ESE 5150 - Internet of Things Sensor and Systems
Final Project: Sensor Hackathon
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FireFighter

Arduino based RC Fire Fighting Ground Vehicle

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Section 1: Abstract

FireFighter is a remote controlled ground vehicle that is built upon the Arduino UNO R3. Our project aims to aid human firefighters in all conditions, including conditions where human intervention is risky or not possible. The robotic vehicle is designed to be remotely controlled by a user. The vehicle comes as a compact and consolidated package equipped with different types of sensors to accurately predict a fire as well as give a general sense of the fire direction. These include the IR Flame sensor to sense fire, MQ-2 Smoke sensor to identify the nature of gases released and aid in fire direction, DHT11 Temperature and Humidity to aid fire direction and monitor the condition of the vicinity. After accurately predicting the direction of fire or fire-like (smoke, temperature, humidity) stimuli, the firefighting vehicle can be advanced to the site of fire. Once the vehicle confirms that it is in the proximity of a flame, the vehicle shoots water to extinguish the fire. Additionally, we have included a water level sensor to indicate the remaining water level in the vehicle's water tank and alert the authorities to bring back the vehicle for a quick refill so as to ensure a sustained firefighting process.

Section 2: Motivation

Every year the Department of Defense and the US Military are requested to support the national civilian forces to extinguish fires across the country. In many situations, army personnel go through tough and life threatening situations placing their lives in danger to save the life of another person or to extinguish a fire. Chemical fires are dangerous and can affect the army personnel involved in the fight to stop the fire. Such situations demand the presence of a product that supports firefighters and complements their efforts. This was the motivation behind FireFighter - our Arduino based RC Firefighting Ground Vehicle. Through this project, we found a way to use technology to solve a real-world problem and make a positive impact on firefighting operations. It also gave us a chance to innovate by identifying pain points and creating new solutions to existing problems. Our product is effective in situations where human intervention is life threatening or not possible to stop a fire, unlike traditional firefighting methods. Moreover, ESE5150 provided us with the opportunity to learn and integrate multiple sensors and actuators so as to apply our learnings throughout the semester. Another motivating force is the satisfaction of successfully implementing a complex system with a real-life value proposition on a critical application.

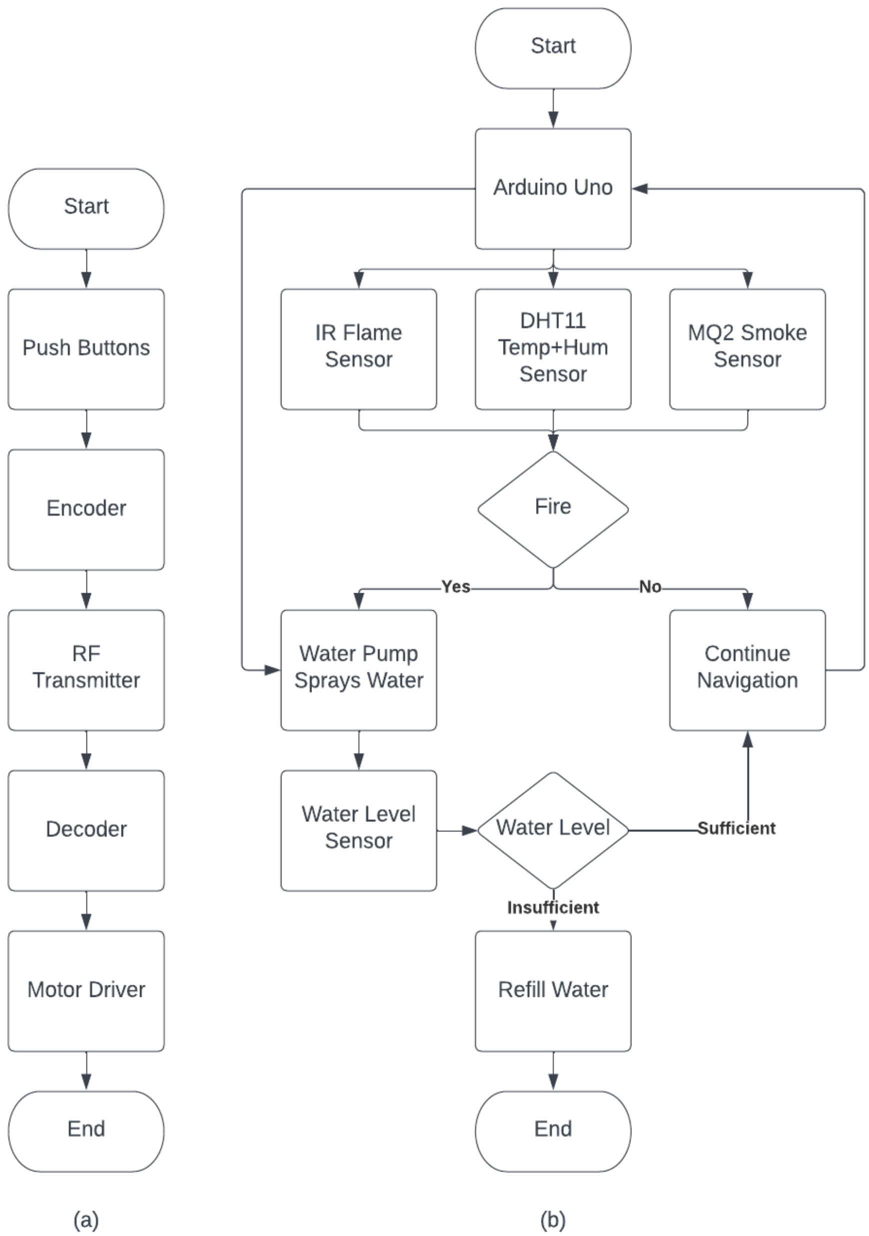
Section 3: Limitations of Current Practice

Traditional firefighting techniques involve the presence of human firefighters who enter into tough locations to extinguish the fire. However, there are many limitations to having human firefighters. Firstly, human firefighters put their own lives at risk by entering into buildings they are unaware of. Secondly, in the case of chemical fires, human intervention is dangerous or not possible because of the kind of gases that might be released. Thirdly, there might be locations or terrains that are inaccessible to humans. Firefighting robots can solve all these limitations.

The market for Firefighting robots has increased in the last few years because the authorities have begun to understand the physical sturdiness and robust balance that these robots provide along with fighting in inhumane conditions. These high-tech devices can enter burning buildings too hot for human survival. They can penetrate smoke too toxic for human lungs. They are often faster, stronger, and more agile than the firefighters they work with. However, the use of these robots is still less compared to traditional practices. Our unique combination of sensors provides a novel approach to combat this problem and create a product prototype that can be later scaled for widespread commercial use.

Section 4: Approach

Our entire approach has been consolidated into a flowchart for simplicity as shown below:



RF Remote Controlled System

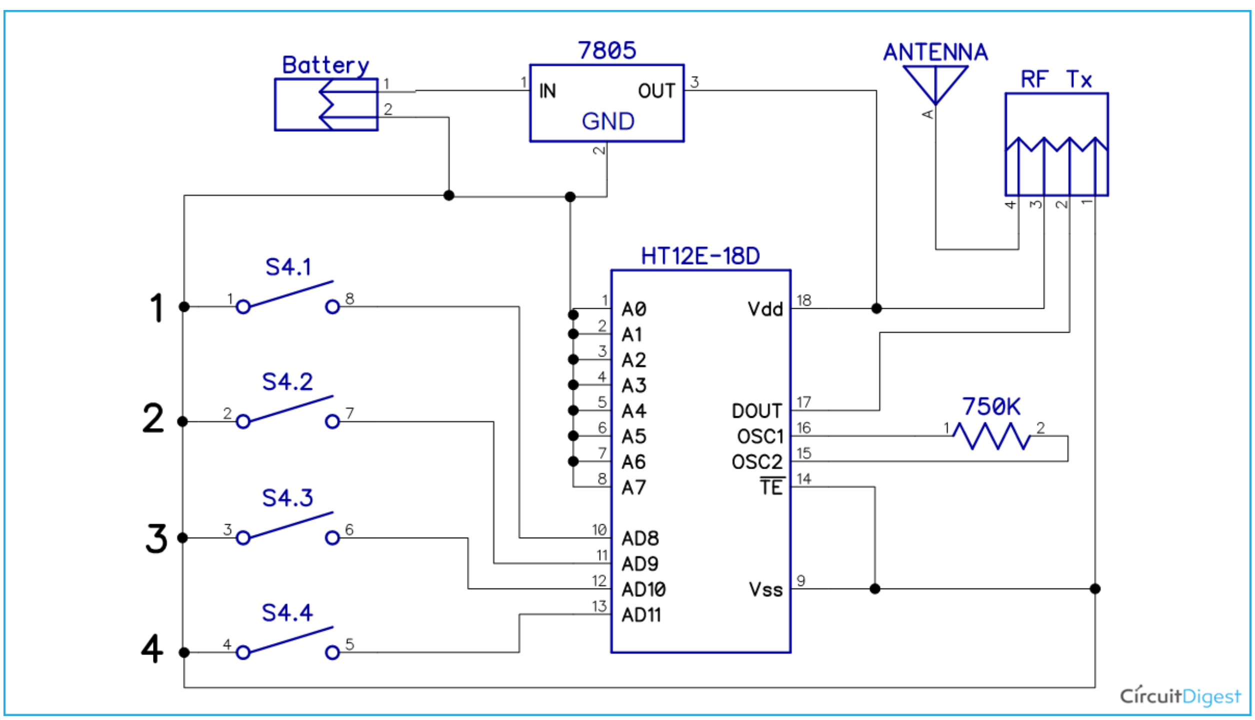
The RF remote controlled system [Fig. (a)] uses four push buttons placed at the transmitter side (remote controller). The transmitting device contains an RF Transmitter and an RF Encoder. This transmitter part will transmit commands to the robotic vehicle so that it can perform the required task like moving forward, reverse, turning left, turning right, and stopping.

In the transmitter part, a data Encoder and an RF transmitter are used. The four buttons are connected to the Encoder. When we press any button, the encoder gets a digital LOW signal and then communicates this signal serially to the RF transmitter. The Encoder IC HT12E encodes data or signal and converts the same into serial form and then sends this signal by using an RF transmitter into the environment.

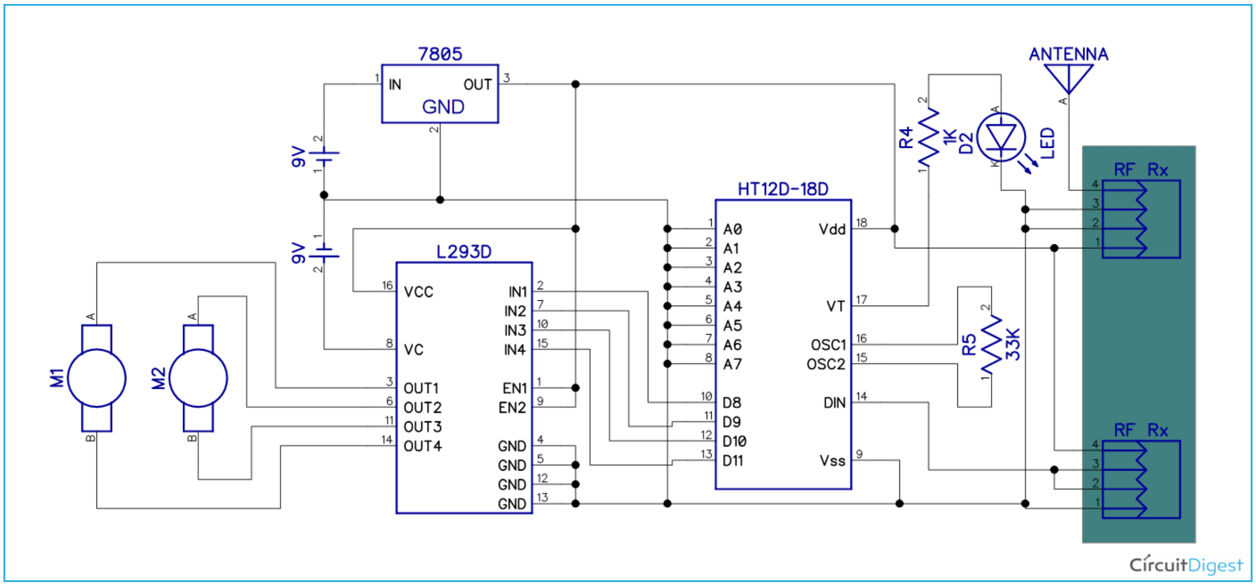
The RF receiver end consists of an L293D motor driver IC which has two channels for driving two motors. L293D has two inbuilt Transistor Darlington pairs for current amplification and a separate power supply pin for giving external supply for motors. We have used an RF receiver to receive data or signal and then connected it to the HT12D decoder. This decoder IC converts the received serial data to parallel and then sends these decoded signals to the L293D motor driver IC. According to the received data, the robotic vehicle moves by using two dc motors in forward, reverse, left, right, and stop directions.

The ASK hybrid transmitter and receiver module operate at 433MHz frequency. This module has a crystal stabilized oscillator for maintaining accurate frequency control for the best range. We have used this module with the help of encoder and decoder ICs which extract data from the noise. The range of the transmitter is about 100 meters at maximum supply voltage, and for 5 volts the range of the transmitter is about 50-60 meters with a simple wire of single code 17cm length antenna. Two 9 volt batteries are used to power the motor driver and the remaining RF circuit. Another 9 volt battery is used to power the transmitter.

Circuit Diagram for RF Transmitter:



Circuit Diagram for RF Receiver:



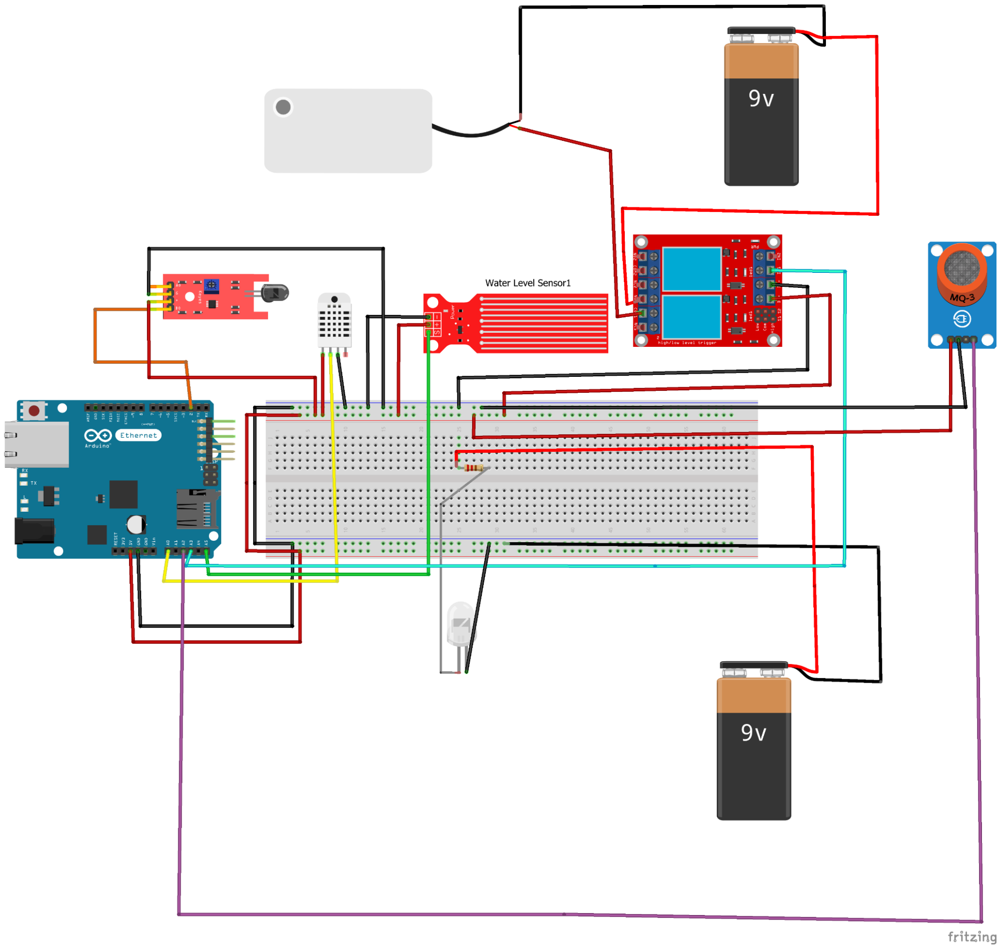
Fire Mitigation System

The fire mitigation system [Fig. (b)] uses an Arduino Uno microcontroller to detect stimuli from the different sensors connected to it. It then processes the data to accurately have a general sense of the direction of fire, detect flames, and put it out.

We have attached an IR flame sensor at the front of our vehicle chassis to detect flames. This sensor has an IR photodiode which is sensitive to IR light. Now, in the event of a fire, the fire will not only produce heat but will also emit IR rays that are not visible to human eyes but our flame sensor can detect it and alert the Arduino microcontroller that a fire has been detected. Additionally, DHT11 temperature and humidity sensor is used to detect the presence of fire in the vicinity of the site of the emergency. This sensor includes an NTC for temperature measurement and detects water vapor by measuring the electrical resistance between two electrodes. If the temperature crosses a certain threshold we can conclude that there is fire in the vicinity. Moreover, an increase in temperature and a decrease in humidity are indications of a possible fire situation. As we navigate the vehicle through the area, we can observe the change in temperature and humidity on our dashboard. If the values correspond to an increase in temperature and a decrease in humidity, we can conclude that the vehicle is moving closer to the fire. To confirm these stimuli even further, we have used an MQ2 smoke sensor to collect smoke data. The air quality during a fire reduces as it consists of more smoke that can be easily detected by this sensor. This stimulus can reassure our direction of fire by adding more data to the already existing temperature and humidity values. When all these stimuli are confirmed we can ascertain that we have detected a flame. We have also used other logical combinations of the outputs of the sensors to detect more situations like approximating the direction of fire, identifying a chemical fire, flameless fires, etc. Once detected, the Arduino will send a HIGH command to the pump to spray water.

Additionally, we have a water level sensor in our water storage tank. In a case where the water level is too low beyond the set threshold, an alert will be prompted to the user to refill the water tank immediately.

Circuit Diagram for Fire Mitigation System:



Below is a consolidated conclusion table based on the different stimuli conditions:

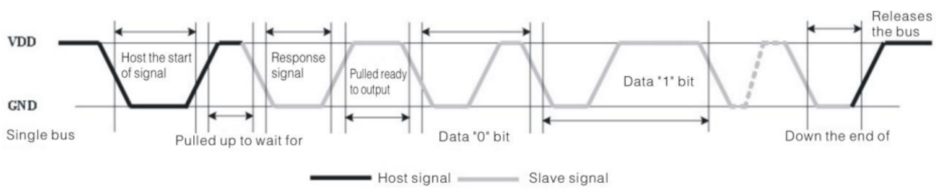
Flame Sensor Bool	**DHT11 Temperature Reading (T)**	**MQ2 Smoke Reading (S)**	**Water Level Sensor Reading (W)**	**Conclusion**
TRUE	T >= 25	S > 600	-	Fire confirmed, high smoke, no humans should enter
TRUE	20 <= T < 25	S > 600	-	Fire confirmed, high smoke, temperature of area increasing
TRUE	T < 20	S > 600	-	Fire confirmed, high smoke, area has just caught fire
TRUE	T >= 25	200 <= S <= 600	-	Fire confirmed, some smoke detected, no humans should enter
TRUE	20 <= T < 25	200 <= S <= 600	-	Fire confirmed, some smoke detected, temperature of area increasing
TRUE	T < 20	200 <= S <= 600	-	Fire confirmed, some smoke detected, area has just caught fire
TRUE	T >= 25	S < 200	-	Chemical fire confirmed, no humans should enter
TRUE	20 <= T < 25	S < 200	-	Chemical fire confirmed, no smoke, temperature of area increasing
TRUE	T < 20	S < 200	-	Chemical fire confirmed, no smoke, area has just caught fire
FALSE	T >= 25	S > 600	-	Fire has been extinguished, but area is still dangerous
FALSE	20 <= T < 25	S > 600	-	Fire could be in proximity
FALSE	T < 20	S > 600	-	Area has just caught fire
FALSE	T >= 25	200 <= S <= 600	-	Fire has been extinguished, some smoke in the area
FALSE	20 <= T < 25	200 <= S <= 600	-	Fire could be farther away
FALSE	T < 20	200 <= S <= 600	-	Area has just caught fire
FALSE	T >= 25	S < 200	-	Fire has been extinguished, area is safe
FALSE	20 <= T < 25	S < 200	-	Fire could be farther away
FALSE	T < 20	S < 200	-	Area is completely safe
-	-	-	W > 300	Water sufficient
-	-	-	W <= 300	Water refill required

Section 5: Sensor Description

Our FireFighter utilizes multiple sensors to collect crucial information on the presence and proximity of fire and takes appropriate actions based on the conditions of the environment. We have provided a brief description of each sensor along with its functionality.

1. DHT11 - Temperature and Humidity Sensor

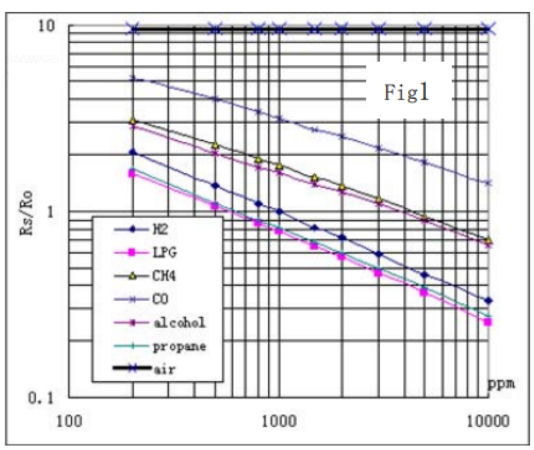
We used the DHT11 temperature and humidity sensor. This sensor is a simple capacitive humidity sensor and thermistor which takes in surrounding air through its exterior-facing substrate and outputs a digital signal to the data pin. The DHT11 measures relative humidity, which compares the amount of water vapor vs the saturation point. More specifically, the DHT11 creates a digital signal via the change of resistance. As resistance between electrodes decreases, the relative humidity increases. The image given below shows the timing diagram of DHT11, which shows the voltage values as the sensor communicates with the microcontroller.



Data Timing Diagram

2. MQ-2 Gas Sensor

We use an MQ2 gas sensor, which is a chemiresistor device, to detect LPG, smoke, alcohol, propane, hydrogen, methane, and carbon monoxide in the air. The device changes its resistance mashed on the types of particles the sensing material interacts with. Another important note about the MQ2 sensor is that it takes several minutes to warm up its temperature to the operating range, which is about 100±20°C. The image given below shows the relation between parts per million to the ratio of the resistances in the MQ-2 output. This shows how the sensitivity of different particles changes per substance and per the number of particles in the atmosphere.



3. Flame Sensor Module

The Flame Sensor module consists of the YG1006 Flame sensor which is a 5mm IR Diode that can be used to detect fire sources or other light sources of the wavelength in the range of 760nm - 1100 nm. It is based on the YG1006 sensor which is a high speed and highly sensitive NPN silicon phototransistor. Due to its black epoxy, the sensor is sensitive to infrared radiation. The flame sensor module consists of a photodiode (IR receiver), resistor, capacitor, potentiometer, and LM393 comparator in an integrated circuit. The working voltage is between 3.3V and 5V DC, with a digital output. When fire burns it emits a small amount of IR light, this light will be received by the Photodiode (IR receiver) on the sensor module. Then we use an Op-Amp to check for a change in voltage across the IR Receiver, so that if a fire is detected the output pin (DO) will give 0V(LOW), and if there is no fire the output pin will be 5V(HIGH). The images given below show: 1) The relation between collector power dissipation and ambient temperature. 2) The relation between spectral intensity and wavelength.

Fig.1Collector Power Dissipation vs. Ambient Temperature

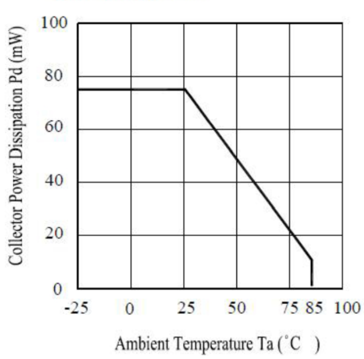
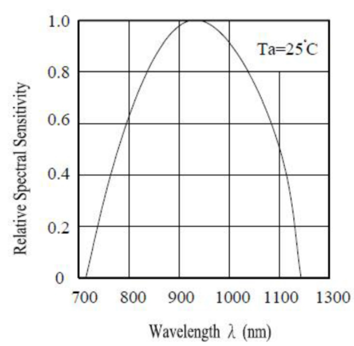
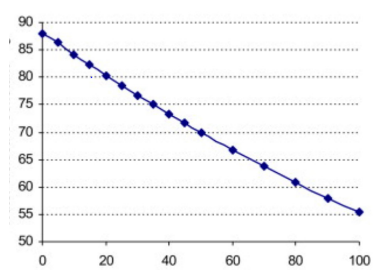


Fig.2 Spectral Sensitivity



4. Water Level Sensor

The water level sensor is used to measure the amount of water remaining in the water reservoir of our ground vehicle. The sensor module consists of a series of ten copper traces, five of which sense traces and the other five are power traces. Each of these traces is placed parallel such that there is one sensor trace between two power traces. These traces work like a variable resistor whose resistance varies according to the water level. The resistance value recorded is inversely proportional to the height of the water and the output voltage is produced according to the resistance value recorded. So, as the water level is high, the conductivity is high, the corresponding resistance is low, and vice versa. The image given below shows a rough sketch of the transfer function between the water level on the x-axis and the recorded resistance along the y-axis.



Section 6: Impact

The purpose of this project is to provide the framework for a firefighting ground vehicle that can be built by anyone, is cost-effective, and is easy to implement. We wanted to identify a real-world problem and provide a solution to that. Firefighting is a dangerous profession that requires a high degree of technical training due to the toxic environment created by combustible materials, with major risks being smoke, oxygen deficiency, falls, elevated temperatures, poisonous atmospheres, and violent air flows. To combat some of these risks, firefighters carry self-contained breathing apparatus as well.

Our product prototype aims to support firefighters by being the front line of attack in the fight against fire. Using the remote control, firefighting personnel can control the ground vehicle, navigate over unfamiliar layouts and confined spaces to get a blueprint of the location, identify the source of the fire, and most importantly, extinguish it. Our unique combination of sensors monitors multiple metrics that provide all the necessary information to the firefighting department. The vehicle is physically sturdy and has a robust balance. Additionally, our ground vehicle is capable of covering varied terrains, reaching confined and inaccessible places (small cracks and crevices) to humans. We believe that our product has the capability to efficiently and effectively extinguish fires, identify the origin of the fire, speed up the firefighting operation to save more civilians, and save countless lives of firefighters who endanger their lives to save people like us.

Section 7: Risks

As with every project, there are risks associated with our product as well. We managed to eliminate some of the risks on our own but there are a few more to attend to in future iterations of our ground vehicle. The first risk we identified and mitigated was closing the water reservoir system. Our water reservoir system was basically a cup in which we submerged the water pump and placed the water level sensor. A tube came out of the reservoir and was connected to the water extinguishing system. We had not covered the reservoir system and this puts our components at risk. So we covered the lid of the cup with plastic wrap.

Secondly, since our vehicle will come in direct contact with fire, it is important to protect and cover our circuitry with fireproof materials. Thirdly, the physical structure including the fireproof material protecting the circuitry must be strong and well-built because buildings on fire can potentially have fallen debris and hence, the vehicle needs to be strong enough to sustain any fall or impact. Additionally, we need a good powering/battery source and a large reservoir to avoid bringing the back vehicle to replace batteries or refill water. Our solution is very cost effective with the right selection of sensors. It is good for a small case implementation. However, when deployed in real-life scenarios, it is important to use higher quality sensors with greater accuracy, durability, and reliability.

Section 8: References

1) RF remote control:
RF Controlled Robot - Project and Circuit Diagrams for RF Transmitter and RF Receiver

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5) Water level sensor:
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https://arduinogetstarted.com/tutorials/arduino-water-sensor

6) Pump:
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Video Link:
https://drive.google.com/drive/folders/1pmn8WFSR098XoKsN2GpODDJDdSf3FZsa?usp=share_link