# UAV-based Semi-Autonomous Data Acquisition and Classification

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*Abstract*—**Air pollution is a major issue contributing to global warming that threaten the quality of life on Earth. Numerous research disciplines are combining their efforts to combat air pollution by developing new methods to monitor and control pollution. For this to happen, researchers need to have instant access to new data. In this paper, we have developed a Semi-Autonomous Unmanned Aerial Vehicle (UAV) loaded with sensors to measure different quantities indicating air pollution, in particular: temperature, humidity, dust, carbon monoxide, carbon dioxide, and ozone. The purpose of this UAV is to automatically patrol high altitudes to obtain sensor readings, and transmit raw data to a centralized server via mobile network for visualization and storage. Actual measurements and data collection is carried out in Qatar. This combination of the UAVs' mobility, remote sensing, and networking facilities allows concerned parties such as researchers, smart city administrators and crowd managers, to view and visualize relevant data with significant ease via a web interface, or an android app.**

***Keywords*—** Data Acquisition, Unmanned Aerial Vehicle, Remote Sensing, Pollution, Data Visualization, Data Classification, Crowd management, Crowd sensing, Smart infrastructure.

## I. INTRODUCTION

Air pollution is one of the major problems that threaten organic life on Earth [1], with a significant impact on public health, economy, and environment. It was found that air pollution has an impact on new births [2], and possibly causing premature deaths due to the inhalation of Particulate Matter (PM), such as dust and smoke [3]. With the development of cities, air pollution is becoming more challenging, as it is directly tied to developmental sectors such as industries, transportation, urbanization, energy generation, and waste management [3]. It is important for such sectors to regulate pollutant emissions and reduce them by enforcing policies. One contributor to the design of such policies is environmental research.

Researchers, in spite of their expertise in their respective fields, need instant access to live data feeds from multiple locations simultaneously. This requires a form of air-quality monitoring that employs remote sensing, covering a large area at different altitudes, and remotely transmitting readings directly for instant access. Such real-time data feeds would aid in the design of policies, as well as provide crowd-based solutions with precursors of where to allocate crowd-sensing participants for higher granularity, or to allocate resources for crowd management (such as transportation, emergency response,...etc).

Different solutions were proposed, such as *The Green Falcon Kit* [4] which comprises of a solar-powered fixed wing UAV that flies on predefined paths with an on-board gas sensing devices. However, it is limited in term of parameters sensed and in terms of mobility. The UAV developed in [5] is capable of measuring different quantities at different altitudes with an autopilot. However, the data could only be retrieved after landing.

In this paper, we introduce a *Hybrid-Autonomy UAV*. This UAV is equipped with sensors to crowd-sense air-quality and pollution parameters in a real-time manner. This massive data is transmitted over the 3G/4G to be stored and visualized simultaneously, allowing remote monitoring and immediate decision making. The developed UAV is a potential element of the smart city infrastructure, as it would provide a low-granularity assessment of air quality at high altitudes. This assessment provides valuable insight into air-quality for all stakeholders. The contribution of this paper lies mainly in the novel system design (and its combination of different aspects) as well as extensive testing experiments. This paper is organized as follows: Section II provides an overview of UAVs and remote-sensing in a smart-city context. In Section III the developed system design is described, as well as the implemented Graphical User Interface (GUI). Section IV entails the details of the experiment design as well as the testing performed. Finally, Section V concludes with a summary of potential improvements to follow this work.

## II. UAVS WITHIN SMART CITIES: AIR QUALITY

UAVs are of significant importance for smart cities, as they replace the unsustainable costs of installing wide sensor networks with dynamic, mobile, cheap, and customizable UAVs [6]. This section provides a general overview of UAVs, their use to obtain quality metrics [7], and relevance to smart cities.

### *A. Unmanned Aerial Vehicles*

UAVs can be categorized into many categories according to their application, which include: safety control, scientific and military research, and commercial applications [8]. These categories comprise a wide range of applications which led to the standardization of the general UAV structure.

In terms of physical structure, UAVs can be classified into two types: *Fixed* and *Rotary* wing. Fixed wing UAVs are similar to aeroplanes, in which flotation is achieved by the means of a forward thrust generated by a propeller engine, while the direction is controlled by the structure of the wing. This allows the UAV to remain in flight for long distances with high speeds, which makes fixed wing UAVs suitable for applications demanding large area coverage, such as geographical surveying, surveillance, or agriculture. On the other hand, rotary wing UAVs (also known as Quad-copters), have four propellers similar to those of a helicopter. They exhibit stability and minute control, which makes them excellent for applications that require the UAV to remain in a single place or move within a limited geofence. UAV operators need to consider which design is suitable for their application to optimize cost, maintain performance, and achieve the desired tasks. To that end, the advantages and disadvantages of each type are provided in Table I.

TABLE I
COMPARISON BETWEEN FIXED AND ROTARY WING UAVS

| Type | Advantages | Disadvantages |
|---|---|---|
| **Fixed** | • High speed<br>• Long distance<br>• Heavy payload<br>• Smooth gliding<br>• Minimal maintenance process | • One directional<br>• Runway is needed to takeoff and landing<br>• Restricted by rules and regulations |
| **Rotary** | • Multi directional<br>• No need for runway to takeoff or land | • Complex design<br>• High cost<br>• Very light payload<br>• Low operational time |

### B. Air Quality Requirements in Qatar

Air quality monitoring generally revolves around monitoring six major pollutants: Carbon Monoxide (CO), Nitrogen Dioxide ($NO_2$), Ozone ($O_3$), Sulfur Dioxide ($SO_2$), Lead (Pb), and dust Particulate Matter ($PM_{2.5}$ and $PM_{10}$) [9], along the major pollutant in Qatar, Carbon Dioxide ($CO_2$) [10]. Out of these pollutants, the major contributions to air quality reduction in Qatar are $CO_2$ and $O_3$ [10]. The World Health Organization (WHO) has provided ranges of permissible values to maintain an acceptable air quality, described in Table II [11].

TABLE II
PERMITTED STANDARD CONCENTRATION LEVEL

| Substance | Permitted Ambient Concentration |
|---|---|
| **$O_3$** | 0.0473 ppm for 8 hours, average 100 $\mu$g/m$^3$ |
| **CO** | 9 ppm for 8 hours average, and 35 ppm for 1 hour average |
| **$CO_2$** | 5000 ppm for 8 hours |
| **Dust** | 10 $\mu$g/m$^3$ annual average and 25 $\mu$g/m$^3$ for 8 hours |
| **Liquefied Petroleum Gas** | 0-1000 ppm, 1800 $\mu$g/m$^3$ annual average |

These quantities need to be sensed with proper accuracy and precision. Gas sensors can be classified according to their principle of operation, such as: optical sensors, electrochemical sensors, electrical sensors, mass-sensitive sensors, calorimetric sensors, and magnetic sensors [12]. Sensors deployed on a UAV for air quality monitoring need to be within the standard specifications prescribed in Table II, which provides constraints on reading accuracy and precision. Other factors that come into the process of choosing a sensor are: its acquisition speed, particularly heating and response times, as well as the quantity being sensed, but more important is the weight. For example, dust particles could be detected using an optical sensor, while an electrochemical sensor is best for gas detection. The sensors deployed on the UAV are different and varying to be able to sense all air quality parameters.

## III. PROPOSED SYSTEM DESIGN

### A. Implemented UAV Architecture

In this section, we describe the implemented UAV design; in terms of data acquisition, navigation, communication, user interface, and data visualization. The UAV selected for our implementation is *Stick 60* model, developed by Hangar 9.

### B. System Design

The UAV system consists of three major components: data acquisition, navigation and central processing. Figure 1 provides an overview of the developed UAV system, as well as the interaction between the UAV's different modules.

The central processing component is made of the Raspberry Pi, a camera, a 5V power bank, and the 3G/4G communication module. It connects to the navigation and the data acquisition module to transmit and receive instructions and readings, respectively. The data acquisition component consists of an Arduino Nano combined with a set of sensors that measure CO, $CO_2$, $O_3$, dust, temperature, and humidity level. These quantities are sampled every seven seconds, then transmitted to the central processing component, all being powered by the 5V power bank. The navigation component, on the other hand, constitutes of a brush-less DC motor powered by a separate 5,300 $mAh$ Lithium Polymer (Li-Po) battery, an Electronic Speed Controller (ESC) to control the speed of the UAV, a Pixhawk flight controller module to pilot the UAV in both autonomous and remote-controlled (RC) modes (to which the UAV follows a specified path), and a pulse position modulation (PPM) encoder linked to the wing-servomotors for direction control. Figures 2 and 3 show the data acquisition and navigation components along the central processing component, respectively.

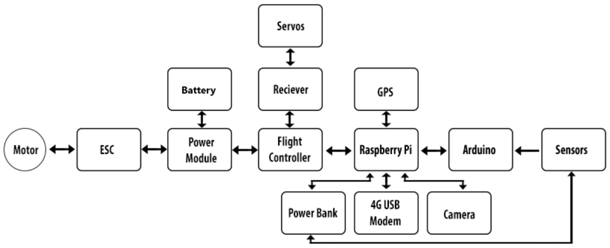


Fig. 1. System Design

The UAV flies in a semi-autonomous manner over a designated area to obtain air quality parameters, then transmits them over 3G/4G with the location and time-stamp.

Semi-autonomous means that the navigation mode combines both aspects of manual RC piloting, and in case no pilot is available, an auto-pilot mode, both being implemented on the Pixhawk Flight controller using ArduPilot. In case of the air quality parameters showing an abnormal situation, the UAV transmits a live video feed to the ground station for appropriate emergency response, in case of any.

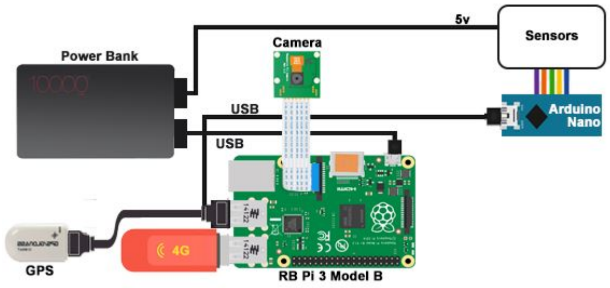


Fig. 2. Data Acquisition Component

### C. UAV-Server Communication

The Flight Controller is connected to the Raspberry Pi via USB to broadcast its status and receive commands from the ground station. This interaction occurs via the MAVLink [13]. The Raspberry Pi connects to GPS to get the location coordinates, and the camera to receive H264 video stream to encode and transmit it as Flash Video (FLV) to Real-Time Messaging Protocol (RTMP) server. All transmissions are done over 3G/4G network. To maintain a constant connection with the Raspberry Pi, a reverse Secure Shell (SSH) tunnel is established, setting up the server as a proxy with a static IP Address, that allows to forward any requests from the client to the Raspberry Pi, after a connection has been established and authenticated. We have developed a Client/Server protocol, in which the client is the Raspberry Pi, streams a continuous message to the server to maintain the connection. The server replies with an acknowledgment (ACK) or a request. The request is either to start or stop data transmission or video transmission. Table III describes the commands used in the communication protocol.

The client has three main threads that operate concurrently:

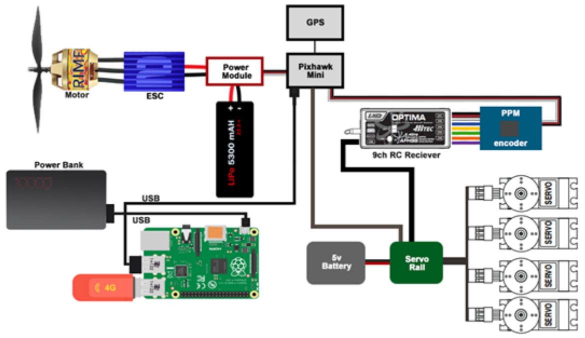


Fig. 3. Navigation System Component

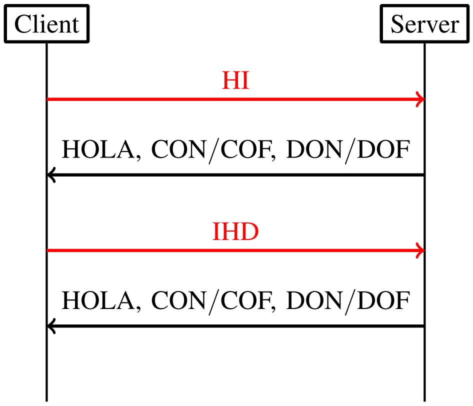


Fig. 4. Communication Protocol Concept

- **Connection Thread**: Responsible to maintain the connection, as well as bidirectional data flow between the client and server.
- **Arduino Thread**: Constantly reads the data from the Arduino, and makes them accessible to the main thread.
- **GPS Thread**: Keeps track of the current position of the UAV, and makes it available to the main thread.

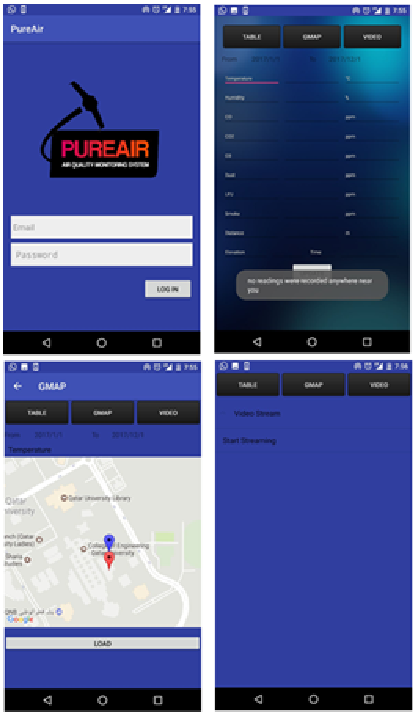
As Figure 4 illustrates, the server can ask for data stream or video stream, or to stop either or both of them. The main thread will continuously monitor the Arduino thread and merge its data with the current location and time-stamp and send them as one packet.

TABLE III
CLIENT/SERVER COMMUNICATION PROTOCOL MESSAGES

| Client | Server | Description |
|---|---|---|
| HI | - | Regularly to maintain open connection. |
| IHD | - | New data is merged with this header and sent. |
| - | HOLA | Default response to confirm no new request. |
| - | CON | Turn on the camera. |
| - | COF | Turn off the camera. |
| - | DON | Turn on the data stream. |
| - | DOF | Turn off the data stream. |

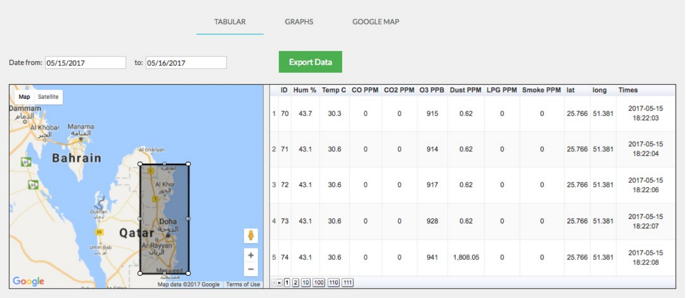
### D. User Interface and Data Visualization Design

At the ground station, stakeholders such as researchers and smart city administrators can visualize the data acquired by the UAV by means of a Graphical User Interface (GUI), implemented on Android application or on a web interface. This allows users to view and interpret the data with ease, in predefined formats with their choice of parameter combinations for their convenience. Data is visualized in three formats: a tabular form, a plot, and a Google map overlay. Both interfaces feature a live video feed available upon request. Figure 5 shows the developed Android application where Figures 6 and 7 show the web user interfaces.



no readings were recorded anywhere near you

Fig. 5. Android Application User Interface



Date from: 05/15/2017 to: 05/16/2017

| | ID | Hum % | Temp C | CO PPM | CO2 PPM | O3 PPB | Dust PPM | LPG PPM | Smoke PPM | lat | long | Times |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70 | 43.7 | 30.3 | 0 | 0 | 915 | 0.62 | 0 | 0 | 25.766 | 51.381 | 2017-05-15 18:22:03 |
| 2 | 71 | 43.1 | 30.6 | 0 | 0 | 914 | 0.62 | 0 | 0 | 25.766 | 51.381 | 2017-05-15 18:22:04 |
| 3 | 72 | 43.1 | 30.6 | 0 | 0 | 917 | 0.62 | 0 | 0 | 25.766 | 51.381 | 2017-05-15 18:22:06 |
| 4 | 73 | 43.1 | 30.6 | 0 | 0 | 928 | 0.62 | 0 | 0 | 25.766 | 51.381 | 2017-05-15 18:22:07 |
| 5 | 74 | 43.1 | 30.6 | 0 | 0 | 941 | 1,808.05 | 0 | 0 | 25.766 | 51.381 | 2017-05-15 18:22:08 |

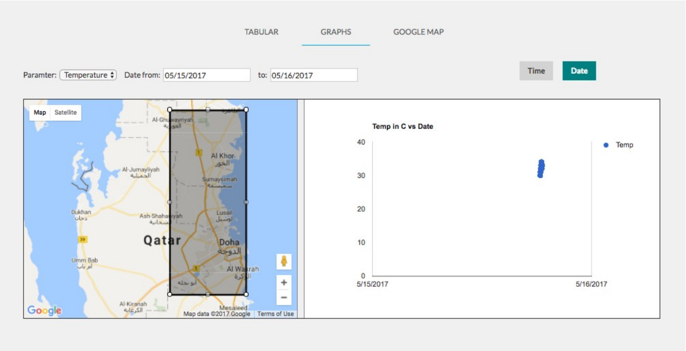
Fig. 6. Website User Interface, Tabular View

## IV. TESTING

To ensure the reliability and efficiency of the proposed UAV system design, we have developed a criteria to test the UAV's functionalities and the integration of all involved components. The criteria comprises of three tests applicable for any UAV system: a payload test, a navigation test, and a data acquisition test. The purpose behind such rigorous testing is to ensure that the UAV is fault-safe as such equipment is usually costly, and to avoid significant losses in case of failure.

The payload test, evaluates the UAV ability to carry the weight of all the developed components: the central processing, the data acquisition, and the navigation. It is a binary test for both, take-off and landing. The UAV passes the test if it takes-off and lands smoothly and safely with the weight. For our UAV, the payload was 0.5kg as specified by Hanger 9, and it has performed through it successfully.

The navigation test checks the ability of the UAV to pilot in both RC mode and auto-pilot mode. In this test, the autopilot's capability to cope with sudden changes, such as a sudden loss of altitude and orientation, was assessed. This test assesses the response time of the autopilot after each sudden event, which was always $< 1s$. The manual RC piloting was also tested by seeing the response range for the controller over a progressive 100m altitude. It was found that the UAV performed as expected with an accuracy of 30m for specified path nodes and locations.



Paramter: Temperature Date from: 05/15/2017 to: 05/16/2017

Fig. 7. Website User Interface, Graph View

The data acquisition test, targets the effectiveness of the UAV to obtain readings reliably. The readings were properly obtained with a time-stamp and a location-stamp then transmitted to the ground station over the 3G/4G network.

The implemented UAV was tested over 12 different progressive flights. Out of the 12 flights, the first one suffered severe problems, and it crashed because of losing communication with the UAV. The problem was solved and the rest of the flights were conducted successfully, maintaining a good connection with the RC transmitter's RF-link and the ground station's 4G-link. The battery power was also found to sustain flight for a duration of 30 minutes.

## V. CONCLUSION

Air pollution is one of the major issues nowadays. In this paper, a hybrid-autonomy air-quality monitoring UAV was developed for the purpose of providing real-time data feeds for researchers and smart city administrators, to combat and minimize the extent of air pollution. The design implemented is unique in terms that it combines data acquisition with autonomous piloting and an on-demand camera feed, to be presented to the users in a convenient interface implemented over both: Android and web interfaces. The implementation was rigorously evaluated using three different tests: payload, data acquisition, and navigation. However, potential improvements can be further pursued, such as increasing flight duration by harvesting energy [14] from different sources like solar-power or wind-energy; or by reducing the power consumed, by increasing the motor efficiency and the data acquisition module, another option is by reducing the overall weight.

## ACKNOWLEDGEMENT

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