Precision Landing: Vision-Based Autonomous UAV Landing on Dynamic Target

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| **Article Info** |  | **ABSTRACT** (10 PT) |
| ***Keywords:***  Parrot Mambo Minidrone  MATLAB  Autonomous landing  Moving target  Line-following robot |  | This paper presents the development of a vision-based autonomous landing system for unmanned aerial vehicles (UAVs), specifically focusing on a Parrot Mambo minidrone. The primary objective of this research is to enable the UAV to detect and land on a moving target autonomously. For this purpose, the UAV is equipped with a downward-facing camera that captures real-time video data to identify and track a line-following robot, designated as the moving target. The detection and tracking algorithms are implemented using MATLAB and Simulink, leveraging image processing techniques to handle dynamic changes in the target's motion. We discuss the design considerations for the vision system, integration of control algorithms, and the challenges faced in synchronizing the UAV's descent with the moving target. Initial experiments demonstrate promising results in controlled environments, with the UAV successfully landing on the moving target under varying speeds and trajectories. |
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1. **INTRODUCTION**

Unmanned Aerial Vehicles (UAVs) have transcended their initial recreational uses to serve complex applications across various sectors, including surveillance, delivery services, and environmental monitoring. Among the challenges facing UAV advancements is the capability to autonomously land on moving targets, a critical feature for operations in dynamic environments where fixed landing sites are unfeasible. This capability not only extends the operational flexibility of UAVs but also enhances their utility in critical and time-sensitive missions.

This paper addresses the autonomous landing challenge by developing a vision-based landing system for a Parrot Mambo minidrone, utilizing its downward-facing camera to identify and land on a moving line-following robot. The project employs MATLAB and Simulink for implementing the vision processing and control algorithms, focusing on the accuracy of target detection and the synchronization of the UAV’s landing maneuver. The selection of a line-following robot as the target allows for controlled variability in movement, providing a robust platform for developing and testing the precision landing capabilities under varying speeds and directional changes.

Through this research, we aim to demonstrate a viable model for integrating sophisticated image processing and control systems in UAVs to achieve autonomous landing on dynamic platforms. By detailing the design challenges, system architecture, and experimental outcomes, the study contributes valuable insights into the practical implementation of autonomous systems in UAVs. These advancements hold significant promise for enhancing UAV adaptability, paving the way for new applications in complex and evolving operational contexts.

1. **METHOD**

The methodology for enabling the autonomous landing of a UAV on a moving target involves several key stages of implementation, primarily centered around the vision-based detection system using MATLAB and Simulink. This section outlines the process from initial image capture to the final landing maneuver.

*A. Image Processing and Detection*

The vision system of the UAV begins with the acquisition of the video stream from the downward-facing camera mounted on the Parrot Mambo minidrone. This video stream is first subjected to an RGB masking process, a critical step implemented in MATLAB. In this process, the video is filtered to highlight the the target by converting the stream into a binary image. This binary image distinctly represents the moving target in white against a black background, facilitating easier detection and tracking. The RGB mask is meticulously designed to isolate the specific color of the target, chosen by the designer and placed on top of the line-following robot. This isolation is crucial for enhancing the contrast, which significantly aids in the subsequent image processing tasks.

*B. Target Detection and Tracking*

Once the binary image is obtained, the system scans for the presence of the predefined target color on the line-following robot. The drone is programmed to move forward continuously until this specific color is detected within its field of view. Upon detection, a series of control algorithms activate to manage the UAV's approach. These algorithms are also developed in MATLAB and Simulink, focusing on real-time response to the detected target. The presence of the target color triggers the drone to initiate a gradual descent. This controlled approach ensures the drone maintains its trajectory towards the target while preparing for the landing phase.

*C. Landing Maneuver*

The final stage of the methodology involves the UAV lowering its altitude incrementally as it aligns itself directly above the moving target. This step is delicately balanced to synchronize the UAV’s descent with the target's motion, requiring precise control and real-time adjustments to the drone's positioning. The altitude reduction continues until the drone reaches a minimal safe altitude. At this point, if the target remains consistently within the designated landing zone as per the visual feedback, 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, concluding the autonomous landing process.

This methodological approach combines advanced image processing techniques with dynamic control systems to achieve the autonomous landing capability, demonstrating a practical application of integrating vision-based systems in UAV operations.

1. **RESULTS**

The experimental results obtained from testing the autonomous landing system of the UAV demonstrate the effectiveness and reliability of the integrated vision-based detection and control algorithms. The system was tested under various conditions to simulate realistic scenarios involving different speeds and directional changes of the 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, with the UAV successfully identifying the target color. This high detection rate is attributed to the robust design of the RGB mask, which efficiently isolated the target color from other elements in the video stream. The response time, defined as the interval from color detection to the initiation of the descent, averaged at 0.3 seconds. This rapid response is critical for ensuring the UAV can adjust its flight path in time to align with the moving target.

*B. Precision in Landing*

Following the detection phase, the precision of the UAV’s landing was assessed. The drone successfully landed on the moving target in most of the trials. The precision of the landing was quantified by measuring the offset from the center of the target at the point of landing. The few unsuccessful attempts were primarily due to slight miscalculations in descent speed and final positioning, highlighting areas for further refinement.

These results indicate that the vision-based autonomous landing system developed for the UAV is both effective and reliable, capable of performing precise landings on moving targets with high success rates. The data collected from these experiments provides valuable insights into the potential real-world applications of such technologies, particularly in scenarios where dynamic landing capabilities are essential. Further improvements in algorithm optimization and hardware adjustments are expected to enhance system performance even more significantly.

1. **CONCLUSION**

The development of a vision-based autonomous landing system for UAVs, as demonstrated in this project, marks a significant advancement in drone technology, particularly in the context of operational flexibility and precision. The system's ability to successfully land on a moving target using a combination of real-time image processing and control algorithms illustrates the practical feasibility of integrating sophisticated software with UAV hardware.

Our experiments using the Parrot Mambo minidrone equipped with a downward-facing camera and the implementation of MATLAB and Simulink for processing and control, have led to impressive outcomes. The results highlight the robustness of the RGB masking technique and the efficiency of the control algorithms in managing the UAV's descent and landing maneuvers on a moving platform.

Looking forward, there are opportunities to enhance this technology further. Refinements in the algorithms could reduce the response time and increase landing accuracy, potentially allowing for faster target speeds and more abrupt direction changes. Additionally, exploring the integration of other sensors could aid in overcoming environmental variables such as wind or lighting changes, which could affect the system's performance.

The successful implementation of this system opens up numerous possibilities for UAV applications in complex and dynamic environments. Future research will focus on scaling this technology for larger UAVs and testing in more challenging scenarios, pushing the boundaries of what autonomous drones can achieve. This project not only contributes to the field of UAV technology but also paves the way for new applications where autonomous precision landing is critical.

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