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Vision-based Control of UAV for Autonomous Firefighting

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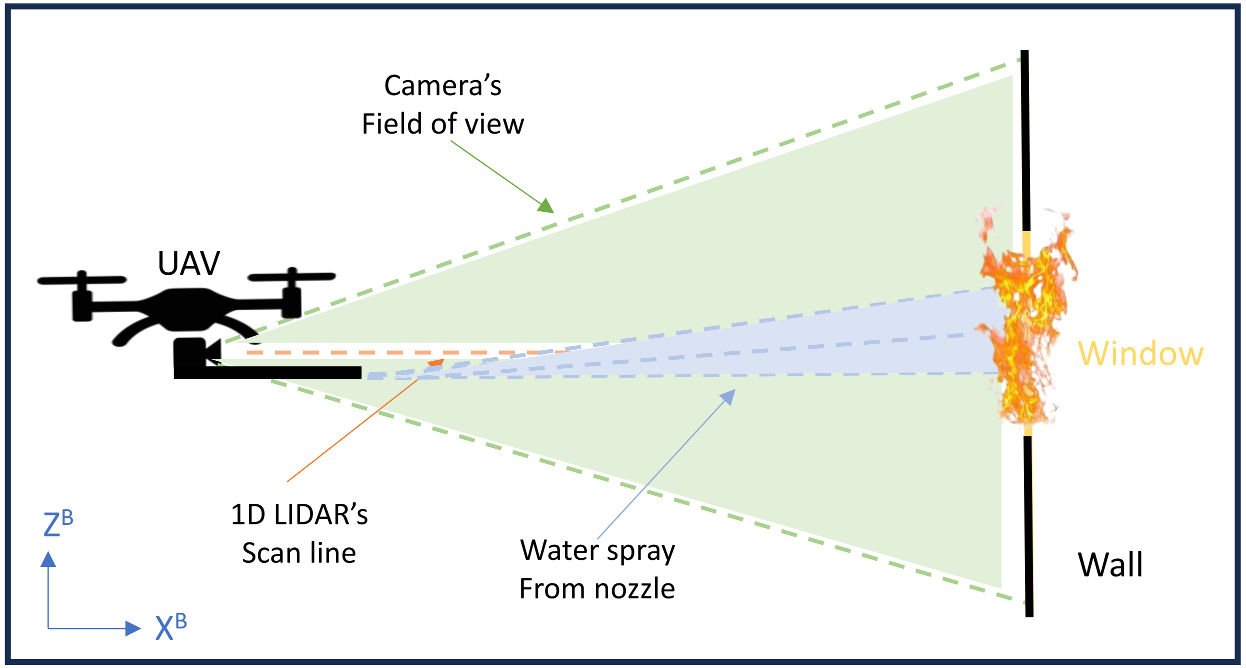


Fig. 1 Schematic diagram of the operation.

Introduction

Fire-related incidents present substantial threats to businesses, communities[1], and operational environments[2]. As rapidly expanding global economy fuels a dramatic increase in the construction of **high-rise buildings**, the world faces a mounting challenge. Urban and industrial environments frequently necessitate the immediate readiness of firefighting personnel to address potential fire emergencies, which can lead to a perpetual shortage of available manpower. To counter this challenge, we propose an integrated approach to autonomous firefighting through the utilization of Unmanned Aerial Vehicles (UAVs)[3]. The UAVs serve a dual purpose: **providing auxiliary support** to conventional firefighting efforts while simultaneously **mitigating risks to human life**.

Fig. 2 Fire accidents in High rise buildings.

Literature survey

- Firefighting Techniques
  - Established
    - Fire trucks
    - Fire Hydrant System
    - Helicopters
  - Innovative
    - Ground Robots
    - Surveillance Drones[4]
    - Firefighting Drones[5][6]

Established:

- Time consuming
- Exhausting
- Life threats to the firefighters.
- Difficult at high altitude and hazardous environment

Innovative:

- Can operate in the hazardous environment
- Can operate in hard-to-reach places.
- Little to no human intervention required.
- Can inspect large areas in less time

Fig. 3 Various traditional and non-traditional firefighting techniques.

Literature survey

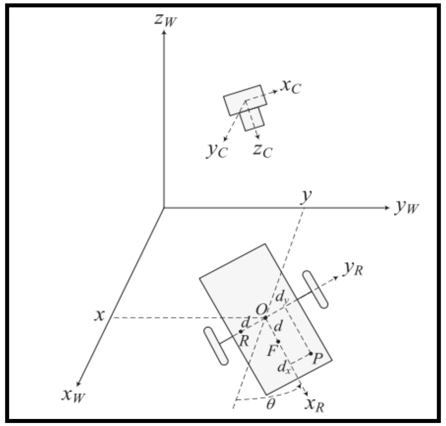


Fig 4.Image-Based Position Control of Mobile Robots with a Completely Unknown Fixed Camera[7]

Pros :-

- Vision based control of nonholonomic mobile robot
- No dependance on camera parameters.

Cons :-

- Fixed camera results in a limited area for maneuvering.
- Impractical to apply on UAVs.

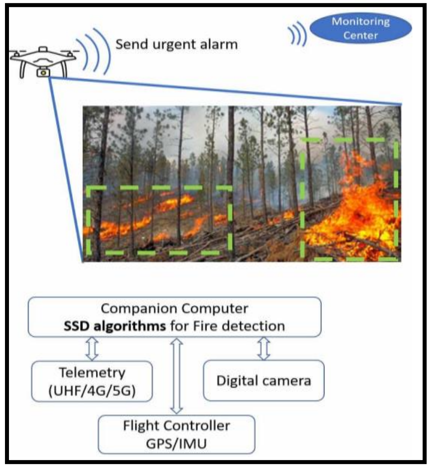


Fig 5. A Visual Real-time Fire Detection using Single Shot MultiBox Detector for UAV-based Fire Surveillance[9]

Pros :-

- Realtime fire detection on low compute devices.
- Custom dataset is used for training.

Cons :-

- Global position of fire is not obtained.
- No extinguishing method discussed.

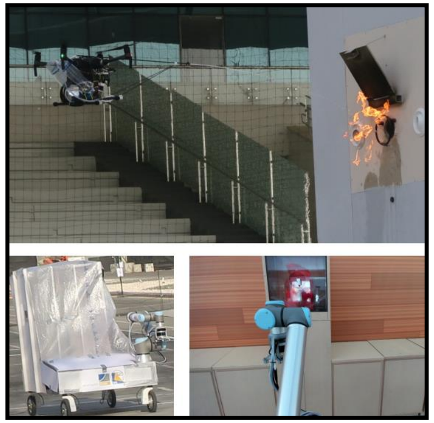


Fig 6. Autonomous Fire Fighting with a UAV-UGV Team at MBZIRC 2020[8]

Pros :-

- UAV- UGV collaborative work
- Shared LIDAR localization.

Cons :-

- Detection of fire done solely on the basis of heat sensors.

Fig 7. Deployment of a UAV-Based Fire Detection System[10]

Pros :-

- Detection of fire at early stage with high accuracy.
- Custom dataset used for training.

Cons :-

- Computation is not done onboard as the data is sent to the control center first.
- No extinguishing method discussed.

Challenges and Objective

The Challenges of vision-based control of UAV are as follows:

Identification and detection of fire:

- Continuous variation – Fire will continuously change its form and will look completely different at different times.
- Deformation – Object may appear deforming in different frames due to dynamic behavior of the flames.
- Occlusion – Objects obscured by other things make it challenging to identify.
- Illumination condition – The same objects may look different depending on the lighting conditions.
- Cluttered and textured background – The object may blend into the background, making it challenging to identify.

Navigation and path following:

- Localization of fire .
- Path and motion planning.
- Controller design and parameter tuning for motion control.

Objective:-

- To develop a computer vision algorithm for object detection.
- To develop a spraying subassembly that the UAV can carry.
- Controller design for motion control.
- Experimental validation of computer vision and control algorithms.

Methodology And Work done

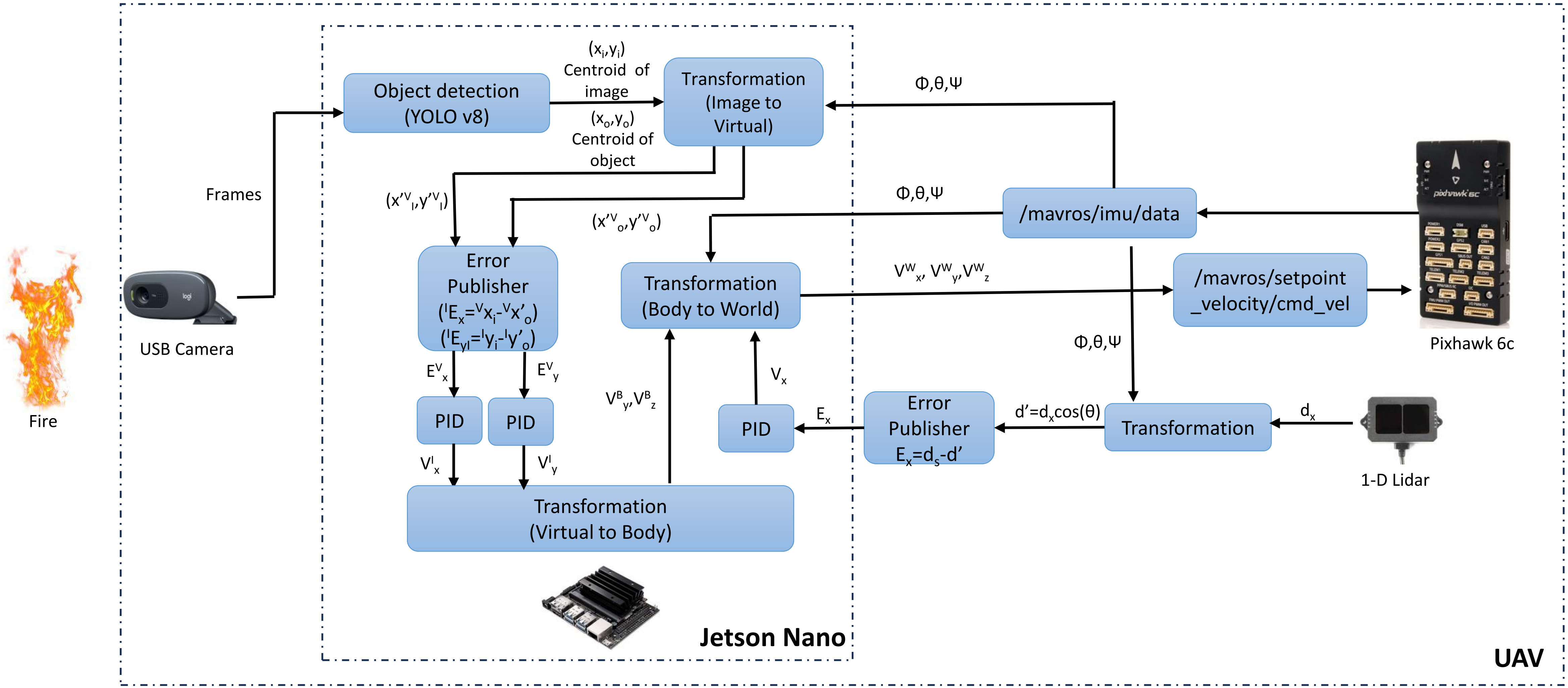


Fig. 8 Control Algorithm

Detection using Deep Learning.

Classical vision methods traditionally rely on handcrafted features and engineered algorithms, while deep learning techniques leverage the power of neural networks to automatically learn hierarchical representations from data[13]. For the detection of fire accurately we are using **YOLOv8** [14] object detection architecture, it is a deep learning model specifically designed for **real-time and high-accuracy object detection** tasks.

In our model training process, we utilized a hybrid dataset comprising fire accident images sourced from **Kaggle**[15] and images collected specifically for our **custom dataset**[16]. Total **1342 images**.

Fig. 9 Samples from Kaggle dataset

To increase model robustness and generalization we have used multiple **augmentations** [17].

- Color Jitter
- Random Brightness
- Random Sharpen
- Random Fog

which introduces variation in color, contrast, brightness, sharpness and smokiness.

Fig. 10 Samples from Custom dataset

Methodology And Work done

Vision based Control Strategy

In case multiple bounding boxes are detected we prioritize the box with the largest area. Centroid of image (x^I,y^I) and centroid of bounding box (x^O,y^O). Error in x^I and y^I is calculated and fed to the **PID** to obtain velocity in y^B and z^B

$$E_x^I = x^I - x^O$$
$$E_y^I = y^I - y^O$$

Motion in x^B direction is modulated by lateral error. LIDAR reading subtracted by the desired spray distance.

$$E_x^B = x^D - x^L$$

Lateral error is also fed to the PID to obtain velocity in x^B

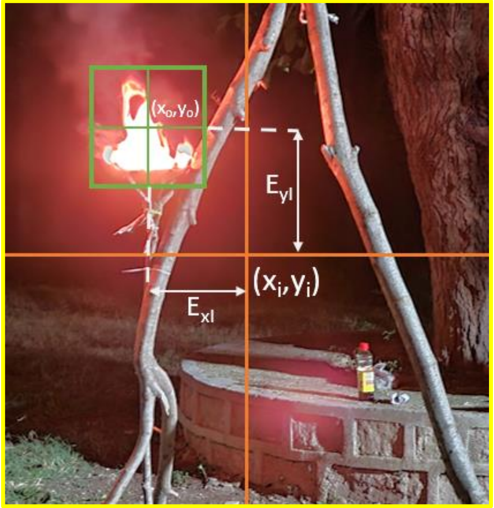


Fig. 11 Onboard camera's view

Moving average techniques are used to mitigate any unwanted fluctuations.

$$e_{n+1}(t) = \frac{1}{n}\sum_{i=n-9}^{n} e_i(t)$$

Error data is subsequently input into three distinct PIDs for controlling v_x,v_y,v_z.

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}$$

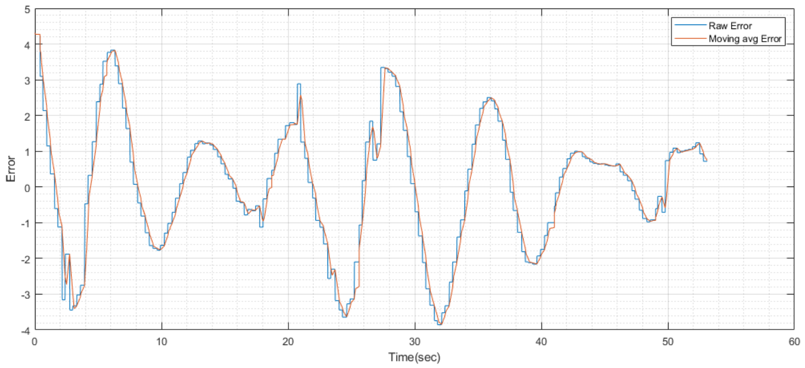


Fig. 12 Comparison of raw error and moving avg error wrt time

Spraying Strategy

Following the precise alignment of the UAV with the fire source, spraying subassembly will receive a signal from AUX PWM output of Pixhawk 6c. This signal actuates the commencement of the spraying operation. We can continuously monitor the area encompassed by the bounding box surrounding the fire source, this area serves as a critical indicator of the fire's extinguishment status. Currently integration of pump subassembly with the UAV has been tested manually.

Flow rate 15 L/min
Pressure 5 bar
Altitude 10 mtrs
Flight time 12 min

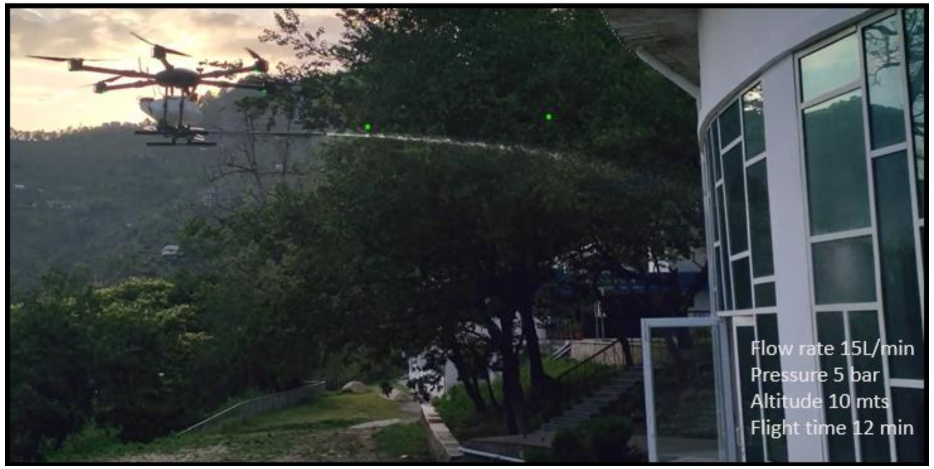
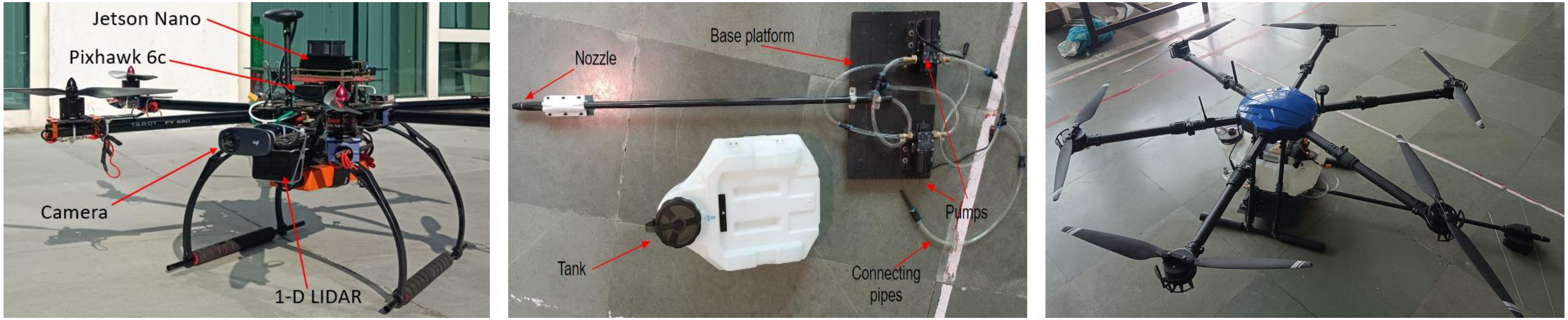


Fig. 13 Manual spraying on a building by UAV.

Experimental Platform and Setup

Experimental Platform and Setup



(a) (b) (c)

Fig. 14 (a) Control test platform (b) Pump Subassembly (c) Multicopter with subassembly

Experimental Platform and Setup

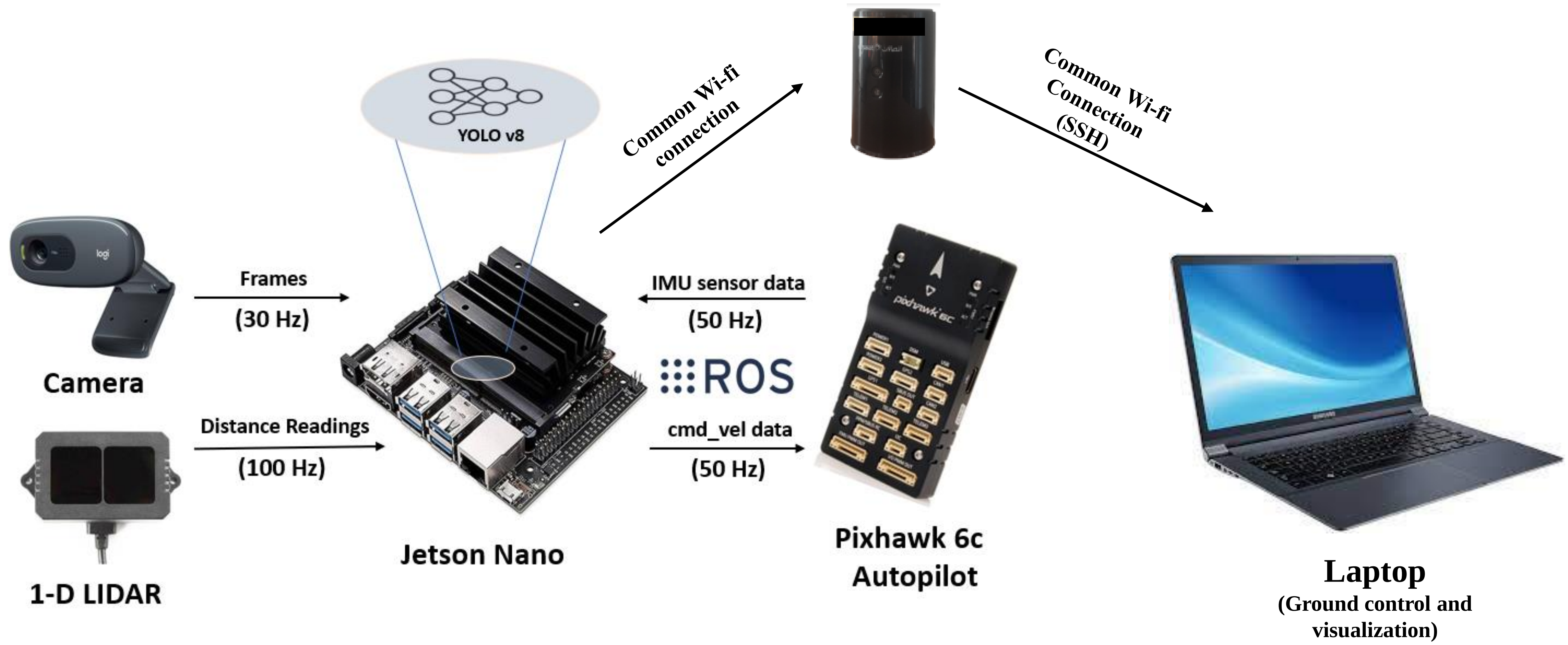


Fig. 15 System overview of sensing and computing components.

Experimental Validation and Results

Experimental Validation and Results

Object Detection Results.

Fig. 16 Detection results on Kaggle dataset and Custom dataset

Experimental Validation and Results

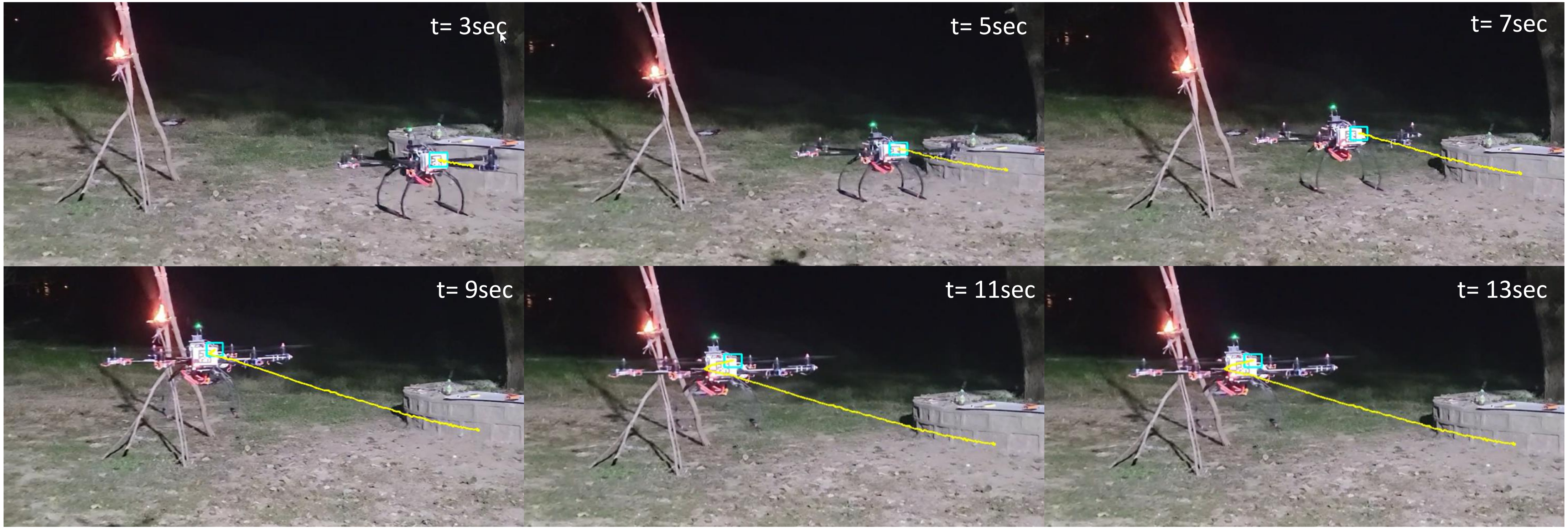


Fig. 17 **Trajectory of the UAV while correcting the error in $y^B z^B$ plane**.

Experimental Validation and Results

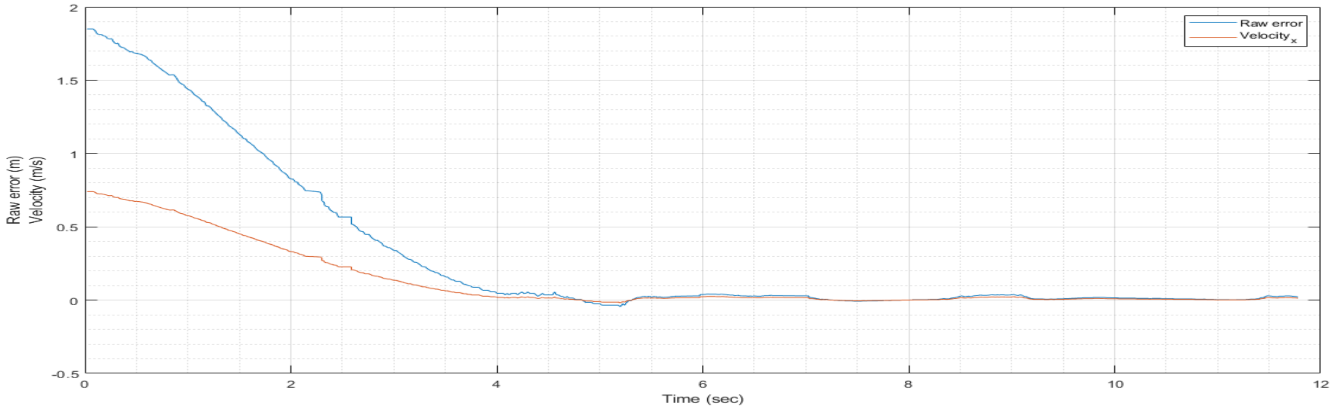


Fig. 18 (a) Error and Velocity$_x$ v/s Time

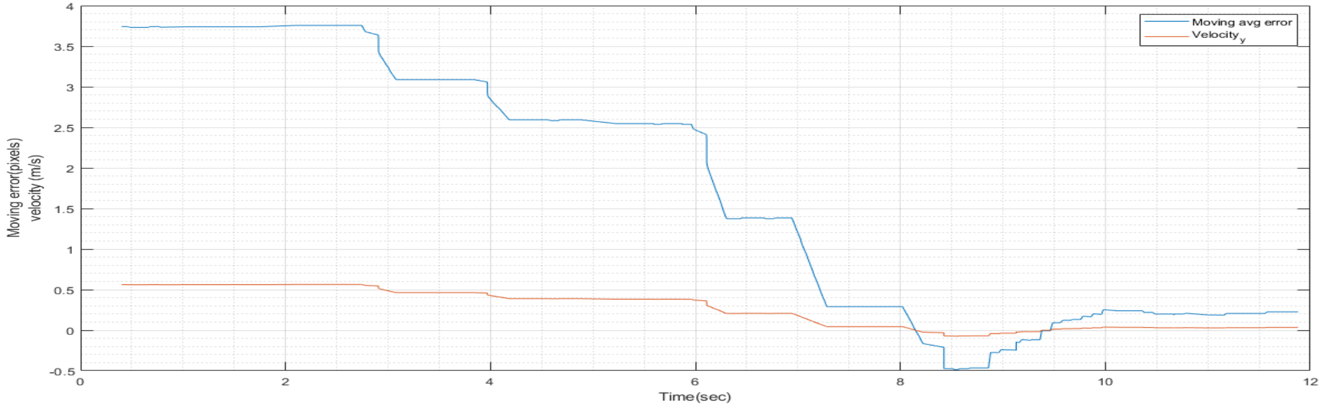


Fig. 19 (b) Error and Velocity$_y$ v/s Time

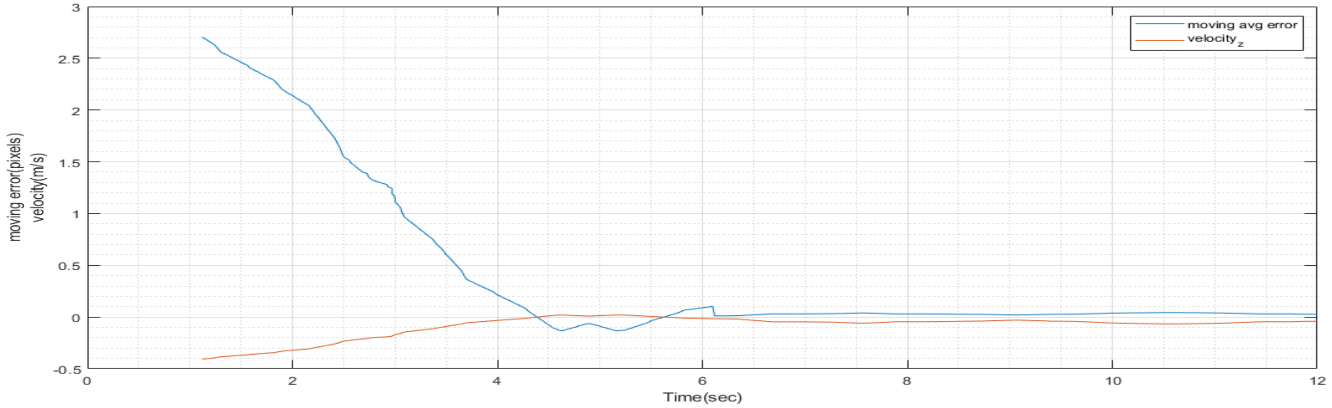


Fig. 20 (c) Error and Velocity$_z$ v/s Time

Experimental Validation and Results

Fig. 21 **Trajectory of the UAV while correcting the error in $y^B z^B$ plane**.

Conclusion and Future Aspect

Conclusion and Future Aspect

Conclusion

1. This work develops a method for **the vision-based localization and control of a** UAV in firefighting situations.
2. Detection of fire is done using an object detection deep learning model and parameters are calculated using the computer vision techniques.
3. Precise 3-D cartesian coordinates of the centroid of fire is obtained using onboard sensors, contributing to the **localization of fire**.
4. A **PID based control strategy** is developed for continuous tracking of fire and maintaining a particular distance from the fire for ensuring accurate spraying.
5. Additionally, the performance of the **spraying subassembly** has been independently verified.

Conclusion and Future Aspect

Future Aspects

1. Currently the model prioritizes multiple fires based on fire spread estimated using area of bounding box in the future we wish to **access fire intensity** and prioritize according to that.
2. We will **estimate the requisite time for extinguishment** and the **quantity of extinguishing material** required.
3. Subsequently we intend to **enhance and refine our control strategy** in alignment with the acquired insights.
4. It is observed that the model's performance is affected by external lighting conditions, hence developing a better detection model, by **training it with a larger custom dataset** may improve the detection results.
5. To avoid false alarms, we can use additional sensors along with camera and lidar, like **thermal sensor** and do sensor fusion.
6. There are **other possible trajectories** that a drone can follow and inspect the fire zone in lesser time with accuracy.
7. **Integration** of the autonomous tracking and control along with the spraying module.

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Thank You