Project Soteria

A Low-Cost Fire Mitigating UAV Implemented Through Stereovision, SONAR and Path Planning Algorithms

Background

- Over **250 million USD** in property lost
- More than **100,000** displaced and left homes by the fires
- Almost **5 football fields** of fire for every firefighter on-site

These are **just** the implications of the LA fires of 2025


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Engineering Goal

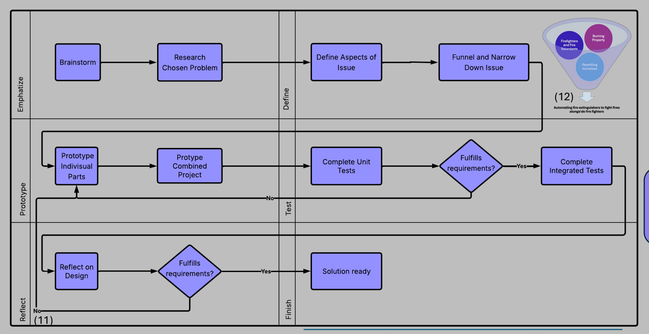
The project's purpose is to design a UAV with a fire extinguisher to **augment firefight ability on-site** and **lower respond times** with the end goal of **reducing wildfire damage and deaths**.

Low-level Objectives

Develop a SONAR system with a cost of less than 30 USD and an accuracy of within 0.1 meters
Develop a water turret with a cost of less than 30 USD and with a top nozzle velocity of at least 5 m/s
Implement an automated flight control system with a cost of less than 30 USD, the ability to hover for 5 minutes and fly a given path with an accuracy of at most a 0.5-meter deviation
Implement a path planning algorithm that had a guaranteed path finding ability and ran under 10 ms
Build an airframe with a dry weight of less than 800 grams and ability to handle drops from 6 feet

Methodology

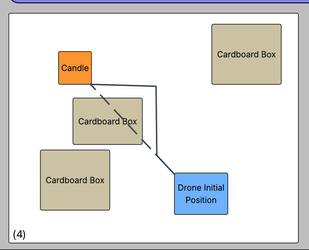
Design Thinking Process



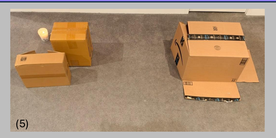
Materials

Main Drone: F450 Drone Frame, 40 A ESCs, 920 kV Motors
Sensors: HC-SR04, MLX 90640, BMP 280, MPU 6050, PMW 3901
5g 180˚ Servos
2 ESP32 and a breadboard
3D Printed Components
Trigger mechanism from a water gun
Total Cost: 270 USD

Test Setup

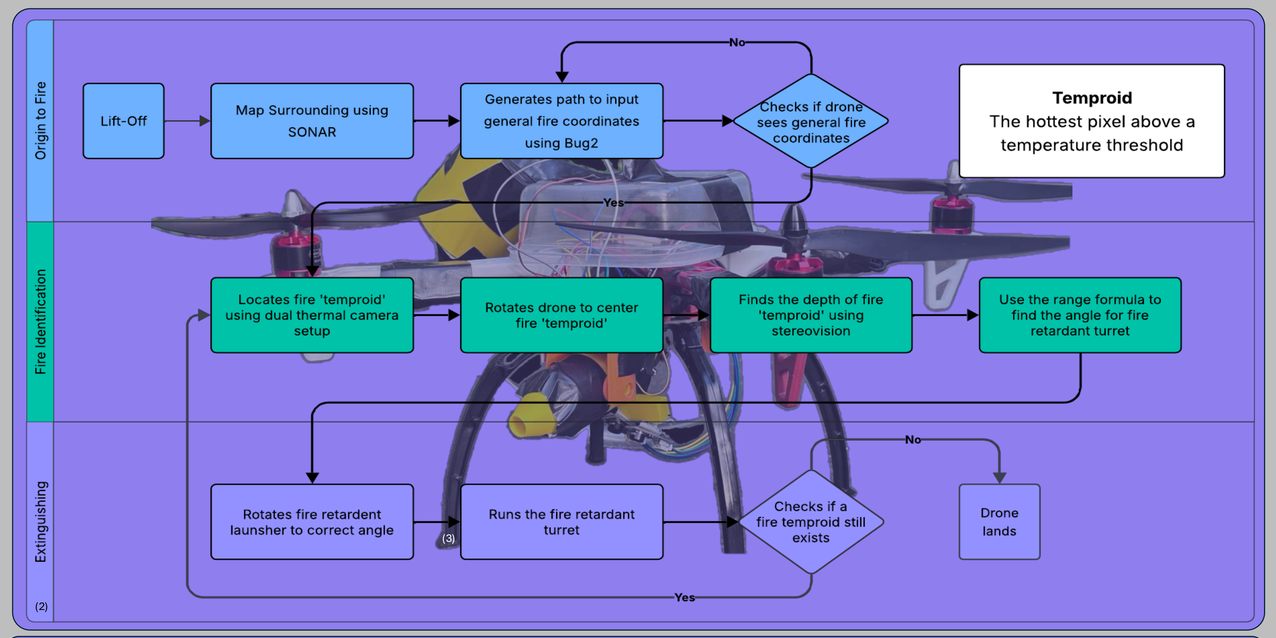


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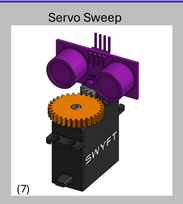
The 40 setups (20 indoor, 20 outdoor) used were generated with 3 – 6 cardboard boxes and a candle.

Design Overview

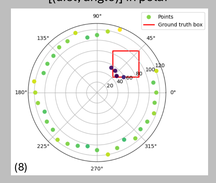


Navigation to General Fire Location: SONAR and Path-Planning

Servo Sweep

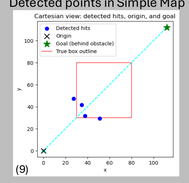

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[(*dist*, *angle*)] in polar



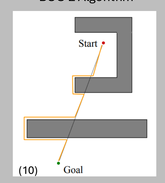
(8)

Detected points in Simple Map



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BUG 2 Algorithm

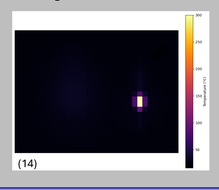


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Fire Identification and Extinguishing: Stereovision and Kinematics

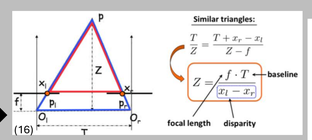

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IR Image of Front IR Camera


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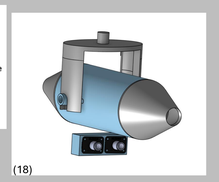
IR Image of Front IR Camera After Drone Rotation


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$$\tan\theta = \frac{v^2}{gR}\left[1 - \sqrt{1 + \frac{2gh}{v^2} - \frac{g^2R^2}{v^4}}\right]$$
(17)

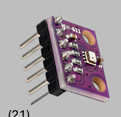

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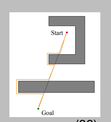
Autonomous Flight Control: Position Estimation and Command Execution

Initial position updated by velocity → Path Planning generates abstracted path command → Modified EspNow RCLink Transmitter locally generates ESP-FC commands on channels → ESP-FC generates ESC commands → ESC generates motor commands (19)



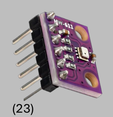
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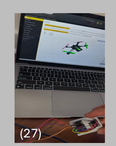


(22)

Safety Thresholds were applied: Maintain 40 cm buffer from all obstacles. If buffer is broken, immediately land

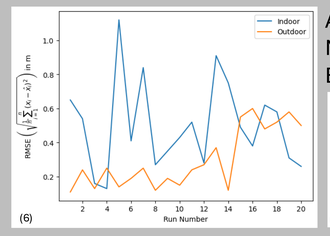

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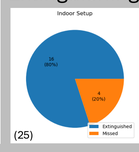
Results

Objective No.	Measurable	Measurable Value
1	Cost (Under $30)	$8.99
	Accuracy (Within 0.1m)	0.07 m
2	Cost (Under $30)	$22.89
	Nozzle Speed (At least 5m/s)	8.37 m/s
3	Cost (Under $30)	$9.49
	Hover for 5 minutes	Fulfilled Requirement
	Accurate path planning (At most 0.5m deviation)	Mean across runs RMSE of 0.4 m
4	Convergence of Path Planning (True)	True
	Time Taken By Path Planning to generate command (Less than 10 ms)	1 microsecond
5	Airframe Mass (Less than 800 grams)	771.1 grams

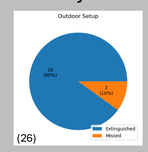


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Across environments:
Mean RMSE / deviation: 0.4 m
Extinguishing Accuracy: 85%



(25)



(26)

All misses were caused by noisy yaw data from MPU6050

Conclusion

Project Soteria achieved an **85%** accuracy across environments with a mean RMSE from an optimized path of around **0.4 m** and extinguished fires in under **1 min** with nozzle velocity of **8.37 m/s**, providing a low-cost prototype that can autonomously navigate towards a fire and extinguish it.

Future Steps

- Creating versions of the launcher compatible with other fire retardants such as fire-extinguishing balls for achieving higher efficiency and foam for combating chemical fires
- Make the launcher compatible with anti-fire coating for trees
- Make the frame out of carbon fiber, which would lower its weight and using GPS and magnetometer instead of PMW + BMP
- More rigorous testing under different circumstances and larger fire sizes

References/Citations

(1) Blanco, A., Ensor, J., & Lovett, S. (2025, January 16). *What started the LA fires?* Thetimes.Com; The Times https://www.thetimes.com/world/us-world/article/what-started-la-fires-cause-los-angeles-stnp86zn8
(2) Flowchart made by Sanat Pandit using Lucid.app, 2026
(3) Photograph taken by Sanat Pandit, 2026
(4) Diagram made by Sanat Pandit using Lucid.app, 2026
(5) Photograph taken by Sanat Pandit, 2026
(6) Graph made by Sanat Pandit using matplotlib.pyplot , 2026
(7) CAD made by Sanat Pandit using Onshape, 2026
(8) Graph made by Sanat Pandit using matplotlib.pyplot, 2026
(9) Graph made by Sanat Pandit using matplotlib.pyplot, 2026
(10) Bug 2. (2025). Bioinspired Perception and Robotics. https://bioinsperobotics.github.io/BIPR/02-Algorithms/01-bug2/
(11) Flowchart created by Sanat Pandit using Lucid.app, 2026
(12) Diagram created by Sanat Pandit using PowerPoint, 2026
(13) MLX90640 IR Array Thermal Imaging Camera, 32×24 Pixels, 55° FOV. (2026). Waveshare.Com. https://www.waveshare.com/mlx90640-d55-thermal-camera.htm
(14) Results graphed by Sanat Pandit using matplotlib.pyplot
(15) Results graphed by Sanat Pandit using matplotlib.pyplot
(16) (2019, August 8). Stack Exchange. https://dsp.stackexchange.com/questions/60080/stereo-triangulation-similar-triangle-derivation
(17) Formula shown by Sanat Pandit using math tool in PowerPoint
(18) CAD made by Sanat Pandit using Onshape
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(20) Image taken and edited by Sanat Pandit
(21) Image taken and edited by Sanat Pandit
(22) Bug 2. (2025). Bioinspired Perception and Robotics. https://bioinsperobotics.github.io/BIPR/02-Algorithms/01-bug2/
(23) Kyle. (2026, September 21). BMP280 Pre-Soldered Pressure & Temperature Sensor for Arduino & Raspberry Pi. ShiliehTek. https://shiliehtek.com/products/shiliehtek-bmp280-pre-soldered
(24) MPU6050 3 Axis Gyroscope and 3 Axis Accelerometer Module adopts 16 Bit AD Converter Data Output IIC I2C for Arduino. (2024). OSOYOO.Store. https://osoyoo.store/products/mpu6050-gyroscope-module
(25) Chart made by Sanat Pandit using matplotlib.pyplot
(26) Chart made by Sanat Pandit using matplotlib.pyplot
(27) Photograph taken by Sanat Pandit, 2026

Sanat Pandit