Study on Wireless Transmission for Reconnaissance UAV with Wireless Sensor Network and Cylindrical Array of Microstrip Antennas

Chien-Chun Hung, Chun-Fong Wu

***Abstract*—**It is important for a commander to have real-time information to aware situations and to make decision in the battlefield. Results of modern technique developments have brought in this kind of information for military purposes. Unmanned aerial vehicle (UAV) is one of the means to gather intelligence owing to its widespread applications. It is still not clear whether or not the mini UAV with short-range wireless transmission system is used as a reconnaissance system in Taiwanese. In this paper, previous experience on the research of the sort of aerial vehicles has been applied with a data-relay system using the ZigBee modulus. The mini UAV developed is expected to be able to collect certain data in some appropriate theaters. The omni-directional antenna with high gain is also integrated into mini UAV to fit the size-reducing trend of airborne sensors. Two advantages are so far obvious. First, mini UAV can fly higher than usual to avoid being attacked from ground fires. Second, the data will be almost gathered during all maneuvering attitudes.

***Keywords*—**Mini UAV, reconnaissance, wireless transmission, ZigBee modulus.

I. Introduction

WIRELESS Sensor Network has been developed for several years. The researchers utilized Micro Electro-Mechanical System (MEMS) to develop small size sensors that are called "smart dust". The smart dust is mainly used in the military because it was patronized by the US Department of Defense (DoD). If UAV carry millions of smart dust and overfly enemy territories, it can cast smart dust on the battlefields to gather intelligence. Over a short span, the military may detach UAV to collect the data from the smart dust through WSN. Then, the UAV can bring the data back to the military base or transmit the data to other ground stations. Accordingly, there is no need to go deep into enemy camps in order to collect intelligence.

WSN could integrate sense, calculation, and network and detect some physical quantities, such as temperature, moisture, light, gas concentration, vibration amplitude, and so on from surrounding environment or specific targets. Therefore, these data can be transferred to observers through WSN so as to draw up strategies. In WSN, there are many ways of transmission, such as IEEE 802.11/WiFi, IEEE 802.15.1/Bluetooth, IEEE 802.15.3/UWB (ultra-wide band) and 802.15.4/ZigBee.

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Since the research is concentrated on reconnaissance system, the concrete method that makes the study practical is to plan a mission profile and utilize design methods in combination with microstrip antenna and commercialized ZigBee system that attaches to 2.4 GHz channel. This research made a mini UAV called "Harpy Eagle" to satisfy the mission profile, which "mini UAV" is the categorization of UAV having a take-off weight magnitude of 5-50 pounds [1].

II. Adoption from Airplane Sizing Methodology to Mini UAV Design

If we want to apply airplane sizing methodology [2]-[7] to mini UAVs, the difference between mini UAV and airplane must take into consideration. Moreover, it is necessary to develop a unique fuel-fraction method [2] and construct the correlating database especially for the mini UAVs so that we will see the possibility of using airplane design method to size mini UAVs [8].

A. Design Process

The process of the design methodology is shown in Fig. 1 [7]. For mini UAVs, the take-off weight can be first estimated by comparing two empty weights. One obtained by the fuel-fraction method [2] while the other by the trend line representing regression bases on historical mini UAVs' weight data. Then, we make an adjustment to the value of guessed take-off weight. We continue this process until these two empty weights agree with each other to within a given tolerance.

Once the weight estimation is completed, the take-off power loading, take-off wing loading, maximum lift coefficients, and aspect ratio can be selected by a performance-matching plot in order to meet performance objectives with an assigned horsepower. Furthermore, Federal Aviation Regulations Part 23 (FAR 23) is applied so far to size mini UAVs.

During the configuration design, it is important to note that the configuration design is a non-unique and iterative process. It is quite possible that more than one and sometimes completely different configurations can be found to satisfy a given mission specification. The configuration design can be broken down into two iterative preliminary design sequences. The objective of preliminary design sequence I is to decide on the feasibility of the given configuration with a minimum amount of engineering manhours. After the preliminary design sequence I, it is demonstrated whether or not the proposed configuration is workable. If indeed it is, then there is a reason to proceed with the second preliminary design sequence. The objective of preliminary design sequence II is to reach a realistic, reasonably detailed layout of a given configuration so that its mission capabilities can be compared to those of other competing concepts with confidence.

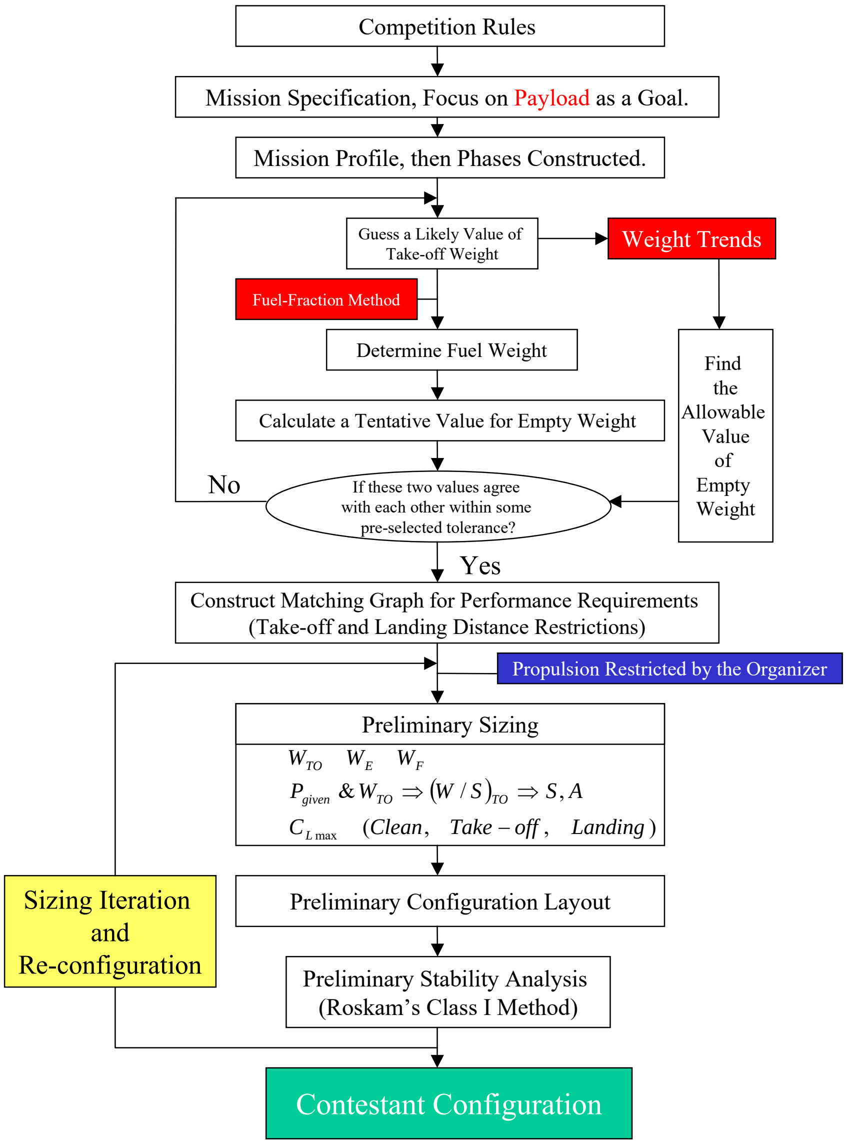

Fig. 1 Mini UAV design process

Engineering methods used in conjunction with preliminary design sequence I are viewed as Class I methods. These methods have limited accuracy but require only a small amount of engineering manhours. Engineering methods used in conjunction with preliminary design sequence II are viewed as Class II methods. These methods have rather good accuracy but require a significant expenditure of engineering work.

B. Weight Estimation

During weight estimation, it is important to predict the minimum weight and fuel weight needed to accomplish a given mission. The empty weight can be obtained by the linear relationship between $\log_{10}W_E$ and $\log_{10}W_{TO}$ with collecting available data from current mini UAVs. However, the Breguet's equations for range and endurance used in fuel-fraction method [2] are not for mini UAVs, the better way is to borrow those recommended values for Type 1 or Type 2 airplanes [2]. For mini UAVs in this category, there are five items that need to be adjusted [7]:

(1) Weight trends.
(2) Fuel-Fraction Guessed for phases excluding Cruise (and/or Loiter) Segment.
(3) Breguet's Range and Endurance equations.
(4) Weight Reduction for wood used in this type of air vehicles.

(5) Center of Gravity (C.G.) Location for major components in this type of air vehicles.

C. Some Particular Performance Requirements

When sizing to take-off distance requirement, we could consider a mini UAV as the tiny replica of single engine propeller-driven airplane. Thus, the requirement of FAR 23 can be adhered to. Defined by (1), the take-off ground run, S_{TOG}, is proportional to the take-off parameter, TOP_{23},

$$TOP_{23} = (W/S)_{TO}(W/P)_{TO} \Big/ \sigma C_{L_{max_{TO}}} \tag{1}$$

where $(W/S)_{TO}$ is the wing loading and $(W/P)_{TO}$ the power loading at take-off. The relationship between the take-off ground run S_{TOG}, and take-off parameter TOP_{23}, is probably needed [7]. The landing distance requirements are always formulated at the design landing weight. In addition, the fieldlength is correlated with the landing stall speeds, which depend on the maximum landing lift coefficients under FAR 23. By using (2), the power-off landing stall speed, V_{S_L}, is

$$V_{S_L} = \left\{ 2(W/S)_L \Big/ \rho C_{L_{max_L}} \right\}^{1/2} \tag{2}$$

Selecting feasible airfoils that could generate sufficient lift for an airplane is very important step to take into consideration [8]. As shown in (3), the maximum lift coefficient for airplane, $C_{L_{max}}$, should be magnified to the maximum lift coefficient for wing, $C_{L_{max_W}}$.

$$C_{L_{max_W}} = 1.05 \text{ to } 1.1 C_{L_{max}} \tag{3}$$

In (4), the section maximum lift coefficient, $c_{l_{max}}$, is obtained from the maximum lift coefficient for wing.

$$C_{L_{max_W}} = k_\lambda (c_{l_{max_r}} + c_{l_{max_t}})^{1/2} \tag{4}$$

where λ is the taper ratio and k_λ is taper ratio correction factor for wing maximum lift coefficient obtained from historical airplane data, k_λ is 0.88 for $\lambda = 1.0$ as 0.95 for $\lambda = 0.4$. The section maximum lift coefficients of wing root and tip airfoils are $c_{l_{max_r}}$ and $c_{l_{max_t}}$, respectively.

D. Stability Analysis

With a scaled preliminary arrangement drawing of the proposed configuration, there is a method to rapidly analyze whether or not the proposed configuration has the satisfactory stability and control characteristics. By Class I Weight and Balance Analysis, Stability and Control Analysis [4], [7], longitudinal X-plot and directional X-plot are constructed as shown in (5) and (6) respectively, which are recommended in the preliminary design phase for an airplane to be inherently stable.

$$S.M. = dC_m \big/ dC_L = \overline{X}_{cg} - \overline{X}_{ac} = -0.10 \tag{5}$$

$$C_{n_\beta} = 0.0010 \text{ per degree} \tag{6}$$

where *S.M.* is the static margin, C_m the pitching moment coefficient, C_L the lift coefficient, $\overline{X}_{cg}$ the distance from leading edge of wing mean geometry chord to center of gravity in fraction of $\bar{c}$, the chord length of MGC. Moreover, $\overline{X}_{cg}$ is the distance from leading edge of wing mean geometry chord to aerodynamic center in fraction of $\bar{c}$, and C_{n_β} is the yawing-moment-coefficient-due-to-sideslip derivative.

III. Unmanned Aerial Vehicle

A. Mission of Reconnaissance UAV

The research would combine a mini UAV with some basic equipment to make a mini UAV with reconnaissance mission which could collect environmental information with payload and transmit data within the specified range; hence, the research set the following mission specification:

(1) Basic design requirement: Use the current vehicle to save the cost of the research.
(2) Airborne system: Possess the preliminary reconnaissance ability.
(3) Payload: 1kg.
(4) Range: There should be 5% fuel remaining after 60 km.
(5) Altitude: 150 m to 350 m maximum cruise altitude.
(6) Cruise speed：60 km/h at basic payload.
(7) Climb: Climb to 150 m at sealevel and landing after 60 minutes loiter.
(8) Landing: On the concrete surface. For reconnaissance, the mini UAV could carry out the take-off or landing on Hsisheng Airport.
(9) Powerplants: O.S. 95AX Engine

The research could define the following mission profile from the aforesaid mission specifications:

(1) Phase 1 (engine start and warm-up) about 2 minutes.
(2) Phase 2 (taxi) to full-power speed about 80 m.
(3) Phase 3 (take-off) at full power.
(4) Phase 4 (climb to cruise altitude) about 150 m altitude.
(5) Phase 5 (loiter) 60 minutes at 60 km/h.
(6) Phase 6 (descent) at low speed.
(7) Phase 7 (landing, taxi, shutdown) about 150m.

The aforesaid mission profile is shown in Fig. 2.

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B. Design of "Harpy Eagle" Mini UAV

1. Matching for Performance Requirements

According to the specifications of FAR23 take-off and landing distances and the method of the cruise speed estimation in Roskam [2], this research could obtain the matching shown in Fig. 3 with substituting the proper values after the calculation.

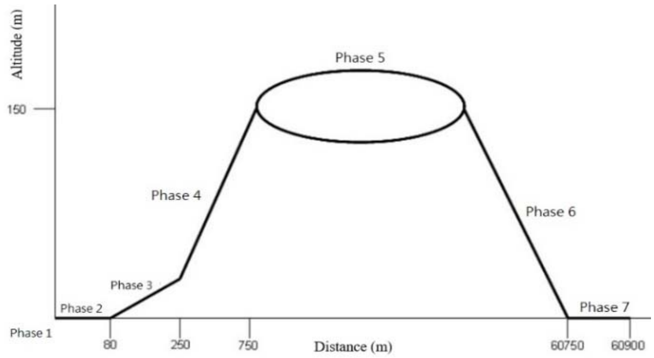

Fig. 2 Mission profile

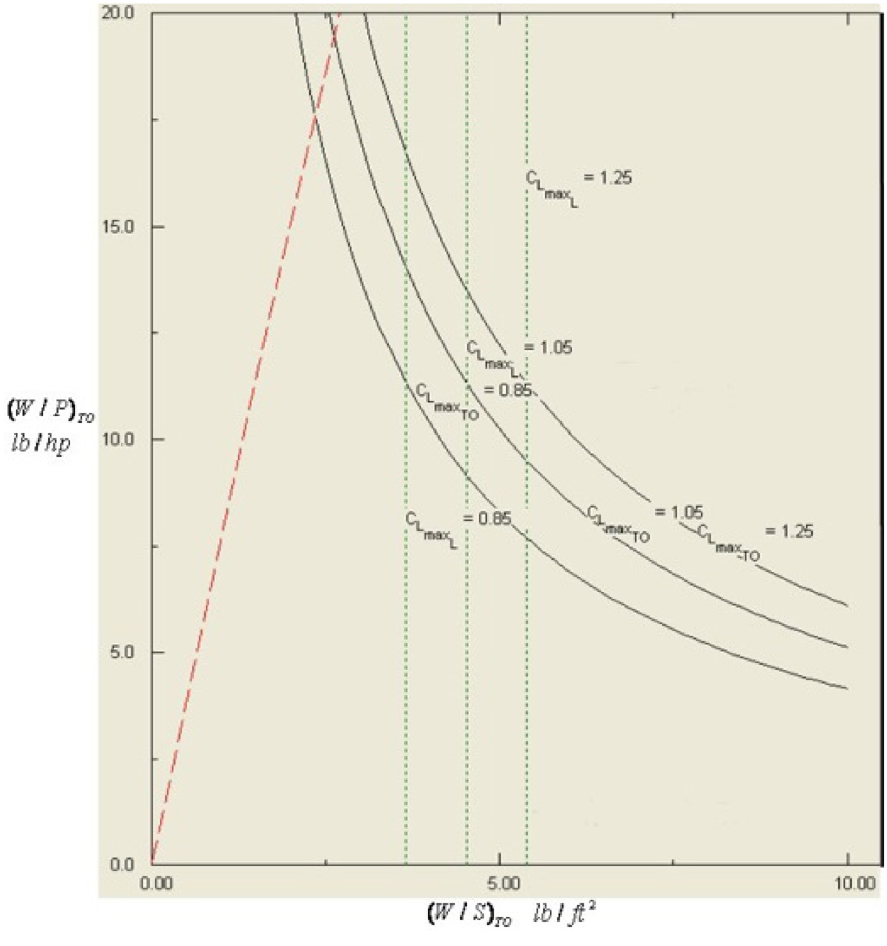

Fig. 3 Harpy Eagle's matching for performance

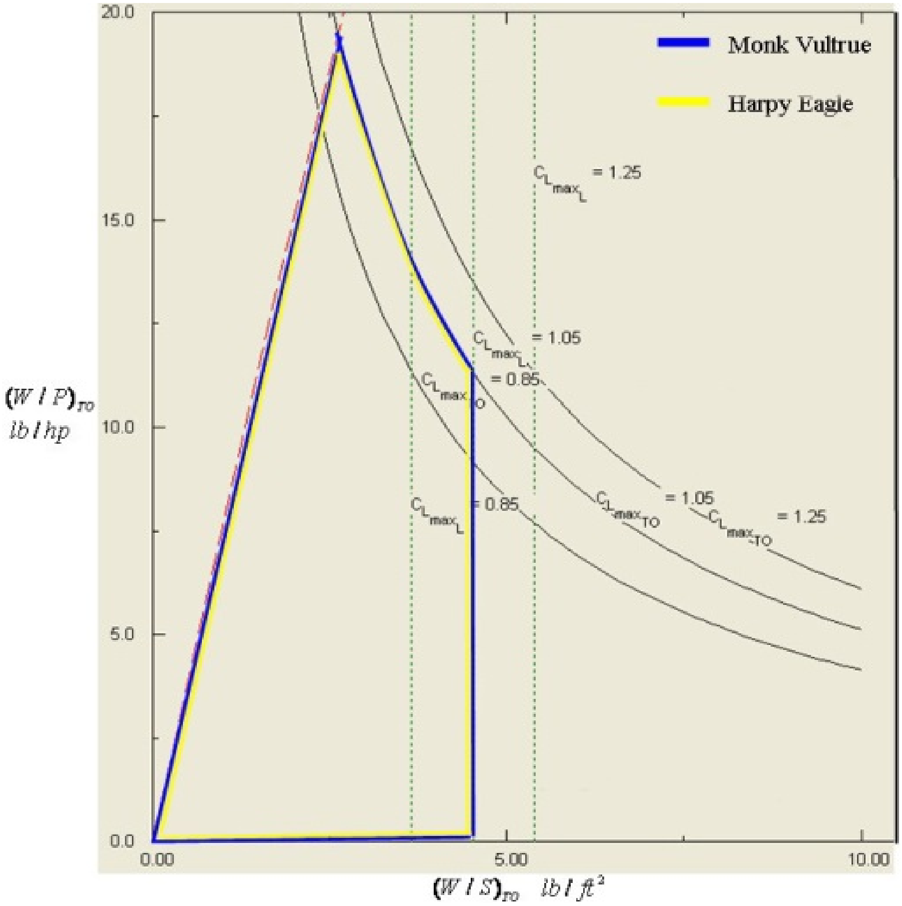

Fig. 4 Compared Harpy Eagle's matching with that of Monk Vulture

TABLE I
HARPY EAGLE'S POWER LOADING AND WING LOADING

power loading		wing loading	
horsepower = 2.8 hp	W/P = 6.34 lb/hp	Wing area = 12.54 ft^2	W/S = 1.42 lb/ft^2
horsepower = 2.8 hp	W/P = 6.64. lb/hp	Wing area = 12.54 ft^2	W/S = 1.48 lb/ft^2

Recently, the fully developed mini UAV in the research team is Monk Vulture [9]. Therefore, the research compared the matching of the Harpy Eagle in Fig. 3 with that of Monk Vulture. It is not unexpected that both matchings were exactly the same as shown in Fig. 4 because the Harpy Eagle's take-off distance, landing distance and cruise speed were similar to Monk Vulture's. For this reason, it would be practicable to borrow the Monk Vulture's airframe if the initial evaluation results show that the wing loading and power loading of the Harpy Eagle were within the range of the matching.

With regard to the technique of making mini UAVs in the research team, the empty weight was between 11.35 lb and 15.07 lb [7]. Therefore, the research could preliminarily estimate the Harpy Eagle's empty weight and the payload that were 13.21 lb (average value) and 2.2 lb, respectively. As to the fuel weight, it was 2.357 lb based on the powerplants mentioned in section III.A. Lastly, the total take-off weight was 17.77 lb. If the research adopted Monk Vulture's wing area, 12.54 ft^2, it could obtain (power loading, wing loading)=(6.34, 1.42) shown in Table I. In this case, it was feasible to borrow the Monk Vulture's airframe (the similar empty weight and the same wing area) because the point would be within the range of Harpy Eagle's matching (so did Monk Vulture's) for a certainty.

The point would be still within the range of Harpy Eagle's matching after the value was recalculated (power loading, wing loading) to (6.64, 1.48) shown in Table I. Since the research adopted the Monk Vulture's airframe, all it needs to do was to change empty weight to 14.04 lb, and both payload and fuel weight remain the same. To sum up, Harpy Eagle's and Monk Vulture's matching were nearly the same. Therefore, it would conform to the take-off and landing distances as well as the cruise speed of the mission specification if the Harpy Eagle exactly adopted the same components as the Monk Vulture such as engine and wing area, with both power loading and wing loading being within the range of the matching.

2. Stability Analysis

Although the research could adopt Monk Vulture's airframe for reference as stated above to carry out the basic reconnaissance mission, neither the payload nor the fuel weight of the Harpy Eagle was the same as Monk Vulture's. Consequently, it was necessary to analyze the longitudinal static stability of the whole airplane [4]. That is, the research should preliminarily estimate the Static Margin (SM) of the airplane. To make the SM of the mini UAVs approach 10%, the research should take every weight of the Harpy Eagle's airframe components (the total weight is called empty weight) and the location of its center of gravity into consideration; furthermore, the research also needs to determine the locations of the fuel tank and payload of the Harpy Eagle to estimate its SM. The location of the Monk Vulture's aerodynamic center is at 2.6 ft (the point that the peak of the fuselage extended forwards for 0.69 ft became the origin of the X-axis) [9]; similarly, the location of the Harpy Eagle's aerodynamic center should be at 2.6 ft. There are two factors that need to be taken into consideration when deciding the locations of the fuel tanks. Firstly, the fuel tank should be set beside the engine as close as possible to avoid the engine flameout. Secondly, the center of gravity should be held in 1.87 ft via fixing the fuel tanks because of the Monk Vulture's fuselage structure. After all basic detective equipment was installed, the center of gravity was at 2.95 ft, and the SM was 30.28%. Although the SM was more than the expected value (10%) from Roskam [2], it meant that the longitudinal static stability of the Harpy Eagle would perform reasonably well; that is, this would reduce rather effect on the Harpy Eagle enduring the gust during the major mission phase.

Compared the matching of the Harpy Eagle with that of the Monk Vulture, the result shown that they were coincidence. If the Monk Vulture's airframe was adopted, the value (power loading, wing loading) would be within the range of the Harpy Eagle's matching with enlarging the fuel tank based on the mission payload. According to the result based on the fuel-fraction method, the enlarged fuel tank could provide sufficient fuel for the mission (1 hour loiter for reconnaissance). Finally, the SM value that was more than 10% could increase the longitudinal static stability. In conclusion, it was feasible to adopt the Monk Vulture's airframe to Harpy Eagle.

IV. Design of Reconnaissance System

A. Framework of Reconnaissance System

According to the information from WSN, commanders could make the right decision and judge soundly. Hence, keeping the battlefield in control was the ultimate goal of military development. The information reconnoitered from the battlefield could be various. For example, using infrared sensors could detect whether there were enemies or using acoustic sensors could locate the direction of enemies. The research only concentrated on whether ZigBee could reconnoiter the battlefield environment and transmit data to UAV ends. To prevent the data link paralyzed from the basic power system destroyed during the war, the data should be stored in UAVs rather than transmitting the data by the current WSN such as GPRS/3G and Internet system. Furthermore, the wireless transport mechanisms should be not only power-saving but also massively-deployed. Therefore, using ZigBee could extend the distance of data transmission to prevent mini UAVs from being attacked during the war. The research would adopt omni-directional antennas integrated with data collection module. The related hardware is discussed in the following sections.

B. Introduction of ZigBee

In 2000 on December, Institute of Electrical and Electronics Engineers (IEEE) set up the team 802.15.4. which took charge of drawing up the norm about the MAC Layer and PHY Layer in low-rate wireless personal and network. In 2003 on May, ZigBee passed the IEEE802.15.4 certification. In 2002 on October, the ZigBee alliance established by Honeywell, Invensys, Mitsubishi, Motorola and Philips took charge of drawing up the norm about NETWORK Layer, Security Layer, Application Frame Work. Moreover, three of them could be tested by each other.

TABLE II
ZigBee RS232-DCE-3.0 Specification [10]

Communication interface	RS232
UART Baud Rate	9600-115200 bps
Communication Range	240 m
Data Rate	250 kps / 500 kps / 1M
Power Supply	DC 9-12 V

The research adopted the wireless transmission module, ZigBee RS232-DCE-3.0 [10], created by Sinpro Enterprise Co., Ltd. It was convenient to do the research on antenna-received signal because the module was able to be external antennas. The specification of the ZigBee wireless module was shown at Table II.

C. Microstrip Antenna

Microstrip antennas have not received considerable attention until the 1970s due to the development of printed-circuit technology, the improved photolithographic techniques, the availability of good substrates with low loss tangent (a quantity related to substrate loss due to dielectric damping) and attractive thermal and mechanical properties. Microstrip antennas have matured considerably during the past 30 years, and many of the limitations have been overcome.

There are plenty of merits that microstrip antennas possess. For instance, microstrip antennas are conformable to planar and nonplanar surfaces, simple and inexpensive to fabricate using modern printed-circuit technology. Moreover, the research team has already been sufficient and usable preliminary results to design efficient antenna module so that it could live up to the requirement for aeronautical communication long-distance transportation. Therefore, the research adopted cylindrical array of microstrip antennas which were one of the preliminary results as wireless transmission module of external antennas.

When UAVs carried out missions, the flight paths were not only straight but from all directions. It is necessary to form an assembly of antenna elements in an electrical and geometrical array. And a high array factor will be obtained to enhance the performance of microstrip antenna if the right arrangement of phase array and choice of array elements have been accomplished. In order to reduce the aerodynamic drag, the antenna mounted on UAV fuselage should be low-profile.

D. Low-Profile Omni-Directional Antenna

To meet the demands of long distance for aerospace communication, the antenna mounted on UAV fuselage should be low-profile. Moreover, to isotropically propagate an electromagnetic energy of equal amplitude in all directions to a far distance, this research will also propose a mini UAV antenna design with an omni-directional radiation patterns and higher radiation efficiency and antenna gain. The preliminary design of low-profile omni-directional antenna on UAV is shown in Fig. 5. Antenna elements are connected with feed network and printed on the soft substrate, and revolved about the vertical axis circle to generate a cylinder.

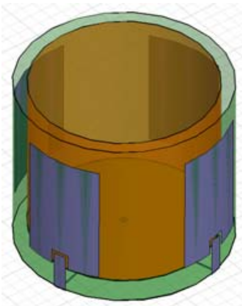

Fig. 5 Design of low-profile omni-directional antenna on UAV

Air substrate is used for low-profile omni-directional antenna in this research; however, high resistance and reactance due to air substrate should be considered. Hence, the antenna element should be designed to offset above drawbacks and for simple structure and small size.

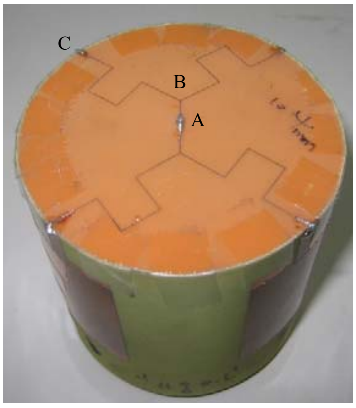

Fig. 6 Feed network of 1 × 4 array

The feed array of proposed low-profile antenna of array, as shown in Fig. 6, is designed on a circular substrate with radius of 40 mm. According to Fig. 6, the feed point A is the center of circular substrate and fed with a probe of 50 ohms. Points A and B will be linked with stretched microstrip lines with width of 0.3 mm and an angle of 125°, and there is a quarter-wave transformer of from points B to C. Point C is also the junction of transformer and feed.

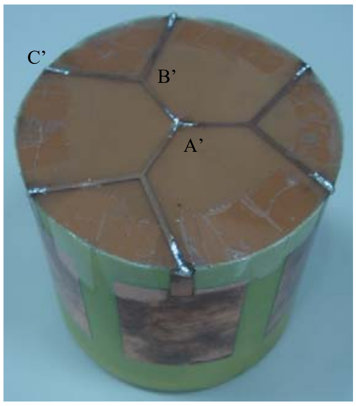

Fig. 7 Feed network of 1 × 6 array

Similarly, the feed network of low-profile antenna is shown as Fig. 7 and designed to compromise the influence of arrangement and purpose of omni-directional radiation pattern. The difference on return loss and gain of different arrays are shown as Figs. 8 and 9, respectively. The legend "planar element" means planar antenna with coupled feed, "single element" means low-profile antenna with one antenna element only, "four elements" means low-profile antenna with 1×6 array, and "six elements" means low-profile antenna with 1×6 array, respectively [11].

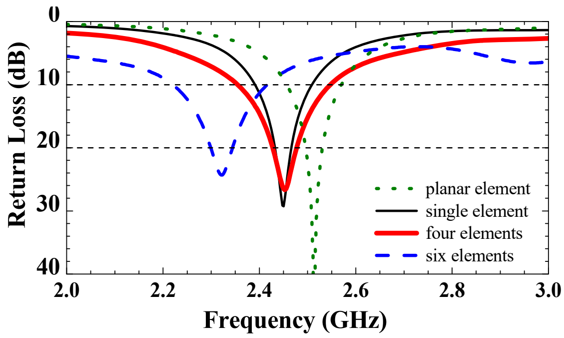

Fig. 8 Measured return loss for low-profile antenna of 1 × *N* array

The 1×4 cylindrical array of microstrip antennas had better 20 dB return loss at 2.4 GHz transmission frequency shown in Fig. 8 and also had higher antenna gain shown in Fig. 9. Therefore, it was suitable to install 1×4 cylindrical array of microstrip antennas on ventral positions of UAVs for receiving wireless signal from the ground after assessment. The research uses 1×4 cylindrical array antennas as shown in Fig. 6.

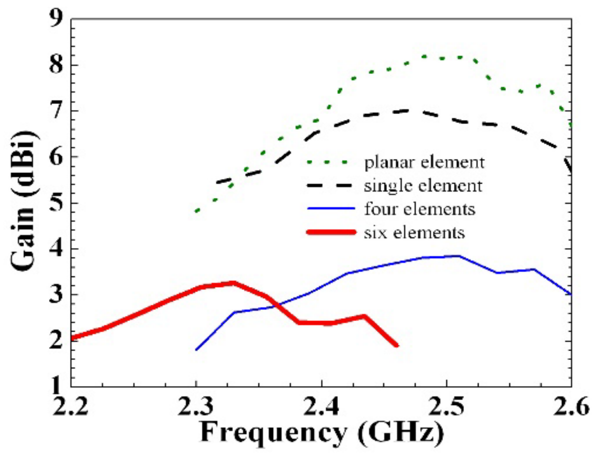

Fig. 9 Gain for low-profile antenna of 1 × *N* array

E. Microprocessor and Sensor

The Ardupilot Mege microcontroller was developed by the Atmega1280 single-chip integration and would be installed on the Harpy Eagle as the receiving-end data processing device. The specification of the device was shown at Table III [12]. The device had four groups of built-in RS-232 ports and it could connect RS-232 transmission interface with ZigBee wireless modulus, GPS modulus and storage modulus simultaneously.

TABLE III
ARDUPILOT MEGA SPECIFICATION [12]

Micro-controller	ATMega1280
Operating Voltage	5 V
Digital I/O Pins	40
Analog Input Pins	16
UART	4
Flash memory	128 kb
SRAM	8 kb
EEPROM	4 kb
Clock Speed	16 MHz

TABLE IV
ARDUIMU SPECIFICATION [13]

Micro-controller	ATMega328
Operating Voltage	5 V
Digital I/O Pins	2
ISP	1
I2C	1
UART	1
Flash memory	32 kb
SRAM	2 kb
EEPROM	1 kb

TABLE V
TMP102 SPECIFICATION OF THE TEMPERATURE SENSOR [14]

Accuracy	0.5 °C (-25-85 °C)
Supply Range	1.4 V-3.6 V
Resolution	12 bits
Digit output	Two-wire Serial interface

The ArduIMU microcontroller was developed by the Atmega328 single-chip integration and would be installed on the ground control end so as to transmit temperature data to wireless signal transmitters. The specification of the ArduIMU was shown in Table IV [13]. The microcontroller mentioned before had a group of built-in RS-232 port and it could connect with ZigBee wireless modulus. In terms of temperature sensors, it adopted TMP102 clips of Texas Instruments. The temperature sensor was a kind of the digital temperature sensor and it could connect with the ArduIMU microcontroller by the I²C transmission interface. The specification of the TMP102 temperature sensor was shown in Table V [14].

V. SYSTEM TESTING AND VERIFICATION

A. ZigBee Wireless Transmission Test

In the testing, the research used terminal software of two laptops and connected with ZigBee wireless transmission modulus by transferring USB to RS232 cable that were externally connected with laptops. To test the wireless transmission effect of coordinator end, the router end would connect with antennas and cylindrical array antennas respectively. For transmission testing, one laptop would continuously transmit characters and observed whether the other one on a plate trailer could receive strings steadily.

B. Microcontroller Programming Test

The research used the application of programming interface of Arduino to program for ground end and UAV end respectively. Temperature sensors were transmitted by I²C interface and microcontrollers on ground end. For the programming of ground end, microcontrollers would let temperature sensors receive the temperature data in every second. To prevent microcontrollers from failing to receive temperature data, it was necessary to add a command that the blue LED light should always shine when microcontrollers received the data from temperature sensors continuously.

For data collecting devices and programming of UAV end, the research bought microcontrollers which had been customized a set of plugs for GPS modulus so that EM-406A GPS modulus could connect with ArduPilot MEGA directly. The UAV end could record recent altitude, latitudinal and longitudinal data and receiving time in the meantime when receiving the temperature data from the ground end. However, the time and the data of latitude and longitude provided by NMEA were unreliable; thus, it should be transformed properly.

C. Integration Test of Reconnaissance System

The integration test of reconnaissance system on “Harpy Eagle” Mini UAV would be carried out on Hsisheng Airport. The photo of reconnaissance system on mini UAV is shown in Figs. 10 and 11 shows a photo as mini UAV flying in the sky. The EM-406A connecting with ArduPilot Mega would have offered flight GPS data. However, the conflict would occur when the ArduPilot Mega dealt with ZigBee signal and GPS data simultaneously and stored them in mini SD card. Instead, the research used the Sony HDR-SR5 with GlobalSat product, DG-100 data recorder, to record basic mission profile and show the wireless transmission of ZigBee module. According to the aforementioned, the ground end reconnoitered the ambient temperature with digital temperature sensors, TMP102. After the ArduIMU received the temperature data, the data would be wirelessly transmitted to UAV end by ZigBee. To clearly show the sensitivity of the system, the research did not only transmit signal in every second via ArduIMU but also create two different man-made ambient temperature specially. At the first test, the digital temperature sensor, TMP102, was heated with fire 10 times for 1 or 2 seconds in every time shown in Fig. 12. At the second test, the temperature sensor was cooled down with an ice bag and both of them were covered with a cloth to block the sun when the Harpy Eagle accomplished the climbing phase of the mission profile as shown in Fig. 13.

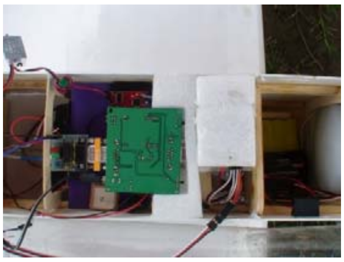

Fig. 10 Reconnaissance system on "Harpy Eagle" Mini UAV

Fig. 11 Mini UAV flying on Hsisheng Airport along the Tahan Creek near Taipei

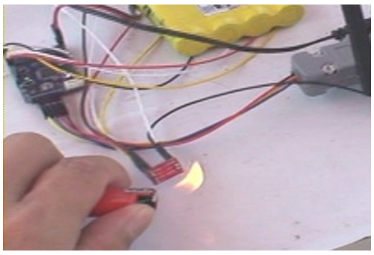

Fig. 12 Heating with fire

Fig. 13 Cooling with ice

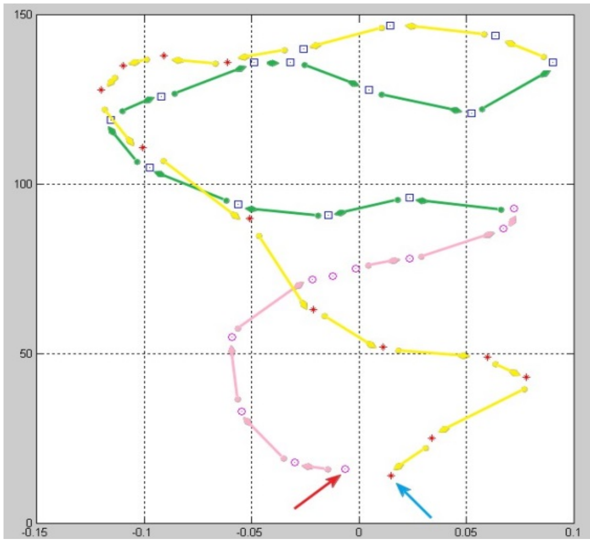

Fig. 14 Flight path for the first reconnaissance test (*y*-axis: Altitude; *x*-axis: Longitude deviation)

At the first test, there were 465 serial numbers of the temperature data shown by UAV end. The first test started with the ArduIMU powered up and ended with the mini SD card taken out after the UAV landing. The video spent 464 seconds in total which started with the ArduIMU that read the first temperature data of TMP102 after powered up with the blue LED light shining and ended with the mini SD card taken out after the Harpy Eagle accomplished a basic mission profile (take-off, loiter, landing). Compared with the video, the ArduIMU sent 465 peace of data. For 1 datum per second, the error of the time was one second. It can be seen that the system possessed the basic reconnaissance. The research set up the flight path of the basic mission profile as shown at Fig. 14. Compared with the Fig. 2, the basic mission profile was almost complete except for loiter phase. The loiter phase of main mission profile as shown at Fig. 14 was shorter than that of the original one as shown at Fig. 2.

When the UAV carried out the mission, the temperature data of the ground end could be transmitted by the ZigBee and could be stored in the mini SD card based on the original testing conception and the 240 m transmission distance of the ZigBee wireless transmission facility [10]. However, the serial number of temperature data would disconnect at the 232th until the 397th after the data stored in the UAV were inspected. Judging from the data stored in the mini SD card, the temperature data of the ground end could be received only at the phase of take-off, landing and climbing altitude that lowered than 50 m. The other flight phases were out of the range of the ZigBee wireless transmission distance.

According to the result of the first test, the actual ZigBee transmission distance was apparently different from what the vendor offered. Therefore, the first priority was to test whether the wireless transmission could work properly so that the research could try to reduce the UAV's altitude within the security clearance at the second test. In the light of the first test process, the Sony HDR-SR5 was still employed in full shooting with the DG-100 data recorder to minute the Harpy Eagle's flight data. There were 426 peace of temperature data in this test. The test started with the ArduIMU began to reconnoiter the ambient temperature after powered up and ended with the mini SD card was taken out after the UAV landing.

The research shown that the data stored in the mini SD card of the UAV end were more than that of the first test result through reducing the UAV's altitude. At the second test, changing the ambient temperature with an ice bag, the average temperature was 31 °C at that day. The 203th datum shown that the ambient temperature began to drop gradually and was lower than the ambient average temperature apparently. Hence, it can be seen that the ZigBee in the Harpy Eagle had operated properly and effectively to collect the ground end ambient temperature data continuously. After the 212th datum, the ambient temperature began to drop to less than 30 °C; meanwhile, the UAV's altitude was between 53 to 63 meters. The last data of the temperature was 26.56 °C that was less than the ambient average temperature by 14.3%. It has been proved that the function of the ZigBee wireless transmission shown up with the effect of lowering the temperature.

The research showed the basic reconnaissance as mentioned in Section IV.A by a single parameter of wireless temperature sensors. The motivation was to meet the future need of the war. However, the research found that the ZigBee wireless transmission distance was below the expectation at the first test for the basic reconnaissance. Thus, the research provided the solution to solve the error in the second test by making the ground pilots reduce the Harpy Eagle' s altitude so that it could reduce the distance between the UAV end and the ground end, and be beneficial to the transmission of temperature data signal. The research also found that the ZigBee could better receive signal by analyzing the temperature data of the second test and comparing with data of every recorders when the mini UAV was away from the ground end under the situations that the flight altitude was less than 61 m. Therefore, the mini UAV, Harpy Eagle, which possessed basic reconnaissance had achieved the mission specification.

VI. Conclusion

The research integrated the handmade mini UAV and the cylindrical array of microstrip antenna with ready-made ZigBee modulus and Arduino microcontrollers to make the mini UAV possess basic reconnaissance function. To verify the basic reconnaissance function, the research made use of the ZigBee to send the manmade temperature variation to the UAV end and then stored it to mini SD card after processed by microcontrollers. Although ZigBee would be subject to the transmission distance and lose part of data, it did not affect the preliminary result, "the mini UAV possessed basic reconnaissance function". Furthermore, adopting microcontrollers could not only reduce the volume but also save power. Above all, the research reduced the UAV mission payload indeed.

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