The Journal of Instrumentation, Automation and Systems

Autonomous UAV System Development for Payload Dropping Mission

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Abstract—In this paper, power and autonomous system in UAV (Unmanned Aerial Vehicle) for payload dropping mission will be presented. The UAV consists of two main parts, airframe and the avionics system. There are two important subsystems of avionics system which will be discussed, power system and autonomous system. There are three Li-Poly batteries applied in this system to power the autonomous system. The autonomous system consists of an *Ardupilot Mega v2.4.2* board (autonomous board), a GPS (Global Positioning System) sensor, attitude sensors, ESC (Electronic Speed Controller), servos, a brushless motor, a camera, a data transmitter, an Audio/Video transmitter, and also a Radio RC receiver. This UAV was designed to participate *Kontes Robot Terbang Indonesia 2013* (Indonesia Aerial Robot Contest 2013), payload dropping category, at Institut Teknologi Bandung, Indonesia. In this competition, provided a mission which the UAV has to drop payloads in some target points which is only known when UAV in the flight time. The UAV has to fly autonomously point-to-point while it also search the true point to drop the payloads by camera capturing. By integrating UAV's system with GCS (Ground Control System), the true point will be known by the operators in the ground control station and the mission can be accomplished.

Keywords—Airframe, power system, autonomous system, *Kontes Robot Terbang Indonesia 2013*, dropping payloads.

I. Introduction

NOWADAYS, Unmanned Aerial Vehicle (UAV) has been developed and used for myriad practical purposes, from civilian tasks [1] into military missions [2]. UAV is widely used because it is safer and more convenient than manned aerial vehicle [3]. There are some types of UAVs, which are classified by various parameters such as weight, engine type, wing loading, maximum altitude, endurances and ranges. For civilian tasks, people commonly use multirotor type and fixed wing type because of easy-manufacturing. In this paper, we want to present about fixed wing UAV for payload dropping mission. The fixed wing UAV has one rotor for its propulsion and has some control surfaces (aileron, rudder, and elevator) to control movement of the UAV. Fixed wing UAV has some advantages compared with multirotor type, such as its long endurance and its ability to carry adequate-heavy payload. Because of the long endurance and adequate-heavy payload needed for our payload dropping mission, we chose fixed wing platform for our UAV.

Figure 1 Fixed Wing Unmanned Aerial Vehicle

It is important to make an optimized UAV's design system based on the desired mission. The optimization is obtained by considering the lack and benefit of some UAV's components then consider the best trade-off between them.

In this paper, power and autonomous system in UAV for payload dropping mission will be presented to show how to integrate UAV's avionics system (power and autonomous system) with UAV's airframe platform. The airframe design of this UAV will be shown in Section II. In Section III and IV, autonomous system and power distribution in UAV will be detailed. Then, system integration (integration between avionics system and airframe platform) will be presented in Section V. In Section VI, result experience and analysis will be presented. Finally, the conclusion of this paper will be shown in Section VII.

II. Airframe Design

This UAV is named as Aksantara. Aksantara's airframe is dominantly made of foam and strengthened by aluminum in UAV's wing and tail boom. Foam is chosen because it is not too heavy and adequate easy-to-manufacture [4]. The dimension of Aksantara can be seen in **Figure 2** and **3**. And the appearance of Aksantara's airframe can be seen in **Figure 4**.

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This paper was submitted on October 23, 2014; revised on November 11, 2014; and accepted on November 17, 2014.

UAV's movement (pitching, rolling, and yawing) is adjusted by controlling UAV's control surface. Aksantara's control surface consists of two ailerons (one in each wing side), one elevator in tail, and two rudders (one in each tail side). In addition, there are two fixed-wheels in the bottom-rear of fuselage and one adjusted-wheel in bottom-front. The adjusted-wheel is controlled parallel with rudder. This adjusted-wheel is very important when UAV take-off and land.

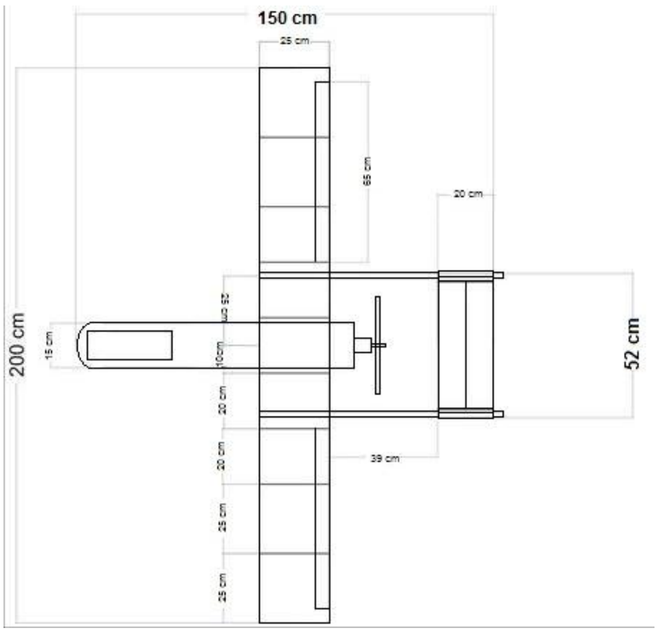

Figure 2 Dimension of Aksantara's airframe (top view)

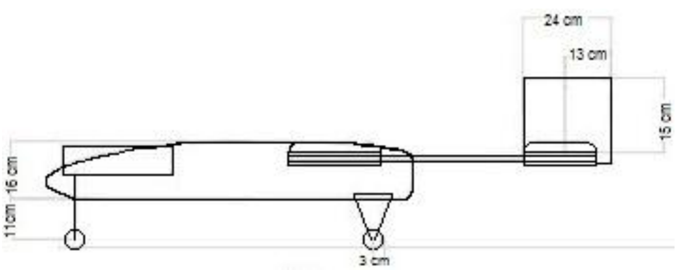

Figure 3 Dimension of Aksantara's airframe (side view)

Figure 4 Aksantara's airframe

III. Autonomous System

The main part of autonomous system is autonomous board. We used *Ardupilot Mega v2.4.2* as UAV's autonomous board. This board is very important because it will control almost of the other parts of this system autonomously to accomplish the UAV's mission. It is not only responsible with UAV's stabilization, control and guidance but also with data transmission-to-ground station and payload dropping mechanism. The *Ardupilot Mega* board will control two servos to embody payload dropping mechanism. The diagram of autonomous system can be seen in **Figure 5**.

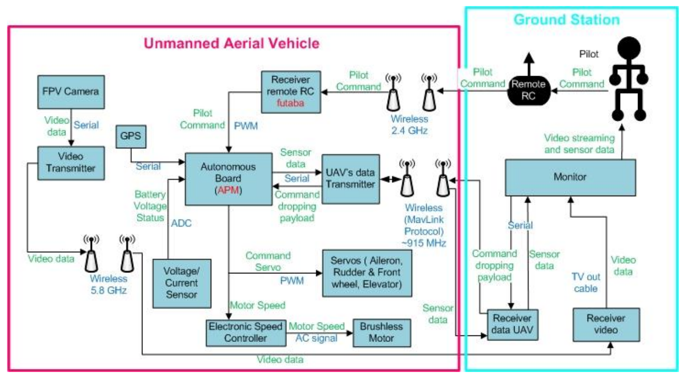

Figure 5 Aksantara's autonomous system diagram

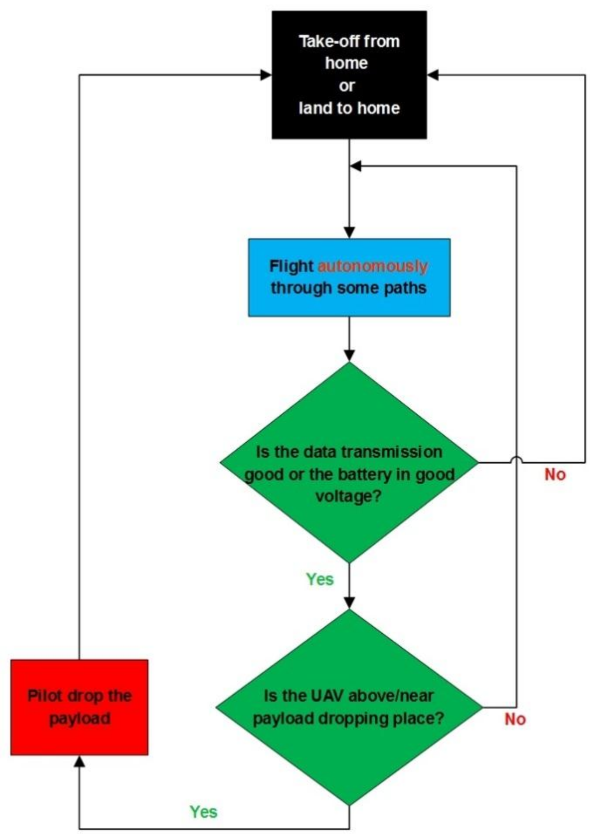

Figure 6 Aksantara's autonomous system process

Figure 5 shows that almost of the avionics system in UAV is integrated with autonomous board, except camera and video transmitter. Camera will transmit streaming video data to ground station independently. Camera will capture the image while the UAV fly autonomously. When the pilots in ground station seeing the monitor and find that the UAV is in the right place to drop the payload, they are allowed to control the autonomous board from ground station to drop the payload by controlling the payload dropping servos. Besides, this autonomous board has failsafe mechanism. This mechanism is used when either ground station lost data transmission from UAV or the battery is in low voltage. If one of these condition is occurred, the UAV will come back to home (place where it start to fly) autonomously regardless the mission have been accomplished or not. The flow chart of autonomous system process is shown in **Figure 6**.

There are three target places in this competition where we must drop the payload to accomplish the mission. But, there are also two fake target places given. That is why we have to find the true payload dropping target from the streaming video captured by camera when the UAV fly autonomously. After the mission has been accomplished, pilot can land the UAV manually by using remote RC. The only condition allowed to use manual mode is when the UAV is going to land or take-off.

IV. Power Distribution

There are two important things that making power distribution topic becomes worthy to be discussed. First is appropriate voltage level for all electronic components in UAV and electronic isolation from motor noise. That's why we have to distribute the power sources properly in order to solve these two important issues. Below is the Aksantara's power distribution diagram.

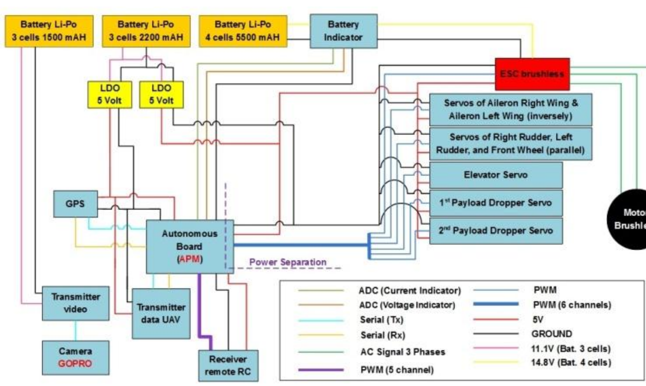

Figure 7 Aksantara's power distribution diagram

A. *Voltage Level*

We used battery Li-Poly (Lithium Polymer) for Aksantara's power sources because Li-Poly battery has light weight and be able to store large energy in small package [6]. There are three Li-Poly batteries used for Aksantara's power source. These are 5500 mAH 4 cells battery, 1500 mAH 3 cells battery, and 2200 mAH 3 cells battery. We chose three LiPoly batteries with different specification to optimize the UAV's total weight and also to comply with voltage level requirement of some electronic components, such as camera and video transmitter. We chose 4 cells for brushless motor because this motor need power in this voltage level. However, the other electronic components need 5 Volt power source. So, the 3 cells 2200 mAH battery was converted by two LDO (Low-Dropout) regulators with output voltage ~5 Volt. These two LDOs were used because of electronic isolation case which will be discussed then.

B. *Electronics Isolation*

Electronic isolation is needed to isolate electronic components from motor brushless, such as direct back EMF (Electric and Magnetic Field) effect [5], which can impact power source voltage level obtained by electronic components whereas every electronic components has voltage level constraint. Therefore, electronic isolation is implemented in order to there is no electronic trouble, such as autonomous board get auto-restart.

As shown in **Figure 7**, power source for brushless motor is different with power source for autonomous board. However, power source for Electronic Speed Control (ESC) which will control brushless motor speed is taken from autonomous board. Furthermore, Pulse Width Modulation (PWM) signal which control ESC output is also triggered by autonomous board. That is why we implement power separation in autonomous board and also use two LDOs to convert one 3 cells (11.1 Volt) battery into two 5 Volt power sources. Because by default, *Ardupilot Mega v2.4.2* has feature which user can choose whether do power separation between input PWM signal (from receiver remote RC) and output PWM signal (to servos and ESC) or not. In this board, there is a diode which can control the power flow (rectifier) and also a pin jumper. If user place the jumper, user just need to give power in output PWM signal side. But if user removes the jumper, user need to give power in both input PWM signal side and output PWM signal side. And we chose to remove the jumper because we wanted to do power separation. Here is the image to illustrate the power separation in *Ardupilot Mega v2.4.2*.

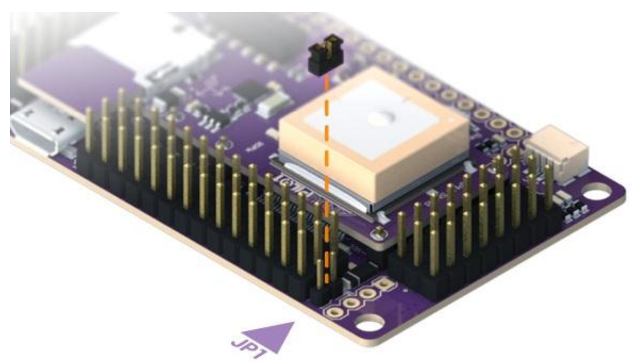

Figure 8 Illustration of power separation in *Ardupilot Mega v2.4.2*

V. System Integration

Firstly, we want to present some of important components/devices used in this UAV's project. We used autonomous board from *Arduino*, *Ardupilot Mega v2.4.2*, as shown in **Figure 9**. All sensors needed (gyroscope, accelerometer, magnetometer, and GPS) are included in this board by default. However, we added external GPS sensor instead of using the default GPS sensor because the default sensor is not adequate good in sensing. We used GPS module from *Mikrokopter*, *MK GPS v2.1*, as shown in **Figure 10**. This GPS module use *U-BLOX LEA6S* as its module receiver and this GPS module is also completed by additional compass sensor. By default, *Ardupilot Mega* board has a data protocol to send data inter-peripheral named as mavlink protocol which is basically used UART (Universal Asynchronous Receiver/ Transmitter) communication. So, we chose data transceiver from *RCTimer* which has implemented this data protocol. The picture can be seen in **Figure 11**. And the last, we used brushless motor *BL2832* from *EMAX* as shown in **Figure 12**. This motor draws current until 69 Ampere for 60 seconds (in full thrust/speed condition).

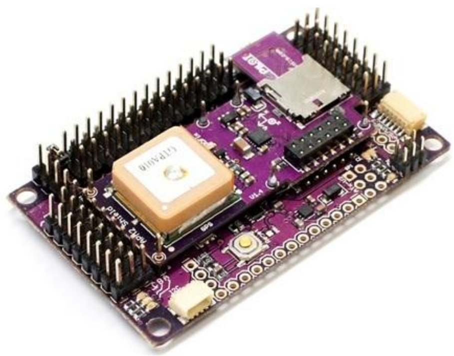

Figure 9 Autonomous Board (*Ardupilot Mega v2.4.2*)

Figure 10 GPS module (*MK GPS v2.1*) from *Mikrokopter*

Figure 11 UAV's data transceiver from *RCTimer*

Figure 12 Brushless motor (*BL2832*) from *EMAX*

All of the avionics components place in airframe should be managed so it can be efficient in wiring and it can be effective in function. Furthermore, we also considered every batteries placement carefully because it could impact in CG (Center of Gravity) of airframe position. **Figure 13** illustrate avionics components placement in Aksantara's airframe.

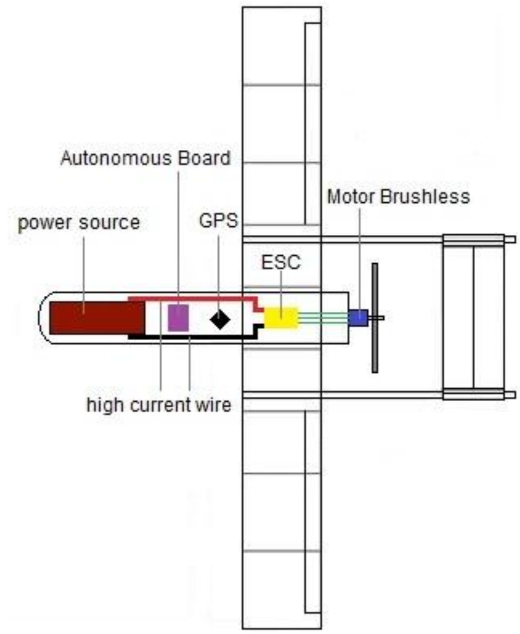

Figure 13 Electronics components placement

Figure 14 System Integration (side view)

Figure 15 System Integration (front view)

In ground station, Aksantara's status was monitored by GUI (Graphical User Interface) software which is default from *Ardupilot*, *Mission Planner*. Below is an interface example of Aksantara's status in *Mission Planner*.

Figure 16 Main menu (included Attitude status) in *Mission Planner*.

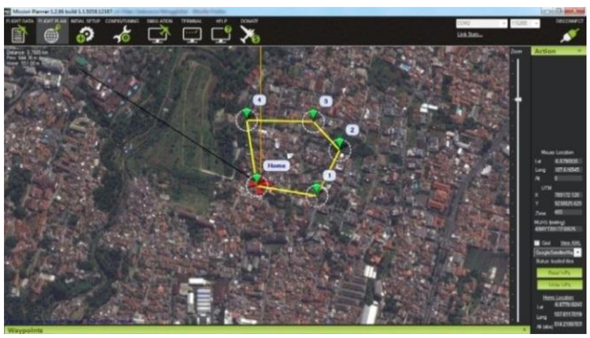

Figure 17 Waypoint plan's interface in *Mission Planner*.

VI. Result and Analysis

A. Result

We implemented some method/procedure to ensure that Aksantara was finished as well as we hoped. First, Aksantara's airframe was tested by seeking the appropriate CG of Aksantara. Then, we did flight test to analyze Aksantara's performance. But this first flight test was done with manual flight mode (without autonomous system). And the result was pretty good. It could also do maneuver-movement adequate good.

Then, we tested avionics components separately and also calibrated some sensors. And the last, we did flight test with all integrated components, including the autonomous system. When Aksantara started to take-off manually (in manual flight mode) with full thrust/motor-speed, suddenly we got lost to control Aksantara with remote RC. Then unfortunately Aksantara flied with full motor-speed but it was uncontrolled. Finally Aksantara got crashed. We will discuss the reason analysis and its proposed solution in the next section.

B. Analysis

The most possible reason why we got lost control is because of some troubles in autonomous system, such as error/noisy digital signal. This analysis is obtained because when Aksantara got crashed autonomous board did not get auto-reset proven by attitude status in *Mission Planner*. Then, there are some possible reasons why error/noisy digital signal are happened.

First, this trouble can be happened because of not standard wiring. Therefore, if there is some big vibration, there will be some wire become not fixed or unconnected unexpectedly. The only one solution for this case is using the standard wiring which is very robust in vibration.

Second, this trouble can be happened because of electric and magnetic field (EMF) induction caused by high current flow. This assesment comes from high current wire (look at **Figure 13**) which can distribute current until 96 Ampere when the motor in full thrust/speed. And Aksantara's lost control was happened when it went for take-off and needed full thrust from motor brushless. There are two possible solutions for this case. First, by rearranging the electronic components placement so the autonomous board is not in the high EMF induction area which makes this board become throuble. Second, by implementing the Faraday cage to nest high current wire. The conductor used for Faraday cage should be connected to ground channel of Aksantara's avionics system. By using this method, EMF induction effect can be vanished.

Third, the error/noisy digital signal can be happened because of direct back EMF effect from motor brushless [5]. Because, although we had done electronic separation in our flight test, we only embodied power separation whose ground channel has not been isolated perfectly. One of the best solutions is using optocoupler (optical isolator) between autonomous board side and ESC-plus-motor brushless side. This method is used to be implemented in signal/data transfer process between peripherals whose ground channel have to be isolated each other [7]. Below is the example diagram of optocoupler implementation.

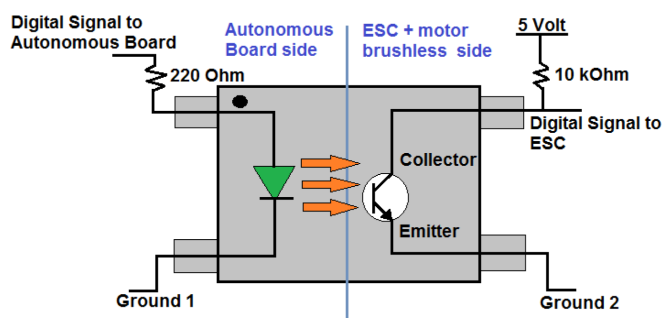

Figure 18 Diagram of optocoupler implementation.

VII. Concluding Remarks

Aksantara's airframe has been ready-to-fly. It had been verified in the pretty good flight test. Refinement should be implemented in the Aksantara's avionics system and the integration system. This refinement is needed to vanish EMF induction effect and error/noisy digital data which cause autonomous board trouble. Improvement in avionics system can be implemented by adding Faraday cage and optocoupler isolation. In the other hand, standard wiring and correct electronic components placement should be applied in the integration of the avionics system.

ACKNOWLEDGMENT

This work was partly supported by Edy Sofyan from LAPAN (National Institute of Aeronautics and Space), Indonesia.

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