PROJECT B-EAGLE

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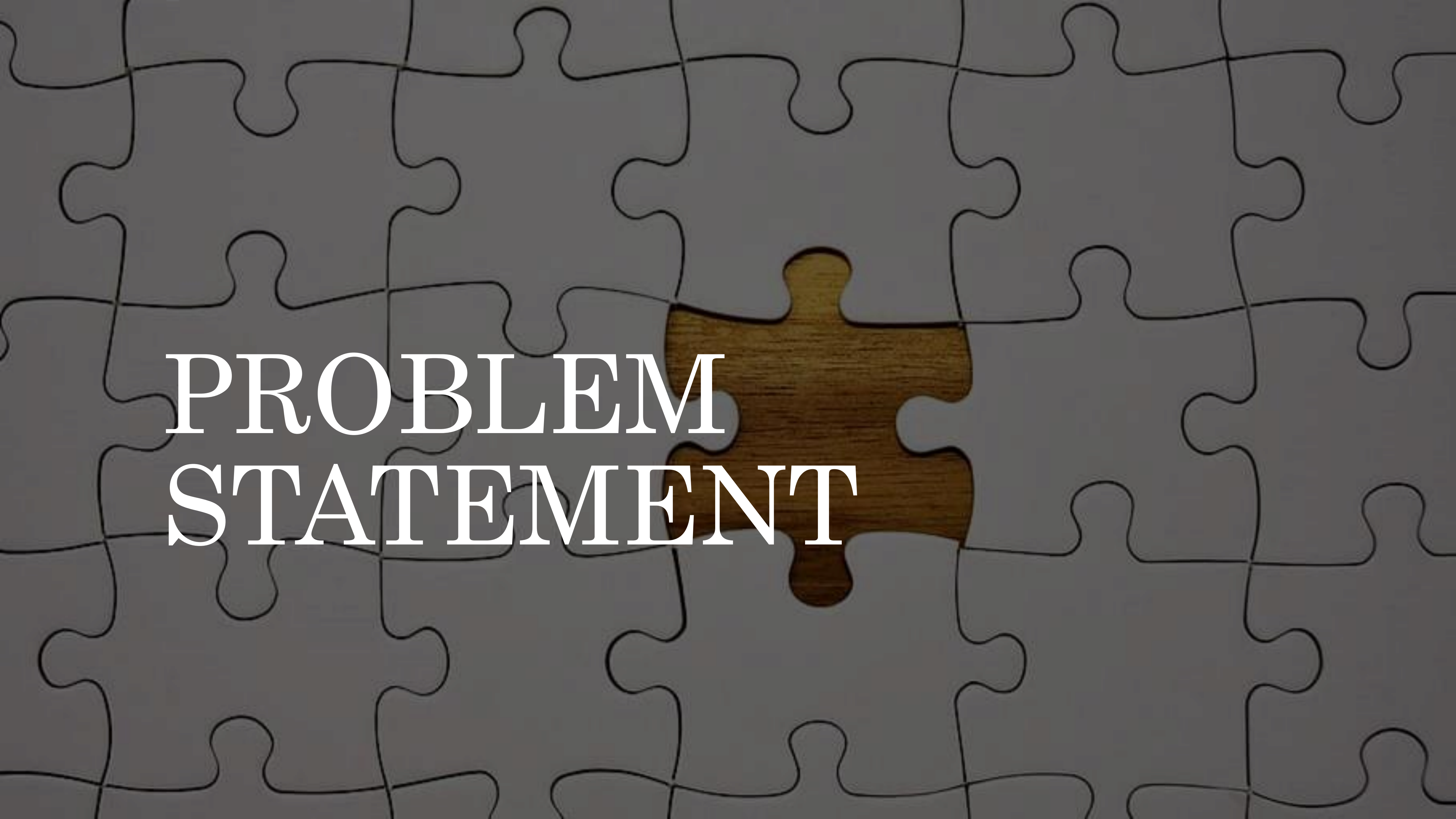


PROBLEM STATEMENT

WHAT PROBLEM ARE WE SOLVING?

- A **gas leak** refers to an unintended leak of natural gas or another gaseous product from a pipeline or other containment into any area where the gas should not be present.
- Gas leaks can be hazardous to health as well as the environment.
- Gas leak sources need to be detected accurately to control disasters.
- We are solving the problem of accurately locating sources of gas leaks even in environments inaccessible to humans.

HOW CRITICAL IS THE PROBLEM?

- While residential leaks pose risks to human safety, leakage in every piece of the natural gas industrial chain – wellheads, compressors, valves, pumps, gauges and pipe connectors – has serious implications for the climate.
- Oil and gas companies want to help reduce the quantity of lost gas due to the associated costs and liabilities. Global fugitive methane costs over $30 billion in lost revenue per year, according to a 2012 study. And just 5 percent of leaks in the production and transport system are responsible for more than half the methane emissions

https://news.stanford.edu/2019/06/07/trying-stop-natural-gas-leaks-wake-destruction/

THE SOLUTION

WHAT SOLUTION DO WE PROPOSE?

- We propose a leak source search system mounted on small sized drones or rovers that will accurately reach the source of the gas leak or fire.
- Subsequently, the drone/rover might act as a beacon locating the source exactly or could manage the hazard if relevantly equipped.

OBJECTIVES OF THIS PROJECT

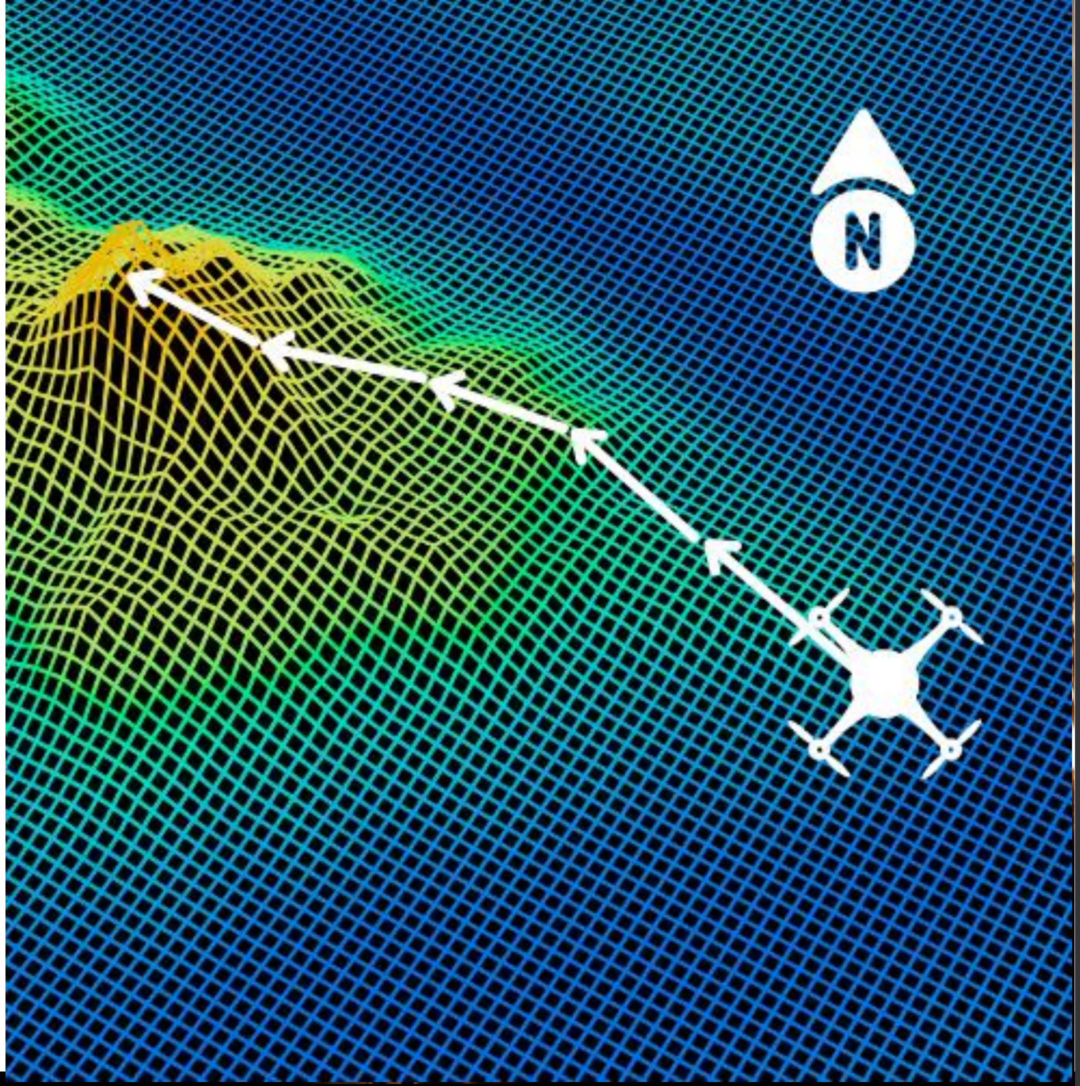
- To create a Gas Leak Source Search System.
- To equip a drone with this system and make it reach the source.
- This drone would act like a beacon, informing the user about the exact location of the source.

B-EAGLE

Nose of Beagle and Flight of Eagle

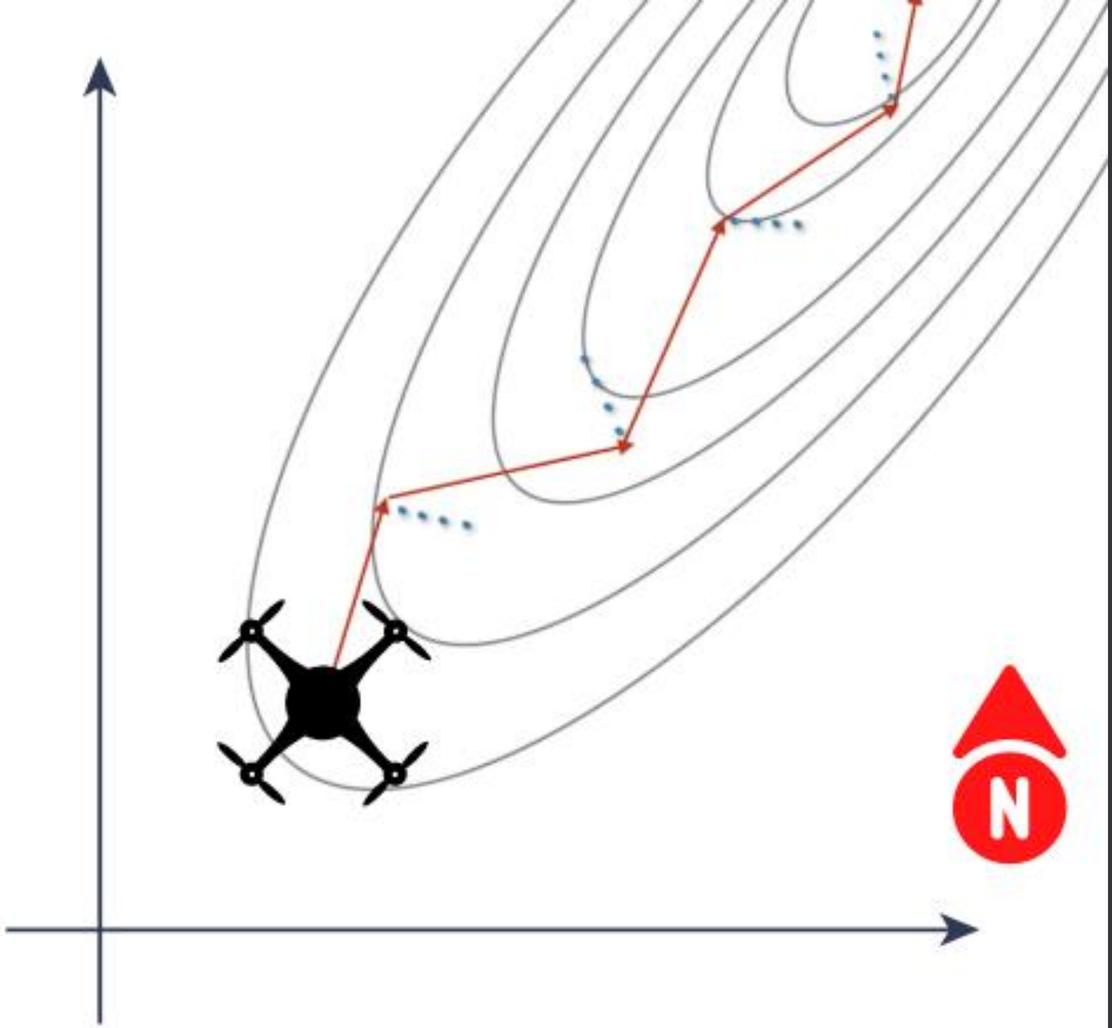
KEY IDEA

Assuming that at the source of the gas, intensity is at its peak, the problem translates to peak detection



PROPOSED METHOD

Thus, if the intensity of gas ppm be considered the cost function, we can perform gradient 'ascent' and reach the source.

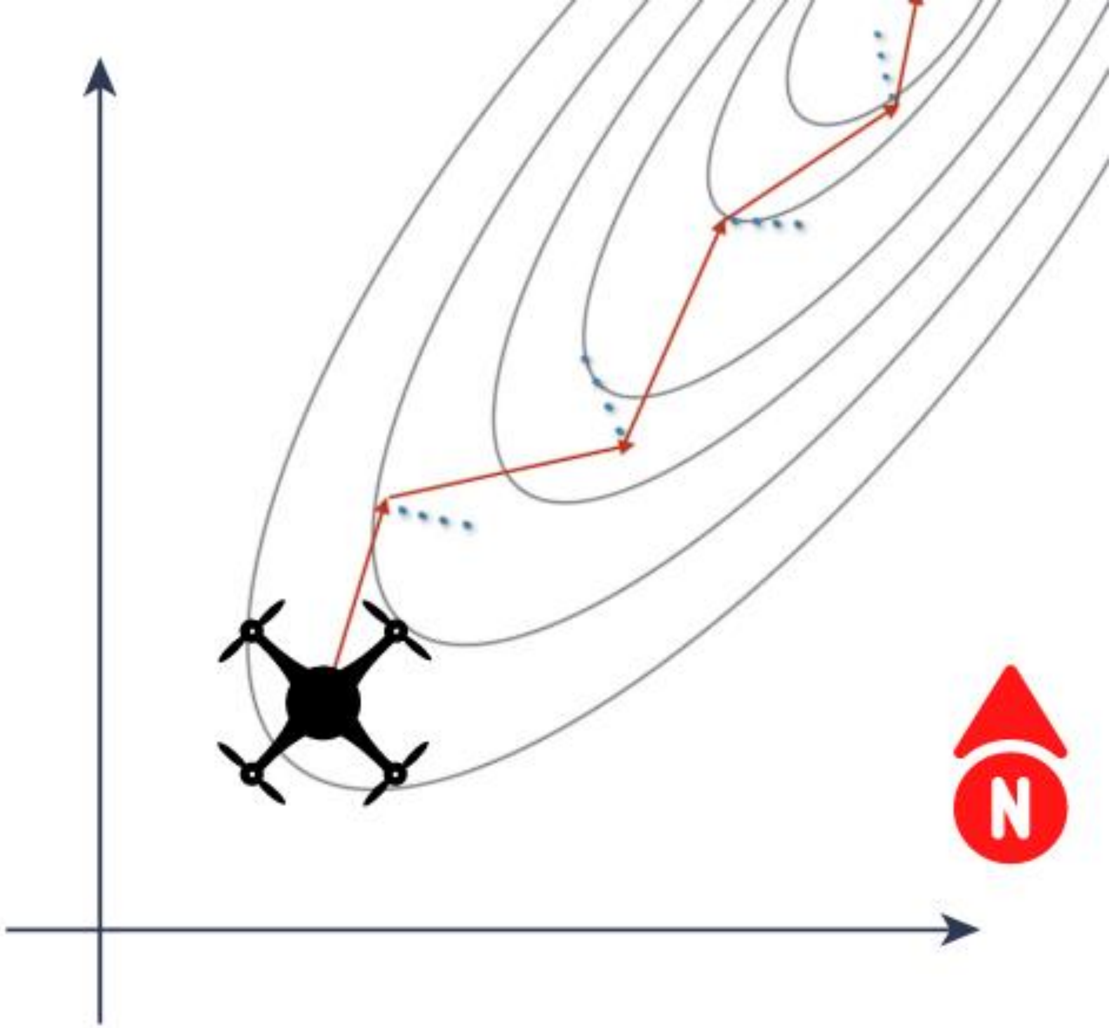


Gradient Ascent

For k = 1, 2, 3…

$$I_x = \frac{\delta I}{\delta x}; I_y = \frac{\delta I}{\delta y}; I_z = \frac{\delta I}{\delta z}$$

$$x_{k+1} := x_k + \alpha I_x \,; y_{k+1} := y_k + \alpha I_y; z_{k+1} := z_k + \alpha I_z$$

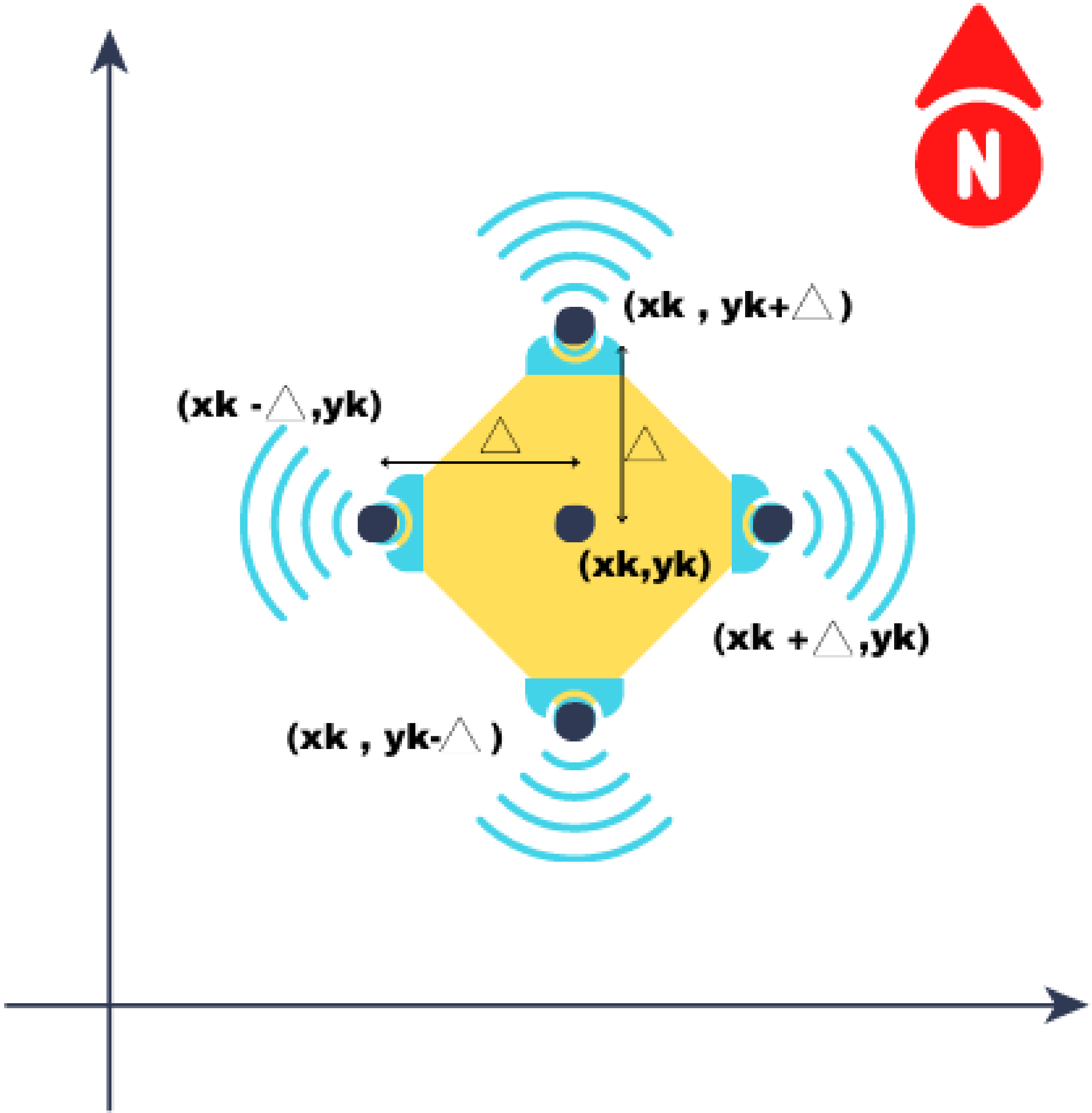


HOW DO WE FIND THE GRADIENTS?

The physical manifestation of the computer algorithm

CONCEPT

6 gas sensors placed at four corners of the device and up and down



CONCEPT

For the given position of the device, we have gas intensity values at 4 different locations.

$$\frac{\delta I}{\delta x} \approx \frac{I(x+\Delta, y, z) - I(x-\Delta, y, z)}{2\Delta}$$

$$\frac{\delta I}{\delta y} \approx \frac{I(x, y+\Delta, z) - I(x, y-\Delta, z)}{2\Delta}$$

$$\frac{\delta I}{\delta z} \approx \frac{I(x, y, z+\Delta) - I(x, y, z-\Delta)}{2\Delta}$$

APPROXIMATION

The sensor data can be used to approximately find the gradients.

NOTE THAT WE NEED THE CHANGE IN COORDINATES MUCH LARGER THAN 2Δ FOR THIS APPROXIMATION TO WORK, SAY 10 TIMES.

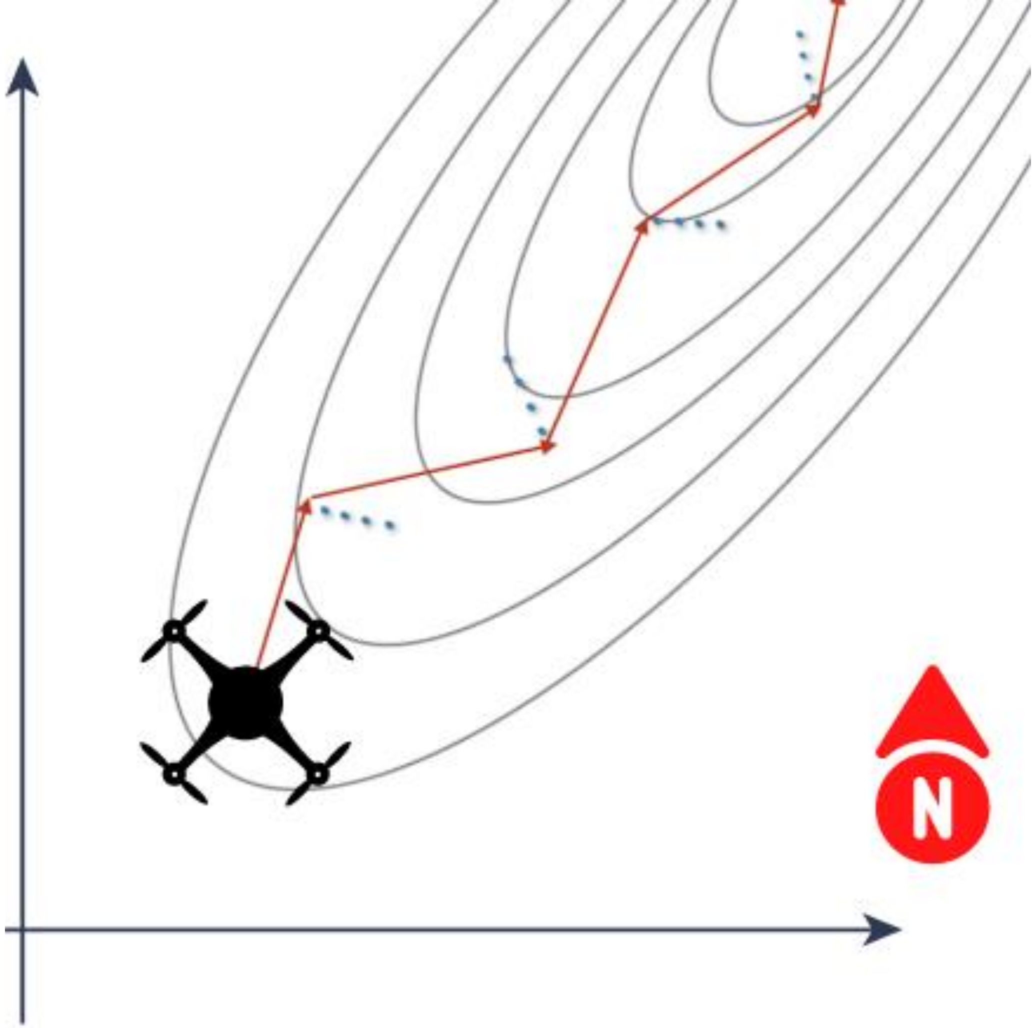
Normalized Gradient Ascent (Constant Step Size)

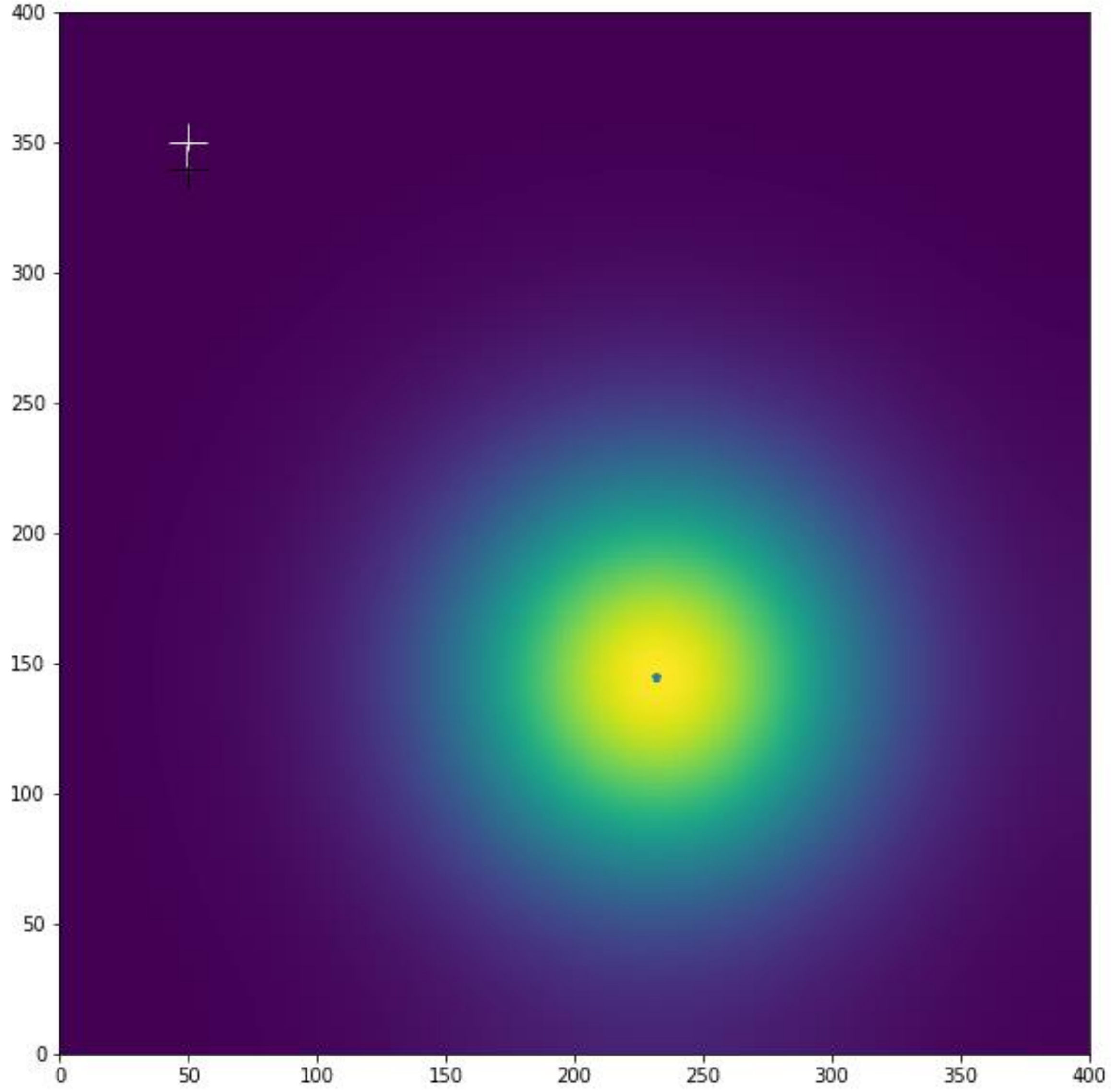
For k = 1, 2, 3…

$$I_x = \frac{\delta I}{\delta x}; I_y = \frac{\delta I}{\delta y}; I_z = \frac{\delta I}{\delta z}$$

$$J_x = \frac{I_x}{\sqrt{I_x^2 + I_y^2 + I_z^2}}; J_y = \frac{I_y}{\sqrt{I_x^2 + I_y^2 + I_z^2}}; J_z = \frac{I_z}{\sqrt{I_x^2 + I_y^2 + I_z^2}}$$

$$x_{k+1} := x_k + \alpha J_x\, ; y_{k+1} := y_k + \alpha J_y; z_{k+1} := z_k + \alpha J_z$$



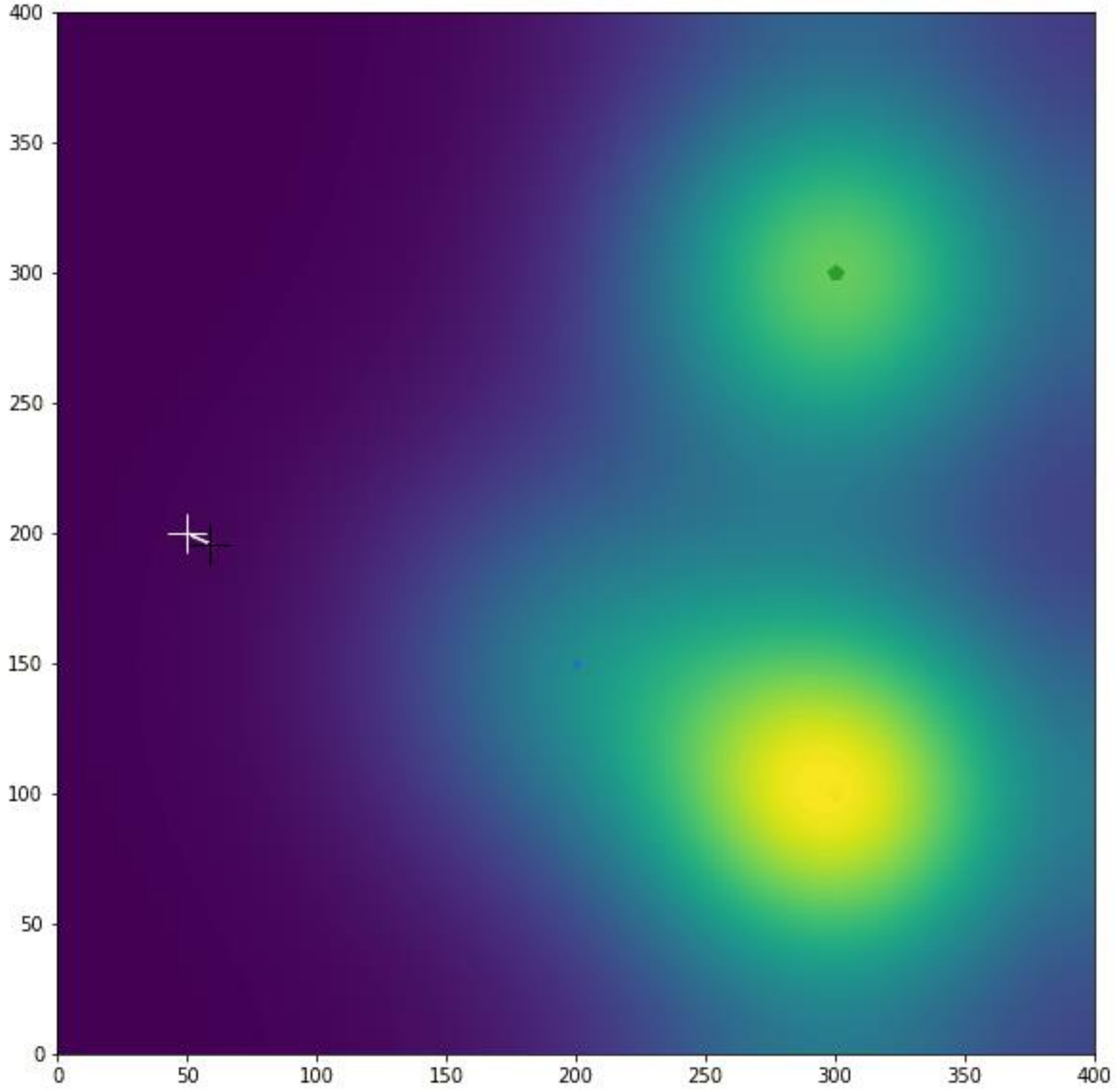


SIMULATION(2D)

Single point source with gas intesity growing as gas leaks.

The white + is the source and black + is the drone.

Observe as it locates the source.

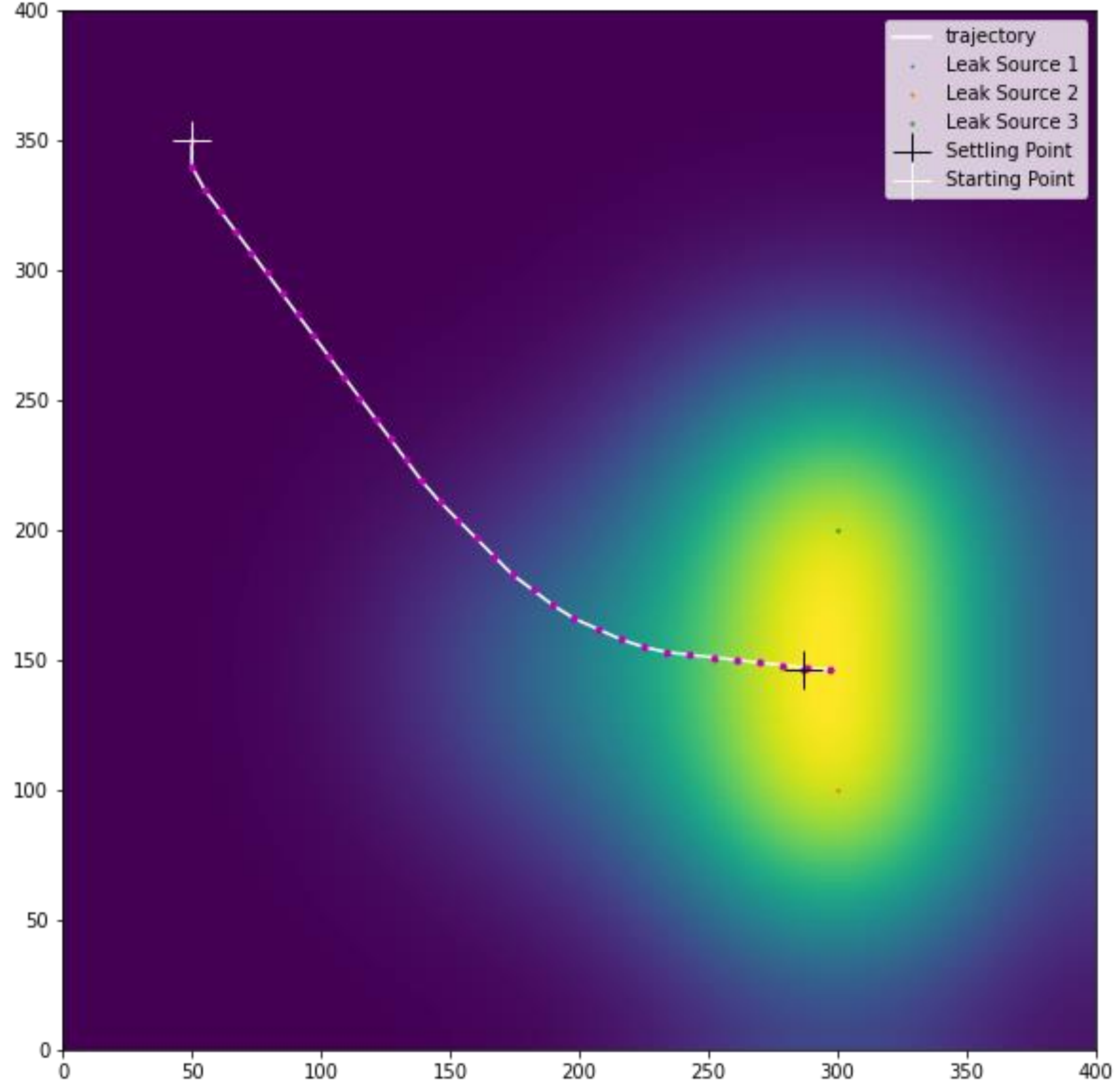


SIMULATION(2D)

3 sources of gas leaks, with the size of markers proportional to leak rate (2 major and 1 minor closer to the lower right leak)

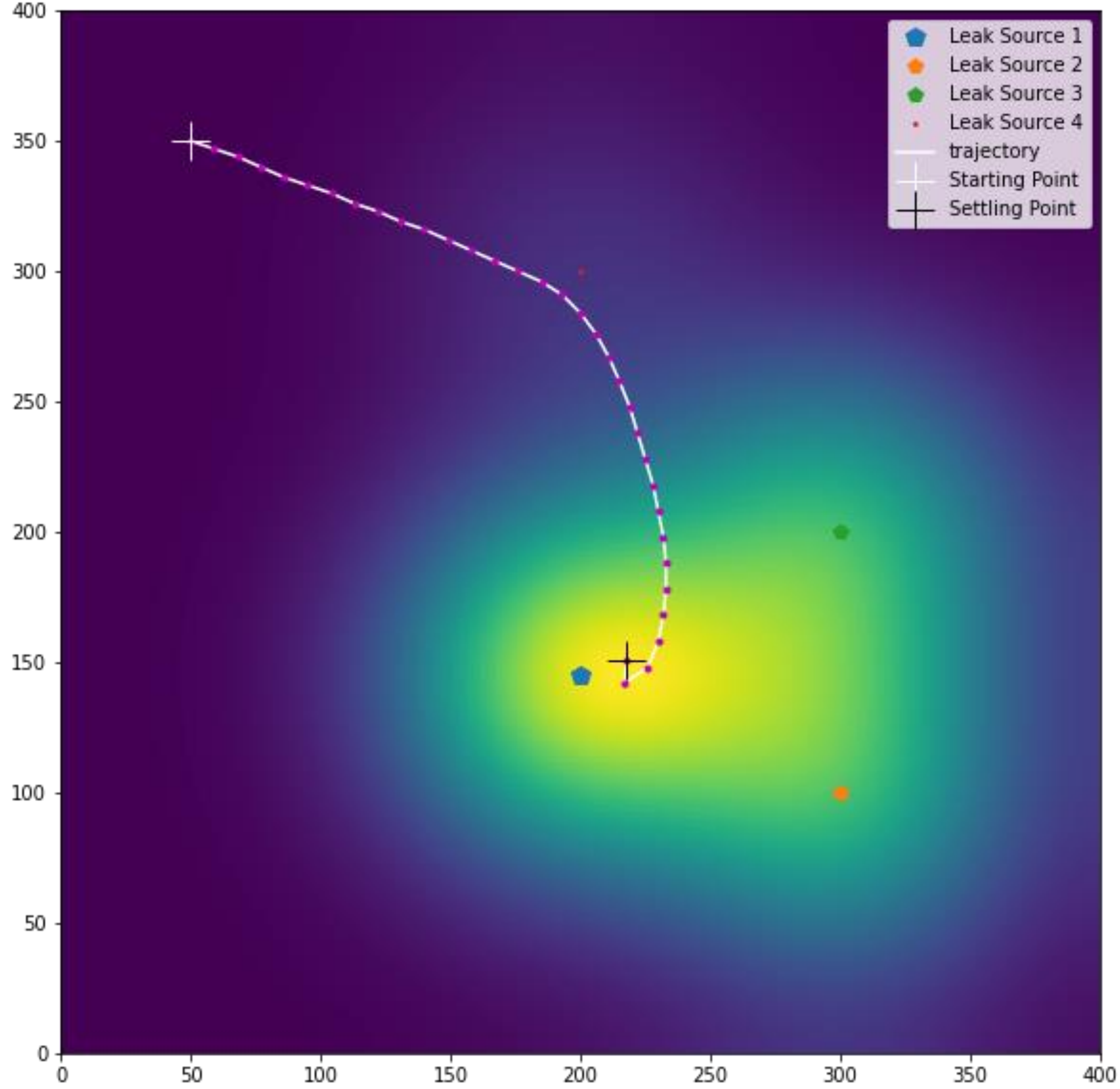
The white + is the source and black + is the drone.

Observe as it locates the nearest peak



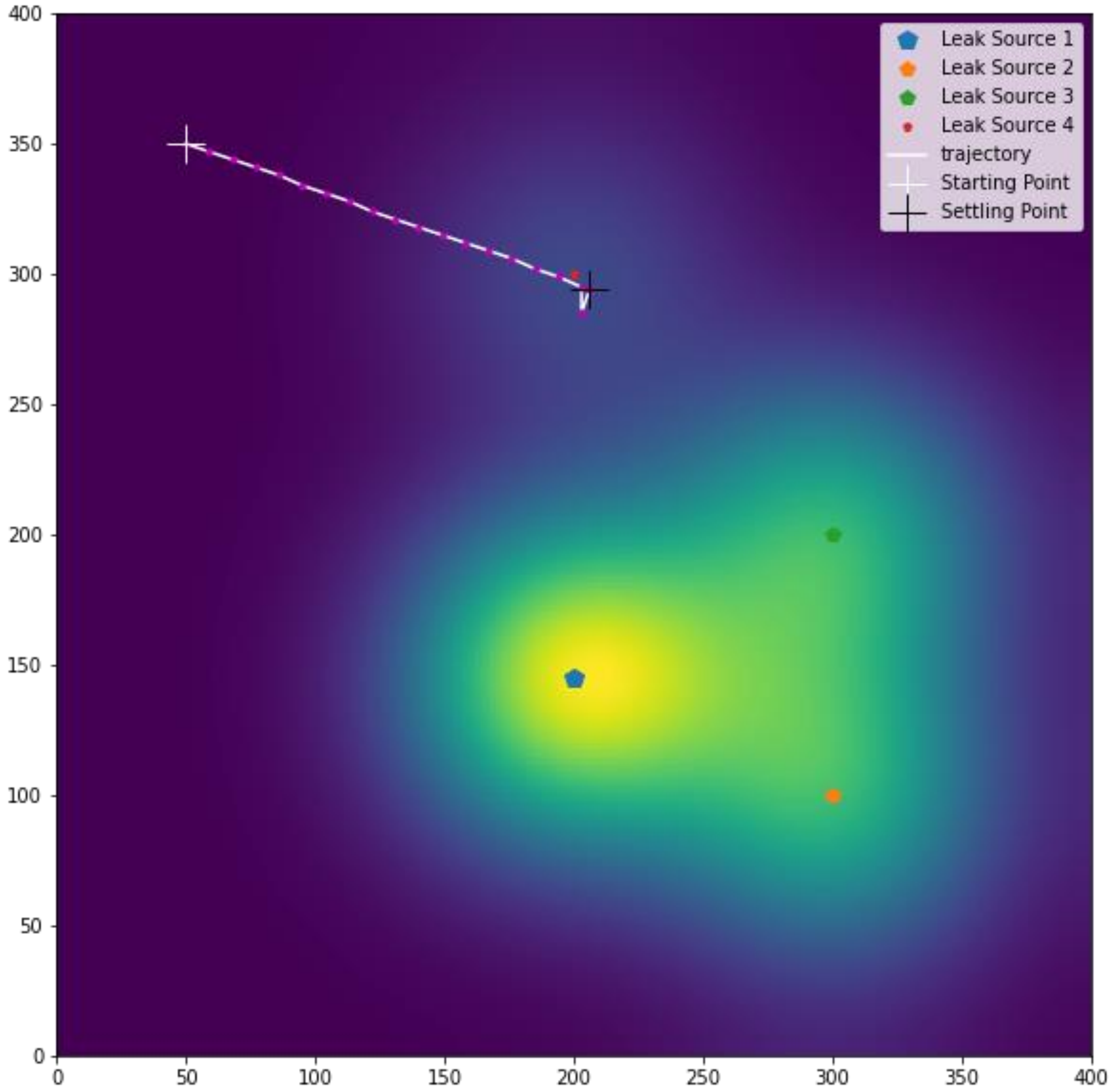
SIMULATION(2D)

Here it reaches out to the midpoint of the peaks because of the symmetry



SIMULATION(2D)

Here again with 4 source, it reached out to the biggest leak sources.



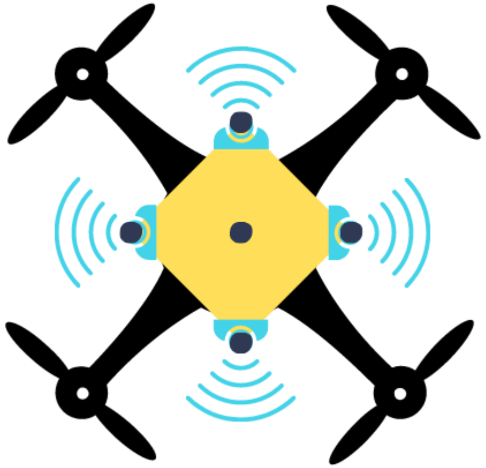
SIMULATION(2D)

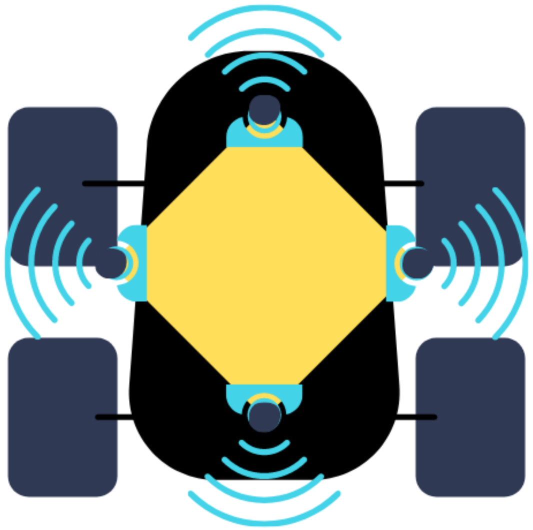
Here again with 4 source. Just like the previous one.

But settles at local maxima.

Difference?

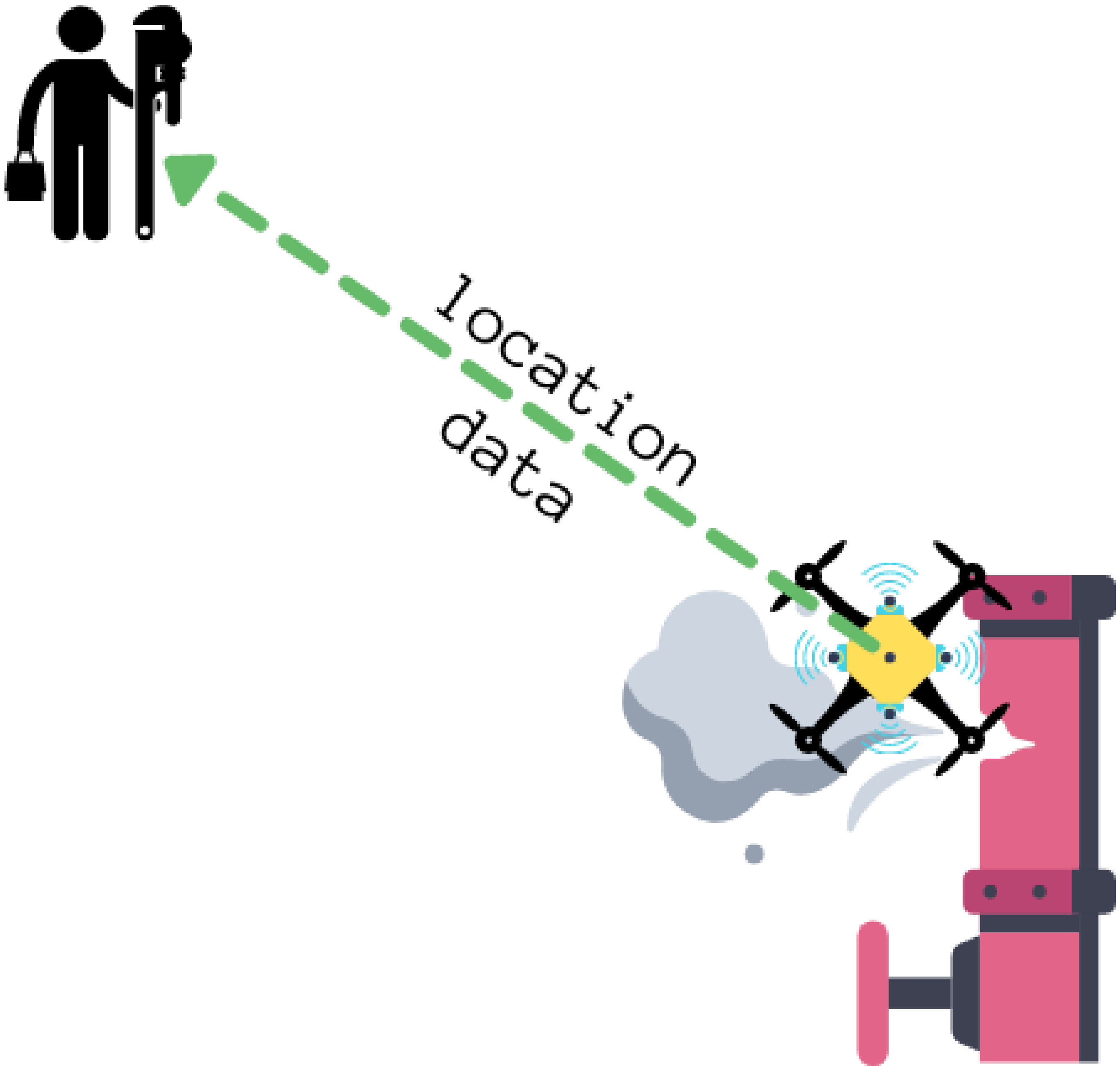
The gases didn't mix well enough.





VISION

Thus, we can mount this system on a drone (6 sensors, 3D) or a rover(4 sensors, 2D) to reach to the location of leak/smoke



VISION

The drone communicates its coordinates to the control center and remedy is deployed

IDEA EVOLUTION

Concepts and Prototypes

PRE-PIVOTAL PROBLEM STATEMENT

- To build an intelligent gas leak detection system which monitors levels of inflammable gases in a space, regulates it and reports it to prevent accidents.
- Monitor the changing levels of the gas with respect to space and time using multiple sensors and report the location and intensity of the leak, alerting users' when a threshold is crossed.

MARK III

Light glows/buzzer rings when gas sensor value crosses a threshold + Connects with android app to show the gas sensor value + Notifies users' phones on the gas value crossing threshold for more than 5 seconds.

[Link to the demo]

HANDHELD DEVICE: CONCEPT

The user will manually hold the sensor frame and move about as directed by the modified gradient ascent computations.

HANDHELD DEVICE: LIMITATIONS

- The path calculated by the drone may not be feasible for the human to follow.
- The handheld device will force to adjust the drone according to human mobility convenience and this may cause the drone to enter the region of zero gradient and hence the gradient ascent may fail.

SENSORS & ELECTRONICS

What we propose to use for the project

Gas Sensor : MQ-5 Gas Sensor

- Sensitive for LPG, natural gas, coal gas
- Output voltage boosts along with the concentration of the measured gases increases
- Fast response and recovery
- Adjustable sensitivity
- Signal output indicator

https://www.evelta.com/mq-5-gas-sensor/?gclid=CjwKCAiAv_KMBhAzEiwAs-rX1EMtIDK7u77anf9uhUfvCu7p34FVltsV-cY0yD18UzMlj8welI1iuBoCcS0QAvD_BwE

Flight controller : PIXHAWK 2.4.8

Pixhawk is a flight cntroller providing readily-available, low-cost, and high-end, autopilot hardware designs.

It can be easily combined with a companion microcontroller (raspberry pi in our case) to do the computation part for the path calculation.

Features

- Sensors: Gyrometer, Accelerometer, Barometer, Magnetometer
- 7V supply voltage
- Micro SD card to record flight data

https://robu.https://robu.in/product/pixhawk-px4-autopilot-pix-2-4-8-32-bit-flight-controller/in/product/pixhawk-px4-autopilot-pix-2-4-8-32-bit-flight-controller/

Rasberry Pi 3 Model B+

We will do our flight trajectory calculations and send the control signals from rasberry pi to the flight controller.

5V supply, 40-pin GPIO Header, 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2

4 USB 2.0 ports

LIPO 3000mAh 11.1V battery

Rechargeable Power Supply for RC Cars and Quadcopter - 11.1 V, 40/80 C

Light weight, weighing only about 215grams.

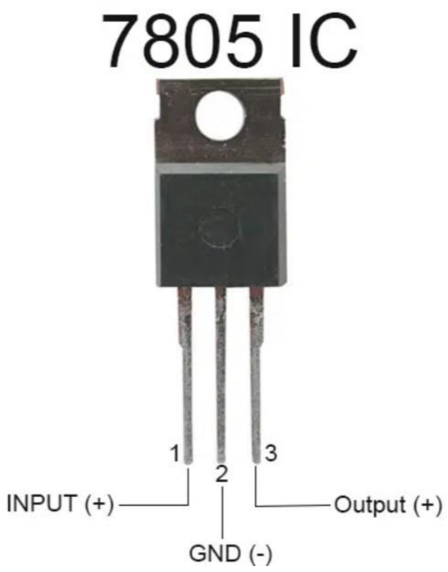
3000*0.001*40 = 120A (max current output)

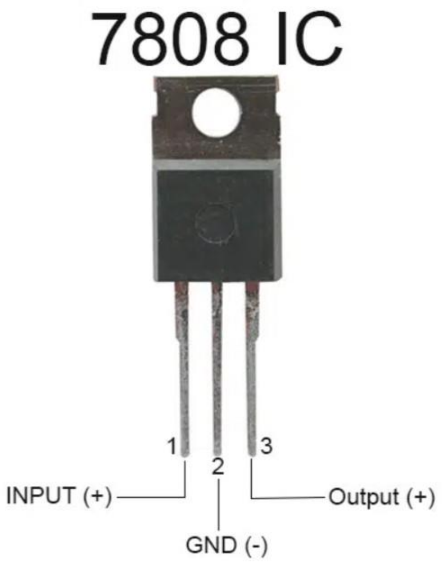
LiPo 11.1V 3000mAh

Voltage regulators

7805 IC for 5V output.

7808 IC for 8V output.





[7805 IC]
[7808 IC]

TRANSMISSION FROM DRONE TO CONTROL CENTER

Domestic Disaster Management

- Radio waves can penetrate nonconducting materials, such as wood, bricks, and concrete, fairly well.
- Good choice to communicate the location of drone to the control center.

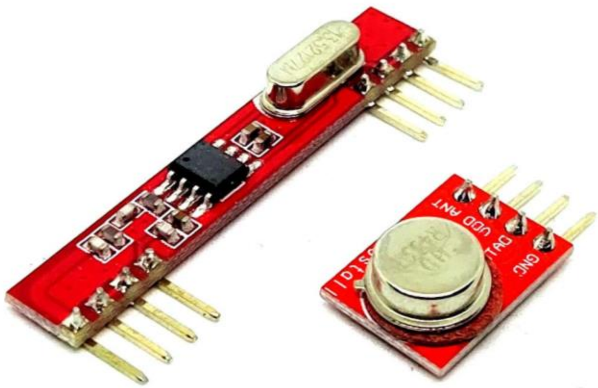
Industrial Disaster Management

- Metallic environments make electromagnetic waves impossible to use.
- Despite being mapped,
- Acoustic signal transmission (ultrasonic signals)

TRANSMISSION FROM DRONE TO CONTROL CENTER

Domestic Disaster Management

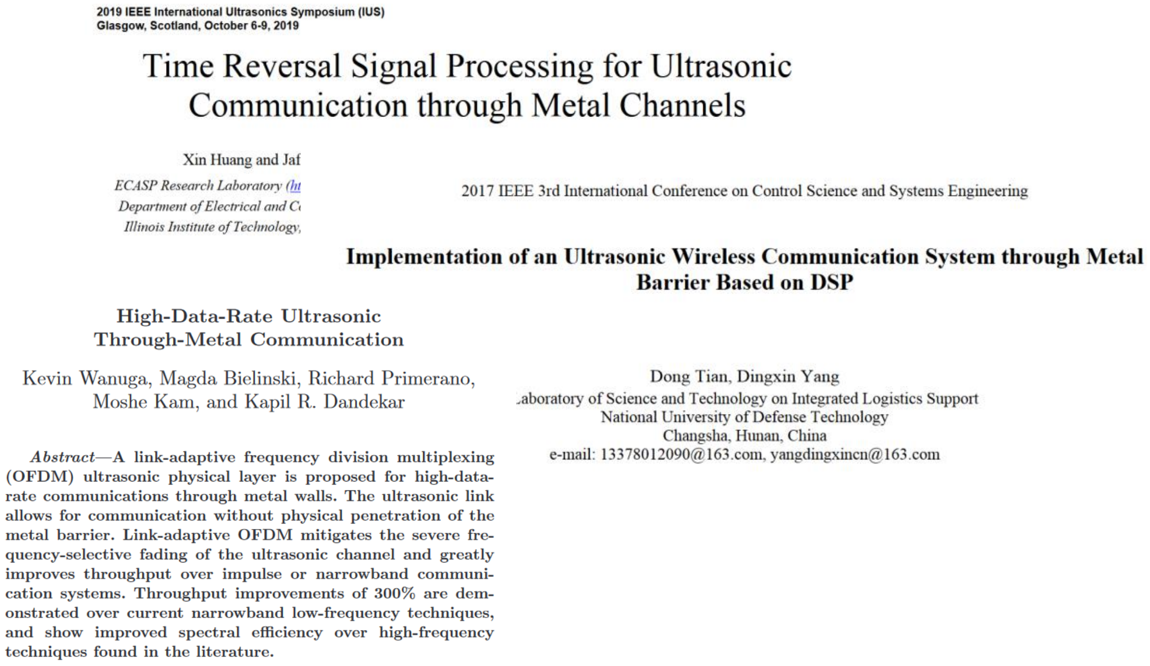
433MHZ RF Transmitter Receiver Wireless Module With upto 100 meters Range



https://www.electronicscomp.com/433mhz-rf-transmitter-receiver-module-india?gclid=Cj0KCQiA-eeMBhCpARIsAAZfxZD2_2rQBY_Ha3zfbDZHr1cExnxg3OL2hq2_SIZfQNZeTzk3AVRMeDcaAiduEALw_wcB

Industrial Disaster Management

Still Experimental



2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

Time Reversal Signal Processing for Ultrasonic Communication through Metal Channels

Xin Huang and Jaf
ECASP Research Laboratory (ht
Department of Electrical and Co
Illinois Institute of Technology,

2017 IEEE 3rd International Conference on Control Science and Systems Engineering

Implementation of an Ultrasonic Wireless Communication System through Metal Barrier Based on DSP

Dong Tian, Dingxin Yang
Laboratory of Science and Technology on Integrated Logistics Support
National University of Defense Technology
Changsha, Hunan, China
e-mail: 13378012090@163.com, yangdingxincn@163.com

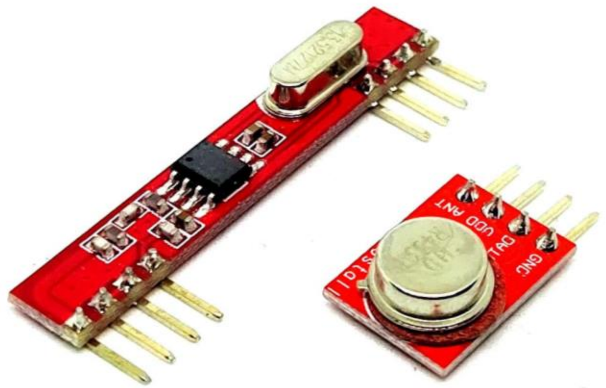
High-Data-Rate Ultrasonic Through-Metal Communication

Kevin Wanuga, Magda Bielinski, Richard Primerano, Moshe Kam, and Kapil R. Dandekar

Abstract—A link-adaptive frequency division multiplexing (OFDM) ultrasonic physical layer is proposed for high-data-rate communications through metal walls. The ultrasonic link allows for communication without physical penetration of the metal barrier. Link-adaptive OFDM mitigates the severe frequency-selective fading of the ultrasonic channel and greatly improves throughput over impulse or narrowband communication systems. Throughput improvements of 300% are demonstrated over current narrowband low-frequency techniques, and show improved spectral efficiency over high-frequency techniques found in the literature.

TRANSMISSION FROM DRONE TO CONTROL CENTER

433MHZ RF Transmitter Receiver Wireless Module With upto 100 meters Range



https://www.electronicscomp.com/433mhz-rf-transmitter-receiver-module-india?gclid=Cj0KCQiA-eeMBhCpARIsAAZfxZD2_2rQBY_Ha3zfbDZHr1cExnxg3OL2hq2_SIZfQNZeTzk3AVRMeDcaAiduEALw_wcB

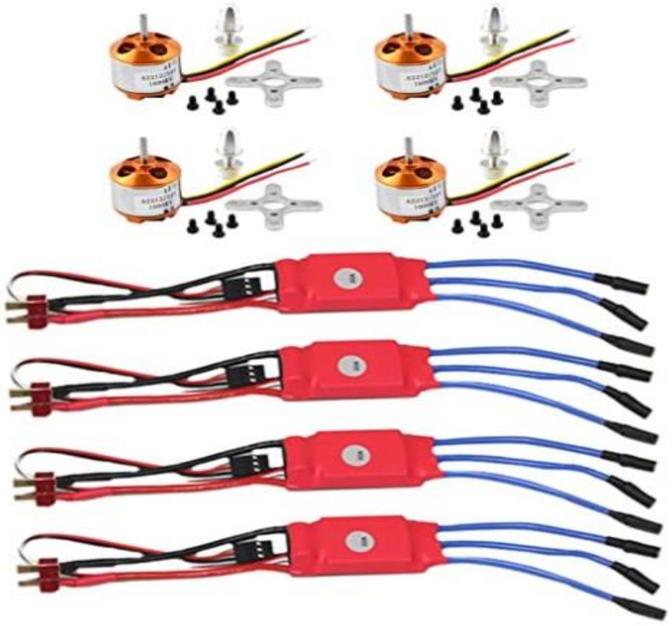
We will be using RF for communication

Drone, Assemble

Frame kit Quadcopter

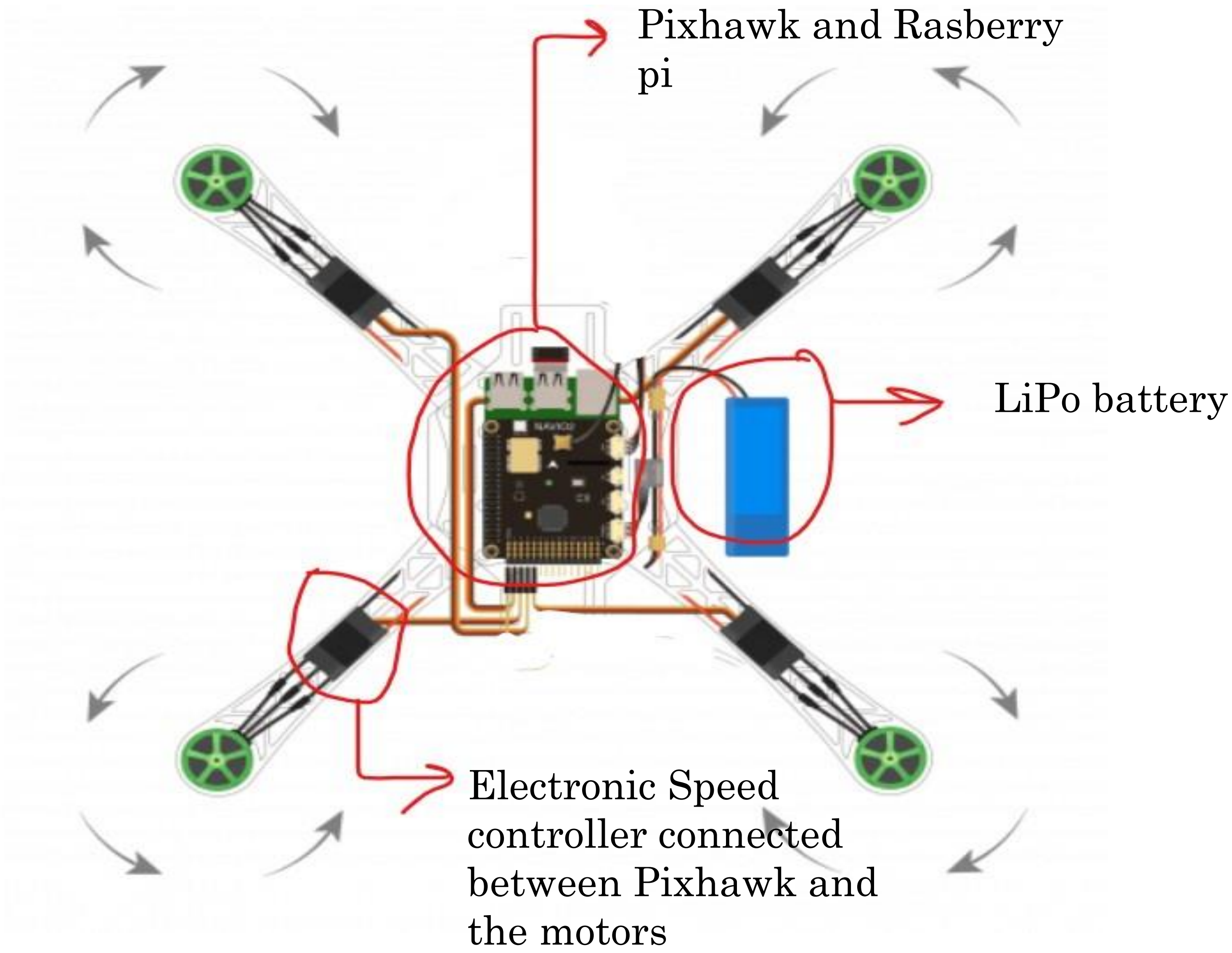
Propellers

Connection holders

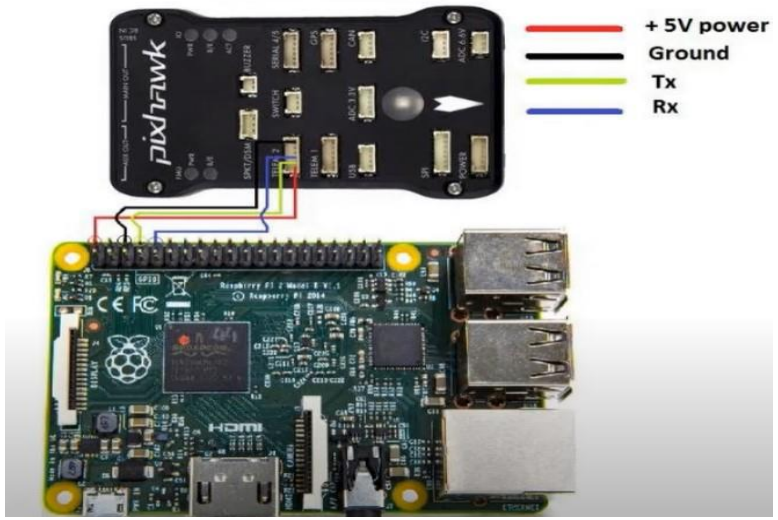


KV1000 Brushless Motor and four 30A ESC

- We will use this drone : link .



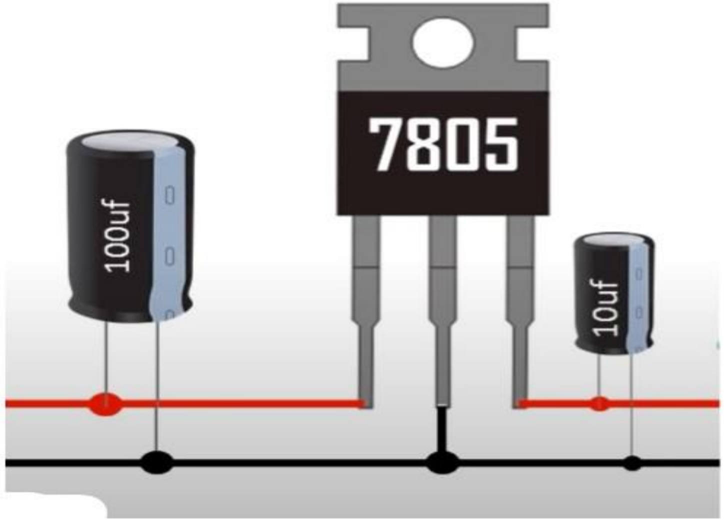
- The chassy frame will contain the rasberry pi and pixhawk attached in the middle alaong with the LiPo 11V battery.
- The propellers and other connections are shown here.
- The connection between rasberry pi and pixhawk is shown here :



- Rasberry Pi 3 requires a supply voltage of 5V and Pixhawk requires a supply voltage of 8V.

- Following is the voltage regulation circuit.

LiPo 11V supply



Output Voltage of 5V

- Similar is the circuit for 8V output, just we will use 7808 IC instead there.

DRONE: THE SETUP

Setting Up The drone

- For the drone to fly autonomously, we need to program it. Before that we have to connect our flight controller(Pixhawk) to our onboard computer (Raspberry Pi) and install necessary packages on Rpi to communicate with Pixhawk.

- We plan to work with:
  - Rpi 3/4 with Raspbian OS
  - Pixhawk with PX4installed
  - We can communicate with Rpi through SSH by WiFi or an ethernet cable.

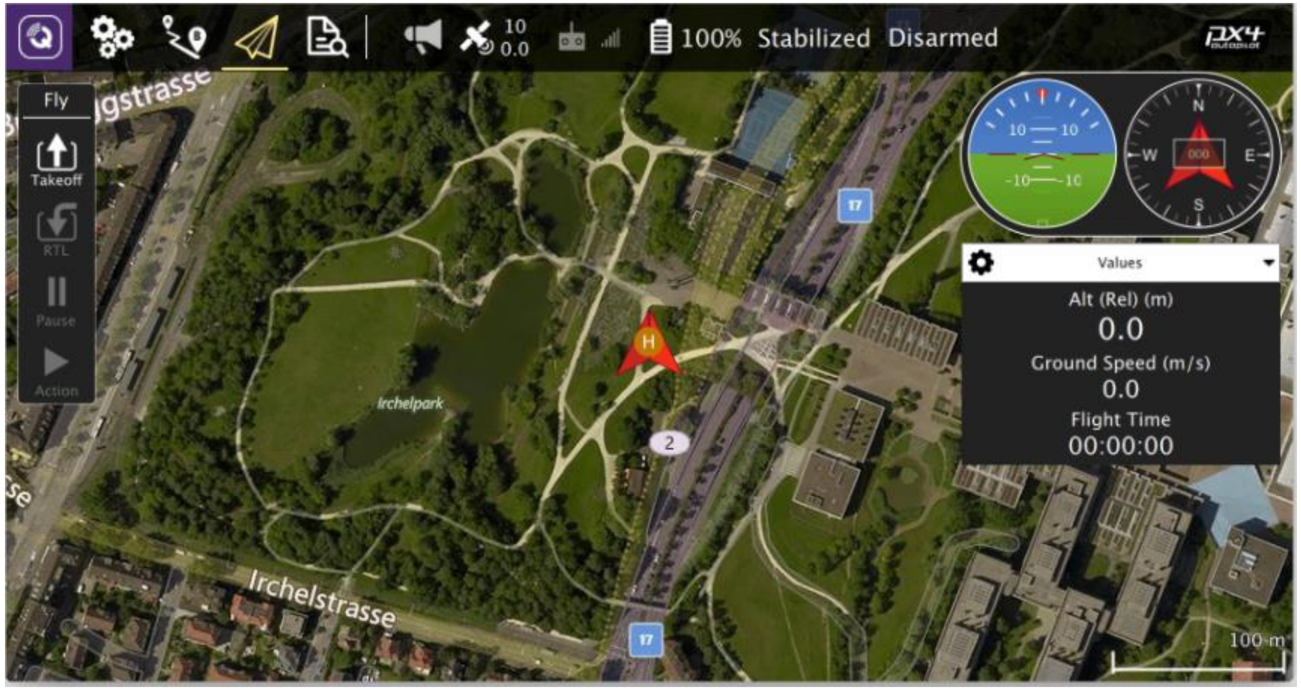
Setting Up The drone

- To accomplish this we have chosen Clover. Clover is an educational kit of a programmable quadcopter that consists of popular open source components, and a set of necessary documentation and libraries for working with it.

- The Clover platform contains a pre-configured image for Raspberry Pi with the full set of required software for working with peripheral devices and programming autonomous flights.

- This preconfigured image is what we will be incorporating into our drone.

- We will also use **QGroundControl** to flash, configure and calibrate the flight controller. We will have to flash the latest stable version of clover (https://github.com/CopterExpress/Firmware/releases/download/v1.8.2-clover.13/px4fmu-v4_default.px4) to our flight controller.



About Clover And ROS

- Clover is an open-source ROS-based framework, providing user-friendly tools to control PX4-powered drones. Clover is available as a ROS package but is shipped mainly as a preconfigured image for Raspberry Pi.
- The Robot Operating System (ROS) is a widely used set of software libraries and tools that help you build robot applications. ROS is already installed on the RPi image.
- In order to achieve Pixhawk Communication, clover uses MAVROS. MAVROS (MAVLink + ROS) is a ROS package that allows controlling drones via the MAVLink protocol.
- http://wiki.ros.org/mavros
- https://www.ros.org/
- https://clover.coex.tech/
- https://clover.coex.tech/en/image.html

Programming the Drone

```
# Takeoff and hover 1 m above the ground
navigate(x=0, y=0, z=1, frame_id='body', auto_arm=True)

# Wait for 2 seconds
rospy.sleep(2)

# Fly forward 2 m
navigate(x=2, y=0, z=0, frame_id='body')

# Wait for 2 seconds
rospy.sleep(2)
# Perform landing
land()
```

- Once we have installed necessary stuff in Rpi and our flight controller, programming it is quite easy.
- We can connect to our drone with Wi-Fi and use SSH to interact with drone’s API (thanks to ROS).
- Here’s an example of python code which makes the drone take off, move 2m forward and then land:

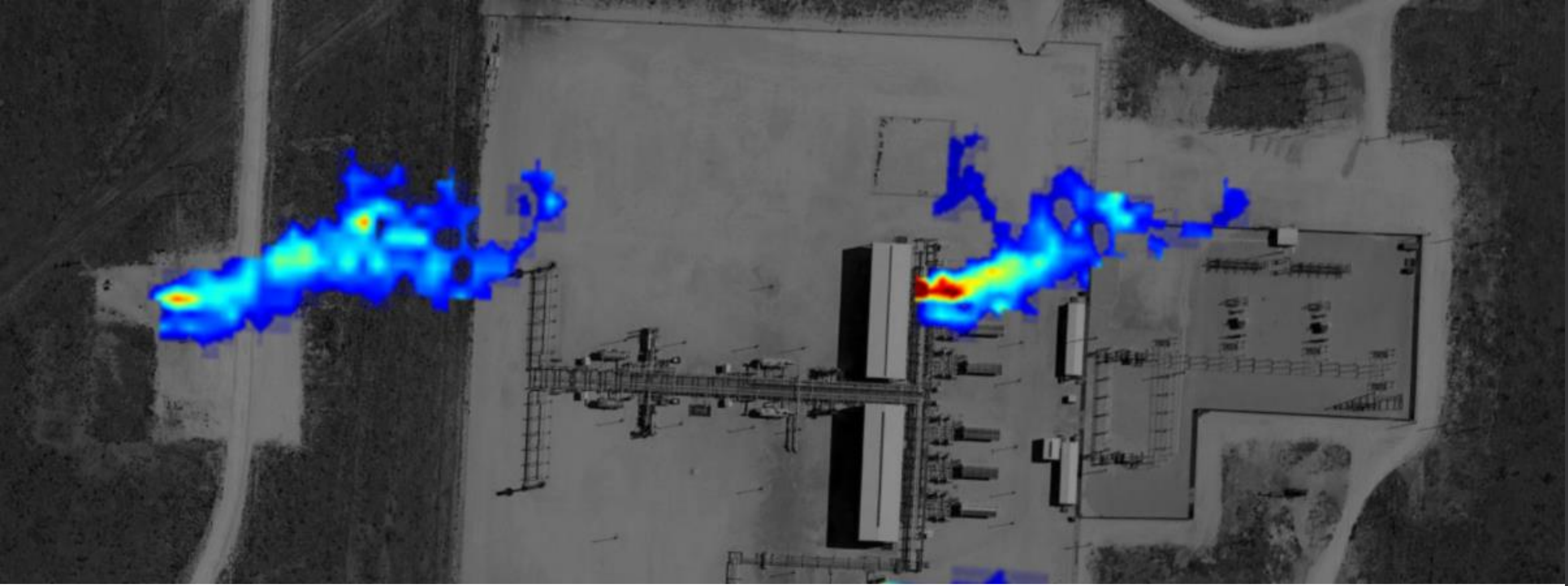
```python
def changeLoc(I,delta,stepSize):
  dIx = (I['E']-I['W'])/(2*delta)
  dIy = (I['N']-I['S'])/(2*delta)
  dIz = (I['U']-I['D'])/(2*delta)
  lenI = sqrt(dIx**2+dIy**2+dIz**2)
  dx = stepSize*dIx/lenI;
  dy = stepSize*dIy/lenI;
  dz = stepSize*dIz/lenI;
  return (dx),(dy),(dz)

def find_source(delta = 0.2,stepSize = 0.5 ,x=0, y=0, z=1, yaw=float('nan'), yaw_rate=0, speed=0.5, frame_id='body', tolerance=0.2, auto_arm=False):

    I = {'E':pi.read(E),'W':pi.read(W),'N':pi.read(N),'S':pi.read(S),'U':pi.read(U),'D':pi.read(D)}
    trajectory = [[x,y,z]]
    error = stepSize+1
    while error>=stepSize:
      dx,dy,dz = nextLoc(I,delta,stepSize)
      res = navigate(x=dx, y=dy, z=dz, yaw=yaw, yaw_rate=yaw_rate, speed=speed, frame_id=frame_id, auto_arm=auto_arm)
      if not res.success:
        return None


      trajectory.append([dx+trajectory[-1][0],dy + trajectory[-1][1],dz + trajectory[-1][2]])
      try:
        #error is the distance between current point and previous-to-previous point
        error = sqrt((trajectory[-1][0]-trajectory[-3][0])**2+(trajectory[-1][1]-trajectory[-3][1])**2+(trajectory[-1][2]-trajectory[-3][2])**2)
      except:
        pass
      I = {'E':pi.read(E),'W':pi.read(W),'N':pi.read(N),'S':pi.read(S),'U':pi.read(U),'D':pi.read(D)}

    land()
    return trajectory

trajectory = find_source()
```

The Code

What next?

The solutions discussed till now are what was achievable by us in terms of a readily usable prototype. But when we thought about scaling our solution for industrial usage, we developed a modified design.

The next section covers our ideation for a gas leakage detection & monitoring system for an industrial scale. As the technology involved is a bit out of scope for us, our analysis is more on the qualitative side than on the quantitative side.



LiDAR-based gas mapping system

Light detection and ranging (**LiDAR**) techniques use **lasers** to create 3D (**topographic**) or gas concentration (**atmospheric**) imagery of the surveyed environment. Both uses for LiDAR can be performed using either pulses of laser light (pulsed lasers) or laser light that stays on all the time (continuous-wave lasers).

Why is this needed?

To enable large-area gas leakage detection & gas emission monitoring, and that too with a good accuracy & resolution, an advanced system such as LiDAR is needed.

Improved measurement technologies are needed for a wide-range of gas detection and monitoring applications including:

(1) gas leak detection for the industry

(2) emissions monitoring for industrial facilities & production sites,

(3) verification of geological and soil carbon sequestration efforts

(4) environmental research to quantify ecosystem dynamics, including carbon cycling.

Our target use case

We have designed our system for the industry (factories, production units, warehouses) where the gases are used in an indoor setting. In this case, we want to provide our customers dealing with gases (both hazardous & non- hazardous) with real-time 3D mapping of a large area enabling them with:

› gas leakage **source detection**

› gas leakage **rate quantification**

› gas **concentration & spread analysis**

Our proposed solution

We are planning on using LiDAR technology based on **frequency-modulated continuous-wave (FMCW) ranging**, for high-resolution 3D imagery and simultaneous path integrated gas concentration measurements via **wavelength modulation spectroscopy (WMS)** integrated with an **efficient system of lightweight & mobile** LiDAR sensors.

Explanation of the entire system:

(1) Our **mobile LiDAR sensors** are fitted on rails or hanging cables on the roof of the factory. Using the motion of the sensors allows us to create a **synthetic aperture** and thus, we can cut cost on the size & number of sensors required.

(2) Continuous real-time LiDAR measurements are performed by transmitting laser beams on the factory grounds and collecting light backscattered from the objects on the topography.

Our proposed solution

(3) Imagery is generated by spatially scanning the transmitted laser beam. Encoder measurements of the transmitted beam angle are collected to enable reconstruction of the point measurements into images.

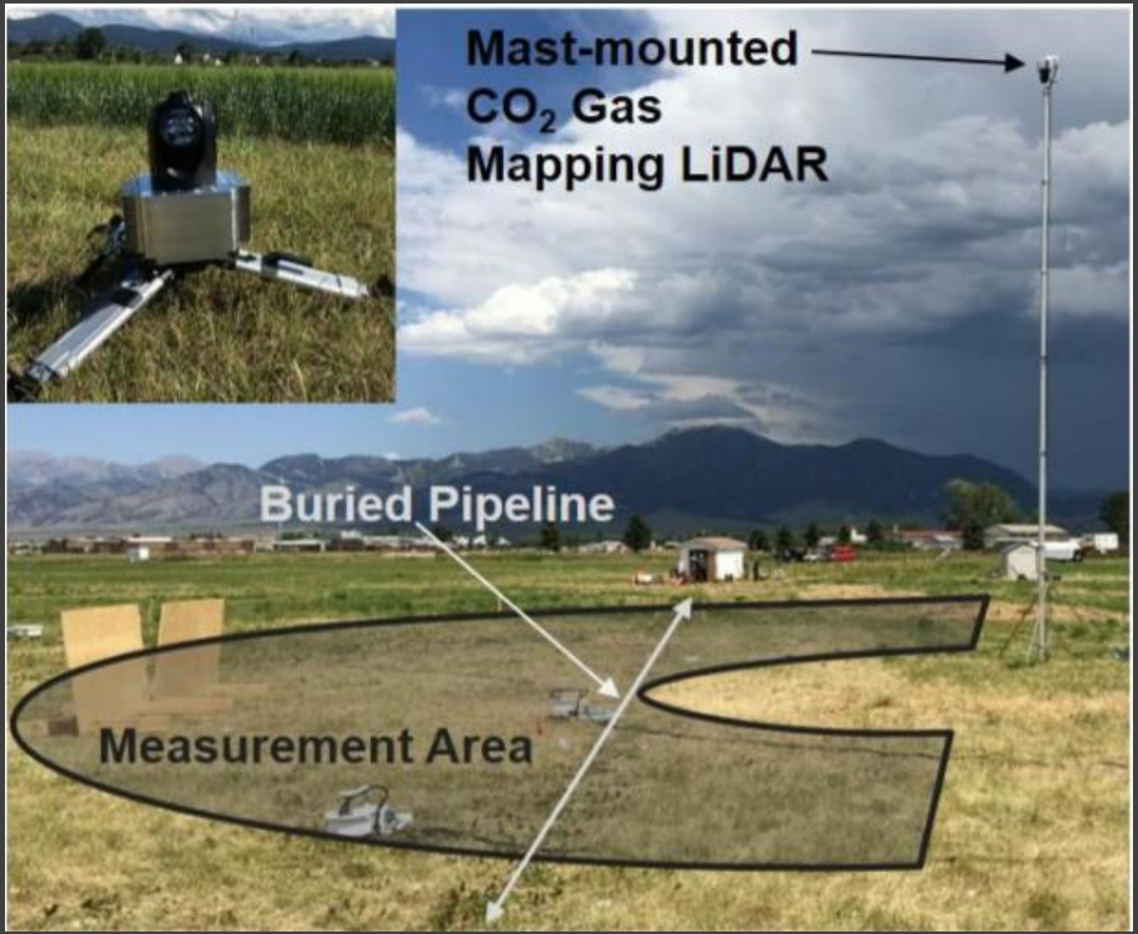
(4) The **combination of range and path-integrated gas concentration measurements** allows computation of the **average gas concentration** between the sensors and each point on the factory grounds.

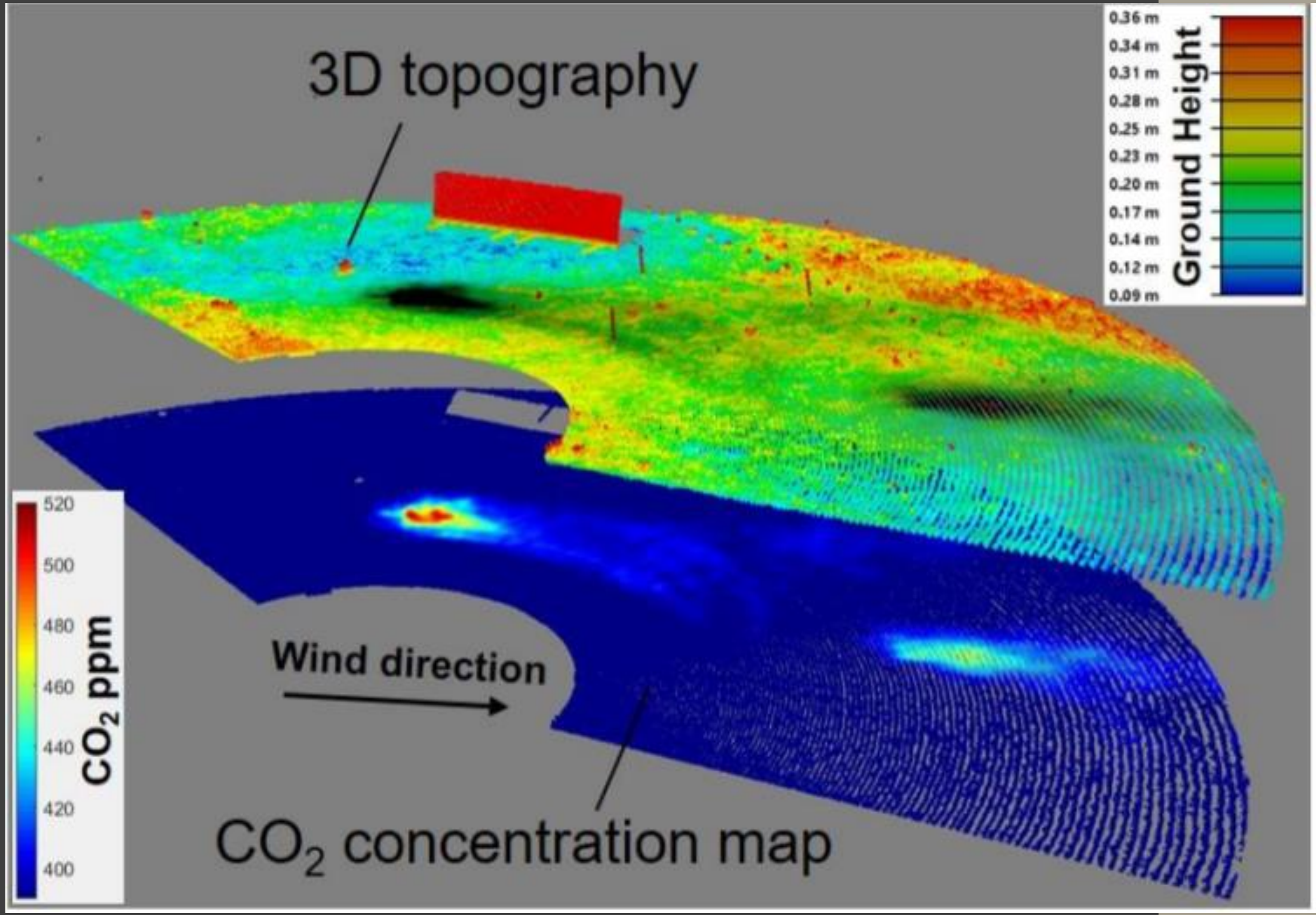
(5) The **average concentration** can be used to estimate the **quantity of anomalous gas**, even in the cases where distinct plumes of the gases are not clearly visible.

(6) The wavelength of the laser has to be chosen corresponding to the gas to be detected as the laser interacts with the molecules of the gas. Our system allows us to deploy **multiple LiDAR sensors**, each monitoring **a different gas**.

A similar example where a fixed LiDAR sensor has been used to monitor CO2 levels coming from a buried gas pipeline. This is in an outdoor setting, visible in the image on the left.

We can see the two distinct plumes through which the gas is coming out in the image on the right. Both, the topography & CO2 concentration plots are made available.





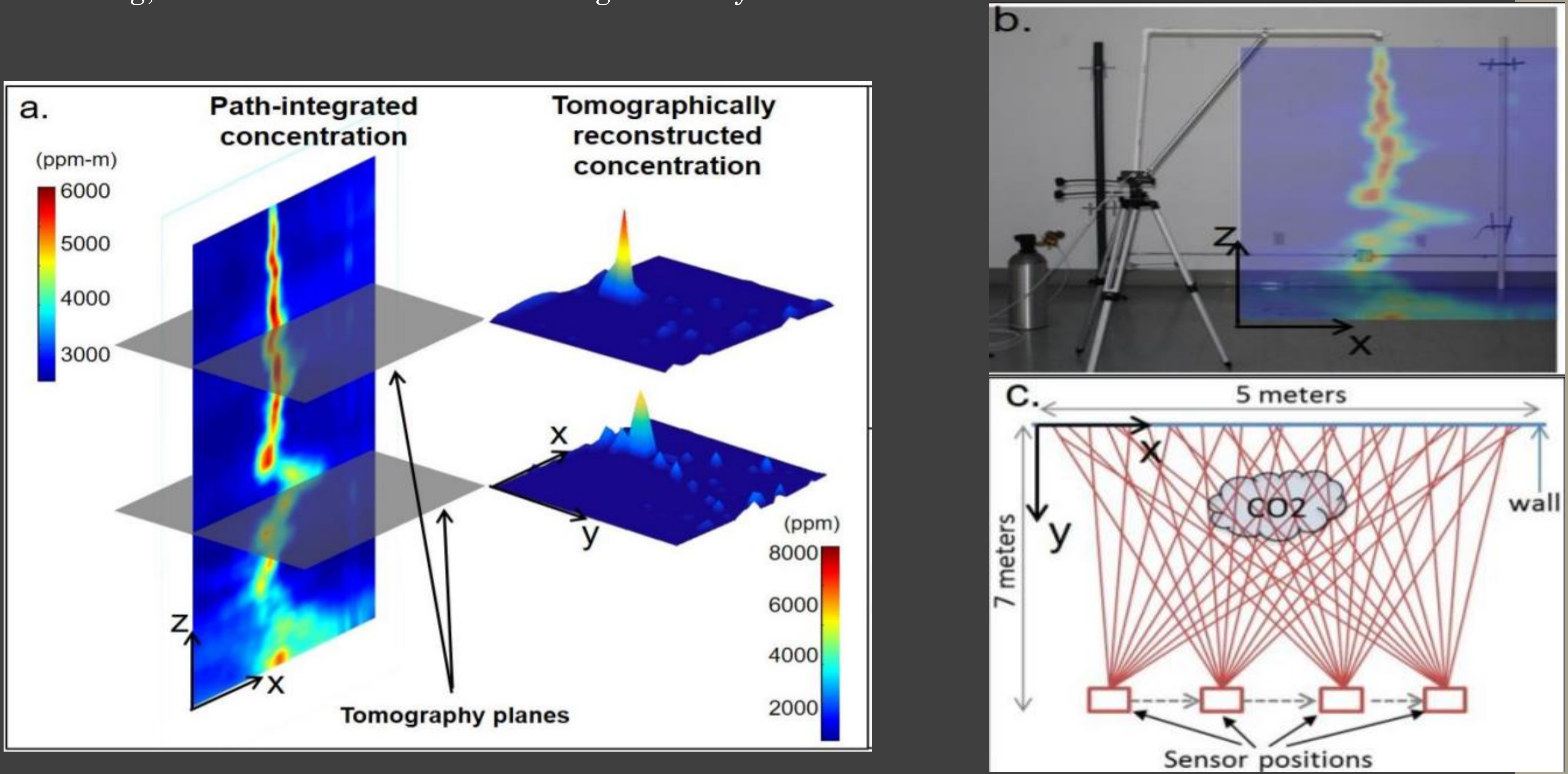
Bringing motion into the picture

The most novel element of our design is that the motion of our LiDAR sensors will allow us to cut down on cost by reducing the **number of sensors**, the **quality of the sensor involved**, and hence also **power** as the sensors use a lot of power.

When combined with sensor motion, the type of data we are receiving in the previous section also enables **3D gas plume reconstruction** via **tomography** for **volumetric localization** and **3D concentration estimates.** This allows us to see where the gas has spread after the leakage.

Combining this with positional elements of the sensors like **location, orientation, angle & range of the transmitted beam** allows us to bring into the picture the **objects like machines & parts** on the factory grounds. Our 3D model will be able to capture the gas leaks & spreads even if they occur behind the **obstacles**.

Here is an example of a plume of CO2 gas captured with multiple LiDAR sensors placed at slightly different locations. Using tomographical methods, the plume is reconstructed in 3-D setting, with the concentration of the gas clearly visible.




FEW STARTUPS
Which have already addressed this problem

Viper Vantage

Experts at combining specialized drones with sophisticated thermal and optical imaging sensors for oil and gas industry, manufacturing, building, utility, and industrial inspections; spraying; surveillance; and surveys.

ULC Robotics

ULC Robotics provides drone-based methane and gas leak detection services that **reliably detect, locate and quantify methane leaks.** From gas producing wells and gathering lines to transmission and distribution pipelines, we provide actionable data that deliver safety, efficiency and cost benefits to your pipeline leak detection drone programs.

DETECT TECHNOLOGIES

Detect Technologies is revolutionizing the industrial sector with cutting-edge technologies. Their digital solution powered by AI and with data acquired by drones, map and predict potential oil and gas leakage in the pipes, ensure fast detection of fire incidents, and deliver advanced analytics to improve efficiency.


THANK YOU