OPEN SOURCE AND MODULAR AUTONOMOUS DRONE AS AN ARTIFICIAL INTELLIGENCE RESEARCH AND EDUCATION PLATFORM

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Abstract

This paper presents customized quadrotor helicopter as an open source and modular autonomous drone development platform for aerial informatics research and education. Apart from description of hardware and software involved, we focus on several issues regarding drone equipment, human drone interaction and its abilities.

We showed, how to perform basic drone tasks using voice recognition and natural language processing. And also more advanced capabilities such as autonomous navigation based on GPS, object identification, pedestrian detection, human detection using HOG algorithm with SVM classifier, 3D scanning for detecting forest illegal logging by processing captured images as ortho photos and analyze them using Google Earth Engine explorer, for training and classification. In this project, we developed drone with various sensors like, ultrasonic sensor for obstacle avoidance, humidity and temperature sensors for calculating the respective measures, barometer sensor for measuring altitude. We developed the drone that will fly both in indoor and outdoor environments. We also introduce companion computers to be used together with drone's flight controller to allow researchers and students to implement more advanced abilities.

Index Terms – autonomous drone, voice recognition, ultrasonic sensors, 3D scanning

1. INTRODUCTION

Unmanned aerial vehicles (UAV) or commonly known as drone is an aircraft without human pilot aboard and typically controlled remotely via radio link. Since there is no presence of human pilot in these aircrafts, usually it is also monitored using ground station application. Today these drones can fly autonomously with none or little human intervention. Autonomous drones are really helpful in many fields such as army forces, logistics, farm lands, media coverage, site exploration and surveillance. So building an autonomous drone can saves manpower, reduce labor cost and increase productivity especially in difficult locations.

Quadrotor helicopter or quadcopter has been an interesting research subject due to its control challenges and performs acrobatics flying demonstrations. This paper discusses smaller scale (less than 4 kg) quadcopter or micro-aerial vehicles (MAVs) equipped with several sensory equipment and a companion computer. This research area has been growing rapidly in the past years with some significant progress has been made such as high speed maneuvers, autonomous navigation for both indoor and outdoor environment. Due to its size constraint, MAVs have limited payloads to carry sensory equipment, computation power needed to perform artificial intelligence abilities such as obstacle avoidance.

In this paper, we present two intelligent aspects, an autonomous navigation system and its functions. We have various sensors installed such as temperature sensor, humidity sensor and ultrasonic sensor. We also have an android mobile application to interact with quadcopter and displaying sensor data. We present autonomous drone which receive commands from an mobile app and the response are sent back the app display in some cases. The mobile application can also be used to control the drone remotely via wifi.

2. MOTIVATION AND SCOPE

Autonomous aerial vehicle or drone research has been getting very popular since past decades. Unlike helicopters, it comes with multi rotors which makes it more stable but also can be acrobatic. Since drone has many useful applications, it is very compelling to build an autonomous drone with intelligent capabilities.

Many tech giants such as Microsoft and Amazon has stepped into autonomous drone research since past years. Microsoft has development group of aerial informatics and robotics platform which aim to standardize how artificial intelligence agents should operate in the real world, they have developed and share open source system to train autonomous drone. Also at Amazon Prime Air has developed drone to deliver consumer products although currently is still being tested intensively, but it is definitely a big potential for future transportation.

Usually drone mission and navigation is planned from ground station, navigation path is built using waypoint settings to set different location pinpoints which user specifies.This has been really useful in many outdoor operations such as surveillance, dropping payloads, executing task for example in agriculture for sowing seeds or spraying pesticides and even find missing cattle and sheep in an area of interest. They are also being used by insurance companies for inspecting damage to buildings.

With Waypoint GPS navigation, a site can be surveyed at the correct locations. The drone can fly directly to each specified location while the pilot on the ground concentrates on operating the camera to take aerial photographs of video. The drone takes the shortest route to each waypoint saving battery and filming time.

The advancement of drones to deliver parcels will very much require even more advanced waypoint technology. The costs of having a pilot for every drone delivering parcels would be expensive. But if drones are preconfigured with their destination waypoints to deliver parcels, they can go straight to the location and then to the next location taking the shortest route possible.

2.1 Objectives

The overall objective of this paper is to build an intelligent, user-friendly, personal assistant drone. Currently, besides of getting temperature and humidity data, we aim for a drone also have below capabilities as well:

1) Outdoor autonomous navigation based on waypoint settings and GPS data
2) Indoor autonomous navigation based on ultrasonic sensors and camera for obstacle avoidance.
3) High resolution camera to capture images and videos and use them for 3D scanning large object.
4) Human detection using companion computer and camera installed in drone for indoor navigation human obstacle avoidance
5) Cooperative controls with android smartphone device built-in IMU sensors.
6) Forest illegal logging activity detection

2.2 Scope

Personal Drones have been all the rage for the past few years, as toys, and primarily as new devices for capturing amazing aerial photography. As the technology has matured and become more mainstream, a number of practical and very interesting uses of Drone technology have emerged.

- *Real estate* : Personal drones or quadcopters are used by real estate agents as a marketing tool for selling homes. Using Quadcopters for 3D scanning, agents can now film the video of difficult to see elements of a home to demonstrate more vividly the scenic view surrounding landscapes of a home and even visually show the proximity of the home to neighboring homes, pools, tennis courts, and playgrounds. As a result, use of quadcopters in real estate marketing is exploding and many photographers are being hired by agents do to their specialized skills in aerial photography of homes, a new an emerging job market.
- *Aircraft Inspections* : EasyJet was the pioneer for this new use of Drone technology. Airlines are evaluating quadcopters equipped with high definition cameras to speed up this process. The quads can fly all around the planes, taking HD photos and videos that the engineer can then review them instead of physically having to inspect the plane.
- *Search/Rescue Missions* : Like full-size aircraft, they can carry High Definition cameras, and even thermal imaging equipment to help find people and animals. Recently, due to the extreme flooding in Texas, Drone use for search and rescue

received a great deal of media attention as quadcopters were used to search for flood victims. Many organisations like American Red Cross are interested in using drones for disaster relief efforts.

- *Construction/Surveying* : Some companies are even using quadcopters to capture aerial views of constructions sites and using them to compare the 3D modeling done by the architect. They are used in surveying, inspections, showing clients an aerial view of construction status, monitoring of employees and also in surveillance.
- *Mining* : To help and keep employees safe in mines, drones are also being used to inspect for dangerous areas such as pit walls and mine entrances, especially when the area is known to be dangerous and considered unsafe for mine workers. Drones are also used for mapping and modeling, similar to other constructions jobs.
- *Product/Food Delivery* : One of the innovative uses for drones that quickly received a lot of media attention was product and food delivery via drones. Major companies like Amazon, FedEx, DHL, and Dominos are exploring the use of Drones for local delivery of their products. Amazon has gone so far as to patent their technology and Dominos actually delivered two real pizzas in the UK using their Domidrone. A big challenge for companies right now is Federal Aviation Administration (FAA) restrictions on the commercial use of Drones. The FAA is working on revised guidelines that are due out in the year 2015. Until then, drones for product delivery are just experimental.
- *Explore Lava Lakes* : Studying volcanoes is difficult to do because of the extreme temperatures and toxic gases. Heat suits have solved a large portion of this problem, but they are li. Drones have been recently used to take aerial photography and air samples of various volcanoes around the world. This has allowed scientists to get additional data, and also to create virtual models of the volcano's craters. Virtual models allow scientists to study changes over time in the crater, which assist with predicting eruptions.
- *Disease Prevention* : Microsoft is experimenting with using drones for medical purposes. Drones are equipped with bug collection device and then flown around outdoors in various areas of interest. The Drone returns with the collected bugs which are then used by scientists for analysis. The Analysis is then used to predict outbreaks for local areas. In this way, scientists could publish warnings to people living in high risk and/or remote areas of possible Malaria and other life threatening diseases.

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3. LITERATURE REVIEW

3.1 Waypoint Navigation

Autonomous waypoint Navigation using GPS and Atmega328p on-board controller are used to develop and test the low cost waypoint navigation system [1]. The coordinates of the pre-defined flight path are fed to the microcontroller. Using the Haversine formula, the distance between the current position obtained from the GPS and the first waypoint are calculated. Once the distance is calculated, we can calculate the time duration of flight by fixing the reference velocity to the quadcopter. Similarly, the same can be calculated for succeeding waypoints as well as to perform return to home operation. From the calculated values ,the Pulse Width Modulated signal is generated by the controller which controls the quadrotor attitude.

The Virtual-Waypoint Based Artificial Potential Field Method for UAV Path Planning [2], Artificial potential field method is used which is known for path planning and for its advantages of the concise mathematical description, the convenience for real-time control and the simple algorithm structure. It also has a strong portability. By changing the source of the artificial potential field, it can solve the obstacles avoidance problem and terrain avoidance of the multi-agent system.

The path planning result of artificial potential field is achieved by two forces. One is attraction generated by the target point and tends to pull the UAV to the target point. The other force is repulsion generated by threat sources and makes the UAV to keep away from the threats. Hence, the UAV moves in the direction of resultant force. But, the problem of Goal Unreachable with Obstacle Nearby (GNRON) arises when the planning point falls into local minimum area. Researchers put forward different potential functions considering the GNRON [2].

They proposed the model based on virtual waypoint that will introduce additional force. Once getting into local minimum, the UAV will compute the measure factor for the current planning area between the planning point and the target point. Based on the measure factor, virtual waypoint will be placed and generates additional force that breaks the force balance of minimum points, thus continue path planning.

Autonomous Avoidance Technique based on the Waypoint Optimization Algorithm [3]. Autonomous obstacle avoidance technology which usually includes obstacle detection and flight planning. Obstacle detection needs optical sensors to obtain the vehicle position, shape and speed. The flight planning need to carry out an online trajectory planning and guidance based on the detection results.

They focused on the multiple waypoints optimization algorithm based on optimal feedback guidance method for autonomous obstacle avoidance. Therefore, the obstacle avoidance problem is transformed into a navigation point constraints problem and derived with the specific waypoints constraint expressions to realize autonomous obstacle avoidance process. From the simulation results, it is proven that this method can effectively avoid the obstacles and meet the flight height constraints and angle constraints to achieve a safe landing.

3.2 3D Scanning

According to [10], Integrated three-dimensional laser scanning and autonomous drone surface-photogrammetry at gomantong caves, The caves were mapped to the overlying land surface with unprecedented precision, by integrating aerial photogrammetry using an autonomous drone. Three-dimensional cave scanning at millimeter resolution was performed using a FARO Focus3D instrument, generally at ¼ resolution mode, with additional scans at full resolution where required for specific geomorphological analyses. Data processing was done with Faro Scene software. By differentially corrected geodetic GPS, the integration of terrestrial LiDAR scanning with conventional cave cartography has enabled to generate cave plans with centimeter precision and which allow these biogenic features to be quantified for the first time.

And by conventional compass-based cave surveying techniques, the cave was also surveyed using conventional compass based survey techniques with a Suunto KB-14/360R compass, a Bosch DNM 6 digital inclinometer custom-fitted with a laser pointer (±0.1 degree precision), and a Leica Disto. These data provide exceptional insights into the interplay of biology and geomorphology, with direct benefits for sustainable management planning.

3.3 Video Stabilization

Regarding the video stabilization, local feature descriptor is one of the most important elements [19]. The jittery frames include horizontal movement, vertical movement, rotation, and the combination of all the jitters. The jitters in the videos can distort the spatio-temporal volumes, trajectories, or features. Those jitters can be removed from the videos by using video stabilization technologies. Video stabilization falls into two types: hardware-based stabilization during recording and software-based, post-processing digital video stabilization [20]. The Post-processing digital video stabilization is defined as “the process of removing the unwanted motion from input video sequence by appropriately warping the images” [21].

One of the local feature descriptors, ORB is a combination of FAST (Features from Accelerated Segment Test) corner detector [22] and BRIEF (Binary Robust Independent Elementary Features) descriptors. If the sharpness of overlaid stabilized images used as a metric to measure stabilization performance, SURF descriptor performed best, followed by SIFT descriptor [23].

3.4 Ultrasonic sensors for distance measurement

The main reasons for the usage of US sensors are that they are quite compact and lightweight, give high accuracy and sensitivity detecting objects compared to other sensors like the IR sensors which fail in case of certain surfaces, light changes etc. as stated in [25]. The reflection of the sound waves back indicate presence of an obstacle and the time taken to send and receive this signal is the distance calculated between the user or the surface on which the sensor is attached and the obstacle in front. The US sensor sends a pulse duration to the Arduino board, which converts this into distance values and sends it to the PC/smartphone through USB. The calculated data from the US sensor needs to be sent to OpenCV for which a communication with Arduino board from OpenCV has to be established. This is done using the Arduino package for OpenCV. absence of objects correctly classified as negative using MOG algorithm is higher for the indoor captured images. But images captured outdoor were correctly classified as negative using the Canny's algorithm.

3.5 Barometer for measuring altitude

Altitude regulation is a fundamental control problem of quadrotor UAVs (unmanned aerial vehicles) to ensure required performance for hovering and autonomous navigation [12]. There have been a number of successful indoor applications [13], [14] where the localization of aircraft can be done easily by mounting a variation of sensors on-board and in environment [15]. However, many challenges remained in their outdoor applications in unknown and dynamic environments. Vision servo based approaches proposed in heavily depend on the ground station computation power and therefore quadrotors are constrained in limited ranges. Learning based control algorithms [16] can hardly be employed in unfamiliar environments since they rely on repeated training. Hence control algorithms such as classical PID controller, back-steping [15], slide-modeling [17] are still playing major roles in development. One problem in outdoor applications, among many, is the observation of translation velocity due to the fact there is no on-board sensor available for its direct measurement. Although, in theory, it can be deduced from acceleration and position measurement by differential and integration, but as the low cost sensors, such as MEMs based barometer and sonar, suffered from severe drift and noise, make the estimates obtained unfeasible in practice. The attempts on this regard has been made by many researchers [18] by means of applying Kalman filter based techniques.

4. EXISTING WORK DONE

4.1 Structure of the UAV

Following our vision of rapid prototyping, we selected lightweight glass fiber quadcopter frame with landing gear and built-in power distribution board. The decision has been go through three steps design processes wherein we first determine required payloads including frames, motors, flight controller, companion computer, camera and battery. Then based on total payloads we determine required electronic speed controller, motors power and propellers size and finally decide which frame size and model can be purchased.

Ideally, a quadcopter should have a thrust-to-weight ratio of at least 2:1. A thrust-to-weight ratio of 1:1 indicates the quadcopter is hovering. This is what we'll use as a basis in our calculations, as hovering gives us a good reference point.

DC motors perform most optimally when they are producing the greatest mechanical power. They output maximum power at a point where the motor's rotational speed is half of its maximum rotational speed.

To find the motor's maximum rotational speed, we take its listed RPM, and multiply by the battery's maximum voltage.

$$1100\ rpm/V \ * \ 11.1V \ = \ 12,210\ rpm$$

Hence, the rpm where maximum power is output by the motor is at half of this value:

$$12210\ rpm\ /\ 2 \ = \ 6105\ rpm$$

However, this gives us the scenario where we are using the battery's maximum voltage. Since we want to examine the case where the quadcopter is hovering, the voltage at the hovering point should be half of the max voltage. Hence we divide again by 2:

$$6105\ rpm\ /\ 2 \ = \ 3052\ rpm$$

The full step done above is demonstrated by this equation:

$$rpm_{\max Power} = \frac{Kv * 0.5 * Battery\_Volts}{2} \qquad (8)$$

So, we have found that for the motor to be most effective while hovering, it is spinning at 3,052 rpm.

When we attach the propellers to the motor, they will spin at the same rpm as the motors.

Next, we look at the propellers and how they are affected by rpm, and how they convert this to thrust.

To start, we have two equations:

$$Power = Prop\ Const\ {*}rpm^{Power\ factor} \qquad (1)$$

(where rpm is in *thousands*)

And

$$T = \frac{\pi}{4} D^2 \rho v \Delta v \qquad (2)$$

T=thrust [N]
D=propeller diameter [m]
v=velocity of air at the propeller [m/s]
Δv=velocity of air accelerated by propeller [m/s]
ρ = density of air [1.225 kg/m³]

Equation **(1)** makes use of a propellor constant and a power factor, which are dependent specifically on the dimensions of the propellor used. This information could be found in a data table, such as this one:

https://www.aircraft-world.com/Datasheet/en/hp/emeter/hp-propconstants.htm

Prop Size	PROP CONSTANTS	POWER FACTOR
7*4	0.028	3.30
7*5	0.028	3.40
7*6	0.039	3.40
8*3.8	0.045	3.40
8*6	0.087	3.40
9*3.8	0.048	3.55
9*4.7	0.146	3.00
9*6	0.119	3.55
9*7.5	0.204	3.40
10*3.8	0.136	3.40
10*4.7	0.187	3.30
10*7	0.337	3.30
11*3.8	0.183	3.40
11*4.7	0.283	3.30
11*7	0.398	3.40
12*3.8	0.230	3.60
12*6	0.629	3.30

Equation 1 gives us the power of the propellor given a certain rpm. So we plug in the propellor constants and power factor to get:

$$P = 0.187 * 3.052^{3.30}$$

$$P = 7.429\ W$$

Next, we use the second equation to relate the propellor power to thrust.

$$T = \frac{\pi}{4} D^2 \rho v \Delta v \qquad (2)$$

T=thrust [N]
D=propeller diameter [m]
v=velocity of air at the propeller [m/s]
Δv=velocity of air accelerated by propeller [m/s]
ρ = density of air [1.225 kg/m³]

A commonly used rule is that velocity of the air at the propeller is v=½Δv of the total change in air velocity: Therefore, and equation 3 is derived.

$$T = \frac{\pi}{8} D^2 \rho (\Delta v)^2 \qquad (3)$$

Equation 4 gives the power that is absorbed by the propeller from the motor. Equation 5 shows the result of solving equation 4 for Δv and substituting it into equation 3. In doing so, Δv is eliminated and torque can be calculated.

$$P = \frac{T \Delta v}{2} \Rightarrow \Delta v = \frac{2P}{T} \qquad (4)$$

$$T = \left[\frac{\pi}{2} D^2 \rho P^2 \right]^{1/3} \qquad (5)$$

Hence, we can now see how the propeller's power is related to the thrust it generates.
By using the following values:

D = 25.4cm
ρ = 1.225 kg/m^3
P = 7.429

We get thrust $T = 1.89\,N$.
With four propellers, the total thrust is 7.56N.
Since thrust describes force (F=ma), we can simply divide by the gravitational constant g = 9.81 ms^-2 to obtain the mass it could support while hovering.

This is equivalent to about 0.77kg in total. This would be the ideal weight of the drone based on the parts we have selected and we summarize our UAV structure as below:

- Motors : 4x28mm 1100 KV
- Height : 170mm
- Weight : 405g (frame only)
- Propellers : 4x10 inch (CW & CCW)
- Electronic speed controllers : 4x30A
- Battery : 1x3700 mah 3S 11.1 V LiPo
- Pixhawk flight controller
- GPS module with compass Ublox 7N

4.2 Open source platform

Our drone uses open hardware and software for flexibility and community support. The actuators for all drone movements are in Pixhawk flight controller integrated with electronic speed controllers and motors, and a companion computer Raspberry Pi which we use to integrate various sensors. We use Python as development tool and also Drone-kit Python SDK to build our own drone application, server side websocket based application in RPi and an android based mobile application for user interaction. All components were assembled ourself using

Pixhawk flight controller

Pixhawk is an independent, open-hardware project aiming at providing high-end autopilot hardware to the academic, hobby and industrial communities at low costs and high availability. It provides hardware for the Linux Foundation DroneCode project. It originated from the PIXHAWK Project of the Computer Vision and Geometry Lab of ETH Zurich (Swiss Federal Institute of Technology) and Autonomous Systems Lab as well from a number of excellent individuals (Contact and Credits).

The Pixhawk autopilot module runs a very efficient real-time operating system (RTOS), which provides a POSIX-style environment (i.e. printf(), pthreads, /dev/ttyS1, open(), write(), poll(), ioctl(), etc). The software can be updated with an USB bootloader. It supports multiple flight stacks: PX4 and APM.

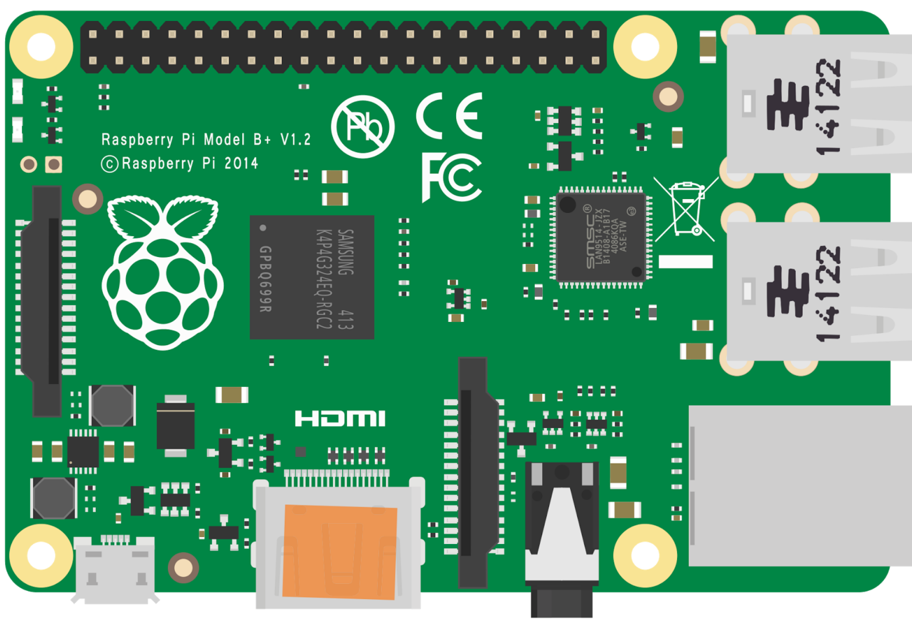
Key Features

- 168 MHz / 252 MIPS Cortex-M4F
- 14 PWM / Servo outputs (8 with failsafe and manual override, 6 auxiliary, high-power compatible)

- Abundant connectivity options for additional peripherals (UART, I2C, CAN)
- Integrated backup system for in-flight recovery and manual override with dedicated processor and stand-alone power supply (fixed-wing use)
- Backup system integrates mixing, providing consistent
- Redundant power supply inputs and automatic failover
- External safety switch
- Multicolor LED main visual indicator
- High-power, multi-tone piezo audio indicator
- microSD card for high-rate logging over extended periods of time

Raspberry Pi 3 B

- Raspberrry pi is a series of small single board computers which is mainly used for computation and to add peripherals to the drone. We have the following peripherals connected to it.
    - Camera module
    - Integrated WIFI
    - Sensors : 1x temperature, 1x humidity and 4x ultrasonic (left, right, front and bottom)



*fig(ii).*Raspberry Pi 3 B board

PiAnywhere 4G + LTE

- Pianywhere is 4G & LTE module with GPS. It provides internet connectivity and can extend control range of the drone system more than what normal drone system can do and make the drone accessible within the 4G network.

- 4G (100mbps down/ 50mbps up) – Ultra fast internet connectivity for your raspberry pi, excellent for large downloads and video streaming.

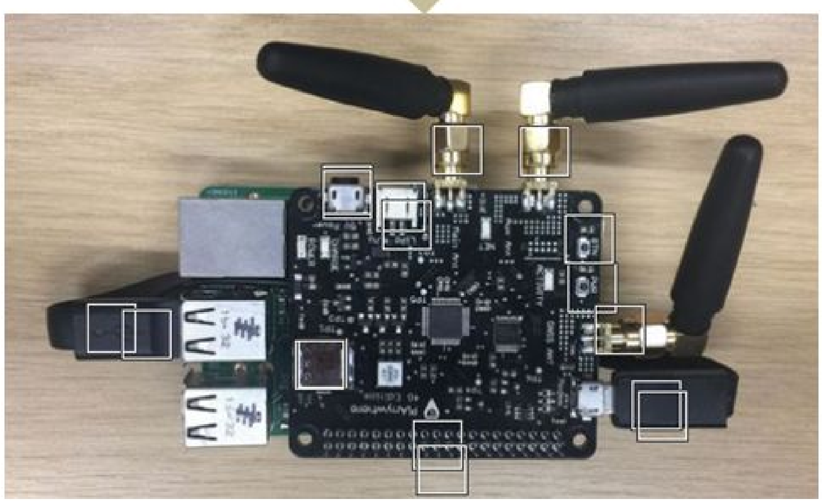
- The Pi Anywhere 4G & LTE Hat for the Raspberry Pi Beta provides 4G mobile data for the Raspberry Pi mini computer. Our intelligent HAT module provides your Raspberry Pi with mobile data, GPS positioning information and battery support. This is the perfect module for hackers, scientists, and creators as it gives your Pi powerful connectivity wherever you are. Simple plug out module into your Raspberry Pi and start playing.

- The HAT can integrate easily with the software on your operating system giving you access to general internet data through the mobile network. Using our API this hat gives you the ability to send SMS (text) messages. We also give easy access to the GPS onboard which exposes location data.

HAT Features

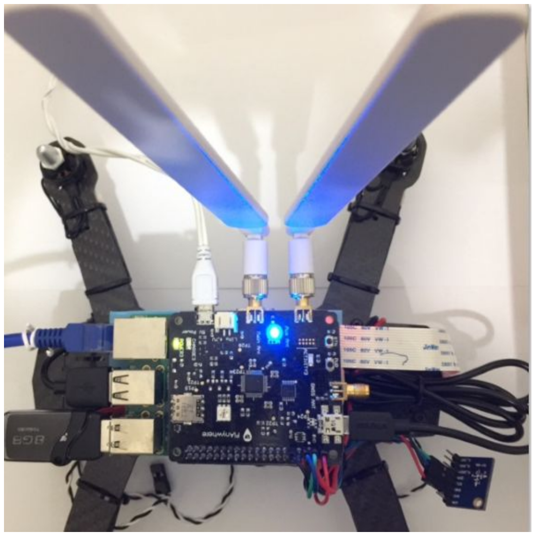
- Supports any nano sim. Slot your sim card in and get going
- 4G Mobile Data for the Raspberry Pi
- Easy set-up, with a single terminal command setup our software to streamline Pi Anywhere with your Raspberry Pi.
- Wake up your Pi or trigger events with text messages.
- Optional external antenna for better reception.
- High-efficiency power regulation up to 3 amps.

Pianywhere Hardware Setup with Raspberry Pi



*fig(iii).*Pianywhere with Raspberrypi

We decided to install enhanced antennas on Pianywhere for better reception of signal.



*fig(iv).*Pianywhere with enhanced antennas

Pianywhere Easy Setup

To use turn on the PiAnywhere by plugging in the power cable to the USB port labelled 5V Power. Next, we press the button marked btn to turn on the modem. We then connect the other USB port to the raspberry pi and finally turn on the raspberry pi by pressing the pwr button.

Also, you can use PiAnywhere on a windows system. All you have to do is use these drivers and install them: https://drive.google.com/file/d/0B4StAjolU_LeVjRx…

The PiAnywhere has the GPS feature, but it needs to be activated. First minicom needs to be installed in order to test the GPS. This is done by using the following command:
$sudo apt-get install minicom

This is a terminal that operates in the command window, enter the minicom terminal using:
minicom –D /dev/ttyUSB2

In order to operate the minicom press CTRL+A and then Z, this will show all the different options that can be used. The echo local will need to be enabled. This is done by pressing CTRL+A then E. Once this is enabled you can enable the GPS this is done by typing inside the minicom terminal:
AT+CGPS=1
It will show a message of Ok!
The to get the information of the GPS location use the following command:
AT+CGPSINFO

Software Requirement:

- Raspbian OS
- Ardupilot
- Dronekit
- Python 3.5+
- Node.js
- Android SDK
- SpaCY Natural Language Processing for Python

Capabilities of a drone:

Here are the basic and enhanced capabilities of our drone.

Basic capabilities:

- The basic movements of the drone are up, down, left, right, forward and backward.
- Drone can be started only by its owner (via smartphone).
- Drone can be controlled with voice recognition (via smartphone).
    - It can be basic movements with natural language.
- Drone is equipped with camera and able to capture images and videos.
- Drone has GPS equipped for location awareness. So it must be aware of the location during flight.
- As drone is controlled via smartphones, there are apps in smartphones to do the following functions:
    - Movement controls
    - Change flight mode
    - Drone waypoint setting
    - Sensors reading

Enhanced capabilities:

- Auto Pilot:
    - Stabilize, Alt Hold, Loiter, RTL, Auto, Acro, AutoTune, Brake, Circle, Drift, Guided, Guided_NoGPS, Land, PosHold, Sport, Throw, Follow Me, Simple, Super Simple
- Sensors Integration:
    - Temperature
    - Humidity
    - Ultrasonic (obstacle detection)
- 3D scan flight mode
- Machine Learning:
    - Human/Face detection

- Indoor navigation at hallways

4.3 Waypoint navigation

“Waypoint” is nothing but a reference point in physical space. Waypoint GPS Navigation allows a drone to fly on its own with it’s flying destination or points pre-planned and configured into the drone mobile android application. This instructs the drone where to fly; at what height; the speed to fly at and it can also be configured to hover at each waypoint. It is basically a route and destination planner for the drone.

We use the waypoint feature in pixhawk flight controller to navigate along a desired path.There are certain steps to be followed to use the waypoint feature.

Absolute altitude

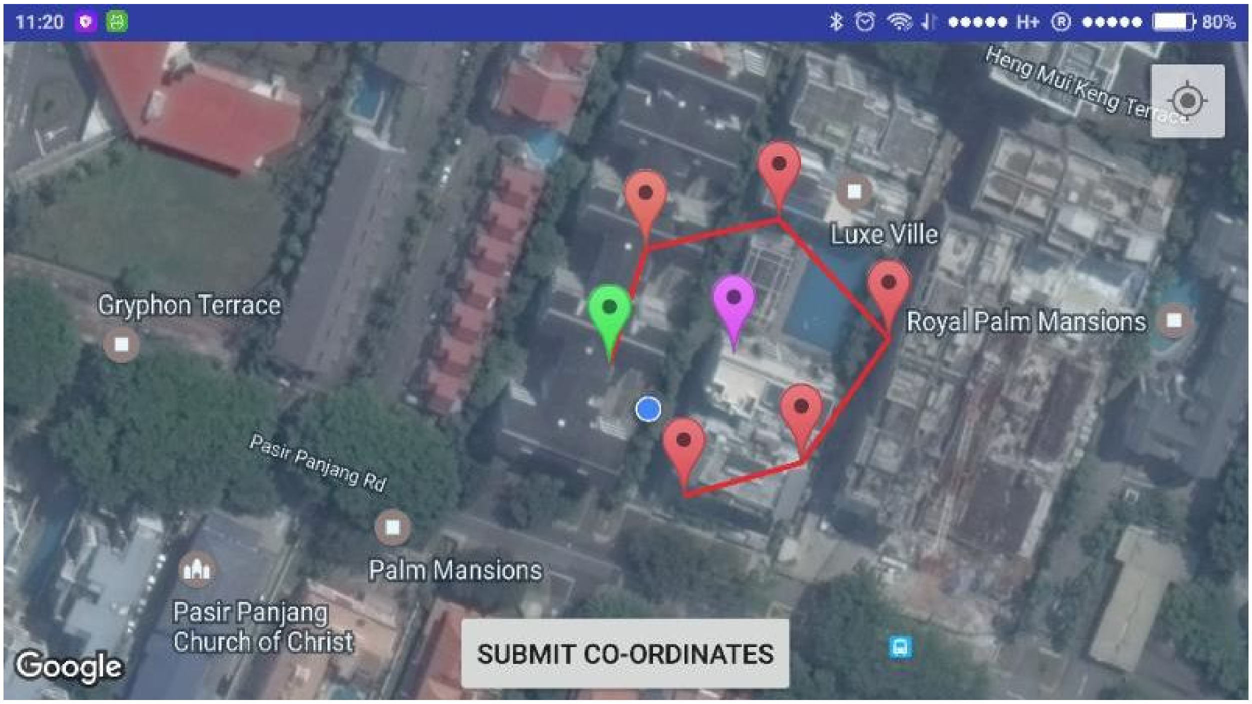
Absolute altitude is the height of the aircraft above the terrain over which it is flying. It can be measured using a radar altimeter (or "absolute altimeter"). Also referred to as "radar height" or feet/metres above ground level (AGL).

Relative altitude

Relative altitude is the height relative to the plane/copter's initial position.

Steps to be followed

1.Get the latitude and longitude from drone GPS and mark the drone location in map.
2.Get waypoints by clicking on coordinates in map.
3.Draw polylines between the drone location and waypoints
4.From drone GPS location and get the absolute altitude using google elevation api.
5.Input the relative altitude from the app.
6. Send the drone location, waypoints, absolute altitude, relative altitudes to server to create waypoint mission file.
7.The maximum number of waypoints to be set is limited to 8.



*fig(v).*Getting Waypoints and drawing polyline in the app.

The basic idea of the main loop with 1 point in the path is:

1. Coordinates of WP1 is noted
2. GPS gives the current location
3. Pass these two coordinates to the FC
4. Calculate the Distance between two waypoints
5. and the waypoints to be followed.
6. The waypoints are marked using a polyline.

Uses For Drone Waypoint GPS Navigation Technology:

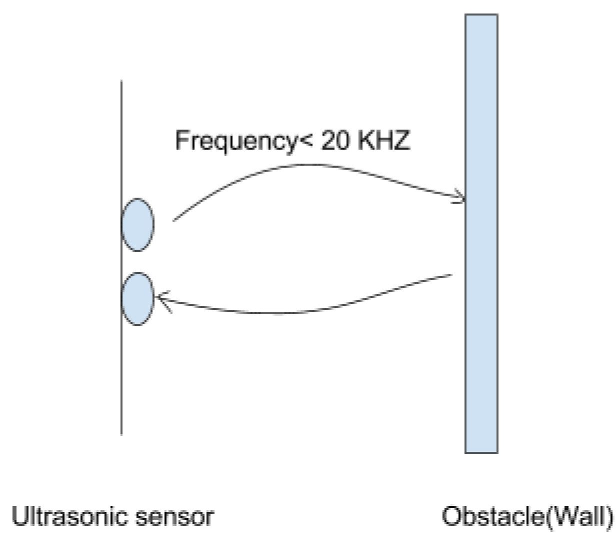
Drones are being used more and more in all types of site surveys from building construction, railway and road maintenance, power stations, dams, archaeology sites and environmental surveys. They are also being used by insurance companies for inspecting damage to buildings. Drones are also being used in agriculture to inspect crops, fencing, glasshouses and even find missing cattle and sheep.
With Waypoint GPS navigation, a site can be surveyed at the correct locations. The drone can fly directly to each specified location while the pilot on the ground concentrates on operating the camera to take aerial photographs of video. The drone takes the shortest route to each waypoint saving battery and filming time.

The advancement of drones to deliver parcels will very much require even more advanced waypoint technology. The costs of having a pilot for every drone delivering parcels would be expensive. But if drones are preconfigured with their destination waypoints to deliver parcels, they can go straight to the location and then to the next location taking the shortest route possible.

4.4 Sensors Integration

Ultrasonic sensor

Ultrasonic sensors are used to measure the distance of an object using sound waves.It sends a sound wave at a specific frequency and waits for it to bounce back.By recording the time elapsed for the wave to hit and the wave to bounce back we can calculate the distance



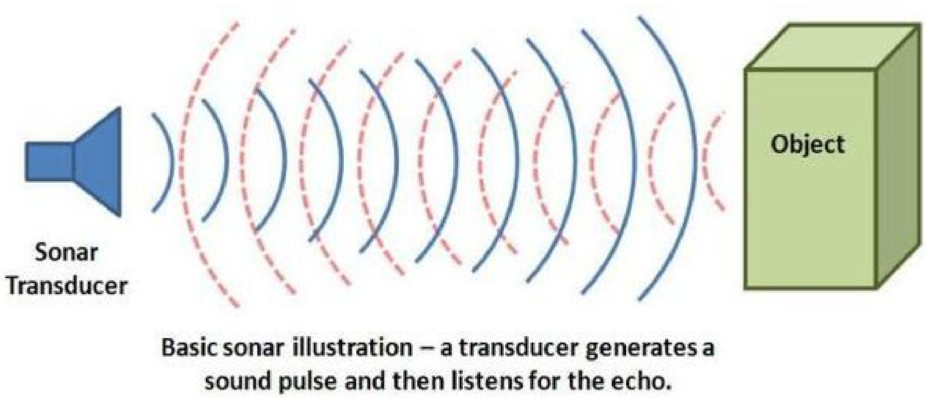
*fig(vi)*Working of an ultrasonic sensor

$$distance = \frac{speed\ of\ sound\ \times time\ taken}{2}$$

Since it is known that sound travels through air at about 344 m/s (1129 ft/s), you can take the time for the sound wave to return and multiply it by 344 meters (or 1129 feet) to find the total round-trip distance of the sound wave. Round-trip means that the sound wave traveled 2 times the distance to the object before it was detected by the sensor; it includes the 'trip' from the sonar sensor to the object AND the 'trip' from the object to the Ultrasonic sensor (after the sound wave bounced off the object). To find the distance to the object, simply divide the round-trip distance in half.

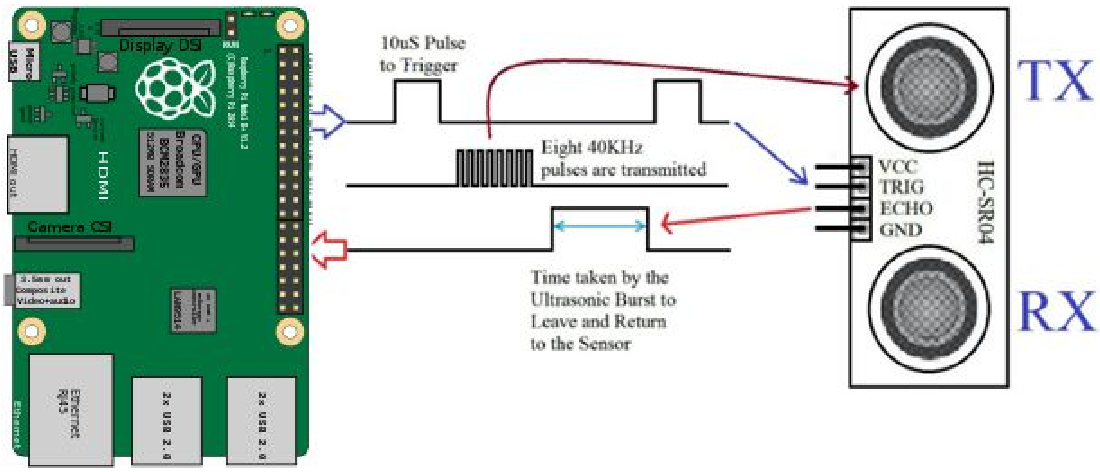
We use Sonar_HC-SR04 sensor attached to the raspberry pi to measure distances.

*fig(vii).*HC-SR04 ultrasonic sensor



*fig(viii).*Basic theory of sonar transducer

One of the GPIO pins of Raspberry Pi is configured as output pin which is connected to Trigger pin of the ultrasonic sensor and another GPIO pin of Raspberry Pi is configured as input pin which is connected to Echo pin of the ultrasonic sensor..



Time of flight measurement

The ultrasonic sensors use 40khz piezoelectric resonant transducers to generate the ultrasonic pulse.

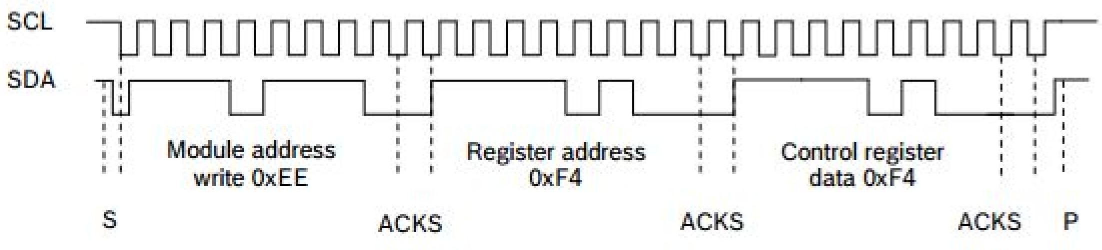
Barometer

A barometer is a scientific instrument used in meteorology to measure atmospheric pressure. Pressure tendency can forecast short term changes in the weather. Numerous measurements of air pressure are used within surface weather analysis to help find surface troughs, high pressure systems and frontal boundaries.

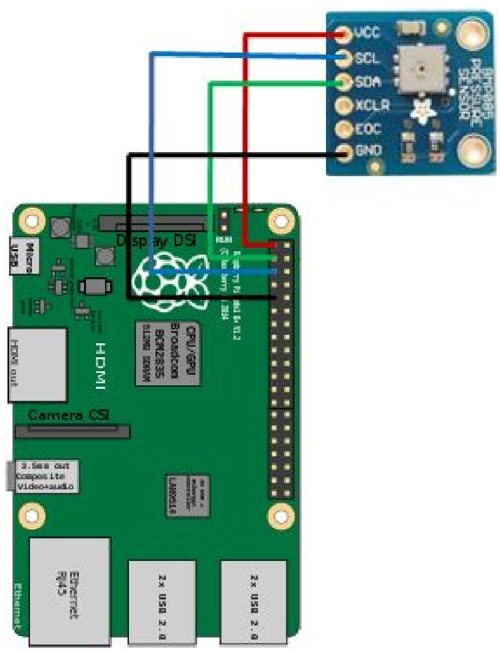
Bosch's BMP085 is a rock-solid barometric pressure sensor. It features a measuring range of anywhere between 30,000 and 110,000 Pa. 'Pa' meaning the Pascal unit, which you'll probably more often see converted to hPa (hectoPascal), equal to 100 Pa, or kPa (kiloPascal), which is 1000 Pa. As a bonus the BMP085 also provides a temperature measurement, anywhere from 0 to 65 °C.

The BMP085 has a digital interface, I2C to be specific. This means there may is a bit more overhead to get it talking to your microcontroller, but in return you get data that is much less susceptible to noise and other factors that may hamper an analog signal. I2C is a synchronous two-wire interface, the first wire, SDA, transmits data, while a second wire, SCL, transmits a clock, which is used to keep track of the data.

The I2C bus is used to control the sensor, to read calibration data from the E2PROM and to read the measurement data when A/D conversion is finished. SDA (serial data) and SCL (serial clock)
have open-drain outputs.



fig(ix).I2C protocol timing diagram for starting pressure measurement

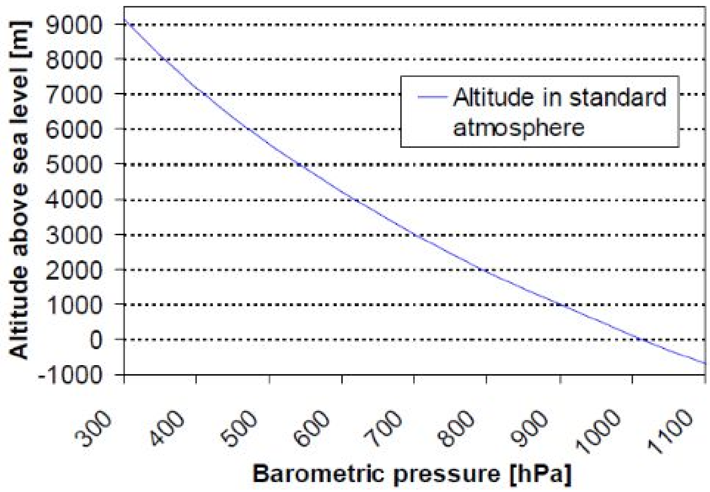


fig(x).BMP085 barometric sensor connection with Raspberry Pi

With the measured pressure ***ρ*** and the **absolute altitude** the presusure at sea level can be calculated.

$$p_0 = \frac{p}{\left(1 - \frac{altitude}{44330}\right)^{5.255}}$$

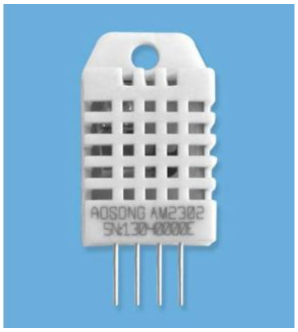
Thus, a difference in altitude of Δ altitude = 10m corresponds to 1.2hPa pressure change at sea level.



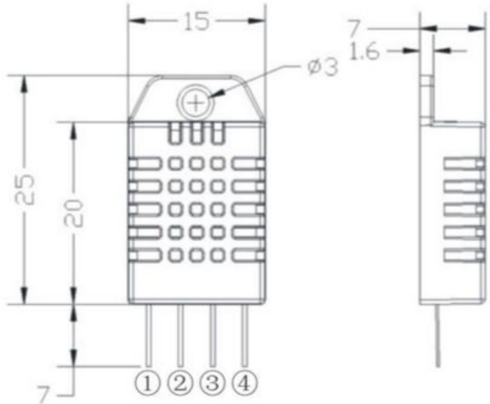
*fig(xi).*Altitude vs Barometric pressure

Humidity and temperature sensor : AM2302

AM2302 capacitive humidity sensing digital temperature and humidity module is one that contains the compound has been calibrated digital signal output of the temperature and humidity sensors. Application of a dedicated digital modules collection technology and the temperature and humidity sensing technology, to ensure that the product has high reliability and excellent long-term stability. The sensor includes a capacitive sensor wet components and a high-precision temperature measurement devices, and connected with a high-performance 8-bit microcontroller. The product has excellent quality, fast response, strong anti-jamming capability, and high cost. Each sensor is extremely accurate humidity calibration chamber calibration. The form of procedures, the calibration coefficients stored in the microcontroller, the sensor within the processing of the heartbeat to call these calibration coefficients. Standard single-bus interface, system makes integration quick and easy. Small size, low power consumption, signal transmission distance up to 20 meters, making it the best choice of all kinds of applications and even the most demanding applications. Products for the 3-lead (single-bus interface) connection convenience. Special packages according to user needs.

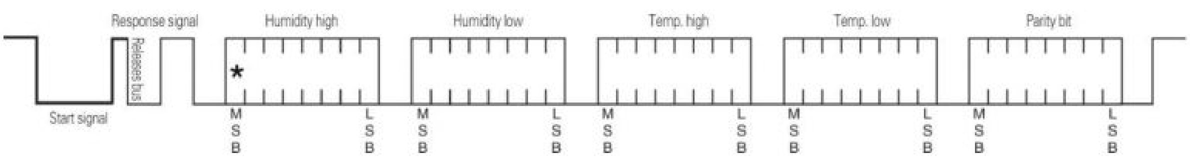


fig(xii).Physical map

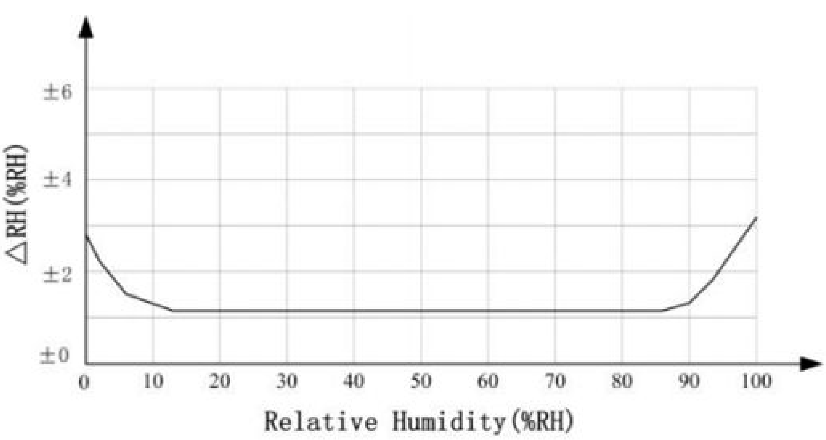


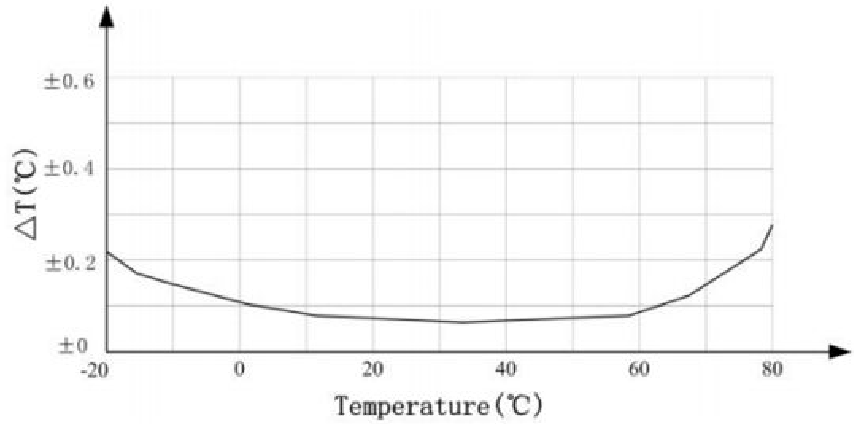
fig(xii).Dimensions (unit: mm)

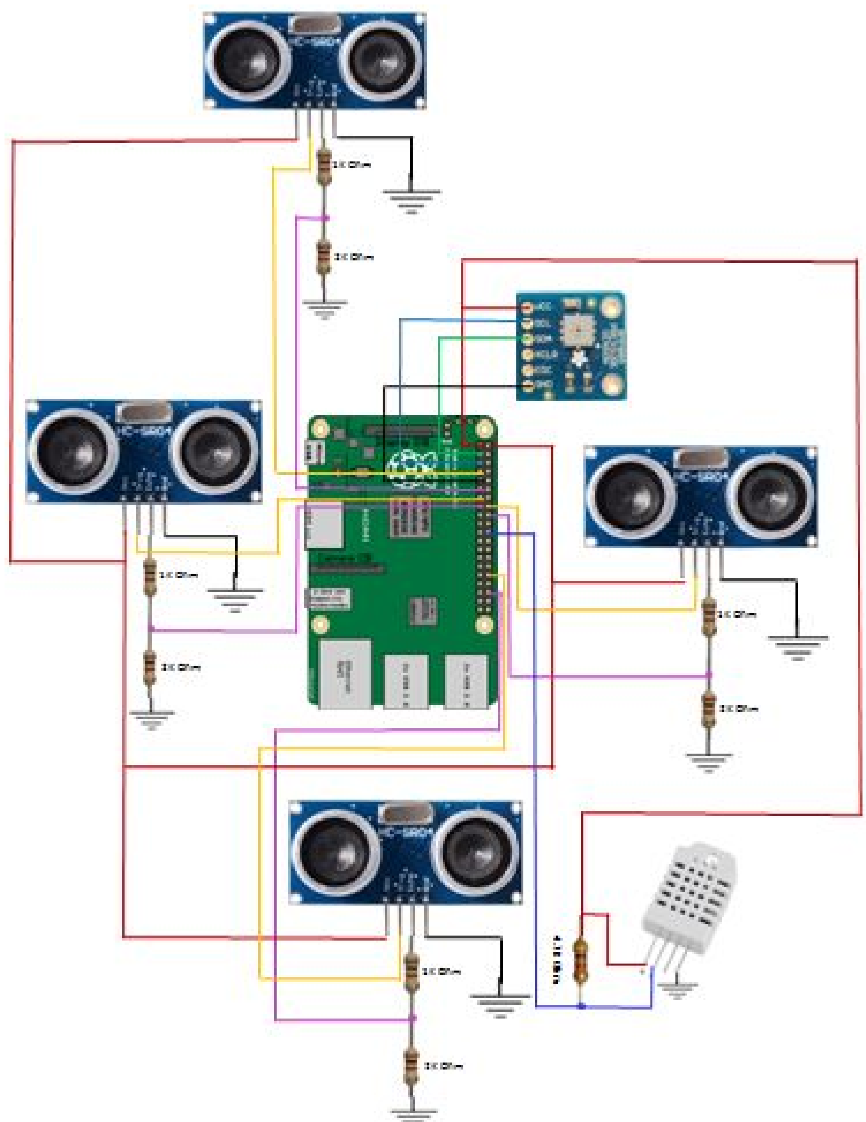
AM2303 device uses a simplified single-bus communication. Single bus that only one data line, data exchange system , controlled by the line to complete. Equipment (microprocessor) through an open-drain or tri-state port connected to the data line to allow the device does not send data to release the bus, while other devices use the bus; single bus usually requires an external pull-up resistor (about 5.1k Ohms), so when the bus is idle, its status is high.Because they are the master-slave structure, only the host calls the sensor, the sensor will answer, so the hosts to access the sensor must strictly follow the sequence of single bus, if there is a sequence of confusion , the sensor will not respond to the host.



fig(xiii).AM2303 single-bus communication protocol







fig(xiv).Raspberry Pi integrated with sensors for the drone system

5. WORK IN PROGRESS

5.1 3D Scanning

Aerial photography is very popular these days for taking a high quality pictures from sky. Drones are used to take pictures from different angles can be used to generate 3D models of the landscape or specific object. This can be done using camera attached to the drone. We are using photogrammetry to collect and measure group of points from series of pictures. First, drone will be flight in autonomous circle flight mode to take pictures of an object from all angles. Then it will slowly descend and slowly perform helical motion to again take pictures from different angles and altitudes. Pictures are saved into companion computer storage and to be processed offline using 3D model generator.

There are number of image mapping softwares available which maps the picture taken from the drone into a 3D model. Some popular softwares are Autodesk recap 360, Altizure, Pix4Dmapper, Dronedeploy and Agisoft Photoscan

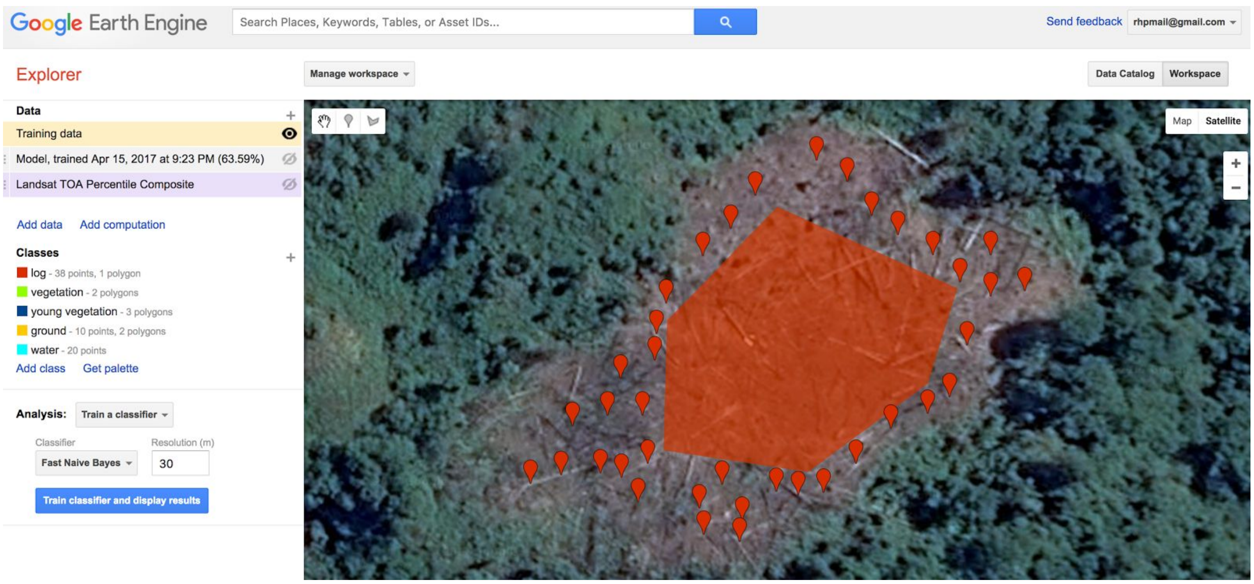
UAV Photogrammetry

Photogrammetry is the science of making measurements from photographs, especially for recovering the exact positions of surface points. Moreover, it may be used to recover the motion pathways of designated reference points located on any moving object, on its components and in the immediately adjacent environment. Photogrammetry may employ high-speed imaging and remote sensing in order to detect, measure and record complex 2D and 3D motion fields (see also sonar, radar, lidar etc.). Photogrammetry feeds the measurements from remote sensing and the results of imagery analysis into computational models in an attempt to successively estimate, with increasing accuracy, the actual, 3-D relative motions within the researched fie

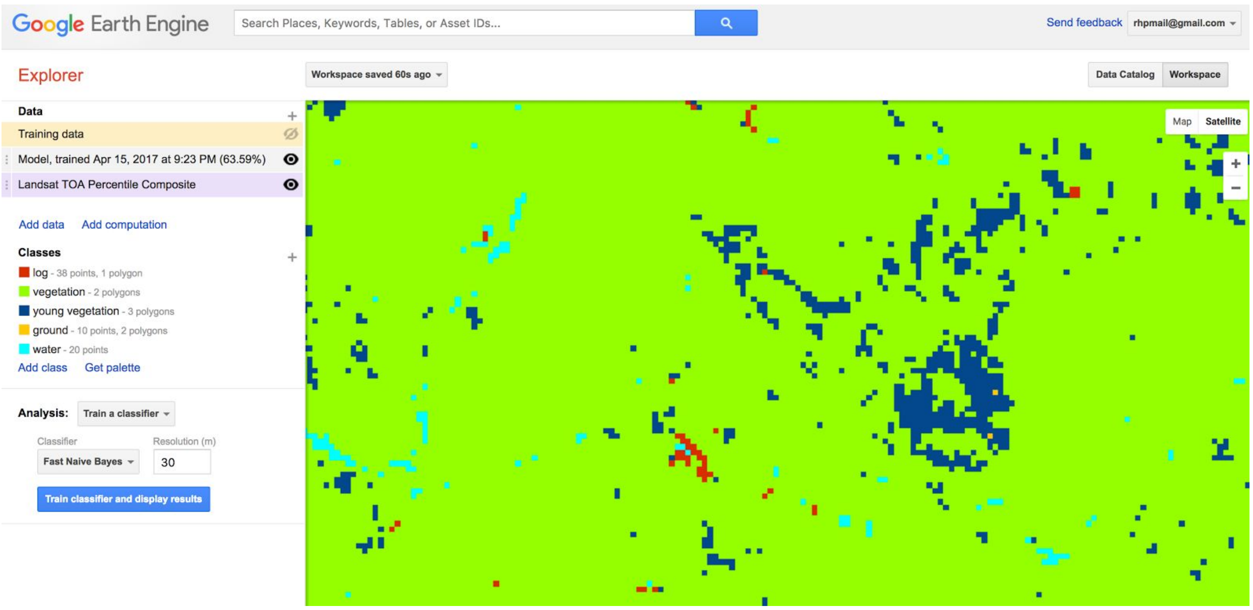
Unmanned Aerial Photogrammetric Survey is the use of Unmanned Aerial Vehicles (UAVs) to take photos for use in photogrammetry, the science of making measurements from photographs. 3D reconstruction is done using a open source 3d mapping software.

Orthophotography

This paper also presents orthophotography for aerial images taken by our drone for detecting forest illegal logging by processing captured images as ortho photos and analyze them using Google Earth Engine explorer, for training and classification. This would help conversation activists to quickly identify affected locations.



This tool allow us to train different classifiers like vegetation, ground, river or suspected illegal logging sites using satellite imagery data sets.



After training the model, we can use it and apply to our ortho maps pictures taken from our drone camera. This picture shows orthomosaic highlighting areas with possibly illegal logging activities.

Basic principles of photogrammetry software

Human brains perceive depth by comparing the images seen through the naked eye.An object is seen through two eyes.If you close either eye the object’s position seems to be changed.A closer object will seem to shift more than the object that is far.This is the principle behind creating a 3D model from multiple 2D images.It is known as stereoscopic vision.Our brain uses this information to calculate and tell us the how far is the object processing it in the subconscious mind.Photogrammetry is analogous to stereoscopic vision,where it compares two 2D images to determine the position and shape of an object using a software.Photogrammetry is old but never used.Due to evolution of powerful computers ,it has now been implemented to generate 3D models.

Autodesk Recap 360 & Recap Pro

In this project, we use Autodesk ReCap 360 software for making 3D model. Autodesk ReCap 360 is an online service that creates high resolution textured 3D models from photos or laser scans. ReCap™ Photo is used to generate an (.RCS) point cloud format that can be used to link into Revit to create models. The stitching process will also produce an (.RCP) format to be viewed and shared on the WEB and iPad.

Steps involved in making 3D models :

1) *Knowing the environment:*
    - Using Google Earth Engine explorer, train different classifiers like vegetation, ground, river or suspected illegal logging sites using satellite imagery data sets.
    - Looking up the weather data prior to flying your site is vital. Wind will affect the picture quality due to unstable flight.
2) *Capturing the right photos:*
    - ReCap 360 has a limitation of 250 photos per publish.
    - Selecting the right combination and overlap is important. The overall rule is to have one photo every 5 to 10 degrees. Have the same object in at least 3 pictures
    - Establish a flight path. Varied altitudes gives needed coverage for proper stitching (site conditions prevail)
    - 15' high and far enough back to get the bottom and top of object in one frame. This is to give adequate close-ups and the details needed for a good stitch
    - 30' high and far enough back to get the sidewalk and top in one frame, the more of the object the better
    - 50' high up to get as much of the object in one frame.

3) *Uploading the photos* in Autodesk Recap 360 application.

4) *Processing photos* using many publishing settings in Autodesk Recap 360 such as

- *Quality* for the 3D point cloud.
- *Smart Cropping*, which ignores areas that are "behind" the cameras used in your capture.
- Use *Smart Texturing*, which usually improves texturing.
- Set which *export formats* you wish the 3D model generated from the photos to be published in.
- *Preview* – Using this mode, we can see if you took the photos well and if they stitch together well at all, without having to wait too much.
- *Ultra* – Uses 5 cloud credits. This is the final delivery format and will take some time to process, depending on the size of the scene.

5) Once your photos have been submitted and fully calculated, you will receive an email notification with a link to open the created 3D scene. Once you have a completed

project, we can open the project and see it.

6) *Manually stitching images:*

Unstitched photos are photos that ReCap 360 could not use for the model creation, usually because they have little similarity with the rest of the photos. Adding those photos might increase the quality of the generated 3D model, but it requires a manual stitching process. We can manually stitch those photos, by manually defining matching points between an unstitched photo and stitched photo.

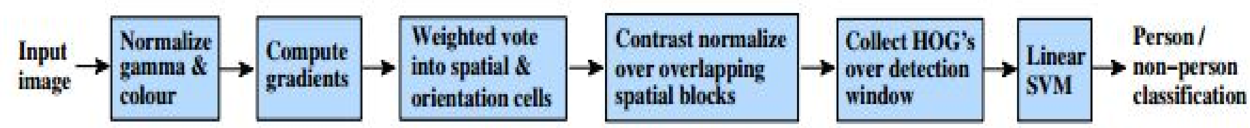
7) There are also some advanced tools for survey points and distance in AutoDesk ReCap 360.

Application	**Platform**	**Scalability**	**Type**	**Vendor / Creator**	**Guide price**
123D Catch	Android, iOS, Microsoft Windows, Web-based	Yes, multiple images	Close-range	Autodesk	Free download
Altizure	Web-based	Yes, multiple images	Close-range, Aerial, UAS	Everest Innovation Technology	US$59 / 416 4K Images
Pix4Dmapper Pro	Microsoft Windows, cloud computing, OS X, Linux	Yes, multiple images	Aerial, Close-range, UAS	Pix4D SA	One-time-charge, monthly and yearly rental licenses
ReCap 360	Web-based	Yes, multiple images	Close-range, UAS	Autodesk	$300 per 1 Year
Python Photogrammetry Toolbox	Linux, OS X, Microsoft Windows	Yes, multiple images		Arc-Team	Free

VisualSFM	Linux, OS X, Microsoft Windows	Yes, multiple images	Close-range	Changchang Wu	Free

5.2 Human Detection

HOG stands for Histograms of Oriented Gradients. HOG is a type of “feature descriptor”.The intent of a feature descriptor is to generalize the object in such a way that the same object (in this case a person) produces as close as possible to the same feature descriptor when viewed under different conditions. This makes the classification task easier.(HOG) with SVM for human detection.Here HOG works as feature descriptor and a linear SVM as classifier.The intent of a feature descriptor is to generalize the object in such a way that the same object produces as close as possible to the same feature descriptor when viewed under different conditions.This algorithm uses an object description based on overlapping histograms of gradients.



5.3 Indoor Navigation

Canny edge detection is used in image processing where extract the structural information from an image and hence interpret the size of the object. In order to detect the edge of an object,noise in the data should be removed. Removing noise from the image is a tedious task. We need to remove the noise and preserve the edges as well. Canny edge detector does really good in this case. First it applies a gaussian low pass filter for the image to remove the noise then the edges are sharpened. It also helps in reducing the data to be processed. It is the optimal and reliable algorithm for edge detection.

We implement this algorithm to detect the edges in the hallways which aids in detecting the walls and indoor navigation.

Our goal is to train the image classifier with different samples with edges sharpened using Gaussian low pass filter.

Steps involved in Canny edge detection:

1.Apply gaussian low pass filter for the image to remove the noise

2.Find the intensity gradients of the image

3.Threshold should be applied twice to identify potential edges.
4.Finalise the edges that has been detected and eliminate weak and edges not connected to strong edges.
5.A specific pattern is trained such that our drone detects the pattern and navigate towards it avoiding and maneuvering obstacles.

6. CONCLUSION

We achieved autonomous flight for quadcopter and applies 3D scan, human detection and cooperative controls to improve human drone interaction.
Drone innovation and technology have improved immensely. Combining latest drone technology with sensors and software / algorithms (cameras, infrared, sensors, 3D mapping and software) we can resolve various real world problems using aerial informatics.

We have several ways to control our drone via mobile application over WIFI or mobile network. Ground control station can communicate via separate radio link channel. Mobile application runs on android platform has the basic controls to control the drone and also to activate autonomous flight. Due to WIFI range constraints our drone can be operated within a range of 50 m, but with 4G extension module, our drone can practically be accessed anywhere. Using the camera in the pi module and ultrasonic sensors, we also implement algorithms for obstacle avoidance and object detection.

7. REFERENCES

[1]M.Rengarajan, Dr.G.Anitha, *“Algorithm development and testing of lowcost waypoint navigation system” in IRACST – Engineering Science and Technology: An International Journal (ESTIJ), ISSN:2250-3498,Vol.3, No.2, April 2013.*
[2] Yuecheng Liu, Yongjia Zhao, *“A Virtual-Waypoint Based Artificial Potential Field Method for UAV Path Planning”* in Proceedings of 2016 IEEE Chinese Guidance, Navigation and Control Conference August 12-14, 2016 Nanjing, China.

[3] Guoxing Shi et al., *“Research on Autonomous Avoidance Technique Based on The Waypoint Optimization Algorithm”* in Proceedings of 2015 IEEE, International Conference on Mechatronics and Automation, August 2-5, Beijing, China.
[4] Kun Wu et al., *“A Path Following Algorithm with Waypoint Switching Strategy for Unmanned Aerial Vehicle Based on the Geometric”* in Proceedings of 2016 IEEE Chinese Guidance,Navigation and Control Conference August 12-14, 2016 Nanjing, China.
[5] Lucas Vago Santana et al., *“Outdoor Waypoint Navigation with the AR.Drone Quadrotor”* in 2015 International Conference on Unmanned Aircraft Systems (ICUAS) Denver Marriott Tech Center Denver, Colorado, USA, June 9-12, 2015.
[6] S. Shair et al., *“The Use of Aerial Images and GPS for Mobile Robot Waypoint Navigation”* in ieee/asme transactions on mechatronics, vol.13,no.6, december 2008.
[7] MHA Hamid et al., *“Navigation of Mobile Robot Using Global Positioning System (GPS) and Obstacle Avoidance System with Commanded Loop Daisy Chaining Application Method”* in 2009 5th International Colloquium on Signal Processing & Its Applications (CSPA).
[8] L. Doitsidis et al., *“A Framework for Fuzzy Logic Based UAV Navigation and Control”* in Proceedings of the 2004 IEEE International Conference on Robotics & Automation New Orleans, LA,April 2004.
[9] Pierre-Jean Bristeau et al., *“The Navigation and Control technology inside the AR.Drone micro UAV”* in Preprints of the 18th IFAC World Congress Milano (Italy) August 28 - September 2, 2011.
[10] D. A. McFarlane et al., *“Integrated three-dimensional laser scanning and autonomous drone surface-photogrammetry at gomantong caves, sabah, malaysia”* in Karst and Cave Survey, Mapping and Data Processing–poster 2013 ICS Proceedings.
[11] Antonio Gomes et al., *“Bit Drones: Towards using 3D Nanocopter displays as interactive Self-Levitating programmable matter”* in Real Reality Interfaces #chi4 good, CHI 2016, San Jose, CA, USA.
[12] H. Liu et al., *“Auto Altitude Holding of Quadrotor UAVs with Kalman Filter based Vertical Velocity Estimation”* in Proceeding of the 11th World Congress on Intelligent Control and Automation Shenyang, China, June 29 - July 4 2014.
[13] S. Bouabdallah et al., *“Design and control of an indoor micro quadrotor”*, in pages 4393–4398. IEEE International Conference on Robotics and Automation. 2004.
[14] Karl Engelbert Wenzel et al., *“Automatic take off, tracking and landing of a miniature uav on a moving carrier vehicle”*, in Journal of Intelligent & Robotic Systems, 61(1-4):221–238, 2011.
[15] S. Bouabdallah and R. Siegwart, *”Backstepping and sliding-mode techniques applied to an indoor micro quadrotor”* in pp. 2247–2252. IEEE International Conference on Robotics and Automation. 2005.
[16] F. L. Mueller, A. P. Schoellig, and R. D’Andrea. *“Iterative learning of feed-forward corrections for high-performance tracking”*, in Intelligent Robots and Systems (IROS), 2012 IEEE/RSJ International Conference on, pp. 3276–3281. IEEE.
[17] A. Benallegue, A. Mokhtari, and L. Fridman, *“High-order sliding-mode observer for a quadrotor uav”*, in International Journal of Robust and Nonlinear Control, 18(4-5):427–440, 2008.

[18] Y. Cheng, J. L. Crassidis, and F. L. Markley. *“Attitude estimation for large field-of-view sensors”*, in Journal of the Astronautical Sciences, 54(3-4):433–448, 2006.
[19] Jung Yeol Kim and Carlos H. Caldas, *“Exploring Local Feature Descriptors for Construction Site Video Stabilization”,* in The 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC 2014).
[20] Lee, K. Y., Chuang, Y. Y., Chen, B. Y., and Ouhyoung, *“M. Video stabilization using robust feature trajectories”* in 2009 IEEE 12th International Conference on Computer Vision, 1397–1404, 2009.
[21] Morimoto, C., and Chellappa, R. Evaluation of image stabilization algorithms. Proceedings of the 1998 IEEE International Conference on Acoustics,Speech and Signal Processing, 1998, 2789–2792 vol.5, 1998.
[22] Rosten, E., and Drummond, T. Machine Learning for High-Speed Corner Detection. Computer Vision – ECCV 2006, Lecture Notes in Computer Science, A. Leonardis, H. Bischof, and A. Pinz, eds., Springer Berlin Heidelberg, 430–443, 2006.
[23] Weerasinghe, I., Ruwanpura, J., Boyd, J., and Habib, A. Application of Microsoft Kinect Sensor for Tracking Construction Workers. Construction Research Congress 2012, American Society of Civil Engineers, 858–867, 2012.
[24]BMP085 Digital Pressure Sensor Datasheet from Bosch Sensortec, BST-BMP085-DS000-05.
[25] D. Jain, “Path-guided indoor navigation for the visually impaired using minimal building retrofitting.” Proceedings of ACM ASSETS, 2014.