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Propeller type wall-climbing robot for inspection use

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Abstract

Use of a wall-climbing robot for inspection or maintenance of wall surfaces has been anticipated for a long time. Three quite different models have been developed in our laboratory. The present model can move on a wall by using the thrust force of a propeller and can fly whenever it is required. Its mechanism and control system are discussed.

1. INTRODUCTION

A robot capable of moving on a vertical wall has been looked forward to a long time. It could be used for wall inspection, rescue and fire-fighting in high-rise buildings. Three quite different types of wall-climbing robot models have been developed in our laboratory over the last 20 years. The first model, shown in Fig.1, has a large sucker and crawlers as a moving

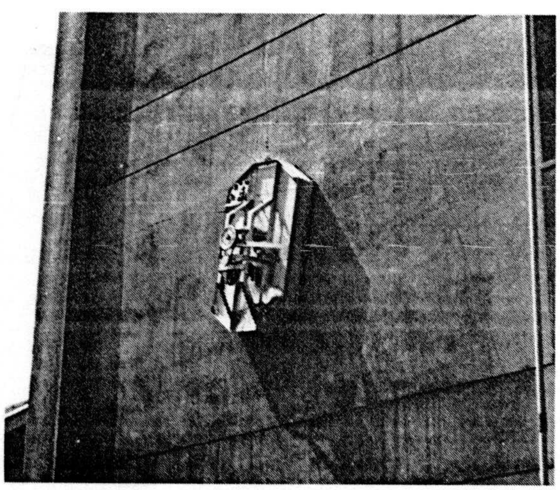

Figure 1. A large sucker model.

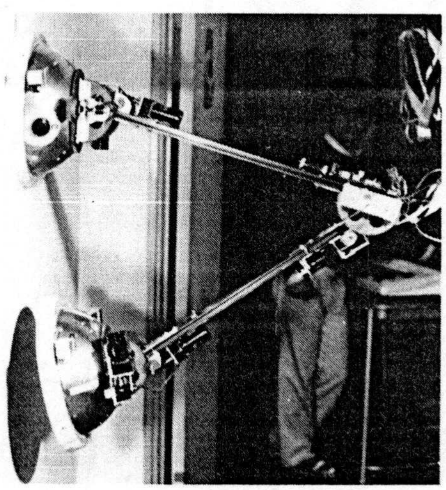

Figure 2. A biped walking model.

mechanism.[1] Recently, many varieties of this type model have been developed for wall inspection in Japan. The second type, shown in Fig.2, is a biped walking model, which has a small sucker on each foot.[2][3] As this can be applied to almost all irregular wall surfaces, it has a wider applicability than the former.

In general, the walking motion is not very quick so that the walking model takes much time to climb up to higher places on the wall. Unfortunately, a robot would be required to climb up to higher places on buildings in a short time for the inspection or emergency purposes. The third model, shown in Fig.3, aims at these purposes.[4]-[8] It has propellers, and their thrust forces are inclined a little toward the wall to make use of the frictional force between the wheels and the wall surface, as well as to support the robot itself. Sometimes unexpected strong winds occur on the walls of high-rise buildings. In such cases, the control system to compensate for the wind load is important to avoid having the robot falling from the surface. This situation has been previously discussed in detail in Refs.(6)-(8).

On the other hand, often there are many obstacles at the lower part of buildings, such as trees, eaves, entrances, etc.. In such cases, it would be useful if the robot could fly over these obstacles and can reach the upper wall surface. Moreover, if the robot falls from a higher place on the wall surface by accident, it needs to make a soft landing to avoid endangering itself or its surroundings. These maneuvers can be done by employing a mechanism and control system enabling it to fly. As the robot has an enough thrust force to sustain itself in the air, it can fly or land. This is the fourth type model and its control mechanism is discussed in this paper.

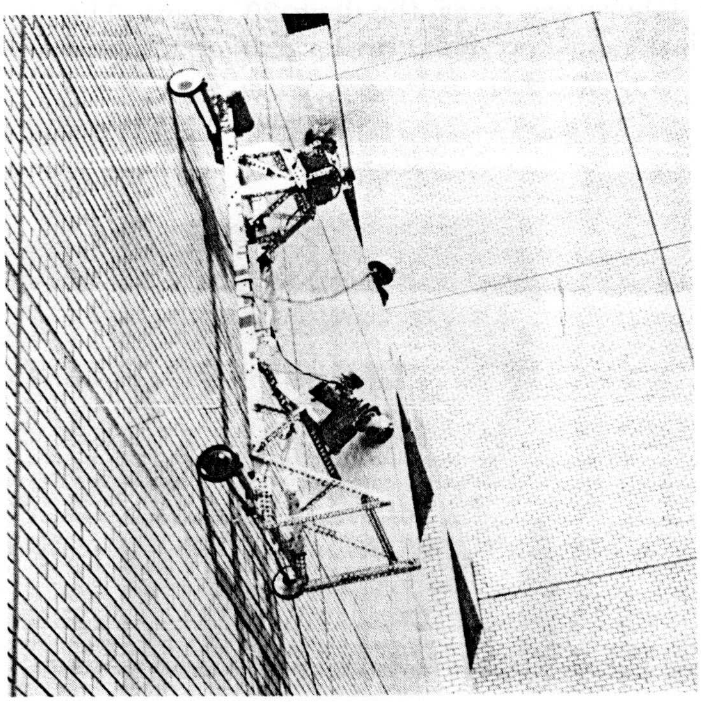

Figure 3. A propeller type wall-climbing robot model.

2. MECHANISM OF THE ROBOT

2.1 Wall-climbing mechanisms of insects and small animals

The wall-climbing mechanisms of insects and small animals are of interest. A black fly, a grasshopper, a small frog and many other small animals can walk on vertical window glass. They have their own spacial feet mechanisms. Most of these small insects and animals have microscopic mechanisms utilizing adhesive cilia or body skin.

On the other hand, a small bee, like the one shown in Fig.4, is shown flying along a glass surface. It can sustain its weight by the reaction of the air flow produced by its wings. This, then, is an another mechanism for moving on vertical surfaces, and is the model for the present fourth type of robot mechanism.

2.2 Thrustor of the wall-climbing robot

An example of a conceptual model is shown in Fig.5. A conventional thrustor is a combination of an engine and a propeller. Although a small jet engine and rocket motor can be made available for emergency use, they are expensive and noisy compared with the conventional engine and propeller. There are two types of propellers : those with larger diameters similar to helicopter rotors, and smaller ones similar to light plane propellers. The former can produce a larger thrust force for the same engine power. However, the wind load is larger, and it is difficult to design a wall-climbing robot using this type. Therefore, the latter has been used for the model concerned here.

Figure 4. A small bee flying along a glass.

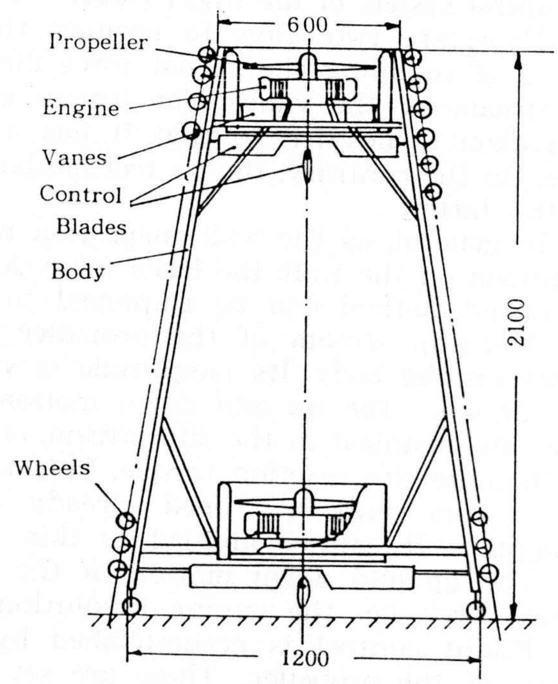

Figure 5. Schematic of a conceptual model.

2.3 Mechanism of the flight model

To use a robot for the inspection of a wall surface, first, it is necessary for the robot to reach and attach itself to the wall surface at the lower part of the building. However, often there are obstacles such as trees, eaves and entrances at the lower part of the building. In such cases, it may be difficult for the robot attach itself to the wall directly. As the robot has enough thrust force to lift itself up in the air, it can fly over these obstacles employing a suitable mechanism and control system.

Almost the same situation will occur at higher parts of the buildings, where there are long eaves or steps on the wall surface.

Moreover, there is danger of the robot falling from the wall surface by an unexpected strong wind or accident. In such cases, the robot must make a soft landing, or the fall would be very dangerous for the robot itself and its surroundings. These situations can be avoided by designing the robot so that it is able to fly or land.

However, its major purpose is not flying like a helicopter, but moving on a wall surface using its wheels, since moving on a wall is safer. Therefore, it has a long body with many wheels and its thrust force has a component toward the wall to produce frictional force between the wheels and the wall surface. The robot was designed for this requirment. Two propellers have been installed at the top and bottom of the trapezoidal body. Many light weight wheels have been arranged on the outside of the body. So that, any outer plane can touch the wall surface. When the robot touches the wall, the thrust force axis is inclined a little toward the wall, and the frictional force of the wheels is produced automatically.

2.4 Control system of the flight model

There are two ways to produce the control force in the air. One is a method of inclining the thrust force directly. The other is that the propeller slip stream by the vanes. The former can produce larger force, however, its mechanism is heavier, so that it has a larger time lag of control than the latter. On the contrary, the control mechanism is easy to construct and regulate for the latter.

In general, as the wall-inspection robot is used in a calm or weak wind conditions on the wall, the large force does not need for the control. Therefore, the latter method can be employed to the flight model.

The slip stream of the propeller rotates and thus producing reaction torque on the body. Its magnitude is variable for changing the thrust force depending on the up and down motion of the robot. The regulating stream vanes are installed in the slip stream, and a couple of the vanes are controlled to eliminate the reaction torque. This motion is sensed by a gyroscope. Such a gyroscope unit has been already developed for the control of model helicopters. It can be applied to this model with a small adjustment.

The up and down motion of the robot is produced by controlling the thrust force, i.e., the engine revolutional speed.

Flight control is accomplished by control blades installed in the slip stream of the propeller. These are set in the down stream of the regulating vanes. Two blades are set closswise. Each of them are controlled independently to produce a side force in any direction.

Both the regulating vanes and the control blades are employed in each engine slip stream, as shown in Fig.5.

As the body is symmetrical along the thrust axis, a righting force is not produced by the thrust force, when the robot is inclined in the air. Therefore, the control blades in each engine slip stream should be adjusted independently to produce a righting force around the center of gravity. This control occurs automatically by the onboard computer.

The flight control can be summarized as follows :

(1) avoidance of the rotational motion produced by the reaction torque is accomplished by the automatic control of regulating vanes ;

(2) the up and down motion of the robot is controlled manually by the engine revolutional speed ;

(3) the side movement of the robot is developed by the side force produced by the control blades ; and

(4) the control of inclined angle of the body is made by the independent control of the upper and lower blades.

3. MECHANISM AND TESTING OF THE LABORATORY MODEL

3.1 Mechanism and control system of the laboratory model.

Before the construction of a flight model, an investigation was carried out by using a laboratory model, shown in Fig.6. It had a mechanism and control system similar to the flight model. It was designed to obtain experimental data easily. The mechanisms and communication system were as follows :

(1) the rotational mechanism,

(2) the up and down motion,

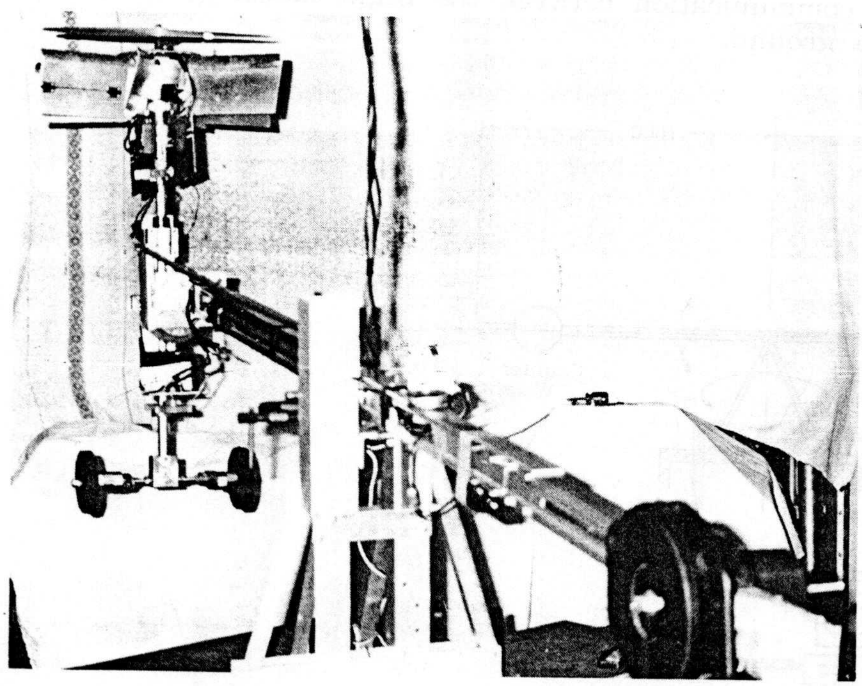

Figure 6. A laboratory model.

(3) the side movement, and
(4) wireless communication between the computer and the model.

A model which had a propeller driven by a motor and a simply-shaped body was set at the end of a bar. At the other end of the bar a counter-weight was installed. When the propeller was rotating, the weight was almost balanced. The bar was supported with a hinge and a pivot, so that it could move both up and down, and to the sides. The model was also supported by a similar mechanism at the end of the bar. It could rotate about the motor axis when the reaction torque of the propeller was produced. The laboratory model had five degrees of freedom.

The rotating angle produced by the reaction torque was sensed by a potentiometer. It was adjusted by regulating vanes with feedback signals from a computer. The movements up and down and to the sides were controlled by regulating the motor revolutional speed and the angle of the control blades, respectively. As each control was independent, the equations of motion were simple. The angles and angular velocities were taken as the feedback veriables in each direction.

3.2 Wireless communication system and its preliminary testing

Wireless communication is required to control the prototype in the air or at higher places on a wall. The radio controller of a model plane was employed to simulate the control system for the laboratory model. As shown in Fig.7, the sensor signals from the model were given by wire to the computer. The feedback signals to the model were given by radio signals. Two channels were used. These were the control signals to the servo-motors of the regulating vanes and control blades. The preliminary experiment demonstrated that this method was an effective and easy way to control the robot. This can be developed for the mutual communication between the flight model in the air and the computer on the ground.

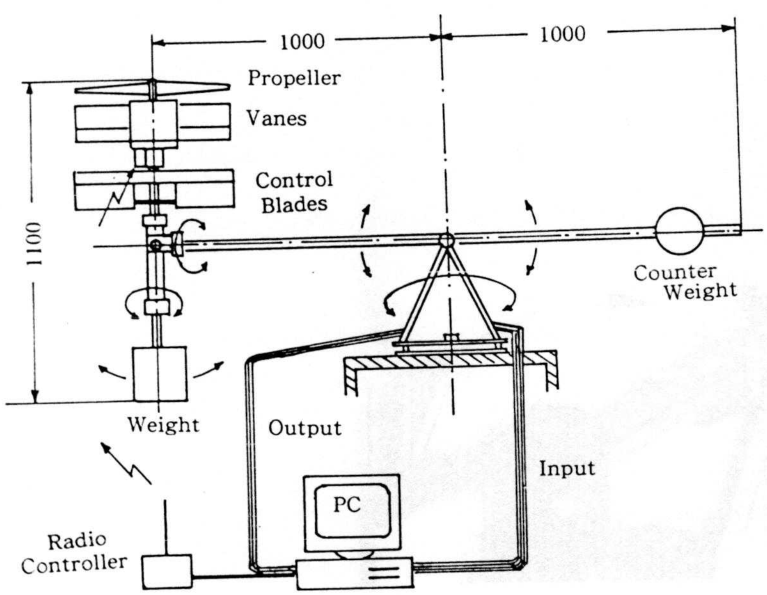

Figure 7. Schematic of a control system.

3.3 Experimental results

The experiment was carried out in three stages. First, the rotation of the model by the reaction torque could be controlled easily by the vanes, and the model could be fixed at any position of rotation. For the flight model, this control will be accomplished by using a gyroscope unit, which has been widely used for model helicopter control.

The second control was an up and down motion of the model. This was sensed by a potentiometer as the inclination angle of the bar at the support point. The model could be fixed at a given height by controlling the motor revolutional speed. For the flight model, the height control would be made manually.

The third stage was the movement of the model to the sides. This was accomplished by changing the control blade angle. Strictly speaking, the magnitude of the thrust force might be changed by controlling the blade angle, since the drag force of the blade decreased the thrust force. Therefore, the revolutional speed of the motor had to be changed to maintain a constant height. However, as the drag force was small compared with the side force, this effect did not appear in the model. In this case, a constant side force was acting on the model, and the position could be adjusted by feedback control of the rotational angle and the angular velocity of the bar.

4. CONCLUSION

Three different types of wall-climbing robots have been developed in our laboratory. The first model had a large sucker and could be utilized on flat and/or wide wall surfaces. The second was a biped walking model, which had a small sucker on each foot. This could be applied to almost all irregular wall surfaces. The third model could move on a vertical wall at high speeds. It had propellers and the thrust force supplied both the forces to lift the robot itself up and produce the frictional force between the wheels and wall surface to be safe on a wall.

When the third model is employed to inspect a wall surface, it is necessary for it to reach and attach itself to the wall surface, at first. Often there are obstacles at the lower parts of the buildings, such as eaves, trees, entrances, etc.. Therefore, it would be very useful, if the robot could fly over these obstacles and reach the upper wall surface. Moreover, when the robot falls from the wall surface by accident, a soft-landing control has to be employed to avoid danger to the robot and the surroundings. For these purposes a flight model has been considered. The mechanism and control systems for such maneuvering have been discussed. A laboratory model was constructed and tested. As a result, it was demonstrated that the laboratory model could be controlled easily, and similar control methods can be applied to the flight model. The flight model is now in preparation.

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