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Research on Suspended Fire Fighting Robot Prototype

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Abstract. A suspended fire fighting robot was presented, and the prototype was developed. The robot changed its posture by the blowing forces from the fans; the PID algorithm was analyzed and applied to control the rotating speeds of the fans in order to realize posture adjustment. A high speed propeller driven by an engine pushed the robot approach to the target; the relation between steering angle and thrust force was studied; a sliding table structure was developed to make the robot move steadily by changing the gravity position; the control algorithm of the propulsion system was analyzed.

Introduction

With the development of the society, more and more high buildings emerged, high building fire disaster also happened frequently [1, 2]. The existing fire fighting equipment are not useful in the high-rise building fire, and those developed high building fire fighting robots had some disadvantages in practical application. This paper presents a fire fighting robot suspended below a helicopter [3, 4], its working principle is shown in fig.1. The working process of the robot is that a helicopter carries the robot to the firing building; the robot descends itself to the firing floor, using a sensor to detect the external force, control the balance by a program, and the control algorithm makes the robot rotate to the building; then the robot detects the distance between building and itself by sensor in real-time, a propulsion system makes the robot close to the building; the camera on the robot can monitor the fire site; through the adjustment of injection angle, the fire fighting gun automatic sprays; when the fire is almost quenched, the firemen in the robot get into the building and carry out fire rescue work, sent the injured into the robot; in the end, the helicopter carry them away from the building.

Fig. 1 Suspended fire fighting robot working principle diagram

Develop a full functional fire fighting robot requires big investments with uncertain risks, so a prototype for testing is developed to verify its feasibility. The fire fighting robot prototype is shown in fig.2, its appearance size is 1 meter long, 0.7 meter wide and 1 meter high. On the top of the robot, a winch is installed; the winding steel wire in the winch realizes the robot moving up and down. The prototype uses four fans to balance external forces and realize rotation, with the control algorithm making the front of the prototype face to the target. CCD camera and ultrasonic sensor are installed at the front of the prototype, at the back of the robot installed engine and propeller as the propulsion system. At the bottom, a spray pipe is installed, using stepping motor to control the jet angle.

Fig. 2 Suspended fire fighting robot prototype

Posture adjustment system

The prototype installs four same size fans, whose diameter is 300mm, by blowing from the fans make the robot rotate, using frequency converter control the speed of the fans to adjust the blowing force. No.1 fan or No.3 fan can make the robot rotate in clockwise, No.2 fan or No.4 fan can make the robot rotate in anti-clockwise. No.1 and No.2 fan are used as the main drives for attitude control, No.3 and No.4 fan are used to balance external forces, rotating diagram is shown in fig.3.

The principle of posture adjustment is: the robot rotates in low speed to the set position with both sides of the fans in same rotating speed, robot keep in that position because of rotation resistance. The key to realize the posture adjustment is to build a relationship between rotating angle and frequency.

$$d\theta = \frac{a}{2}\int_{t1}^{t2} d^2 t + \omega\int_{t1}^{t2} dt \quad (1)$$

$$\frac{F1 - F2}{M} = a \quad (2)$$

$$F_1 = k_1 n^2 \quad (3)$$

$$n = k_2 p \quad (4)$$

$$\omega = \omega_0 + a * t_1 \quad (5)$$

$$d\theta = \frac{k_1(k_2p)^2 - F_2}{2M}\int_{t1}^{t2} d^2t + [\omega_0 + \frac{k_1(k_2p)^2 - F_2}{2M}t_1]\int_{t1}^{t2} dt \quad (6)$$

Where, F_1 - Blowing force; F_2 - system resistance; a - acceleration; n - rotating speed; p - frequency value; M - robot quality; k1, k2 - ratio value.

The suitable control of the frequency converter output can realize the rotation control of the robot. Electronic compass detects the angle θ relative to earth's magnetic field in real-time. If angle θ is less than angle δ, No.2 fan is activated to make robot anti-clockwise rotate, if angle θ is big than the angle δ, No.1 fan is activated to make robot clockwise rotate.

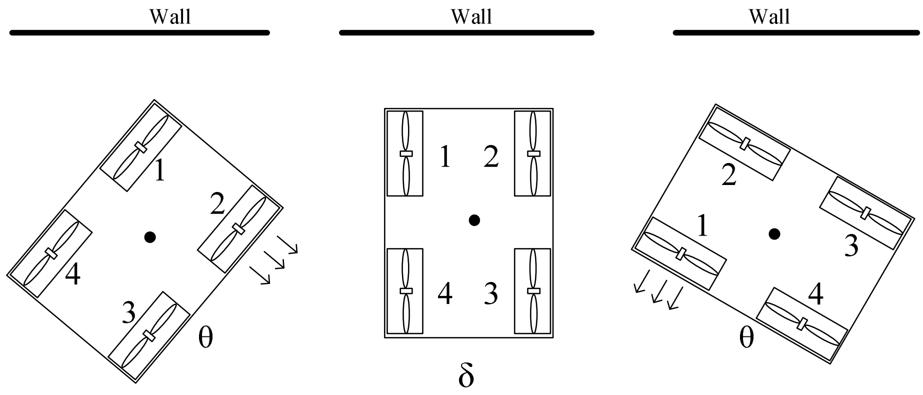

Fig. 3 Robot posture adjustment system diagram

PID algorithm has the advantages of simple structure, strong robustness and easy to realize[5], PID algorithm is used to control the rotating speed of No.1 fan and No.2 fan, the relationship is built between angle β and frequency to realize posture adjustment.

$$u_{(t)} = K_p\left[|\beta|(t) + K_D \frac{d[|\beta|(t)]}{dt}\right] \quad (7)$$

$$\beta = \theta - \delta \quad (8)$$

When $\beta < 0$, $u_{(t)}$ input object is from No.2 frequency converter, When $\beta > 0$, $u_{(t)}$ input object is from No.1 frequency converter. Set target angle as 180° with different start angles to test the algorithm, test results were shown as table 1, the angle adjustment accuracy was within 5°.

Table 1 Robot posture adjustment experiment data

test number	start angle(°)	target angle(°)	time(s)
1	206	180	19
2	143	183	24
3	223	184	27
4	128	177	36
5	121	181	37
6	247	185	41
7	108	176	43

Propulsion system

The robot is suspended in air, with a high rotating speed propeller providing a thrust force, ultrasonic sensor detecting suspension height and the distance between robot and wall, the controller calculates the requiring thrust force which makes the robot get close to the target in setting distance. The robot propulsion system diagram is shown in fig.4.

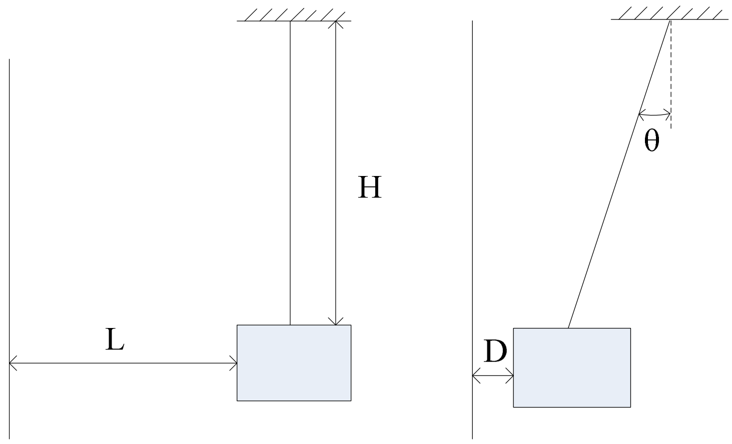

Fig. 4 Robot propulsion principle diagram

Based on setting distance X and suspension height H, the trigonometric function is used to calculate angle θ.

$$\sin\theta = \frac{X}{H} \tag{9}$$

Where, θ- angle; H - robot suspension height; L - sensor measured distance; D - setting distance; X - offset distance, X = L – D.

According to the calculated angle and the gravity of the robot, the thrust force can be calculated.

$$F = G \bullet \tan\theta \tag{10}$$

Where, F - thrust force; G - robot gravity.

The actual angle θ is smaller than 6 ° , so sinθ≈tanθ, the calculate formulation changes to

$$F = \frac{G(L - D)}{H} \tag{11}$$

Robot gravity G is already known, by measuring L and H with sensor, according to the setting distance D, the thrust force can be calculated.

In the actual propulsion, robot turn upward, controlling the gravity position could avoid upward. A sliding table structure is composed with stepping motor, rail, screw, loading platform, controlling motor rotation can realize the adjustment of gravity position. To realize steady movement, different steering angles with different platform displacement are tested, platform displacement S and steering angle α are drawn into the relationship in curve as shown in fig.5, according to the experimental curve, we build a function between platform displacement and steering angle.

$$S = -0.22\alpha^2 + 21\alpha - 48 \tag{12}$$

Set screw motor speed as 1000r/min, according to the steering angle to control platform displacement with the function shown above, the robot realized steady propulsion in the actual test.

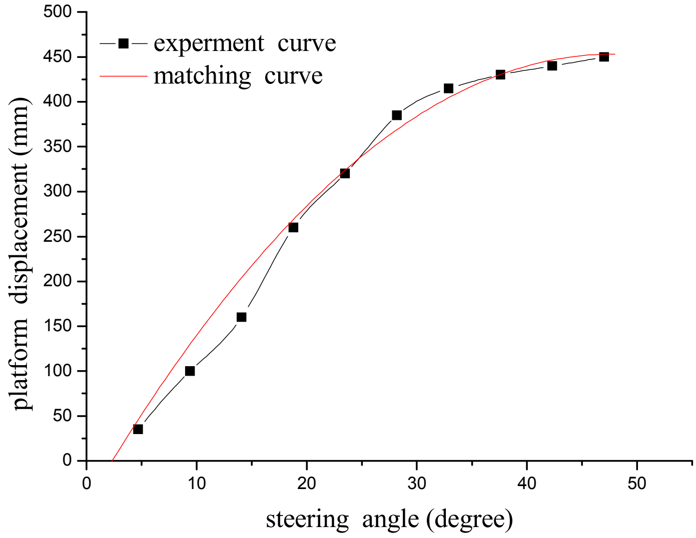

Fig. 5 Relationship between steering angle and platform displacement

Accuracy control of the thrust force is made to realize robot propulsion distance control, the actual control object of robot propulsion system is steering gear, by setting the steering angle to adjust the engine speed and finally change the thrust force. We find out the relationship between steering angle and thrust force in propulsion control system. Through the test of different steering angle in different thrust force, the test results are shown in fig.6. According to the drawing, the function between force F and steering angle α is built.

$$F = -0.0425\alpha^2 + 4.068\alpha + 11 \quad (13)$$

The function between setting distance D and steering angle α for propulsion control system is:

$$-0.0425\alpha^2 + 4.068\alpha + 11 = \frac{G(L - D)}{H} \quad (14)$$

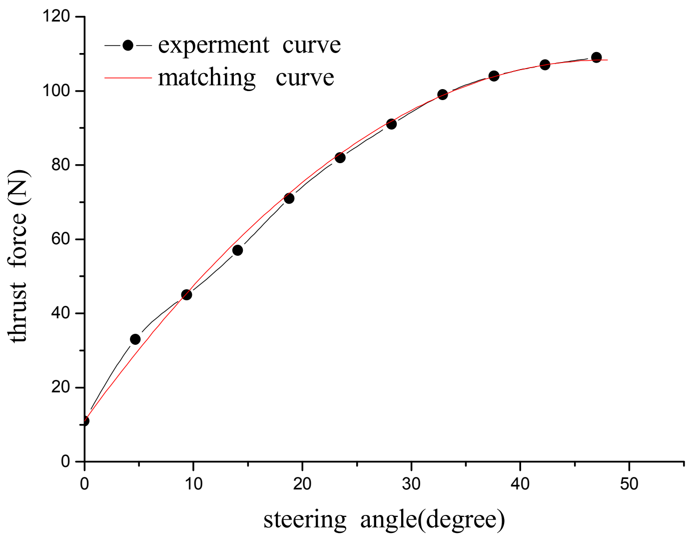

Fig. 6 Relationship between steering angle and thrust force

The propulsion control system test was done, the robot was suspended in height of 4.5 meters, setting different distance D and the actual distance were shown as table2, the test results showed that the control precision of the propulsion system was within 30mm.

Table 2 Robot propulsion experimental data

setting distance(mm)	200	180	150	120	100	80	50	30
actual distance(mm)	225	202	168	135	84	68	49	43

Conclusions

(1) A suspended fire fighting robot is presented; a prototype is designed and manufactured.
(2) PID algorithm is used to control the rotating speed of the fans to realize posture adjustment; the experiment tests show the adjustment accuracy within 5 degrees.
(3) The propulsion system is constituted by engines, propellers, rod, steering gear, ultrasonic sensor, and a sliding structure, the control of gravity position is made to realize steady movement, the propulsion control algorithm is analyzed, test results show the propulsion system accuracy within 30mm.
(4) The experiments verify the feasibility of suspended fire fighting robot.

Acknowledgements

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