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Low Cost Open Source based UAV for Aerial Photography

Nuryono S. Widodo* — *Electrical Eng. Univ. Ahmad Dahlan,*
Anton Yudhana — *Electrical Eng. Univ. Ahmad Dahlan*
Sunardi — *Electrical Eng. Univ. Ahmad Dahlan*

Abstract*— Aerial Photography as a means of remote sensing applications becoming more popular nowadays. Aerial photography offers a more customized and low cost solution for taking ground data informations, especially compared to satellit imagery based remote sensing system. Combined with the appropriate processing software, an aerial photography imagery could be used to capture various ground data informations, a detailed model of a location, even a 3D model of the ground sourface could also reconstructed using aerial photography imagery. The field of applications for aerial photography spread widely from civilian purpose to military ones. The civilian applications it self ranging from agriculture to recreational purpose of aerial photography. This paper presents the possibility to build an aerial photography system with an autonomous capabilities based on the open source hardware and software iniative. The open source design used in this paper starting from the autopilot flight controller, to the ground controller station software and also the camera controlling software. An autonomous aerial photography requires autonomous flight capability of an aircraft, and autonomous camera control system. The experimental result shows that the hardware and software presented in this paper could be configured to build an UAV for the basic platform of an autonomous aerial photography.

***Keywords*— Open Source, UAV, Quadcopter, Ardupilot, Aerial Photography**

I. INTRODUCTION

Aerial photography as one of remote sensing application needs an aircraft platform to bring the image acquisition device (camera). The aircraft must have an adequate payload capability as well as stabilization and localisation capability that lead to an autonomous flight capability of the craft with the camera attached. Alongside with the aircraft, there is a need for a camera that able to performs the image acquistion process at the right place and time. This paper describes what it takes to build an aerial photography system based on the open source hardware and software iniative.

II. REFERENCES AND SYSTEM SETUP

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A. UAV (Unmanned Aerial Vehicle)

An unmanned aerial vehicle (UAV), as explicitly stated in its name is an uninhabited aircraft where there is no pilot or human carried on-board the aircraft. From technically aspect point of view, UAV can be defined as an aircraft equipped with necessary data processing units, sensors, automatic control, and communications systems and is capable of performing autonomous flight missions without the interference of a human pilot. A more strictly definition of UAV as AIAA(American Institute of Aeronautics and Astronautics) has, defines that an UAV is an aircraft which is designed or modified, not to carry a human pilot and is operated through electronic input initiated by the flight controller or by an onboard autonomous flight management control system that does not require flight controller intervention.[4]

There are various UAV configurations with different size, endurances levels, and capabilities. Based on their shapes and geometric structures, we can characterize UAV into the following four categories:

- Fixed-wings UAV, which refer to unmanned winged airplanes, that has a similar take-off and landing scheme with conventional airplane, where a runway or catapult launching system is required.
- Rotary-wing UAV, commonly called rotorcraft UAV, or by its take-off and landing scheme called a Vertical Take-off and Landing(VTOL) UAV. A rotorcraft UAV can fall into a conventional helicopter, a coaxial rotors or multi-rotors.
- Blimps such as baloons and airships
- Flapping-wing UAV, which mimics a bird or flying insect.

Each category has its special characteristic it self, flight endurance for instance, the fixed wing UAV commonly has a long flight endurance compared to the rotorcraft UAV. On the other hand the rotorcraft has a distinct advantage on its maneuverability and hovering capability.

B. Quadcopter

The vehicle consists of four rotors in total, with two pairs of counter-rotating, fixed-pitch blades located at the four corners of the aircraft, an example of which is shown in Figure 1. Due to its specific capabilities, use of autonomous quadrotor vehicles has been envisaged for a variety of applications both as individual vehicles and in multiple vehicle teams, including surveillance, search and rescue and mobile sensor networks.

Fig. 1 A Quadcopter

The particular interest of the research community in the quadrotor design can be linked to two main advantages over comparable vertical take off and landing (VTOL) UAVs, such as helicopters. First, quadrotors do not require complex mechanical control linkages for rotor actuation, relying instead on fixed pitch rotors and using variation in motor speed for vehicle control. This simplifies both the design and maintenance of the vehicle. Second, the use of four rotors ensures that individual rotors are smaller in diameter than the equivalent main rotor on a helicopter, relative to the airframe size. The individual rotors, therefore, store less kinetic energy during flight, mitigating the risk posed by the rotors should they entrain any objects.

Furthermore, by enclosing the rotors within a frame, the rotors can be protected from breaking during collisions, permitting flights indoors and in obstacle-dense environments, with low risk of damaging the vehicle, its operators, or its surroundings. These added safety benefits greatly accelerate the design and test flight process by allowing testing to take place indoors, by inexperienced pilots, with a short turnaround time for recovery from incidents.[1]

This simple explaination taken from [4] is suitable to understand how the quadcopter controlled to have an specific attitude or maneuver. The front and the rear propellers rotate counter-clockwise, while the left and the right ones turn clockwise. This configuration of opposite pairs directions removes the need for a tail rotor (needed instead in the standard helicopter structure). Figure 2 shows the structure model in hovering condition, where all the propellers have the same speed.

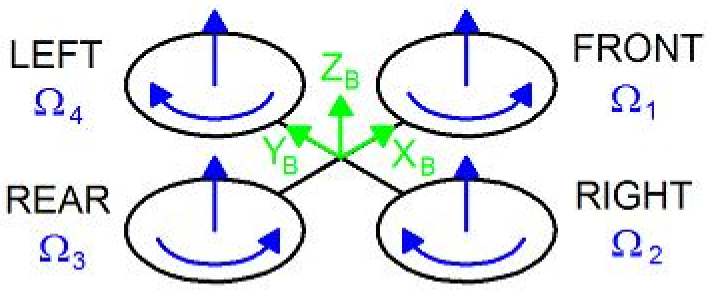

Fig. 2 Sketch of a Quadcopter

In figure 2 a sketch of the quadrotor structure is presented in black. The fixed-body B-frame is shown in green and in blue is represented the angular speed of the propellers. In addition to the name of the velocity variable, for each propeller, two arrows are drawn: the curved one represents the direction of rotation, the other one represents the velocity. This last vector always points upwards hence it doesn’t follow the right hand rule (for clockwise rotation) because it also models a vertical thrust and it would be confusing to have two speed vectors pointing upwards and the other two pointing downwards.

In the model of figure 2 all the propellers rotate at the same (hovering) speed $\Omega_H[rad\ s^{-1}]$ to counterbalance the acceleration due to gravity. Thus, the quadrotor performs stationary flight and no forces or torques move it from its position.

The four quadrotor targets are thus related to the four basic movements which allow the helicopter to reach a certain height and attitude. It follows the description of these basic movements:

Throttle (U_1[N])

This command is provided by increasing (or decreasing) all the propeller speeds by the same amount. It leads to a vertical force WRT body-fixed frame which raises or lowers the quadrotor. If the helicopter is in horizontal position, the vertical direction of the inertial frame and that one of the body-fixed frame coincide. Otherwise the provided thrust generates both vertical and horizontal accelerations in the inertial frame. Figure 3 shows the throttle command on a quadrotor sketch.

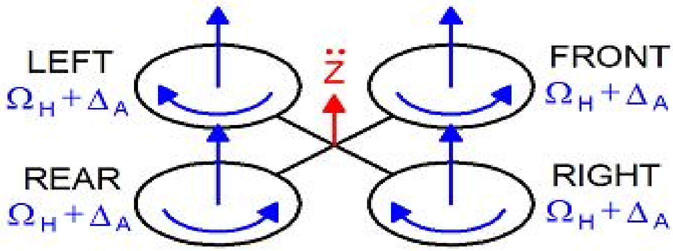

Fig. 3 Throttle command on a Quadcopter

In blue it is specified the speed of the propellers which, in this case, is equal to $\Omega_H + \Delta_A$ for each one. Δ_A[*rad* s^{-1}] is a positive variable which represents an increment respect of the constant Ω_H . Δ_A can't be too large because the model would eventually be influenced by strong non linearities or saturations.

Roll (U_2[N m])

This command is provided by increasing (or decreasing) the left propeller speed and by decreasing (or increasing) the right one. It leads to a torque with respect to the x_B axis which makes the quadrotor turn. The overall vertical thrust is the same as in hovering, hence this command leads only to a roll angle acceleration (in first approximation). Figure 4 shows the roll command on a quadrotor sketch.

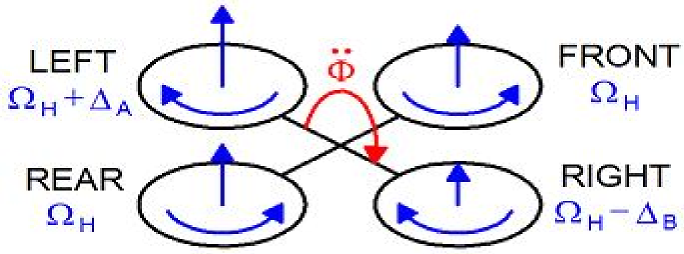

Fig. 4 Roll Command on a Quadcopter

The positive variables Δ_A and Δ_B[*rad* s^{-1}] are chosen to maintain thevertical thrust unchanged. It can be demonstrated that for small valuesof Δ_A, $\Delta_B \approx \Delta_A$. As in the previous case, they can't be too large because the model would eventually be influenced by strong non linearities or saturations.

Pitch (U_3[N m])

This command is very similar to the roll and is provided by increasing (ordecreasing) the rear ropeller speed and by decreasing (or increasing) the front one. It leads to a torque with respect to the y_B axis which makes the quadrotor turn. The overall vertical thrust is the same as in hovering, hence this command leads only to a pitch angle acceleration (in first approximation). Figure 5 shows the pitch command on a quadrotor sketch.

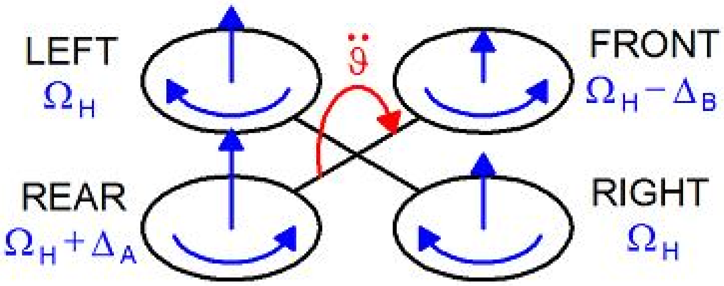

Fig. 5 Pitch command on a Quadcopter

As in the previous case, the positive variables Δ_A and Δ_B are chosen to maintain the vertical thrust unchanged and they can't be too large. Furthermore, for small values of Δ_A, it occurs $\Delta_B \approx \Delta_B$

Yaw (U_4[N m])

This command is provided by increasing (or decreasing) the front-rear propellers' speed and by decreasing (or increasing) that of the left-right couple. It leads to a torque with respect to the z_B axis which makes the quadrotor turn. The yaw movement is generated thanks to the fact that the left-right propellers rotate clockwise while the front-rear ones rotate counterclockwise. Hence, when the overall torque is unbalanced, the helicopter turns on itself around z_B. The total vertical thrust is the same as in hovering, hence this command leads only to a yaw angle acceleration (in first approximation). Figure 6 shows the yaw command on a quadrotor sketch.

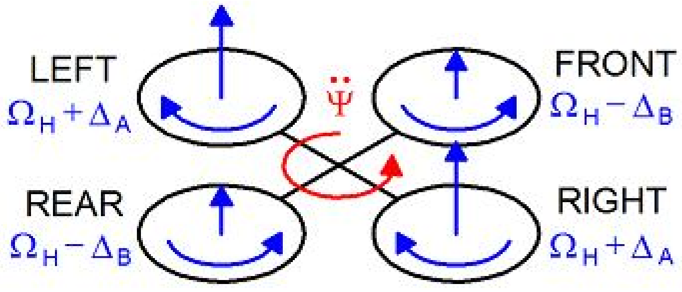

Fig. 6 Yaw command in a Quadcopter

As in the previous two cases, the positive variables Δ_A and Δ_B are chosen to maintain the vertical thrust unchanged and they can't be too large. Furthermore it maintains the equivalence $\Delta_B \approx \Delta_A$ for small values of Δ_A. Many research to derive a mathematical model for a Quadcopter has been conducted in the past, more detailed mathematical model for a quadcopter can be found in [1],[2],[3],[4].

C. Ardupilot flight controller

Ardupilot Mega(APM) is an open source electronic flight controller capable of controlling many types of unmanned aircraft, ranging from fixed wing to multi-rotors and conventional helicopter, it is even could be used on unmanned ground vehicle. Combined with the appropriate hardware and software, APM could transform any Radio Controlled Aircraft or vehicle into an unmanned vehicle with an autonomous flight capability. The minimalistic configuration for APM based unmanned vehicle shown on figure 7 below.

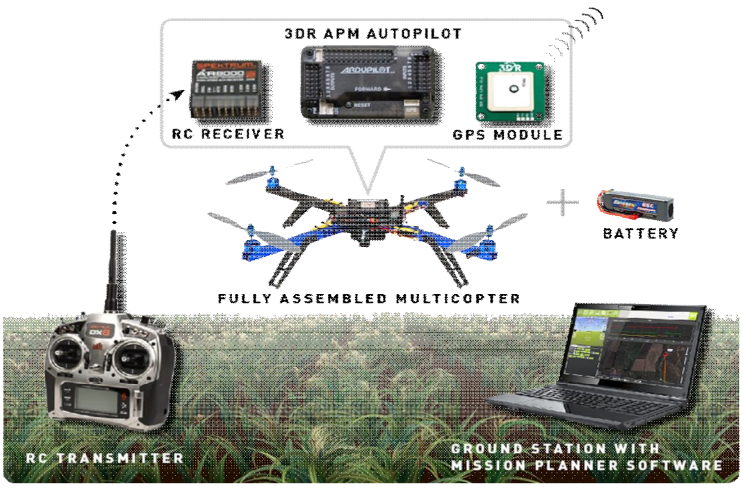

Fig. 7 APM Based UAV

Components needed to build an APM based UAV could be explained briefly below:

1. Multicopter or any other type of aircraft, equipped with brushless motors, electronic speed controller(ESC) and propellers.
2. A radio control setup to manually control the aircraft and to activate its automatic modes. Any RC transmitter/receiver system with at least six channels could be used here.
3. Flight Controller with an autopilot hardware with GPS module, APM with its on-board sensory devices combined with off board sensory devices could provide an autopilot flight controller for your aircraft. A GPS module is essential for providing the autopilot with location data that allows the autopilot to interact with the real world.

4. As any other vehicle, an APM based UAV requires power source for its actuation, for an aircraft a rechargeable lithium polymer (LiPo) battery is the most suitable battery type available nowadays due to its power to weight ratio efficiency.

Ardupilot Mega(APM) is a result of a long research and development supported by an open source comunity at Ardupilot, it was started base on the popular Arduino board around 2008. The first dedicated Ardupilot board was released in 2009. APM ver 2.5+(also called APM 2.5.2) was used on this paper,the board it self costs around $100. Board layout of APM 2.5+ can be seen on figure xx below:

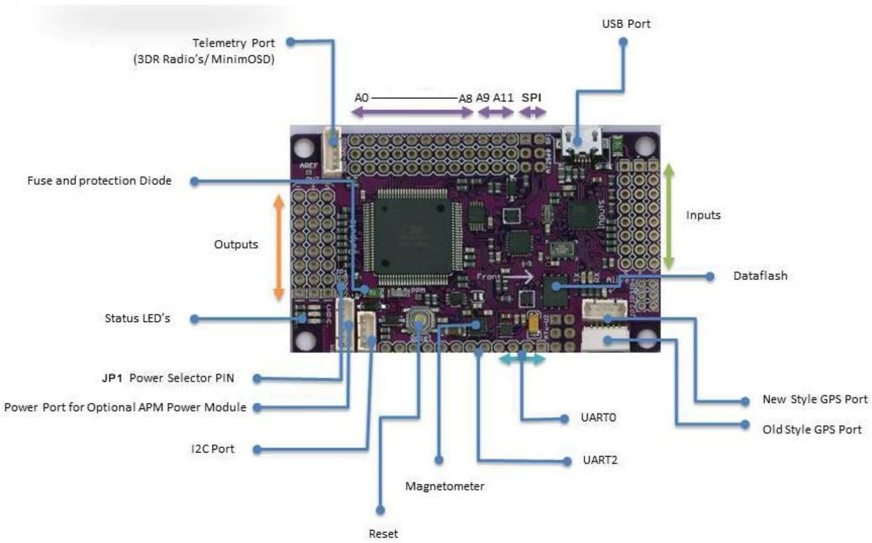

Fig. 8 Board Layout of APM 2.5+

APM 2.5+ is based on ATMega2560 microcontroller from ATMEL for the main processsor, a smaller ATMega32U2 used as USB interface and and PPM decoding. One of the advanced feature of the APM 2.5+ is in its capability to do flight data logging, with this feature user could do more tuning on flight controller parameter to have a better aircraft attitude and stabilization. As for the Attitude and Heading References System the APM has 3 type of sensor device, each described below:

1. MPU-6050 3 axis accelerometer and gyroscope sensor. The MPU-6050 devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die together with an onboard Digital Motion Processor™ (DMP™) which processes complex 6-axis MotionFusion algorithms. The MPU-6050 use I2C for data interface between the chip and the main processor. The device can access external magnetometers or other sensors through an auxiliary master I²C bus, allowing the devices to gather a full set of sensor data without intervention from the system processor. The device's user-programmable gyro full-scale range are ±250, ±500, ±1000, and ±2000°/sec (dps) and the user-programmable accelerometer full-scale range are ±2*g*, ±4*g*, ±8*g*, and ±16*g*.
2. HMC5883L digital compas from Honeywell inc.. The Honeywell HMC5883L is a surface-mount, multi-chip module designed for low-field magnetic sensing with a digital interface for applications such as lowcost compassing and magnetometry. The HMC5883L includes a high-resolution HMC118X series magneto-resistive sensors plus an ASIC containing amplification, automatic degaussing strap drivers, offset cancellation, and a 12-bit ADC that enables 1° to 2° compass heading accuracy. The I2C serial bus allows for easy interface.
3. The MS5611-01BA is a new generation of high resolution altimeter sensors from MEAS Switzerland with SPI and I2C bus interface. This barometric pressure sensor is optimized for altimeters and variometers with an altitude resolution of 10 cm. The sensor module includes a high linearity pressure sensor and an ultra low power 24 bit ΔΣ ADC with internal factory calibrated coefficients. It provides a precise digital 24 Bit pressure and temperature value and different operation modes that allow the user to optimize for conversion speed and current consumption. A high resolution temperature output allows the implementation of an altimeter/thermometer function without any additional sensor. The MS5611-01BA can be interfaced to virtually any microcontroller. The communication protocol is simple, without the need of programming internal registers in the device. Small dimensions of only 5.0 mm x 3.0 mm and a height of only 1.0 mm allow for integration in mobile devices.

To be able to fly autonomously on a predefined geo location waypoints, the APM needs a GPS sensor/board, this device with the conjuction with the on board sensory device on APM will be used for autonomous control of the vehicle.

Optional off board devices, such as radio telemetry and power module board could be added to enhance the functionality of the APM and the Ground Control Station software.

D. Brushless Motor, ESC and Propellers

The quadcopter based UAV described in this paper utilizes four brushless motors for the actuation, combined with two counter clockwise popellers and 2 clockwise propellers. The brushless motor has a very different feature and characteristic compared to its conventional DC motor counterpart, although both of them use DC power supply for the electrical power source, a Li-Po battery in this case. A brushless motor is actually similar to a 3 phase motor, considering that use the same principle as the 3 phase motor. A brushless motor needs a special electronic device called ESC (electronic speed controller), this device is responsible to act as a commutating circuit to drive the motor. Here is a detailed view of a brushless motor. This is an outrunner motor, where the motor casing, commonly called the bell is rotating together with the output shaft. In this type of brushless motor the coil is the stator and the rotor, which is series of permanent magnet attached to the motor bell.

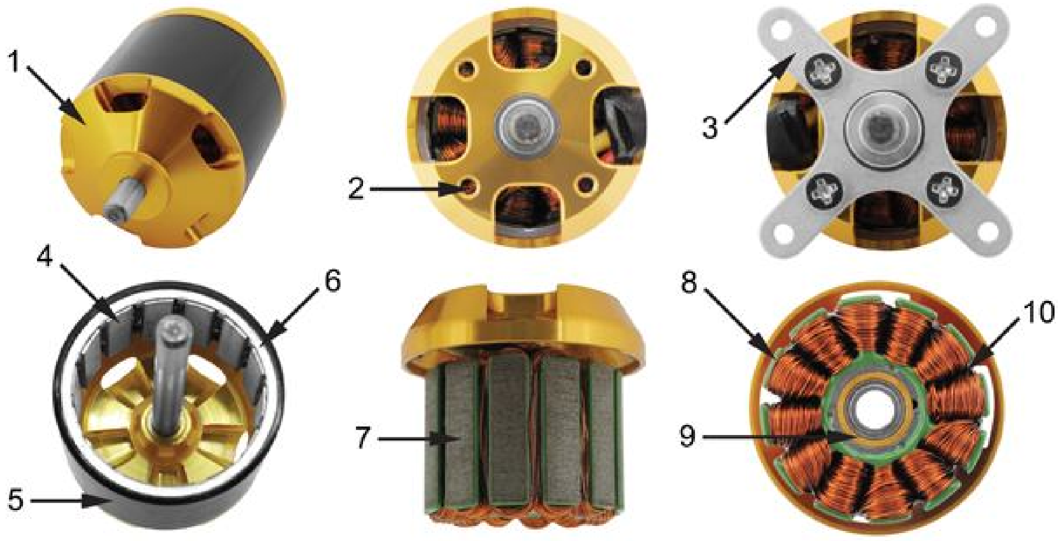

Fig. 9 Outrunner Brushless Motor

An Outrunner Brushless Motor

1. Machined aluminum housing with cooling holes that pump air through the motor while it runs.
2. Rear threaded mounting holes.
3. A machined aluminum cross style.
4. Permanent Magnet.
5. Rotor housing.
6. Rear locking ring maintains magnet spacing and also helps to strengthen the rear end of the flux ring assembly.
7. Stator plates with epoxy coated on the inner surface to prevent winding shorts.
8. High Temperature rated wire is used for winding the motors to minimize the risk of burning up the motor.
9. Ball bearings.
10. High temperature adhesives used to secure the stator windings and prevent them from shifting and getting pinched or shorting out .

The motors we use in this UAV are Turnigy 2830-11 brushless motor, according to its datasheet, it has maximum thrust around 890 gram and maximu power about 210 watts, it can be used with a Li-Po battery between 7.4 V and 14.8V (2 cell -4 cell Li-Po Batteries). ESC used in our UAV are Turnigy 25A ESC with a 25A maximum continous current and 35A Burst Current, the ESC is suitable to be used with 2-4Cell Li-Po Batteries, just the same as the motor.

Propellers used in this experiment are 10X4.5 propeller, with nylon/plastic material, for a better performance a carbon fibre propeller also available in the same size, but due to the fact that carbon fibre propellers are far more expensive than the plastic propellers, we choose not to use them. The brushless motor, ESC, and propellers can be seen on figure 10.

Fig. 10 Brushless Motor, ESC and Propellers

E. Ground Controller station software

Coherently with the Open source nature of the APM hardware and firmware design, there are various open source GCS software developed for the APM based UAV, namely: Mission Planner, APM Planner and the later released Android based GCS software as Andropilot and DroidPlanner. Mission Planner and AndroPilot were used in this experiment, this paper will focus on the Mission Planner for more detailed insight explained here.

Fig. 11 Mission Planner GUI

Mission Planner is a ground control station for APM based vehicle whether is it a plane, a copter/rotorcraft or a ground vehicle/rover. Mission Planner can be used as a configuration utility or as a dynamic control supplement for the autonomous vehicle. Here are just a few things user can do with Mission Planner:

- Load the firmware (the software) into the autopilot (APM and Ardupilot based autopilot board) that controls the vehicle.
- Setup, configure, and tune your vehicle for optimum performance.
- Plan, save and load autonomous missions into the autopilot board with simple point-and-click way-point entry on Google or other maps.
- Download and analyze mission logs created by the autopilot.
- Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator.
- With appropriate telemetry hardware user can:
    - Monitor the vehicle's status while in operation.

- Record telemetry logs which contain much more information the the on-board autopilot logs.
- View and analyze the telemetry logs.
- Operate the vehicle in FPV (first person view)

CHDK (Canon Hack Developement Kit)

CHDK is a firmware enhancement that operates on a number of Canon Cameras. CHDK gets loaded into the camera's memory upon bootup (either manually or automatically).

It provides additional functionality beyond that currently provided by the native camera firmware[].

CHDK is not a permanent firmware upgrade: user could decide how it is loaded (manually or automatically) and user can always easily remove it. Some of the added features resulted from using CHDK on the Canon Camera are very suitable to build an autonomus aerial photography system, scripting and usb remote for instance. The Scripting feature allow the user to preset and control CHDK and camera features using uBASIC and Lua scripts. Some of the most common application is enabling time laps triggering to capture image continously in a periodical manner. The USB remote feature, using the right configuration with one of the APM board output pin, can be used to perform location based capturing trigger for the camera.

III. RESULT AND ANALYSIS

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A. Completed System

The completed UAV can be seen on figure 12.

Fig. 12 Completed UAV

TABLE I
APM BASED UAV

Font Size	Bill Of Materials			
	Part	**Unit Price ($)**	**Quantity**	**Subtotal**
1	Frame set	35.00	1	35.00
2	Landing Skid	19.00	1	19.00
3	APM 2.5+	100.00	1	100.00
4	Power Module	19.00	1	19.00
5	GPS	35.00	1	35.00
6	Radio Telemetry set	42.00	1	42.00
7	Brushless Motor	15.00	4	60.00
8	ESC	16.00	4	64.00
9	Propellers	1.50	4	6.00
10	Battery	50.00	1	50.00
11	RC Transmitter& Receiver	90.00	1	90.00
12	Digital camera	100.00	1	100.00
13	Screw & Fasteners	15.00	1	15.00
14	Cables&Connector	25.00	1	25.00

Bill of materials needed to build an APM based UAV are shown in Table 1.

B. Aircraft Performance

Combination of the selected parts resulting a quadcopter with a thrust around 3400grams, around twice to the weight of the quadcopter with the battery and camera attached. So there is a plenty thrust headrooms for stabilization, maneuvering and winds compensations. There is a little tendency of drift due the accuracy of the GPS, but it is still acceptable for the aerial photography application, considering that the system does require an overlapping on the capture imagery to enable further image processing stage(image stitching). User could compensate this effect with a more dense waypoint to ensure that all the target area are covered on the imagery taken. The APM has a special feature regarding the GPS accuracy with the use of offset setting in the location based even trigger.

IV. CONCLUSIONS

This paper described what it needs to build a low cost UAV for aerial photography applications. *The experimental results indicate that the UAV built in this research has the capability to be used as a basic platform for autonomous aerial photography system.* The Ardupilot Mega(APM) used in this paper along with the appropriate hardware and software configuration offers a posibility to build a low cost UAV for aerial photography applications. A GPS based autopilot combined with an open source camera software on a Canon pocket camera can be configured to perform an autonomous aerial photography with the cost under $1000. Further development on the image processing portion promises a fully autonomous aerial photography system with an image stitching capabilities, resulting in an automatic panaromic view reconstruction of ground location from the captured ground imagery.

ACKNOWLEDGMENT

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