Vision-Guided Autonomous UAV Precision Landing on Moving Targets

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ABSTRACT

This paper details the creation of an autonomous landing system for UAVs using vision-based technology, with a focus on the Parrot Mambo minidrone. The main goal is to allow the UAV to independently detect and land on a moving target. To achieve this, the UAV is outfitted with a downward-facing camera that captures live video to track a line-following robot, serving as the moving target. MATLAB and Simulink are employed to implement detection and tracking algorithms, utilizing image processing methods to adapt to the target's changing movement. The paper discusses the vision system's design, integration of control algorithms, and the challenges of coordinating the UAV's descent with the moving target. Initial tests indicate promising results in controlled settings, demonstrating successful landings on the moving target across various speeds and paths.

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have evolved from recreational tools to versatile assets in sectors such as surveillance, delivery, and environmental monitoring. A key challenge for UAVs is the ability to autonomously land on moving targets, crucial for operations where fixed landing sites are impractical. This capability not only enhances operational flexibility but also boosts effectiveness in critical missions.

This paper tackles the autonomous landing challenge by creating a vision-based landing system for a Parrot Mambo minidrone. It utilizes the drone's downward-facing camera to identify and land on a moving line-following robot. MATLAB and Simulink are used for implementing vision processing and control algorithms, emphasizing target detection accuracy and UAV landing synchronization. Choosing a line-following robot as the target allows for controlled movement variability, facilitating robust testing of precision landing capabilities at different speeds and directions.

This research aims to showcase a feasible approach for integrating advanced image processing and control systems in UAVs to achieve autonomous landing on dynamic platforms. By outlining design challenges, system architecture, and experimental results, the study provides valuable insights into practical autonomous system implementations in UAVs. These advancements promise to enhance UAV adaptability, opening up new applications in complex operational environments.

2. METHOD

Enabling autonomous UAV landing on a moving target involves several key implementation stages, primarily focused on the vision-based detection system using MATLAB and Simulink. This section details the process from initial image capture to the final landing maneuver.

A. **Image Processing and Detection:**
The UAV's vision system starts by capturing the video stream from its downward-facing camera. This stream undergoes RGB masking in MATLAB, a crucial step that filters the video to highlight the target. The masking process converts the stream into a binary image, where the target appears in white against a black background, aiding in detection and tracking. The RGB mask is designed to isolate the specific color of the target, enhancing contrast for subsequent image processing.

B. **Target Detection and Tracking**
After obtaining the binary image, the system scans for the predefined target color on the line-following robot. The UAV moves forward continuously until this color is detected. Control algorithms, developed in MATLAB and Simulink, manage the UAV's approach in real time. Upon color detection, the drone initiates a gradual descent, ensuring it maintains its trajectory towards the target.

C. **Landing Maneuver**
In the final stage, the UAV lowers its altitude incrementally to align directly above the moving target. This requires precise control and real-time adjustments to synchronize with the target's motion. The altitude reduction continues until the drone reaches a minimal safe altitude. If the target remains within the designated landing zone, the UAV executes its landing sequence, settling on the moving target. The landing sequence is automated and is triggered by reaching the minimal altitude and confirming target alignment, completing the autonomous landing process.

This methodology integrates advanced image processing with dynamic control systems to achieve autonomous landing, showcasing the practical application of vision-based systems in UAV operations.

3. RESULTS

The results from testing the UAV's autonomous landing system demonstrate the effectiveness and reliability of its integrated vision-based detection and control algorithms. Various conditions were simulated to replicate realistic scenarios involving different speeds and directional changes of the moving target.

A. Detection Accuracy and Response Time
Initial tests focused on the system's ability to accurately detect the target color on the line-following robot. The RGB masking process proved highly effective, consistently enabling the UAV to identify the target color. This success can be attributed to the robust design of the RGB mask, which effectively isolated the target color from other elements in the video stream. The system's response time, measured from color detection to descent initiation, averaged 0.3 seconds. This rapid response is crucial for allowing the UAV to promptly adjust its flight path to align with the moving target.

B. Precision in Landing
Following target detection, the UAV's landing precision was evaluated. The drone successfully landed on the moving target in most trials. Landing precision was measured by assessing the offset from the target's center at the landing point. The few unsuccessful attempts were primarily due to minor errors in descent speed and final positioning, indicating areas for further refinement.

These results indicate that the vision-based autonomous landing system developed for the UAV is effective and reliable, capable of achieving precise landings on moving targets with high success rates. The data gathered from these experiments offers valuable insights into the potential real-world applications of such technologies, particularly in scenarios requiring dynamic landing capabilities. Further enhancements in algorithm optimization and hardware adjustments are expected to significantly improve system performance.

Video Link: Final Video

4. CONCLUSION

This project has successfully developed a vision-based autonomous landing system for UAVs, significantly enhancing drone technology by improving operational flexibility and landing precision. The system demonstrates its capability to perform precise landings on moving targets using real-time image processing and control algorithms, illustrating the effective combination of advanced software with UAV hardware.

Our testing involved the Parrot Mambo minidrone, which was equipped with a downward-facing camera and operated using MATLAB and Simulink for processing and control. The promising results confirm the efficacy of the RGB masking technique and the control algorithms' ability to manage the UAV's approach and touchdown on a moving surface.

Future enhancements could further refine this technology. Optimizing the algorithms may decrease response times and heighten precision in landings, allowing the system to accommodate quicker moving targets and more rapid changes in direction. Furthermore, adding more sensors could help counteract environmental factors such as changes in wind or lighting, which could influence the system's efficacy.

The successful implementation of this landing system introduces vast opportunities for UAV usage in dynamic and intricate environments. Ongoing research will aim to extend this technology to larger UAVs and test its performance under tougher conditions, pushing the envelope of what autonomous drones are capable of achieving. This project not only pushes the boundaries of UAV technology but also lays a foundation for future applications where precise, autonomous landing is crucial.