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Research Article

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Design, Modeling and Fabrication of a Fire Extinguishing Robot

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Abstract Fire Extinguishing has been very unsafe for human beings since the inception. Sometimes fire reaches such a high level that it becomes impossible for a human being to cater it. For this purpose now a days fire extinguishing robots are being used. To date different designs for this purpose have been used, we propose that six flame sensors should be used to increase the detecting range of the robot in result enhancing the intelligent efficiency of the robot. The paper presents the design for the robot. Mathematical modelling is presented for the robot. Results obtained from mathematical modelling are further verified using MATLAB®. Velocity and Pressure analysis for the robot is done using Ansys®. The fire extinguishing robot is fabricated using the data obtained.

Keywords Fire extinguishing robot, motor, amplitude, speed

1. Introduction

Fire extinguishing has been uncertain and unsafe for human beings since its inception. The unwanted fire has to be damped out as soon as possible to diminish the danger of deterioration all around. Sometimes it becomes extremely difficult for human beings to intervene in the case of large fire. So, appointment of a human being in such cases can be very dangerous. For this purpose mobile robots which can do patrolling in such areas are recommended [1]. Fire extinguishing robots are being made for finding and extinguishing fires [2]. Firefighting robot now a days are being proposed to be made with independent control systems and mechanisms [3]. Such robots can be used in industries, domestic purposes and places where there is possibility of accidental fires [3]–[5].

Now a days it is desired that these fire extinguishing mobile robots should have their independent control systems and mechanism [2]. The main hurdles that are faced during the patrolling of the fire extinguishing robot are occurrences of errors while following the path and required intelligence to complete the task.

Many designs for such robots have been proposed in which different mechanisms have been used to extinguish the fire, but we have proposed to use six flame sensors covering the angle of 360°. The details of design are discussed in section 2.

Mathematical Modelling for the robot is presented in section 3. Analysis of results obtained through mathematical modelling are discussed in section 4. Fabrication and testing of the robot is discussed in section 5.

2. Design

The design of firefighting robot is optimized to have its performance at the best such as, to detect the exact location of the fire and sense the surrounding environment with high accuracy. In return it reduces the human effort and risk of the job. Figure 1 shows the isometric view of Fire extinguishing robot developed in SolidWorks® environment.

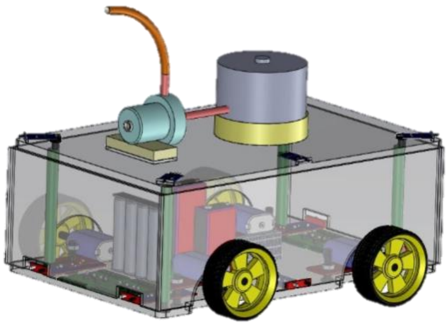

Figure 1: An Isometric View of Fire Extinguishing Robot

The architecture of the Fire Fighting Robot is shown in the Figure 2. This consists of a frame called chassis with four wheels. Each wheel is rotated by an independent brushed DC motor. The independent drive of the motors causes the fire extinguishing robot to be easily controlled by the Arduino based programed circuit. Six proximity sensors have been placed equidistant on the periphery of the base to detect the obstacles during the movement. A tank is fixed on the roof top as a water reservoir. A water pump pushes the water stream to put of the fire when disturbance is sensed. Six flame sensors have been placed on the rooftop for the flame detection so as to cover the 360° angle in the horizontal plane. Each flame sensor covers 60° around it.

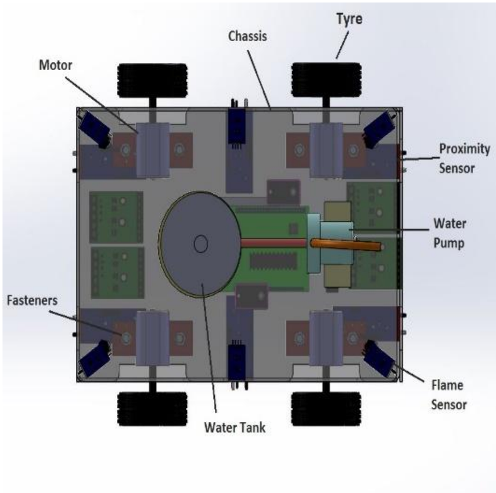

Figure 2: Top View of Fire Extinguishing Robot

3. Mathematical Modelling

A simple DC motor converts electrical energy into mechanical energy by rotating the shaft which is further connected with a mechanism. For the mobility of the Fire Extinguishing Robot four independent DC motors are being used. In a current carrying armature rotating in a magnetic of an electromechanical system like motors, the speed is directly proportional to the voltage applied [6-7].

$$v_b(t) = k_b \frac{d\theta_m(t)}{dt} \tag{1}$$

In equation 1 k_b is the constant of proportionality. Laplace form equation for the loop transformed armature circuit as shown in figure 3 can be written as:

$$R_a I_a(s) + L_a(s) I_a(s) + V_b(s) = E_a(s) \tag{2}$$

Whereas in equation 2 R_a, I_a, L_a and E_a are armature resistance, current, inductance and back e.m.f respectively. Armature current and the torque developed by the motor are also directly proportional to each other.

$$T_m(s) = K_t I_a(s) \tag{3}$$

$K_t$is the constant of proportionality. Substituting the values of armature current and voltage obtained in equation 1 and 3 subsequently, equation 2 can be rewritten as:

$$K_b\, s\, \theta_m(s) + \frac{(R_a + L_a(s))}{K_t} T_m(s) = E_a(s) \quad (4)$$

Inductance for a DC motor is usually assumed to be small for as compared to the resistance. So, it can be neglected. Mechanical loading on a motor is shown in figure 4. J_m is the equivalent inertia and D_m is the viscous damping. From figure 4 relation developed between Torque and Speed is shown in equation 5.

$$T_m(s) = (J_m s^2 + D_m s)\theta_m(s) \quad (5)$$

Using the data obtained in equation 5, a transfer function was obtained as shown in equation 6.

$$\frac{\theta_m(s)}{E_a(s)} = \frac{K_t}{(R_a(J_m s + D_m) + K_b K_t)s} \quad (6)$$

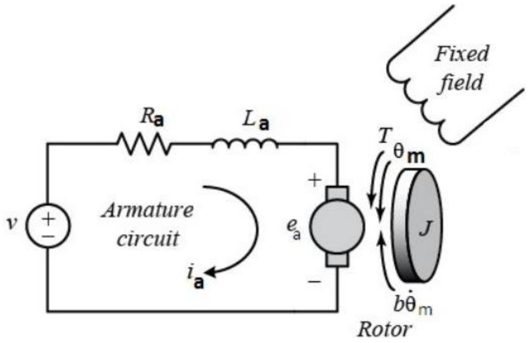

Figure 3: Schematic Diagram of a DC motor [7]

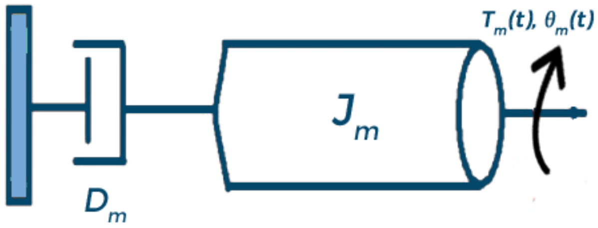

Figure 4: Equivalent Mechanical Loading on a DC motor

4. Analysis

Transfer function obtained in section III of this article was further analyzed for verification of the model obtained. In this regard a MATLAB® environment was created. Transfer Function was implemented by using a tool box Simulink.

Open Loop Model

By substituting all the constants, the transfer function obtained for the open loop model is:

```
Transfer function:
          0.005905
---------------------------
6.635e-007 s^2 + 6.4e-005 s
```

To verify the model a step response was observed as shown in figure 5. Time in seconds is shown on horizontal axis whereas the distance (amplitude) is shown on vertical axis. It can be seen that as the time increases, an increase in amplitude is observed. The distance covered by the robot is directly linked to its speed. The voltage applied to the motor is also directly linked to the speed. So, it can be said that the robot covers an increasing distance as an increasing voltage is applied to it. The distance covered by the robot is increasing linearly but it is approaching infinity, but for our application it is desired that the fire extinguishing robot reaches the fire place.

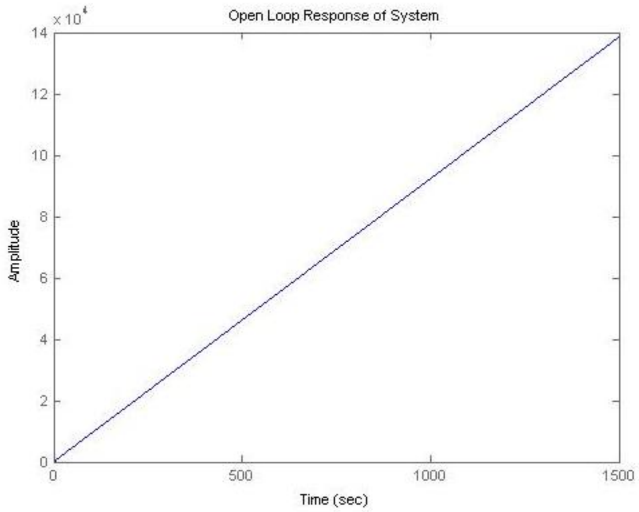

Figure 5: Open Loop Response of the System

Closed Loop Model

It was noted that performance of the Fire Extinguishing robot can be enhanced by developing a closed loop system. Transfer function obtained for the closed loop system is as follows:

```
Transfer function:
                 0.005905
-------------------------------------
6.635e-007 s^2 + 6.4e-005 s + 0.005905
```

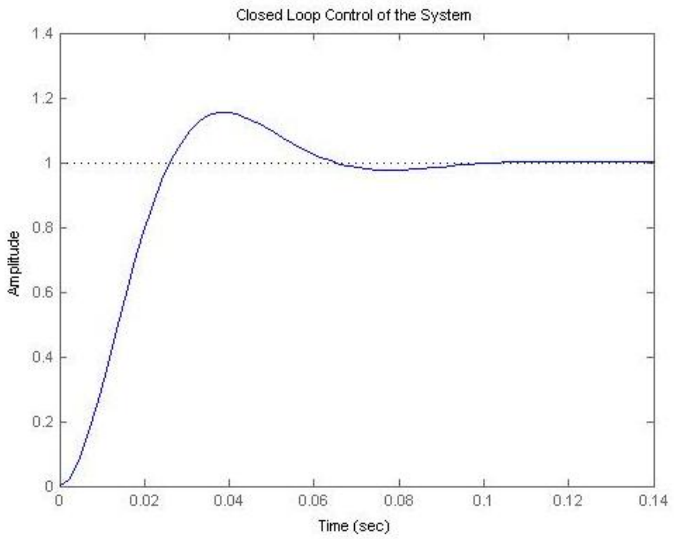

Figure 6: Closed Loop Response of the System

Closed loop behavior of the system is shown in figure 6.A rise time of 0.0177 seconds and settling time of robot was observed to be at 0.0842 seconds. The robot reaches its maximum peak amplitude 1.15 at 0.0395 seconds. At this time an overshoot is observed in the system. The system becomes stable at 0.0842 seconds. Now each motor starts moving at a desired speed without overshoot in the robot. Closed loop results are more beneficial in terms of precision and results with minimized errors are obtained. For eliminating the overshoot a design based on PID controller implementation is recommended.

The design of the nozzle is approximated due to measurement method constraints and corresponding results are included in the lines below. The nozzle designed for Fire Fighting Robot is analyzed in Ansys Workbench® environment with the following conditions:

1. The design is optimized according to the information available about the actual nozzle using the reverse engineering method.

2. Dimensions are approximated up to 0.5 mm due to measurement constraints.

3. Flow through the nozzle is taken ideally laminar in the analysis with actual flow speed provided at the inlet.

4. The density-based analysis is done however not practically executed.

5. The material of the nozzle is approximated due to limited options available in the Ansys Workbench®.

The nozzle is analyzed by splitting the designed nozzle into two sections along its length and displaying the results on the cut section. One half of the nozzle is suppressed to show the internal flow conditions in the form of changing colors. The red color in the results shows the maximum value of the variable while the blue color corresponds to the lowest value of the measured variable.

Velocity Contour

The velocity contour is generated by providing data as explained in the following lines. The system is opted for 'double precision' so as to extract the accurate results. Boundary walls of the nozzle are given 'no-slip condition' and the section is taken as 'symmetry' so that it may not affect the flow. The system is taken 'density based' according to the analysis conditions of velocity variation with ideally no density variation. It then opts for 'steady flow' as there is no dependence on time when the flow is fully developed. Flow is considered 'laminar' which is not practically applicable within the available nozzle due to sharp corners present at the outlet side in the internal surface. As the system is steady so the solution is initialized with 'standard initialization'. In the end, the calculation is started by iterating the process for 50 times and recording the result after every iteration.

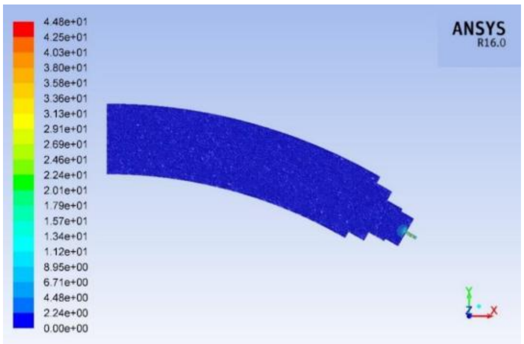

Figure 7: Velocity Contour of Nozzle

Figure 7 depicts the velocity variation within the nozzle. Velocity at the inlet is provided 0.2457 ms^{-1} which are the actual velocity measured experimentally. The maximum velocity at the outlet comes out to be 44.8 ms^{-1} as shown above in Figure 7.

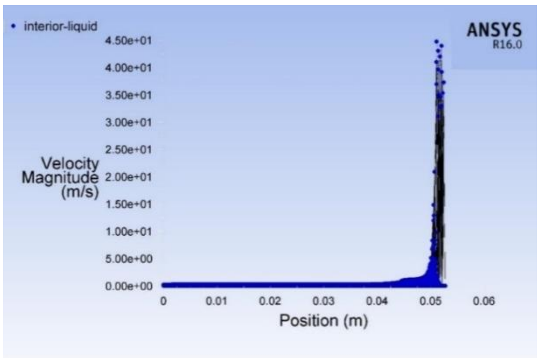

Figure 8: Velocity Variation Along Nozzle

Pressure Contour

Using all the data and condition given above for velocity contour generation, Pressure Contour is developed within the same environment of Ansys Workbench®.

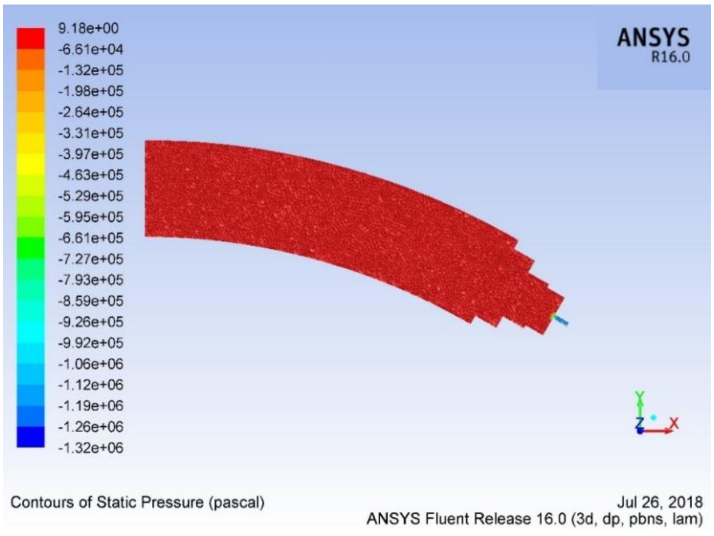

Figure 9: Pressure Contour of Nozzle

As the red color corresponds to the maximum value of the measured variable, the nozzle is having its maximum pressure at the inlet side. Blue color shows its minimum value within the prescribed conditions. $P_{max}$is 9.18 Pa while P_{min} is -1.32e06 Pa due to the extremely small opening at the outlet as compared to the inlet side and body of the nozzle. The corresponding graph is shown in Figure below.

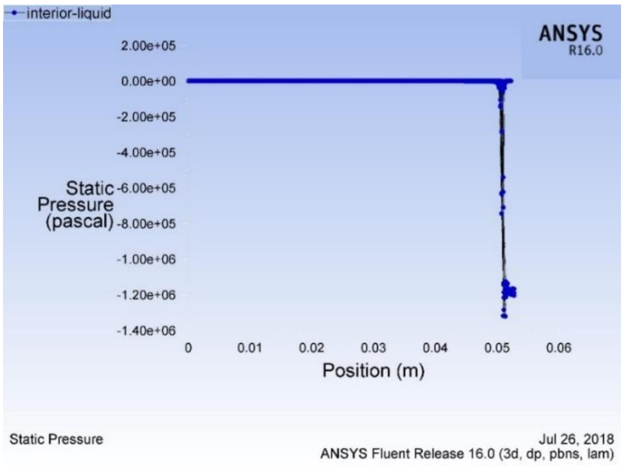

Figure 10: Pressure Variation Along Nozzle

5. Fabrication and Testing

The fabricated fire extinguishing robot is shown in figure 10.The fabrication includes assembling of different parts of the Robot at different locations of the chassis that are optimized experimentally.

Figure 10: Fabricated Fire Fighting Robot

The Fire Fighting Robot is tested with a different number of obstacles put in the arena one by one. The goal was to put the fire out avoiding a different number of obstacles. The robot was first tested with three obstacles as shown in Figure 12. The robot successfully reached the fireplace and extinguished the fire.

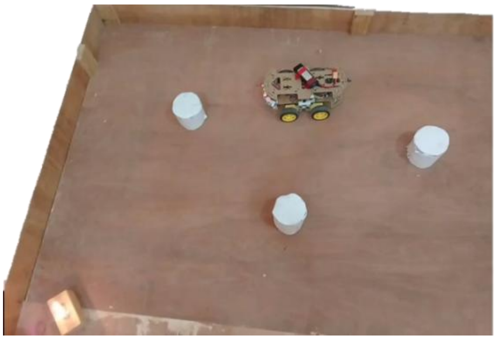

Figure 12: Testing with Three Obstacles

Then the Fire Fighting Robot was tested for four obstacles and five obstacles turn by turn. The robot reached and extinguished the fire with accuracy. Testing of the robot with five obstacles is shown in Figure .

Figure 13: Testing with Five Obstacles

6. Conclusion

We have presented a design for a fire extinguishing robot, mathematical modelling for the robot. We used SolidWorks® to design the bed, the modelling of the system was verified by MATLAB®.

The prototype of Fire Fighting Robot can frequently be modeled, designed and developed in the way as explained above. It can run and avoid obstacles in the direction provided by the controller. This can extinguish the fire within its range defined by its indoor arena. It is concluded that desired results and verified model may be used for the control, design and development of a fire extinguishing robot. A control design will produce precision and accuracy.

References

[1]. R. J. Cotter, "(12) United States Patent," 2003.

[2]. S. C. Purbarani, Q. A'Yunina Moa, G. Jati, M. A. Ma'Sum, H. A. Wisesa, and W. Jatmiko, "Implementation of grid mapped robot planning algorithm in a continuous map for fire fighting robot," in *2015 International Symposium on Micro-NanoMechatronics and Human Science, MHS 2015*, 2016, no. August.

[3]. T. Rakib and M. A. R. Sarkar, "Design and fabrication of an autonomous fire fighting robot with multisensor fire detection using PID controller," in *2016 5th International Conference on Informatics, Electronics and Vision, ICIEV 2016*, 2016, no. November, pp. 909–914.

[4]. T. L. Chien, H. Guo, K. L. Su, and S. V. Shiau, "Develop a multiple interface based fire fighting robot," in *Proceedings of the 2007 4th IEEE International Conference on Mechatronics, ICM 2007*, 2007, pp. 47–60.

[5]. K. Su, T. Chien, and J. Guo, "Design a low cost security robot applying in family," in *International conference on autonomous robots and …*, 2004.

[6]. N. S. Nise, *Control Systems Engineering, 6th Edition*. 2011.

[7]. M. F. Shah, Z. Kausar, and F. K. Durrani, "Design , Modeling and Simulation of Six Degree of Freedom Machining Bed," vol. 53, no. May, pp. 163–176, 2016.