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A vision-based landing system for small unmanned aerial vehicles using an airbag

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ABSTRACT

Statistics show that the landing accounts for the largest portion of all mishaps of unmanned aerial vehicles (UAVs) due to many difficulties including limited situational awareness of the external pilot and the limited maneuverability during the low speed flight before touchdown. In this paper, a vision-based automatic landing system using a dome-shaped airbag is proposed for small UAVs. Its isotropic shape allows airplanes to approach in any direction to avoid crosswind unlike net-assisted landing. The dome's distinctive color improves the detection owing to its strong visual cue. Color- and shape-based detection vision algorithms are applied for robust detection under varying lighting conditions. Due to the insufficient accuracy of navigation sensors, a direct visual servoing is used for terminal guidance. The proposed algorithm is validated in a series of flight tests.

1. Introduction

Landing is the most accident-prone stage in the entire flight envelope of both manned and unmanned airplanes. For commercial and military airplanes, the instrument landing system (ILS) has been developed and now widely used at major airports. It has dramatically improved the overall safety of landing even when the visibility is as poor as in Category III-A/B (Templeman & Parker, 1968). However, since the ILS is only available around certain airports and the onboard equipment needed for ILS is too heavy and complicated for typical UAVs, they are usually landed manually by pilots or portable external aiding systems. For manual landing, the pilot obtains visual cue by naked eyes or through the relayed video taken by the onboard camera. Piloting outside the vehicle needs a lot of training due to the limited situation awareness. As a consequence, a large portion of mishaps happen during the landing phase. Many fixed-wing military UAVs are known to suffer a significant portion of accidents due to human factors during landing and as for Pioneer, almost 70% of mishaps occur during landing (Manning, Rash, LeDuc, Noback, & McKeon., 2004; Williams, 2004). Therefore, it has been very much desired to automate the landing of UAVs, preferably without using expensive aiding systems.

Automatic landing of airplanes on runway has been well investigated using various techniques for both manned and unmanned aircraft (Duranti & Malmfors, 2005; Looey & Joos, 2006; Malaek, Izadi, & Pakmehr, 2006). Global Hawk relies on a high-precision differential GPS and a radar altimeter for landing (Loegering, 2002). For tactical UAVs, external aiding systems are favored. Sierra Nevada Corporation's UCARS and TALS[1] are externally located aiding systems consisting of tracking radars and onboard transponders, which measure the relative position and altitude of the inbound aircraft and relays back to its onboard flight controller for automatic landing. They have been successfully used for landing many military fixed-wing and helicopter UAVs such as Hunter or Fire Scout on a runway or even on a ship deck. Some UAVs can be retrieved in a confined space using nets or other special arresting devices. Scan Eagle is retrieved by a special arresting cable attached to a tall boom, to which the vehicle is precisely guided by a differential GPS.[2] These external aids listed above rely on special equipment, which are not always available or applicable to smaller UAVs due to complexity, cost, or other limits from the operating environment. Therefore, automatic landing systems that are inexpensive, passive, and reliable are highly desirable.

Vision-based landing has been found attractive since it is passive and does not require any special equipment other than a camera and a vision processing unit. A vision-enabled landing system will detect the runway or other visual markers and guide the vehicle to the touchdown point. There are a number of previous works, theoretical or experimental, for fixed-wing and helicopter UAVs (Bourquardez & Chaumette, 2007; Saripalli, Montgomery, & Sukhatme, 2002; Trisiripisal, Parks, Abbott, Liu, & Fleming, 2006). Notably, Barber, McLain, and Edwards (2007)

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[1] http://www.sncorp.com.
[2] http://www.insitu.com/scaneagle.

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Nomenclature

(a,b,c)	tuning parameters for color-based detection
(I_R,I_G,I_B)	RGB values of a pixel
(x,y)	image coordinates
ϕ_i	Hu's moments
B, C, S	body, camera, and local Cartesian (spatial) coordinate system, respectively
(ϕ_c, θ_c)	camera installation angle
$\mathbf{R}^{A/B}$	transformation matrix form B to A frame
k	relative distance from camera to object
f	focal length
(ϕ,θ,ψ)	Euler angles (roll, pitch, and yaw, respectively)
$\mathbf{w}_T^C$	unit vector in the direction of line of sight in the camera coordinate system

proposed a vision-based landing for small fixed-wing UAVs, where a visual marker is used to generate roll and pitch commands to the flight controller.

In this paper, for the landing of small fixed-wing UAVs, a vision-based landing system using an air dome is proposed (Fig. 1). An air-filled dome secured on the ground serves as a shock-absorbing arrestor as well as a visual marker. It can be reliably detected by relatively simple but reliable vision algorithms, which is suitable for visual servoing of fast-moving airplanes under various lighting conditions. Since the position error of typical navigation sensors available for small UAVs are quite large compared with the size of the dome, the vehicle would not be able to land on it even if the flight control is capable of perfectly tracking the desired path based on its poor navigation solution only. Therefore, instead of using the dome's coordinates estimated by fusing the vision with the navigation solution, it is proposed that the feature detection results are directly applied to steer the vehicle into the air dome, in a manner referred to as *direct visual servoing*.

This paper is organized as follows. In Section 2, the overall approach and its component technologies are explained in detail. In Section 3, the experiment results of the proposed method are presented and discussed. In Section 4, the conclusion and closing remarks are given.

2. System description

The proposed landing system consists of three major components: an air-filled dome, a vision processing system, and a flight control system ready for visual servoing. Before commencing the descent, the UAV looks for the dome using the images obtained by the onboard camera. When the onboard camera detects the dome, its location is estimated by combining the vehicle's location calculated by the navigation system and the image coordinates of the dome. Once its location is computed, the vehicle starts descending on the glide slope that leads to the dome. As the vehicle approaches and the vision system locks on to the dome, the flight control switches from glide slope tracking to direct visual servoing, where the offset of the dome from the center of the image taken from the onboard front-looking camera is used as the error signals for the pitch and yaw control loops. Unlike the conventional landing, the vehicle does not flare but continues to fly along the glide slope into the dome with an incident angle that would not cause the vehicle to bounce off. Before the final impact, the vehicle maintains a speed slightly higher than its stall speed in order to maintain minimal maneuverability. In Fig. 1, the proposed landing procedure using the dome is illustrated.

2.1. Air dome

The dome is constructed with sturdy nylon dyed with a strong red color, which would have a high contrast to typical outdoor environment. The prototype dome is a hemisphere of 4-m diameter. The dome can be easily transported in a compact package, inflated/deflated using a portable air blower or a chemical gas generator and secured to the ground using pegs. The dome can be used as a stand-alone air cushion for landing of small UAVs or as a backup air cushion when used with a net. Since the air-filled dome can absorb quite a large shock during landing, the vehicle would not need to make any special maneuver but simply fly into it at a low speed with a reasonable incident angle. The dome allows landing from any direction unlike the net-based recovery, which has to be installed to face the wind to avoid crosswind landing.

The dome also functions as a visual marker. It provides a distinctive feature both in color and shape. Its vivid color can be

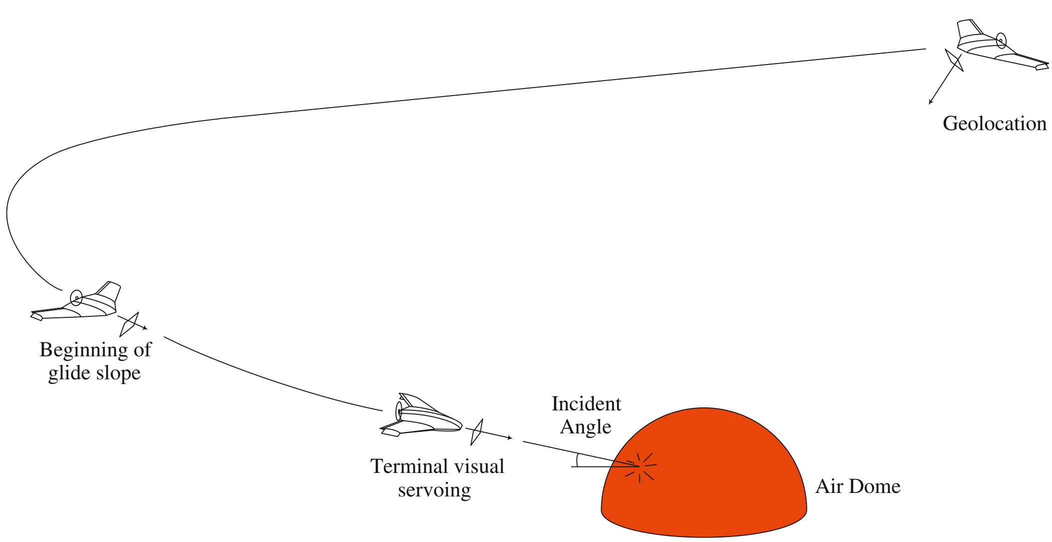

Fig. 1. Proposed dome-assisted landing procedure of a small fixed-wing UAV using the dome.