PORTABLE QUADCOPTER-BASED PARTICULATE MATTER SENSOR SYSTEM FOR AIR POLLUTION MONITORING

Introduction

Health Impacts of PM
- damage lung tissues
- respiratory/heart diseases
- permanent lung problems
- DEATH

SO...
few/insufficient monitoring stations
- unavailabile of air quality data
- lack of public awareness
- lack of standards/policy guidelines to maintain healthy air quality levels

Problems are exacerbated in developing countries... DUE TO **high capital & operational costs** of traditional air quality monitoring equipment!

Aim

Explore cost-effective yet accurate air quality monitoring alternatives

Potential application of **unmanned aerial vehicles (UAVs)** fitted with **low-cost PM sensors**
- affordable
- portable
- wide range
- flexibly deployed and maintained
- relay accurate air quality information
- GPS module helps drones identify air pollution hotspots and sources from recorded flight route and coordinates

Why Quadcopters to Monitor Air Quality?

- **Temporal Resolution:** frequency at which data is collected
- **Spatial Resolution:** area that one data point represents.

Successful Implementations
Massachusetts Institute of Technology (MIT) alumni operated autonomous drones over urban waypoints, providing real-time, detailed spatiotemporal data of PM 2.5 concentration and composition. It identified air pollution hotspots and sources, surpassing limitations of stationary systems!

Temporal Resolution	Spatial Resolution	Low Cost	Small Size
monitor pollution change over time identify peak pollution times, areas	monitor pollution variance over locations, identify pollution hotspots, spatial variability of pollutants	improve accessibility/ scalability (resource-limited regions) enable long-term monitoring efforts	portability, maintenance

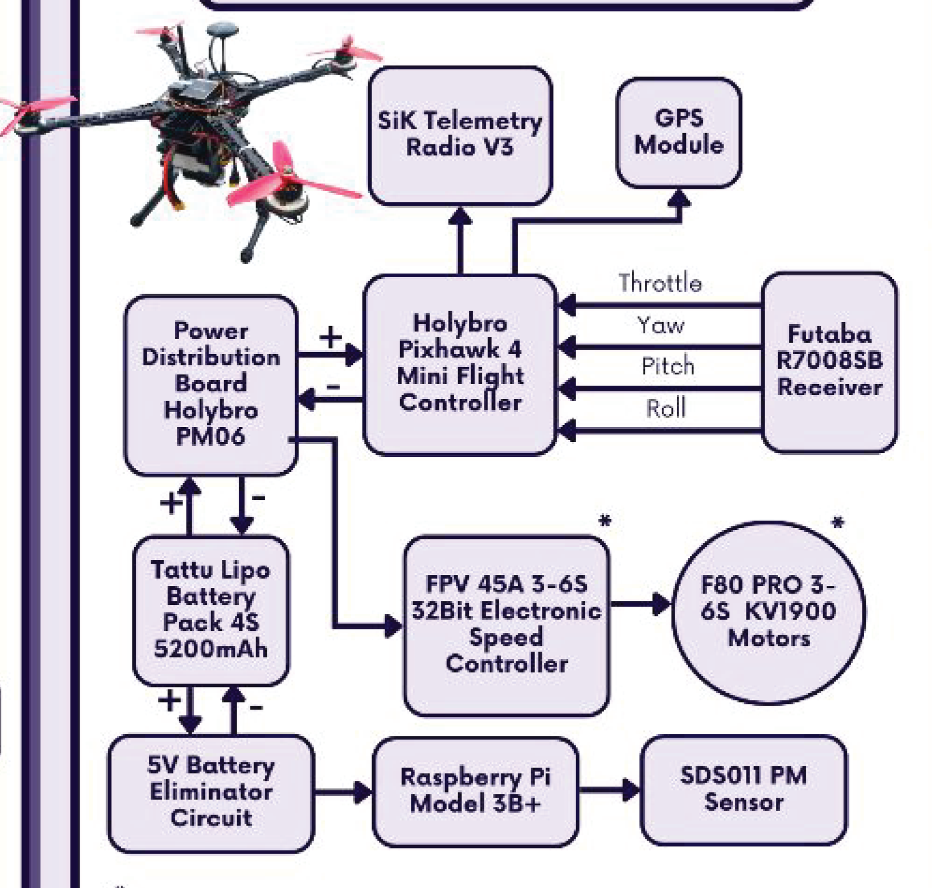
Mode of Monitoring	Temporal Resolution	Spatial Resolution	Cost	Size
UAVs/ Quadcopters	Meet specific needs by adjusting sensor reading frequency.	High spatial resolution due to ground proximity, unhindered by cloud cover (unlike satellites).	Cost-effective. **(S$1035.67)** Accessible components, minimal infrastructure needs, durable design Reduces setup/maintenance expenses.	383*385* 240mm
Satellite Systems	Geostationary: **30 mins** Polar-orbiting: **1 - 3 days** Less effective in tracking air quality changes over shorter timescales.	Multi-functional Transport Satellite 2 (geostationary): **250m - 4km** Extensive coverage but diminished spatial detail.[9] Less variations in local air quality detected.[1]	Satellite: ~USD290 million Repair: ~USD1.5 million a year Launch: ~USD10 million	6*6*7m
Traditional Stationary Monitoring Systems	Hourly depends on reading frequency of sensors	Cannot capture high spatial variability of PM 2.5 Substantial infrastructure needed and large size limits installation flexibility. High cost limits units deployed, producing regional-scale measurements and local data gaps	Regulatory-grade PM monitors: **>USD10,000** Station: costs **~SGD121000 - SGD242000** Require regular maintenance, calibration and part replacement, costly due to skilled personnel needed.	4.2*3.5* 2.5m
Essentially...	comparable	increased	0.86%	9.68x10-4 x

= quality is uncompromised
- **Greater Mobility:** travels far and wide per flight journey, decreasing cost per unit area analysed.
- **Portability**: can be easily transported between countries for worldwide deployment.
- **Autonomy**: reduces manpower needed and cost
- **GPS module:** records flight route and coordinates: maps air pollution hotspots and sources

Project Process

1. Electronic Schematic + Blueprint of Drone Planned
2. Model holders/ adaptors for electronics (Solidworks 2021) → Assemble/secure electronics to drone
3. Connect Raspberry Pi to PM sensor and battery → Drone calibration (QGround-Control) → Write Python script to read/ send PM values to cloud (AdafruitIO)
4. Test electrical units, software, mechanics
5. Test flights → Collect PM readings (around Singapore)
6. Process and analyse data

Electronic Schematics



*There are 4 sets of ESCs and Motors on the quadcopter

Materials

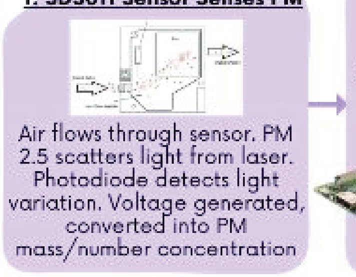
1. SDS011 PM Sensor
2. S500 Drone Frame
3. FPV 45A 3-6S 32Bit ESC
4. Brushless Motor F80 Pro KV1900
5. Gemfan Hulkie 5055S-3 Propeller
6. Tattu Lipo Battery Pack 4S 5200mAh
7. SiK Telemetry Radio V3 (Ground, Air)
8. Pixhawk Mini 4 Flight Controller Set
   - PM06 Power Distribution Board
   - GPS antenna
9. Raspberry Pi Model 3B+
10. RC controller (FUTABA T14SG)
11. RC Receiver Futaba R7008SB

Software

QGroundControl
- ground control station software using MAVLink protocol to communicate with drones
- provides **sensor data real time** from Pixhawk (e.g. coordinates, altitude)
- enables **mission planning**/ semi-**autonomous** flight via telemetry

Methodology

1. SDS011 Sensor Senses PM



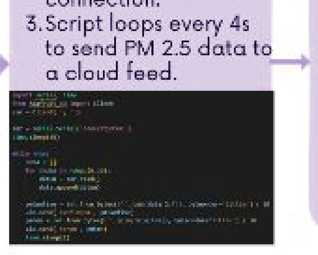
Air flows through sensor. PM 2.5 scatters light from laser. Photodiode detects light variation. Voltage generated, converted into PM mass/number concentration

2. Connected RPi receives readings

PM Sensor connected to Raspberry Pi 3 Model B+ that received PM 2.5 readings.

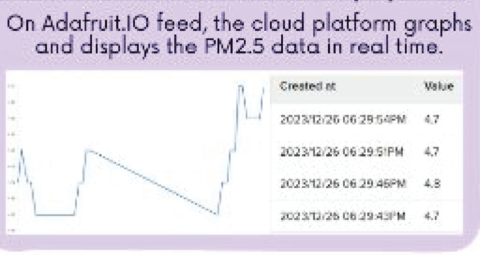
3. RPi Runs Python Script

1. RPi is powered on
2. RPi waits 45s to establish a wireless connection.
3. Script loops every 4s to send PM 2.5 data to a cloud feed.



4. Adafruit.IO Feed Receives & Displays Data

On Adafruit.IO feed, the cloud platform graphs and displays the PM2.5 data in real time.

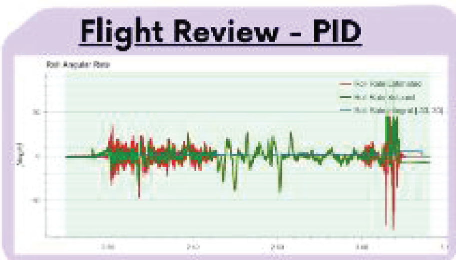


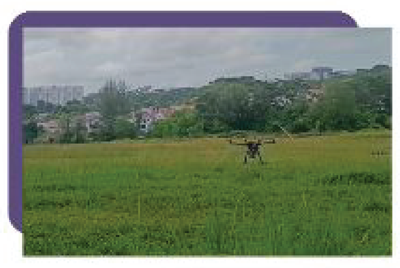
Test Results

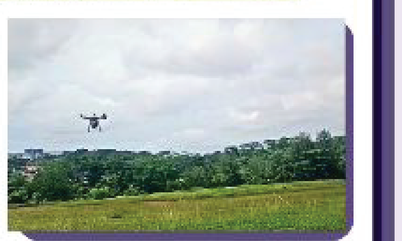
Flight Tests

Run	Events
1	• Drone takes off upon throttle-in input • Low sensitivity of yaw, pitch, roll controls • Slow response to input • Good vibrations of frame
2	
3	• Drone takes off upon throttle-in input • Better response to input
4	

Flight Review - PID







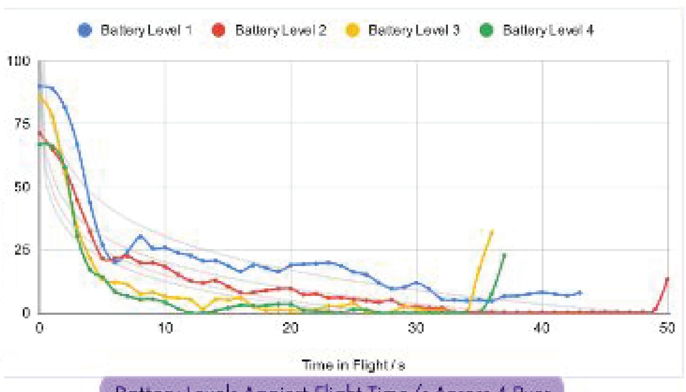
Yaw, pitch, and roll rate graphs check for flight stability and if the PID algorithm is tuned well.
- Estimated line is relatively consistent with setpoint line.
- Some overshooting and slow response time
- Tracking is not consistent
  - Can be enhanced by further tuning the rate controller using QGroundControl PID Tuning setup.
  - use new LiPo battery, efficient motors and propellers

Battery Endurance

Graphs of battery life over time in flight were plotted from data in the PX4 autopilot log to obtain maximum flight time approximations.

Sharp decrease in battery level within first 6 seconds as lift-off expended significant power.
At takeoff, average rate of battery level decrease (0-6s) is 9.58 units/s.
In flight, the average rate of decrease is 0.534 units/s.

Rate of battery decrease/ units/s	Run 1	Run 2	Run 3	Run 4	Mean
During take-off, for 6s	9.38	6.97	12.8	9.12	9.58
While cruising	0.635	0.491	0.457	0.555	0.534



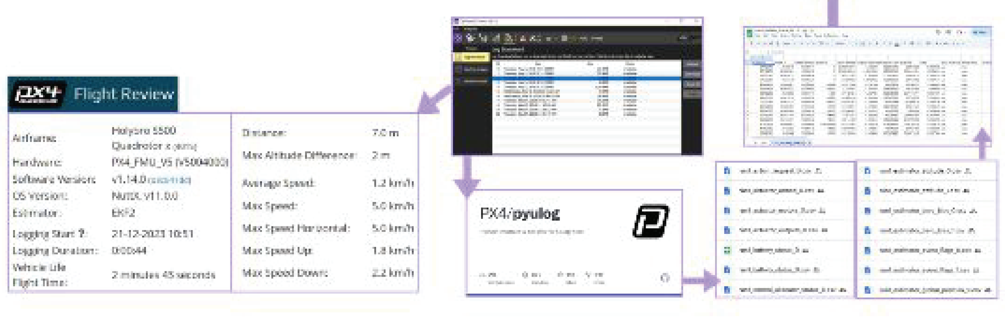
Battery Levels Against Flight Time/s Across 4 Runs

Flight Time

Values for speed during flight and flight life were derived from the PX4 ULog Flight files.

Flight log files were analysed on the PX4 Flight Review website.

We used Pyulog to parse ULog files in PX4 autopilot middleware to convert and display .csv files for specific analysis.



Data Processing

Comparison of Quadcopter PM Readings to Existing Stations

Region (Specific Location)	NEA Readings/ μg/m³	Mean Stationary Reading/ μg/m³	Mean Hovering Reading/ μg/m³
North (Khatib MRT)	5	4.7	-*
South (Mount Faber Park)	8	7.9	-*
Central (Bishan Park)	5	6.7	-*
East (Pasir Ris Park)	15	15.2	-*
West (Old Holland Road Field)	6	5.0	4.7

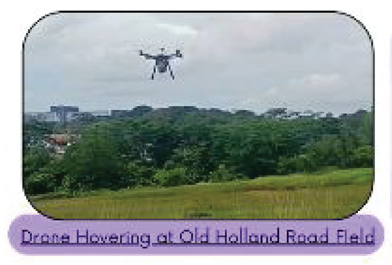
*Unable to hover drone in these areas

>25 readings of PM2.5, 4s apart were taken while the drone was both **stationary and hovering.**

This tests both the **reading accuracy** and the **effect of altered airflow by propellers** on the composition of PM around the drone.

Drone Stationary at Mount Faber Park

Drone Stationary at East Coast Park (left) and Bishan Park (Right)



Drone Hovering at Old Holland Road Field

As shown, the PM sensor on the quadcopter has **similar readings** to the official NEA reference, proving that the low-cost sensor provides **accurate, localised readings** reflective of the air quality at a specific location.

Range

Mean flight time
(Battery Life Calculation)
1 min 25s
(Averaging of 4 runs in the PX Autopilot Log)
2 mins 2s

Maximum Speed Value X Maximum Flight Time = Range (in vertical/horizontal directions)

Horizontal Range = 7.2 km/h ×2.0360h = 0.244 km **=244 m**

Vertical Range = 1.9km/h ×2.0360 h = 0.0643 km **=64.3 m**

Assessment

Tracking inconsistencies possibly due to:
- **low centre of gravity**, attached PM Sensor and RPi Module below
- **high inertia** due to drone's mass
- external factors like **strong winds**
- **inefficient motors/propellers**, poor power to weight ratio to generate optimal thrust

LiPo battery was also slightly **bloated** after flight tests, possibly degrading flight performance.

Range is not ideal, as ideal flight time is 30 mins, and a range >1km.
However, flight time can be optimised with **larger motors/propellers** to generate more lift/thrust, and a new LiPo battery source. These measures ensure the drone is **powered optimally** to cover an **extensive area.**

Conclusion

Drones are FEASIBLE...
- **Ease:** accessibility of equipment, ease of assembly, maintenance
- **Accuracy:** accurate PM readings
- **Costs:** low material, manpower, maintenance costs
- **Additional Perks:** specific GPS locations, flight routes, autonomy
- **Future Long Term Impacts:** map high-PM concentration areas
  - identify sources of PM
  - initiate meaningful policy changes in resource-limited regions

POSSIBLE IMPROVEMENTS

1. **Optimising Range & Battery Life**
   - Larger motors, propellers to generate efficient thrust
2. **Flight Endurance [Weather Conditions]**
   - Waterproofing: improve deployment flexibility
   - Optimising PID algorithm: flight stability in high winds
3. **Air Monitoring Abilities**
   - Incorporate a greater variety of sensors
4. **Autonomy**
   - Use GPS for autonomous navigation via waypoints
   - Help drones autonomously conduct rounds via preset commands.
   - Pathfinding algorithms to improve operational efficiency in dense areas

>IMPROVES THE TOTAL DISTANCE COVERED AND ENVIRONMENTAL DATA COLLECTED
>PROVIDES A MORE COMPREHENSIVE VIEW OF LOCAL AIR QUALITY

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DSTA Defence Science & Technology Agency
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