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PREPARING FOR FUTURE FOREST FIRES: EMERGING TECHNOLOGIES AND INNOVATIONS

(*Mempersiapkan Pengendalian Kebakaran Hutan di Masa Datang: Teknologi dan Inovasi Baru*)

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ABSTRACT

Forest fires are part of the global ecosystems occurring for a long time in earth history. These forest fires are part of the processes which establish the ecosystems and directly influence plant species composition within the ecosystems. However, the anthropogenic effect has changed this relationship causing an increasing number of forest fires Human activities have also changed world climate and future climate is expected to increase in temperature with dire consequences on the earth environment. These changes will profoundly impact on the earth's socio-economic and human well-being. One of the effects of higher global temperature is increasing forest fires occurrences with stronger intensities. There is a need to develop innovation and new technologies to manage these future fires. This paper aims to review various innovations and new technologies that can be used for the whole spectrum of forest fire management, from forest fire prediction to forest restoration of burnt areas. Emerging technologies such as geospatial technologies, the Internet of Things (IoT), Artificial Intelligence, 5G & enhanced connectivity, the Internet of Behaviors (IoB), virtual and augmented reality, and robotics are discussed and potential applications to forest fire management are discussed. Adaptation of these technologies is vital in the effective management of future forest fires.

Key words: Climate Change, Future Fires, Innovations

ABSTRAK

Kebakaran hutan merupakan bagian dari ekosistem global yang terjadi sejak lama dalam sejarah bumi. Kebakaran hutan ini merupakan bagian dari proses yang membentuk ekosistem dan secara langsung mempengaruhi komposisi spesies tumbuhan di dalam ekosistem. Namun, efek antropogenik telah mengubah hubungan ini yang menyebabkan peningkatan jumlah kebakaran hutan Aktivitas manusia juga telah mengubah iklim dunia dan iklim di masa depan diperkirakan akan meningkatkan suhu dengan konsekuensi yang mengerikan pada lingkungan bumi. Perubahan ini akan sangat berdampak pada sosial ekonomi bumi dan kesejahteraan manusia. Salah satu dampak dari peningkatan suhu global adalah meningkatnya kejadian kebakaran hutan dengan intensitas yang lebih kuat. Ada kebutuhan untuk mengembangkan inovasi dan teknologi baru untuk mengelola kebakaran di masa depan ini. Tulisan ini bertujuan untuk mengkaji berbagai inovasi dan teknologi baru yang dapat digunakan untuk seluruh spektrum penanggulangan kebakaran hutan, mulai dari prediksi kebakaran hutan hingga restorasi hutan pada kawasan yang terbakar. Teknologi yang muncul seperti teknologi geospasial, Internet of Things (IoT), Artificial Intelligence, 5G & konektivitas yang ditingkatkan, Internet of Behaviors (IoB), virtual dan augmented reality, dan robotika dibahas dan aplikasi potensial untuk manajemen kebakaran hutan dibahas. Adaptasi teknologi ini sangat penting dalam pengelolaan kebakaran hutan yang efektif di masa depan.

Kata kunci: Perubahan Iklim, Kebakaran di Masa Depan, Inovasi

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INTRODUCTION

Forest fires are one of the global ecosystems processes occurring for a long time in the earth's history. These forest fires are part of the ecosystem processes which directly influence terrestrial plant species composition (Johnson and Miyanishi, 2001, Shlisky *et al*., 2007). However, the Anthropocene effect has changed this relationship and forest burning has been increasing and affecting large areas of forests (Bowman *et al*., 2011, Syaufina and Ainuddin, 2011). As the earth's climate changes, global forest fires are expected to be affected by these changes (McLauchlan *et al*., 2020). This paper will discuss these changes and the roles played by emerging technologies to manage these future fires.

Climate Change

Human activities have caused an increase in greenhouse gases, particularly carbon dioxide mainly from burning fossil fuels. Atmospheric carbon dioxide increased exponentially with about 30 years of doubling time since the beginning of the industrial revolution (Hofmann *et al.*, 2009). In 2019, atmospheric carbon dioxide concentrations increased in at least 2 million years and increased 47 % since 1750 (IPCC, 2021: Summary for Policymakers). The increasing atmospheric carbon dioxide causes changes in the earth's climate through its radiative effect. It absorbs energy and radiates back thermal infrared energy to the atmosphere increasing global average temperature.

The global surface temperature has increased faster since 1970. During 2011-2020 exceeded and were higher than the most recent multi-century warm period, around 6500 years ago during Holocene (IPCC, 2021: Summary for Policymakers). An increase in global surface temperature has also caused an increase in global mean sea level rise, which has been risen faster since 1900.

An increase in carbon dioxide affects plant physiology and causes a reduction in the transpiration of plants. In an elevated carbon dioxide environment, plant stomata reduce their opening and allow less water to move out of the plant cells. This will cause a reduction in canopy transpiration which will lead to a reduction in evapotranspiration. This changes the amount of water vapor in the atmosphere affecting the hydrological cycle and global temperature. Cao *et al*., (2010) use the National Center for Atmospheric Research (NCAR) coupled Community Land and Community Atmosphere Model to investigate the radiative and physiological effects of carbon dioxide increase on climate. The total effect was an increase in land surface warming, 3.33 ± 0.03 K, and global runoff by $14.9 \pm 0.7\%$. Reduced plants transpiration, led to decreases in land's relative humidity. This study showed the role of radiative forcing and the physiological effects of plants on global warming.

Future Climate

Computer simulations using various models have shown that global surface temperature will continue to increase and global warming of 1.5^{o}C and 2^{o}C will be exceeded during the 21st century. Under very low greenhouse emissions scenarios (SSP1-1.9), the average global surface temperature during 2081-2100 is very likely to be 1.0^{o}C to 1.8^{o}C compared to the average global surface temperature during a period of 1850-1900. In the same periods, global surface temperature, using intermediate scenario (SSP2-4.5) will increase by 2.1°C to 3.5°C and by 3.3°C to 5.7°C under the very high GHG emissions scenario (SSP5-8.5). Warming can be averted with efforts from various governments by deep reductions in carbon dioxide and other greenhouse emissions during the coming decades (IPCC, 2021: Summary for Policymakers). These temperature increases may lead to changes in the atmosphere processes which result in drier conditions resulting in longer forest fire seasons and more severe forest fires.

Emerging Technologies

Emerging technologies are novel, fast-growing technologies, appearing into prominence by mainstream applications with future high potential for a significant impact on the industry and human well-being. These technologies are characterized by five attributes: radical novelty, relatively fast growth, coherence, prominent impact, and uncertainty and ambiguity (Rotolo, *et al*, 2015). These technologies can be further adapted to prepare humanity for the future impact of climate change, such as disaster prediction and mitigation.

Man-made and natural disasters have impacted millions of lives annually, mostly from low-income economies. During the last few decades, the frequency of occurrence of these disasters is increasing steadily. With the increase of global temperature, it is expected that the frequency of occurrences of disasters will increase. This will result in a high number of losses of life, destruction of properties and infrastructure, and economic loss.

Forest fire is one of the disasters expected to increase in the future climate. Climate change increases surface temperature and enhances the drying of soil and organic matter in the forests. Organic matter acts as fuel for forest fire the drying of the fuel, increases the risk of a forest fire. The climate changes also create a drier condition, increased drought, and a longer fire season. These conditions also increased the intensity of forest fire and increased the rate of spread of the fire, making forest fire control difficult. High intensity and rapid growth forest fire will overwhelm and strain the forest fire management system. These fire intensities are beyond the thresholds in which fire suppression crews are ineffective in holding the fire line and making direct suppression ineffective. This will lead to more events of uncontrolled forest fires.

Application of Emerging Technologies for Forest Fire Management

Forest fire management is the integration of fire ecology knowledge with fire control for landscape management. It includes various activities such as fire education, fire prevention, pre suppression, detection, fire control, and suppression and forest recovery (Nuruddin, 2019). Forest fire prevention is one of the components of forest fire management and the main objective of a forest fire prevention program is to prevent the occurrence of a forest fire. One of the strategies of forest fire prevention is to increase public awareness about forest fire, including fire risk and its danger (Ahmad Ainuddin, 2005). Analyzing the causes of a forest fire can help develop forest fire campaigns and advertisements. The annual recurrent haze episodes have brought forest fire to the news and raised public concern on the need to prevent forest fire. The public should also be informed through a public awareness campaign using mass media and distributing educational material on a forest fire. Technological advances can help forest fire management through better incidence forecasting, response, mitigation, and forest restoration (Jain *et al*., 2020).

Emerging technologies such as geospatial technologies, the Internet of Things (IoT), artificial intelligence, 5 G and enhanced connectivity, the Internet of Behaviors (IoB), virtual and augmented reality, and robotics may be applied to manage future forest fires.

Geospatial Technologies

Geospatial technologies are technologies used to locate, map, and analysis the Earth and human activities. These technologies deal with the acquisition, storage, processing, production, and dissemination of geoinformation and include remote sensing, geographic information system, global positioning system, and information technology (Reddy, 2018). The convergence of these technologies and advancement in computing power has enabled massive data analysis into useful information for visualization and decision making.

Geospatial technologies such as remote sensing, geographic information system, and geo-positioning system have been used in forest fire management for peat forest fire hazard analysis (Razali *et al*., 2010, Sitanggang *et al*., 2011) and hotspots spatial distribution (Yukili *et al*., 2016). Researchers have started developing early warning and detection systems for forest fires (Yuan *et al*., 2017). Sitanggang *et al*., (2013) developed predictive modeling based on hotspots locations and able to predict their occurrences. Pulvirenti *et al*., (2020) developed near real-time mapping of burned forest areas using Sentinel-2 data. These studies showed the versatility of the technology for forest fire management.

Unmanned Aerial Systems (UAS) or drone technologies are advancing at a fast past. These technologies have the potential to be harnessed for various aspects of forest fire management. Ausonio *et al*., (2021) proposed a conceptual framework using a swarm of drone's system for forest fire fighting in a Mediterranean scrub landscape, while Aydin *et al*., (2019) proposed using drones for dropping fire extinguished balls for fire suppression. Drones are versatile platforms and can be equipped with multiple sensors and devices (Alkaff *et al*., 2020). Drones can be equipped with advanced imaging technology to give a better real-time situation of the ongoing forest fires. Islam *et al*., (2019) equipped UAV with adaptive imaging rate VR to monitor the frontline fire. This will allow better tactical decisions on controlling the fires. Drones' technology is being developed to increase the flight duration and capability to carry a heavy payload.

These are examples of many research that are ongoing in applying geospatial and drones' technologies for forest fire management. The outcome of these research will be useful in controlling global future forest fires.

Internet of Things (IoT)

The Internet of Things (IoT) is an enabled service by interconnecting sensors and devices based on interoperable info-communication technologies. This enables remote sensors to exchange data and can be controlled by users. It is a fast-growing technology due to the convergence of many technologies, such as the internet, computing, wireless sensor networks, and communication. Many IoT technologies have been developed and promoted in the consumer market, such as smart homes where smart sensors and appliances are embedded and connected to the internet. This enabled the user to monitor the home environment and control for comfort and energy efficiency.

IoT can be used for prevention, detection, controlling forest fires. Many countries have a network of weather stations to collect meteorological information for forest fire forecasting. In peat swamp forests, the peat water level is important to monitor since it indicates the dryness or dampness of the peat. Water level and soil moisture sensors can be set up with other meteorological data to evaluate the risk of forest fires. Sali *et al*., (2021) develop an IoT-based system to monitor peatland forest management and monitoring system in the Raja Musa Forest Reserve, Malaysia. Real-time monitoring peat hydrological and meteorological data were obtained from sensors deployed at the site and transferred to a cloud-based storage system. Data were visualized in a dashboard for monitoring. Novakovic *et al*., (2021) proposed an IoT-based system for the forest fire susceptibility assessment. Each sensor node periodically performs measurements and analyses the meteorological changes to calculate two output variables, i.e., forest fire risk estimation and fire outbreak detection. The node which estimated forest fire risk above a threshold will send the information and location to the

emergency team. This system will be continually improved for scale-up applications.

Artificial Intelligence (AI)

Artificial intelligence (AI) refers to technology that enabled computers and software to mimic the problem-solving and decision-making capabilities human mind in deriving solutions. AI technologies enables the machine to extract, aggregate, integrate, and analyze extensive heterogeneous data to provide solutions. AI continues to learn from each interaction while gradually improving its performance over time. Over time, different types of AI technologies such as machine learning, neural network, natural language processing, predictive analytics, and expert systems are being developed and improved. These technologies have been used in many applications such as GPS, image recognition, medical radiology, and social media.

AI is being used in forest fire management. Sitanggang *et al*., (2014) use machine learning techniques for hotspot modeling. The models were able to predict most likely occurrences of the hotspots near the roads and rivers, cities, non-logging concession areas, and moderate peat depth areas. Castelli *et al*., (2015) used AI to predict a burned area using forest and meteorological data. AI is also being used in remote sensing applications analyzing forest fuel images.

5G and Enhanced Connectivity

5G is the 5^{th} generation telecommunication mobile network. This is an advanced connectivity network enabling different machines, sensors, devices, and objects to be connected. 5G technology has a high data speed, a theoretical peak speed of 20 Gbps, low latency, more reliability, large network capacity, and increased availability. These capabilities make 5G has higher performance and improved efficiency and provide better services in rural areas.

In forest fire management, 5G can be utilized for the establishment of a high-performance telecommunication network connecting autonomous unmanned vehicles or robots. A study by Sharma and Singh (2021) used multiple UAVs for forest fire detection. These UAVs use 5G for efficient communication between the UAVs and ground stations. 5G can provide high-performance flight ability and control of the UAVs. Work is being undertaken to use 5G in the recording, delivery, and analysis of real-time images of forest fire taken from UAV to the ground control, where the information can be used for tactical activities for forest fire suppression.

Internet of Behaviors (IoB)

Internet of Behaviors (IoB) is an aggregation of data containing valuable insights about user behaviors, desires, and expectations (Javaid *et al*., 2021). It is an extension of IoT where the interconnection of devices produces a vast amount of data. IoB combines technology, data analytics, and the psychology of behavior. IoB's objectives are monitoring and analyzing human behavior data, such as likes & dislikes, choices of services, lifestyles patterns, and trends and explaining these behaviors using big data analytics and machine learning. This will allow companies to personalize marketing efforts and create products that meet the criteria that entice consumers to buy their products.

One of the main causes of forest fire is humans and a lot of resources have been allocated to create awareness among the population on the ignition of forest fires. IoB can monitor the community near high-risk forest areas and develop programs that educate and create awareness on the ecological role of forest fires and to reduce the risk of forest fires. More activities should focus on the prevention aspect of forest fires which can help to reduce the occurrences of forest fires by a human.

Virtual and Augmented Reality

Virtual reality (VR) is an experience similar to the real world simulated using computer technology, while augmented reality (AR) simulates artificial objects in the real-world Shen and Shirmohammadi (2008). These technologies create an immersive environment, transform the way individuals interact and are used for remote experiences and training scenarios. VR immersed the user inside an experience and interacted with the computer-generated scenes. In AR, the computers use sensors to determine the position and orientation of the camera and superimpose the images and information generated by the computer with the real world. Both technologies create an immersive environment and convincing experiences for users.

VR and AR have been used for educational purposes since computer-generated images can be created to simulate a real-life situation. In forestry and forest fire management, much research has been conducted to apply VR in various operations. Nam *et al*., (2019) used VR to develop a novel interaction and visualization technique called Worlds-in-Wedges to visualize inventory data and create an immersive image of spatial data of different forest stands in the United States. The user can compare and visualize 3 different plots side by side. Another researcher Ba (2019) used VR to simulate motion characteristics and optimization of suspension systems in patrolling forest fire vehicles. This will help to improve the overall design of the forest fire vehicle. Vicens *et al*., (2006) developed a low-cost augmented reality solution that allows an accurate selection of all the items an aircraft can visualize from its airborne position and integrates this information in a 3D terrain visualization system in real-time. This allows the pilot of the real-time airplane to see better and able to coordinate activities of forest fire control more effectively.

Effective forest fire suppression can be achieved with near real-time simulations. Cha *et al*, (2012) developed a virtual reality-based fire training simulator integrated with fire dynamics data capable of calculating heat, toxic fumes, smoke, and flame. The simulator will mimic fire situations and provide virtual experience and training physical behavior of smoke and flames.

Robotics

Robotic technology is the design, construction, and operation of machines to help and assist humans. It integrates various disciplines such as mechanical engineering, electrical engineering, and computer science. These machines are called robots and are used for repetitive tasks or jobs dangerous for humans. There are many types of robots, but the most common robots are industrial robots designed to assist manufacturing and industrial production. These robots are programmable machines made up of sensors, actuators, and programmable processing units. These robots can be programmed to operate autonomously or semi-autonomously and currently, efforts are being made to include AI in the operation of the robots.

Many attempts have been made to develop robots in forest fire management. Roldán-Gómez, (2021) surveyed robotic technologies for forest fire management and found that robotics technology can be used in the 3 phases of forest fire management, prevention, suppression, and the restoration of the burnt ecosystem. Aerial robots have been proposed to perform surveillance of forest fires. UAVs equipped with vision-based systems can be used to monitor and detect forest fires (Yuan, *et al*., 2017), while Haksar and Schwager (2018) developed a deep reinforcement learning (RL) based strategy for aerial robots to suppress forest fires. On the ground, Couceiro *et al*., (2019) proposed a robotic system that helps reduce the accumulation of forest fire fuels by grinding the material for mulch. This will reduce the accumulation of combustible material and lower the risk of forest fires.

Forest fire fighting robots are being developed to be used in a real-time field situation. Several companies are commercializing their forest fighting robots (Pransky, 2021). These robots are equipped with AI-assisted advanced imaging technology and created to withstand extremely hot temperatures and dangerous conditions when suppressing forest fires. Continuing development is being done to perfect these robots for field use and effective forest fire suppression (Bogue, 2021). These robots will be one of the forest fighters' many tools to suppress forest fires.

DISCUSSIONS

Emerging technologies as discussed above, are relevant and have high potential application for the management of forest fires. Currently, there are research conducted to apply emerging technologies in different phases of forest fire management (Figure 1). Forest prevention is one of the important activities in forest management since this involves local communities. Application of IoB can help understand and profile local communities much better and develop a forest fire prevention program that can cater to different age groups and focus on a group with forest fires risk.

The development of educational material for forest fire prevention programs using VR &AR technology can help raise awareness on the role of fires in the ecosystem. VR &AR technologies can simulate future fires and changes to ecosystems. This can motivate the users since they are looking into the future. Similar simulation games have been developed by climate activities where users can see the impact on their locality if the sea level rises. They can observe the seawater coming and can see flooding that can occur.

Geospatial technologies through remote sensing were used to characterize different forest fuel categories, but the convergence of remote sensing, GIS, and GPS has enabled more complex work on forest fire management, such as forest fuel modeling to be done. This is essential information for the prediction of forest fires incidents. With the progress in LIDAR technology, more forest inventory metrics will be readily available, especially on standing trees. This information enables vertical distribution biomass of forest stands is known and coupled with AI technology, 3D characteristics of a forest fuel model is derived and will be helpful in forest fire spread modeling. The pace of advancement of this technology will improve the capability to monitor forest fire occurrences and predictive ability can be enhanced with the integration of AI. This will be an additional tool for forest fire managers.

The convergence of emerging technologies can integrate various technologies into a single system but perform multi-functions. Drones equipped with geospatial technologies, AI with IoT sensor with 5 G enhanced communication can perform forest fire surveillance, forest fire detection, and forest fire communication control. The development of autonomous terrestrial forest fire fighting robots equipped with fire detection capability with AI is in

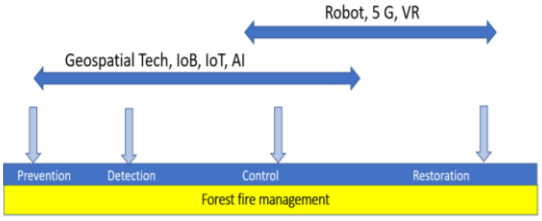

Figure 1 Schematic diagram of applications of emerging technologies for forest fire management.

progress (Bogue, 2021) and may be part of many tools for managing future forest fires.

CONCLUSION

Climate change is expected to impact the earth's climate by increasing global surface temperature and changes in the global hydrological cycle. These changes the earth's environment that favors longer forest fire season with the fire having higher intensity.

Emerging technologies such as geospatial technologies, Internet of Things (IoT), Artificial Intelligence, 5G & enhanced connectivity, Internet of Behaviors (IoB), virtual and augmented reality, and robotics are potential technologies that can be used to manage future fires.

Collaboration between inventors, entrepreneurs, funders, and forest fire management managers is needed to develop effective integrated solutions for managing future forest fires.

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