Introduction of Real-Time Video Surveillance System Using UAV

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Abstract —As the use of UAV (Unmanned Aerial Vehicle) such as drone has been increased recently, aerial video shooting technology and surveillance system began to attract global attention. The video surveillance system using an UAV requires high speed wireless transmission technology to obtain high resolution video images in real-time under poor on-air channel environment, accurate positioning trace technology to identify the actual position of the shooting area, and remote control technology for safe flight of an UAV. In this paper, solutions for two important technical issues that should be resolved and coupled in VSSU (Video Surveillance System using UAV) were suggested. One is a RTPA (Real-Time Position Analysis) method to estimate shooting location and area of an interesting zone. Another one is high-speed transmission method for wireless data-link to minimize distortion of valid images information even in poor wireless channel environment. The suggested high-speed transmission method provided same or higher transmission quality than existing wireless data-link transmission method, and more flexible data size to transmit both of mass video data and small control data. Also, the demanded performance of suggested methods was verified through simulation and actual realization. To analyze performance of the RTPA method, actual location and shooting area about shooting images were measured in three different locations by using Quad-copter. And then both location and shooting area of its predictability region were calculated based on GPS (Global Positioning System) information and camera status information by applying RTPA method. The result of this study can be applied to various surveillance applications.

Index Terms—UAV (Unmanned Aerial Vehicle), VSSU (Video Surveillance System using UAV), RTPA (Real-Time Position Analysis), Wireless Transmission, ASS (Aerial Surveillance System), GCS (Ground Control Station), INS (Inertial Navigation System)

I. Introduction

Recently, there are attempts to use UAV for acquisition of video images in various fields such as surveillance, reconnaissance, transportation, and disaster monitoring [1]. Helicam, which is a remote-controlled mini unmanned helicopter, used to obtain aerial pictures from camera equipped in its body, is used actively in the broadcasting field in order to obtain a difficult place for people to access.

Along with the broadcasting field, areal-time aerial video shooting technology using unmanned flight equipment has been further emphasized in the video surveillance field to be directly related to the life and safety of people. And the requirements are derived from various surveillance applications such as natural disasters, fires, crimes, management of cultivated land, and military reconnaissance. Especially, we will adapt the result of this paper to the development of Aerial Video Surveillance System which manages a cultivated land in the manner of Nazca Lines as shown in Fig. 1.

Fig. 1. Example of an aerial video surveillance system for nazca line type cultivated land

A. *UAV Video Surveillance System*

In general, conventional video surveillance system uses a fixed CCTV (Close Circuit Tele Vision) to monitor places of concern and interest [2]. But due to the limitation of shooting area of the fixed CCTV caused by height of installation, it has been replaced by a PTZ (Pan, Tilt, Zoom) camera to overcome limitation of shooting area.

However, a PTZ camera also has a fundamental limitation on height and distance due to an installation location inevitably. These limitations of distance and height are able to be overcome by shooting video images with the camera mounted on a vehicle for the ground or sky. Between them, using an aerial shooting can be more efficient to overcome the limits on distance and height.

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There was an aerial photography using manned aircraft in the past. However, the aerial photography by using a conventional manned aircraft is restricted to not only the regulation such as safety issues and flight clearance, but also a high cost issue. Accordingly, the demand for aerial shooting technology with speedy mobility and economic efficiency is emerged. Therefore, the revolutionary aerial photography technology using UAV appears on the aerial shooting method.

UAV designates an aircraft which is operated in accordance with areal-time remote control or a programmed flight plan without operation of pilots. Andan UAV Video Surveillance System means integrated technologies and configuration of equipment to execute mission for surveillance or reconnaissance using UAV [3].

B. Technical Issues of UAV Video Surveillance System

The video surveillance system using an UAV requires high speed wireless transmission technology to obtain high resolution video images in real-time under poor on-air channel environment, accurate positioning trace technology to identify the actual position of the shooting area, and remote control technology for safe flight of an UAV. There are two important issues that should be resolved and coupled in an UAV surveillance system.

The first issue is to identify the actual position of the shooting area from the video obtained through the camera. An UAV surveillance system acquires the current flight status and positioning information from the various sensors mounted on a UAV. It can immediately utilize the acquired information during the flight for surveillance of targeting area such as identification of current shooting area location, whole flight route, and etc. But it is very difficult to match the video images of shooting area, which are obtained from a camera mounted on UAV, with actual positioning information. In other words, there is a big difference between the actual positioning and video images of shooting area due to a number of factors such as the flight direction, shooting direction, angle of camera, and so on.

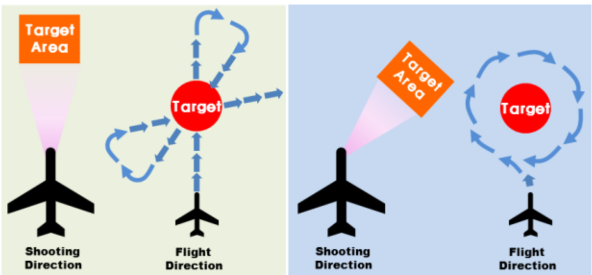


Fig. 2. Flight path according to flight direction and shooting direction

For an example, when we need to continuously acquire the video images of the specific target area, it requires a long flight time because UAV has to fly the circumference of the target area as shown in Fig. 2. Also, when we need to obtain the video images of the specific route, unnecessary shooting images might be collected because of the differences between shooting distance and flight direction due to flight altitude and horizontal angle of the UAV.

The second issue is to transmit and receive high resolution video images in real-time. As shown in Fig. 3, the UAV is generally turning around the Ground Control Station and performs reconnaissance missions. At this case, when the UAV moves from position of UAV1 to UAV3, the transmitted signal has a frequency shift phenomenon from the maximum plus (+) Doppler frequency to the maximum minus (-) Doppler frequency. In addition, while moving from UAV3 to UAV4, a reverse direction frequency shift phenomenon occurs. When the Doppler frequency keeps changing, it can occur to the link disconnection which can lead to fatal failure of flight control or mission failure. As UAV data link subsystem is required high reliability, the frequency shift phenomenon should be solved [4].

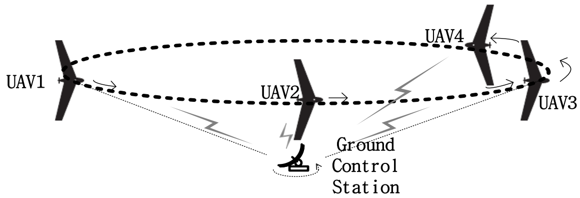


Fig. 3. UAV reconnaissance flight model

C. Solution Proposal for Technical Issues

In this paper, we are going to resolve and couple the two technical issues mentioned above on the aerial shooting using UAV as follows.

For the first issue which is the inconsistency of positioning between the flight path and actual shooting area, we apply the prediction method by applying Vincenty Formula for calculating of the aerial shooting position and area that had been proposed by authors before [5]. Also we advance prediction method that is able to reset flight route during UAV flying through position message handshaking with ground control station via wireless transmission equipment.

For the second issue which is a Doppler frequency shift problem by high-speed movements, we are to apply a QPSK (Quadrature Phase Shift Keying) demodulation technology to recover a Doppler effect on high-speed movements. In this paper, we suggest an unmanned aerial video surveillance and reconnaissance system called VSSU (Video Surveillance System using UAV) which coupled and interfaced with two solutions to resolve two technical issues, and verification results under the simulation and test environment.

II. VSSU (Video Surveillance System Using UAV)

A. Configuration of VSSU

The proposed UAV video surveillance system in this paper is composed of two subsystems. One is Aerial Surveillance System that shoots a target area for surveillance and transmits video images and flight recording data to the Ground Control Station through a down-link. The other one is Ground Control Station that receives information for surveillance from Aerial Surveillance System through a down-link and transmits flight control data through up-link.

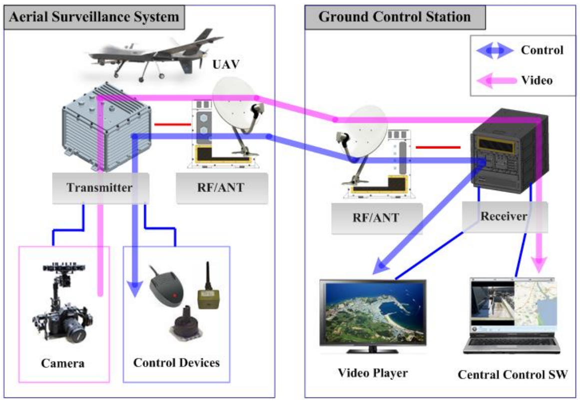


Fig. 4. The configuration of VSSU

Fig. 4 shows the configuration of proposed VSSU (Video Surveillance System using UAV), and Table I shows the function of components of VSSU.

TABLE I: FUNCTION OF VSSU COMPONENTS

Class	Component	Function
Aerial Surveillance System	UAV	Flying object for surveillance
	Camera(PTZ) Gimbal	HD (High Definition) Camera for shooting target area.
	Control Devices	GPS, 3-Axis accelerometer, etc
	Transmitter	Transmit video images and flight recording data to Ground Control Station via RF/ANT (Radio Frequency/ANTenna)
	RF/ANT	Changes digital data to analog data, transmits the radio signal
Ground Control Station	RF/ANT	Recieves radio signal, chages the analog signal to digital data
	Receiver	Receives the video and flight recording data from the Aerial Surveillance System
	Central Control SW	Shows the result of analyzedreceiving video images and flight recording data. Controls the UAV by sendig flight control data
	Video Player	Plays video received from UAV

We applythe RTPA(Real-Time Positioning Analysis) method for shooting area and QPSK demodulation mechanism in VSSUto resolve two issues mentioned in section I as follows.

First, the RTPA is applied to bothof INS(Inertial Navigation System) and control of gimbal camera on the Aerial Surveillance System. In case of Ground Control Station, it is used for the Central Control SW.

Second, the QPSK demodulation mechanism is applied to the transmitter of Aerial Surveillance System and the receiver of Ground Control Station.

In the following section, we will describe the description of each solution and how to implement.

B. Real-Time Positioning Analysis

In general, it is very difficult to predict positioning information of shooting area in real-time because of the difference between the direction of flight route and shooting. For the real-time positioning analysis, basic information such as the status data of the PTZ camera to acquire coordinates of shooting target area is required except INS data that is provided by a conventional unmanned aerial surveillance system.

Table II shows the basic information and limitation which are applied to RTPA method. The proposed RTPA method calculates positioning information based on location of UAV, distance and angle between UAV and shooting area.

Status information of the PTZ camera is absolutely necessary to calculate anestimated positioning of shooting area. Also, topographic information is required to take into account the three-dimensional topography using GPS map data.

TABLE II: BASIC INFORMATION FOR REAL-TIME POSITIONING ANALYSIS

Source	Data
Unmanned Aerial Vehicle	- Navigation Height, Position Info. via GPS - Direction of Navigation, Slope
PTZ Camera	- Direction, Focal Length, Ratio, Value of PAN/Tilt/Zoom
Topography	- Height(including 3D information)
Limitation	- Measured Shooting Area is based on a plane and the height of horizon

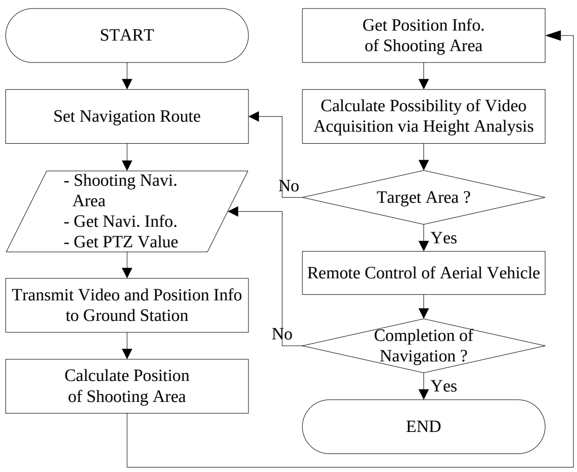


Fig. 5. Flow chart of real-time positioning analysis

Fig. 5 shows the operational flow of RTPA to transmit more meaningful video images using a PTZ camera, navigation information, and GPS. If we can calculate the position and area of shooting target based on INS data and status information of PTZ camera, a real-time remote flight control in Ground Control Station is possible.

To transmit high quality video recording information and surveillance data via poor wireless transmission channel surroundings caused by speedy flying, the prediction algorithm for the aerial shooting area that had been proposed should be integrated with transmission equipment and modified as show in Fig. 5 [6]. The flowchart as shown in Fig. 5 represents that it determines pre-set flight path and shooting availability through 3D (Three Dimensional) topography information. Then, according to the determination, it can control the flight route in real time during the flight by resetting the flight path through a series of process for path determination whether shooting of target position is possible or not [6], [7].

If an operator of Ground Control Station wants to monitor the shooting area by controlling pan, tilt, and zooming value of a camera mounted on UAV, he must be able to predict the position of the shooting area in real time. To do this, firstly, it needs to calculate the position information of the prediction area that is shot in UAV. In order to obtain the position information of the shooting prediction area, the data for the position and status information should to be gained based on direction and angle of the camera mounted on UAV. And then, the position information of shooting prediction area can be calculated based on UAV positioning information, distance from the predicted point, and azimuth from the predicted point obtained by using Vincenty Direct Formula [8].

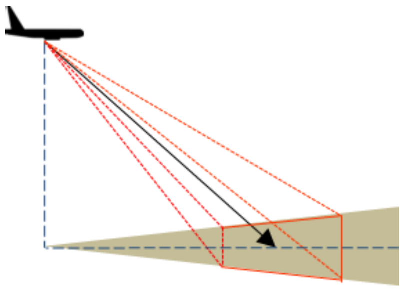


Fig. 6. The shape of shooting area

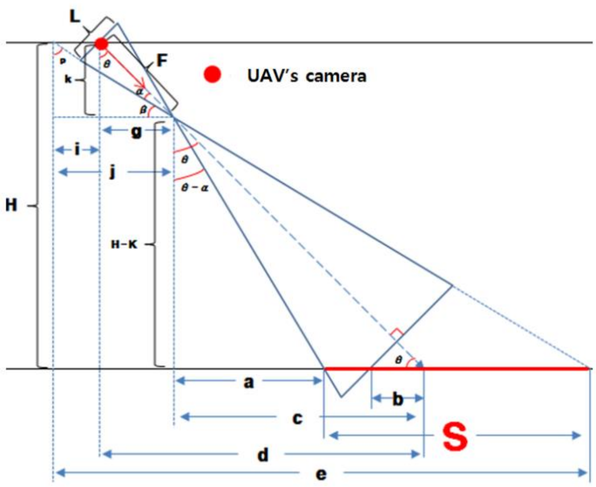


Fig. 7. The calculation process for length of side line

In case of calculating shooting target area, the shooting direction of a camera should be considered whether it is perpendicular to the ground or not. When the shooting direction of a camera is perpendicular, it is relatively easy to calculate shooting area which is rectangle or square. In this paper, we introduce how to calculate the shooting area when the shooting direction of a camera is not perpendicular to the ground [6], [7].

$$
\begin{aligned}
S = &\left(\tan\left(\theta + \left(tan^{-1}\frac{L}{2F}\right)\right) \times H\right) \\
&- \left(\left(\tan\left(\theta + \left(tan^{-1}\frac{L}{2F}\right)\right) \times cos\theta \times F\right) \\
&- \left(\sqrt{F^2 - (cos\theta \times F)^2}\right)\right) - \left(\sqrt{F^2 - (cos\theta \times F)^2}\right) \\
&- (\tan\left(\theta - \left(tan^{-1}\frac{L}{2F}\right)\right) \times (H - cos\theta \times F))
\end{aligned}
\quad (1)
$$

In Fig. 6, it shows the shape of shooting area when the camera is not perpendicular to the ground. In this case, in order to calculate the area of the shooting area, it is required to know the length of side line and front line. Fig. 7 shows how to calculate the length of side line when the camera is not perpendicular to the ground, and its operational procedure is shown in (1).

In Fig. 8, it shows how to calculate the front length of the shooting area when the camera is not perpendicular to the ground, and its operation procedure is shown in (2).

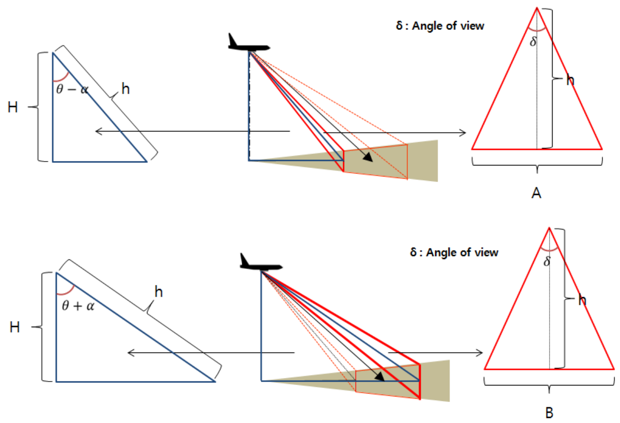


Fig. 8. The calculation process for length of front line

$$
\begin{aligned}
A &= \tan\frac{\delta}{2} \times 2 \times \frac{H}{\cos(\theta - \propto)} \\
B &= \tan\frac{\delta}{2} \times 2 \times \frac{H}{\cos(\theta + \propto)}
\end{aligned}
\quad (2)
$$

As shown in Fig. 9, the shooting area is calculated via (3) using the value of side length and front length that are obtained from (1) and (2). It is possible to calculate more precise shooting area via the compensation process that manipulates effects of camera image ratio.

Additionally, the shooting area can be divided into N parts that have the same length of side line. The geographic information, which divided into N points, is obtained using the location of UAV, the distance to each points, and azimuth. After decision of the shooting availability by comparing the geographic information mentioned above and the height of shooting area, it is possible to set the flight route of UAV to obtain more effective video images for the particular region [6]. The proposed algorithm has been advancing to reduce inconsistency rate of positioning and apply to a cultivated land in the manner of Nazca Lines.

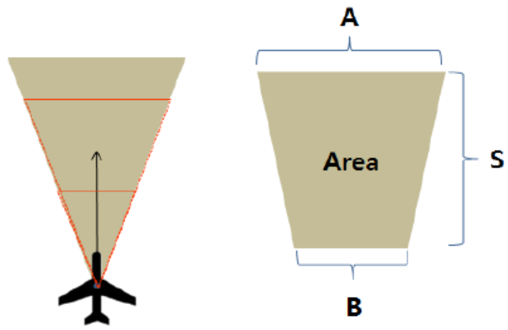


Fig. 9. Shooting Area when the Camera is not perpendicular to the Ground

$$Area = \frac{(A+B)\times S}{2} \tag{3}$$

C. Wireless Transmission for a Mass Surveillance Information

The current UAV system for surveillance has been changing to provide high resolution video images and more accurate positioning information. In this paper, we propose an effective wireless transmission technology which provides same or higher transmission quality than existing wireless data-link transmission method, and more flexible data size to transmit both of mass video data and small control data.

TABLE III: THE SPECIFICATION FOR WIRELESS TRANSMISSION

Item	Characteristics
Access Method	PSK(Phase Shift Keying) series/Spread Spectrum
Image Compression	H.264
Video Stream	MPEG2(Motion Picture Expert Group) or Self-Defined
Variable Bandwidth	28MHz@45Mbps
Physical Data Rate	Up to 8Mbps
Application Data Rate	Variable(~ 8Mbps)
Error Correction	BER(Bit Error Rate): 10^{-5}
Uplink Data Rate(Tm/Tc)	16kbps
Digital Up/Down	35dBc
Video Channel Multiplexing	2 Channels Input/ selected 1 Channel Encoding

Under poor wireless transmission channel surroundings caused by speedy flying, the suggested method is able to transmit high quality video recording information and surveillance data via accessing to various wireless networking services architecture such as One-on-One, Many-on-One, One-on-Many, Over the Horizon. Table III shows wireless transmission specification to provide surveillance information including high resolution video images which are acquired via UAV.

Table IV shows the main system parameters which are applied with frame structure for uplink and down link of wireless transmissions. The wireless transmission for the surveillance information via UAV uses a different frame structure according transmission mode. As shown in Fig. 10, in case of 8Mbps/4.416Mbps for downlink transmission mode, it consists of synchronous channel, head channel, TM (Tele-Metry), and data channel including video images. In case of 76.8kbps/spread 76.8kbps for uplink transmission mode, the transmission frame which consists of synchronous channel and data channel is transmitted using spread or non-spread method [7]. Fig. 10 and 11 show the frame structures for downlink and uplink transmission mode, respectively.

TABLE IV : SYSTEM PARAMETERS FOR FRAME STRUCTURE

Parameter	8.000Mbps	4.416Mbps	76.8kbps	76.8kbps
symbol rate/sec	4.992MHz	4.608MHz	72kHz	72kHz
bandwidth	6.240MHz	5.760MHz	90kHz	90kHz * 64
modulation	QPSK	QPSK	QPSK	QPSK
frame length	0.5ms (2,496sym.)	0.5ms (2,304 sym.)	5ms(360 sym.)	
no. of frame/sec	2,000	2,000	200	
CTC input/frame	4,000	2,208	384	
transmission rate	8,000Mbps	4,416Mbps	76.8kbps	
code rate	5/6	1/2	2/3	
CTC output	4,800	4,416	576	
# of preamble sym.	80 (16/48/16)		72 (16/48/8)	
# of data sym.	2400	2208	288	
# of header sym.	16		0	

* CTC : Convolutional Turbo Code

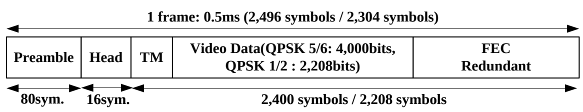


Fig. 10. Frame structure for downlink transmission mode of 8Mbps/4.416Mbps

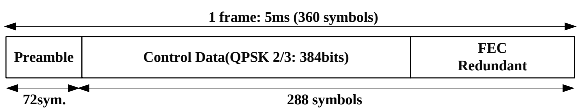


Fig. 11. Frame structure for uplink transmission modeof 76.8kbps/spread spectrum 76.8kbps

The signal received from the down-link may contain even the timing gap between the transmitter and receiver, the difference of carrier frequency, and Doppler frequency shift effect. Fig. 12 shows the Doppler Frequency Shift Model for VSSU, and (4) shows the received signal model that reflects above factors.

$$r(k) = S(k+\Delta k)\cdot e^{\left[-j\cdot 2\pi \cdot \frac{\{\Delta f_c + f_d(k)\}}{f_s}\cdot k\right]} + n(k) \tag{4}$$

$f_d(k)$ is Doppler frequency based on time domain, and the moving speed rate Δv[km/h] can be calculated using (5).

$$f_d(K) = K \cdot f_0,$$
$$f_0 = \left(\frac{\Delta v}{3600}\right)/\left(\frac{c}{f_c}\right)/f_s, \text{ (C: Speed of Light, } 3\times 10^9\ m/s) \quad (5)$$

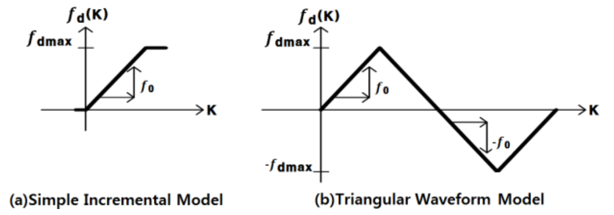


Fig. 12. Doppler frequency shift model for VSSU

To compensate Doppler effects caused by speedy flying, we assign 10km/hto the value of speed change rate Δv, and we get $138.9/f_s$ Hz as the value of frequency shift f_0 when increases or decreases during $1/f_s$ period under 15GHz carrier frequency. In Table V, we shows required functions for the reliable receiving of transmission signals and proposed demodulation method.

TABLE V: FUNCTIONAL REQUIREMENT AND DEMODULATION

Function	Requirements	Demodulation Method
Preamble detection	Extract in the range of +/-1	• Apply the peak power detector of differential correlation method
Timing Recovery (TR)	Need the insensitive method according to the difference of frequency	• Apply Gardner Estimator and interpolator[9]
Carrier Recovery (CR)	Require the tracking of Doppler frequency according to the time variation	• Offset estimation by correlate with Preamble • Automatic control of the loop filter gain by locking test[10]

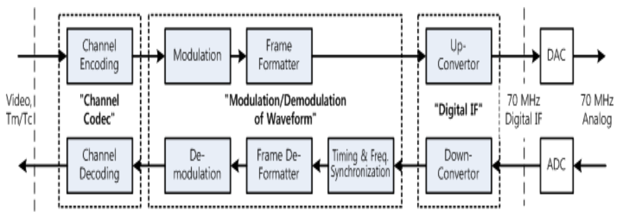


Fig. 13. Common block diagram of transmitter/receiver

Fig. 13 shows the common function block diagram for wireless transmission equipment to transmit surveillance information such as video images, positioning, and control which are applied with demodulation method and frame structure mentioned above.

D. Implementation and Testing of VSSU

To verify the validity of RTPA and applicability of wireless transmission for mass surveillance information, we have implemented the VSSU and installed a simulated environment in a lab. Fig. 14 shows the system configuration of VSSU to verify wireless transmission technology for effective acquisition of video recording information via real-time position analysis.

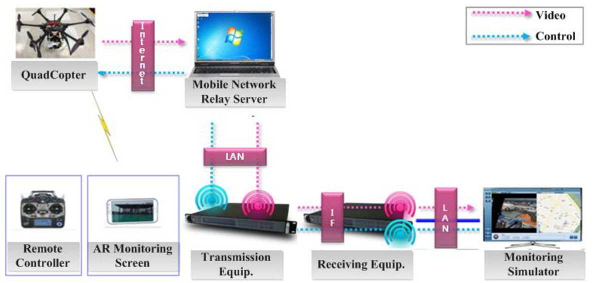


Fig. 14. System configuration of VSSU

The simulated VSSU consists of the Aerial Surveillance System and Ground Control Station. Aerial Surveillance System is composed of Quad Copter, Remocon, Gimbal network camera, INS, and Transmitter as shown in Fig. 15. We used a Quad Copter as a substitute of UAV and implemented PTZ functions by using a Gimbal network camera. Also we used a simple INS to obtain flight information and developed wireless transmitter/receiver to communicate with Ground Control Station. For the data communication between the transmitter and quadcopter which delivers surveillance information including acquired video images, positioning and control data, we use LTE (Long Term Evolution) networks.

Fig. 15. Components of aerial surveillance system

The Ground Control Station is composed of a receiver and control tower simulator which is connected using Ethernet. We implemented control tower simulator to monitor the received video images and trace the flight route and shooting area. Fig. 16 shows components of Ground Control Station. The transmitter in Aerial Surveillance System and the receiver in Ground Control Station were connected by IF (Inter Frequency) instead of RF (Radio Frequency).

To analyze performance of the RTPA method, actual location and shooting area about shooting images were measured in three different locations by using Quad-copter. And then both location and shooting area of its predictability region were calculated based on GPS information and camera status information by applying RTPA method.

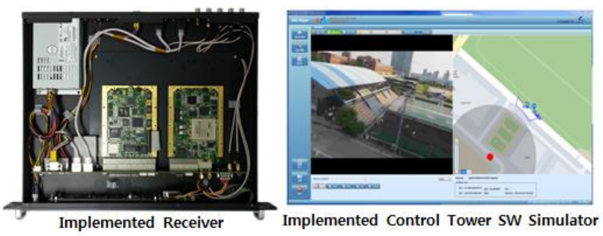
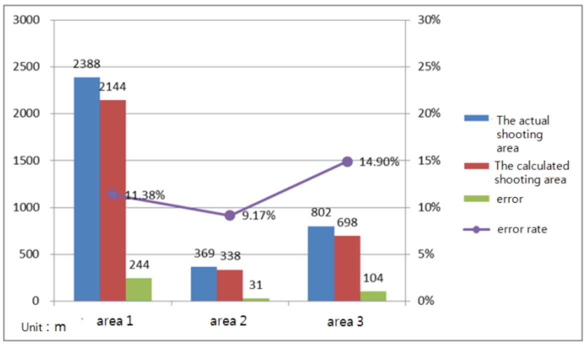
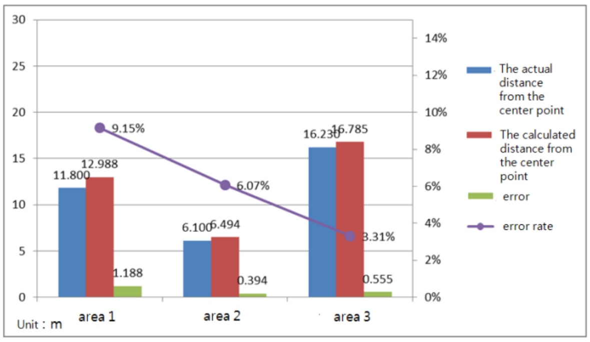


Fig. 16. Components of ground control station

Fig. 17 shows the error rates between actual measurement and estimation using RTPA against shooting area and distance at three different shooting places. The average error rate of distance and shooting area between three different actual shooting places and calculated distance based on center of shooting images was 6.18% and 11.82%, respectively [6], [7], [11]. The major reason of ascertained error rate, that calculated with amount of more/less than 10%, was analyzed to induce from receiving error of GPS signal that exist inaccuracy with amount of 20 meters based on horizon and vertical. Considering the ascertained error rate, the suggested RTPA might be applied UAV video surveillance system because it could provide effective video images more than 90% based on the center of the interesting shooting zone.



(a) Shooting AreaError: Actual vs. Calculated

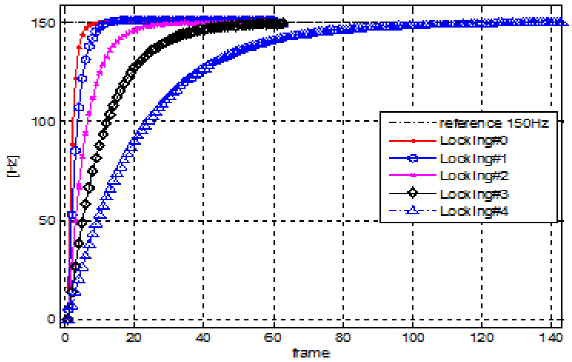


(b) Distance Error : Actual vs. Calculated

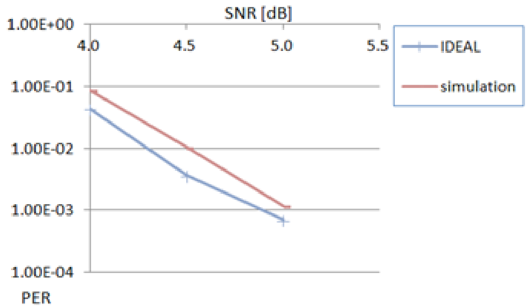
Fig. 17. Analysis of shooting area and length: Actual vs. Calculated

To verify whether the implemented QPSK demodulator is able to recover Doppler effects caused by speedy flying or not, we traced the change rate of Doppler frequency on the every level of locking state. Through in the manner of this simulation process, we acquired an acceptable test result that can be fully tracked for the frequency change ±138.9Hz per second. The margin of required performance was deduced through the verification under testing environment using implemented transmission equipment. Moreover, the BER performance analysis which drawing SNR (Signal to Noise Ratio) satisfied a BER performance goal(10e-5), and PER (Packet Error Rate) performance analysis that deriving SNR satisfied a PER performance goal(<5%) were verified through several simulation during design process, respectively. For the performance analysis of implemented transmission equipment, verification environment error such as tuning and frequency errors of Radio Frequency (RF) equipment, was considered with 3dB SNR Margin. Through this process, the implemented transmission method, that operates within the range of 0.3dB (@ PER=1.0e-3) performance deterioration comparing with a theoretical value under frequency shift environment, was proved suggested design specification by measuring SNR according to the transmission mode.

Fig. 18 shows output signal of loop filter and measured PER performance of proposed QPSK demodulator.



Loop Filter Output Signal



PER Performance of QPSK Demodulator (Channel CODEC: CTC2/3)

Fig. 18. Test results of output signal and PER performance of proposed QPSK demodulator

III. Conclusions

The current UAV system for surveillance has been changing to provide high resolution video images and more accurate positioning information.

In this paper, we suggested solutions for two important technical issues that should be resolved and coupled in an UAV video surveillance system. The proposed wireless transmission technology was verified to be able to provide same or higher transmission quality than existing wireless data-link transmission method, and more flexible data size to transmit both of mass video data and small control data. Under poor wireless transmission channel surroundings caused by speedy flying, it was able to transmit high quality video recording information and surveillance data via accessing to various wireless networking services architecture such as One-on-One, Many-on-One, One-on-Many, Over the Horizon.

Also, we proposed RTPA method that is able to re-calculate shooting location and area of image information for resetting of safe flight route by applying Vincenty Formula with acceptable error rate.

The design specification for wireless transmission of VSSU, transmission frame structure and parameter, and functional requirements of demodulation was suggested. To verify the VSSU, we simulated the function of each component. Through the verification processes, we obtained meaningful error rates for difference of distance and shooting area, and PER performance using implemented VSSU under lab environment.

Based on the result of implementation and verification, we will setup design concept and develop Aerial Video Surveillance System which monitors Nazca Lines Type cultivated land. And we will proceed with further research that utilizes the result of this paper for various application fields including military application as bellows:

- Miniaturization of Transmitter and Receiver to be equipped on UAV
- Antenna and RF for Transmitter and Receiver
- Development of INS applied effective prediction algorithm for acquisition of meaningful video images and shooting area
- Development of rectification algorithm for compensation of lens distortion

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