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Hybrid Aerial and Scansorial Robotics

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Abstract— **We present an approach that builds upon previous developments in unmanned air vehicles and climbing robots and seeks to emulate the capabilities of bats, insects and certain birds that combine powered flight with the ability to land and perch on sloped and vertical surfaces. As it approaches a wall, the plane executes an intentional pitch-up maneuver to shed speed and present its feet for landing. On contact, a nonlinear suspension dissipates the remaining kinetic energy and directs interaction forces toward the feet, where microspines can engage small asperities on surfaces such as brick or concrete. The plane can then take off by disengaging the spines and lifting off, pointing its nose up and away from the wall to slowly build forward speed until it can resume normal flight.**

Fig. 1. Sequence of the plane performing a powered perching maneuver on a concrete wall. The plane is initially flying around 10 m/s, detects the wall at 6m and iniates a pitch up. The motor is turn off as soon at touchdown is possible, and the plane generally contacts the wall while moving at between 0-3m/s in the horizontal direction. The landing gear finally absorbs the impact and engages the spines. The entire process takes less than one second.

I. INTRODUCTION

In comparison to other small robots, unmanned air vehicles have the ability to travel very rapidly to remote locations, including sites such as the tops of buildings or bridges that are hard to reach with terrestrial robots. However, they are subject to a severe tradeoff between payload and mission life. In contrast, climbing robots can remain perched at remote sites for hours or days, providing a secure, stable platform for inspection or surveillance. The work described in this paper is aimed at combining the best attributes of aerial and vertical surface (scansorial) robots. We focus on landing and perching on vertical surfaces for a couple of reasons. Vertical surface landing allows us to use gravity to slow the plane and engage gripping mechanisms. Also, vertical surfaces tend to be relatively safe, unobtrusive and uncluttered locations for sheltering a small, fragile vehicle – particularly if it can take shelter under the eaves of a building.

Our work builds upon developments in acrobatic maneuvers for small unmanned air vehicles and on climbing robots that attach to vertical surfaces using arrays of miniature spines. In other recent publications we describe the dynamic model of the plane and its highly damped, nonlinear suspension that dissipates kinetic energy on landing and directs interaction forces toward the spines to engage them [1], [2].

II. PREVIOUS WORK

Several researchers have demonstrated approaches by which a small plane can execute the maneuvers needed to land and perch on a target such as a branch or pole. Some of the initial work in this field includes [3] on indoor hovering and level flight and how to transition back and forth between these states as well as methods for autonomous landing and takeoff from a specially designed stand. Recent work [4] has used a similar motion capture system to demonstrate perching on a wire using a pitch-up maneuver to slow the airplane before contact. Work on autonomous hovering [5] made use of a 30g Microstrain IMU (3-axis attitude sensor) to control the attitude of the plane and transition between regular flying and hovering. Other lightweight sensors [6] and autopilot boards, like the Paparazzi open-source autopilot [7], are becoming available, providing a basis autonomous perching and takeoff.

From the literature on climbing robots, light weight and low-power technologies for climbing vertical surfaces are particularly relevant. The work described here utilizes the microspine technology developed for Spinybot [8] and RISE [9] to climb a variety of vertical surfaces including concrete, stucco and brick. The miniature spines perch on asperities (small bumps and pits) on the surface and a compliant suspension promotes spine engagement and ensures that the overall load is distributed among the spines.

Relatively few hybrid aerial/terrestrial platforms have been demonstrated. However, one early example is a flying/walking platform [10] that combines a small flexible wing MAV with the Whegs technology from CWRU. The USAF Academy has also investigated innovative concepts for flying and perching [11].

III. SYSTEM OVERVIEW

Our approach uses an aerobatic airplane to fly toward the wall, intentionally stall just before impact, and dissipate the remaining kinetic energy with a suspension that keeps forces on the microspine toes within a safe region, as shown in figure 1. The details of the perching strategy implemented on a glider can be found in [1]. This landing method allows the plane to approach the wall at its normal flying speed. Once the plane has pitched up, it is essentially ballistic. The entire maneuver requires < 0.75s, which minimizes the effects of disturbances.

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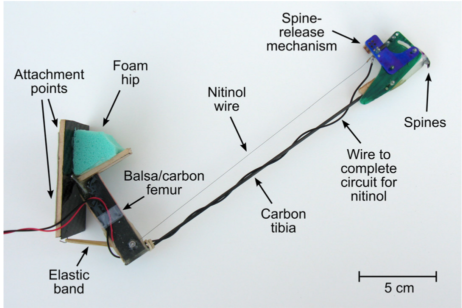

Fig. 2. Suspension to absorb energy while landing, including spine-release mechanism. A nitinol wire pulls back on an arm to lift the spines off the wall during takeoff.

The airframe that we are using is a modified Flatana airplane, with a brushless motor and 9x3.8 APC propeller, to which we added a Paparazzi autopilot [7], 3-axis accelerometer (ADXL335), 3-axis gyroscope (IDG500) and ultrasound sensor (Maxbotix MB1320) for wall detection.

We developed a highly compliant and damped suspension (fig. 2) to permit a relatively large envelope of initial contact conditions: 0-2.7m/s forward velocity, up to 3 m/s downward velocity, and pitch angles from 50-110 deg. [2]. The suspension has effectively three joints with bending at the hip and knee, and stretching at the spines. Each foot has five spines to share the load over several asperities.

The aircraft then re-launches from a perched position into normal flight. Following the release of the spines, thrust from the propeller moves the plane away from the wall backwards, at which point it can do a 180-degree roll and resume normal flight.

IV. POWERED PERCHING

A multiple exposure photograph illustrating the perching sequence is shown in figure 1. On this figure, the plane is initially flying around 10 m/s; it detects the wall at 6m and iniates a pitch up. As the pitch angle approaches 75 deg, the motor is turned off. As the pitch approaches 90 deg, the plane's flight is essentially ballistic and the plane contacts the wall while moving at roughly 2.5m/s in the horizontal direction and 2m/s in the downward direction. At impact, the landing gear absorbs the remaining kinetic energy and engages the spines.

V. TAKEOFF

Various strategies can be used to take off from vertical surfaces depending on the airframe configuration, its orientation on the wall and the complexity of the takeoff mechanism. For example, an airplane with a low thrust-to-weight (T/W) ratio would probably benefit from a jumping mechanism (as in [12]) to increase its initial speed and reorient itself for flight. Although we are interested in low T/W airframes for efficiency reasons, we describe here an aproach used with an acrobatic platform with $T/W > 1$. This strategy allows for a smooth and controlled takeoff and prevents any loss of elevation in tight spaces. We anticipate that future work with low T/W planes will be able to incorporate some of the same components and methods that we describe here.

Our approach consists of releasing the spines using a specially designed mechanism and starting the takeoff once free from the wall. Then, using the high T/W ratio and propwash over its control surfaces, the airplane holds its nose up and away from the wall to build horizontal speed before resuming flight. To release the spines, a nitinol wire pulls on an arm that lifts the spines away from the wall, taking <0.15 seconds to fully disengage the spines.

VI. CONCLUSIONS

Autonomous landing and perching followed by takeoff have been demonstrated on vertical surfaces. The approach is particularly useful for landing on locations where horizontal surfaces may be cluttered and where a runway for landing and takeoff is not available.

VII. ACKNOWLEDGMENTS

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