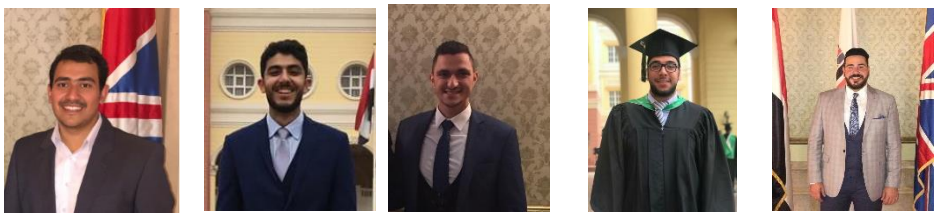
Fire Fighting Robot for Building Evacuation



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ABSTRACT

Technology is one of the fastest paced industry is in modern times. The use of technology has facilitated daily tasks and simplified them as well as reduced the time that each activity occupied. Nowadays, the main focus in technology is not only to shorten the time that takes for a task to be occupied, but also to make sure that the human nearby either operators or surrounding civilians are as safe as possible and that any damage done should be damage to machines and not humans. The use of technological advancements is mainly focused on in areas of high human risk, such as toxic environments, harsh environments, metal industries such as hot metal rolling and rescue operations. The advancements made recently in the rescue operations and precisely firefighting operations has been one of the most focused on fields due to the fact that many human lives have been lost in fire, both firefighters and civilians trapped in the fires. As new technologies emerged, it was only a matter of time to fuse together technological advancements with firefighting. To reduce the level of danger the fire fighters encounter on each mission, robots would go into the building and assist with putting out the fire. There are numerous functions of firefighting robots that include but are not limited to Locating the fire, estimating size of fire, identifying number and positions of trapped people, controlling the spread of the fire And Suppressing the fire.
Today there are two types of firefighting robotic systems which are currently in use Fixed Systems and Mobile Systems. In fixed systems, the method of fire extinguishing is rapidly, examples include, automatic fire monitors. While in mobile systems, there are other features that help the operator move through the building and perform more complex tasks. This work will show how we can implement the firefighting robot to be an essential machine that help firefighters in extremely hot areas and in the area where they are exposure to a dangerous like explosion and falls.

1. Problem Definition and Objectives

Firefighters are exposed to many risks when performing their work especially in places of extreme heat and smoke, and many of them may be subjected to suffocation or other diseases caused by high temperature. As a result, we want to invent a device that will help them cope with fires in such dangerous places

1.1. Aim of the project

This project aims to investigate a robot that can deal with different types of fire with different techniques of proofing to work in the elevated temperature area to help firefighters.

1.2. Objectives of the project

To achieve the project, aim the following objectives are required:

- To work at elevated temperatures area.

- To have capability use different fire proofing chemicals.
- Can be driven from far space remotely.
- To extinguish the fire and cool the area so as not to ignite again.
- To give the firefighter a realistic view to the damaged area with air temperate

2. Brief Introduction and Summary of Previous designs

Many models that vary in functions and shape as well as sizes have been manufactured in recent times. But even with these differences, the main objective remains the same which is putting out fires without putting the lives of fire fighters in any harm or danger.

2.1. Summary of Previous Designs

2.1.1. Design 1 (Thermite RS1-T3)

Thermite RS1-T3 has a rate of 78 liters per second. It has a 25 hp air cooled engine that runs on Diesel. Its nozzle can be adjusted to eject a different range of flow rates ranging from 37 -78 l/s. It has a zero-degree turning radius which helps it turn tight corners easily. It can tow objects that are up to 1,750 pounds. And has a long control range that extends up to meters. Its operating time is 10 Hours which can be utilized in long missions.

Figure 1: Thermite RS1-T3

2.1.2. Design 2 (Thermite RS1-T2)

Thermite RS1-T2 is the upgraded model of Thermite RS1-T2. It has higher capabilities than its predecessor such as having a 3Hp diesel engine but the cooling method here is water. The adjustable nozzle has a higher flow rate range, 78 to 157 liters per second. The towing power is the same as the previous model which is 1,750 pounds and the battery life is also the same

Figure 2: Thermite RS1-T2

2.1.3. Design 3 RXR-M80BD

RXR-M80BD is different from the previous two models as it runs a battery and DC motors. The battery working time is up to 3 hours. Its control can extend up to 1000 meters. The nozzle can be adjusted remotely to produce either jet or free strafe. Has several sensors that can monitor humidity, multi gasses, and temperature. Has a GPS system and can also be connected to the internet for data uploads and live communications. Its flow rate can reach up to 80 L/s.

Figure 3: RXR-M80BD

2.1.4. Design 4 Darpa100

This simple design is mainly made up of a controllable nozzle and a motor that controls the rotation of the wheels and the robot speed. It has a speed of 6-8 km/h. can carry a load from 300-500 kg. The robot can be controlled from 100 meters away. The nozzle can be adjusted to give a flow rate ranging from 30 to 84 litter per second. The water inlet is 4 inches. The water canon angle has a maximum value of 70 degrees.

Figure 4: Darpa100

3. Methodology / Approach to the problem

In order to complete this project, we put a strategy to follow. This is explained in the following schematic

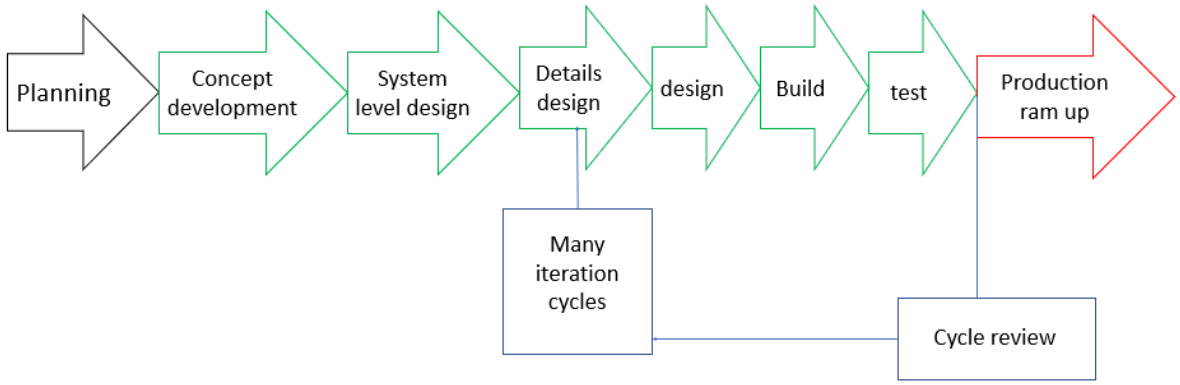

Figure 5: The design process for the fire-fighting robot

3.1. Planning

By the researching about the background information and in the history of the firefighting, it is founded that the fire takes about 1 hour minimum by taking into consideration the crowded streets, the distance if the firefighting units are far away from the fired place also if the fire is huge or from the type of plastic or wood which takes long time period to putting out the fire. After going to the market and see the traditional ways for firefighting, it made us to think in a new technology which is a new product integrated from an existence product but with some new technologies.

3.2. Identify opportunities

By going to the market and ask the people about the issues of the firefighting exists and what they want to make fire extinguishing easier. According to (fire resource, 2013), firefighters are living in dangerous all the time and they have high risk to die in the building or have a serious injury. But by taking this survey, it showed that the average of the firefighters fears a heart attack. This issue is important beside that the fighters enters the building with fifty percent of getting out without injuries. The second issue is how long the fighters are taking to extinguish the fire it may take too much time according to the type of the fire.

People suggest making some improvements to make this job easier like invent a machine for extinguishing the fire. People hope to minimize the time and risks of this job because firefighters have families as everybody have. An autonomous machine-like robot will save people life and will reduce the expenses of the fire.

Countries now are ready for involving the new technologies in the field of mechatronics to make a robot its job to enter the fired place and starting to extinguish the fire by using water coming from the tanks or powder according to the fire type.

3.3. Studying of competitive strategies for firefighting robot

The first strategy for firefighting robot According to (Yang, 2010), is that the robot will get an alarm when the fire is started to grow in the building, consequently and involuntarily the robot will track the fire without helping from outside like a control unit or something like that. After the robot extinguished the fire it will calculate the shortest way to come back in straight line to the zero point which is the started point. According to (Brian Y. Lattimer, Ph.D.2016), Second strategy is fixed system, which the robot is responsible for a fixed place which have high hazard of setting fire such as the fixed automated monitors which is helping the tracking of fire and send the alarms for the robot. This robot contains IR/UV sensors which is helps the robot to track the fire to minimize the time of tracking and reaching the fire. According to (Brian Y. Lattimer, Ph.D.2016), Third strategy is outdoor ground-based mobile robotic systems which take the shape of vehicles that are operated by using batteries or diesel engine. It can travel 2.4 – 20 km/h which is good according to its inventory place. The concept of this strategy is to control it by using an external operator by remote control. The extinguishing system is fixed onboard the robot itself, like

nozzles, tanks, foam nozzles, moving arms to bush the water into high range distance. The control system is consisting of sensors and wireless for sending the information about the fire.

3.4. Resources allocation

This part is extremely important to allocate the resources locations to make the product easier in accomplishing. It is like managing the project by classifying each place where the product will be prepared. Before doing this step, identification for the project must be done briefly with identification for the systems and subsystems to the small components to allocate the resources correctly with minimum fluctuation. The product is to make firefighting robot with the technology of fire self-tracking can be controlled by application on the mobile. After giving a brief of the product it's, systems can be predicted before starting the practical work, with adding the places which the meetings and the practical work will done because this is the key of the success.

3.4.1. Systems and subsystems predicted

Control systems consists of Arduino, raspberry-pi, motor-driver, different types of sensors and servo motors.
Pneumatic system
Suppression system consists of nozzles, tanks, pipes, powder, powder pall gun, and distributor.
Materials such as steel for body and top, rubber for the transmitting chain that responsible for the motion, fiber glass for high strength, ceramic wool for the high temperature insulation.
Transmission power torque such as motors with high ampere, sprocket, gears
Brake system

4. Concept design

4.1. Identify costumer's needs:

Any product should realize the requirements of the market to achieve the needs of the customers as the customer search for the ideal product to buy it. Accordingly, the first process in the design operation is to identify the costumer's needs. For fire fighter robot design there are several re-equipment should be taken in consideration in the design to achieve the needs of costumer and be able to compete in the market. The requirements will be arranged according to their priority as following:

- The robot is to have several effective firefighting techniques to deal with any class of fire as there are six classes of fire ranges from A to F. There is a standard procedure for every class of fire such as water, foam, dry powder, carbon dioxide and wet chemical, for example, class A which results from solids burning such as wood, fibers or paper could be extinguished with any mean except of carbon dioxide. Class B results from flammable liquids can extinguished with only foam, dry powder or dry dioxide only and so on (Types of fire extinguisher, n.d.). Based on that the best design is the one with several extinguish options.
- The ability for identifying the type of fire and send it to the user.
- The firefighting robot is to have the ability to reach the fire location alone without helping from an external unit.
- Obstacles avoidances, like detecting objects that in front of it and avoid it or move it.
- The ability of climbing stairs.
- The robot is remote controllable, as the main purpose of making the robot is to eliminate the hazards facing firemen during their work to keep them safe and to have wide control signal range with a simple interface for the user to be easy and attractive to use.
- Having long fire extinguish range and could be achieved by having powerful water head pumps or special nozzle design for long distance or elevated level fires.
- The robot must have source of power that can stand for along working time to be enough for extinguish the fire.
- The robot spare parts are to be available in markets.
- Easy to maintain and to have the ability to withstand in elevated temperatures with no effect on the robot performance.
- The body of the robot must made from a material which resistant high material. So, choosing the material of the robot's body is an important thing in the product of the fire fighter robot.
- The variety in the methods of extinguishing the fire is important requirement in the fire fighter robot to be able to deal with all type of fire, the robot should have several ways to extinguish the fire. The most popular ways that used in extinguish the fire are the water, foam and powder.

- Can be controlled through application using by mobile to reduce the fluctuation in time
- People knows that the insider heat can damage the circuits, so they are seeking for high internal cooling system.
- Safety guard for the important components to avoid the damage during the falling of the heavy parts during the fire.
- High definition camera to make the picture clearer to get more information
- Sound detection to identify the sounds to differentiate between them if there are people get trapped inside the fired place.
- High internal and external insulation

4.2. Metrics and specifications

Table 1 consipt design metrics

Metric #	Need #	Metric	imps	units
1	11,15	Outer body material heat resistance	5	
2	7	Adjusted water Height from nozzle	3	
3	12, 1	Water tank	3	
4	12, 1	Foam tank	2	
5	11,5,4,10	Transmission chain	4	
6	18, 11	Test the Ceramic wool for long time exposing to high temperature direct and indirect	5	
7	15	Fiberglass stiffness	3	
8	6	IR sensors	4	
9	7	Water distributor	3	
10	15	Travelling speed	5	
11	1, 2	Flame sensors	2	
12	15	Robot weight	5	
13	8	High torque motors	5	
14	1,7	Canon for firefighting ball	3	
15	8	Lithium battery	3	
16	16, 4	camera	3	

4.3. Concept generation

Finally, after long iterations and practical working, the proper designed is finally reached. First the outer body is consisted of stainless steel 304 ss following by ceramic wool which gives a high insulation for the internal components. The internal body is consisted of fiber glass which is characterized by high strength. The torque source is 2 dc motors which rotate the gears that meshed with the rubber belt. Butane paint is used according to its high integrated temperature resistance. Air tank is available to supply the powder tank with pressurized air, sin. The used control system is Arduino and raspberry-pi. The supportive sensors that used is IR sensor, IMU(MPU6050), Waterproof temperature sensor, Alcohol smoke sensor, Carbon monoxide smoke senor. By identifying each sensor, the IR sensor is replacement for the ultrasonic sensor due to is issue that stated in design 2. The gyroscope is used to measure the angular velocity to take the decision of rotating. Waterproof temperature sensor is used to

measure the temperature. By involving the alcohol smoke sensor and carbon monoxide sensor, it gave us the availability of identifying the type of the fire without using the neural network. Pi cam and webcam is used to send information about the situation inside the fire which is more efficient and for fire self-tracking by using the image processing and fire detection. By involving the remote control, it will duplicate the control system efficiency cause if any error happened during the extinguishing, the robot will send and alarm for the user and the classic control will be activated by using the remote-control. the issue about moving in straight line is solved by involving the technology of Pid control to minimize the error between the results and the standards. By adding solenoid valves, it gave the ability of automatic opening according to the demand. So, this robot can say that it is an automated firefighting robot

Body material	Paint type	Moving methods	Motion source	Integrated component	Control board	Attached sensors	Control logic	Swathe control equipment
Stainless	Acrylic	Solid wheels	4 dc motors	Processed air tank	Arduino	Ultra-sonic sensor	Classic control	Solenoid valves
wood	butane	Air wheels	2dc motors	Powder tank	Raspberry pi	IR sensor	Fuzzy logic	Manual valves
Fibber glass	Normal	chain	1 dc motor with steering mechanism	Foam container	Node MCU	Lidar	PID	Normal open flow
Composite (stainless steel +fiberglass ceramic)	Spray	Rubber belt		Water tank		webcam	PID+fuzzy	
				Powder ball shooter		Pi camera	Neural network	
						IMU(MPU6050)	Neural network +Pid	
						Waterproof temperature sensor	Deep learning	
						Air humidity and temperature sensor	Machine learning	
						Alcohol smoke sensor	Remote controller	
						Carbon monoxide smoke senor		
						Laser pointer		

Figure 6: concept design for fire-fighting robot

5. Material selection

5.1. Introduction to Material selection

Material selection considered as the first step for product design. Before choosing the fitting material for the product, the metallurgy of that material must be known, and it falls into the environment which the material is selected for. Such as if the acting environment is chemicals or corrosive environment such as chloride which can be in the air cause corrosion by the behavior hygroscopic corrosion. It can be involved into the elevated temperature environment can cause thermal fatigue failure. It is clearly that there are a wide range of materials could be responsible for doing the same work under the same conditions. The reason is due to the daily development of production industries that can afford wide range of materials with different prices. For example, the strap of the car can be rubber or iron both will do the job.

For the firefighting robot, material selection was very important as choosing the most applicable material for the right duty. The main issue for the robot is the high integrated temperature. Which is mean temperature being not constant it is depend on the type of fire such as the fire from wood is different from fire caused by plastic. So according to these conditions highly protection must be afforded for the body and the rest of parts of the robot.

Structure Component	Function	Weighted material
outer body	Protecting the internal components from the high integrated temperature and acting as base for the toping	Stainless steel (301, 304L, 316)
Internal body	Acts as supportive for the outer body gives more protection for the internal components	Wood, fiber glass composite
Insulation materials	Used as elimination for the elevated temperature which transferred to the internal components by convection	Mineral wool (ceramic wool, glass wool). fiberglass
belt	Its function is to connect 2 shafts together for the motion tracking (source of motion)	Rubber belt, iron chain
Thermal Paint	Acting as shield for the outer body to minimize the heat transferring by the process of radiation and minimize the oxidation with the outer air	Acrylic, butane, Normal, Spray
Self-aligned Bearing	Supporting for the rotating shafts	Stainless steel
Shafts	It is used for transmitting the torque from the motor to the belt.	Iron, stainless steel
Gears	It is used for Transmitting the rotary motion from the right shaft to the left shaft.	Iron, Artelon

5.2. Material elimination and minimization

There are 4 factors are very important before choosing the material for the service in the high elevated temperature. Service life, allowable deformation, environment, cost.

5.2.1. Service life

Service life must be designed according to the importance of the product itself. For the firefighting robot it must be designed for service of 10 years minimum cause it is hard to replace the outer body if any failure is happened. For the variation of the thickness for any steel type, the service life will depend on the maximum temperature that the robot will expose to while working, in addition to the maximum stress applied on the robot, also depend on the temperature which is constant or high variable temperature. The strength during high temperature is totally based on the time inside the elevated temperature.

5.2.2. Allowable deformation

Another factor for the elevated temperature deigns is the amount of deformation that is allowable for the body during its life service. This will indicate which will be the priority the creep or the creep rapture. For the robot, the working in the elevated temperature will be cyclic which will can fail by fatigue.

5.2.3. Environment

Studying of the metal behavior in special environment is hard, but in the environment of elevated temperature the corrosive action increased, and the heat transfer may increase the corrosively. This type of factors needs testing for the samples cause the laboratory analysis cannot solve this problem.

5.2.4. Cost

Before designing, it must be taken to the consideration the time and the cost of the material because different material can do the same job to avoid losing valuable alloying elements due to any type of failure. As concept the high cost gives more high temperature resistance.

The outer body structure for the robot is extremely important as it protects all the components from the outside high temperature during the extinguishing process. So, it must be chosen carefully according to the available materials in the market. By identifying the suggested materials for the outer body. It is founded that the austenitic stainless steel characterized by high tensile strength and its ability for the high temperature resistance. The suggested materials for the outer body are 301, 304L, 310 stainless steel.

By analyzing each of this material's cost comparing it to the desired properties, it is concluded that 304 ss is the most efficient material applicable to the desired function for the outer body.

Choosing the insulation materials is depending on its physical properties. By using the heat transfer analysis by ANSYS, it is determined that 2 layers of insulation will satisfy the desired heat reduction.

The inner body structure will be made out of fiber glass composite with reinforcement the location of motors, bearing and battery. It was chosen according to its mechanical properties, water resistance comparing to its cost.

The robot motion system which concluded in the driving belt will be made out of rubber due to is light weight and can with stand at elevated temperature.

The painting material also is chosen to protect the robot body from environmental impacts as well as survive at high temperature. Accordingly, we choose butain paint as it can be surviving until radiation temperature of 700 degree.

6. Calculations

The following calculations will show the final calculation results for each component of the robot

6.1. Kinematic calculations:

The first step in the calculation of the design of the fire fighter robot is calculation the reaction forces of the nozzle which may be effect on the motion of the fire fighter robot. the reaction forces of the nozzle depend on the outlet velocity of the water at the outlet. There are some parameters that control on the outlet velocity of the nozzle like the inlet and outlet diameters of the nozzle (Di, Do) respectively, the inner velocity of the flow at the inlet of the nozzle (Vi), the mass flow rate(q) which changed by the changing in the diameter, the height of the end point of the outlet of the nozzle and the inlet point to a reference plan (Ho,Hi) and the losses of the energy according to the unit of the gravity between the outlet point and the inlet point of the nozzle all of these parameters must take in considered to calculate the out let velocity of the flow (Vo).

Nozzel results CALCULATION		
inlet velocity	5.771340208	m/s
outlet velocity	31.59440001	m/s

After calculation the velocity of the outlet flow, there are the forces of the flow water on the body of the robot in the three coordinates X, Y and Z. there are two angles to identify the position of the nozzle the first angle is alpha, is the pitch swing angle which the nozzle make with the X-axis in X-Z plan and the second angle is beta, is the pitch revolute which the nozzle make with the X-axis in X-Y plan. But because in this design there is no motion of the nozzle around the Z-axis, beta will be neglected and will equal zero. The forces of the nozzle are divided to two forces Fi and Fr, Fi is the recoil force at the inlet of the nozzle and Fr is the recoil force at the outlet of the nozzle.

Water reaction forces calculations		
fx	55.43641	**N**
fy	0	**N**
fz	55.43641	**N**

6.2. Torque and power calculations:

Torque and power are considered the main parameters to make the robot move. So to calculate the required torque which needed to make the robot move, the characteristics of the robot should be knowing like the total mass of the robot which is represent the main fraction force to the motion of the robot, the specifications of the tires as the radius and the number of the tires, and the dimensions of the robot as the width and the length.

ROBOT CHARACTERISTICS		
ROBOT TOTAL MASS	54	kg
TIRE RADIUS	0.3	m
ROBOT LENGTH	1	m
ROBOT WIDTH	0.6	m
# OF WHEELS	4	--
TIRE WIDTH	0.14	m

According to data calculated above the robot friction force with ground due to the driving belt is calculated

Friction FORCE		
GROUND FRICTION	0.4	--
ROBOT TOTAL MASS	54	kg
FRACTION FORCE	233.855	N

The robot acceleration is calculated to determine the motor torque, sizing and battery will supply the robot with the power.

ROBOT ACCELERATION		
START SPEED	0	m/s
FINAL SPEED	2	m/s
ACCELERATION	4.33064	M/S^2
Minimum Time To Accelerate	0.46183	S

Assuming that the parameters of the robot are constant, pitch angle, revolute angle and jet velocity of the nozzle would have an impact on the robot attitude. When working in the fire position, the robot will move back and tip over under the action of the jet recoil. To ensure that the robot could normally work rather than move back, it needs to meet that Fx≤Fir+fg+Fgmax, according to the following equation:

$$\upsilon_{out}^2(\cos\alpha\cos\beta-\mu_r\sin\alpha-\sin\alpha\tan\gamma)\le\frac{d_i^2}{d_o^2}\upsilon_{in}^2+\frac{4G(\mu_r+\tan\gamma)}{\rho\pi d_o^2}$$

Accordingly we will start to calculate the torque needed to drive that robot

REQUIRED TORQUE PER WHEEL		
SYSTEM EFFICIENCY	70	%
ROBOT ACCELERATION	4.33064	S
STAIR ANGLE	45	Degree
ROBOT TOTAL MASS	54	kg
TIRE RADIUS	0.3	m
Number of wheels	2	--
REQUIRED TORQUE PER WHEEL	43.5696	N.m
POWER	456.259	Watt
TOTAL REQUIRED TORQUE	87.1391	N.m
TOTAL POWER	912.519	Watt

ROBOT BATTERY		
SUPPLAY VOLTAGE	12	V
REQUIRED WORKING TIME	1	Hr
REQUIRED CURRENT	76.0432	AMP
CAPACITY OF BATTERY PACK	76.0432	AMP.HR

6.3. Shaft analysis

To make the design of the shaft, needed to study all the effected forces on it by drawing the free body diagram in order to calculate the shear forces and drawing the shear forces diagram then determine the bending moment at each section of it to draw the bending moment diagram to know which part had the maximum bending moment to avoid the fraction or deflection.

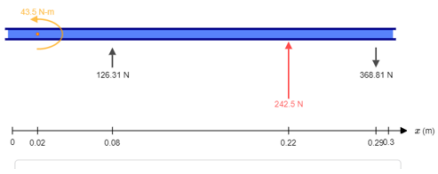

Figure 9force diagram

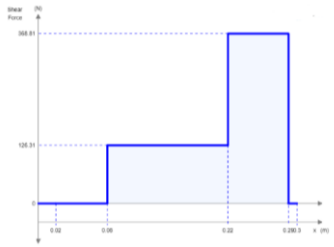

Figure 8 shear diagram

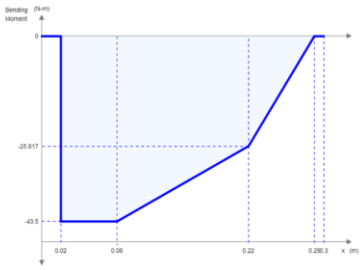

Figure 7 bending moment diagram

The remaining calculation is to check that the shaft is safe and can with stand the robot loads under different operating condition

Fatigue load			
safety factor	ns	1.2	assume
material		steel 1020	
yield stress	sy	580	Mpa
ultimate tensile stress	uts	690	Mpa
mean moment	Mm	34.65	N.m
amplitude moment	Ma	43.5	N.m
mean torque	Tm	43.5	N.m
amplitude torque	Ta	43.5	N.m
endurance stress	se	345	Mpa
surface finch factor	kf	0.75	
diameter DET	d	0.016610423	m
diameter MSST	d	0.01661922	m
diameter DET	d	16.61042271	mm
diameter MSST	d	16.61921953	mm

Shaft stress		
section radius	0.01	m
torque at section	43.5	N.m
shear force	386.8	N
bending moment	43.5	N.m
fluit radius	0.0001	m
grove diameter	0.00001	m
moment o inertia	7.85E-09	m^4
second moment of area	1.57E-08	m^4

D/d	2000	
r/d	10.0000	
bending stress concentration	1.2	
torsion stress concentration	1.4	
bending stress	66.4968153	Mpa
shear stress	38.7898089	Mpa
maximum stress	84.337603	Mpa
minimum stress	-17.840788	Mpa

CHECK STATIC			
principle stress			
σ 1	84.33760304	Mpa	
σ 2	0	Mpa	
σ 3	-17.84078776	Mpa	
shaft material			
material	AISI 1020		
yield stress	351.571	Mpa	
safety factor	1.2		
MSST check			
applied stress	102.1783908	Mpa	safe
allowable stress	292.9758333	Mpa	
DET check			
applied stress	94.52922443	Mpa	safe
allowble stress	292.9758333	Mpa	

shaft deflection		
load per unit length	58457.98253	N/m
Length of the beam	0.2	m^4
Modulus of elasticity	2.0E+11	Pa
Area moment of inertia	6.36429E-07	m^4
deflection	9.568E-06	m

7. Practical work

7.1. Steel Production

The first step after the steel was chosen was to save the previously drawn Solidworks drawings into sheet drawings which involves transforming the outer body from a box shape into a flat sheet plate, this includes cutting lines as well as bend lines and all information needed to be cut and bending using cnc machine.

Figure 10: steel body after manufacturing

7.2. Fiber Production

To manufacture the fiber glass body, we made another mold with different dimension to satisfy the dimension of the inner body where the fiber glass body will be mounted. Using chopped mate fiber glass with epoxy resin the body is molded.

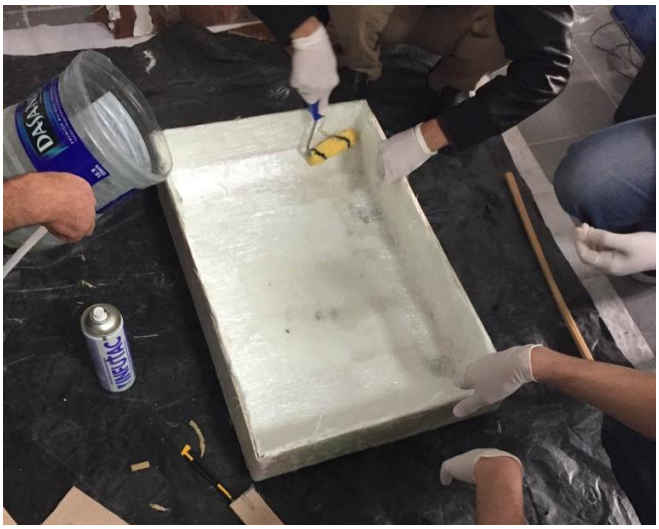

Figure 11: fiber glass fabrication process

7.3. Pulley Production

In order to manufacture the pulleys that would pull the belt, we choose the cnc router to shape the artilon plate with a thickness of 2 cm each pulley is 30 cm diameter. Once the production of the 8 pulleys was completed, 2 pulleys were inserted into one shaft and a pipe that acts as a spacer between them was added. There holes were drilled into the 2 pulleys adjacent to each other in order to place screws in the pulleys and pull them closer together and prevent the spacer pipe from moving.

Figure 12 assembly of the pulley and the shaft

7.4. Pneumatic Circuit

The main function of the pneumatic system is the delivery of powder to cover the fire and extinguish it successfully. The air tank is a pressurized tank that supplies pressure to the entire pneumatic circuit. The main function of this high pressure is to provide the force needed to propel the powder to the desire distance.

Figure 13 pneumatic circuit

7.5. Small scale design

During the design process, several problems were encountered along the way, such problems included:

- The belt teeth misalignment: after the belt teeth were aligned with the gear teeth, once the gear started rotating, the teeth go out of alignment and climb over the gear teeth instead of going into the grooves. Several solutions were attempted to solve this issue such as

- Removing all of the teeth and realigning them one by one to their correct positions.
- Reducing the length of the belt to remove the slack that occurred when the robot was not in contact with the ground.

- The battery required to power the motors for a long time was not available in Egypt and importing it was difficult due to Customs laws therefore as a replacement, a car battery was used. But as the battery was not being charged as it was designed for, the battery was depleting quickly and using two or more batteries was not practical due to the size and weight of each individual battery.
- The outer body of the small design was made up of wood, therefore cutting into it and changing the shape to suit the desired need was easier as well as less time consuming than the larger scale design to the steel being used for the outer body.
- Testing the smaller design didn't require a large space which the larger design needed in order to operate and maneuver.

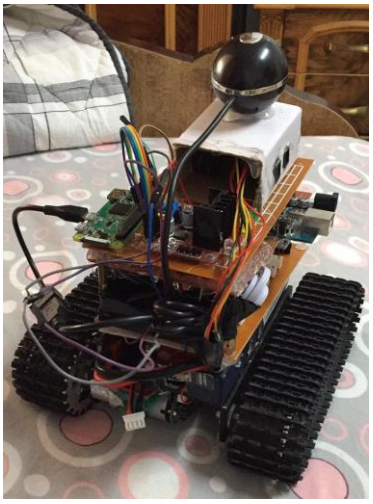

Figure 14prototype of the robot

8. Control System

The goal is to make an autonomous firefighting robot that can navigate and avoid obstacles throw the fire taking the data from the attached camera as well as the attached sensors (e.g. distance proximity, Temperature and smoke sensors). Also, to identify the fire type and the best way to put it out based on the data that will be processed from the attached sensors. In advance, it is required to have machine learning techniques to identify the fire class Based on the sense of the surrounding area. The result, control and any input or output data will be done by the artificial intelligence techniques and the impeded (IOT) system connected to android device by the Raspberry pi and Arduino micro-controller.

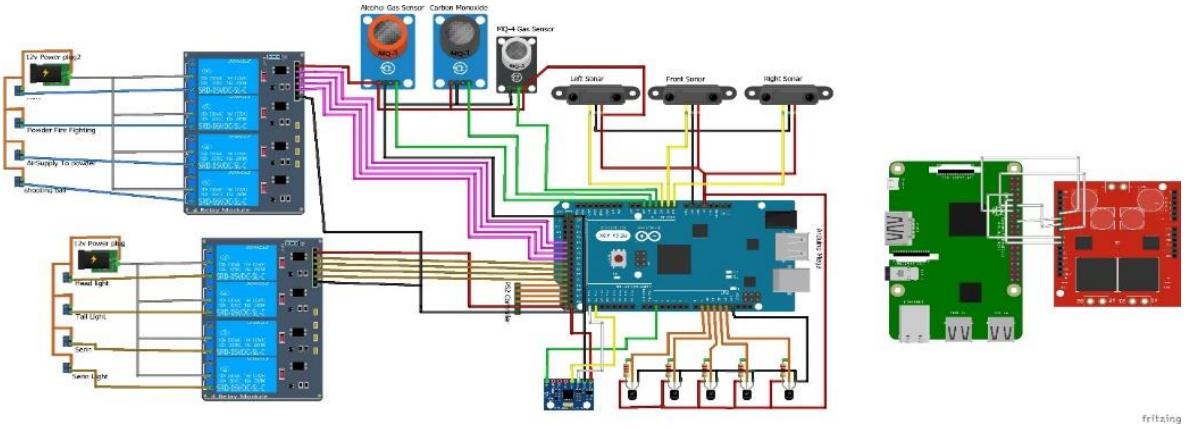

Figure 15circuit schematic

8.1. Remote controller

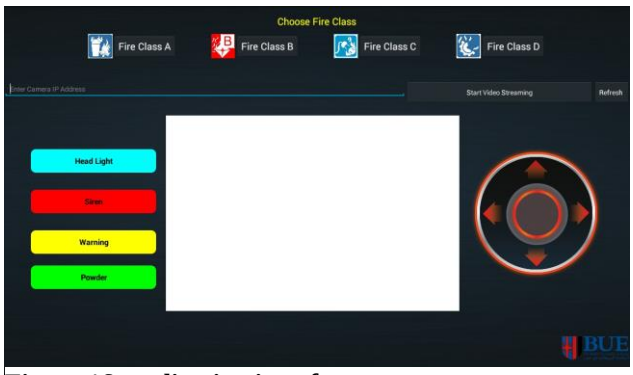

Figure 16 application interface

According to what stated above that the operator must control the robot far away from the fire location, the control distance may be more than kilometers as the fir can be in nuclear area, natural-gas plant and areas where the fire fighting is extremely dangerous to the fire fighters to stand near form it. Accordingly, the controller has to unlimited range like wising Wi-Fi system to send and revive date from controller and robot. On other hand, making remote controller over the Wi-Fi network can easily done if the robot and controller share the same Wi-Fi network which called “local host system “.in order to make it global where the controller can communicate with the robot over any Wi-Fi network there should be another connection in between. We choose fire-base real time data base in order to connect the application with the robot over any Wi-Fi network.
The following pictures shows the application with its block code.
This remote gives the ability to control several features from a distance. There are analogue values for

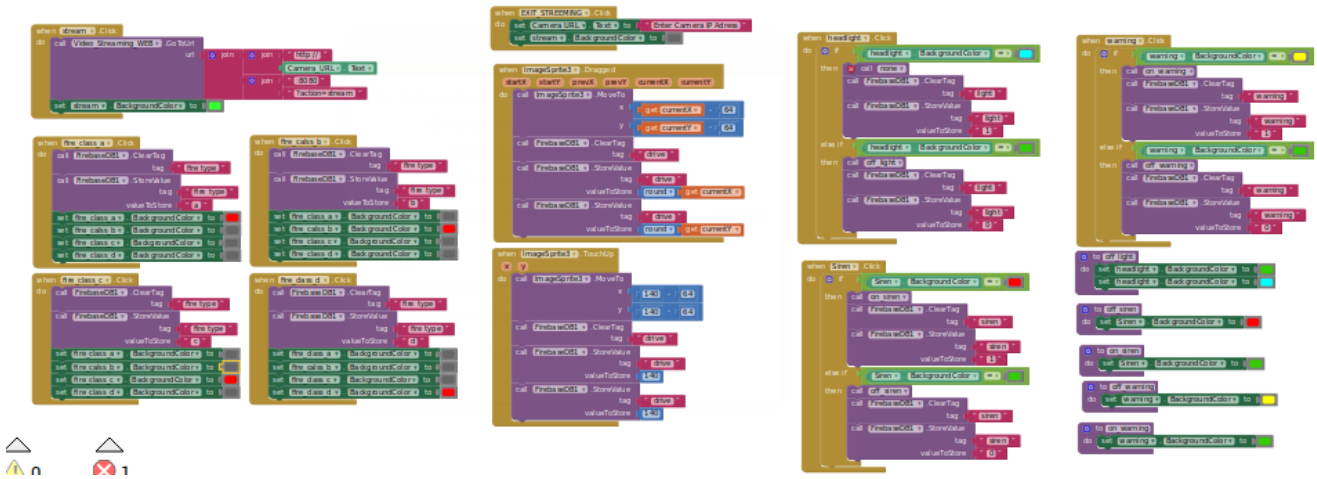

Figure 17 application code

the motion control. The fire type is also selected. Several other options are also available for selection such has lights, sirens and powder ejection. As well as live streaming of the camera.

8.2. Fire base

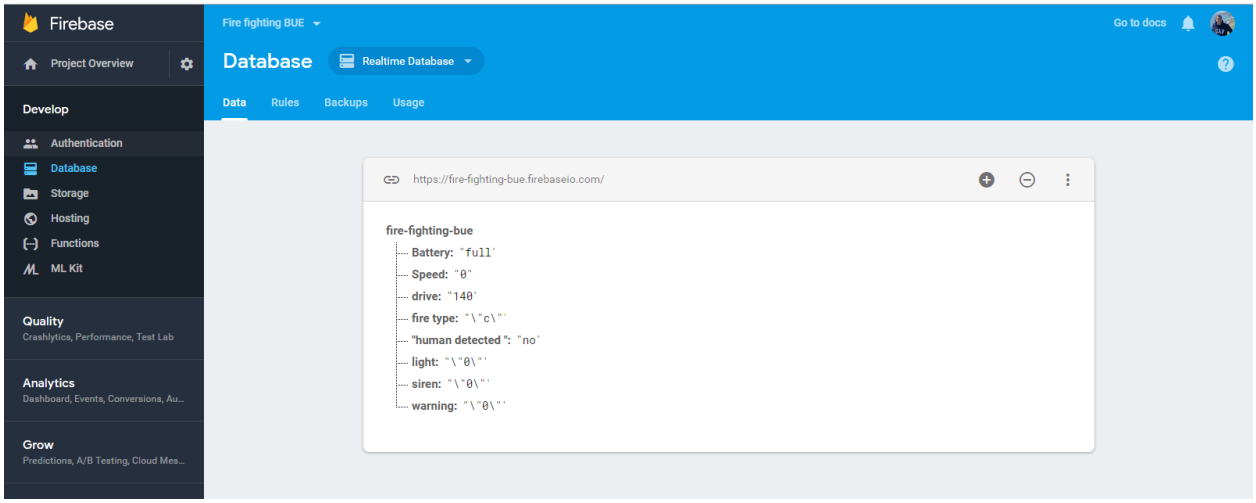

Figure 18 real time data base

8.3. Artificial intelligence

8.3.1. Fuzzy logic controller

Fuzzy control is a logical analysis that used to generate a relation between numbers of inputs that will lead to number of outputs. The result outputs could be assumed partial or linguistic, that when compared to Boolean, both inputs in addition to outputs can be either 0 or 1, Yes or No or be True or False. Fuzzy

logic can be used in any control system to improve its performance by making it logically autonomous. Such as smart washers, new air conditionings or mechanical machines.
The basic fuzzy control of any system consists of the following items:

- Fuzzification: it is a process where the user enters the data input to the system and the inputs are usually linguistic such as the service is regular, or the food taste is bad
- Interface Mechanism: this part is mainly consisting of the rules that have been specified by the user that consider the logic that will lead the inputs to the outputs.
- Rule-Base: it is where each rule gets Wight to determine its importance relative to other rules
- Defuzzification: at this process the outputs are converted to real decisions.

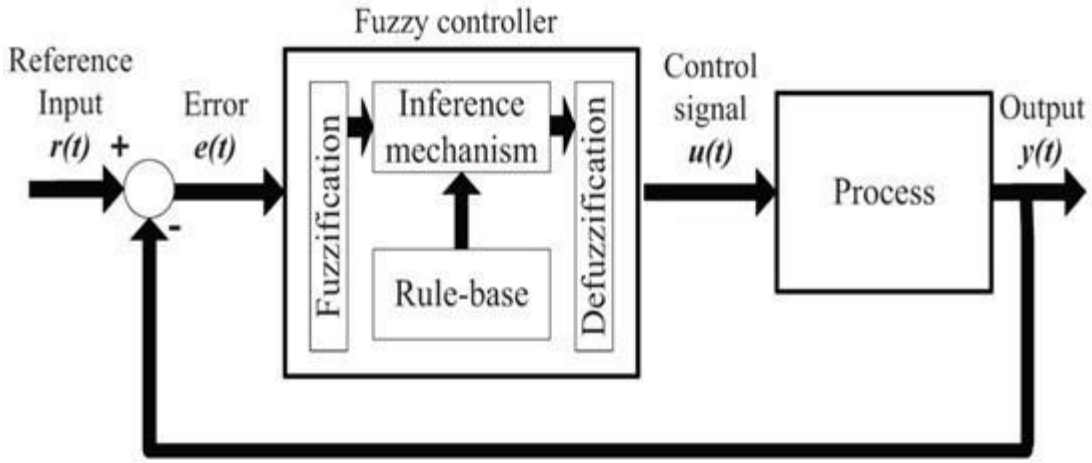

Figure 19 fuzzy controller diagram

Fuzzy logic control in the firefighting robot:

The fuzzy logic in the fire-fighting robot used in the movement mechanism to improve the moving direction and stability. The inputs of the fuzzy logic used are three infra-red distance sensors (IR) that used to indicate the near objects and avoid it if it is possible, as two sensors for the left and right directions and one for the forward direction. The maximum sensing distance for the sensors is 150 cm which used to set the upper and lower limits for the membership function as following:

- Short Distance in the range of 0-30 cm.
- Medium Distance in the range of 30-90 cm.
- Long Distance in the range of 90-150 cm.

For two driving motors there are six outputs as three for each motor as following:
The direction of the motor, the opposite's direction of the motor and the third output is the motor speed.

8.3.2. Neural Network

Image processing is one of hardest application to handle using computer, and it can be classified to be the row data for machine learning,
In order to make a good color tracking or object detection program you will need a very big data base and huge training data. Accordingly, we will use python language because it has a lot of libraries and setups that make the image process simple. There are many types of neural network base on the complicity and the precision you need of your final product. For this application we use and the feedforward networking. Which is compatible with python programing and taking into consideration to reduce the processing time on the micro controller board which is in our case is the raspberry pi.

open cv (open computer vision) is a very useful library in python which help to make image analysis easy because it contains per trained data and can be used to accelerate and minimize the processing time.

For the neural network, the robot raspberry pi camera is programmed to search for and recognized the fire color with all its different shades. Every color has a combination of three basic colors, red, blue and green. The composition percentage creates different colors as well as different shades. The red color represents the main color of the fire. Once this has been seen, the red color is converted to white and all the other clouds are converted to black which called “mask”. Then a circular contour is created around the fire, now a white area. The center of this circular contours is obtained and that is presumed to be the center of the fire.

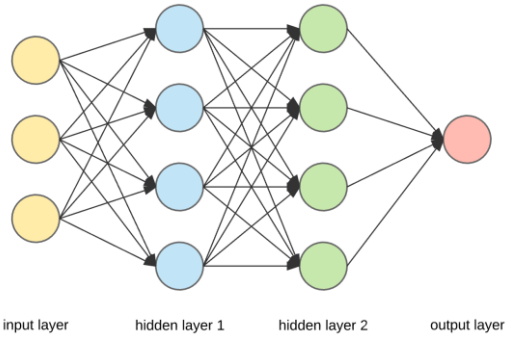

Figure 20 neural network flow chart

How object- color tracking work

The following steps is the algorithm we follow to make the robot follow a colored object

- The pi camera captures an image
- Image size is reduced to reduce processing time.
- Red color is recognized and turned white while all else is tuned black.
- A contour is drawn around the white color
- The center of the contour is obtained.
- The obtained center is measured from the global contour positions
- the new coordinates position used to drive the motors positions
- The vision system is which is consist of IR sensors help to supply the processor with the third axis perception and get the real distance.
- The distance help to avoid obstacles while tracking
- The network uses a single hidden LSTM layer in each time step, with recurrent connections between time steps.

How the code will work

- The IR sensors will be connected to the Arduino board because the raspberry pi board does not include analog to digital converters
- The distance will be transferred to the raspberry pi board using serial communication.
- he neural network will detect objects as the previous mentioned algorithm

9. Results

At the end the product comes out of this design project is a full-scale robot that can deal with 5 class of fire and can be operated remotely from any distance or with the built-in autonomous mode that can detect the fire and go to it to proof it as fast as it can. The following pictures shows the real model robot.

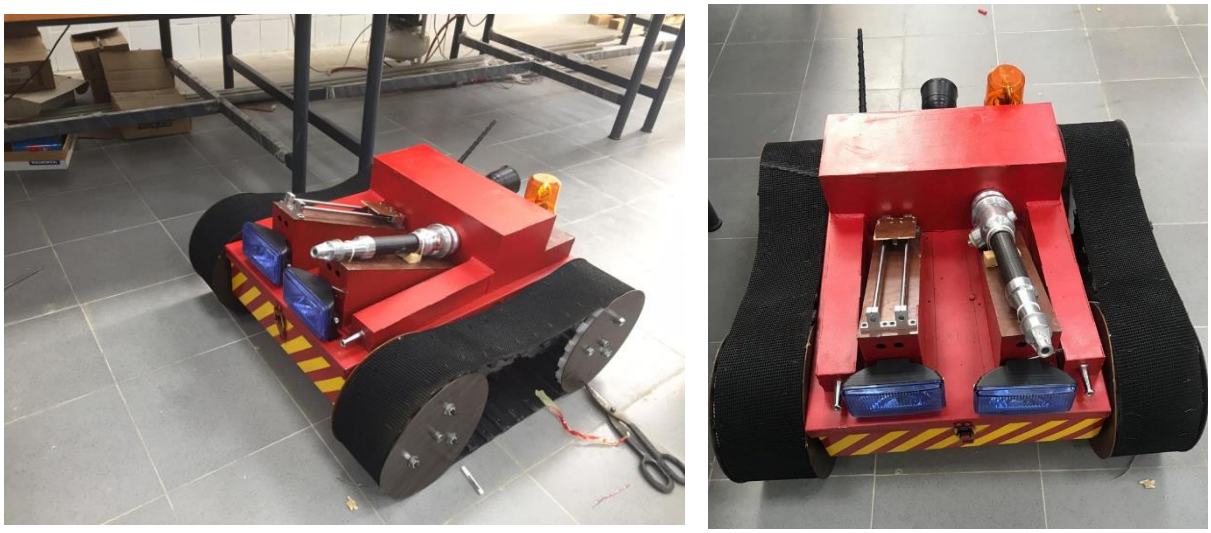

Figure 21 final product

10. Future development

The first issue for the design is the weight of the motors. The designer replaced the gear box with a high torque motor to feed the gears with high torque, but it was not enough to make a complete rotating motion. So, it is suggested to make a gear box with light weight batteries to make the motion easier. So, due to the limitation of the market the designer couldn't deign a successful rotary motion system. By transferring to the motion mechanism, the issue is observed in the rubber belt accuracy. The problem with the belt is the tolerance which the manufacturing couldn't afford the precise production process for making the rubber belt. So, it is suggested to make the belt by casting which is not available in the market. By moving to the control system, the issue is observed in the robot's motor driver. The controlling of the robot's motors needs a motor driver with high processors to bear the large information and data that the robot sends it to the control circuit. To get this motor drivers, an online order must be applied which will come in range from 1 month to 2 months, which is recommended as future work.

11. Conclusion

To conclude, in light of scientific progress, the responsibility for human protection has increased and decreasing the risks which may be faced. Fires are considered a threat to people's lives. As a result, there is needed to find more innovative solutions to extinguish fires. The damage of Fire not only harms civilians but effects on the lives of firefighters who have to approach the fire during the firefight operation.so, all of these reasons lead to the appearance of the firefighting robot. The firefighting robot is one of the latest technics to extinguish fires as firefighting robot which used various methods to extinguish fires like the water jests, powder, foam fluid and fire extinguisher balls. Each firefighting robot should meet the requirement of markets. These requirements like the robot is to have several effective firefighting techniques to deal with any class of fire, the ability to reach the fire location alone without helping from an external unit, the ability of climbing stairs, remote controllable, body of the robot must made from a material which resistant high temperature and easy to maintain. In the design of this robot, First the outer body is made of stainless-steel cold rolled machined to provide ductility and high strength to bear the high impacts. The internal body is made of fiber glass which its strength is tested in the laboratory to make sure that it will be efficient for the internal component and due to its light weight, it will minimize the weight. The paint that used for this design is acrylic which is characterized by high temperature resistance. 4 dc motors will be used for the motion process. The torque will be transmitted to the shafts to rotate the gears which is meshed to the chain. Tanks for air, foam and powder will be provided and reasonable for the materials will be used during the fire. The control system here is consisting of Arduino with raspberry-pi. The sensors which is connected to this circuit will be proximity IR sensor, gyroscope sensor, air humidity and temperature sensor. These sensors are responsible for calculating the distance from the objects and the distance from the fire also will give the orders of turning right and left by using the gyroscope sensor by measuring the angular velocity. By involving the technology of neural network, it gave us the ability of fire's self-tracking by using an attached camera. This robot with attached control unit is an automated firefighting robot which can be enhanced in the future to be faster and more accurate in detecting fire. The motion system is the rubber belt, which is characterized by light weight, easier than the iron chain in its manufacturing. There are the calculations of the forces which effect on the body of the robot to make sure that there are no forces impede the motion of the force and prevent happening any failure in the system.

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GDP36 fire fighting robot

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