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Twenty-first century technology of combating wildfire

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Abstract. Wildfire causes havoc and serious destruction of forest resources and wildlife. It also causes occasionally serious damages to human lives and properties. Current technology of fighting wildfire employs fire retardant chemicals, which pollute the environment seriously, and damages both wild and aquatic lives. Based on the new novel technology, it is possible that in the near future the industrial emissions that pollute the environments and cause health problems would be completely captured in frozen solid forms of emissions products. One of these is the frozen carbon dioxide, which is known as dry ice, which would be available than in hundreds of millions of tons in any country. Cost analysis shows that the power and cement industries would significantly benefit by selling the dry ice captured using the technology, just at $0.07 per kg. The present paper discusses the new technology of applying dry ice that would thus be abundantly available in fighting a wildfire. The paper discusses how the new technology would be by far superior to current technology that employs fire retardant chemicals in terms of environmental protection and the cost-effectiveness over the current technology.

1. Introduction

Wildfire remains a deleterious threat to the animal existence, animal habitats, local weather pattern, organic flora and fauna. Researchers have found out that any affected habitats would experience a non-hygienic environment and atmosphere due to the high level of nuisance smoke and carbon dioxide from the wildfire [1]. The wildfire is a strange phenomenon that catches the firefighters unaware because it occurs in a secluded area that is filled with dry leaves, tree and wood logs as depicted in

Figure 1. The start-up of the fire known as surface fire and the out-of-control is called crown fire as shown in Figure 1 which might be caused by artificial agent such barbeque party and smoking or through natural action like an elevated temperature during summer and concentration of sunlight via lenses on a particular point for a longer time. Besides, wildfire destroys millions of hectare of forest on a yearly basis[2]. According to the fire rule of the game: one minute typifies one cup of water, two minutes typify a hundred litres of water and ten minutes stand one thousand litres of water. For decades, forest fires have been a major concern to the European Union (EU), and as a result, the European Forest Fire Information System (EFFIS) was established by the EU in 2000 [3] to provide a robust database on wildfires for Middle East, North Africa and European.

The annual report issued by the EFFIS in 2016 recorded over 54,000 wildfires across Europe, engulfing an area of almost 376 thousand hectares. The values reported in 2016 indicates a decrease in the various wildfire incidents by about 20% when compared to the average reported forest fires incidents between 2006-2015 [4]. This percentage reduction can be accredited in part to technological advancements in early forest fire detection. However, forest fires remain a major issue that is claiming lives and properties; and early detection and quick response are necessary to combat it. There are several types of forests fires such as crown or tree fires, ground fires and surface fires [5]; each of them requiring specific counteractions to successfully combat them. Forest fire detection has been carried out in several ways, from manned to the unmanned systems. In recent times, forest fire detection has witnessed tremendous improvement through the use of the latest technology; some of which involves the installation of Infrared cameras to indicate the presence of fire. However, much focus is on the potential detection of fires by examining broader smoke areas, or by recognizing environmental parameters prior to the spread of the forest fire.

Figure 1: Fire-brigadiers wrestling with wildfire[1]

2 Monitoring of Wildfire with Latest Technology

2.1 Unmanned Aerial Vehicles

The adoption of aerial vehicles in combatting forest fires began in the 1920s through the dropping water off aircraft to extinguish forest fires [6,7]. However, in these nascent years, using aircraft in the extinguishing of fire was not very successful. Therefore the aircraft were used for the detection of forest fires instead. After the Second World War, in late 1960, the use of aircraft to extinguish forest fires remerged with the use of aeroplanes and helicopters [6,7]. However, it was found to be both costly and risky as pilots are expected to fly really close to the fires. Also, the annual number of firefighting related aircraft accidents raised public concerns about its reliability and the merits of its use.

Developmental advancements of unmanned aerial vehicles (UAVs) have created a unique opportunity for the use of aircraft in forest firefighting as they can replace piloted aircraft. In recent years, various UAVs have been assessed as answers to the early awareness of wildfires [8]. An example of such was a sophisticated drone (enhanced with multi-rotor and a blimp) fabricated by Krüll *et al*. [9]; another is the project (project code: 2263) by Balkan-Med area as to monitor and forecast the trace of forest fire as shown in Figure 2 [10,11]. A rudimentary configuration of the system uses a network of ground cameras to provide steady surveillance of the forest region targeted. However, challenges involved in this implementation are the sites where the cameras ought to be installed which may include national parks and forest reserves. Also, it is a given that camera-based systems raise a lot of false positive signals. Therefore, to provide solutions to these concerns, a multi-rotor UAV is kept stand by to investigate signals given off by the ground cameras. This will solve the problems of false signals as well as put to efficient use the limited flight time of drones.

A more comprehensive configuration involves chiefly, the use of both a fixed winged and rotary winged UAVs which allows for close monitoring of difficult terrain that does not favour the use of ground cameras. The fixed winged high endurance UAVs which can last up to 8-10 hours are equipped with infrared cameras to provide long term surveillance of the region as depicted in Figure 2. As soon as increments in temperature levels are detected by the cameras, signals with the GPS coordinates of the region is sent to the controlled station. The UAV will, however, continue to patrol and monitor the region. When the signals are sent and received, two smaller rotary winged drones will be deployed to observe the region in close proximity to confirm whether or not a false signal was given off. Further advancement of the studies involves the use of surveillance data to explore the possibilities of implementing artificial intelligence to further improve forest fire monitoring systems using UAVs.

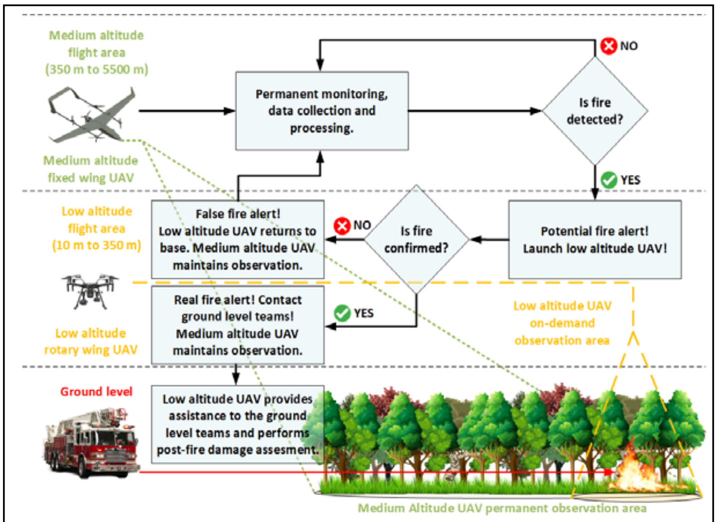

Figure 2: Network of unmanned aerial vehicles wildfire

2.1.1 *Wire-less Sensor-Network Technique*

The work of Alkhatib [2] has indicated that the wireless sensor network (WSN) is a suitable network to give a quick signal on the outbreak of a forest fire in the target area. This sensor is presently receiving global attention because of its usefulness in detecting forest fire, sensing its environment and computes the data. The wireless sensor network (WSN) has the potential to raise alarm, trip off during power surge, communicate distress messages and differentiate between the smoke of fake fires from real fires [28]. This WSN can also be adopted for early detection of a fire outbreak [28]. The wireless device tracks the presence of carbon (IV) oxide, carbon (II) oxide, nitrogen (II) oxide, pressure, relative humidity and temperature in the atmosphere. Consequentially, the sensors are economical self-organizing and self-healing wireless networking. A series of investigation has been conducted through WSN, specifically in a wood fire early detection. FireWxNet wireless device is seen to have the potential to supervise weather conditions of a harsh wildfire territory [13]. Also, in Figure 3, web cameras and wireless sensor-network have been used as a hybrid wood fire detection.

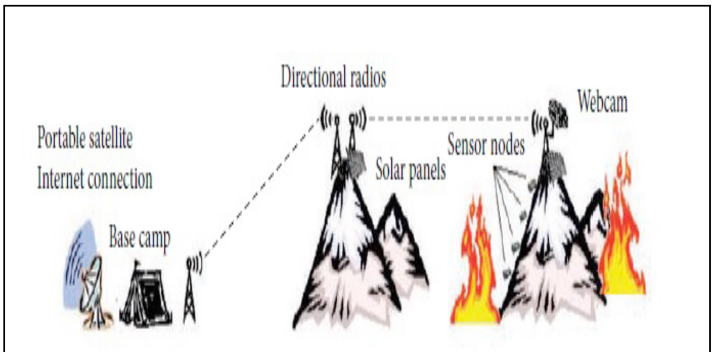

Figure 3: Schematic diagram of FireWxNet [13]

Interestingly, the adoption of GPS by Conrad et al. (2009) [14] showed that forest fires destroy nearly 2,554 acres yearly and this causes loss of socio-economic, human life and environment. Their study revealed that the use of GPS and fire-sensors devices as shown in Figure 4 are more suitable and effective than the beautiful look-out towers, aerial patrol and public phone lines.

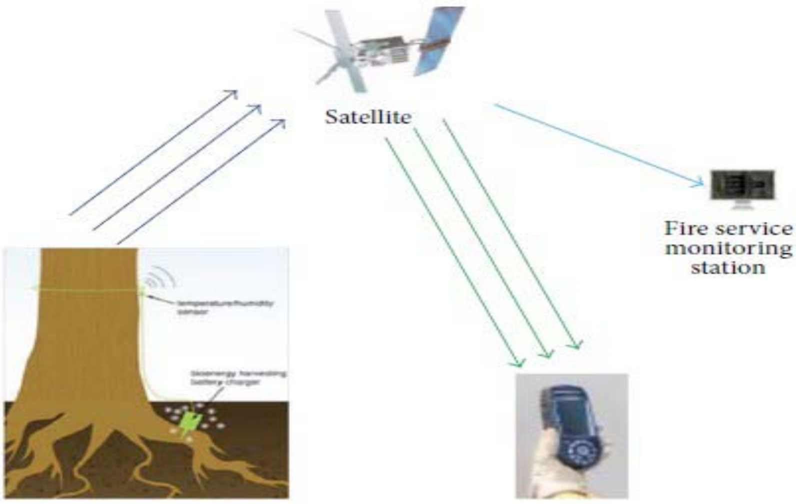

Figure 4: Outlook of GPS in detecting forest fire [14]

European Union has launched multi-sensor devices to monitor, protect and preserve their ecology from the activities of wildfire. Specifically, in the area volatile to the harsh weather condition as depicted in Figure 5 [15]

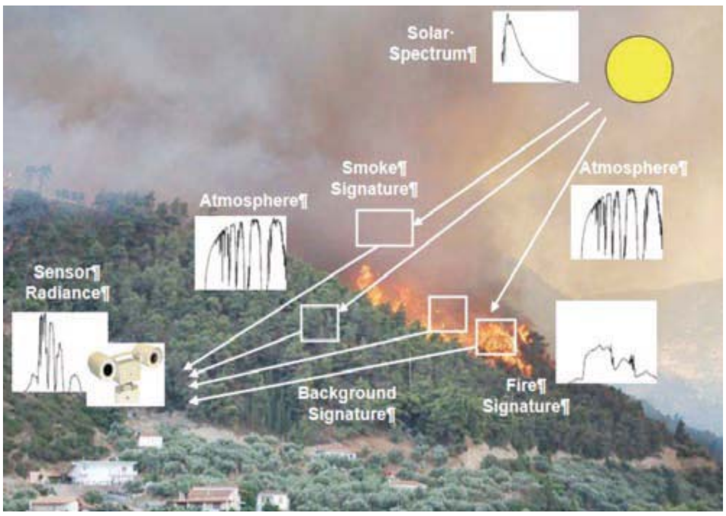

Figure 5: Wildfire monitoring with multi-sensor devices [15]

2.1.2 Spacecraft Technique

Spacecraft based technique has been adopted by researchers to have timely information and feedback on the occurrence of wildfire of such, are the advanced very high-resolution radiometer [4] and common resolution imaging spectroradiometer [5,16]. This method suffers limitless drawbacks in terms of accuracy, feedback and early detection due to the absence of antenna, frequency translation, downlink transmission, amplification reception and transponders in the mounted satellite for forecasting forest fire occurrence. In addition, the feedback of geostationary spacecraft (GEOS) and low earth orbit Spacecraft (LEOS) show that both satellites are not suitable for detecting wildfire because they are situated on orbits of 22,800 miles far apart from the earth. Substantially, inverse square law predicts that the GEOS and LEOS would become insensitive to the intensity of the infrared and optical radiation give off by wildfire flame at a far distance [Alkhatib Ahmad].

2.1.3 High-Tech Sensor and Camera Devices

In recent time, wildfires are supervised for early detection via cordless sensor and camera devices. Broadly speaking, the sensors are capable of tracking the nature of the smoke, thermal level of the fire, and backscattering of laser rays from the smoke of the wildfire [2]. These high-tech devices for monitoring wildfire operate on various algorithms according to their demands from manufactures;

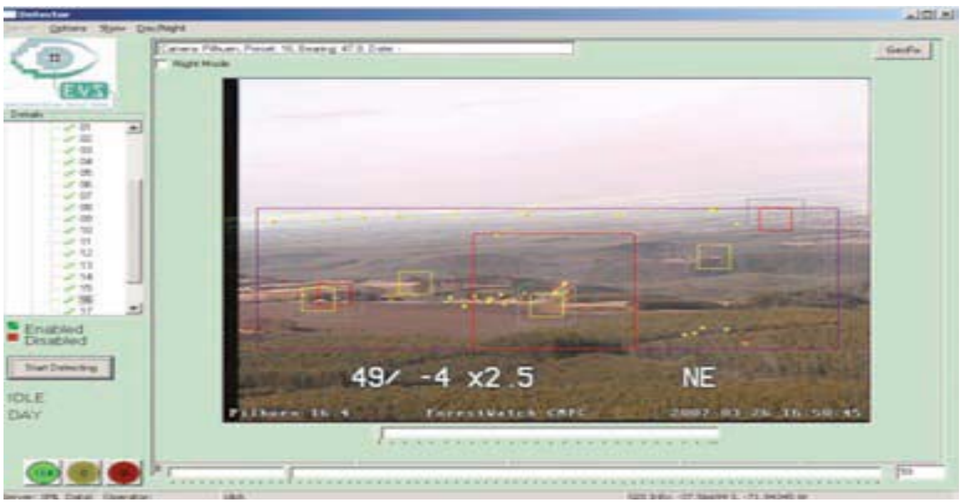

Figure 6: Outlook of forest watch gadget [17]

however, they all monitor and send a signal to the control room on the amount of smoke and fire on the location of interest as represented in Figure 6.

Consequential, the Thailand government has adopted the use of camera devices (AlarmEYE) that can detect black, infrared and colour frequency of forest fires [18,19]. Also, Fire companies in Australia are using EYEFi equipped with GIS technology to visualize the smoke level and predict the time of forest fire [18–20]. France is utilizing UraFire with underlying science of clustering motion dependent on time input to observe smoke [18,21,22]. Additionally, forest fire finder, which uses the principle of how much chemical constituent of the atmosphere is absorbed by sunlight, is used to detect forest fire. It can also distinguish the occurrence of organic smoke from a forest fire and industrial smoke as far as 15 km away as depicted in Figure 7. This method is employed in Portugal to address wildfire menace [18,23].

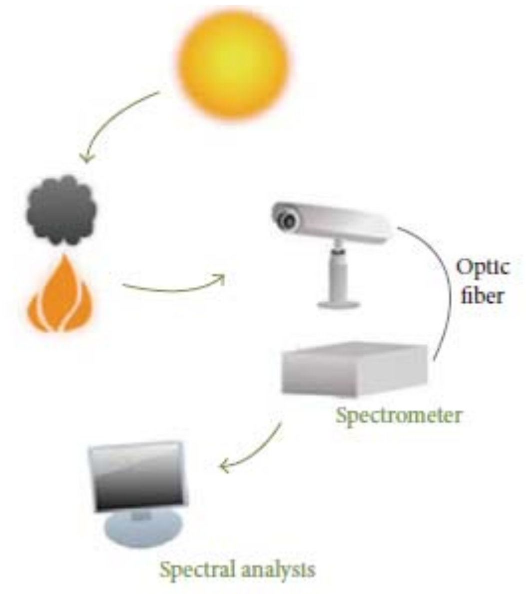

Figure 7: Forest fire detector [23]

Besides, forest watch is a semiautomatic device that can detect smoke of wildfire in the proximity of 16-20 km and deliver feedback in the range of 0.25 Mbps 3 G [19]. Fire agencies in South Africa, Greece, Swaziland, USA, Chile, Slovakia and Canada have adopted the forest watch technology to track the occurrence of a wildfire [2,19]. In recent time, fire watch with automated features that can detect and recognize smoke in the nearness of 10-40 km is being embraced by fire agencies in Cyprus, Czech Republic, USA, Spain, Greece, Germany, Estonia and Mexico [19]. Figure 8 portrays how the optical sensor system moves revolve 360^0 within 4 to 6 minutes during the day and rotate 8-12 minutes at night hours. Transfer of data from the site of interest to the central office is equally noted in Figure 8.

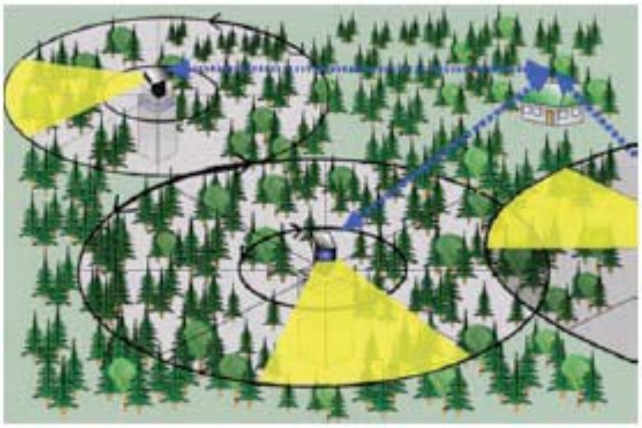

Figure 8: Schematic diagram of the fire watch [24]

Consequentially, three types of wildfire, research burning, agency burning and private burning were tested with EYEfi, Forest watch and fire watch methods are depicted in Table 1 [8]. In that, tower observer in Figure 9a gave precise and fast feedback to the control room ahead of EYEfi, Forest watch and Fire watch. This result shows that the detection effectiveness is dependent on the distance from the camera and fire magnitude. Matthews et al. (2010) observed that the manufacturers EYEfi, Forest watch and Fire watch failed to integrate the localization calculations of the land topography.

Figure 9a: Comparison of Tower observer with EYEfi, Fire watch and Forest fire [19]

Table 1: Performance of EYEfi, Forest watch, Fire watch and Tower observer on Research Fire [2]

Specimen	EYEfi	Forest watch	Fire watch	Tower observer
6-research fire	0	0	1	6
6- stationary plus two at night	0	3	3	nil

More importantly, Table 2 shows the comparison that exists among unmanned aerial vehicle, wireless sensor network, spacecraft technique and high-tech sensor camera devices.

Table 2: Summary of fire detectors technology [2]

Comparison	UAV	WSN	SCT	HTCD
Cost	Moderate	Moderate	Very High	High
Efficiency	High	High	Low	Moderate
False alarm(s)	Low	Moderate	Low	Moderate
Accuracy	High	High	Moderate	Moderate
Detection delay	long	Small	Very long	Long
Fire behaviour information	Yes	Yes	Yes	None
Other purposes	Yes	Yes	Yes	No

Unmanned Aerial Vehicle (UAV), Wireless Sensor Network (WSN), Space-Craft Technique (SCT) and High-Tech Camera Devices (HTCD)

2.1.4. Carbon (IV) oxide Technique

Wildfires of any size and ferocity can be quenched fairly rapidly if we could drop from helicopters a large number of small chunks of dry ice (solid CO_2) and liquefied CO_2, dry ice + water slush in vast quantities in and around the fireplaces. The immediate surroundings where the fire has not touched yet (say about 100 meters from the fire lines) should be completely cleared of any trees, plants, shrubs or anything that can catch fire. This clearing should be done as fast as possible. These clean areas should also be covered (up to 2- 3" thick) heavily with chunks of dry ice (-78 C) and liquefied CO_2 up to a width of 15 meters in the direction of approaching the fire. Liquefied CO_2 should be sprayed along with water from helicopters directly on the inferno and around and in places where the fire has not touched yet. Liquefied CO_2 sprayed from helicopters would create a thick layer where oxygen will be mostly displaced. The water dropped from a helicopter will force the dry ice to accelerate the release of CO_2 and replenish the CO_2 that is diffusing out.

In a region where intense wildfire is approaching fast, the following should be done to protect the houses which are at least 200 meter from the fire lines: Spread dry ice chunks surrounding each house (outside up to a width of at least 1 m, 2-3" thick and parallel to the sides) and on the roof and inside, and outside verandah, after evacuating all the people. Spread liquefied CO_2 or CO_2 gas inside enough and close all windows and doors. Remove as many trees and dry combustible staff from yards as soon as possible if fire approaches the house through the ground. Then it will stop at the outside as the immediate area will be cold and filled with CO_2. Even if fire penetrates inside somehow, its intensity will be substantially less, as inside of the house is filled with CO_2. If fire touches the roof, it will not be intense if dry ice is spread there. Following the above methods, the inferno will be quenched, and the fire approaching line will retreat. If $1.08 MN is spent for the liquefied CO_2 (50%) at a cost of $50-55 per ton, see new emission capture technology below and dry ice (50%) at a cost of $50-55 per ton, then these materials should be able to quench (when dropped from helicopters and trucks) complete wildfire (20 m high) over an area of $1\ km \times 1\ km$. It will save lives and properties. The wildfire in Carr [sees Fig. 9b], California can be extinguished in a far shorter time and with fewer personals and with less or no water when the above technique is used.

The above ingredients will be much more effective than any current fire retardant chemicals. Unfortunately, modern technologies cannot produce dry ice or liquefied CO_2 cost effectively.

To use dry ice in a vast amount to combat such huge wildfire fast we need different technology. The firefighter team must carry oxygen cylinders to breathe well during close combat with fire.

3. Sustainable Green Power Technologies

De and Oduniyi have developed a new technology to capture industrial emissions without uses of any chemicals/reagents [25]. The capture process produces very cost effectively a vast amount of liquefied CO_2 and dry ice. The cost of dry ice/liquefied CO_2 thus produced or liquefied can be as low as $50 to $70 per ton in markets (current market price is $1000 to $3000 per ton). Once implemented in industries, this new technology can ensure clean energy from coal and natural gas power plants and help mitigate global warming. The vast amount of dry ice that will be captured during the said process can quench wildfires like those in Carr, California. Wildfires also release a huge amount of CO_2 and other toxic gases that are bad for the environment and health. Such CO_2 can also contribute to global warming. Thus, the new technology will have a double blessing for us. With the vast amount of dry ice or liquefied CO_2 that is available at a very low price ($27 per ton of dry ice at the coal/natural gas power plant), we can quench such wildfires easily, fast and very cost-effectively. The technology can be adapted by any industries such as cement, power, steel etc. that produce a lot of emissions. The cost includes the cost of separate capture of associated toxic gases (in small amounts).

Thus, the new technology when employed in power plants and cement industries will not only capture [25]. The unique feature of the new technology is that the capture of emissions is paid back by sales of just 30% of the captured products. Thus, it is profitable for industries (power plants, cement and steel plants etc.) to employ the technology unlike existing emission capture technologies [excluding government incentives]. This technology cannot only ensure a fully green planet for us in future but also could provide us with the means to quench wildfires rapidly. In addition, the investigation of Dirisu *et al.* [27] recommended that firefighter should not exceed 85 seconds in and out of a building under fire.

Despite all that said above, severe punishment is needed for anyone deliberately setting the wildfire. Punishment also should be there for negligence that can cause a wildfire. All dead and dry wood must be removed as precautionary measures to prevent wildfire.

Figure 9b: The sun sets over an area affected by the Carr Fire, which had burned more than 160,000 acres [26]

4. Strategy of Rapidly fighting wildfire

A scheme of rapid wildfire fighting is shown in Fig. 10. The central area A is the inferno where the fire is raging to a great height. The surrounding area B and C are two areas where the fire is gradually spreading and area D and E fires have not touched yet. With helicopter dry ice is dropped in areas B, C and D. The dry ice in area D should also be spread by firefighters and the dry ice should cover the entire circle up to a width of at least 25 m and 3" thick. The area E (width 25 m) also should be covered with dry ice after clearing all trees, debris and shrubs. With helicopter liquefied CO_2 and water or dry ice + water, slush should be dropped on the inferno area A.

Dry ice in area B and C will soon sublimate and fill the space with gaseous CO_2. Fire will be quenched in these areas soon. While the inferno in area A is being battled, it will not find easy to spread to area B and C as long as these areas are being sprayed with liquefied CO_2. Dry ice will displace ground air completely while liquefied CO_2 spread from a helicopter over B and C will displace air up to a height of 30 m. This will prevent the fire from inferno area A to spread to B and C. Then the area D & E should be also be sprayed with small chunks of dry ice. When a fire in areas B and C have subsided with the above procedure, area D should be cleared of trees, shrubs (grasses) and debris. Then again, some dry ice should be spread over area D. While area E is cleared of all debris and shrubs and covered with dry ice up to a width of 25 m and thick ness 3", the fire will not spread further. If dry ice and liquefied CO_2 is collected from coal and natural gas power plants where dry ice should be available at $27 to $30 per ton, then the cost of fighting wild fire(inferno) over a radius of 50 m and surrounding would not exceed $16000. Once thus quenched vast area can be freed of wildfires. This estimate assumes that while Inferno is raging over a radius of 50 m, an area with diameter 100 m (with centre coinciding with that of the inferno) will be covered with CO_2 gas up to a height of 10 m.

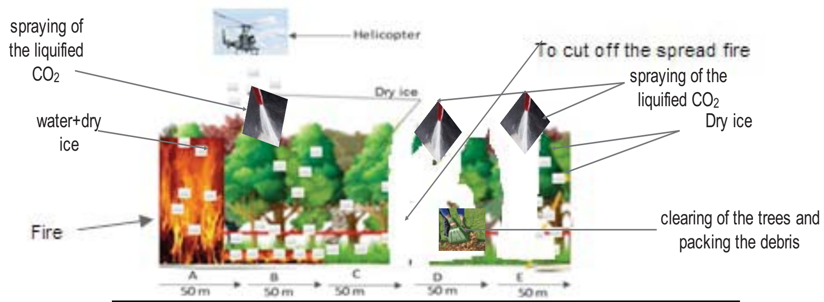

Figure 10: Schematic diagram of combating wildfire

Halting the spread of the fire in Figure 10, first the helicopter to spray liquefied CO_2, dry ice plus water slush in large quantity are positioned at area A. Second, the dropping of dry ice plus water slush is significantly available in area B. Third, a drop of dry ice chunks to cover the floor with up to 1.5 to 2" thick is seen in area C. Four, clearing of wood and debris and then dropping off dry ice chunks to cover up to 1" thick in conjunction with spray liquefied CO_2 are provided in area D. Fifth, clear wood and debris and spray liquefied CO_2.

Lastly, the firefighters on the ground who are clearing wood and debris must have an oxygen tank and mask. Once the fire is contained fully it will not spread further. The whole area of Figure 10 will be engulfed easily with a huge ball of CO_2 that will displace the air. Part of the water sprayed on the ground from the helicopter will dissolve CO_2 from dry ice and prevent the spread of fire further.

5. Conclusions

Conclusively, this study has compared various techniques for detecting and fighting wildfire. Wireless sensor network which is quite expensive looked suitable for the early detection and in the fight against the spread of wildfire. It would be seen that the method of spraying and spreading liquefied CO_2 and dry ice are cost-effective over other methods of putting out wildfire as stated in this research. More importantly, since the end product is CO_2 after the fire is quenched, then, the vegetation would grow back faster than other techniques of fighting the fire. We have proposed an innovative method of controlling a future wildfire in the sense that the emissions from coal and natural gas power plants can be captured cost-effectively and dry ice/liquefied CO_2 can be made available at the power plants at the rate $27-$30 per ton and at $50-$70 in the markets. This study recommends individual, private bodies, state and federal government of a nation to adopt the method in Figure 10 in addressing the imminent and future occurrence of wildfire.

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