Design and Implementation of UAV System for Autonomous Tracking

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Abstract

Unmanned Aerial Vehicle (UAV) is diversely utilized in our lives such as daily hobbies, specialized video image taking and disaster prevention activities. New ways of UAV application have been explored recently such as UAV-based delivery. However, most UAV systems are being utilized in a passive form such as real-time video image monitoring, filmed image ground analysis and storage. For more proactive UAV utilization, there should be higher-performance UAV and large-capacity memory than those presently utilized. Against this backdrop, this study described the general matters on proactive software platform and high-performance UAV hardware for real-time target tracking; implemented research on its design and implementation, and described its implementation method. Moreover, in its established platform, this study measured and analyzed the core-specific CPU consumption.

Keywords: High-Performance UAV, Autonomous Tracking UAV, UAV Platform, UAV Hardware Platform, UAV Software Platform, UAV System Architecure

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1. Introduction

Existing UAVs can be divided into the following areas according to their way of application. First, UAVs are utilized to gain video images in hobbies, academic data collection, and commercial filming. There are a variety of sensors utilized to take video images including more affordable video image sensors capable of VGA-grade image taking and broadcasting equipment-grade video image sensors capable of filming 4K UHD resolution-grade ads and programs. Depending upon video image sensor types, the supporting gimbal size and weight are determined. The loading weight and size determines the output of an aerial vehicle and which affects the flying vehicle's size, number and capacity of turning motor. Secondly, the purpose is to implement a specific function while UAV is flying. For instance, an aerial vehicle utilized in agriculture flies by following the GPS signals set by an operator and sprays agricultural chemicals or nutrition. Or they communicate wirelessly with diverse sensors arranged in the filed while flying to obtain sensor data. Third, UAVs are utilized for video image monitoring such as exterior inspection to see if there is any problem in disaster prevention system, building or large-scale structure, and thermal leakage based on an infrared camera. In addition to real-time video image monitoring, they record filmed images in a storage medium to implement analysis.

As listed above, UAVs are broadly utilized these days by operators who actively intervene in operating flying vehicle(s) on the ground to produce video images. Most UAVs utilized in the agricultural field are controlled based on the calculation of collected GPS coordinates. Such restrains are caused by the hardware and software inside UAVs. For a more proactive UAV than the existing systems, high-performance hardware and software are necessary. This paper described a high-performance UAV hardware system for real-time target tracking and design and implementation of software platform operating it.

The UAV for real-time target tracking is designed and implemented for the following purposes. First, it should be able to video-record and track a target in any circumstances [1]. Second, to enhance the tracking rate of tracking algorithm, preprocessing of images being filmed should be possible. For the real-time control of aerial vehicle and gimbal, the delay time from video image sensor to track algorithm should be minimized [2][3]. Third, during the operation time of aerial vehicle, it should operate on low power. Forth, it should be able to store the video image being filmed by the flying vehicle in raw video images [4]. This can be utilized to improve the tracking algorithm in the future. To satisfy the requirements above, this study designed and produced FPGA board and CPU board. For video image preprocessing and integrity, FPGA programing was conducted. For CPU board, each software module was produced for gimbal control, flying vehicle control, video image storage and tracking algorithm implementation and which were integrated in the operating software.

This paper is structured as follows. In the main discussion, high-performance hardware composition and module roles were listed for a proactive UAV along with suggestions and implementation details of the overall operational software that integrated each software module and software to operate it. In the study experiment, based on CPU board operating software CPU core allocation and consumption were measured and experimental results were analyzed.

Based on the platform studied in this paper, we makes working autonomous tracking UAV system.

2. Related Work

The UAV system materialized in this study utilizes a multicopter aerial vehicle to conduct tracking and flight control.

UAV refers to an aerial vehicle with at least 3 rotors (rotating wings). It does not need a tail wing to prevent antitorque like single-rotor-based helicopters and can adjust each propeller speed to generate thrust and torque to control directions.

UAV can take off vertically and hover like helicopters and have a simple mechanical structure. In order to calculate a proper motor speed according to stability and control input, flight control is indispensable. To this end, a motor, transmission, receiver, and power distribution board are required.

With the recent advancement in the electronic field, it has become possible to make such components even smaller at a more affordable price, providing more aerodynamically efficient vehicles with good controllability than helicopters for easy access to general people. However, these vehicles have a shorter flight time because their rotor-turning motor consumes larger energy than that of helicopters, which generates the same output.

2.1 Basic components of UAV hardware

The hardware components of a UAV aerial vehicle are as follows; The CPU board, FPGA board, Flight Controller, and power board designed and produced in this study are described in the design part.

- Motor

These days, brushless motors are frequently utilized. Existing motors with a brush has a limitation of losing force with rotation speed increase. However, brushless motors with a microprocessor control device allow swift speed change to deliver flight precision and high efficiency. But, since all brushless motors operate within a strict temperature limit, their efficiency drops beyond the limit.

- Transmission (ESC)

According to the throttle (output) stick control via controller, receiver throttle channel signals are transmitted to the Electronic Speed Controller (ESC) to control brushless motor output.

1. Control device (receiver) connection transmits signals from the receiver.

2. Motor connector: Three cables transmit alternating current (AC) from transmission to motor. Of the three cables, 2 spin the motor by changing current directions alternately.

- Propeller

Airplane propellers push backward the air in front and make an airplane move forward as much as the distance it pushed the air backward.

In general, propellers are measured in the unit of inch. For instance, in the case of 10x4.5, 10 represents the diameter of a virtual circle drawn when a propeller spins and 4.5 means twisted propeller angle which is the distance that a propeller moves forward by making one rotation.

- Sensor

Gyro detects directions on its own based on gravity to level out an aerial vehicle. Accelerometer is utilized together with Gyro and measures the angle based on gravitational acceleration. Barometer is used to measure the altitude. Atmospheric pressure decreases with altitude and by measuring the changes, altitude can be identified. However, an error may occur depending upon topography and weather and the seawater level is the basis of altitude measurement, not the sea level. Magnetometer detects the direction of magnetic field to function as a compass. As it indicates the north for precise direction setting, it is an essential component in GPS use. Optical flow and sonar detector measure altitude while being several meters away from the ground. They are essential components for automatic landing.

- Antenna

Antennas are indispensable to stably receive video images. Basically, dipole antennas are utilized, which are similar to those used in RC controllers or internet routers. However, their benefits are less than sufficient thus; diverse kinds of antennas are employed. For video transmission devices, mushroom-formed antennas are often employed and directional antennas in the shape of a broad plate are mainly used as a receiver.

- Monitor

AV monitors are utilized in general. TV or navigation supporting RGB external input or PMP are usable. A notebook can be also utilized as a monitor. In this case, a device capable of changing RGB into digital signals and transmitting to the notebook via USB is necessary. It will be beneficial to check via the notebook while saving the real-time transmitted video in a file. However, depending upon notebook computer specifications, video reception may be delayed by 0.5~1 second.

- Gimbal

Gimbal is a device that holds the camera steady. In order not to be affected by the vibration from an aerial vehicle, it helps maintain level all the time. There are 2-axis gimbal and 3-axis gimbal and 3-axis gimbals are used more often as they are more stable than 2-axis gimbals.

- OSD

On Screen Display (OSD) is a device to check flight information. It displays on screen information such as battery power (remains), flight hours, airframe inclination (posture), bearing, start-point direction and distance, altitude, and speed. OSD is mounted on an aerial vehicle to overlay the received information through accelerometer, GPS, etc. between the camera and video transmitter and send it to the video transmitter.

- WiFi module

A WiFi module is utilized for communication with ground control system. The ground control system takes care of aerial-vehicle manual operation, real-time video check, target setting for tracking, target setting cancellation, etc. it can monitor the sensor data included in image headers or functions such as the tracking coordinate of tracking algorithm. The module is used for stages before tracking commencement and flight control after tracking termination.

- Real-time video transmitter module

The real-time wireless video transmission module sends the video image filmed by image sensor to the ground control system. The video images sent by the real-time video transmitter are preprocessed by the FPGA board which, then, adjust the sizes of image sensor video and visible light image sensor video and delivers the videos of both sensors. In this time, an operator selects the video more favorable for tracking in the ground control system. The chosen video is sent to an aerial vehicle through WiFi and the FPGA board receives the corresponding command and sends out only the chosen video images.

2.2 UAV’s Flight

- Hovering

While hovering, lift, gravity, thrust and drag are all in equilibrium. When all propellers spine at the same speed to increase thrust and make lift greater than gravity, a UAV begins to take off. On the contrary, when thrust is decreased, a UAV begins to descend.

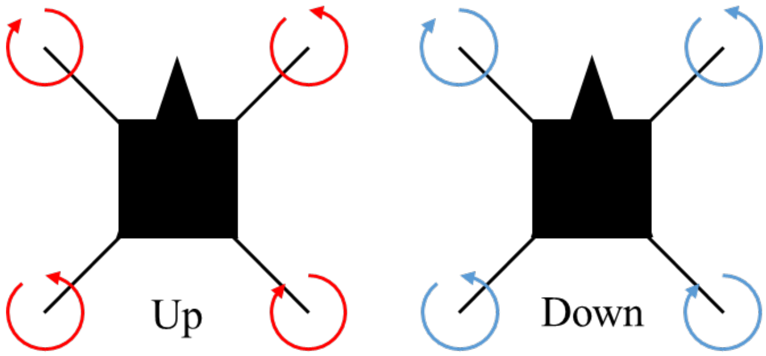

Fig. 1. Hovering Flight

- Backward and Forward

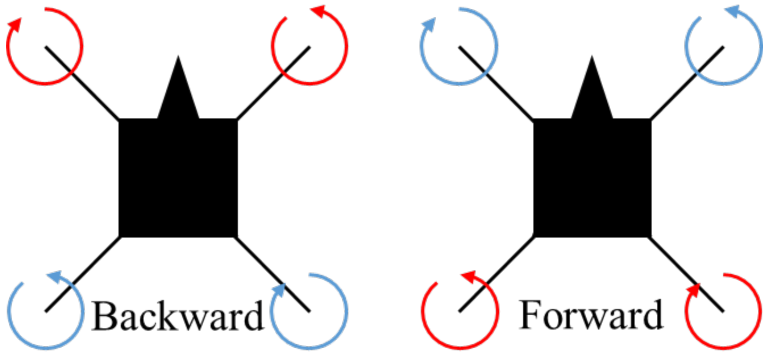

Fig. 2. Backward and Forward

As shown in the **Fig. 2**, the rotation speed gap between a UAV's frontal and rear propellers makes it fly forward of backward horizontally.

- Move Left and Move Right

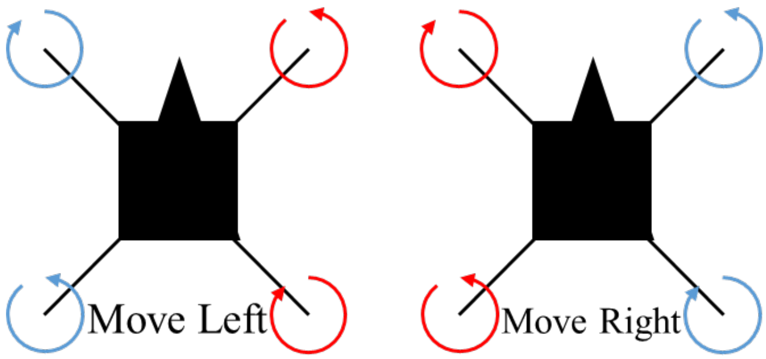

Fig. 3. Move Left and Move Right

As in the **Fig. 3**, the rotation speed gap between a UAV's left and right-side propellers make it fly to the left or right.

- Turn Left and Turn Right

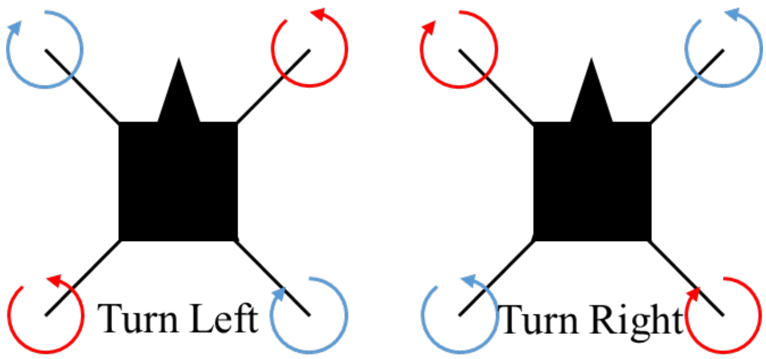

Fig. 4. Turn Left and Turn Right

As in the **Fig. 4**, the rotation speed gap between a UAV's propellers located on both sides of its frontal and real diagonal fine makes it take a left turn or right turn.

3. Autonomous Tracking UAV System

The main discussion of this study explains the hardware and software designed and implemented in this study.

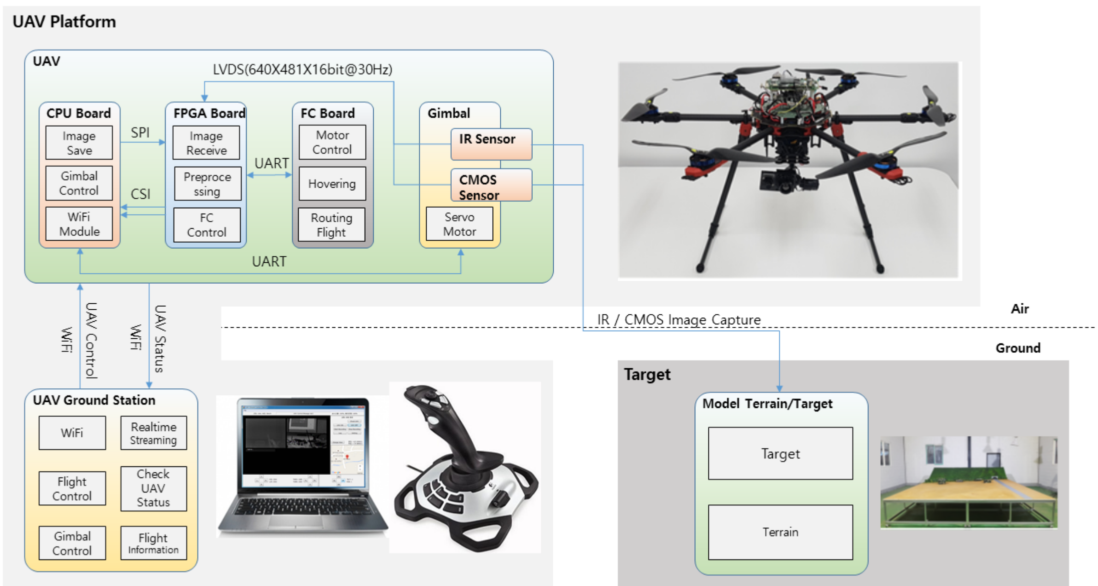

Fig. 5. Autonomous Tracking UAV System

Fig. 5 is the Autonomous Tracking UAV System schematizing the ground control system and aerial vehicle roles as well as software and hardware structures. It exhibits each hardware functional blocks and communication interface.

UAV is made to fly in the ground station. The UAV and UAV Ground Station are connected via WiFi to support joystick-based UAV flight control. The Ground Station performs UAV status information monitoring and UAV flight control, real-time video image receiving gimbal control, etc., implementing target designation finally. UAV receives orders from the Ground Station and controls its FC and gimbal. It sends the video image received from IR/CMOS to FPGA and FPGA conducts video image preprocessing. The preprocessed video image is transmitted to the CPU board using CSI. The CPU board implements tracking based on the received video image and controls gimbal and FC based on the track results.

The section on components for real-time target tracking explains the hardware and software components necessary to produce a real-time track aerial vehicle [5].

3.1 Hardware

Fig. 6 is the main hardware components utilized in the designing and implementation of this study and communication block diagram. The components are explained as follows;

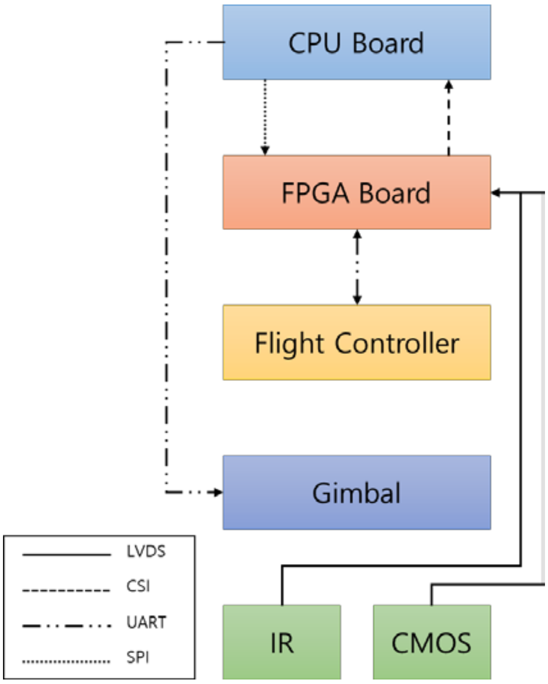

Fig. 6. Main Hardware Component and Communication Block Diagram

- Image sensor

Image sensors consist of an infrared and visible light image sensor (Complementary Metal-Oxide-Semiconductor: CMOS). One single aerial vehicle is equipped with two different types of image sensors at the same time in order to control the aerial vehicle by implementing track algorithm regardless of weather and time in tracing the target of aerial vehicle. If the view is obscured, the infrared image sensor can be chosen to work. If the visible light image sensor is used to track a target when the view is clear, it can take video images for tracking.

- Gimbal

Gimbal is employed to stabilize image sensors and bring a target in the center of image taking area. For this study, a gimbal model was selected, which is capable of controlling the weight of 200g, the weight of an instrument combining the infrared image sensor and visible light image sensor. As the larger the gimbal, the heavier it is to affect an aerial vehicle's flight time and wing motor selection, the weight of sensor combined instrument should be considered. in addition, since gimbal is controlled based on the CPU board tracking results, a model capable of UART communication was selected for gimbal control.

- Flight controller

FC implements the control of an aerial vehicle's movement. Presently, most UAVs employs a remote controller to operate an aerial vehicle's lift off, landing, direction change, and altitude change. The UAV designed and produced in this study needs a user's proactive flight control based on the tracked results, in addition to passive flight control. Proactive flight control is calculated based on the present location data in the CPU and sensor data values. UART-based FC control is possible using the operation of the calculated values. The **Fig. 7** below is a picture of the flight controller board implemented in this study.

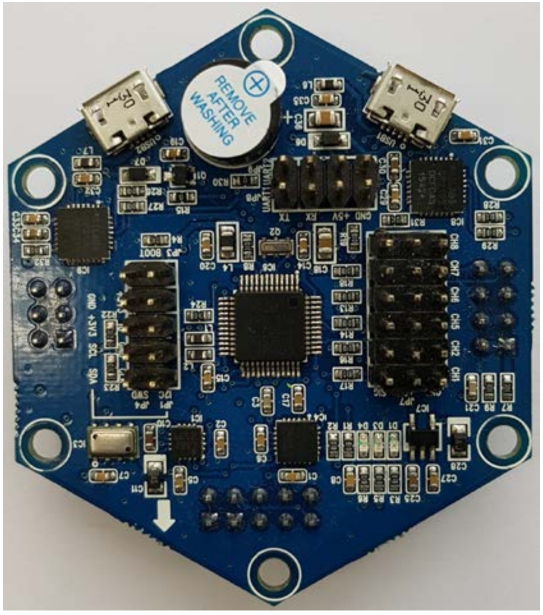

Fig. 7. Flight Controller Board

- FPGA board

The FPGA board is utilized for the videos preprocessing of infrared image sensor and visible light image sensor, GPS and sensor information monitoring, and additional communication for FC control. Moreover, it takes care of the processing of real-time video transmitted to the ground control system [6]. The FPGA board implements I2C, SPI, and UART communicates with the image sensors, FC and CPU board. GPS information is utilized for an aerial vehicle's return function and closed-loop test. In this study, a total of 3 types of flight related sensors are employed in FPGA board. Gyro sensor inquires and calculates an aerial vehicle's flight direction and horizontal values. Altitude sensor inquires an aerial vehicle's altitude and conducts a proactive tracking of a target. GPS and sensor value inquiry is conducted using I2C communication at 30 ms intervals in the FPGA board then, included in video image data header to be transmitted to the CPU board. The **Fig. 8** below is a picture of the FPGA board implemented in this study.

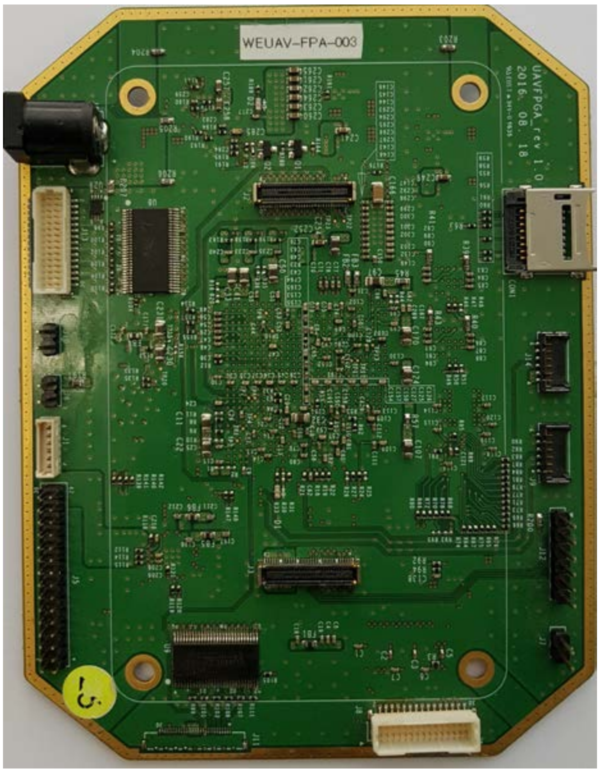

Fig. 8. FPGA Board

- CPU board

The CPU board receives the preprocessed infrared images and visual light images from the FPGA board using 2 CSI (Camera Serial Interface) channels. The received images are utilized in implementing the tracking algorithm according to the order of ground control system. Aerial vehicle control command of the ground control system is received via WiFi and transmitted to the FPGA board in SPI communication. Gimbal control consists of the gimbal control in the ground control system and that implemented by the tracking algorithm. For gimbal control, UART is employed. The GPS and sensor data transmitted from the FPGA board are extracted from image headers and used for aerial-vehicle control in connection with tracking algorithm results. The **Fig. 9** below is a picture of the CPU board implemented in this study.

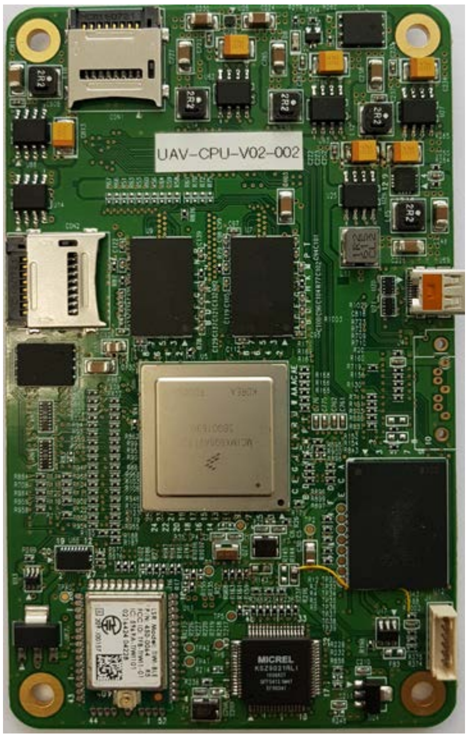

Fig. 9. CPU Board

- Electrical distribution board

The electrical distribution board receives battery power and supplies it to other boards connected within an aerial vehicle. The **Fig. 10** below is a picture of the power distribution board implemented in this study.

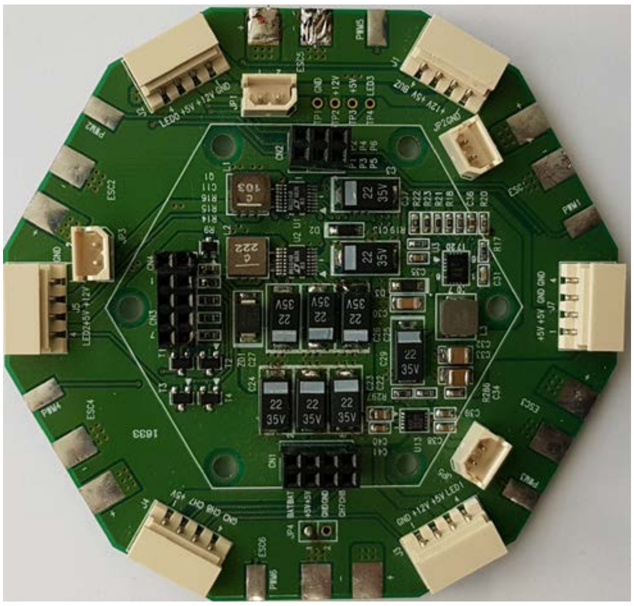
Fig. 10. Power Distribution Board

3.2 Software

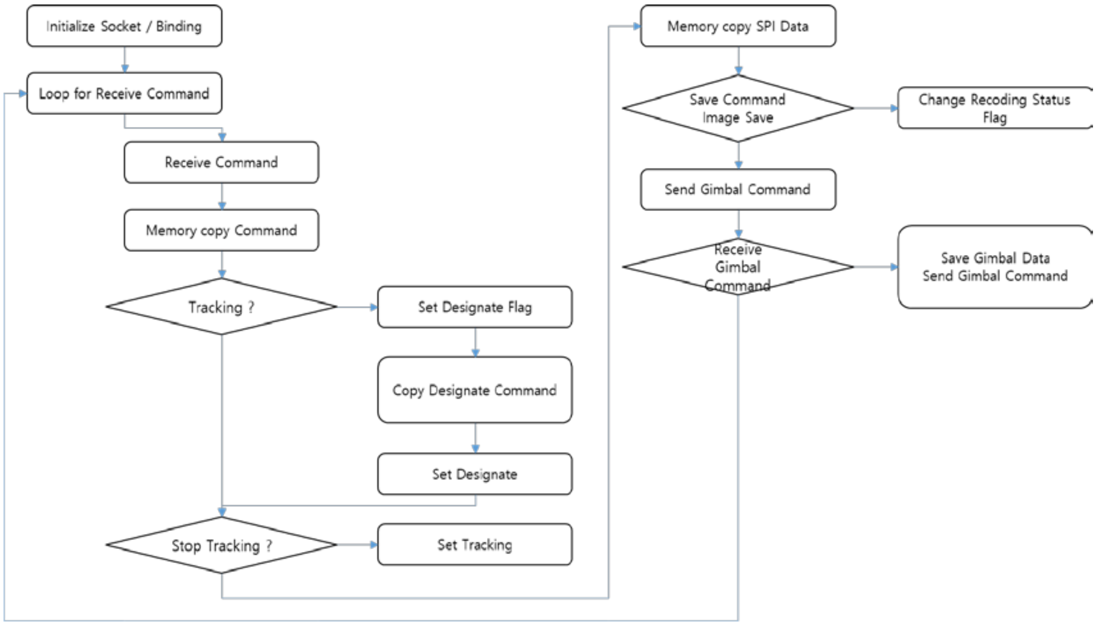

Fig. 11. UAV Operating Software Flow Diagram

Fig. 11 is the diagram of operating software flow exhibited in the overall flow. Each flow is explained as follows;

The video images obtained by the FPGA board are received and the tracking algorithm is implemented. After the tracking algorithm implementation, based on the tracking results, gimbal control is performed using the UART so that a target is located in the center of the image. The obtained video image is saved in a file using a microSD slot within the CPU board. The header part of the obtained video image is transmitted to the UAV status information collection module. The data included in the header part are video acquisition number and checksum, cracking coordinates if tracking is under way, and many other sensor values. The sensor monitoring information is transmitted to the aerial vehicle status data collection module. The collected aerial vehicle status data are sent to the communication module with the ground control system. The aerial vehicle status data are sent to the ground control device using the WiFi module. The command sent by the ground control system is received by the WiFi module. The ground control system command is delivered to the FC to control the aerial vehicle.

4. Experimental Classification Results and Analysis

With respect to the CPU core-specific consumption measurement, symmetric multiprocessing (SMP) is supported by the kernel. However, if competition is fierce among cores, real-time processing in the CPU scheduling could be delayed. In this consideration, this study implemented thread-specific core allocation in its operating software platform. The loaded CPU consists of 4 cores which are i.mx6qp of FreeScale. Each core operates at 1Ghz operation velocity. **Table 1** shows thread-specific core allocation and its core consumption.

The consumption of corresponding core was measured as in **Fig. 12**. In the measurement of CPU core-specific consumption, two cases were compared – the case where the CPU board performs the whole functions including video image receipt, image save, gimbal control, tracking algorithm implementation, and aerial vehicle control; and the case where it performs only image receipt.

Table 1. CPU Core Allocation and Core Consumption Table

Core	Function	Idle	Tracking
Core 0	IR/CMOS CSI Save Image	15%	30%
Core 1	Communication	0.3%	5%
Core 2 Core 3	Tracking	0%	65%~70%

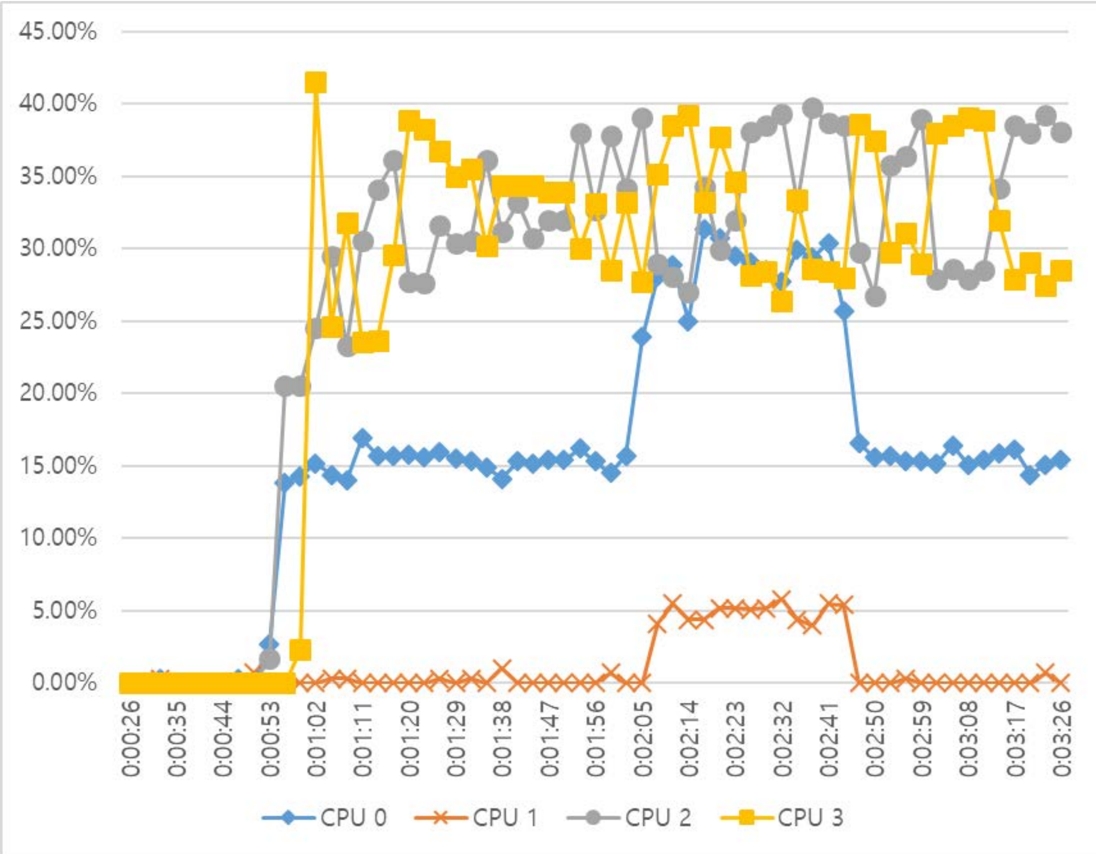

Fig. 12. Graph on Core-specific CPU Consumption

Fig. 12 shows the performance measurement results in relation to CPU consumption. The graph represents consumption measurements in each core using Linux top command. After the CPU board power is turned on, its consumption is measured every 3 seconds and displayed on the screen. The X axis represents the time of implementation; Y axis, core-specific consumption. At around 53 seconds, the operating software was implemented. As a result, Core 0 showed about 15% consumption rate. It means core consumption utilized to receive infrared/visible light video images from the FPGA through CSI. Together with the operating software, the tracking algorithm was also run and Core 2 and Core 3 consumption amounts prove it. While tracking implementation, Core 2 and Core 3 consumption was maintained at around 65 to 70%. About 2 minutes and 5 seconds later, a file storage function was implemented, which is proven by increased Core 0. In the event of file saving, core consumption increase was about 15%. Memory was copied into file saving buffer on the received video to cause consumption increase. In the event of tracking, Core 1 consumption increase occurs about 5% because of the core use for the process of saving in the storage thread within the operating software by generating semaphore.

The result of the tracking can be confirmed as follows. The image of the current sensor is received from the FPGA board, and the CPU board receives the image from the FPGA and waits for a tracking command. The operator transmits a tracking command using the ground station to perform the tracking mode. When the tracking result is transmitted to the FPGA board using the SPI, the FPGA board displays a 200x200 pixel square based on the tracking result center point, and transmits it to the ground station. We added the screen shot image of ground station software in **Fig. 13.**

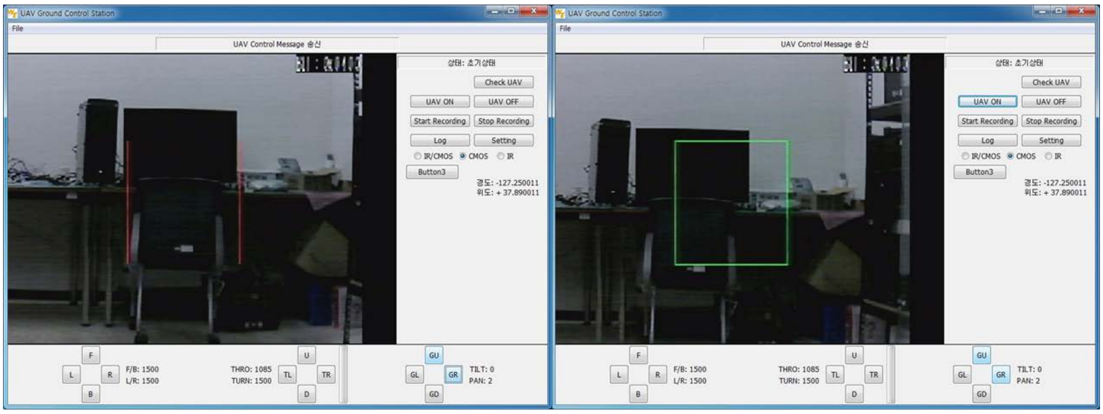

Fig. 13. Display Tracking Status in Ground Station(Left:before tracking,Right:after tracking)

5. Conclusion

In order to implement the tracking algorithm and control an aerial vehicle based on video images taken in real time, there needs to be FPGA that can do a real-time parallel transaction for input videos and high performance CPU capable of tracking a target in real time. This study explained the design and implementation method of hardware and software platform for a higher performing UAV.

In the present system, an operator checks on the ground the video filmed while flight with his or her eyes then transmits the tracking command for a target to implement real-time target tracking and aerial vehicle control. However, such a method requires an operator to control its lift and flight until it reaches a certain area. In this case, a use should actively intervene in the early stage. Against this backdrop, the future study goal is to form a system that has a recognizer of a target and implements deep learning to load the accumulated target recognition data on the CPU board, transmit a command on recognized targets during automatic flight and perform automatic tracking of such. To this end, the kind of CPUs such as Tegra chipset by NVIDIA will need to be utilized, which are appropriate to implement GPGPU-based recognition and target tracking, as a replacement of mx6qp processor. To shorten the video transmission time delay, PCIe interface-based high-speed data transmission method will need to be considered instead of the CSI-based transmission method [7].

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