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Advancing Autonomous Quadcopters for Wildfire Response & Suppression

Improving NASA's Advanced Capabilities For Emergency Response Operations (ACERO)

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Abstract:- The Autonomous Control and Emergency Response Operations (ACERO) is a project developed by NASA where they use quadcopters to mitigate and aid in various different types of natural disasters like earthquakes, tsunamis, landslides, wildfires etc. In this specific paper, we're focusing on ACERO's quadcopters in mitigating wildfires which are designed to operate in harsh environments, providing crucial data and support during wildfire incidents. Despite these amazing inventions, there is still room for significant improvements to further improve wildfire suppression and response capabilities. This research paper provides a concept project that aims to build upon ACERO by introducing a series of six main improvements to the quad copter model: Fire Detection System, Autonomous Coordination, Safety Protocols, Communication Infrastructure, Testing and Validation, and Flight Control Systems and Surfaces etc. By implementing these improvements, we believe to enhance the accuracy, efficiency, and safety to wildfire response operations.

Keywords:- *ACERO, NASA, Quadcopters, Wildfires, AI, Autonomous Coordination.*

I. INTRODUCTION

The Advanced Capabilities for Emergency Response Operations (ACERO) is a project led by Nasa's Ames Research center in Silicon Valley California. ACERO's goal is to utilize quadcopters and advanced aviation technology to enhance natural disaster emergency response systems, especially disasters like wildfires. Its main focus is to reduce the risk of in-person interaction of mitigating natural disasters like wildfires by using remote controlled quadcopters that are driven by a pilot outside the disaster area. The ACERO team is currently focusing on airspace management technologies in order to setup a smooth workflow that can integrate seamless information transfer as well as enhanced communication between the quadcopters, the pilots and ground crews. ACERO has collaborated with a numerous amount of government agencies, scientific communities, commercial and wildlife industries while also having received funding from NASA's Aeronautics Research Mission Directorate to develop better strategies for natural disaster mitigation management which is currently in ongoing development.

One of the most catastrophic natural disasters that they aim to mitigate are wildfires. Wildfires can occur in many places and very frequently with subtle changes to weather. For example, our home state California has had approximately 87 million acres burned since 2002. 10 of the 20 largest wildfires since 1950 burned in 2020 and 2021, with the largest being the August Complex Fire, scorching over 1 million acres. Despite a quiet fire season last year in California due to above-average rain and colder winters, there is a 77% chance that conditions associated with cooler and drier conditions could develop between September and November. This dry fuel combined with strong Foehn winds makes for quickly raging wildfires that spreads through a highly vulnerable chaparral shrubland community, where vegetation is highly flammable. Major wildfire seasons in California, like 2018 and 2020-21, produced suppression costs well over $1 billion. Other costs, such as burned buildings and lost homes force thousands to evacuate and lose their homes. The 2018 Camp Fire in Butte County, CA caused 85 civilian deaths. On the frontlines, Firefighters risk their lives by battling huge flames while in the air, pilots flying firefighting aircraft run into the possibility of colliding with other aircraft due to low visibility produced by the large amounts of smoke from the wildfire.

Due to the large number of wildfires that take place in California every year, our we came up with this concept project. This project aims to create a custom quad copter project that is inspired from NASA's ACERO project. It aims to take the current ACERO project from NASA and improve its current cons to enhance autonomous control and natural disaster mitigation techniques, hopefully reducing the risks of in-person interactions to mitigate wildfires. Currently ACERO's quadcopters lack a main factor which is situational awareness and a multitude of other tools to operate their quadcopters safety. Current management tools are not also advanced enough to safely integrate a quad copter and monitor a fire for extended periods of time. Based on the considerations taken by our team, these new quadcopters will have these certain improvements: ***1. Fire Detection System, 2. Autonomous Coordination, 3. Safety Protocols, 4. Communication Infrastructure, 5. Testing and Validation, and 6. Flight Controls and Surfaces***.

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II. IMPROVEMENTS

A. Fire Detection System

AI-Powered Cameras and Sensors - each quad copter has advanced cameras and sensors capable of detecting wildfires from afar using AI technology. This provides real-time analysis which utilizes AI algorithms to analyze sensor data in real-time, identifying fire locations and assessing their spread. Infrared terrestrial cameras and Optical Sensors – maps data and allows quadcopters to map out and view active fires and hotspots that may be hidden by smoke, which would not be detected otherwise. We can interlink these devices through a custom satellite and an IOT network specially created by ACERO's engineers.

➢ *Why we need this –*

- *Nature Tech*

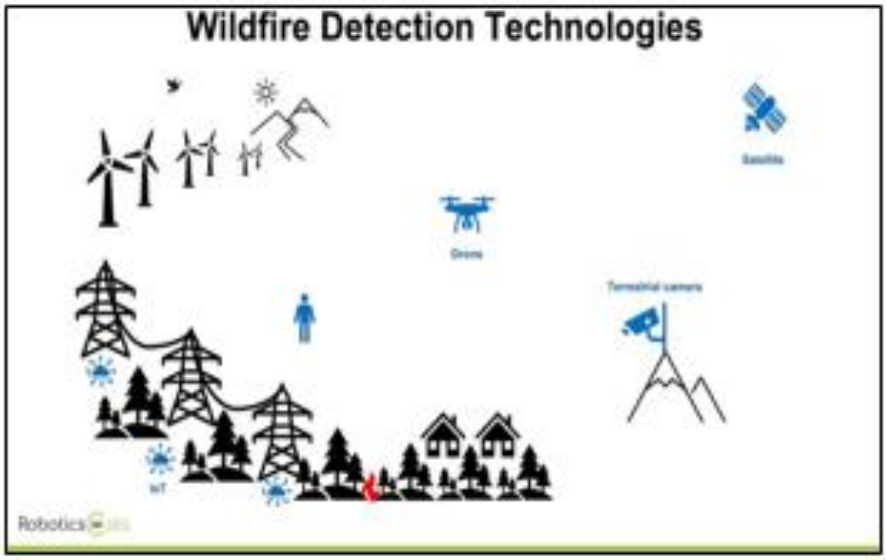
Preserves biodiversity and prevents the destruction of habitats.

- *Climate Tech*

Significantly reduces amount of carbon dioxide into the atmosphere by detecting and managing wildfires early and mitigating their impact.

- *Smart City Technology*

Reduces risk of wildfires impacting nearby communities and infrastructure (ex. Airports, Power Plants, etc.).



Example Shown in the Picture above: Custom Wildfire Detection Technologies Used to Map Out Terrain Infrastructure in Order for the Quadcopters to be Able to Learn and Mitigate Wildfires Using its AI and Optical Sensors. (Source: Robotics Cats).

B. Autonomous Coordination

In the case of a wildfire, quadcopters to be initially flown into the hotspot area manually with a quad copter controller. After reaching the site, they are autonomously controlled so that they could begin their process of mitigating wildfires. Quadcopters will be autonomously operated through advanced flight control systems, sensors (like lidar, and infrared AI operated cameras etc.), and custom software's which will have predefined flight paths, waypoints, strategies to help the quad copter successfully complete its mission. Each mitigation session carried out by the quad copter will have video footage recorded through its cameras and sent to a central server where it is used to train better autonomous coordination for the quadcopters. (similar to tesla's autonomous driving systems). The goal of this specific feature is to reduce human efforts in making any mistakes while maneuvering the Quad copters.

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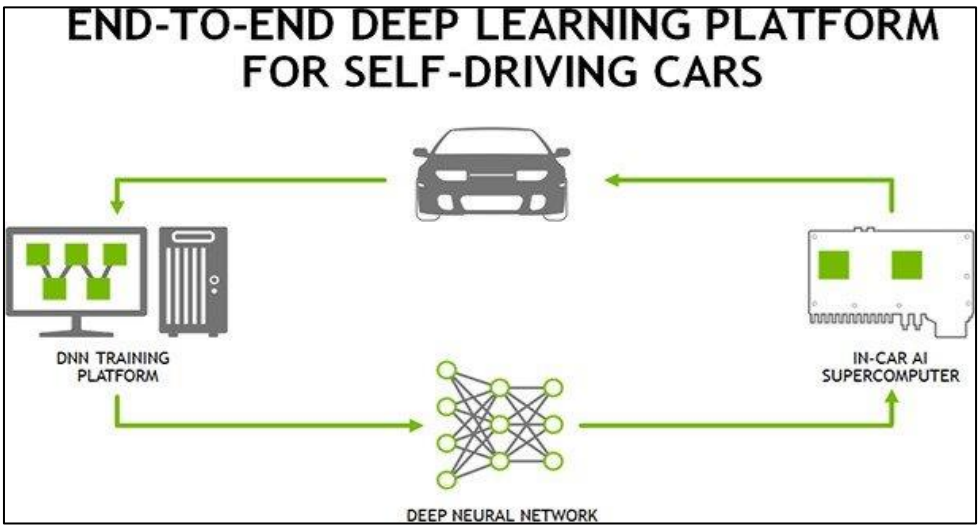

Fig 2 The image at the bottom right (Source: Plumini) is an example of how the quad copter's autonomous coordination will be improved similar to self-driving cars like Tesla for example. Using a centralized server, data collected from the quad copter's lidar and AI cameras will be processed and analyzed and fed into a deep neural network where algorithms will be better enhanced to provide enhanced mitigation techniques for the quadcopters which will be transmitted back to the quadcopters in-built AI supercomputers.

C. Safety Protocols

Before and after the mitigation process, all the quadcopters in our facility will be thoroughly inspected by different chief officers from the respective departments to make sure everything is successfully setup for the mission. In case the quad copter fails its autonomous control during the mitigation process it will switch to manual mode and immediately alert the user to use the controller. (Note: despite the autonomous coordination used to drive the quad copter, the user is still watching the quad copter's activity). In the unfortunate case of a crash, we don't want the quad copter to cause an explosion and complicate the wildfire even more. Procedures are in place so that when the quad copter is in an impact, chemicals are released, disposing of the quad copter properly and safely. For this we've developed a system where the quad copter has built in chemicals that release during impact to form a protective rubber like fire-proof guard that seals the quad copter completely, preventing any complications during the mitigation process. Airbags will also be built in for increased protection and recovery. Most importantly, quadcopters will have safety and warning precautions stickers engraved to warn the public around its vicinity. These will be officially verified by the government and registered with the respective safety and registration labels.

D. Communication Infrastructure

Quadcopters will be able to communicate with other quadcopters using their own custom communication networks that will be installed in their operating systems. Quadcopters will also be manually controlled through a quad copter controller that will be provided to the operators. Autonomous control will be controlled and programmed by the central server hosted in the facility. There is also a designated control center that will take care of the quad copter missions. An IOT system and satellite connection will be linked with the quad copter so that data could be transferred to the central server. Encryption and security protocols will be simultaneously ongoing while all of this takes place in order to protect any data breaches. Jammers like devices will also be installed inside the quadcopters in order for in-quad copter communication only and to prevent external devices from being able to cause intercept the quadcopters.

E. Testing and Validation

Instead of conducting real-world flight tests, which can be expensive and dangerous, testing is done in a completely virtual environment that is low-cost and low-risk. Operators can pretrain certain scenarios and tactics to refine strategies that are used in real-world situations. High-fidelity quad copter simulations can be used to represent real environments. Past historical data obtained from imaging systems and sensors, such as infrared cameras and LiDAR sensors can be visualized in real-time for interpreting wildfire detection, mapping, and monitoring. Physical sets can also be placed with custom made markers that can be programmed to wildfires, obstacles etc., for the quad copter to maneuver through. VR headsets linked to the quadcopters mapped with these immersive simulation-testing technologies can help operators to enhance situational awareness by assessing how the quad copter can practice flying through conflicting conditions, such as fog, strong winds, high elevation, and dense vegetation. Virtual environments also allow operators to conduct extensive wind tunnel testing and computational fluid dynamic simulations to fine-tune the aerodynamics of the quad copter which eliminates the expensive and time costing process of building models and operating wind tunnel facilities.

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F. Flight Control Systems and Surfaces

These are some of the design elements that can be incorporated into quadcopters to improve their hardware, aerodynamics, and control systems. To reduce drag and turbulence, streamlined propeller blades with a tapered and swept-back shape could be designed. This is accomplished by reducing the blade surface area at the tip. We can reduce drag by making lightweight propeller blades out of composite materials like carbon fiber rather than metal. Using more efficient propulsion and energy systems, brushless motors and propellers with high efficiency can be built for use with heavy payloads. Regenerative brakes and solar panels integrated into the quadcopter's construction can absorb and store thermal and kinetic energy as electric energy, allowing it to be used later when the quadcopter's energy is depleted. Making a smooth and curved fuselage could assist reduce air resistance and generate more lift. The quadcopter's bottom will have a container-like structure with fire-extinguishing ingredients sprayed out by nozzles incorporated into the quadcopter to combat wildfires. The quadcopter will also include active control systems, which will include extra sensors such as gyroscopes, accelerometers, and airspeed sensors, allowing for real-time data on the quadcopter's performance. Flight control algorithms will transmit orders to electric actuators, which will modify the pitch angles of the propeller blades to ensure that the quadcopter maintains a stable angle of attack.

III. EXPANDING QUADCOPTERS

Apart from using ACERO'S quadcopters for wildfires, it can also be used to help with other natural disasters, such as earthquakes, tsunamis, tornados, landslides etc., in giving proper assessments of damage and humanitarian aid to victims. As stated previously, quadcopters are equipped with high resolution cameras which can provide aerial coverage of debris and rubble to rescue teams, allowing them to identify hazards and plan evacuation routes more efficiently. The infrared cameras and other thermal sensors can also help rescue teams to locate trapped survivors more easily. These LiDAR-equipped quad copters can help engineers create 3-D models of damaged structures to assess structural flaws that caused certain buildings to collapse during a natural disaster. Real-time data is collected to help authorities become aware of what areas to prioritize for repair and allocate sufficient resources for those areas. Likewise, quadcopters can be used alternatively as a payload-carrying quad copter with cargo compartments and release mechanisms to transport food, water, and first-aid supplies to disaster survivors, reducing the response time and ensures that survivors get the support they need in the middle of a search-and-rescue operation.

IV. CONCLUSION

The advancements stated about NASA's ACERO quadcopters aim to significantly enhance wildfire response and suppression capabilities. By integrating advanced fire detection systems, autonomous coordination, communication infrastructure, newly improved testing and validation methods, and improved flight control systems and surfaces, these quadcopters will be better equipped to operate in harsh environments and conditions more effectively. These enhancements not only improve the ability of quadcopters to fight wildfires, but it also prevents human intervention during dangerous emergency response scenarios. Thus, this project was made to address the potential of NASA and ACERO's technology in addressing natural disasters and safeguarding human lives as well as the environment.

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