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# Micro aerial vehicle type wall-climbing robot mechanism

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*Abstract*— **Nowadays, as the building structures are getting taller and taller, the importance of maintenance or inspection of these structures is being increased. However, it has some problems due to the lack of professional manpower and there is a risk in maintaining those areas that are hard to reach, besides the high maintenance cost. The unmanned wall-climbing robots for the areas hard to reach have been researched to solve the problems. The infrastructure-based wall-climbing robots have high payload and safety but the robots need the infrastructure that should be installed on the target structure. The infrastructure is not preferred by the architects since it can be harmful to the exterior of the structure. For this reason, wall-climbing robots that do not need any infrastructure are being researched. Nevertheless, most of the non-infrastructure-based wall-climbing robots are in the laboratory level since the payload, safety and maneuverability are not satisfactory. To overcome these problems, a flight-possible wall-climbing robot mechanism is proposed in this paper. The robot is based on the quadrotor system that is a well-known aerial vehicle using four rotors. It uses thrust forces induced by the four rotors not only to fly but also to stick on the wall. The flight capability makes its maneuverability and safety greatly enhanced. The feasibility of the mechanism is shown through simulations and experiments with a prototype.**

## I. INTRODUCTION

As the civil infrastructures are getting taller and the number of them is increased, the importance of the maintenance or inspection of them is highly increased [1-2]. In spite of the situation, most of the conventional inspections for the high-rise buildings are labor-intensive, and there are problems by the lack of professional manpower, the risk due to the poor reachability, as well as the high maintenance cost. For these reasons, the needs for unmanned wall-climbing robots to solve the problems are on the rise.

Infrastructure-based wall-climbing robots are the types that have been studied for a long time to inspect an outer wall of a building. A cable-driven type is the most representative wall-climbing robot [3]. Infrastructure-based wall-climbing robots have high payload and safety but are not preferred by the architect due to the infrastructure that can injure appearance of the building.

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To solve these problems, wall-climbing robots that do not need additional infrastructure on the target buildings are gaining attention recently. In the case of non-infrastructure-based wall-climbing robots, adhesion mechanisms such as magnet, vacuum system or adhesion materials have been used to stick on the target wall as shown in Table I [4-9]. Although these types of robots can solve the problems that infrastructure-based wall-climbing robots have , most of the technologies are in the laboratory level since the payload, safety and maneuverability are unsatisfactory.

To overcome these problems, the flight-possible wall-climbing robot mechanism is proposed in this paper. The wall-climbing robot is based on a quadrotor. The quadrotor is one of the well-known Vertical Take-Off & Landing (VTOL) Unmanned Aerial Vehicles (UAV) [10]. The quadrotor is capable of hovering and omnidirectional flight with thrust forces generated by four rotors. For the flight capability, the quadrotor uses four rotors to make the thrust forces and the wall-climbing robot using the thrust forces not only to fly but also to stick on a wall. The flight capability makes the maneuverability and safety of the wall-climbing robot greatly enhanced than the other types of wall-climbing robots. For example, it can reach the remote target and can restore its position to the wall even if it is detached from the wall by an unexpected disturbance while climbing the wall. In Section II-A, the design and steps for mode change are briefly explained. In Section II-B, the condition for both flying and sticking capabilities is derived. These are simulated in Section II-C. Finally, conclusion and future works will be discussed in Section III.

## II. MICRO AERIAL VEHICLE TYPE WALL-CLIMBING ROBOT MECHANISM

### A. *Steps for mode change*

In Fig. 1, the 3D model of the proposed robot system is shown. As mentioned previously, it has flight ability with four rotors that make thrust forces and the forces also make the robot stickable on the wall. After sticking on the wall, the robot can move on the wall with 4 wheels. In addition, ultrasonic sensors are installed to detect the range and pose from the wall. The wireless camera is installed for an application that observes the surface of a wall from a remote place.

Various solutions can be used to stick the robot on the wall when the robot is in flying on the air but in this paper, just a simple solution is selected to show a feasibility of the sticking mechanism. When the robot is flying around the wall, the range and pose can be detected by ultrasonic sensors. Then,

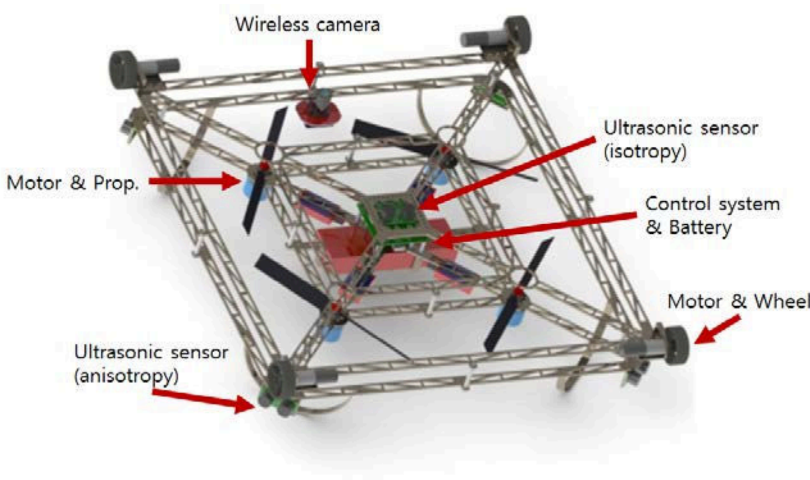


Figure 1. 3D CAD model of the prototype for the feasibility test

the robot moves close enough to the wall to contact with the wall. After contact between the wall and two wheels, the robot changes the pose to stick on the wall. In this time, the thrust forces push the robot to the wall to make the enough frictional forces between the wall and wheels. Finally, the robot does not slip on the wall and can move on the wall with four wheels. The reverse steps make the robot detach from the wall. For the details of the sequential steps, please refer to [11].

## B. Condition for flying and sticking

It is the main concept of this robot mechanism that the proposed robot based on the quadrotor system uses thrust forces not only to fly but also to stick on the wall. As noticed from Fig. 2, the total thrust force ( $F_T$ ) is the sum of thrust forces ( $F_n$ ) by the four rotors and it must be greater than the total weight of the robot ( $W$ ).

$$F_T = \sum_{n=1}^{4} F_n \tag{1}$$

$$F_T > W \tag{2}$$

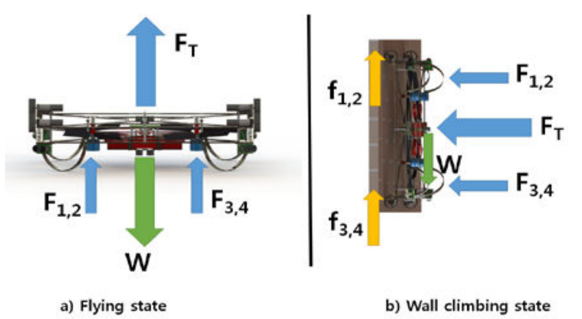


Figure 2. Force distribution.

From Fig. 2(b), the frictional forces ( $f_n$ ) between the wheel on the robot and the wall are calculated by the product of the thrust force ( $F_n$ ) and the frictional factor ( $\mu$ ) and the total frictional force ( $f_T$ ) is the sum of frictional forces. To avoid the slipping when the robot is stuck on the wall, the total frictional force ( $f_T$ ) should be greater than the total weight of the robot ( $W$ ).

$$f_n = \mu F_n \tag{3}$$

$$f_T = \sum_{n=1}^{4} f_n \quad \mu F_T \tag{4}$$

$$f_T > W \tag{5}$$

From the equations (2) and (5), it is noticed that the maximum allowable weight ( $W$ ) is dependent on the value of friction factor ( $\mu$ ) as follows:

$$\mu_{(>1)} F_T > F_T > \mu_{(<1)} F_T > W \tag{6}$$

As noticed from the equation (6), if the total weight of the robot ( $W$ ) is designed for the case that the frictional factor ( $\mu$ ) is less than 1, it also satisfies another case that the frictional factor ( $\mu$ ) is greater than 1.

## *C. Simulation and experiment*

To show the feasibility of the proposed mechanism, some simulations in 2-D environment by WORKING MODEL 2D as in Fig. 3 and an experiment with a prototype as in Fig. 4

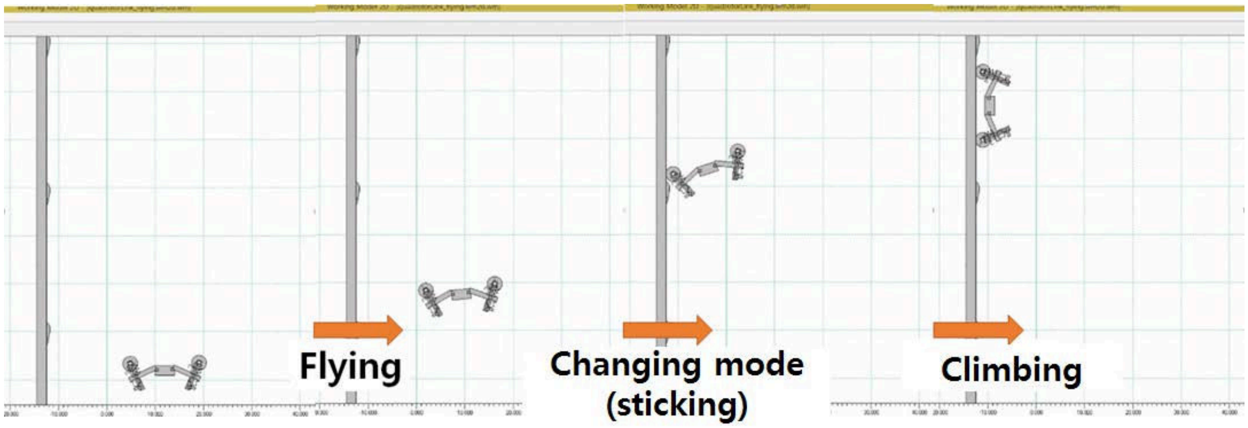


Figure 3.Simulation with Working Model 2D software

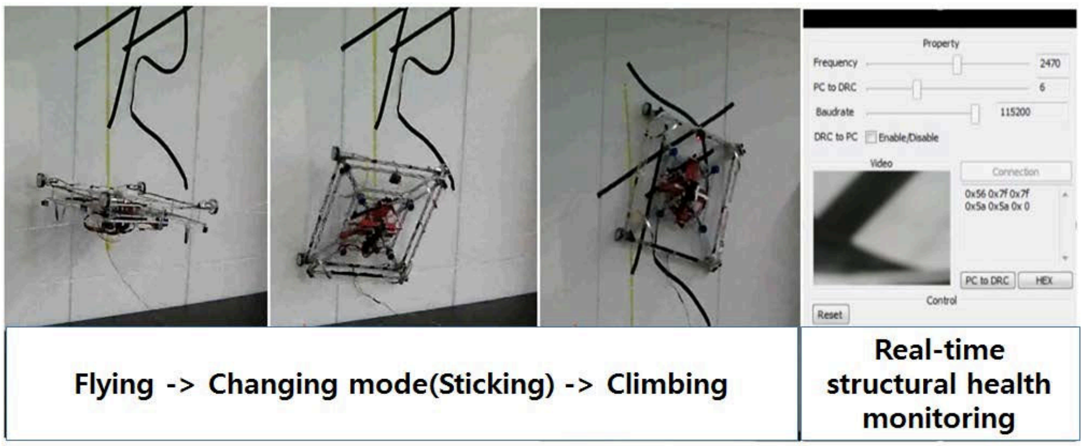


Figure 4. Experiment for the mode change from flying to climbing on the wall and real-time structural health monitoring.

have been conducted. Simply, in these experiments, roll, pitch and yaw are controlled by a PID controller with inputs calculated by the equations (7) - (10) [12].

$$\text{altitude input} = T_1 + T_2 + T_3 + T_4 \tag{7}$$

$$\text{roll input} = -T_1 + T_2 + T_3 - T_4 \tag{8}$$

$$\text{pitch input} = -T_1 - T_2 + T_3 + T_4 \tag{9}$$

$$\text{yaw input} = T_1 - T_2 + T_3 - T_4 \tag{10}$$

The feasibility of this robot mechanism was shown from the test for the mode change from flying to sticking on the wall as in Fig. 4. The proposed robot can fly but also stick on the wall, if it satisfies the condition that the robot weight ( $W$ ) is less than the product of the total thrust force ( $F_T$ ) and friction factor ( $\mu$ ) between the robot and the wall. Also, it can be used for the structural health monitoring with some equipment such as a camera. For example, the crack on the surface of wall can be detected in real-time using the camera installed on the robot. As shown in Fig. 4, the lines on the wall are detected while the robot climbs on the wall through the wireless camera in real-time.

## III. CONCLUSION

In this paper, a micro aerial vehicle type wall-climbing robot mechanism has been proposed. The robot is based on the quadrotor with four wheels to move on the wall. As derived previously, it has flight and sticking capability on the wall, if the robot weight is less than the product of the total thrust force and friction factor between the robot and the wall. As a result, the maneuverability and safety are more enhanced than the conventional non-infrastructure-based wall-climbing robots. The robot can perform several missions such as cleaning, maintenance for large structures or surveillance by installing an additional onboard equipment. As shown through the experiments, once a camera is installed on the robot, it can be used to inspect a wall of large structures.

Although the feasibility of the proposed robot has been shown by the experiments with a prototype, the pose control should be improved to be used in the real environment due to the vibration effect. The vibration effect makes the sensor data of IMU unstable. As a result, it makes the control very hard. In the future, the vibration effect to IMU will be mitigated by some anti-vibration solution to test in the outdoor environment.

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