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Description	

A Design for UAV Irregular Surface Landing Capability

Tsung Hsuan Huang, Armagan Elibol, and Nak Young Chong

***Abstract*— Unmanned Aerial Vehicles (UAVs) have been taking an important place in our daily lives. Their usage for the inspection purpose is mostly limited to non-contact type sensors such as optical cameras and/or laser sensors. Lately, wall-climbing UAVs have been proposed to gather data using contact-type sensors. However, the major drawback is that they can solely be used for planar surfaces. In this paper, preliminary design studies of a compact robotic mechanism to allow UAVs to land on any shape of surfaces is presented. This robotic platform is designed by two swivel arms with four vacuum suction cups. When approaching the target surface, the 3D shape of the surface is planned to be detected using the data provided by sensors (e.g., RGB-D camera and related others). With the 3D shape, the platform will set up landing gear adjustments accordingly. This mechanism is intended to be light-weight, modular, expandable, self-balanced, attachable to most of the existing UAVs.**

I. Introduction

In recent years, UAVs have been used more and more to help humans in different tasks. Although they were mainly employed for aerial video and image capturing tasks, nowadays, they have been used in various other tasks (e.g., Inspection [1]–[3] and agriculture [4]–[6]). Different designs [7], [8] have been developed accordingly to the nature and needs of tasks. Visual inspection (e.g., wall, dam, and many others [9], [10]) is one of the areas in which UAVs have become an indispensable tool thanks to their ability to obtain data through optical sensors available on board. Lately, researchers have been working on designing UAVs that are capable of landing or touching to the surface being inspected [8], [11], [12]. Existing designs could only allow UAVs to land on a flat surface [13], [14], which limits the functions and applicability of UAVs. Some of them can only consider connecting with vertical surface [1] and others can only operate on horizontal surfaces [15]. However, in real life, there are many non-planar surfaces that also need inspection or to do other tests. Therefore, there would be of interest to design a UAV that is capable of landing on uneven and/or non-planar surfaces. This would allow them to collect data from such surfaces for inspection and monitoring tasks.

This paper presents a cooperative robotic mechanism for UAVs to land on any shape of the surface. This novel design allows UAVs to take off and land on the surface of any shape. This also makes it possible that UAVs can access complex and dangerous environments (such as industrial facilities to be inspected, disaster sites, after earthquakes, and similar others) and collect data. Since this design is equipped with a replaceable robotic arm, and in addition to providing assistance to rescue crews at the scene of the disaster, it can also assist in the transportation of materials, provide the equipment needed and many others for search and rescue operations to maximize the use of UAVs.

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II. Related Works

Mobile robots, capable of maneuvering on vertical and inclined wall surfaces or flying and gliding to reach higher sites, could replace humans in potential applications such as precise inspection and maintenance, from the human safety perspective, particularly while working along with hard-to-reach locations of civil structures [16]. Wall Climbing Robots (WCRs) are specialized mobile robots that can be used in Periodic inspection and maintenance [17]. WCRs can have higher payload carrying capability. However, they are generally slow and unwieldy. Therefore, in recent years, more and more wall-climbing UAVs have been proposed as alternatives for wall-climbing robots for bridge inspection or other high altitude tasks [12], [18].

In [19], Kamel et al. presented the mechanical designs of UAV platforms with a tiltable rotor. They demonstrated a transition from horizontal to upside flight and physical interaction with a wall. Their design is limited to land only on the planar surface. The dynamics remain of the tiltable rotor technology is not entirely feasible and the tiltable rotor also has a speed problem of slow rotor tilting. Also, the maneuverability was harder than general UAVs and it requires high battery power. In [20], it was proposed a UAV capable of perching and climbing with passive technology through the Cooperative robotic platform by a 2-DoF climbing mechanism. Although their platform was lightweight and can perch on the rough exterior surfaces, it still cannot adapt to uneven surfaces and the payload was also relatively low for using different sensors or other equipment for different tasks. The proposed design is using vacuum suction cups to substitute the climbing mechanism. This makes the platform have a better payload capability, more stable on the surface, and more powerful to perch on the surface.

III. Novel Design for Cooperative Mechanism for UAVs

Our cooperative mechanism design is composed of 5 different parts; Main Body, Swivel Arm,Structural Design, Equilibrium and Adsorption, and Operational design.

A. Main Body Design

There are 4 telescopic rods in the center of the main body to connect with the two swivel arms, which can adjust the size of the platform for different UAVs. Sensors are planned to be mounted in the center of the platform (as shown in

Fig. 1) to avoid any possible interference by the robotic arm. Different sensors (e.g., Cameras, Lidar and related others) are planned to be used for 3D modeling of the surface to be landed or perched. And one replaceable robotic arm in the center is attached as shown in Fig. 1 to carry out different tasks. A robotic arm is also designed to be attached to the main body and it is responsible for various tasks that can hold the required equipment to the target to perform the task and can also be replaced with detection instruments, paintbrushes or various types of devices that meet the task requirements for different task needs.

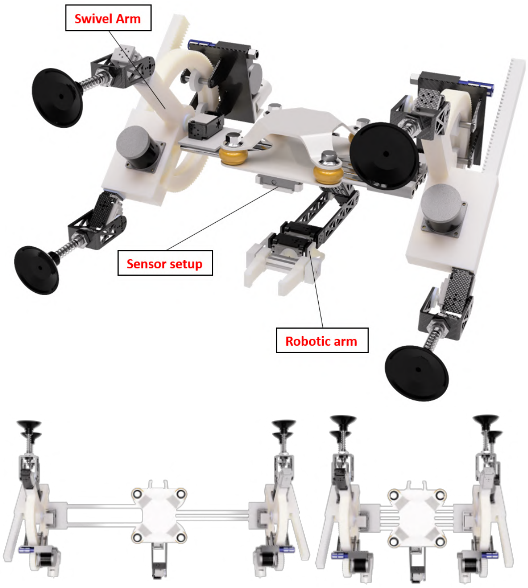

Fig. 1: Main Body Design of the robotic platform. This design is composed of two Swivel Arms and combined with four length-adjustable telescopic rods and a robotic arm. The aimed is to be lightweight and flexible so that can be integrated into different UAVs.

B. Swivel Arm Design

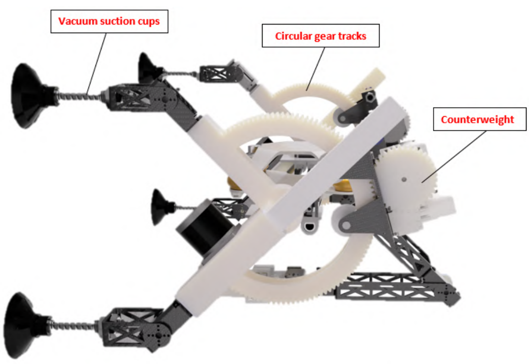

Fig. 2: The figure shows the installation positions of the five motors and the optional rotation range and shows the movement of the movable gear rack with the virtual line standard. The length change of the movable gear carrier is controlled by the motor number 4.

Swivel Arm is the main part that is in charge of perching on the surface and it is composed of extending legs, vacuum suction cups, and the counterweight. There are two identical swivel arms on the side with a circular gear track are used as illustrated in Fig. 2. It is designed to be a track that can let the counterweight be adjusted for different centers of weight while operating. The vacuum suction cup mechanism is designed to be stretchable to match the surface, and the swivel arm on both sides can be rotated and stretch separately to adapt the different shapes of the surface.

C. Structural Design

There are 5 motors on each Swivel Arms. (As shown in Fig. 3) Part numbers of 2 and 3 are servo motors with 180 degrees and 25Kg payload. Part numbers 1, 4, and 5 are stepper motors with 360 degrees and 25Kg payload. Motor number 1 controls the angle selection of the Swivel Arms. Motor numbers 2 and 3 control the position of the vacuum cup to match the target plane. Motor number 4 is designed for the length control of the gear rack on the Swivel Arms to match the target planes of different shapes. Motor number 5 adjusts the position of Counterweights on the circular gear track when gyroscope sensing, to balance the whole system.

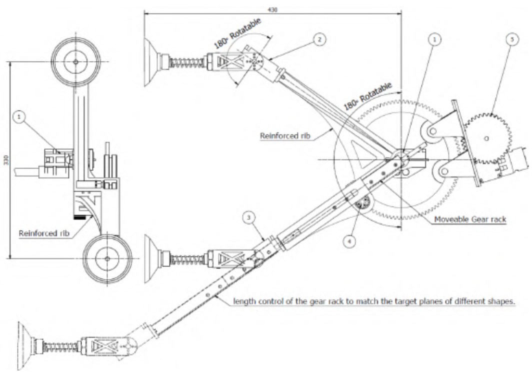

Fig. 3: Designed Swivel Arm. There is a circular gear track in the center of swivel arm and it is for the counterweight. The counterweight is planned to change its position while the attached UAV is flying. Counterweights are crucial part of the design as they are aimed to balance the whole system.

The material of this robotic platform is Carbon Fiber Reinforced Polycarbonate (PC) Filament, by using a 3D printer with 40 percent infill density and full honeycomb patterns. In terms of strength, two reinforcement ribs are designed to strengthen the structural strength. Use high-strength infill patterns and reinforcement ribs to reduce weight. The weight of this robotic platform is currently 2Kg, while the drone is 1Kg. we estimate any quadrotor with a payload of 5kg or more can carry this robotic platform.

Vacuum system designed to use 650mm-Hg DC vacuum pump with 50mm Vacuum Cup. According to the suction cup friction formula and vacuum holding force formula the vacuum system and vacuum cup can provide the friction force of 65.97(N) and the holding force 39.27(N).For the force required by the system to adsorb on the target surface, for a 90-degree glass plane, the robotic platform will be subjected to a torque of 12642N.mm, so the suction cup above the Swivel Arms requires at least 38.31N holding force and 14.7N friction force, while the lower The suction cup requires 14.7N of friction. For a 180-degree glass plane, the upper and lower suction cups need at least 14.7N. It can be seen from the above values that the vacuum system of this design is enough to secure the platform on the target surface.

D. Equilibrium and Adsorption

Four vacuum suction cups are used to be responsible for stabilization process on the surface. Each of them operates with 4-DoF, and is equipped with damping to effectively buffer when it is adsorbed on the wall. Counterweights are designed to balance when extending four vacuum suction cups while the attached UAV is flying. Counterweights are provided on the left and right circular gear track, and the counterweight is composed of hardware such as a motor required of the vacuum system. The concept of combining hardware into a counterweight is to minimize the weight of this platform and keep our platform compact.

E. Operational Design

When the UAV takes off, the swivel arms on both sides are planned to turn and make the vacuum suction cups facing to the front for the preparations of landing to the target surface. Fig. 4 shows the illustration of this operation. Regardless of the flying and/or tilting mechanism of UAVs, the swivel arms are planned to keep the same position while flying. At the same time, the counterweight is considered to move backward and begin to balance the entire platform on the track. During the flight, the counterweight will adaptively change its position to keep the platform balanced.

When approaching the target surface, the 3D shape of the surface is planned to be detected using the data provided by the available sensors (e.g., RGB-D camera and related others). With the 3D shape, the platform will set up landing gear adjustments accordingly. Some examples of landing setup are given in Fig. 5. And start the vacuum system to provide vacuum suction to fix on the target surface, after setting is completed, it will start landing on the target plane.

To complete the overall landing action. According to the vacuum value to determine whether the vacuum system and vacuum cup are operating correctly and fixed firmly on the target surface.Before ensuring that the vacuum system is firmly fixed on the target surface, the UAV will not stop operating until the vacuum value determines whether it is firmly on the target surface. In case of sudden abnormality of the vacuum cap system UAV will be activated to ensure that the UAV and the robotic platform will not fall down.

IV. CONCLUSIONS

Lately, UAVs have been more and more advanced, and they have been employed for several different purposes thanks to their compact design and data gathering capabilities. Recent studies have led to the development of UAVs with landing capabilities on planar surfaces. In this paper, we presented

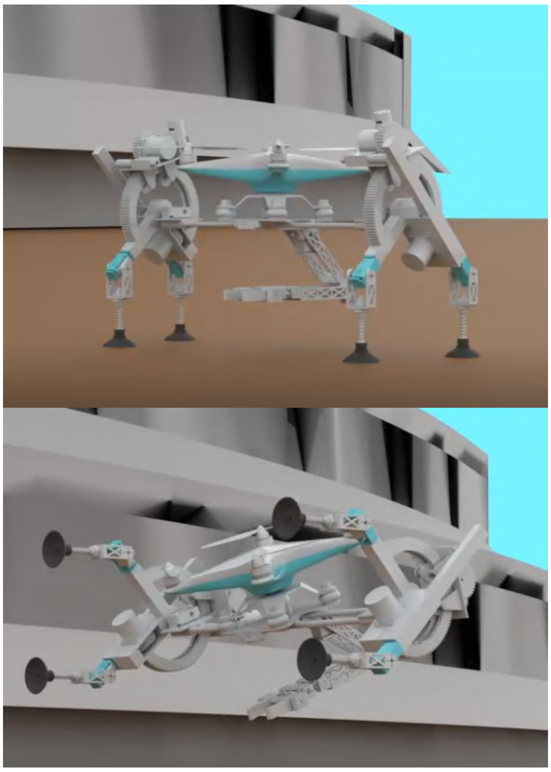

Fig. 4: Balance while flying; the flight attitude of UAVs is planned not to be affected by the balance of the platform. The counterweight will change its position automatically by the circular gear track to balance all the systems.

Fig. 5: Some examples of landing on arbitrarily shaped surfaces. Only core stander setups are illustrated. This mechanical design is flexible to any shape of the surface thanks to its swivel arms. Swivel arm and vacuum suction cups are adjustable according to the shape of the surface to be landed.

a preliminary mechanical design that is aimed at enabling UAVs to land on arbitrarily shaped surfaces. The presented design is composed of 2 Swivel arms with 4 suction cups. Counterweight mechanisms are also included for smooth operation in terms of balancing. Such a design would make UAVs to be employed in more complex tasks, which can create several possibilities for UAVs.

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