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Conceptual Design Specification (CDS)

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Project Title	Early Detection of Forest Fires - Conceptual Design Specifications
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Executive Summary

The Ontario Ministry of Natural Resources and Forestry requires a design that detects wildfires earlier. This design must be implementable across all of northern Ontario.

The most important functions of the design are separated into primary and secondary functions. Primary functions include detecting, locating, and transmitting the information. Secondary functions include transmitting the intensity of the fire and detecting heat signatures other than wildfires, the latter being an unintended function.

The most important objectives are earlier detection, accurate locating, economic feasibility, safety, ecological harmlessness, and durability.

Constraints will be used to screen solutions to separate ideal ones from the rest. Solutions must not negatively impact remote/indigenous communities, account for the safety of remote/indigenous communities, cost no more than C$31 million, be able to operate between -30°C and 20°C, withstand a wind speed of 15.4 km/h, withstand 398.5mm of rain and 227.2cm of snow annually, and operate in 50 cm of snow, be operable without electricity, Internet, or cellular coverage, be feasible with current technology

The environment in which the design will service (northern Ontario) is generally characterized by very little existing infrastructure, a cold climate, and biodiverse forest regions. Some of these forest regions have adapted to the presence of wildfires.

The stakeholders that have been identified include the Ministry of Environment and Climate Change, indigenous communities, and the National Aboriginal Forestry Association.

Thirty possible ways of detecting fire were generated through unstructured brainstorming. These ideas were narrowed down to the three alternative designs using the functions and constraints.
The first design uses a wireless sensor network to detect temperature, humidity, and carbon monoxide levels and wirelessly relay it to a server.
The second design uses a satellite to detect a possible forest fire, and several drones to further investigate whether or not a fire is burning.
The third design involves the use of camera watchtowers that will surveil the forest and send possible images of forest fires to a computer for analysis.

After comparing the three alternative designs using the objectives we generated, the design that best met all our objectives was the AVHRR satellite accompanied by drones.

The AVHRR satellite and drones design accounts for several real-life conditions. It accounts for data loss, due to dynamic weather conditions using a commanded downlink. The drones will use color CCD cameras because it will be exposed to wind, dynamic flames sizes, and smoke, and the drones will be simulated to determine whether or not it can withstand extreme weather.

1.0 Introduction

Wildfires in Ontario cause significant damage to the economy, infrastructure, and lives of remote and indigenous communities. This damage is caused solely by the 2.8% of wildfires that "escape current early detection methods" [Appendix A]. As a result, the Ministry of Natural Resources and Forestry needs a design that can detect wildfires in a short timeframe to allow fire services ample time to take action. This document covers the foundations of the project by providing functions, objectives, constraints, and other necessary information which will aid solution generation. Once the project requirements are complete, ideas were generated, resulting in three possible solutions: the use of drones and satellites, watchtower cameras, and wireless sensor networks. After discussing alternative solutions, the drones and satellites design is chosen as the most effective and the implementation of the design is discussed.

2.0 Problem Statement

Ontario's Ministry of Natural Resources and Forestry, our client, is looking for a design that will detect wildfires to stop its effects. In northern Ontario, there has been an average of 791 wildfires in the past ten years [1]. Technologies such as satellite surveillance and manned watched towers have been employed but none has been effective [2]. The client needs a design that can detect fire within a short timeframe.

3.0 Detailed Requirements

The expectations were generated by structured brainstorming which factored the limitations set by the Ministry of Natural Resources and Forestry.

3.1 Functions

The primary goal of the design is to detect wildfires in a shorter time.

3.1.1 Functional Basis

The functional bases for the following project are:

- Sense energy
- Process information
- Generate information

3.1.2 Primary Functions

- Detect a localized area where heat is generated
- Find and transmit location of generated heat

3.1.3 Secondary Functions

- Transmit the amount of heat produced in a given amount of time

3.1.4 Unintended Functions

- Detect heat signatures other than wildfires such as campfires

3.2 Objectives

The objectives were developed through structured brainstorming and ranked the importance of objectives using a pairwise comparison chart [Appendix B].

Table 3.1 Design objectives, goals, and metrics

Objectives	Associated Goals	Metrics
Early Detection	Detect forest fires in a smaller timeframe	Detect wildfires within a timeframe such that the area does not exceed 200 hectares [3]
Accurate Location	Identify location of fire to a certain accuracy	Location should be accurate to 500m [5]
Ecologically Harmless	Minimal waste emission Minimal sound/light emission Minimal size Minimal active chemicals/materials	Less than 50% of current waste emissions Produce less than 10dB [6] of sound and 100cd/m^2 [7] of light Surface area will be measured in m^2. Volume will be measured in m^3 No active chemicals/materials
Durability	Operable in a wide range of environmental conditions	Operable between -48°C and 36°C Withstands wind speeds of 109km/h Withstand snow depths of 208cm [8]
Reliability	False alarms should be minimal	Number of false alarms should not exceed 5% of all observed alarms [5]
Inexpensive	Cost should be less than current spending	Cost under C$31 million [4]
Utilizes Current Government Technology	-	-

3.3 Constraints

There are certain limitations that must be adhered while generating solutions for the early detection of wildfires. The solution must:

- Not negatively impact remote and indigenous communities [Appendix A]
- Cost less than C$31 million [4]
- Be operable between -30°C and 20°C, and be able to withstand a wind speed of 15.4 km/h [8]
- Withstand 398.5mm of rain and 227.2cm of snow annually and be operable in 50cm of snow [8]
- Be operable without electricity, Internet, or cellular coverage [12]
- Be implementable by 2018 fire season [Appendix A]
- Be feasible with current technology [Appendix A]

4.0 Service Environment

Generally, northern Ontario is characterized by a cold climate [8], considerably biodiverse forests [10], and sparse infrastructure [11].

4.1 Physical Environment

The climate is cold year-round with high precipitation.

Table 4.1 Climate data (averages) in Big Trout Lake, Northern Ontario [10]

Winter temperature (°C)	-30
Summer temperature (°C)	20
Annual rainfall (mm)	398.5
Annual snowfall (cm)	227.2
Year-round snow depth (cm)	22
Winter snow depth (cm)	50
Wind speed (km/h)	15.4

Table 4.2 Climate data (extremes) in Big Trout Lake, Northern Ontario [10]

Maximum temperature (°C)	36
Minimum temperature (°C)	-48
Wind speed (km/h)	109
Hourly wind speed (km/h)	70
Daily rainfall (mm)	85
Daily snowfall (cm)	37.0

Snow depth (cm)	208

[Appendix C] contains additional data.

4.2 Living Things

The two types of forests in northern Ontario, Hudson Bay lowlands and boreal forest, has its own unique ecological characteristics [10].

Table 4.3 Common animals and plants in the Hudson Bay lowlands [10]

Animals	Woodland caribou, polar bear, arctic fox, arctic hare, Canadian geese
Plants	White birch, dwarf birch, willow

The boreal forest region is "heavily influenced by natural disturbances" [10]. Species here have adapted to large wildfires, and some even require these to reproduce.

Table 4.4 Common animals and plants in the boreal forest [10]

Animals	Black bear, lynx, caribou, great owl, pine marten, porcupine
Plants	White birch, black spruce, jack pine, balsam fir, fern/moss/shrub/fungi

4.3 Virtual/Built Environment

Infrastructure is exceedingly sparse. However, a few remote communities contain winter roads and airports [11].

There is little Internet coverage [12] or cellular coverage, apart from larger indigenous communities [14]. In addition, there is nearly no electricity [9].

5.0 Identification of Stakeholders

The stakeholders are arranged in order of descending influence on and interest in the design. The safety and incomes of indigenous people can be directly affected by the design; thus, they are listed first. Ontario's government is second since it has high influence but low interest in the design. NGO's have high interest but low influence, and they are listed second-to-last. Businesses are listed last since they have low interest in and influence on the design.

Table 5.1 Stakeholders and how the design would affect their concerns.

Category	Stakeholders	Impact on Stakeholders
Indigenous communities	Inuit, First Nations, Metis	- Increase personal and housing safety through protecting them from wildfires - Less possibility of losing jobs from forest

		industries as decreasing forest fires [14] - Will cause Fire lookouts lose jobs [15]
Government of Ontario	Ministry of Environment and Climate Change	- More water resources can be protected from post-fire sediment [16][17] - Reduce the concentration of CO_2 from the CO_2 that wildfire produces [18]
NGOs	Canadian Interagency Forest Fire Centre	- The fire management will be more efficient throughout Canada [19]
	Wildlife Conservation Society Canada	- More trees and wildlife will be saved from the wildfires [20]
Businesses	Forest industries	- More timber will be protected for wood manufactures [21]
	Real estate	- Less space for constructions

6.0 Alternative Designs

The following alternative designs were generated using structured brainstorming [appendix D]. Then, the ideas were narrowed down through multi-voting [appendix E].

6.1 Design 1 - Wireless Sensor Network

This design uses information about the temperature, humidity, and carbon monoxide level at a location to detect a fire. Numerous sensors are placed throughout Ontario's forests, all relaying information wirelessly to a server [22].

The three sensors in each node are used to collect information from the environment [23]. This data is input to a microcontroller, passed to a radio-frequency module, and transmitted by an antenna to the next node [24]. The antenna has a transmit range of approximately 1 km [27].

The nodes form a mesh network [24] 1km apart from each other, interacting once every hour, eventually connecting to the gateway [22]. The data-processing server receives all the information [22] and analyzes it using an artificial neural network (ANN).

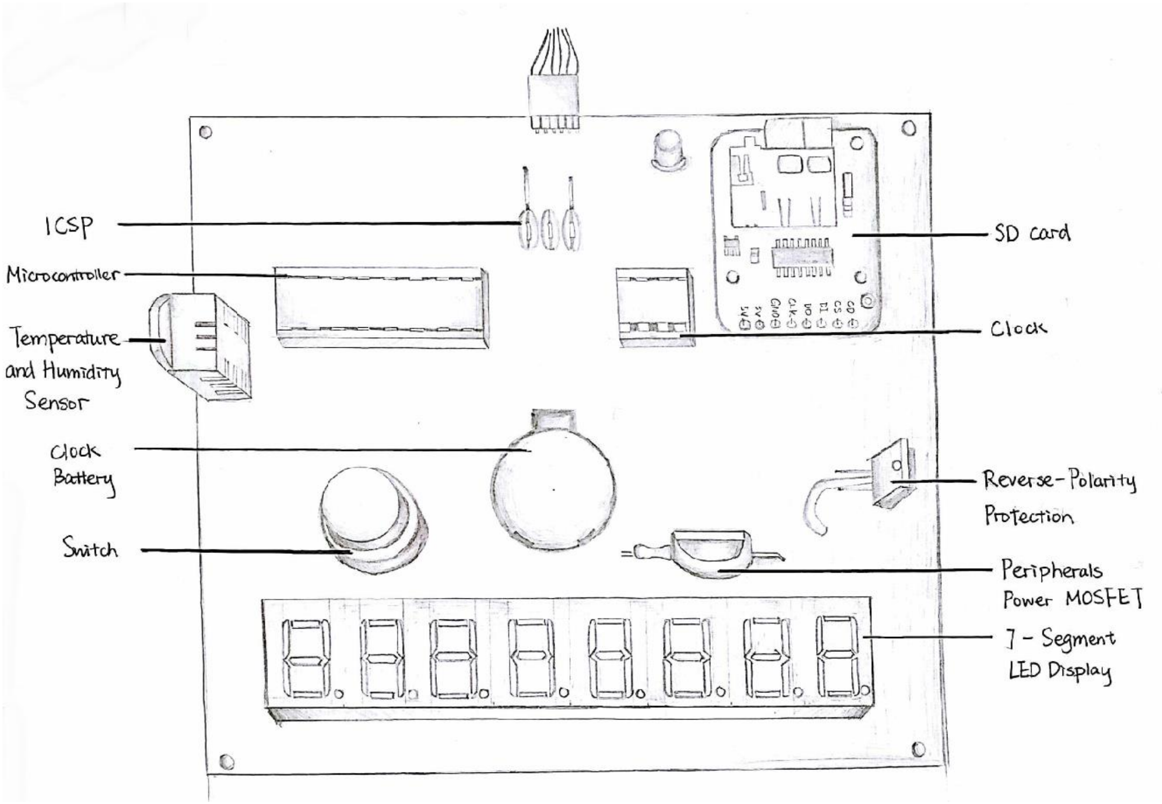

Figure 6.1.1. Conceptual sketch of sensor board design

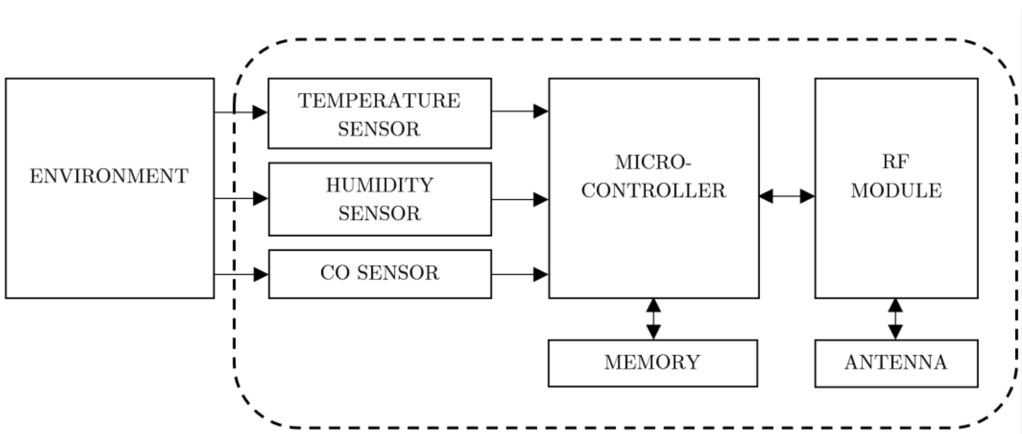

Figure 6.1.2. Architecture of sensor node [24]

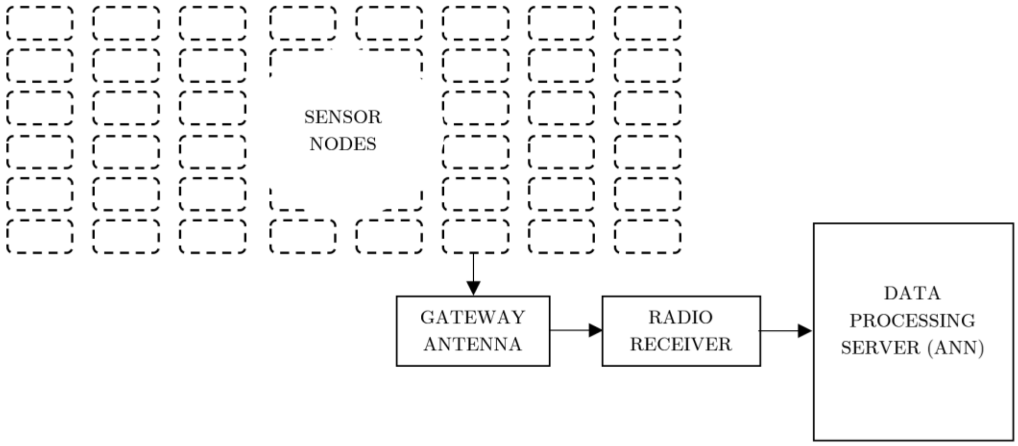

Figure 6.1.3. Mesh network and gateway[26]

The sensor nodes are autonomously powered by a rechargeable battery and two types of energy harvesters [24]:

1. Vibration energy (piezoelectric)
2. Solar energy (photovoltaic)

The voltage produced by these harvesters must be conditioned first. The power produced is partially used to recharge the battery and partially fed into a voltage supervisor. The node is powered by the supervisor whenever energy is readily available from the environment, and by the battery otherwise [24].

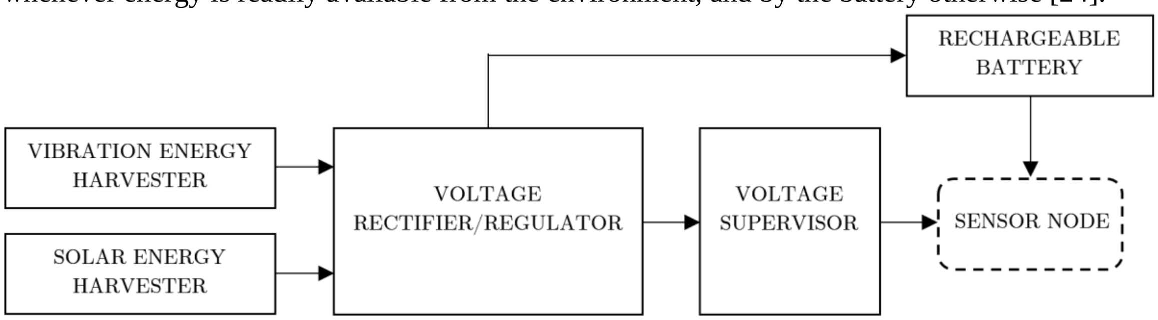

Figure 6.1.4. Architecture of power delivery [24]

6.1.1 Performance

Table 6.1 Performance of wireless sensor network with respect to the objectives

Objectives	**Performance**
Early Detection	1.5 hours. Data is sent to the server every hour and the server completes the computation in half an hour.
Accurate Location	Max 1km inaccuracy, since sensor nodes are placed 1km apart. It will be smaller depending on the architecture/training of the ANN

Ecologically Harmless	No waste apart from heat Produces no light and virtually no sound Approximately 10cmx10cm in size [23] Contains metal, which can be harmful
Durability	Operable between -40°C and 85°C [28] Wind and snow cover does not affect the sensors
Reliability	Error probability is roughly 2.3% for fires and 1.8% for smoldering fires [27], depending on the architecture/training of the ANN
Inexpensive	Fits the budget, but only marginally [Appendix F]
Utilizes Current Government Technology	Does not meet this objective

6.2 Design 2- AVHRR Satellite Integrated with Drone

This design uses a satellite and drones to detect wildfires. The satellite from a remote distance maps the location of the fire through using a special feature called Advanced Very High- Resolution Radiometer(AVHRR).

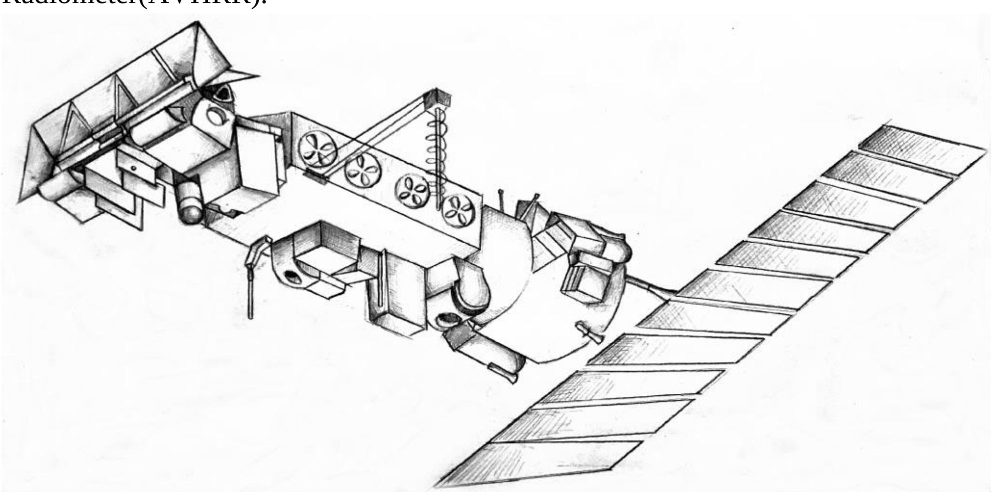

Figure 6.2.1 - AVHRR Satellite for detecting wildfires

The Advanced Very High-Resolution Radiometer(AVHRR) is a multi-spectral scanner that is built within the satellite which detects five bands of electromagnetic radiations emitted from the earth's surface. These bands include two types of thermal and near-infrared radiation and one type of visible radiation [29]. The satellite orbits the earth and scans it for band energies in a 1.1km pixel to form an image that is 2,048 pixels wide [30]. Locations of wildfires can be determined by using information from the emissions of the band energies in that location. With the AVHRR satellite, the forest can be mapped every 102 minutes [31]. The orbiting period of the AVHRR satellite is 101-102 minutes, allowing it to map the earth's surface approximately 14 times a day [31]. The AVHRR acquires data through the following format:

- High-Resolution Picture Transmission (HRPT)
- Local Area Coverage (LAC)
- Global Area Coverage (GAC)

The HRPT format produces images of the highest resolution that can be transmitted to the ground station for processing and it is mostly used for wildfire detection [29].

After the satellite maps the forest for a potential fire, a drone will be deployed to further investigate whether or not a fire is burning. The drone uses hydrogen fuel and has a flight time of more than 4 hours in which it covers 100km [32]. Moreover, it works in temperature below -20°C [32].

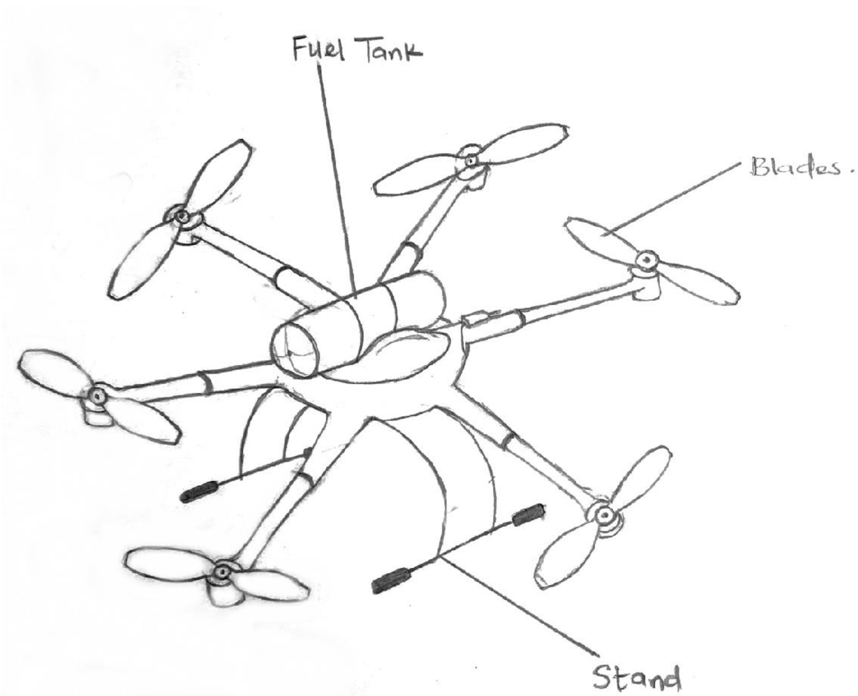

Figure 6.2.2 - Hydrogen Fueled Drone.

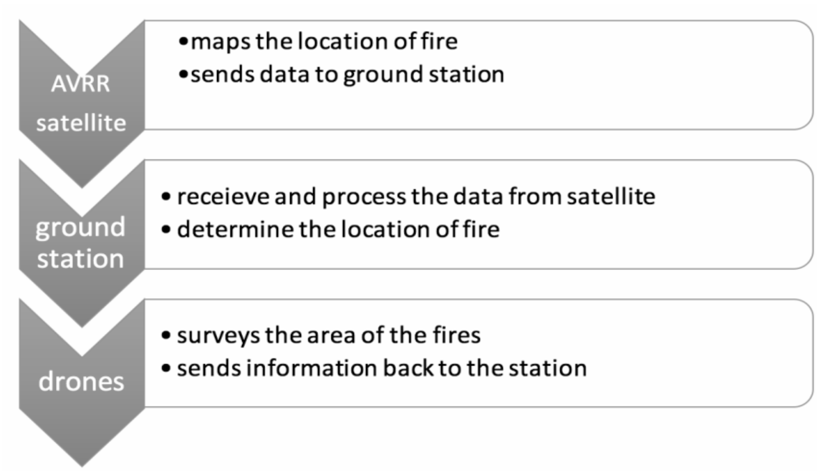

Figure 6.2.3 - Procedure followed by Design

6.2.3 Performance

Table 6.2.3 Performance of AVHRR satellite integrated with drone with respect to the objectives

Objectives	Performance
Early detection	Approximately 102 minutes [33] and the time for data processing depends on the workers at the ground station. The drone spends a maximum of 4 hours in the air but will take less to detect the fire.
Accurate Location	100% accurate location since a drone is sent to verify the location of a fire.
Ecologically Harmless	The drone uses hydrogen fuel which is a safe flammable fuel. [32]
Durability	Drone is made of carbon fibre and operable in temperature lower than -20°C [32]
Reliability	Does not use alarms but accurately detects fire.
Inexpensive	Each drone cost C$11,500 to C$19,000 [34]. It takes about C$128,000 to construct an AVHRR ground station [35].
Current Government Technology	Satellites are already in use by government.

6.3 Design 3 - Camera Watchtower

The proposed design consists of a completely rotatable (360^0) camera [36] that is attached at the top of a watchtower and is connected to a monitoring host computer using a cable. These cameras have fire detection conductive technology such as the ability to capture images, pan, tilt, zoom, and focus laser illumination [36][37] for night vision.

The visual images captured by these cameras are then transferred to a computer located inside the watchtower, from which the data is transmitted to a satellite through an antenna. Images from the camera are analysed by the computer. A fire detection software installed in the system identifies the location of the fire by associating the location on the image with a corresponding location on the ground using digital topographical information stored in the computer [43]. Triangulation is used when the fire is located on the dead ground and is not in line of sight of a single camera [36]. If a fire is detected, a signal is sent from the antenna to a satellite that communicates the message to a surveillance station.

The height of the watchtower is approximately 16m. This has been estimated higher than the average height of trees in Northern Ontario forests [Appendix G].

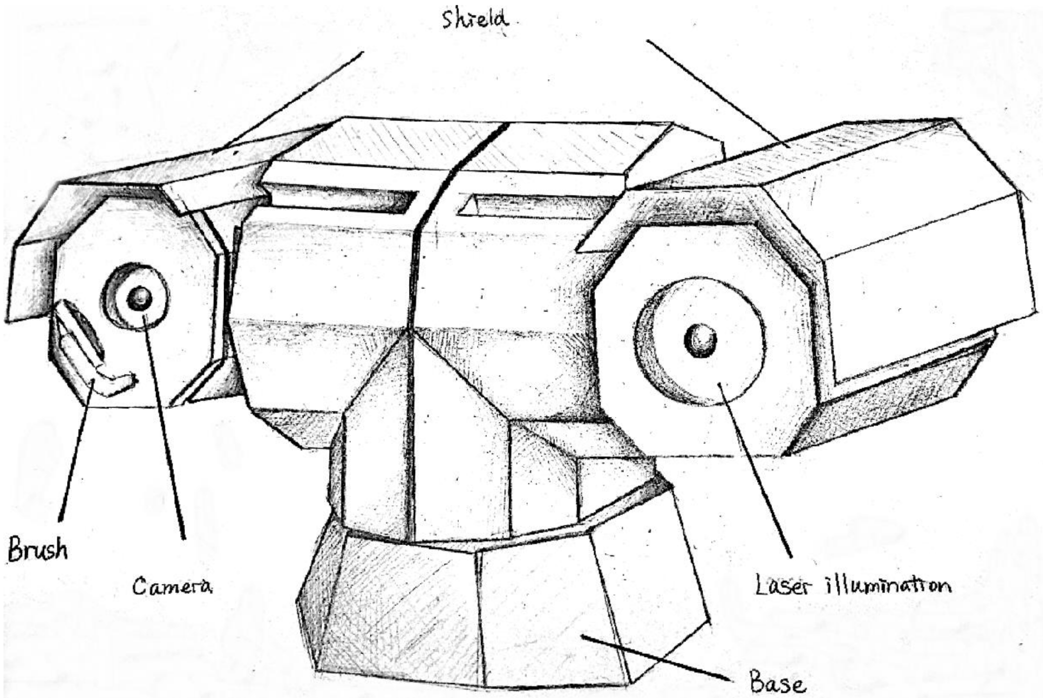

Figure 6.3.1 Conceptual sketch of proposed camera

This design involves the installation of 10 [Appendix H] such camera watchtowers that would cover a forest area of 76 million hectares.

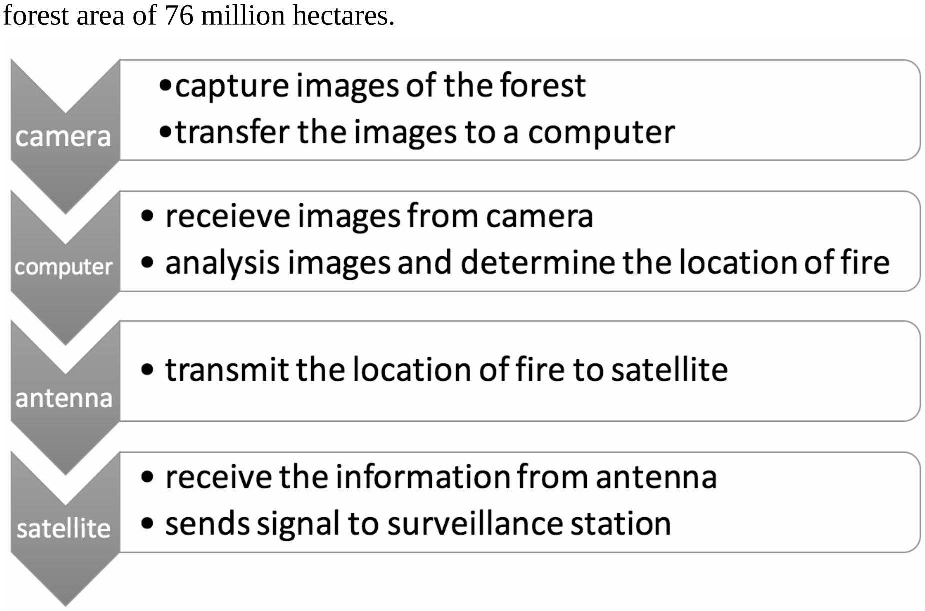

Figure 6.3.2 - Procedure followed by the camera watchtower.

6.3.1 Performance

Objectives	Performance
Early Detection	Approximately 6 minutes [43] as the camera takes 6 minutes to take a 360^0 turn
Accurate Location	Accuracy of location depends on the efficiency of the computer detecting software
Ecologically Harmless	Installation of watchtower
Durability	Operable in -40^0C to 55^0C [36]. The camera has an attached brush to remove dust, snow and rain, and is covered with metal to protect it from harsh weather conditions.
Reliability	The computer software will determine if the images taken by the camera are reliable
Inexpensive	The cost of installation of one camera watchtower is between C$38314.50 and C$102,172.00[39].
Utilizes Current Technology	This design is a combination of current technologies being used in different forest areas.

7.0 Proposed Conceptual Design - AVHRR Satellite Integrated with Drones

According to the graphical decision matrix [appendix I], the AVHRR satellite integrated with drones was considered as the best option available for the client.

The recommended design is chosen because it best meets the needs of the Ministry of Natural Resources and Forestry under several considerations:

- Accurate and reliable: satellites are able to monitor the entire area of northern Ontario. As a result, any potential fire can be detected quickly. In addition, the deployment of a drone to a location where a fire is suspected to exist ensures that the location is accurate and that the reliability of the system is optimal.
- Cost-effective: the required technology already exists within the Government of Canada. Thus, building and launching new satellites is not necessary. Moreover, the use of drones allows fire-management troops to be deployed less often.
- Easy to implement: drones in this scenario can simply be purchased “off-the-shelf”.
- Widely-used: the concept of this design has already been tested extensively by the military, climate organizations, and large corporations such as Google. The implementation of this design with certain alterations to facilitate the detection of wildfires should not be an issue.
- Environmentally harmless: the client’s need for this design manifests in preserving forest and saving costs on fire suppression, so it is a necessity for the design itself to not be harmful to the environment.

8.0 Measure of Success

Before the design can be implemented, the benchmarking tests needed to be performed are discussed below. However, one of the advantages of our solution is discussed in section 7.0 as most the technology is already established. Implementation of the technology should be straightforward as most of the experimentation, testing has already been performed by various organizations, governments and military.

8.1 Data Loss and Delay in Transmission

Due to the weather conditions in Ontario, it is crucial to discuss the data loss experienced due to signal attenuation in dynamic rain condition such as rain. The satellite system will be using a commanded downlink to retrieve satellite data that will be further analysed on ground.
The commanded downlink method of retrieving is the best model available to account for dynamic weather conditions [40].

8.2 Survival of Drone in Extreme Weather

Different drone models should be tested and simulated in a practical scenario by starting from the flight performance factoring in extreme wind speeds, snow and rain. The testing will include systems testing including drone parts and cameras.

8.3 Cameras in Object Detection

The following method was chosen because the drone will be exposed to wind, dynamic flame sizes, distance of flame and smoke. The most effective practical solution available to us is using color CCD cameras and processing the data using a neural network. The method is discussed in more detail in [Appendix J].

9.0 Conclusion

The engineering design team devised three alternative solutions to solve the problem of early detection of wildfires in Northern Ontario. Section 6.2 (AVHRR Satellite Integrated with Drone) is the conceptual design, as it satisfies most of the objectives. The team concluded that this solution meets all of the needs of the client. The following step after the proposed documentation is to implement the solution in the forests which will start with quantitative test performing.

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Appendix A: Client Statement

Engineering Strategies and Practice
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Client Statement

Early Detection of Forest Fires

Each year in Canada, approximately 9,000 wildfires burn 2.5 to 3 million hectares of forest [1, 2]. The vast majority of Canadian wildfires are detected within a timeframe that allows for them to be evaluated by Fire Rangers, and when needed extinguished before they escalate (grow to greater than 200 ha in size). However, a small number of wildfires (approximately 250 of the 9,000) escape current early detection methods, allowing them to grow beyond the ability of Fire Rangers to extinguish quickly. Though they are in the small minority of all wildfires, those that escape early detection and grow unchecked and account for 97% of the forest that is burned [1].

Globally, over the last few decades the number of wildfires have increased due to factors such as climate change, rising human population and shifting human land use patterns [6]. Each year over the last decade, Canada has spent between $500 million and $1 Billion fighting forest wildfires [2]. The 2017 fire season in British Columbia has resulted in record losses that will increase these figures substantially.

The impacts of wildfires are highly variable and complex. In some cases, the flames from a larger fire in a remote area may have no direct contact with a community, however the smoke will require evacuation. Earlier detection of fires could potential result in significant and tangible social, environmental and economic benefits.

The methods currently used for wildfire detection in Canada range from the high tech (satellite imagery) to low tech (a person in a watch tower), and each method has its costs and benefits.

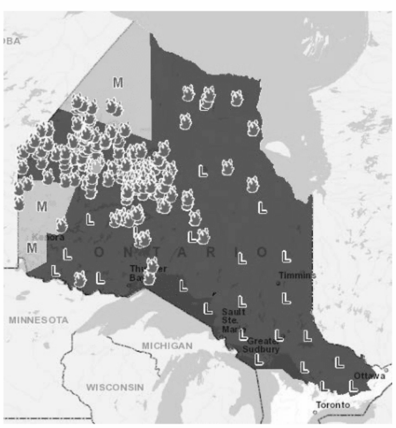

Figure 1: 152 Active fires in Northern Ontario as of September 4th, 2017. [4]

In Ontario, the Ministry of Natural Resources and Forestry is interested in proposals to facilitate wildfire detection specifically for Northern Ontario. The goal is to detect wildfires as early as possible to allow time for fire service personnel to decide on an appropriate action, be that extinguishing the fire or letting it burn itself out. On average, over 700 wildfires occur each year in Northern Ontario [3]. As of September 4, 2017, there were 152 active forest fires in Northern Ontario [4] even though forest fire danger ratings [5] have been Low (L) to Moderate (M) [4]. The primary sources of ignition for these fires are lightning strikes and the activities of people [4].

Ontario has relatively small, but densely populated infrastructure / wildland interface areas (Southern Ontario) and much larger areas of sparse interface (Northern Ontario) (see Figure 2). However, in the sparsely populated areas there are high value cultural and natural resources and communities, particularly Indigenous communities. In most of these sparsely populated areas infrastructure, such as cellular communications and roads, are not present.

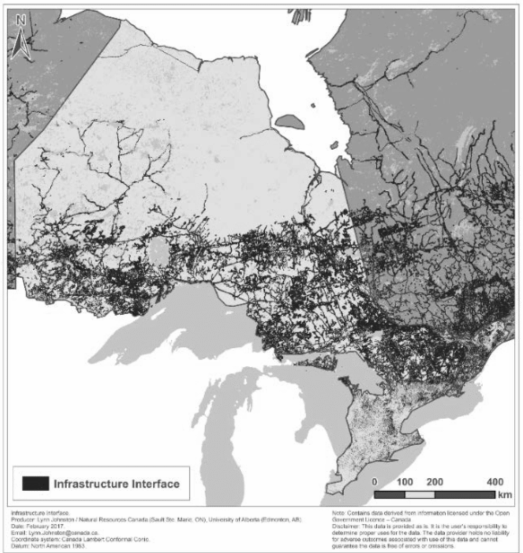

Figure 2 - The dense infrastructure of Southern Ontario contrasted with the sparse infrastructure in Northern Ontario. [7]

Additional considerations:

- The solution must be economically feasible. Any implementation and maintenance costs should be comparable to the resources currently being expended on wildfire detection. Ideally, a more efficient wildfire detection method is being sought, one that allows the Ministry to do a better job of detecting wildfires, but without spending more money.
- The ability to detect wildfires earlier in their life cycle is needed. It is easier to extinguish a smouldering tree than a multi-hectare blaze would be a positive outcome.
- The Ministry is looking for innovative solutions; at the same time, solutions that utilize current technologies and resources in more efficient ways are valid options.
- Ontario-centric solutions are the only ones under consideration, and the solution must be implementable across all of Ontario.
- Implementation should be in time for the 2018 fire season, therefore the proposed solution must be technically feasible with current technology, not purely theoretical and/or untested solutions.
- Solutions must account for the safety of remote and Indigenous communities regardless of low population density.
- Solutions must not negatively impact the quality of life for remote and Indigenous communities.

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Appendix B - Pairwise Comparison Table

	A	B	C	D	E	F	G	Total
A	-	1	0	1	1	1	1	5
B	0	-	1	1	1	1	1	5
C	0	0	-	1	1	1	1	4
D	0	1	1	-	1	0	0	3
E	0	0	1	1	-	1	0	3
F	0	0	0	0	0	-	1	1
G	0	0	0	0	1	0	-	1

A- Early Detection
B- Accurate location
C- Ecologically harmless
D- Durability
E- Reliability
F- Inexpensive
G- Utilizes current government technology

Appendix C: Climate Data in Big Trout Lake, Northern Ontario [10]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Daily Temperature (°C)	-23.7	-20.5	-13.4	-3.1	5.9	12.0	16.2	14.8	7.9	1.3	-9.1	-20.3	-2.7
Daily Maximum (°C)	-18.5	-14.2	-6.0	3.2	12.0	17.4	21.2	19.5	11.7	4.4	-5.6	-15.7	2.5
Extreme Maximum (°C)	1.9	7.7	12.2	24.4	32.4	31.7	35.6	32.9	30.6	24.4	12.2	4.7	35.6
Daily Minimum (°C)	-29.0	-26.7	-20.8	-9.4	-0.3	6.6	11.2	10.2	4.0	-1.8	-12.5	-24.9	-7.8

Extreme Minimum (°C)	-47.8	-46.7	-42.2	-32.8	-20.6	-7.2	-1.1	-1.1	-7.8	-19.3	-36.0	-44.4	-47.8
Average Rainfall (mm)	0.0	0.0	2.2	12.0	27.8	70.8	90.9	87.8	73.8	27.6	4.6	1.0	398.5
Extreme Daily Rainfall (mm)	0.8	0.3	16.0	33.0	28.6	60.9	75.2	84.1	83.8	36.8	20.4	14.5	84.1
Average Snowfall (cm)	26.0	22.6	28.2	21.3	10.4	3.4	0.0	0.0	9.3	25.9	48.4	31.7	227.2
Extreme Daily Snowfall (cm)	28.4	15.2	33.6	28.2	26.4	13.6	2.5	0.0	21.0	36.8	34.4	18.5	36.8
Average Snow Depth (cm)	52	60	59	29	1	0	0	0	0	2	18	39	22
Extreme Snow Depth (cm)	135	193	208	147	45	8	0	0	13	25	90	108	208
Average Wind Speed (km/h)	14.4	13.9	14.2	15.5	15.0	15.6	14.6	14.9	17.4	17.9	16.9	14.1	15.4
Most Frequent Direction	W	W	NW	N	E	NW	NW	SW	NW	NW	W	W	NW
Maximum Hourly Wind Speed (km/h)	69	57	70	61	61	63	68	69	67	61	64	55	70
Maximum Wind Speed (km/h)	94	82	89	104	98	106	109	100	96	81	91	76	109
Direction of Maximum Wind Speed (km/h)	NW	W	W	W	N	SW	NW	W	NW	W	NE	NW	NW
Average Vapour Pressure (kPa)	0.1	0.1	0.2	0.4	0.6	1.0	1.3	1.3	0.8	0.6	0.3	0.1	0.6
Average Relative Humidity at 6:00am (%)	81.4	81.5	81.3	81.3	82.0	81.3	82.4	86.2	87.1	86.3	85.8	83.4	83.3

Average Relative Humidity at 3:00pm (%)	77.0	74.2	68.6	60.4	53.8	56.5	57.4	61.0	66.2	74.2	80.2	79.8	67.4
Average Pressure at Station (kPa)	98.8	99.0	99.1	99.1	98.9	98.6	98.6	98.7	98.8	98.8	98.8	98.9	98.8
Average Pressure at Sea Level (kPa)	101.8	102.0	101.9	101.9	101.6	101.3	101.2	101.3	101.5	101.5	101.6	101.8	101.6

Appendix D - List of idea after structured brainstorming

1	Infrared sensor
2	Drones and satellites
3	Smoke sensor
4	Microwave sensor
5	Beam detector
6	Tomographic motion sensor
7	Monitor animal activity
8	App to maintain forest from phone
9	Ultrasonic sensors
10	planes
11	satellites
12	Tower watch
13	Detect soil/ground heating up
14	CO2 detector, O2 detector
15	Detect water concentration in soil
16	Rate of photosynthesis
17	Robarts / rovers

18	Cameras on watchtowers
19	Humidity sensor
20	Air concentration detection
21	Atmospheric pressure sensor
22	Spectral analysis
23	Network of underground chemical cable that light up on fire
24	Electronic nose
25	Neural networking
26	UAV
27	Radar sensor
28	Predict fires
29	Put sensor in metal, metal has a melting point that is the same as the temperature of fire
30	Wireless sensors (CO_2, smoke, temperature, humidity)

Appendix E - Multi-voting (30 ideas in total, each team member had 6 votes)

	Ideas	votes
1	Infrared sensor	0
2	Drones and satellites	5
3	Smoke sensor	1
4	Microwave sensor	0
5	Beam detector	0
6	Tomographic motion sensor	0
7	Monitor animal activity	0
8	App to maintain forest from phone	2

9	Ultrasonic sensors	0
10	planes	2
11	satellites	4
12	Tower watch	2
13	Detect soil/ground heating up	0
14	CO2 detector, O2 detector	3
15	Detect water concentration in soil	0
16	Rate of photosynthesis	0
17	Robarts / rovers	1
18	Cameras on watchtowers	5
19	Humidity sensor	0
20	Air concentration detection	1
21	Atmospheric pressure sensor	0
22	Spectral analysis	0
23	Network of underground chemical cable that light up on fire	2
24	Electronic nose	0
25	Neural networking	1
26	UAV	0
27	Radar sensor	0
28	Predict fires	0
29	Put sensor in metal, metal has a melting point that is the same as the temperature of fire	1
30	Wireless sensors (CO2, smoke, temperature, humidity)	6

Appendix F: Cost Breakdown of Wireless Sensor Network

Prices were found using Google and Amazon searches and may fluctuate.

Required component	**Approximate Cost**
PCB	$1.50
Microcontroller	$8
SD card 64 MB	$2
Clock and clock battery	$2.85
ICSP	$4.74
Temperature and humidity sensor	$5.80
CO sensor	$3.11
Transceiver module	$5.25
Other components (e.g. resistors, MOSFETs)	$5.20
3x AA rechargeable batteries	$9
Piezoelectric harvester	$19.99
Photovoltaic harvester	$14.61
Voltage regulator	$2.67
Voltage supervisor	$0.70
Total	**$85.42**

The total area of northern Ontario's forests is 76 million hectares [11]. If each sensor node has a range of 1 km, around 242 000 sensors will be required. Hence, the cost of the sensors alone will be C$21 million. This figure does not include manufacturing costs, nor the cost of the other components, such as the data-processing server, of the design.

Appendix G - Average height of trees in Northern Ontario forest [42]

This has been used to determine the approximate height of the watchtower

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TABLE 3. Summary statistics of diameter at breast height (DBH) outside bark and total tree height (HT) for northern Ontario data used to validate the models.

Species	Number of trees	DBH (cm)				HT (m)			
		Mean	Min.	Max.	Std. Dev.	Mean	Min.	Max.	Std. Dev.
Jack pine	550	14.81	2.50	42.10	7.92	13.32	2.15	24.96	6.42
Black spruce	616	11.34	2.10	33.30	6.12	10.25	1.30	24.80	4.93
White spruce	82	12.99	2.50	48.10	9.66	9.82	2.30	28.97	6.38
Trembling aspen	343	17.24	2.50	50.90	10.36	16.47	3.40	33.94	6.77
White pine	240	21.59	2.50	78.20	14.55	15.05	2.74	31.90	7.95
Red pine	148	22.56	2.60	68.50	22.56	16.05	2.09	36.38	8.16
Balsam fir	204	8.03	2.50	27.80	5.26	7.17	1.80	22.95	4.24
Yellow birch	44	15.64	2.50	66.70	14.04	13.76	3.27	27.50	6.03
Balsam poplar	26	23.53	4.00	45.30	10.70	20.18	5.59	29.02	6.03

Appendix H - Calculation representing the method used to obtain number of camera watchtowers required

Estimation of number of camera watchtowers to be installed –

Total area of Northern Ontario Forest = 760000 km^2

Range of 1 camera = 100 miles = 160.934 km

Area of forest covered by 1 camera = 81366.4717314 km^2

Therefore, number of cameras required to cover the given are =

760000 km^2/81366.4717314 km^2 = 9.34045662578 = **approximately 10 cameras**

Appendix I: Graphical Decision Matrix

Objectives	Wireless sensor network	Satellites integrated with drones	Cameras on watchtowers
Early detection - 25%	40%	40%	80%
Accurate location - 25%	60%	100%	40%
Ecologically harmless - 20%	80%	100%	80%
Durability - 10%	40%	80%	90%
Reliability - 10%	40% -> 90%*	80%	80%
Inexpensive - 5%	10%	80%	80%
Current technology - 5%	0%	50%	40%
Total	**58.5%**	**77.5%**	**69.0%**

*Initially the accuracy will be low, as it will take time to train the neural net.

Appendix J - Description of Technology Used for Flame Detection

The conclusion from the paper [41]**:**
"In the paper , described the fire flame detection method using a color CCD camera, and showed the result of experiment which is performed to verify the effectiveness of the method. In this method, the flame color area is extracted and the processing order of the extracted area is determined by the variance, using the color information. A space-time fluctuation data on the contour of the flame color area is produced by the polar coordinate transformation and the time series processing. Entering the distribution of frequency component on the space-time data into the neural network, the fire flame is detected. As a result of the experiment, it was shown that our method could not be influenced by the wind, the distance, the flame size changing, the flame shape changing, the white smoke and so on. Accordingly, it is considered that our method is useful for fire detection in the ordinary scene. We will investigate eliminating of the influence of the black smoke, detecting 3D position of flame and so on." [41]