An Autonomous Unmanned Aerial Security Surveillance System to Enhance Security in Remote Territories

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ABSTRACT
The current state of security in Kenya is marred by security breaches, expensive and inefficient. Criminal activities go undetected and unnoticed despite the use of sophisticated equipment and trained workforce like surveillance helicopters and manned soldiers hence leading to loss of lives and destruction of equipment and property. This research presents the background information, problem statement, research questions and objectives, justification of the problem, scope and limitations of the developed prototype. It presents an IT software development and research approach that will be applied to study the various types and ways of automating UAV using relevant or any related literature. Further, the project presents how the design, development, and evaluation of autonomous aerial security surveillance UAV are accomplished. With the use of Unmanned Automated Aerial surveillance vehicles, we can be able to curb the criminals by surveying the security prone territories where it is not safe for a human to go and report in advance. A construction research method and a simple prototype developed and presented that will be used to obtain, analyze, interpret and present the findings. The implication of the study is that it will provide a basis for further development, automation and adoption of UAV in aerial security surveillance and reporting to authorities the information that will be used to raise alarms and enhance security.

General Terms
Quadcopter, Drone, UAV, Border Security, APM Controller, Aerial Surveillance, Mission Planner.

Keywords
UAV, API, APM, DRONE, REST.

1. INTRODUCTION
Unmanned Aerial Vehicles (UAVs) are becoming popular within Kenya for recreation, entertainment, and military use. Some other areas of the world such as the United States and Sweden UAVs have been used in military and government operations especially in security surveillance. The rapidly advancing technology has made these drones more effective and less costly, and this has made the interest of many organizations to adapt and explore the use of UAVs in various applications. Some of the areas where the use of UAVs can be applied or incorporated include Entertainment, Search and rescue missions and Surveying among others. [34] Research on UAVs found that Drones have been used in other places to monitor for environmental abuses by private corporations and deployed by forestry trusts, environmental researchers and private companies to survey and assess otherwise inaccessible areas. Suggestions have been made applications of UAVs include use in, mining companies, hydroelectric power companies and corporations that monitor power lines, companies that monitor forestry.

Using UAVs for remote aerial security surveillance has the advantages regarding workforce needed and the overall response time. This would help in making quick, sound decisions. Some of the decisions include what type of vehicle to use, what level of warning is needed and the attack strategy to use to combat crime. By staging the UAV at strategic insecure territories, such as within long borders and the areas where the terrain is rugged and most prone to be used by criminals, a live video feed of the area could be transmitted within minutes to monitor or track the object or the intrusion.
The drone described in this paper uses four brushless motors for the actuation, combined with two counterclockwise propellers and two clockwise propellers. The APM hardware firmware is Open Source. Ground controller Station software of various kinds have been developed for the APM based UAV they include [34]:

- Mission Planner
- APM Planner
- Andropilot
- Droid Planner

2. METHODOLOGY
2.1 System Overview
The creation of the vehicle required the interaction between different hardware and software components. The vehicle for this project is divided into the following components, Frame and Propellers, the Autopilot and APM controller, the flight management system, the video receiver and transmitter and the GPS transmitter, Mission Planner and lastly Integration System and Monitoring System. The basic drone avionics architecture consisted of the Payload, Flight controller, Ground station, Sensors and the Actuators. The diagram below showed the basic avionic architecture of the drone.

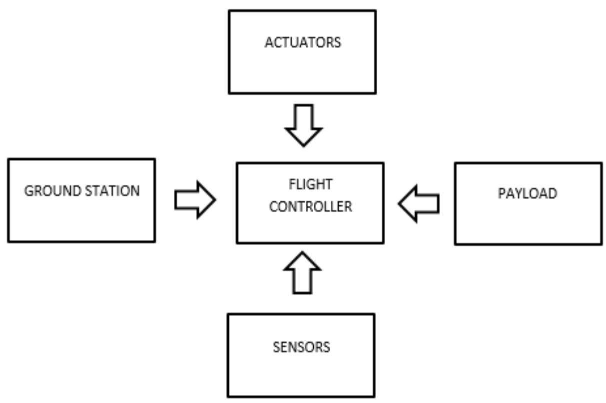

Fig.1: Basic avionics architecture of the system

2.2 System Components

2.2.1 Flight Computer/ aircraft control system

The flight control system is used to fly the UAV. The flight controller ensures the stabilization and control of the multirotor is attained, to this part a two-way radio for remote controlling and an onboard computer with GPS navigation was attached to the aircraft control system [31].

The APM 2.5 is a completely open source autopilot that allows the user to make any fixed, rotary wing or multirotor vehicle into an autonomous vehicle that is capable of performing programmed GPS missions with waypoints.

In APM 2.5, assembly need not be done since the board is already assembled, configured ready for firmware installation. Its underlying software is the Arduino Mega; it has several pins for different components that can be integrated into the APM 2.5 controller which includes the Receivers, the external GPS module, the USB control port, the input and Output pins, Power input pins and other auxiliary inputs and outputs. Most of these controls and inputs are not necessary for basic drone set up and only a few mandatory ones are needed for setting up a drone.

To set up a drone the power module is connected to the power supply LiPo battery, the Electronic speed controllers are connected to the Output pins, and the Input pins have are connected to the RC receivers. Finally, the Telemetry is attached to the telemetry pin, and the GPS receiver is properly connected to the GPS pin to receive accurate GPS fixes. When the Drone is in flight, turbulence and flight motion contributes to the shaking of the APM and thus to absorb the shock, shock absorbers that come with the APM are mounted. The APM is loaded with the Open source firmware that supports different vehicles types including Multicopters, helicopters, and rovers [18]. In order to set up the APM controller, the open source Mission Planner was downloaded, at the time of this writing it was v1.3.44 build 1.1.6240 11550.

2.2.2 Sensors

Some sensors are used to provide functionality such as maintaining flight without the intervention of human input.Sensing payload extends beyond intelligence collection and reconnaissance surveillance and target acquisition, the sensors are interfaced with microprocessors to allow UAV to fly complete missions autonomously [31].

2.2.3 Video Capture and transmission Component

For video capturing, RunCam camera module was used which is a configurable camera with high viewport and vision capabilities and configurations. More details about this camera can found on the manufacturer's manuals.

2.2.4 Integration API

The integration API consists of a REST webservice that was installed on tomcat 8 servlet container. And used MYSQL community database as the data store.

2.3 System Configuration

2.3.1 Firmware installation and configuration

- Power the APM (not necessary) since connection was via USB anyway
- Connect the APM to the PC via the USB cable see the highlighted section below.
- Click the initial setup Tab highlighted below.
- Select the install firmware on the left menu
- The vehicle type is selected in our case we used the Quadrotor ‘X’ configuration

This process can be done using the mission planner setup wizard.

2.3.2 Magnetometer and accelerometer calibrate

It is necessary to calibrate the magnetometer so that the vehicle knows which way its heading and which way its level.

To calibrate the magnetometer

- Connect to the Board
- Connect mission planner
- Select mandatory hardware
- Select frame type ‘X’
- Compass calibration, live calibration
- And move the apm in all axis in spherical motion to get data points

To Click the calibrate accelerometer

- Place APM level and press any key
- Place APM on its left click done
- Place the APM on its right side click done
- Place APM on nose down click done
- Place APM on nose up click done
- Place APM on its back click done

2.3.3 Radio receiver configuration

The APM inputs were connected to the RC Channels as shown in the Fig.2 below. Channel 5 was not connected to any inputs.

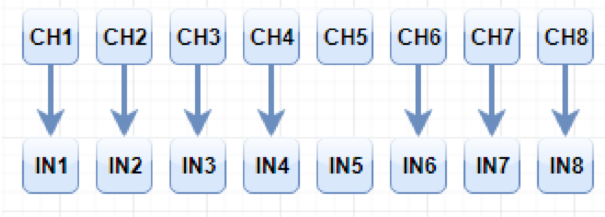

Fig. 2 APM inputs

Calibration of the RC channels

- Connect receiver to board
- Select radio calibration
- Click calibrate radio
- Move all the sticks to the extreme limits
- Click Done to save

Selection of the flight modes

- Click the flight modes
- Select mode using channel five
- Click save modes

2.3.4 ESC Calibration

The steps that are involved in the wiring calibrating the ESC are as follows:

STEP 1: Turn on the transmitter and set throttle to maximum

STEP 2: Plug in the Lipo battery, LEDs on the APM cycle through blue, yellow and red. This tells the APM that the next time we plug it in we want to do ESC calibration

STEP 3: Unplug the LiPo and then plug it in again still with the throttle high, First 3 beeps indicate that a 3S battery is attached.

STEP 4: Wait for the next beep indicating the ESC has captured the maximum throttle then pull the throttle low ESCs Long beep indicates that the calibration is complete

2.3.5 System Integration API

The System Integration API is used in linking the drone and the Rover and or with any other third-party systems or hardware. The integration API was developed in Java REST framework; the data exchange format was simple JSON instead of XML.The API architecture is as shown below in Fig 3. It was preferred to use REST over soap because REST was light compared to SOAP and the message exchange was the lightweight JavaScript Object Notation Object and hence optimize the performance. The communication from the drone to the API was via HTTP.The API was implemented using Java language and MySQL database community version and which is open source was used for data storage. The database was designed and the API was bundled as a war file using Gradle build tool which is also open source. The war file was then deployed to Tomcat application server.

The project structure for the API that was adopted was maven project structure which was used to develop our API and it conformed to the standard J2EE structure:

The API was developed using the MVC structure of model view and controller paradigm. The requests come via Resteasy main Dispatcher which was configured on the web.xml.

If a resource was found the request was routed to the appropriate handler on the API for execution before the result is returned. Hibernate was used as the ORM framework that abstracted the database operations for, below is a snippet of the above operation for inserting the data into the database.

```
public Location insertPhone (Location location) {
  try {
     em.getTransaction().begin();
     em.persist(location);
     em.getTransaction().commit();
  }catch(Exception e){
     log.error(e);
     em.getTransaction().rollback();
  }
  return location;
}
```

2.3.6 Ground Control Station

One Open source software that was used for configuring different vehicle types including rovers and aerial vehicles was called Mission Planner. This component is used in initial setup and configuration of the drone, copter or rover and setting up of the flight parameters. It is also used in setting up flight missions. [1] Mission planner is used for configuration and dynamic control supplement for the autonomous vehicle.

Mission planner was used to plan missions by setting up waypoints that were then loaded onto the APM 2.5 firmware, and this was used to guide the drone in a particular mission that it had to follow with the given waypoints. A waypoint is a position within the earth's surface and is comprised of the longitude and the latitude. After setting up a mission on a map, the waypoints were then written to the firmware. Mission planner was chosen for the ground station and Mission planning because of the ease of use and that it was open source and customizing was easy.

For Monitoring the drone, a combination of mission planner and a web portal that had been developed was used, this web portal was linked to the integration API, by frequently polling the API the web portal could display the position of the drone and the rover at any specific time, and it allowed the monitoring personnel to set up a mission on planned on receiving a distress signal from any vehicle that is in tracking mode and is visible on the map. Flight parameters could be read in real time in mission planner as well as the web portal; this is because the flight parameters are sent from the drone to the ground station in real-time via the RC frequencies.

The ground station consisted thus of the following:

- Video display unit
- Mission Planner
- API monitoring center

The autopilot was responsible for controlling the plane, but the ground station was the command center. The flight path that is configured and generated by the ground station is transmitted to the autopilot to follow. It allows interaction between the users and the aircraft and in specifying the flight path and tracking the movement of the plane. The APM uses the MAVlink protocol for communicating with the autopilot

2.3.7 System Assembly and Wiring

Several tools were used in the assembly and installation of the different components into the final product. Assembly of the drone entailed frame assembly, propeller mounting, ESC mounting, and calibration.APM 2.5 installation, SIK Radio mounting, GPS installation, Camera mounting and Video Transmission System installation and Power mounting. Server configuration and installation of server components and installing the app server were also done. Finally, API application installation was done.

F450 frame from DJI Innovations was used, more information can be found in the user manual. The frame and associated components were components together; these included the Bottom Board, Frame Arms. The motors were also attached to the frame and the propellers attached.

The below figure shows the Connection of the ESC to the power distribution board according to the DJI user manual; Fig. 3 below shows our ESC connected onto the board.

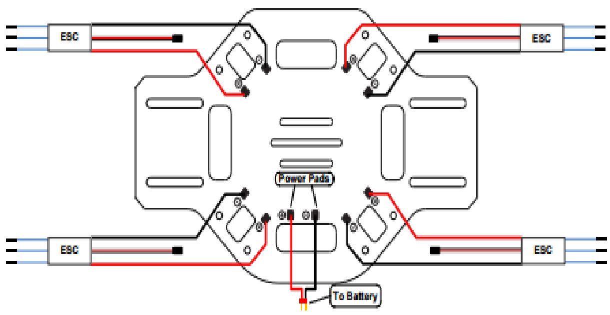

Fig. 3: ESC Wiring on the power distribution board

In total there are 4 ESC one for each motor. After the components are wired together including the mounting of the motors and the wiring of the ESCs, the next thing was to calibrate the ESCs.The DJI manual gives a step by step guide on the assembly of the whole system with diagrams to aid in the connections. Wiring the controller is also documented in the Ardupilot documentation.

3. RESULTS

3.1 Manual Flight Testing

For manual mode, the RC receiver was set to loiter flight mode and the propellers armed. The throttle was then raised higher, and the drone was gradually taking off as the thrust was getting higher. The drone attained an altitude of 25 meters, we lowered the throttle gradually, and the drone descended gradually until it safely touched the ground. Approximate wind speed was 10cm/s.The ascend to the safe altitude was seamless with no shaking, and no noise was detected. The GPS was able to lock quickly due to the clear sky. The Pitch was tested and initially, the vehicle was moving at 500cm/s. It was settled for 200cm/s which was better so that we could complete a flight without depleting the battery faster. During this initial test, the drone's weight was about 1.3 Kg.Manual flying was tested with additional payload, in this case, the camera was mounted, the telemetry, the RC receiver, the GPS modules and the Camera video transmission modules. When the copter was armed during this second scenario with the weather partially cloudy, the GPS was able to attain a fix, the flight was good both take off, in-flight and landing.

3.2 Manual Launch with Autonomous Flying

To trigger the autonomous mode, the copter was armed using the RC receiver and then switched to auto mode. The plane was able to take off successful and was able to follow the mission below that was planned for test and loaded onto the controller. The copter was armed without the payload the take-off was smooth without much payload. The cloudy weather was not a good scenario for the drone because the GPS fix could not be stable.

The copter was loaded with the other components, and then the mission loaded onto the APM 2.5, and then armed and autonomous mission triggered. The copter was able to take off successfully and hit the second-way point successfully, it took the course to the third way and successfully hit the waypoint. At this instance, the plane started jerking off, and it started climbing higher and higher it resumed its mission to completion and we attributed this unexpected behavior to the addition of more weight and the high power demand by the additional electronic components that were added onto the vehicle and a partial loss of the GPS signal.

3.3 Live video streaming

The link between the on Board camera was tested and the transmitter was able to send the video signals to the ground monitoring and display device. The video clarity was excellent, and we used Channel 8 from the receiver to get clear video stream. The delay was negligible, and the objects on display were identifiable, the stream had little noise, and angle of coverage was 145 degrees. The camera was stationary, a gymble was not used for mounting the camera, so the position was fixed on the drone and not movable. In some advanced configurations, the camera is normally fixed to a gymble and wired onto the APM auxiliary channel hence allow the motion of the camera from the ground station.

3.4 Integration API

The motion of the drone changes the position in real-time, and this has to be recorded in addition to other parameters that were gathered during flight. These flight parameters and the location of the drone were submitted to a central system for integration to other systems. The central monitoring system assisted in tracking the drone in real-time and locating any other vehicle that has been configured on to communicate to the API.

4. DISCUSSIONS

4.1 Flight Analysis

The tests focused mainly on the planes ability to fly and to maintain stability while in flight. The results showed that the drone needed much throttle to take off, and the take-off was done manually using the RC Turnigy radio transmitter. It was also noted that some propellers were not rotating unless the throttle was increased. The first test that was done showed that the plane was able to rise gradually at a slow speed of approximately 15 cm/s.In the first test the camera modules, RC transmitters, and the receivers were not mounted. This led to recalibration of the ESCs' before doing the next test.The "All at once" method was used to calibrate the ESCs' and resumed the tests. In all the tests that were done the weather was calm, hence the reason the plane was stable on its flight to the altitude. At 30 meters the plane was stable, and we tested the yaw and noted that the plane had very little forward thrust, the roll was good. The factors that affect the flight performance include the weather conditions, the controller and the overall weight of the system. The drone can fail to fly as a result of a combination of any of these factors or all of these factors.

4.2 Weight and Power

Another factor that affected flight performance was the weight and the power, the power of the drone is supplied by the propeller and due to the high power consumption due to the various components that were using the LIPO battery, and the overall system thrust is reduced. Drones with higher power-to-weight ratio have payload capacity meaning they can carry more. Heavier drones impact the power that is required to carry the payload, and this pays off in flight duration possibilities. This means upgrading the battery, but heavy battery means the payload that can be carried is reduced. The lift is a key factor here, drones of the same mass but one which has large rotors and another one with small rotors, the drone that has large rotors will create more air thrust using the same power with the airflow being slower than the one that is generated by the small rotor drone.

The Centre of gravity of the vehicle was also a key factor in ensuring the performance of the plane was optimal. According to the flight observation the plane's COG was okay, the components were arranged aligning them to the center of the vehicle so that the COG was at the center, and the benefit of this was that the propellers would have uniform rpms since no extra power was needed while the load was evenly distributed among the four propellers. The frame was made of plastic and hence the weight due to the frame alone was not an issue.

4.3 Video streaming

The link between the on Board camera and was tested and the transmitter was able to send the video signals to the ground monitoring device. The slight noise that was observed on the display monitor was likely due to noise because of the interference between the RC and telemetry that were mounted on the drone. The other reason was that of the power fluctuations caused by the low capacity battery that also at a point became overused and this led to the overheating and caused one connection to melt.

The drone vibration also was a contributing factor in the noise that was observed because the camera was not dumped and hence the shaking which led to some noise on the video that was observed. The quality of the identified object was not tampered with since it was still possible to identify a person on the ground even while the person or object was in motion. The video was streamed, but it could not be able to save the footage for future reference, and that was because of the type of camera that was used, It was still be possible to save the video but it was necessary to mount another camera with the ability to record to an external memory or stream to a server which can be able to save the footage for future reference.

4.4 GPRS and Data transmission API

Mobile network was used to send the data to the central system integration API, and the data was sent using GPRS, and AT commands were used in our code to initiate the transmission, some delays put to allow the network to connect and then initiate session before transmitting the data. This led to a delay before the device could actually send the data to the API. The network that was used was 2G, 3G and 4G failed to initiate a session so old Sim card for Safaricom and Orange networks are the ones that were used because they were able to connect. The data transmission was done using the HTTP GET method where parameters were appended to the API endpoint and then initiated the GET method with the real-time data

4.5 Database and Persistence

The data was persisted to a MySQL database and the persistence framework we used was Hibernate a java framework that abstract the database for us. The app was multithreaded and concurrent queries could be done the performance was good for the tests that were done.

4.6 Weather conditions

On Hot days it is advisable to plan for short flights and longer downtimes between the flights. This is because the motors will need to work harder in hotter environments in generating lift which in turn causes shorter flight times. The heat generated could potentially cause overheating leading to the melting of the wires in some cases. The downtimes during the hotter weather conditions allows the electronic components time to cool down allowing for more stable temperatures

During cold weather, the flights should be shorter while the battery is monitored, this is because the efficiency of the LiPo battery decreases. The likelihood of the battery voltage dropping below the critical level is high and this could lead to cutting off the ESC and motors.

Drones should not be flown on rainy, snowy or sleet conditions. Planning in advance helps in worst-case scenarios, precipitation probability, and intensity should be used in this case to help with planning.

Flying drones in fog conditions are not advisable because the visibility of the drone is hindered. It is usually important to fly the drone while it is visible from the ground station. Visibility index should be used in determining the occurrence of fog on a given day. If the visibility is below 0.5 miles then there is a likelihood of fog occurring. According to the current FAA laws, it is prohibited from flying a drone Beyond Visual Line of Sight (BVLOS).

Humidity values of close to 1 imply that the drone will get wet. It will also affect the equipment in the long-term. During high-speed winds the aircraft finds difficulty in holding and maintaining its position, this results in shorter flight times, difficult maneuvering and inaccurate position hold. Flying the drone in gusts that exceed the drone's top speed could lead to losing control of the drone. During the cloudy weather, the challenge that the drone was having was the loss of GPS fix, this led to fly away scenarios in which the drone climbed to a higher altitude and almost not return, but luckily we had set the failsafe so that the copter could land in case it lost its GPS signal. On a clear sky, the drone was able to fly safely and it completed the mission without any issue or glitch. It was able to complete the mission successfully and the stability of the plane was good. The drone stayed at the set altitude throughout the mission. On a windy day, the copter had a considerable sway especially after losing its GPS and on the addition of the extra load. We could not accurately determine the speed of the wind.

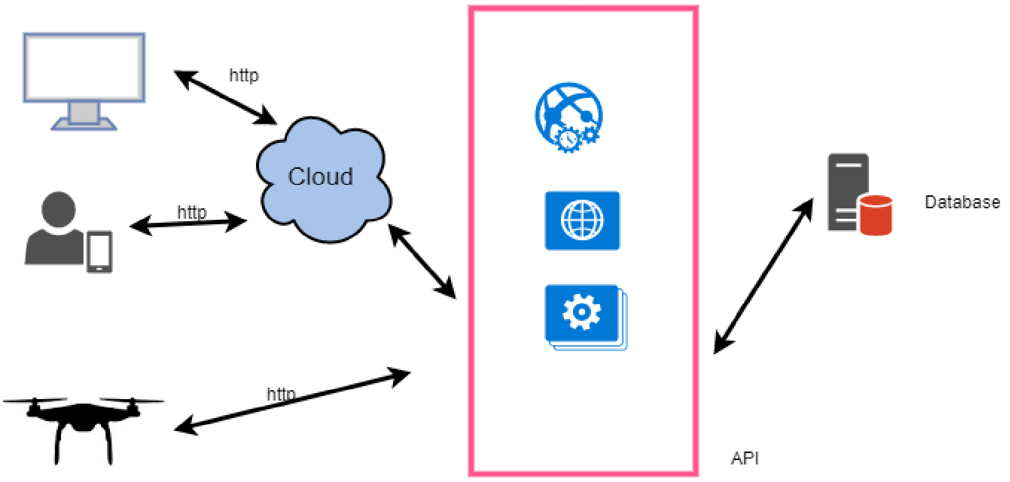

Fig. 4 Integration API component architecture

Fig. 5 Mission planning on mission planner

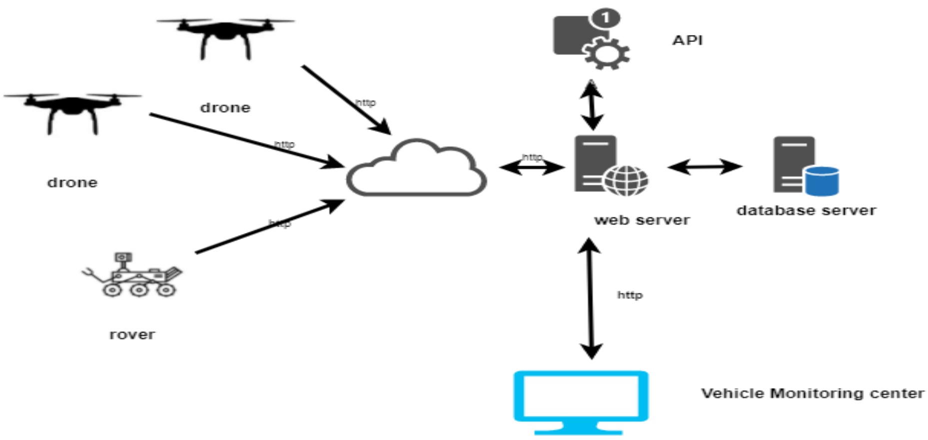

Fig. 6 Integration API and Interaction to Drones and Rovers

5. CONCLUSION

5.1 Achievements

The project objectives have been met, a system prototype was successfully developed and it did unmanned aerial security surveillance, the objective was thus successfully achieved, a research on available UAVs and their applications was also done successfully. Further the model for the system was developed and thorough experiments done on the prototype that was developed. An evaluation and analysis were done on the developed prototype. The prototype was able to fly in auto mode while it streamed the video to the display unit. The system was integrated to the central monitoring API.

5.2 Failures

While attaining the system objectives, the failures in battery power due to the high power consumption of the components led to the addition of a heavy battery and this prevented the successful mission on subsequent tests.4G sim card also could not function properly and hence hindering the integration of the rest API.

5.3 Future work

Improvement on battery power in terms of weight and capacity is an area that can be researched to come up with powerful long-lasting batteries and yet light ones. A look into incorporating charging modules like solar panels so that the vehicles can have long duration and range while on air. Of importance is the research on the payload capacity with regard to speed and uplift. These are areas that are of importance for further research on the areas of unmanned vehicles

6. ACKNOWLEDGMENTS

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