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A Bio-Inspired Model for Precise Control of Nozzle End of a Fire Hose Through Remote Controlled Operation

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Abstract*:. Today, there are a few autonomous fire-fighting robots but the absolute autonomous decision making in places that involve discrete thinking is still unresolved. With remotely operated fire-fighting robots, this problem can be solved to an extent. The project involves use of a remote power source to reduce the weight of the robot and a bio-inspired design of the fire hose manipulator mimicking the elephant's trunk using which the hose tip could be moved precisely up to 5° on every direction. The hose can be manipulated to direct the water towards the fire, using the live video feed from a camera and raspberry pi set up that are on board. The movement of the robot and the fire hose manipulator can be remotely operated using GUI interface. The response of the robot for various intensities of flame, the angular freedom of the manipulator and the projectile of water-flow were studied and calibrated for better performance.

***Keywords*:. bio-inspired, fire-fighting, remote controlled, two-layer thermal insulation, GUI interface, servo motor assembly**

I. INTRODUCTION

A low- complexity, deterministic algorithm model[1] was developed for a scalable autonomous fire-fighting model[2] has been shown to be a model with minimal hardware requirement and stratospheric UAVs[3] have been implemented for fire-fighting. The model suggested here is solely based on the better critical thinking ability of humans in making discrete decisions. The ability of the elephant's trunk[4] in stretching out in all six cartesian directions and its ability to spray water is tried and mimicked in this model. This will serve to provide precise positioning of the nozzle-end and this will greatly avoid the wasting of extinguishing material. The use of remote-controlled operation of this model serves to increase the safety of the operators as opposed to the conventional fire-fighting methods where the fire-fighters life is jeopardised. The power source for running the autonomous and remotely operated systems are usually integrated with the model. Thus, batteries installed with these systems when exposed to extreme temperatures might cause explosion. This problem is also addressed in this model by tapping energy from a distant power source. The pilot scale model of this design was demonstrated by extinguishing a candle flame, with the extinguishing material being water. The safety, reliability, feasibility, advantages and limitations of this model have been discussed in the following section.

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II. PROCESS DESCRIPTION AND WORKING

A. Principle

The model is remotely operated using a GUI interface[5] from a remote device. The instructions are communicated to the processor board in the fire-fighting robot which is connected in the same network as the remote device. The camera device fitted to the vehicle is connected to the same processor board which in turn sends those signals wirelessly to a remote desktop which is also connected to the same network. The live video feed from the camera that is received on the monitor provides us clue as to where the vehicle should be moved. In the event of a conventional fire-fighting, the fire fighter could be exposed to toxic gases and smoke[6] which might obscure its ability to respond in that situation. In the suggested model, since it is only the vehicle that enters the fire-scenario, the safety of the controller can be ensured. The pilot scale model of this design operates on two 12 V DC motors[7], which are again controlled using the GUI interface from a remote device. The bio-inspired model of the elephant trunk adopted in this design is made using three servo motors, two of which aid in the upward and downward motion and the third one was used for left-right motion. This assembly helps in providing all six cartesian degrees of freedom to the hose tip with 10-degree accuracy in motion. With this assembly being used in controlling the nozzle end of the fire-hose, the pump which is connected to a reservoir is actuated from the control station to gush water through the nozzle. Since, this water is pumped out directly on to the source of fire accurately, the quantity of water used in putting out the fire turns out to be low. A detailed flowchart of the working of this model is shown below.

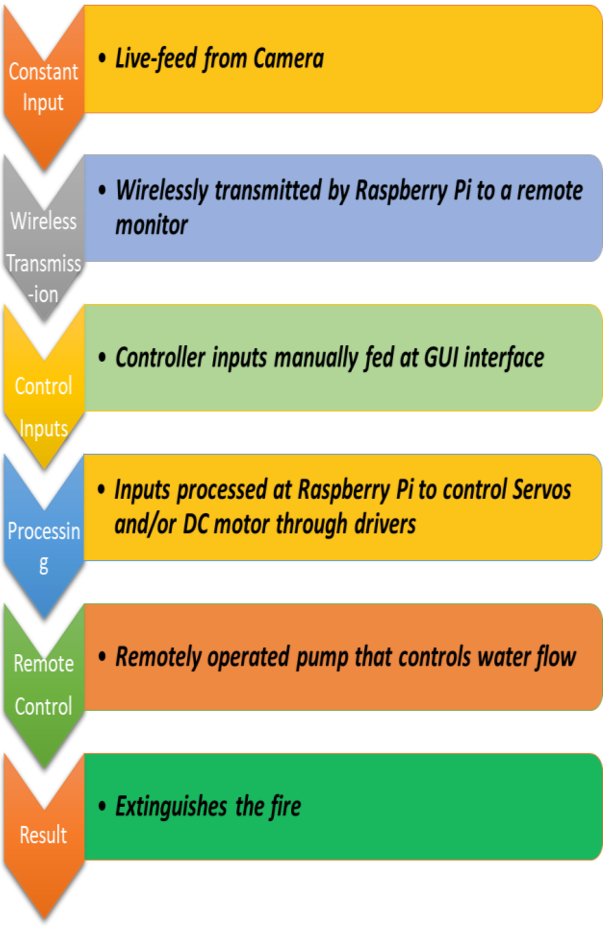

Fig. 1.A scheme representation of the working process of the bio-inspired fire-fighting model

B. BLOCK DIAGRAM:

The block diagram is a representation of the overall working where the signals are wirelessly being transmitted[8] from a mobile device to a processor that controls the locomotion of the vehicle along with the servo motor assembly. It also shows that the raspberry pi board sending out signals wirelessly to a remote desktop. This when done simultaneously helps us in moving the vehicle in the required direction.

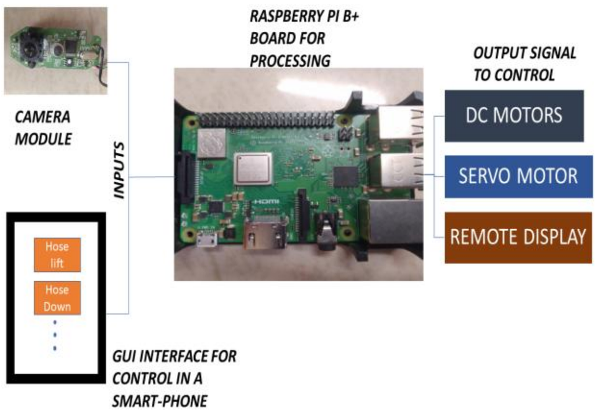

Fig. 2. A block diagram showing the flow of inputs to the Raspberry Pi board and its control on the servo motor and DC motor systems

C. MECHANICAL FABRICATION:

The pilot scale model was made using a stainless-steel chassis and the raspberry pi was powered using a 20000-mAh power-bank which was carried on vehicle. This source provides a 5V DC power supply used for powering the raspberry pi board and this in-turn powers up the servo motor assembly and the camera (15 fps) which was maintained in-line the nozzle end of the hose so that the view that is obtained on the remote monitor is the place that is pointed by the hose-tip. The front end of the vehicle was fitted with a castor-wheel which facilitates free motion while the vehicle has to be turned. The weight the vehicle is reduced by using a remote power source and having a remote water reservoir. The hose is initially made to run in the underside of the vehicle and is drawn to the top side and then attached to the servo motor assembly. The camera is also attached to this assembly so that when the direction of the hose when changes the camera is also pointing the right direction. A representative CAD model of this design was made using SolidWorks 2017.

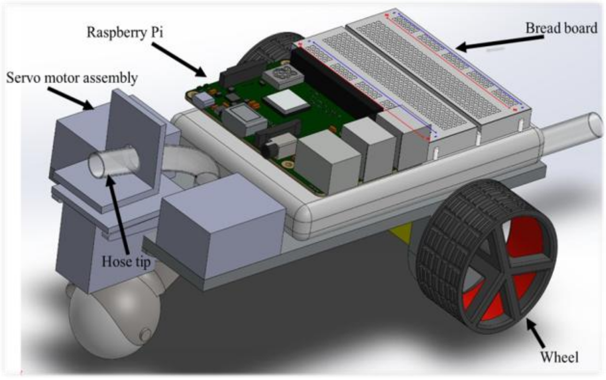

Fig. 3. A representative model of the suggested model designed using SolidWorks 2017. Camera, wire connections, pump, water reservoir and outer body are not shown in the model for better understanding.

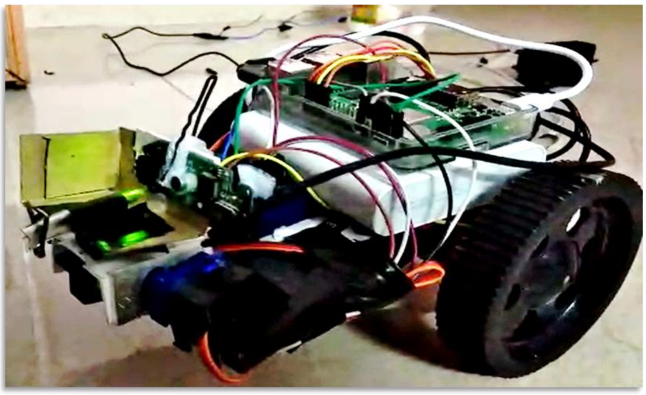

Fig. 4.A real time image of the pilot-scale model after fabrication. The fabrication of pilot scale model did not include the surface insulation of the model. However, the insulation part is briefly discussed in the forthcoming

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III. RESULTS AND DISCUSSIONS

A. Real time working:

The pilot-scale model was tested by moving the vehicle from a remote location to put out a candle flame. The camera used in this model was a 15 fps (frame per second) camera[9] and there was a wireless transmission lag of two seconds with the camera feed and a one second lag with the motor driver. Water[10] being the extinguishing substance, the model was able to point the flow right at the source of flame owing its precision to the bio-inspired servo motor assembly mimicking an elephant trunk. This model when scaled up, if uses water can be efficiently used to put out fire of class A category that are caused by burning of solid materials like wood, paper, textiles, etc.,

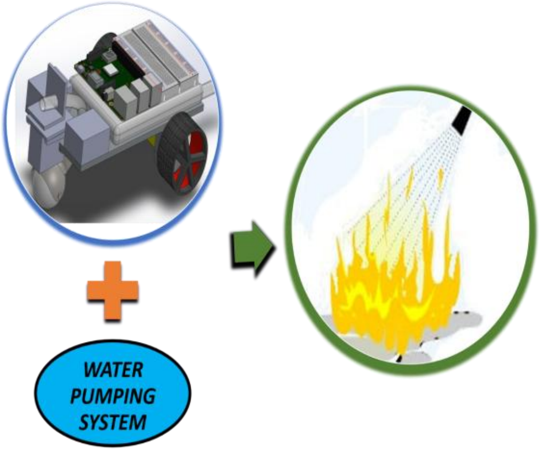

Fig. 5.The synergistic use of the suggested model with a pump for metering water to put out a fire

The camera feed in case of this pilot model was obtained from a camera that captures visible light. However, in intense fire break-out situations there is a lot of smoke that hinders our sight. Also, temperature information at the fire location might come handy in putting out the fire, so a high-temperature furnace camera can be used as a potential sensor in this system. The feed obtained from these cameras being thermal image they can act as an instant temperature information obtained at the scene. This will help in providing information as to where the source of fire is.

B. Effect of temperature on batteries:

This model runs on linear power supply which calls for the use of batteries. Though batteries perform better at elevated temperatures, doing so for prolonged time might reduce the battery life and also the nominal capacity of the battery. Every 8 degree rise in temperature reduces the battery life to half [11]. Therefore, if these batteries have to be carried on the vehicle to the fire-fighting location, that will obviously cause the batteries to fail. This is not desirable if the whole vehicle goes dead in the middle of a rescue operation. Thus, in this model we have adopted the 230V (50 Hz) AC to 12V – 2 A adapter circuit tapping power directly from an outlet to the vehicle. 220 – 230V (50-60 Hz) being the domestic supply voltage range in an Indian context, this can prove to be more beneficial, since the weight of the battery is also not required to be carried by the vehicle. These wirings could be laid on the inside of the hose which is explained in the section.

C. Suggestion for thermal insulation:

Also, in order to protect the feed wire from the camera, a novel approach is being suggested in this design wherein the powerlines and feed lines are being laid inside the fire hose. The material used for the fire-hose which is usually a compound woven material with a fabric insulation, acts as the primary insulation while the water conveyed in the hose can act as secondary insulation[12]. Thus, a two-layer safety system is provided to the feed wires and power wires. A schematic representation of this idea is presented below,

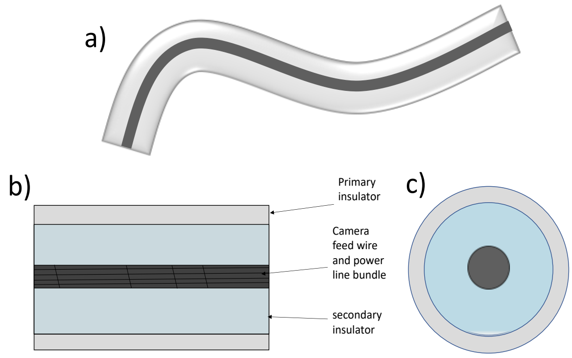

Fig. 6. The power line and camera feed line bundle running freely through the hose with the water in the hose, acting as a secondary insulation to protect the wire

D. Heat transfer from outside the hose surface to material inside

Thus, the heat transferred from the surroundings to the water and thereby to the wirings running inside can be greatly reduced. The total heat transferred* (Q) from the surroundings to the water inside can calculated using,

$$Q=2\pi kN[((Ti-Tp))/\ln(Ri/Rp)]$$

*for steady state heat transfer.

Where,

N - Length of Pipe.

Tp - Temperature of fluid inside pipe.

Ti - Temperature on the outside surface of insulation.

Rp - Inner radius of hose.

Ri - Outer radius of the hose which is the inner radius plus the thickness of the hosing material.

k - Thermal conductivity of hose material.

The above equation is derived from Fourier's equation for heat conduction, for steady state heat transfer for radial heat conduction across hollow cylinder.

A sacrificial protective casing for the vehicle is suggested here, which would be a self-extinguishing material that is provided pores and then sandwiched with a layer sodium or potassium bicarbonate[13], which when rises above 50 degree Celsius decomposes to carbon-dioxide and sodium oxide. This decomposition reaction rate is increased with increase in temperature.

The self-extinguishing material will be directly exposed to the surrounding and insulates the bot from most of the heat. As the temperature raises, it triggers the decomposition reaction and the carbon-dioxide is forced through the pores of the outer layer and aids in extinguishing the fire[14] in that area. The decomposition reaction occurs as follows.

$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$

$Na_2CO_3 \rightarrow Na_2O + CO_2$

E. Flow rate and range at different angles:

The servo motor assembly, when holding the hose tip at normal position was able to project water to a distance of 52 cm during which the hose tip was maintained at a height of 12 cm. At maximum position, that height achieved was 15 cm and the water struck the ground at 48 cm. Since the path of flow traces a parabola[15], the path of the water flow can be defined by parabolic equations.

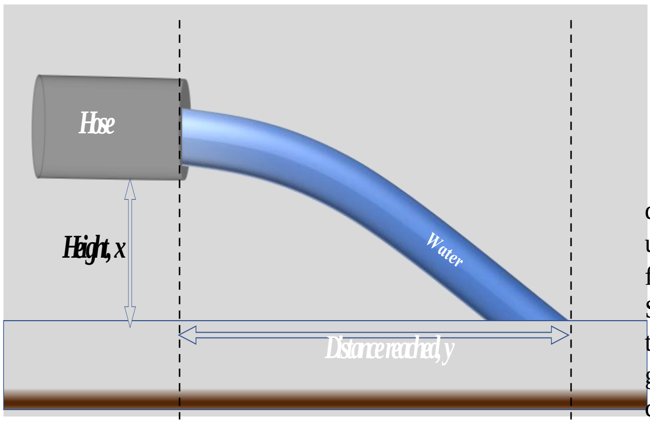

Fig. 7.A diagram showing the reach of the hose and the height of the hose from ground to find the equation governing the flow path

From the observations, the distance through which the water can travel is identified to be within,

$12.394\sqrt{y} < x < 15.011\sqrt{y}$,

where x is the elevation of the hose tip from ground (derived using the general equation for parabolic curves)

This base information can be used to in manoeuvring the vehicle for effective use of the extinguishing water, which in the above case was water.

F. Time response:

The pilot-scale model was set-up with a hose of length two meters and the reach of the jet from the nozzle is about 30 cm and the time required for covering similar test paths of different lengths by two similar models were observed one of which with the bio-mimicked servo motor assembly and the other without to reach a target following these paths. It was found that the model with the servo motor assembly (model 2) had quicker ability to reach the target owing to the increased degree of freedom that was offered by the assembly. The model one had delayed response as the whole vehicle has to turn in the event of the target not being aligned with the vehicle's path.

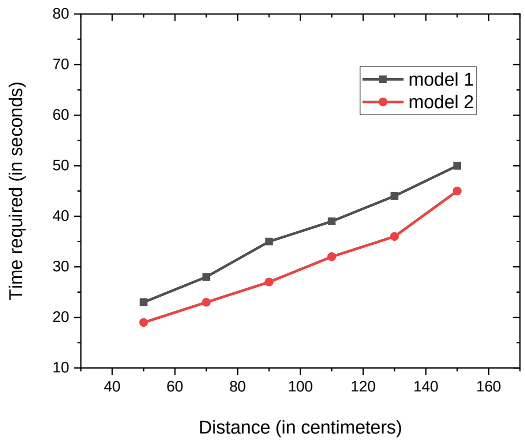

Fig. 8. A graph that shows comparison between the time response between model 1 (without the servo motor assembly) and model 2 (with the bio-mimicked assembly)

IV. FUTURE DIRECTIONS:

This vehicle was ideated to fight Class-A fires, which arise due to burning of solid materials and for this, since water is used as an extinguishing substance, a flexible hose setup is feasible. But when it comes to Class B, C, D, and F (European Standard EN2), where water cannot be used for extinguishing, the hose setup might not be feasible for carrying high pressure gases, dry and wet chemical powders and foam. A suitable conveying has to be built specifically for these different classes of fire. Currently the hose material used when dragged along its path, undergoes wear and tear due to the abrasions, which could be greatly resolved by the usage of Kevlar[16] like material with low thermal conductivity 0.04W/(m×K) and high abrasion resistance[17] as the plying material around the fire hose.

V. CONCLUSION

This pilot scale model of the fire-fighting robot is effective enough to fight against fire on a small scale. The vehicle could be manoeuvred to locations that are inaccessible or too dangerous for humans to extinguish a fire. This vehicle is ideated as an aid to fire-fighters and it needs the discretion of a human mind to control it. The remote operation of the vehicle and the access to the live-feed of the scenario inside the fire break-out can be analysed better with temperature feeds from a temperature sensor or directly by using a high-temperature furnace camera that captures thermal images. This fire-fighting vehicle can increase the safety of the fire-fighters and also help conserve water, especially in the event of a fire breakout in arid regions and places with water scarcity. With enough funding, this pilot-scale model of vehicle can be scaled up to fight against large fires with increased safety, reliability and advantage.

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