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Article · March 2015

DOI: 10.1109/URAI.2014.7057485

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The 11th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI 2014)
Nov. 12-15, 2014 at Double Tree Hotel by Hilton, Kuala Lumpur, Malaysia

Collaborative Control of UAV/UGV

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Abstract –In this study, a cooperative UAV and UGV platform is proposed to obtain a wide range of visual information. The UAV recognizes a pattern marker on UGV and tracks the UGV without user control. It can provide wide range of visual information for a user in the UGV. The UGV by a user is controlled equipped with an aluminum board. And the UAV can take off and land on the UGV. The UAV uses two cameras; one camera is used to recognize a pattern marker and another is used to provide a wide range of visual information to the UGV's user. It is guaranteed that the proposed visual-based approach detects and tracks the target marker on the UGV, and then lands well. The experimental results show that the proposed approach can effectively construct a cooperative UAV/UGV platform for obtaining a wide range of vision information.

Keywords – UAV, UGV, Vision, Quadcopter, Trajectory Following

1. Introduction

Recently, UAV and UGV have been actively researched. The UAV takes off from the UGV, tracks its location, and lands at the UGV. In this situation, image recognition is commonly used by the UAV for recognizing the UGV. A black and white circle is positioned on the top side of the UGV and the UAV recognizes this circle while moving[1][2]. In another study, two LEDs are located at top positions on the UGV and UAV; the distance between these two LEDs from a watching position is used for positional determination[3]. However, previous studies[1-3] have suggested that black colors and LEDs are inefficient during the day; it is difficult to keep track of a black circular object when the sun appears or if the light shines on the UGV and UAV, causing the disadvantage of improper tracking.

In this study, a cooperative UAV and UGV platform is proposed. The UAV is placed in front of the field of view of a camera to collect a wide range of information so the UGV's user can keep tracking the UGV by the UAV. A UAV in the air is difficult to observe from the ground because of limited sight. Therefore, UAVs are suitable for reconnaissance and surveillance missions. However, the short operating time of UAVs offers a disadvantage when attempting to reach a destination: owing to the constraints of time, it is difficult to convey visual information to the UGV's user. To perform the duties required for the user, the operating time of commercially available UAVs is usually 20 to 25 minutes; this time may also be shortened. Therefore, in this study, to overcome these shortcomings, the UAV is fixed on the UGV when no visual information is required. The UAV takes off and provides visual information when required by the UGV's user. After the end of the mission, the UAV lands on the UGV to charge. After charging, if the UGV's user requires a wide range of visual information, commands are given to the server PC for the UAV to take off.

2. Overall System

The overall platform of the proposed UAV/UGV is shown in Fig 1; this figure includes information about the UAV, the UGV, and the server PC. The UGV is a mobile robot with four wheels controlled by the user. The UAV consists of a converted DJI Phantom 2 frame. Normally, the UAV is located on top of the aluminum board on the UGV, and the UGV's user gives the takeoff commands using the server PC. During takeoff, the bottom camera of the UAV transfers an image of the marker to the server PC. Simultaneously, the front of the camera provides the user with a wide range of visual information. The server PC recognizes the camera image markers and transmits packets of current locations to move the UAV.

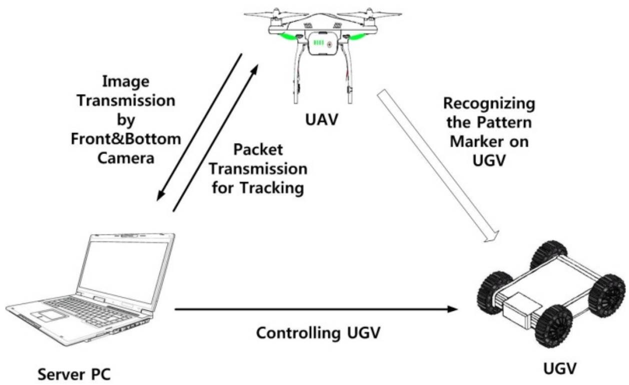


Fig. 1. Overall System

The control structure of the overall system is shown in Fig 2. The UAV is composed of two microcontrollers. A Phantom 2 NAZA-M is embedded in the microcontrollers. Gyro sensor, compass sensor, and GPS are used for hovering and attitude control; a bus signal from each motor provides input for controlling the motors.

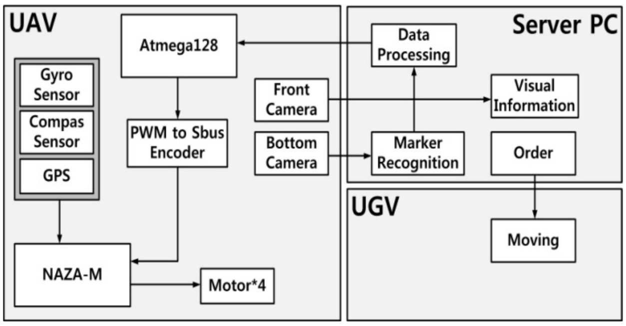


Fig. 2. Control Architecture

3. UGV-UAV

3.1 UGV

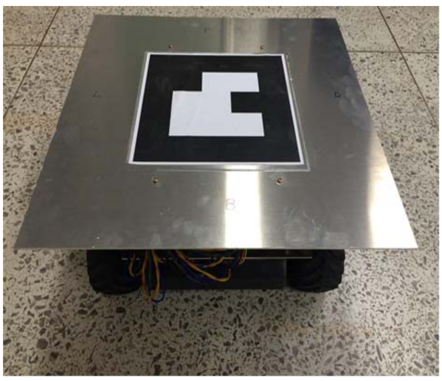
The UGV is shown in Fig 3. The structure includes four wheels, each of which are controlled by four respective motors. The microcontroller for communication and PWM output uses a DSP, and a WiFi module is used for communication between the UGV and the server PC.

For takeoff and landing, the UAV is attached to the aluminum plate on top of the control board. The marker is located in the center of the plate. Aluminum plates allow easy takeoff and landing for the UAV; the aluminum board is larger than the UAV.

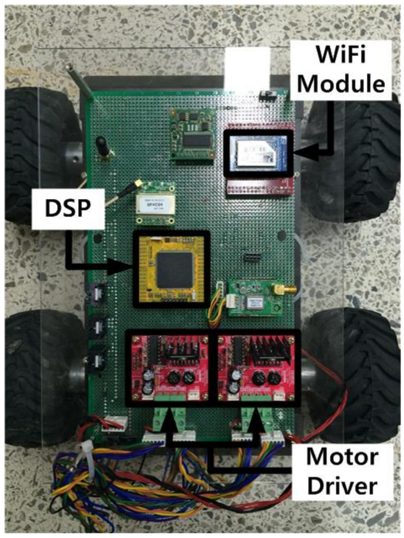
The UGV is controlled by the user's commands from the server PC. The UGV is shown in Fig 3. Packet commands from the server PC are listed in Table 1.

Table 1 Transmission packets of the UGV.

Command	Start Bits		Communication packet	Parity Bits
Front	FF	AA	04	52
Back	FF	AA	05	51
Left	FF	AA	06	50
Right	FF	AA	07	4F
Parity Bit = ~((0xFF+0xAA+(04~07))&0xff)				



(a)



(b)

Fig. 3. Composition of UGV :
(a) Overall Composition (b) Internal Composition

Table 2 Specifications of the UGV.

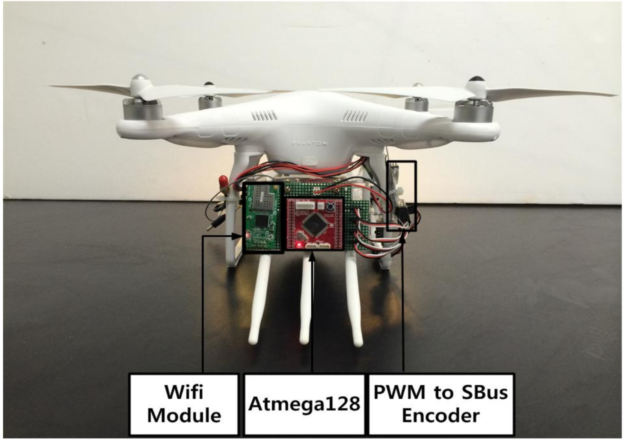
	Body	Including aluminum board
Length	340 mm	410 mm
Width	340 mm	410 mm
Height	160 mm	220 mm
Weight	4.3 kg	
Actuation time	90~100 min	

3.2 UAV

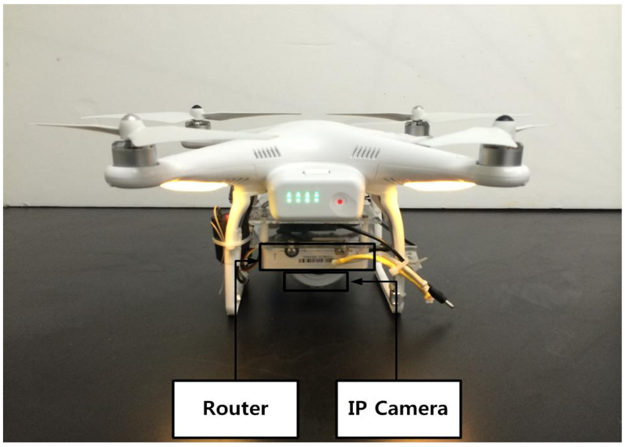
A DJI Phantom 2 is used for the frame and motors of the UAV. For autonomous tracking, the UAV is remodeled and equipped with controllers and other devices, as shown in Fig 4. A WiFi module is attached for communication between the server PC and the microcontrollers. An IP camera is attached at the bottom to recognize the UGV's marker. For smooth communication of the IP camera images, the IP camera and router communication are wired. The router is equipped on the bottom of the UAV.

Table 3 Specifications of the UAV.

	Except propeller	Include propeller
Length	285 mm	490 mm
Width	285 mm	490 mm
Height	180 mm	
Weight	2.6 kg	
Actuation time	10~15 min	



(a)



(b)

Fig. 4. Composition of UAV :
(a) Front Composition (b) Rear Composition

4. Tracking Method

The marker recognition method is used for reliable tracking of the UAV. The marker recognition algorithm is based on Visual Studio; the server PC uses the OpenCV library program for processing. Depending on the positions of the markers for the four attitude control values, the values are transmitted via WiFi.

The UAV is moved through four attitude controls: roll, pitch, yaw, and height. As shown in Fig 5 (a), position error, e, is obtained at the center of the image, along with the UAV Q^c at the center of the pattern with the UGV M^c.

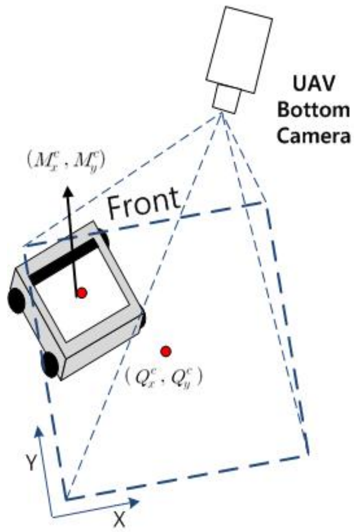
$$M^c = \begin{pmatrix} M_x^c \\ M_y^c \end{pmatrix} \quad Q^c = \begin{pmatrix} Q_x^c \\ Q_y^c \end{pmatrix}$$
$$e = \begin{pmatrix} e_x \\ e_y \end{pmatrix} = M^c - Q^c \tag{1}$$

As shown in Fig 5 (b), the angle difference, θ_m, of the x-axis of the UGV is defined for the UAV and UGV to determine the twisted angle and establish the overall picture through coordinates. The space angle, θ_e, of the UAV and UGV can be obtained by subtracting $90°$ from θ_m.

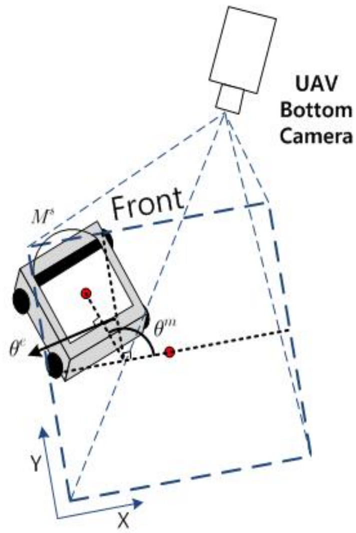
$$\theta_e = \theta_m - 90° \tag{2}$$

The top length of the marker, defined as M^s, is used to control the height of the UAV's. In actual experiments, the UAV maintains an approximately 2 m t height for simpler tracking. The marker length value, M^d, is defined at a distance of 2 m between the marker and the UAV, according to prior camera experiments. The error, e_z, is obtained by subtracting the length of the reference marker from the length of the real image marker.

$$e_z = M^d - M^s \tag{3}$$



(a)



(b)

Fig. 5. UGV Tracking with UAV Collaboration :
(a) Roll, Pitch (b) Yaw, Height

The four parameters, obtained earlier by using PD controller, Q^m, are calculated.

$$Q^m = \begin{pmatrix} Q_r^m \\ Q_p^m \\ Q_h^m \\ Q_y^m \end{pmatrix} = \begin{pmatrix} P_c + k_p e_x + k_d e_x{}' \\ P_c + k_p e_y + k_d e_y{}' \\ P_c - h_p e_z - h_d e_z{}' \\ P_c - k_p \theta_e - k_d \theta_e{}' \end{pmatrix} \qquad (4)$$

Transmission packets of the UAV are listed in Table 4.

Table 4 Transmission packets of the UAV.

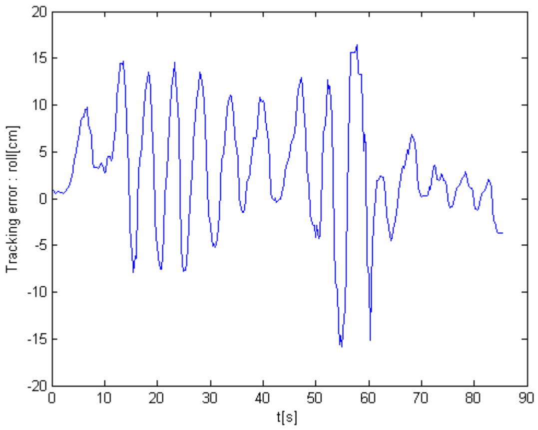
FF	BB	CH1	CH2	CH3	CH4	P
Start Bits		78~108				Parity Bits
Parity Bit = ~((0xFF+0xBB+CH1+CH2+CH3+CH4)&0xFF)						

5. Result of Experiment

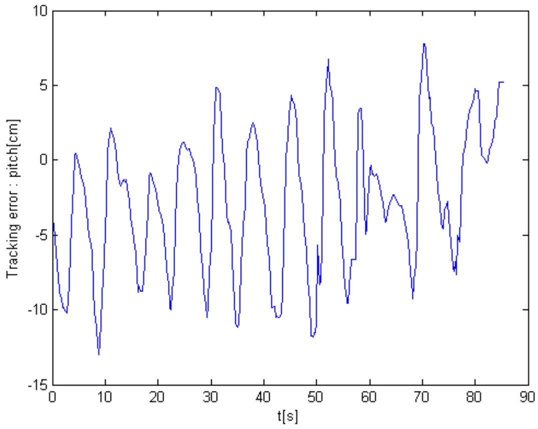
The proposed platform is verified through experiments with the produced UAV and UGV. Fig 6 shows a graph of each UAV attitude control value of roll, pitch, and height during the UGV tracking. Each control value is obtained through expression (5).

$$\begin{pmatrix} E_r \\ E_p \\ E_h \end{pmatrix} = \begin{pmatrix} k_p e_x + k_d e_x{}' \\ k_p e_y + k_d e_y{}' \\ h_p e_z - h_d e_z{}' \end{pmatrix} \qquad (5)$$

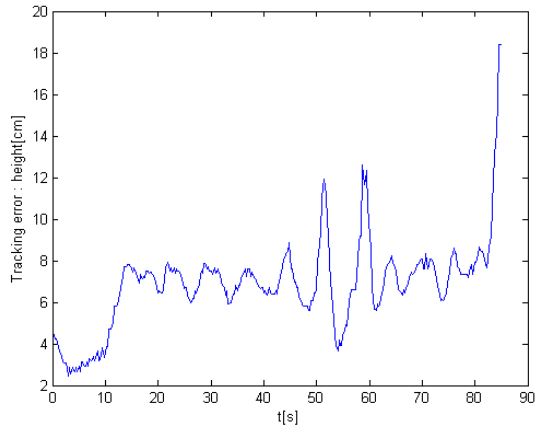
Distance values for each attitude control error are as follows: roll is $E_r = \pm 20[\text{cm}]$, pitch is $E_p = \pm 13[\text{cm}]$, and height is $E_h = 0 \sim 18[\text{cm}]$. During outdoor experiments, the effects of wind on the UAV increased the error, but error-free tracking can be identified in Fig 7.



(a)



(b)



(c)

Fig. 6. Each tracking value:
(a) Roll (b) Pitch (c) Height

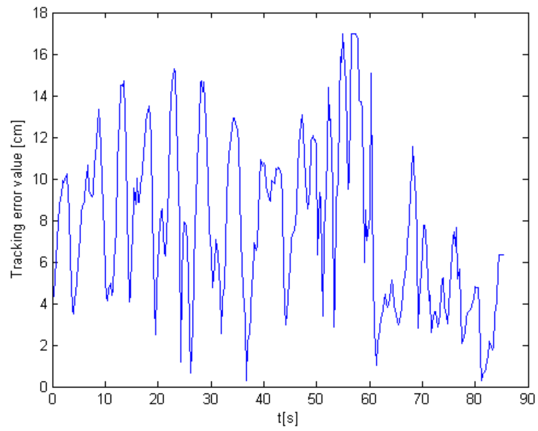


Fig. 7. Error value in tracking

Fig 7 shows an error value in tracking. Error value E_t is obtained by roll and pitch during tracking and through expression (6).

$$E_t = \sqrt{(E_r^2 + E_p^2)} \qquad (6)$$

Fig. 8. Experimental tracking of UGV by UAV

Fig 8 shows the experiment tracking the UGV by the UAV. Images can be received of up to 30 fps, but the communication status is uneven, maintaining approximately 20–25 fps. The tracking algorithm for the sampling time is set to 0.25 s. The proposed research results in collaborative control of the UAV/UGV [4].

6. Conclusion

In this study, a platform was proposed to operate a UGV and a UAV to obtain a wide range of visual information. As a result, the UAV tracks the UGV and visual information is transmitted to the UGV. This visual information is employed by the UGV's user for avoiding obstacles, predicting conditions, and planning driving paths. The single reconnaissance UAV is inefficient for continuous reconnaissance because of its short operating time. However, these drawbacks are overcome through operation with the UGV. In addition, reliable tracking is made possible by using a marker pattern to counteract the effects of external light and objects. The system proposed in this study is expected to be applied for special vehicles requiring omnidirectional paths, broadcasting cars requiring omnidirectional filming, and command army cars changed to UGVs.

Acknowledgement

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (2013R1A1A2005206).

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