Frog Fire-Fighting Robot

Yu-Xuan Li, Qing-Kuan Kung, Ming-Yu Yin, Shou-Xin Zu
Professor Lecturer Lecturer Assistant
Dalian Light Industry Institute

Baoding Jie No 1
Dalian, P.R. China

Abstract

This article describes the structure, moving mechanism and control system of the frog fire-fighting robot, as well as its features which has been studied and manufactured by the authors. The robot can do interim juming up and movement using fire-fighting water as its moving power. It can be controled by telecontrol device or microprocessor in its body. It also be analysed theoretically to the hydrodynamic functions of the jumping movement and the horizontal movement in this article.

1. Introduction

When fires take place in civil, industrial buildings and porks, store houses as well as constructionsides. It is very difficult for firemen to approach the fire, so the effect of extinguishing fire is very poor, and it is often takes place for the firemen to be dead and hurted.

The frog fire-fighting robot reserched by authors can undergo higher temperature and need not any oxygen, comparing to the human being. It has self-discipline ability and can approach the center area of the fire as nearly as posible. which will play a important role in improving the extinguishing effect and declining the death-rate.

The robot does not need to be 'permanent'. It should be allowed to be 'victim' during the period of extinguishing, if necessary. The robot's structure should be simple and the cost low. In that case, we should aviod adopting the device with high technique which is expensive as posible as we can.

2. Structure

The frame of the robot is made of hard aluminum-alloy hollow tube which is a good heat conductor and light in which cooling water guarantees its existing ability in the high temperature circumstance.

The power source of the movement and the control operation mainly is the water of the extinguishing fire, (as well as electricity). The water is supplied by through the canvas tube the robot carries.

The weight of the whole robot is less than 50 kg. Being carried to the fire area by two firemen before goes nearer, the robot can jet water to extinguish the fire.

After it is put near the fire, the robot can look for the fire source and move towards it automatically relying on the water as its power. It is to be considered that there are many blocks in the area, so it is imposible for the robot to move on the wheels. We adopt the reaction of the jetting water to make the robot jump up. After a short time gap, the reaction force of the backward horizontal jetting water makes the robot go forward. In this way, there is no wheels and bearings to be damaged because of the long time high temperature, which will make the robot work more reliable.

We use infrared temperature sensor and servo system which can aim at the fire source automatically and instruct the water jets to change their direction so that the direction of the robot movement is to be changed.

In order to decline the weight of the robot and the resistance of carrying the water tube as the robot goes forward, we only use a water supplying tube. The water can be used for the robot's moving or extinguishing fire when the robot still, respectively.

The robot can receive the instructions by means of a radio telereceiver in it. When it gets 'self-control' instruction, the robot can search heat area and control the directions of its moving and of water jetting automatically.

3. Rising and moving

By the name of frog fire-fighting robot is by reason that its movement imitates frog's style of jumping forward, i.e. that the water of extinguishing fire jets down vertically through the jet mouths makes the robot jump up. After a short time gap, the reaction of the horizontal jetting water makes the robot go forwards.

As to the water used for extinguishing fire, in general in China, the specified pressure is $2.45 \times 10^6\ Pa$ and the rate of flow is 13 liter per second. The water comes from through the canvas tube which connected with the main valve.

When robot jumps up, the water tube will raise up too which pulls a long piece of canvas tube in full of water, which will affect the robot's jumping height. In order to avoid that, the canvas tube is floated with the robot in longitudinal direction, i.e. the water tube can turn around the X axis.

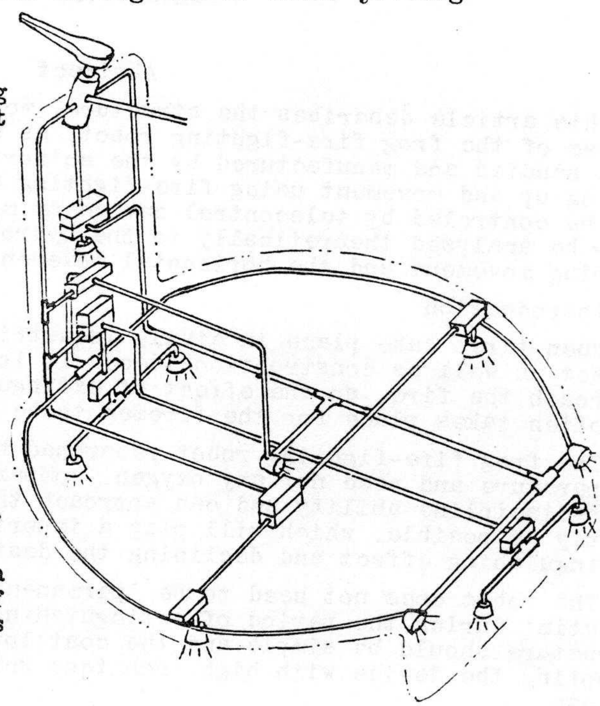

Fig.1-the tube system of the robot

The main water inlet connector connects with a electrohydraulic valve with three positions. The function of mid-position is to close entirely, the up-position is to open the water way for extinguishing fire and the down-position is to open the water way for the raising and moving.

When the down-position is open, the pressured water flows, via the hollow frame, to the six vertical jets fited on the bottom of the chassis. There are sequence valves in the front of the jets. When the pressure of water goes up to the given value, the valves open and the jets eject water down to the ground. Relying on the reaction force of the pressured water, the robot rises. When the robot rises to a certain height, the closed valves of the movable jets with delay action are open, relying on the reaction force of the horizontal water jets, it moving forward.

4. Hydrodynamic analysis

4.1 Vertical jumping force

Assuming that the robot has several vertical hydrodynamic jets, the mass of the robot is m_R : the mass of the pressured water is m_w: the cross section of a single jet is A_f and the pressure on the outlet cross section of the jet is P_f. Considering the atmosphere under the condition of fire area as a constant, therefore, we use the value of the pressure gauge as P_f. That P_f is the function of the height the robot rising to will be analysed as follows:

It is assumed that the whole robot is the fluid control body in the fluidal way, and than the velosity of robot's jumping up vertically is $\vec{v}$. Therefore, the momentum control equation of the time at any moment can be written as.

$$\sum \vec{F} = \frac{d}{dt} \int_R \rho_R \vec{v}_R dR + \int_s (\rho_w \vec{v}_w) \vec{v}_{wr} \cdot d\vec{s} \qquad (1)$$

In Eqn. 1:

$\vec{v}_{wr}$ is the relative velosity of the fluid on the jet outlet control plane against the control plane;

$\vec{v}_w$ is the absolute velosity of the fluid on the jet outler control plane.

If the fluid relative velosity in the control body is $\vec{v}_{Rr}$, therefore, the fluid absolute velosity in the control body would be $\vec{v}_R = \vec{v} + \vec{v}_{Rr}$, and the fluid absolute velosity on the jet control plane is $\vec{v}_w = \vec{v} + \vec{v}_{wr}$. Then Eqn.1 becomes

$$\sum \vec{F} = \frac{d}{dt} \int_R \rho_R (\vec{v} + \vec{v}_{Rr}) dR + \int_s \rho_w (\vec{v} + \vec{v}_{wr}) \vec{v}_{wr} \cdot d\vec{s} \qquad (2)$$

After being extended, Eqn.2 becomes

$$\sum \vec{F} = \frac{d}{dt} \int_R \rho_R \vec{v} dR + \frac{d}{dt} \int_R \rho_R \vec{v}_{Rr} dR + \int_s (\rho_w \vec{v}) \vec{v}_{wr} \cdot d\vec{s} + \int_s (\rho_w \vec{v}_{wr}) \vec{v}_{wr} \cdot d\vec{s} \qquad (3)$$

For the absolute velosity of the whole robot always is $\vec{v}$, hence, the part of Eqn.3 becomes

$$\frac{d}{dt} \int_R \rho_R \vec{v} dR = \frac{d\vec{v}}{dt} \int_R \rho_R dR + \vec{v} \frac{d}{dt} \int_R \rho_R dR \qquad (4)$$

and for $\vec{v}$ bears no relation to control plane, therefore, another part of Eqn.3 becomes

$$\int_s (\rho_w \vec{v}) \vec{v}_{wr} \cdot d\vec{s} = \vec{v} \int_s \rho_w \vec{v}_{wr} \cdot ds \qquad (5)$$

In Eqn.4 and Eqn.5

$$\vec{v} \frac{d}{dt} \int_R \rho_R dR + \vec{v} \int_s \rho_w \vec{v}_{wr} \cdot ds = \vec{v} \left(\frac{d}{dt} \int_R \rho_R dR + \int_s \rho_s \vec{v}_{wr} \cdot ds \right)$$

means that according to the law of mass conservation, the variational rate should be zero between the mass of the control body itself and the mass of entering and exiting the control body. Therefore, Eqn.3 can be written in the form

$$\sum \vec{F} = \frac{d\vec{v}}{dt} \int_R \rho_R dR + \frac{d}{dt} \int_R \rho_R \vec{v}_{Rr} dR + \int_s (\rho_w \vec{v}_{wr}) \vec{v}_{wr} \cdot d\vec{s} \qquad (6)$$

On the leftside of Eqn.6, the forces which act on the robot are

$$\sum \vec{F} = -m_R \cdot g + nP_f \cdot A_f$$

i.e. the difference between the gravity of the robot itself and the pressure of jet water.

First item on the right of Eqn.6

$$\frac{d\vec{v}}{dt} \int_R \rho_R dR = m_R \cdot \frac{d\vec{v}}{dt}$$

i.e. the inertia force formed by the acceleration $\frac{d\vec{v}}{dt}$ and the mass. $\frac{d\vec{v}}{dt}$, i.e. we want the acceleration of the robot rising.

Second item on the right of Eqn.6

$$\frac{d}{dt} \int_R \rho_R \vec{v}_{Rr} \cdot dR$$

is the momentum variafional rate in the control body and it should be zero.

Third item. considering that the relative velocity of the fluid at the jet mouth against the area integral is the flowout rate per unit time. and therefore it can be written as follows:

$$\int_s (\rho_w \cdot \vec{v}_{wr})\vec{v}_{wr} \cdot d\vec{s} = -\rho Q \cdot v_{wr} \qquad (7)$$

and Eqn.6 also can be written in the form

$$-m_R g + nP_f \cdot A_f = m_R \frac{dv}{dt} - \rho Q v_{wr} \qquad (8)$$

$$\frac{dv}{dt} = (nP_f \cdot A_f + \rho Q v_{wr} - mg)/m_R \qquad (9)$$

As to the robot rising process acted by the water power. it can be expressed by Eqn.9 comprehensively, but, in the fact, the function of each item in Eqn.9 is not all the same at the every period.

When the fobot is connected with the pressured water tube, at the instantaneous of the robot jumping up. the robot is subject to the water pressure. i.e.

$$dv/dt = (nP_f A_f - m_R g)/m_R \qquad (10)$$

After jumping up, the fluid flows through the jet at high speed and the pressure P_f reduces. The variations of the momentum and the pressure in Eqn.9 are subuect to the robot's acceleration, and the resistance of the fluid is declining with the increasing of the height. v_{wr} increases but P_f declines gradually. The relation between v_{Rr} and P_f should accord with the law of Bernoulli.

In the certain time, this process is a accelerating process. i.e. $dv/dt > 0$. Though v_{wr} goes up to the maximum value, there is the relation of $nv_{wr}\rho Q < m_R g$ therefore. when the supporting action of water column declines. $dv/dt < 0$, to the end $v = 0$. and than the robot falls. There is a coil-type spring filled with water at the bottom of the chassis in order to decrease the impulsive force when it falls to the ground.

If Eqn.9 is integrated. the robot jumping velocity will be obtained. But it is difficult that all items in the equation will be expressed by mathematical formulae and the analytic solution obtained. Our way is that if

$$P_f = P_{fo} - kh \qquad (11)$$

P_{fo} is system pressure. i.e. the pressure before the robot jumps up.

K varies directly as the jumping height if the pressure declining is linear.

v_{wr} can be solved according to Bernoulli equation, then using computer to do the numerical value integration, we can get the v value. When $v = 0$, i.e. the height of the robot jumping up to.

4.2 The action force of the curve tube

Fig.1 shows the pressured water's flowing process in the robot. According to the principle of momentum, the action force $\vec{p}$ to every curving section of the tube, i.e. to the robot, will be produced.

$$\vec{P} = \rho Q(\vec{V}_1 - \vec{V}_2) + (\vec{P}_1 A_1 + \vec{P}_2 A_2) \qquad (12)$$

In this instance, it can be considered as $|\vec{V}_1| = |\vec{V}_2|$, (considering that the total flowing velosity after being divided into several branches still maintains the above relation), $A_1 = A_2$ and $|\vec{P}_1| = |\vec{P}_2|$, and after flowing curvd tube several times

$$\sum \vec{P} = \rho Q(\vec{V}_0 - \vec{V}_e) + (\vec{P}_0 A_0 + \vec{P}_e A_e) \qquad (13)$$

Shown in Fig.1 $\vec{V}_0$, $\vec{P}_0$ are at the entering section of the canvas tube and $\vec{V}_e$ and $\vec{P}_e$ are at the entering section of jet. Therefore,

$$\sum \vec{P} = (\rho Q \vec{V} + \vec{P} \cdot A) \cdot \sqrt{2} \qquad (14)$$

the direction is the equal divided direction of Y and Z, i.e. the robot's front up direction. It must be considered to the variation of the momentum at jet tube. As a result of all above, the robot moves in the front up direction.

4.3 Horizontal moving force

It is assumed that frog fire-fighting robot has number j horizontal jets for the moving of the robot in horzontal direction, and the cross section of the jet mouth is A_p , and the fluid relative velosity at the exit section is v_{hr} and the horizontal moving velocity of the robot is $\vec{\mu}$. Therefore. the equation can be written as follows

$$m_R \frac{du}{dt} \overset{v}{=} \sum F_h + v_{hr} \cdot \rho Q \qquad (15)$$

The acceleration of the robot's horizontal movement can be calculated. $\sum F_h$, in Eqn.15, includes the canvas tube's pulling force, but we should keep the canvas tube in the state of being pushed forward. According to $\frac{du}{dt}$ in Eqn.15 and the jumping time in Eqn.9, the step distance also can be calculated.

5. Control

We use two ways of radio telecontrol and microprocessor automatic control. If the two ways are all disorder, we will use the way of control water pressure completely.

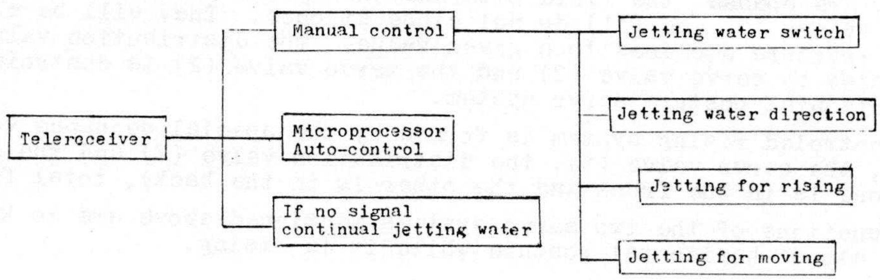

Fig.2 - The control way

Fig.2 shows the radio telecontrol way. The firemen can use the supershort wave radio telemeter with their own eyes near the fire area to control the robot. The telereceiver inside the robot which protected by the flowing water can do the following actions: 1) to open the water valve for extinguishing fire and to control the direction of jetting; 2) to close the valve of the water and to open onather water valve for the robot's rising and moving as well as to direct the moving direction. The water jettings of the rising and the moving will follow the sequence indicated by the hydrodynamic pressure system (see Fig. 3). After being risen, the robot's posture will become balance automatically.

Fig.3 shows the robot's hydrodynamic pressured system. The pressure of the water is $2.45 \times 10^{6}\ Pa$. The instructions sent by the radio telemeter or the microprocessor in the automatic system make the three positions/three ways electrohydraulic valve (1) ON/OFF. When the leftside is on, the fluid flows to the extinguishing fire jet, meanwhile. the pressured water flows through the electro-controled turnvalve (9) to the swing sylinder (11) to control the jetting direction of extinguishing fire and the moving direction. When the turnvalve (9) is at mid-position, the jetting and the moving directions will be controled by the servo valve (10). When the electrohydraulic valve (1) is on the rightside. the jetting for extinguishing fire will stop (by the instruction of telecontrol or microprocessor). The pressured water flows through the distribute valve (4) and then the sequence valves (3) and (3'), along the separate routes, to the left and right jets used for vertical rising. Because the structure of the sequence valves (3) and (3'), they do not be opened until the pressure goes up to the given pressure to guarantee the robot rising. Once they are opened, the fluid jets and the system pressure diclines. The sequance valves (3) and (3') do not close at once. They will be closed when the pressure declines to a given value. The distribution valve (4) is controled by servo valve (2) and the servo valve (2) is controled by the robot horizontal posture servo system.

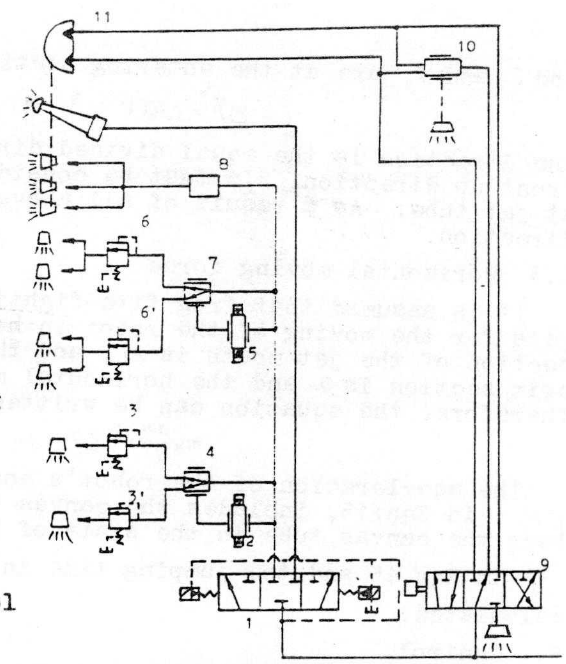

Fig.3-the hydrodynamic pressure system

The controled rising system is formed by the special sequance valves (6) and (6'), the servo valve (5), the distribution valve (7) and the two groups (one is in the front and the other is in the back), total four jets.

The functions of the two servo systems mentioned above are to keep the robot in almost horizontal posture while it is rising.

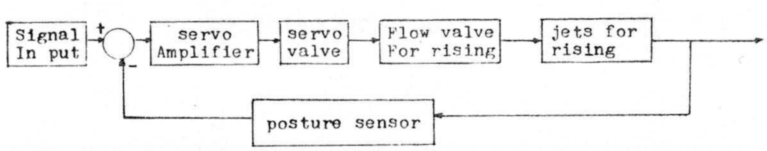

Fig.4-The horizontal posture servo system

The horizontal posture control servo system has two hotizontal posture sensors. One controls the two jets, the front and the back, to control the front and back horizontal posture around X axis; the other controls the left and right two jets to control the two sides horizontal postures around Y axis. We use vibration-type velometer to imitate the principle of the semicircular canals in ear.

The sensors' signals amplified by servo system oprate the servo valve and control the distribution valve to convey the pressured water to the left, right, front and back jets, respectively, to keep the balance of the robot while it is rising.

The pressured water in other route flows through the delay valve (8). (its function is that it is not open before the robot rises at a certain height), and then ejects from the three horizontal jets. The jetting of the pressured water horizontally make the robot moving forward. The moving direction is subject to the swing cylinder which controled by the servo valve.

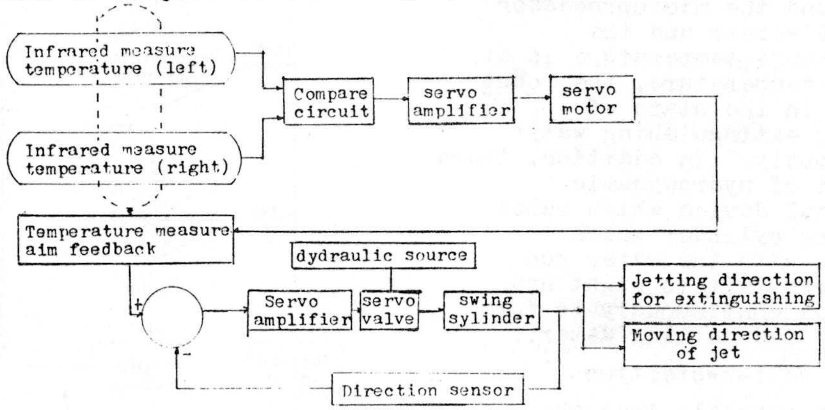

Fig.5-the servo system of automatic direction control

Fig.5 shows the servo system of automatic direction control. The up part is aim heat area servo system. The aim system consists of the two infrared sensors which fited together. The angle between the two sensors' aim directions is 60 degree. After the comparing circuits compare with the temperature electro-potentials which formed at the aim area, the signals which have been amplified by the servo drives the servo motor which control the aim system to form a feedback system.

As mentioned at the beginning, it is no need that the robot has high sensitivity. Hence, it is needed to be higher stability and damping. For instance. the left and right infrared sensors will have no reaction if the temperature difference is less than 150℃.

The aim movement signals which have been amplified by the servo drives the servo valve to convey the pressured water to the swing sylinder which makes the water gun point to the high temperature burning area. Meanwhile, the three moveable jets driven by the connecting rod point at the opposite direction of the water gun. If it is necessary, the jets will make the robot move towards the burning area.

When the tele-instruction makes the turnvalve (9) in the mid-position, i.e. the microprocessor will perform the control. After the microprocessor's automatic system starts (see Fig.6), at first, it will be tested whether the aim system points to the heat area and then the average values of the temperatures measured by the two sensors will be compared. 1). at the low temperature, the set value is less than 100℃, and the robot moves without ejecting any water for extinguishing fire; 2). at the mid-temperature, the set value is from 100 to 400℃, and the robot moves two times before it begins to eject water for extinguishing fire; 3). when the temperature is higher than 400℃, the robot will stop moving to eject water for extinguishing fire. The time of each ejecting is for 5 minutes, and then it repeats the circulation above.

The microprocessor we adopted is 3870 which is the cheap one.

The return function of the whoule robot is controled by the tele-control device trather than by the microprocessor.

Under some particular conditions, if the tele-control system and the microprocessor are in disorder and the circumstance temperature is at the mid-temperature, the robot will be in the state of ejecting extinguishing water continuously. In addition, there is a set of hydrodynamic mechanical device which makes the swing cylinder which connects with the water gun swing from left to right and viceversa continuously to form a fan-shaped jetting water.

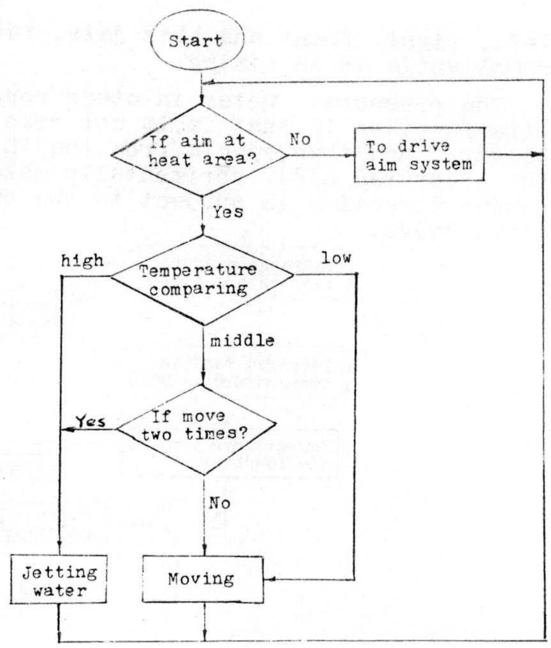

Fig.6 - Microprocessor control

6. The self-protection

It is possible that the extreme temperature in the fire area is sometimes higher than 1000℃. Therefor, it is important for the robot to be self-protection. The working temperature of the microprocessor, servomotor etc. is strict. Eventhough the working time is short, the temperature should not be over 80℃.

All frame is made of light, hard aluminium-alloy hollow tube in which the water flows. The source of cooling water comes from the discharge water out of the servo valve when the electrodynamic turnvalve is at the mid-position; when the electrodynamic turnvalve is at the other two positions, it comes from the swing cylinder.

Every hydraulic cylinder is protected by the giving water and the discharging water, and the part of the connection rod also is hollow, the cooling water flowing in it.

The electro-control device and the microprocessor are fited in the closed boxes, and the cooling water flows in the out of the boxes.