DESIGN AND DEVELOPMENT OF FIRE FIGHTING ROBOT

Abstract

Nowadays robots are used for various purpose in various fields. From use of pick and place in big industries to cleaning of house they are nowadays use everywhere. As they work fast give precise result and most importantly reduces human effort. Human may make mistake but robots don't they work as per the input given to them. Mostly robots are used in huge industries, Hospitals, Factories, Defence, etc. They can also be used to perform dangerous and difficult operations. Extinguishing fire is one part of that, it is important to extinguish or control huge fire to some extent till the fire truck arrives. This fire can be anywhere at home, office, school/college, etc. Extinguishing fire without any injury to human is one of the major problems in today's world. Robots can be used for that purpose too with proper component and material selection, but the materials that used for making these types of robots must have some fire and thermal resistivity property in it. In this paper review of various components and material is discussed

Keywords: Robots, Tensile strength, Thermal resistivity, Fire Extinguisher

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I. INTRODUCTION

Since robots are invented, they had reduced human efforts, had made work easier and faster to do. Before 20's robots were used in very limited fields but nowadays as the trend of robots is going on (after year 2000), they are used for various applications in various fields such as in big industries for pick and place, in hospitals for performing critical operations, cleaning the house or store, etc. This had really reduced human efforts up to good extinct. Made work life flexible, easy and fast. Robots can also be classified according to their movement example, some are just a human hand type called as robotic arm (use for pick and place), some are rigid type works from a particular space/ area, some are walking on robotics legs (two legs, quad, spider legs, etc) and some use wheels for moving from one place to other. These types of movements are also selected according to the purpose. They are also classified according to the control system used. For example, they might be remote controlled or controlled with the help of different sensors along with the controllers. This helps to control all the movements of robots.

In today's worlds as robots are used everywhere to carry out the work, they are also used for fire extinguishing purpose. As extinguishing fire or controlling it upto an extent till the fire truck arrives is a bit difficult purpose, and involvement of human for extinguishing purpose might harm them, As fire can burn the skin of humans and the smoke coming out of it can also lead to burning of eyes, high cough, lung problems and may fall dizzy. So, for this purpose too robots are started to being used as they can go in any space/room with active fire and can extinguish it with help of water or any fire extinguisher. With the help of robot's fire would be extinguish with human safety as there will be no contact of humans with fire, as these robots can be controlled with RC (radio control) from a safe distance or by use of sensors and control system. But for robot to extinguish fire proper selection of components and material must be done, as every part plays an important role in movement if robot as well as the robot will face extreme fire condition so the material that is being used must also oppose fire have, also some components should withstand weight of other components on it therefore the material should have high thermal conductivity with ultimate Tensile strength. Brief explanation on selection of proper components and material is discussed in this review paper.

II. COMPONENTS SELECTION FOR FIREFIGHTING ROBOTS

As selection of components plays a very important role in functioning of robots, as the working of robot depends on those components. The main components for movement of a fire fighting robot are listed below.

1. **DC Motors:** An electric motor is a device used to convert electrical energy into mechanical energy.Motors are used to transmit energy in form of torque. Higher the torque lesser the speed, lesser the torque higher the speed. When the load is more, higher torque is required and when the torque is less more speed is obtained. It is calculated in revolutions per minutes. DC motors also known as direct current motor. A DC motor's rotative force is inversely proportional to the product of the stator's magnetic field strength and the rotor's electric current flow. As we know that there are 6 degree of freedom X, Y and Z (3 linear and 3 rotational) we require these or proper movement of robot. This motion can be obtaining using different types of motors. These motors are

required for transmitting high torque and high speed, some of the motors that can be used in the robot are Stepper motors and Gear motors can be used for transmitting high torque and BLDC motors can be used for speed.

- **Stepper Motors:** A stepper motor comes under the category of brushless motors, which converts the digital pulses into shaft rotation. Hence, the number of discrete steps is there is one revolution of the stepper motor and a separate pulse is sent for every step by the motor. Specifications of stepper motor: It provides high holding torque, which is one of the most important factors. It also provides excellent repeatable movement that is both reversible and is highly controllable [1], it gives accurate motion control [2]. Stepper motor are highly sensitive of nuclear reactor [3]. The stepper motor is a numerically control motor, It is controlled by an input pulse signal, where the frequency of the pulse signal determines the speed and the number of input pulses determines the motor's entire rotational angle. It is a type of electromechanical transmission which transform input signal into angular displacement or linear displacement. This helps to drive mobile device from one location to another. The stepper motors are widely used in applications like robots, printers, process control systems, etc [4]. They can also be used to damped the noise [5]. Stepper motors can be controlled by various microcontrollers [6]. The design of motor driver has a stability performance with low- frequency and high-speed torque characteristic for a wide range [7].

Table 1: Typical Step Angles

Sr. No	Step angle (Degree/°)	Pulses per Revolution
1	0.72	500
2	1.8	200
3	2.0	180
4	2.5	144
5	5.0	72
6	8.0	45
7	15.0	24

- **Gear Motors:** A gear motor combines a motor with a gearbox. The motor's gear head assists in reducing speed while increasing output torque. In gear motors, speed (rpm), torque (Nm), and efficiency (%) are the most crucial variables. Knowing the purpose for which the gear motor is needed is essential before choosing the best one, and calculating the load, speed, and torque is also crucial. [8]. There are variety of gear motors are spur gear motor, planetary gear motors, worm gear motors etc. Gear motors are used for high load carrying capacity [9]. They can be used as it has high torque with less power consumption [10].

- **BLDC Motors:** A synchronous motor employing a DC power source is a brushless DC motor, commonly known as a BLDC motor. The permanent magnet rotor effectively rotates in space thanks to the employment of an electronic controller to switch DC current to the motor windings [11]. The phase and amplitude of the DC pulses is control with the help of controller, this helps to adjust the speed and torque

of the motor [12]. BLDC motors are considered more efficient than brushed DC motors, means BLDC motors convert more electrical power into mechanical power than brushed DC motors when same input is given [13]. BLDC motor is controlled electronically, it can also work hand to hand with various sensors (means it can get input by use of sensors) [14]. BLDC motors are mostly used in systems like drones, health, RC car, etc. The construction of BLDC motor is very simple but its costly to control.

2. **Microprocessor:** The logic and control for data processing are combined on a single integrated circuit in a microprocessor, which is a type of computer processor.The central processing unit of a computer is performed by the arithmetic, logic, and control circuits found in a microprocessor. This circuit has the ability to comprehend, carry out, and execute programs as well as carry out mathematical calculations. The microprocessor is a multifunctional, clock-driven, register-based, digital integrated circuit that takes binary data as input, processes it in accordance with instructions stored in its memory, and outputs the results. There are 2 types of microprocessors that are mostly used for controlling or proper Functioning of robots. They are i) Arduino & ii) ESP32. Comparing both the microprocessors ESP 32 seems to be better than Arduino as it has all types of connectivity including WIFI that Arduino lacks and also the cost of ESP 32 is lesser as compared to Arduino. With its two cores running at speeds between 160 and 240 MHz, 520 KB of internal SRAM, up to 4 MB of external SPI RAM, a large number of peripheral interfaces, and WIFI/BLE capabilities, the ESP 32 enables the creation of a robust, adaptable, and remote-controllable system. [15]. Arduino and ESP 32 enhance portability, simplicity, and much more user-friendly [16]. we can know if the ESP 32 is connected to the WIFI or not as the red-light blinks if the ESP 32 is not connected to the WIFI and if it's connected that a stable green light is seen [17]. The installation of ESP 32 can be done easily, and it does not require a big setup which is an advantage as compared to other systems [18]. ESP 32 is designed by ESPRISSIF with high performance, low power consumption, and a huge array of inputs and outputs [19].

3. **Nozzle:** A nozzle can be used to control the flow of liquid or gas and is frequently employed in pipes with different cross-sectional areas. Nozzles are used to regulate the speed, direction, rate of flow, etc. At the converging part of nozzle, the velocity of fluid increases and pressure decreases, and at the diverging part the pressure of fluid increases and velocity decreases. Stainless steel and ceramic nozzle have low operating pressure than the other material of nozzle [20]. Material used for nozzle are brass material, stainless steel, hardened steel, polymers, ceramics, etc. for example the 11004VS nozzle made of stainless steel has 110-degree spray angle at the pressure of 40 psi. LF 80-5R nozzle can spry with an 80-degree angle at the rated pressure of 40 psi [21].

$$nozzle\ output = spray\ (L/ha) \times travel\ speed\ (km/h) \times nozzle\ spacing\ (m) / 600$$

In fire fighting robot most common application of nozzle is to deliver sufficient amount of water, foam or other fire-retardant to the area which have active fire and try to extinguish out the fire. Mass flow rate is an important factor while selection of nozzle for fire extinguishing purpose [22].

Table 2: Nozzle Life with different Tip Materials

Tip material	Nozzlelife (continuous operation)
Ceramic	20-30 years.
Hardened stainless steel	8-15 years.
Stainless Steel	4-6 years.
Polymer (plastic)	2-3 years.
Brass	1 year.

(**Source:** Bread, 1999; Phillips, 2010)

4. **Sensors:** A sensor is a device that detects events or changes in the environment and sends the information to other electronics. Sensors are always used with other electronic devices. Various types of sensors are used in robots or automatic functioning of robot. In firefighting robot proximity sensors are used to detect nearby object, thermal detectors based on thermistors are used for heat detection. Heat sensors, which are sensitive to temperature, are used to measure ambient heat. Fixed temperature, rise rate, and compensation rate are the three different categories of heat sensors. Gas sensors made of metal oxide semiconductors have a high sensitivity and are inexpensive. [23]. Fire sensors the fire acts as a radiation source both the colour and radiation can be sense by the sensor. Smoke sensor detects the smoke that comes out from the fire. In the early stages of a fire, smoke emits a light beam or electromagnetic radiation that can be detected by passing across the interface of the smoke particles. The three main factors for smoke detection are mass concentration, size dispersion, and volume fraction. Techniques both visible and non-visual are employed for measuring smoke [24].

5. **Bearings:** A bearing is a machine element that constraints relative motion, and decreases friction between moving parts. Use of bearings provide free linear movement of the moving parts or free rotation around a fixed axis. Bearings are classified according to the type of operation, the motion allowed, or to the direction of force applied to the parts. There are mainly two types of bearings: i) Ball bearings & ii) Roller bearings

    - **Ball Bearings:** A ball bearing is a type of rolling-element bearing which uses balls to maintain the separation between bearing races. Ball bearing is used to reduce rotational friction and support axial and radial loads. This is achieved by using at least two races containing balls and transmit the loads through the balls. One of the races is stationary and the other is attached to the rotating part such as hub or shaft. As one of the bearing races rotates the balls rotate with that race as well. Because of the ball that are rolling they have much less coefficient of friction than two sliding surfaces. Ball bearing have lower load capacity than roller bearing due to small contact area between ball and races. Most of the ball bearings are made of high carbon chromium steel called as chrome steel They are also made from other materials such as stainless-steel, ceramics and plastics [25]. The test done on ball bearing have a high sensitivity [26]. The main characterises of ball bearing is that it has high hardness, high degree of

chemical composition, high-capacity adequate material durability [27]. Ball bearing oppose sliding movement [28].

- **Roller Bearings:** The rolling parts, such as rollers, are positioned between two concentric races in a roller bearing, which supports load. The rolling parts roll as a result of the relative motion of races. In a roller bearing, a shaft is inserted into a sizable hole, and "rollers"—cylinders that snugly fill the gap between the shaft and hole—are used. Each roller acts like a log as the shaft rotates, and because the bearing is rounded, the roller never comes loose from the load. Roller bearings reduces friction and accomplice crucial radial axial and tread load [29]. Roller bearing uses rollers instead of balls and have a greater load bearing capacity because of greater contact between rolling element and rings. It has high hardness, high hardening capacity, high strength and static fatigue, and high durability [30].

6. **Base:** Frames or base are one of the most important parts while making any robot or any other jobs as the weight of all the components are directly impacted on the base. As the base has to withstand all the load so the material of the base must have good/high tensile strength so the it will withstand all the load without getting bend or fracture. Temperature and other surrounding factors must also take into consideration before selection of material for base because these things also have a great impact on base. Sometimes the base the also a storage area for various control systems, batteries, etc. These things that are inside the base must be protectively carried without getting destroy due to any condition or impact. Therefore, material selection becomes the most important factor while manufacturing base. (Material selection is further discussed in the paper).

7. **Insulators:** The prevention of heat transfer between items that are in thermal contact or within a radiative influence zone is known as thermal insulation. The usage of suitable materials can result in thermal insulation. avoid the heat flow between objects thermal insulation must be used that provide a region that creates barrier that resist heat from flowing inside the object, thermal radiation is reflected rather than being absorbed by lower temperature body. There are various types of thermal insulators e.g., fiberglass, Rigid foam board, Spray Foam etc. Selection off insulator depends upon the condition that the object will face. Mostly in firefighting robots' insulation boards are used to protect the internal software/controllers. The first layer is paint with Argon paint on the main material then a gap is given and then the insulation board is located this protects the controllers inside [31]. Insulation board has high thermal diffusivity [32]. Therefore, insulation is must in firefighting robots.

8. **Camera:** A camera can be situated on the firefighting robot. This works as an eye for the robot, with the help of which humans can control the robot. This will help in proper movement of robot as we can see the front obstacles on the phone or any screen if we connect our camera with it. This will probably help in controlling the robot from a distance. In firefighting robot if we are controlling the robot from outside a room that has active fire, we will be able to see the fire on the screen and properly control the robot for extinguishing purpose.

9. **Wheels:** A wheel is a circular component that is intended to rotate on an axel bearing. The wheel is one of the main components. It is used to easily facilitating movement or

transportation. In robots' wheels are used for transportation purpose of robots. It works as legs for the robots. Movement of robots is possible due to wheels. The selection of wheels depends upon road condition or on the surface on which it would be working. Factors that are important while selection of wheels are:

- Diameter of wheel.
- Load carrying capacity.
- Climate condition.
- Wheel size.
- Road condition.

III. SELECTION OF MATERIAL FOR COMPONENTS

There are different types of metal and non-metal used for making of any job/product. Selection of proper metal or non-metal is very important for proper functioning or to withstand that particular condition. Some material needs to withstand high load, extreme high/low temperature, moisture, etc. and must also be cheap in cost. Considering this different condition that are going to affect our components proper selection of proper material is done For firefighting robots, the first important factor that material should have high thermal resistivity and the second important factor is that it must have good ultimate tensile strength to bear load of other components. There are different materials that have these proprieties such as Iron, copper, steel, aluminium, stainless steel, Diamond, etc. From all these different materials stainless steel (SS) seems to be the best suitable for firefighting robot as it has high thermal resistivity and ultimate tensile strength [33]. Steel has excellent strength properties at high temperature and also include material safety design. The main properties of steel expose to fire are (a) thermal, (b) mechanical and (c) deformation properties. Thermal properties determine the temperature profile in steel section resulting from fire exposure, mechanical properties include loss of strength and stiffness as a function of temperature. Deformation properties determine the deformation of the steel member under fire condition [34].

There are different grade of Stainless steel each has some special properties. The three main type in austenite, ferrite and martensite. These 3 types themselves have different grades of SS in them example, G304, G316, G430, G420, etc. Each has their different specifications; the thermal resistivity and ultimate tensile strength differ from one another. CSS with Mo, Nb, Cr, V etc can withstand about 300°C but these is not sufficient as the temperature in a room or space with active fire has temperature above 700°C [35]. FR-1 and FR-2 can withstand about 520°C - 570°C [36], these materials are also not sufficient to with fire. Cast austinite stainless steel can withstand up to 400°C [37], these is also not sufficient. Moving to the ultimate tensile strength Q420 stainless steel has tensile strength up to 420Mpa [38], High strength steels Q460 & Q690 can withstand up to 600°C and it has the ability to regain 67% of their initial ultimate strength [39], these Q420, Q460, Q690 materials can be used as it has the thermal resistivity and ultimate tensile strength that is required. If these grade materials are difficult to find because they ae mostly imported we can use G430 which has the same properties as Q420, Q460 and Q690. Cost of G430 is also less comparatively and it gives us the same material properties that is required.

Table 3: Material Properties of G430

Alloy grade	Tensile strength (Mpa)	Maximum temperature (°C)
G430	450	815

IV. SELECTION OF FIRE EXTINGUISHER MATERIAL BASED ON CLASSES OF FIRES

As there are main 5 types of fire each type cannot be extinguish by a single material example: water or carbon dioxide, different types of material are required the extinguish different types of fire. The Different types of fire are classified as Type A, Type B, Type C, Type D, and Type K.

Type A fire is caused by burning ordinary combustible materials such as wood, paper,cloth, trash and other ordinary materials. Type B fire is caused by burning flammable liquids such as gasoline, paints, oil, grease and other flammable liquids. Type C fire is caused due to short circuit or fire in electrical equipment such as wiring, fuse box etc. Type D fire is caused due to combustion of metals and metal alloys, and Type K fire is caused through cooking medium such as burning of vegetable oil, animal oil, fats etc. The most popular fire extinguishing agent is water, however water flow can be lost easily. Water additives could increase the effectiveness of combating fires. Surfactant additives, flame retardants, emulsifiers, thickeners, antifreeze, and other additives are the principal components of water-based fire extinguishing agents. These additives also include fluorocarbon and hydrocarbon surfactants. In the early stages of investigating water-based fire extinguishing agents, modifying water flow, wetting, adhesions, spraying techniques, etc. increased the fire fighting effectiveness. Wet water, viscous water, and enhanced water each have advantages and drawbacks. Water has several compounds added to it to improve fire fighting efficiency [40]. CO2 based fire extinguisher is effective for flammable liquids like petrol, diesel, spirits, Paint, etc. and electrical fire. Other variants of Fire extinguishers like water based and powder based tend to damage electric appliances by water and powder, respectively. Also, the CO2 based due to high pressure and being gas has more extinguishing power than others with similar weight. CO2 fire extinguisher empty in a very short span of time. It cannot be used in metal fires as CO2 itself reacts with some kind of metals [41]. Fire extinguisher powder is also used for fire extinguishing purpose such as purple k, Monex, and sodium bicarbonate, but these can corride the metal especially aluminium. It may be possible to use sprays of slat, dissolved in water, to obtain the effectiveness of a powder fire extinguishing agent, but delivered as liquid spray [42].

The effectiveness of powder extinguisher on its components and particle size. Melamine phosphate is a kind of fires retardant with nitrogen and phosphorus as main compositions, it would release non-flammable gas such as steam and ammonia when heated, and the phosphorus would make the base material carbonization to form carbonized layer [43].

V. ROBOT DEVELOPMENT

Thus, the components that are required for making of fire fighting robots as well the the materials required for extinguishing fire are discussed above. Suitable components are used to make the robot for its proper functioning.

Various types of DC motors can be used as per the functioning or movement required e.g., Gear motors can be used for high torque transmission, stepper motor is used is there is high load on the axial it also gives precision in rotation, BLDC motors can be used to transmit high torque with high- speed depending upon the condition. Microprocessors can used to operate these motors. Arduino and ESP are two microprocessors that are frequently used to control motors. ESP is more effective than Arduino for e.g., Arduino do not have WIFI connectivity as well as the cost of Arduino is more compare to ESP. Proper selection of nozzle is done as per requirement, if high velocity is required convergent nozzle are used and for high pressure divergent nozzle are used.

Figure 1: Working Robot Model

The material for nozzle is also discussed as per force of fluid. Sensors are used to detection or to get input from the environment and work accordingly. For e.g., in this paper proximity sensors are used to detect nearby object, flame sensor and temperature sensors are used to detect fire, smoke sensor are used to detect smoke, etc. Bearings are used to constraint relative motion and to reduce friction.

Figure 2: Control Panel of Robot Model

There are two types of bearings i) ball bearing & ii) roller bearing. Ball bearing has point contact while roller bearing has line contact. Roller bearing are used for heavy loads. All the components are located upon base so the material used for base must have good ultimate tensile strength therefore SS G430 is used as it has good ultimate tensile strength. Insulators are used to resist the flow of heat, as the heat can damage the microprocessors. Board insulators is mostly used in are used for insulation purpose. Camera is used so that the robot be operated from a distance. Wheels are used for transportation purpose; the movement of robots is done by using wheels. Selection of material for components plays an important role as the material must have high thermal resistivity and good ultimate tensile strength. Also, the cost must be taken into consideration, these are the important factor before selection of material, G430 is mentioned in above paper, it has good thermal and ultimate tensile strength also the cost is low. Extinguishing material is another important factor for fire extinguish purpose it depends upon the class of fire. Class A can be extinguished with water, CO2 is used to extinguish class A and B fire, Form type of extinguisher are used for class A, B and C, Powder type extinguisher is used for class A, B, C, D and E type of fires.

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