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PARASWIFT – A HYBRID CLIMBING AND BASE JUMPING ROBOT FOR ENTERTAINMENT

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This paper introduces Paraswift, a mobile robot that is able to climb an ordinary wall and deploy a paraglider for a remote controlled return to ground. The goal is entertainment and technical education through an unusual, eye-catching robot. Multiple requirements must be met – to provide a mechanism that generates strong adhesion for climbing yet is low weight for flying, to ensure a reliable transition from climbing to flying, and to handle collision forces on landing – in a single compact robot. The climbing technology is vortex adhesion with wheeled locomotion. The paraglider is folded into the robot shell on ascent and deployed at launch time using a novel mechanism based on a 2-DOF manipulator arm. Flight is remote controlled, and the robot has a protective frame of glass fiber reinforced plastic with a hard foam core to absorb collision forces on landing. This paper describes our work on the complete system, starting with the design, simulation, and physical testing of individual components, and culminating in the integration phase with successful climbing and flying on multiple walls of varying characteristics. We believe that Paraswift is the first demonstration of a compact robot that is capable of vertical climbing and passive flying.

Keywords: Climbing Robot, Flying Robot, Vortex Adhesion.

1. Introduction

Paraswift is a climbing and flying robot that provides an eye-catching demonstration for entertainment and technical education. The concept is shown in Figure 1 – the robot climbs a building wall, deploys a paraglider, and launches from the wall to make a remote controlled descent to earth. An onboard wireless camera transmits video to a display at ground level, allowing spectators to see the robot eye view. As an entertainment experience, Paraswift is a base jumping robot that draws on public interest in extreme sports. As a technical education experience, Paraswift demonstrates interesting problems and solutions about how to combine climbing and flying in what we believe is the first compact robot to combine vertical climbing and passive flying in one system.

Figure 1. (a) Climbing an outdoor wall, (b) live video from an onboard camera is transmitted to a screen at ground level, (c) flying under remote control.

In addition, the work has practical potential. The most reliable current technology for climbing robots is magnetic adhesion, which works for ferromagnetic surfaces such as metal tanks and pipes in industrial settings. There is also a variety of research on climbing techniques for ordinary walls, but this is a more difficult problem because the surfaces do not offer a straightforward adhesion mechanism like magnetic force, and ordinary walls have a range of characteristics like indentations and flakiness. Thus falling is a significant risk for an untethered robot that is not using magnetic adhesion. This paper demonstrates a deployable paraglider as a possible safety mechanism for climbing robots. This is not the topic of the paper and there would be many research challenges to address, but it can be proposed as a realistic concept for some applications and settings given the presented results.

2. Related work

There are a number of technologies for creating an adhesion force in order to climb vertical or inclined surfaces. Previous work includes suction [1-5], magnetism [6], artificial gecko hairs and dry adhesion [7-10], and electro-adhesion [11]. Suction can be achieved in two ways, either using a closed vacuum chamber that requires a seal between the robot and the surface [1-3], or using vortex generation that does not require a seal [4, 5]. Magnetic adhesion is a reliable technology that is being used in real world applications such as mobile robot inspection in industrial plants, but it is confined to ferromagnetic surfaces. Gecko hairs and dry adhesion are promising technologies but one of the challenges is that dirt and dust accumulate on the climbing pads and the adhesion force diminishes rapidly. Furthermore, these approaches need a large contact area with the surface e.g. with legs [7], whegs [8, 9] or tracks [10], and simple wheels with only line contact are insufficient. Electroadhesion is a promising approach but is difficult to realize due to limited availability of special materials.

3. Paraswift Robot

3.1 Overview

The first stage of the work was to specify goals and constraints for the robot:

- Climb on unmodified building walls
- Fly under remote-control
- Land on unprepared ground
- Onboard camera
- Stylish appearance and good visual experience for spectators

The principal functions are to climb, to transition between climbing and flying, to fly, and to land on an ordinary ground surface. For the climbing mechanism, we required an adhesion technology that would work on a variety of building surfaces and which was not heavy. Suction was the most suitable choice, along with motorized wheels for locomotion. Suction works on varied surfaces, does not damage or mark the surface, and is an economical choice. This required a further decision between a vacuum chamber and a vortex. Vortex adhesion was the best choice for two reasons – (a) the ratio between adhesion force and mass is superior to vacuum so that the robot can have lower weight, (b) no sealing is required between the robot and the wall so that it is easier to climb on walls with geometric irregularities.

For flying, a paraglider was chosen because of its self-stabilizing character and maneuverability at low velocities, and because it is foldable which allows it to be hidden inside the robot while it is climbing on the wall.

The major unknown in the initial stage was the transition between climbing and flying because this is not a problem with standard solutions and it could not be modeled in simulation. In the rest of the paper, sections 3.2 - 3.5 describe the principal functions in more detail. Section 3.6 describes electrical control and the onboard camera.

3.2 Climbing

The climbing mechanism is shown in Figure 2a. Adhesion during the climbing phase is achieved using an impeller that creates a vortex with a low-pressure area at the center as illustrated in the simulation in Figure 2b. A non-sealing carbon fiber case around the impeller keeps the kinetic energy of the vortex inside the system. There is a gap of about 4 mm between the case and the wall, which avoids energy loss due to friction and allows driving over small geometric irregularities. The wheels are standard RC model parts with a friction coefficient of around 1.0 on typical wall surfaces.

The first tests were performed with an impeller from a vacuum cleaner with an outer diameter of 125 mm. Computational Fluid Dynamics (CFD) simulations with ANSYS CFX correlated with these tests and the system was optimized according to our needs. In the implemented climbing mechanism, the case is made of a carbon fiber reinforced polymer structure, weighs 35 g and has size Ø260 mm x 30 mm. The impeller is made of sheet metal and driven by a lightweight brushless motor. The number and form of the rotor blades were determined in the optimization. The impeller weighs 70 g and has size Ø175 mm x 16 mm. The adhesion force is 15 N at a rotational speed of 2900 rpm and energy consumption of 25 W, and 40 N at 7200 rpm and 80 W.

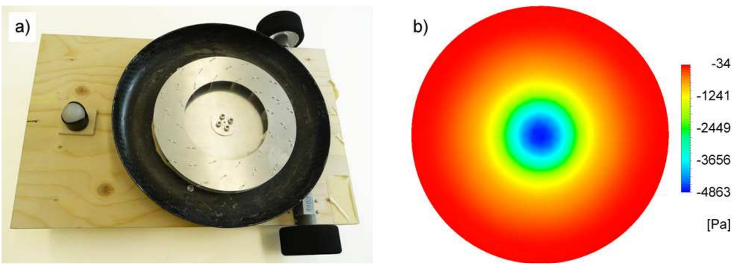

Figure 2. (a) The climbing mechanism of the robot, showing the carbon fiber case, the impeller within the case, and two motorized wheels for locomotion. (b) CFD simulation of the pressure distribution inside the case, with values relative to the environment.

Safety – The case is covered with a grating to prevent accidental contact with the impeller. In addition, the attachment of the impeller to the motor is secured with adhesive, and the robot was handled in operation using safety gloves.

3.3 Transition from Climbing to Flying

The paraglider weighs 200 g and has an area of 0.85 m^2 (HobbyKing Paraglider Parafoil 2.15 [12]). The goal of a minimum deployment height of 10 m led to a decision to actively open the paraglider before leaving the wall so that the robot would have more time to reach stable flight.

The paraglider is folded into the robot shell during climbing as shown in Figure 3a. Bendable carbon fiber rods act as flexural springs that are compressed when the paraglider is folded into the shell, and a securing cord holds the compressed rods in place. Deployment is achieved using a lightweight 2-DOF manipulator-arm with two servos as joints. After the manipulator-arm is expanded in a horizontal position, the securing cord is removed and the rods span the paraglider on its entire width, but it is still folded lengthwise around the manipulator-arm as shown in Figure 3b. Now the manipulator-arm can fully expand and by doing so it opens the paraglider completely as shown in Figure 3c. In this position the paraglider lies loosely on the manipulator arm, and nails through eyelets in the paraglider prevent it from slipping off sideways.

As soon as the vortex is turned off the robot quickly falls away from the paraglider because of its lesser air resistance, the lines tauten and the paraglider takes the robot away from the wall. At this point the robot folds the manipulator-arm back in to protect it during the landing.

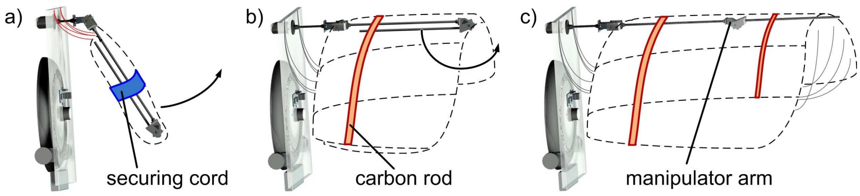

Figure 3. Deployment of the paraglider. (a) The folded paraglider held together by securing cord, (b) the manipulator-arm is half expanded, the securing cord is released and the previously bent carbon rods span the paraglider's entire width, (c) the manipulator-arm is now fully expanded and the paraglider is completely unfolded.

3.4 Flying

The steering mechanism for the paraglider consists of two remotely controlled servos accessing the left and right sets of the paraglider steering lines. This allows control of both banking and the angle of attack of the paraglider before landing.

Figure 4 gives the results for our initial tests on descent velocity versus payload for a paraglider of area 0.85 m^2. This determined that average vertical velocity of the implemented robot would be 4-5 m/s.

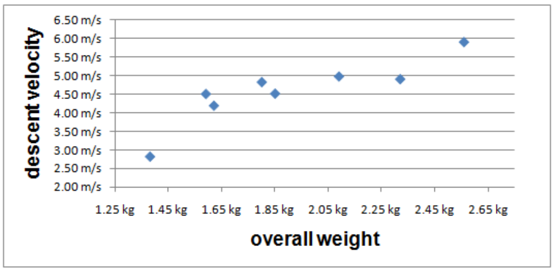

Figure 4. Average vertical velocity of a dummy payload with a paraglider area of 0.85 m^2 for different payload weights.

Safety – Spectator safety during flying is ensured using a safety cord that is attached to the robot and anchored at the bottom of the wall. The rope weighs 15 g so this has no effect on the flight characteristics of the robot (the robot's weight is 1.7 kg).

3.5 Landing

The robot has a protective frame to prevent sensitive components from being damaged on landing. The CAD design is shown in Figure 5a, with the frame being made out of glass fiber reinforced plastic covering a hard foam core. Cushions filled with polystyrene beads provide additional damping for the landing area on the base of the frame (the two struts on the right-hand side in Figure 5a). The frame is also designed to protect the robot in the case of an uncontrolled crash. The frame is covered with the external design shell shown in Figures 5b and 5c, for visual impact. While the robot is climbing, the paraglider is hidden within the design shell. During the launching stage, the front of the shell opens and the paraglider deploys as shown in Figure 5b. The design shell closes again during flight as shown in Figure 5c.

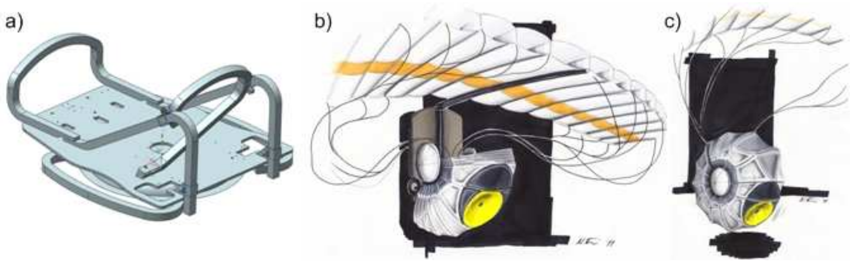

Figure 5. (a) Protective frame. (b) Design shell during transition from climbing to flying. (c) Design shell during flying. (Drawings 5b and 5c made by design team from ZHdK)

3.6 Electronics and Camera

The electronics are based on a Skybotix Coax 3 board to provide a microcontroller, IMU, and altitude sensor. The power source is an 11.1 V LiPo battery, which enables three cycles of base jumping with a 15 m climbing height. The robot is steered – both the wheels and the paraglider lines – with a conventional remote control. Signals are received at 2.4 GHz on the Coax board and are transmitted via SPI to the controller. The drive motors are accessed by RS-232.

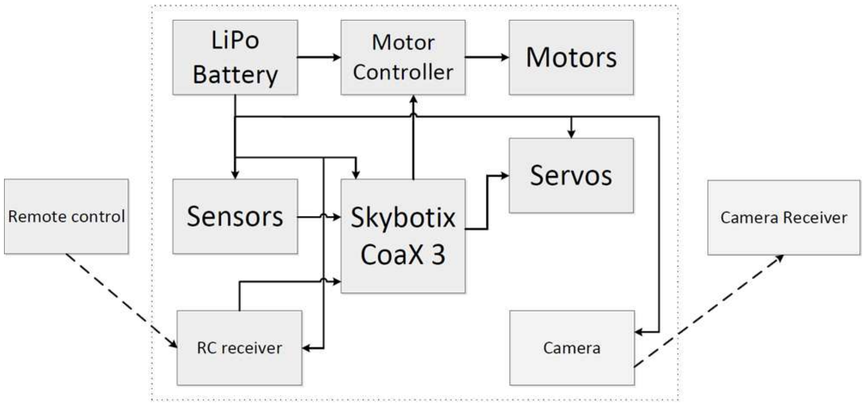

Figure 6. Hardware diagram

The onboard camera is an AXIS M1011-W, mounted on a custom servo-driven pan/tilt mechanism on the robot. The lens has a 20° field of view. The robot is stopped on the wall at a desired height, and the camera is used to capture approximately 200 images for varying pan/tilt angles that are sent by live-stream transmission to a ground laptop. The stitching software PTStitcherNG [13] is used to create a wide-angle panorama of the robot eye view, in typically less than 10 s processing time.

4. Results

The robot is shown in Figure 7 in configurations without the paraglider, with the folded paraglider, and with the design shell. It weighs 1.76 kg without the design shell and is 450 mm long, 300 mm wide and 230 mm high. It weighs 2.18 kg with the design shell. The design shell has been completed as a static shell, and automatic opening and closing of the shell during the transition from climbing to flying was not yet implemented.

Figure 7. (a) The robot. (b) With folded paraglider. (c) With design shell.

Climbing was successful on multiple surfaces such as brick, concrete, wood and glass. Climbing speed is up to 25 cm/s and the robot can handle rough surfaces and geometric irregularities up to 5 mm. The robot is capable of agile changes of direction during climbing under remote control and can climb down walls backwards or head first. Some examples of climbing on different surfaces are shown in Figure 8. The full cycle from climbing to landing is shown in Figure 9, using a red carpet that was secured from an upper window as a climbing surface.

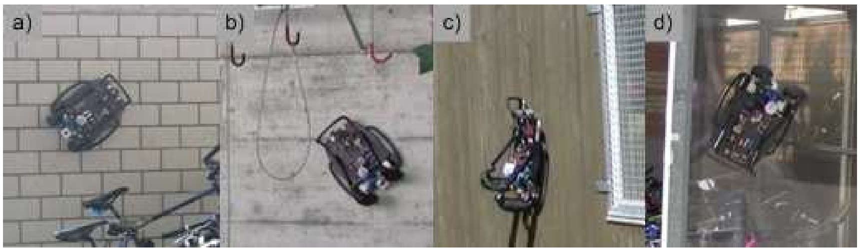

Figure 8. The robot climbing on (a) brick, (b) concrete, (c) wood, (d) acrylic glass.

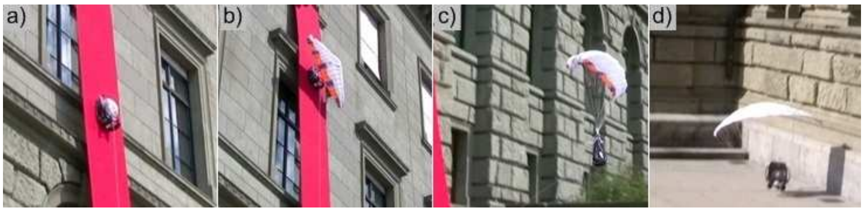

Figure 9. The four key stages of climbing, transition, flying, and landing. The hanging cord visible in (a) and (b) is a lightweight safety cord to constrain the maximum range of the flying robot.

A minimum jump altitude of 10 m was sufficient to allow the robot to reach a stable flight and land safely with a flight time of about two seconds. Steering ability during the flight is limited because the flying speed is low, and attempting to make a large change in direction can cause the paraglider to stall.

But the steering mechanism successfully fulfills the primary goal that it can reliably steer the robot away from the wall.

Most of the testing was done with a safety net but there were also multiple successful landings directly on hard ground surface. One accidental crash of the robot during testing showed that the protective frame was robust enough to prevent damage to the robot for a fall of 12 m onto tarmac, except for small cracks in the frame.

Discussion – As anticipated, the transition from climbing to flying is the key research challenge. Transition has two stages (a) the paraglider is deployed while the robot is still adhering to the wall and (b) the vortex is turned off, the robot falls, and the paraglider starts to fly. Transition is reliable in low wind of up to 5 km/h. Stronger breezes affect stage (a) by pushing the paraglider against the wall, or tilting the whole paraglider. Possible ways to add robustness to transition are to modify the deployment mechanism that supports the paraglider before flight, and to have an anemometer to test that flying conditions are within acceptable parameters. This was not part of the current work.

5. Conclusion

This paper has presented a climbing and base jumping robot with an innovative design that strikingly illustrates the possibilities of recent technology in climbing robots. For the first time, vertical climbing and passive flying are realized in a single lightweight robot that balances the requirements of both functions. With its unique functionality and appealing design, the robot represents an attractive showpiece for entertainment and education about the new generation of mobile robots.

The climbing mechanism of vortex adhesion is lightweight and useful for other applications such as climbing robots that do inspection. The primary research challenge for future work is in the transition from climbing to flying, and ideas for future work were proposed. An interesting possibility is to develop the transition mechanism to handle not just controlled launch of the robot from the wall but also accidental falling.

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