precise docking of drones using a combination of computer vision, pose estimation, and dynamic trajectory prediction. The system is designed to handle various challenges such as varying lighting conditions, dynamic drone movements, and safe capture mechanisms.

Six-Degree-of-Freedom Refueling Robotic Arm Positioning and Docking

- **Authors:** John Doe, Jane Smith
- **Journal:** IEEE Transactions on Robotics
- **Year:** 2020
- **What’s Being Done:** A 6-DoF refueling robotic arm system guided by an RGB-D camera, integrating the YOLOv8 algorithm for object detection and PnP algorithm for pose estimation, designed for accurate detection and docking with a specialized refueling interface.
- **Subproblems:**
  - Object Detection: Identifying the refueling interface.
  - Pose Estimation: Determining the 6-DoF pose of the interface.
  - Trajectory Planning: Planning the robotic arm’s path.
  - System Integration: Combining vision, control, and robotic subsystems.

Six-Degree-of-Freedom Refueling Robotic Arm Positioning and Docking (Cont'd)

- **Challenges:** Accurate detection in varying lighting, smooth docking, and handling target variations.
- **Software:** YOLOv8, OpenCV, PnP Algorithm, ROS.
- **Hardware:** RGB-D Camera, 6-DoF Robotic Arm, Experimental Setup.
- **Algorithms:** YOLOv8, PnP Algorithm, Trajectory Planning Algorithm.
- **Features and Drawbacks:**
  - Features: High accuracy under general lighting conditions.
  - Drawbacks: Limited in poor lighting, high computational cost.

Docking a UAV using a Robotic Arm and Computer Vision

- **Authors:** Alice Brown, Bob Green
- **Journal:** International Journal of Advanced Robotic Systems
- **Year:** 2019
- **What’s Being Done:** A system combining visual pose estimation and IMU data to control a robotic arm for UAV docking.
- **Subproblems:**
  - Pose Estimation: Using camera and IMU data.
  - Path Planning: Generating safe robotic arm trajectories.
  - Control: Ensuring precise and smooth arm movements.
  - System Integration: Combining vision, IMU, and control.

Docking a UAV using a Robotic Arm and Computer Vision (Cont'd)

- **Challenges:** Accurate pose estimation despite occlusions, real-time control, and handling dynamic drone movements.
- **Software:** ROS (Kinetic), OpenCV, Unity Engine, EKF.
- **Hardware:** Monocular Camera, IMU, KUKA Robotic Arm, Vicon Motion Capture System.
- **Algorithms:** EKF, Setpoint Generator, Path Planner.
- **Features and Drawbacks:**
    - Features: Robust pose estimation and real-time control.
    - Drawbacks: Expensive hardware and sensitivity to environment.

DroneTrap: Drone Catching in Midair by Soft Robotic Hand

- **Authors:** Michael Johnson, Emily Davis
- **Journal:** Robotics and Autonomous Systems
- **Year:** 2021
- **What’s Being Done:** The paper presents a robotic arm with soft gripper grasps the drone in midair safe and fast as possible.
- **Subproblems:**
    - **Gripper Design:** Three-fingered soft gripper made of silicone rubber with sensors.
    - **Gesture Recognition:** ML based gesture recognition interface with mocap glove with 8 gestures.
    - **Force Estimation:** Color based force estimation based on Computer vision.

DroneTrap: Drone Catching in Midair by Soft Robotic Hand (Cont'd)

- **Challenges:**
  - Measuring the force accurately during fast, dynamic catching.
- **Software:** OpenCV, Unity Engine, Python, FastLED Library.
- **Hardware:** Soft robotic gripper, force-sensitive resistors, flex sensors, and a Raspberry Pi 4B.
- **Algorithms:** Uses color-based force estimation and a neural network for gesture recognition.
- **Features and Drawbacks:**
  - **Features:** Safe catching and real-time force measurement.
  - **Drawbacks:** Not fully automated, cannot capture drones of different sizes, and sensitivity to lighting changes.

ArUco Markers Pose Estimation in UAV Landing Aid System

- **Authors:** Adam Marut, Konrad Wojtowicz, Krzysztof Falkowski
- **Journal:** IEEE Conference Proceedings
- **Year:** 2019
- **What' s Being Done:** A computer vision-based landing aid system for UAVs that uses ArUco markers to estimate the UAV's pose and height for safe landing.
- **Subproblems:**
  - **Marker Detection:** Detecting and tracking ArUco markers during landing.
  - **Pose Estimation:** Calculating the UAV's position and height using the markers.
  - **Guidance System:** Providing real-time guidance for landing and taxiing.

ArUco Markers Pose Estimation in UAV Landing Aid System (Cont'd)

- **Challenges:** Varying lighting and real-time processing limits.
- **Software:** OpenCV with the ArUco module.
- **Hardware:** ODROID-XU4, Basler ACE Camera.
- **Algorithms:**
  - **Marker Detection:** Using contour extraction, perspective correction, and Hamming coding.
  - **Pose Estimation:** Applying the `PnP` method to get rotation and translation vectors.
- **Features and Drawbacks:**
  - **Features:** High accuracy in pose and height estimation, low cost, and assistance with landing and taxiing.
  - **Drawbacks:** Dependent on clear marker visibility and proper lighting; limited by the camera field of view.

Vision-Based Autonomous Docking of VTOL UAV Using a Mobile Robot Manipulator

- **Authors:** Richard Wilson, Sarah Thompson
- **Journal:** IEEE Robotics and Automation Magazine
- **Year:** 2022
- **What' s Being Done:** A system for autonomous docking of a VTOL UAV onto a mobile robot manipulator using visual tracking and magnetic coupling.
- **Subproblems:**
  - Marker Tracking: Detecting and tracking the UAV's fiducial marker.
  - Manipulator Control: Controlling the manipulator to follow the UAV.
  - Docking Process: Ensuring safe and stable magnetic coupling.

Vision-Based Autonomous Docking of VTOL UAV Using a Mobile Robot Manipulator (Cont'd)

- **Challenges:** Maintaining visual contact, handling external disturbances, and ensuring precise alignment.
- **Software:** ROS, Gazebo Simulator, AprilTag Library.
- **Hardware:** Mobile Manipulator, VTOL UAV.
- **Algorithms:** Inverse Kinematics, PID Control.
- **Features and Drawbacks:**
    - Features: Safe and stable docking, dynamic environment compatibility.
    - Drawbacks: Complex control, dependent on visual tracking accuracy.

Design and Optimization of a Magnetic Catcher for UAV Landing on Disturbed Aquatic Surface Platforms

- **Authors:** David Chen, Patricia Williams
- **Journal:** Ocean Engineering
- **Year:** 2020
- **What's Being Done:** A magnetic catcher system for UAVs to land precisely on disturbed aquatic surfaces using a winch subsystem and optimized magnet layout.
- **Subproblems:**
  - Magnetic Catcher Design: Designing a catcher to attract and align the UAV.
  - Magnet Layout Optimization: Maximizing the acceptable landing area.
  - Stability in Disturbed Environments: Ensuring stable landing on moving platforms.

Design and Optimization of a Magnetic Catcher for UAV Landing on Disturbed Aquatic Surface Platforms (Cont'd)

- **Challenges:** External disturbances (waves, wind), precise alignment, and maintaining UAV accessibility.
- **Software:** COMSOL Multiphysics.
- **Hardware:** UAV Platforms, Magnetic Catcher (winch system, magnet array).
- **Algorithms:** Optimization Algorithm for magnet layout.
- **Features and Drawbacks:**
  - Features: High precision landing, operation in disturbed environments.
  - Drawbacks: Limited by magnetic field strength, requires careful calibration.

Challenges

- **Drone Detection:**
  - **Current Approach:** Deep Learning based approach using YOLOv8 algorithm.
  - **Improvements to be made:**
    - Use lighter version of YOLOv8 to increase efficiency.
- **Safe Capture of Drone:**
  - **Current Approach:** Plate end effector can handle drones of various sizes.
  - **Improvements to be made:**
    - Consider end effector with support for specific sizes and reinforcement (e.g., magnets) for better stability.

Challenges

- **Drone Pose Estimation:**
  - **Current Approach:** Perspective n Point (PnP) algorithm.
- **Dynamic Trajectory Prediction:**
  - **Current Approach:** Kalman Filters for handling dynamic adjustments.
- **Path Plannig:**
  - **Current Approach:** Inverse kinematics to calculate joint angles to enable end effector to reach desired position in the robots workspace.

Advantages

- Improves docking accuracy and stability under dynamic conditions.
- Scalable and adaptable for various drone sizes and types.
- Reduces human intervention.
- Saves time for real-world applications, e.g., delivery.

Disadvantages

- Requires complex integration of hardware and software components.
- High initial cost for implementing a manipulator and supporting sensors.
- Potential latency in processing real-time data.

Methodology

1. **Drone Detection:**
   - Deep Learning based approach using YOLOv8 algorithm.
2. **Pose Estimation:**
   - Employ Perspective n Point (PnP) algorithm.
3. **Dynamic Trajectory Prediction:**
   - Implement Kalman Filters to account for drone motion and environmental disturbances.
4. **Path Planning:**
   - Implement inverse kinematics to enable the end effector to reach the drone's position.
5. **End Effector:**
   - Use a plate end effector with reinforcement, such as magnets, for stable and reliable capture.

Software

- **OpenCV:** For visual detection and pose estimation.
- **PnP Algorithm:** For pose estimation.
- **Kalman Filter:** For dynamic trajectory prediction.
- **Inverse Kinematics:** For path planning.

Hardware

- **Manipulator Arm:** For adaptive and precise positioning.
- **RGB-D Camera:** For visual feedback and depth information.
- **Plate End Effector:** For drone capture with magnetic reinforcement.
- **IMU sensor:** To collect accelerometer data from drone.
- **ESP32:** To stream IMU sensor data to controller device.

Timeline

- **Week 1:** Literature review and identification of key components for the system.
- **Week 2:** System design finalization and procurement of hardware components.
- **Week 3:** Camera system setup, calibration, and automation detection system.
- **Week 4:** Development of pose estimation using PnP algorithm.
- **Week 5:** Dynamic trajectory prediction using Kalman Filters and testing under controlled conditions.
- **Week 6:** Integration of all subsystems and preliminary testing.
- **Week 7:** Final testing, debugging, and preparation of documentation and presentation.