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MULTI-ROTOR DRONE TO FLY AUTONOMOUSLY ALONG A RIVER USING A SINGLE-LENS CAMERA AND IMAGE PROCESSING

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ABSTRACT

The purposes of this research are to develop an lgorithm to perform an autonomous flight along a river and to carry out experiments in which a multi-rotor drone performs the autonomous flight. We, authors firstly developed the algorithm to divide a photo image into a river area and the other parts and determine the direction that the multi-rotor drone should fly ahead. Then, we carried out flying experiments performed by the AR.Drone 2.0 (Parrot) as the multi-rotor drone using a single-lens camera and the image processing developed by authors installing on a personal computer (PC). The multi-rotor drone and the PC were connected each other through a wireless connection (Wi-Fi). The experimental result shows that the drone could autonomously fly along the river for the distance of 83 [m].

KEYWORDS: Multi-Rotor Drone, Autonomous Flight, Single-Lens Camera, Image Processing

INTRODUCTION

Most people who live in remote locations such as mountainous areas cannot take advantages of the electricity due to the limited access to the available system. Then, a small electric power plant such as a micro hydro power plant that utilizes the potential energy of water in a river can be developed in order to solve this problem. To determine a proper location of the micro hydro power plant, a 3D map created from the coordinates of the river path is required. Nowadays, the coordinates are measured by humans walking along the river using a GPS receiver. However, this manual method by humans is very risky for the humans due to the swift water flow of the river and the sharp stones on the riverbed. Moreover, the manual method needs several days to accomplish the job. Therefore, an multi-rotor drone flying autonomously along the river can be used to perform the job in order to avoid the risk for the humans and reduce the working time.

In the last decade, a number of studies on autonomous explorations of a river using an Unmanned Aerial Vehicle (UAV) have been investigated by some researchers [1] – [5]. Most of them reported on a system that can fly along a river using the UAV with a stereo camera [1] – [4], while the other one using a near-infrared camera [5]. Furthermore, a number of studies on manual and autonomous flights using a UAV with a monocular (single-lens) camera have been also reported by some researchers [6] – [10]. Then, mostly their systems were applied to on a ground environment [6, 8, 9, 10]. Yang et al [7] reported an application of a UAV flying through a riverine environment using a monocular camera and the watershed transformation [11]. However, as far as we searched, there is no research reporting on an autonomous flight along a river using a multi-rotor drone with a single-lens camera and the image processing proposed by authors in this paper.

The purposes of this research are to develop the algorithm to perform an autonomous flight along a river and to carry out experiments in which a multi-rotor drone performs the autonomous flight. We, authors firstly developed the algorithm to divide a photo image into a river area and the other parts and determine the direction that the multi-rotor drone should fly ahead. Then, we carried out flying experiments performed by the AR.Drone 2.0 (Parrot) as the multi-rotor drone using a single-lens camera and the image processing developed by authors installing on a personal computer (PC). The multi-rotor drone and the PC were connected each other through a wireless connection (Wi-Fi).

SEGMENTATION OF RIVER SCENES

In the algorithm to segment a river area from a river scene, there are three main steps as shown in Figure 1. In the first step, original photo images of river scenes captured by a single-lens camera of the multi-rotor drone were converted to HSV images. Then, the HSV images were converted to binary images. In the second step, the river area was determined by the bottom one-third of the binary images for the hovering and turning state, while the bottom two fifths of the binary images for the moving forward state. In the third step, the flying direction of the multi-rotor drone was determined by finding the center point of top side of the river area. The flying direction was visualized using the line drawn from the center point of bottom side of the binary images to the center point of top side of the river area.

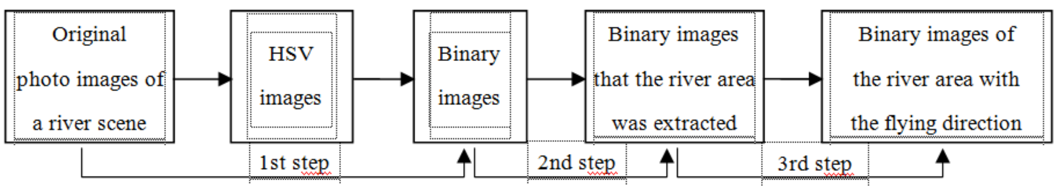


Figure 1: Three Main Steps to Segment a River Area from a River Scene

Original Photo Images

Original photo images of a river scene were captured by the single-lens camera on the multi-rotor drone. Figure 2 shows an original photo image of a river scene which consists of the sky, some regions such as foliage, foliage reflections and sky reflections. A multi-rotor drone must be able to detect the course of the river so that the drone can autonomously fly along the river. The algorithm to segment the river area from the river scene was developed using the binary images.

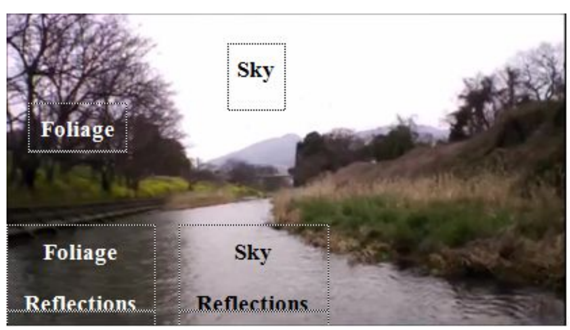


Figure 2: Original Photo Image of a River Scene

Binary Images

The original photo images of a river scene captured by the single-lens camera of the multi-rotor drone were firstly converted to HSV images as shown in Figure 3. To detect the river area, the HSV images were then converted to binary images by thresholding the parameters of HSV images such as the grayness and brightness. Several areas that are outside the river area may appear in the upper sides of the binary images as shown in Figure 3. To overcome this problem, it is better to remove the superfluous areas in order to find a clear river area.

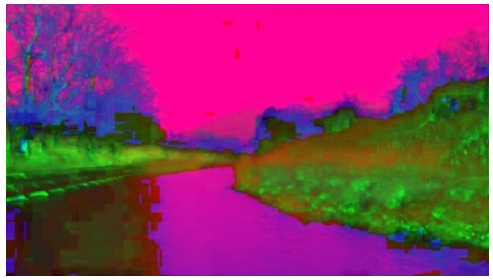
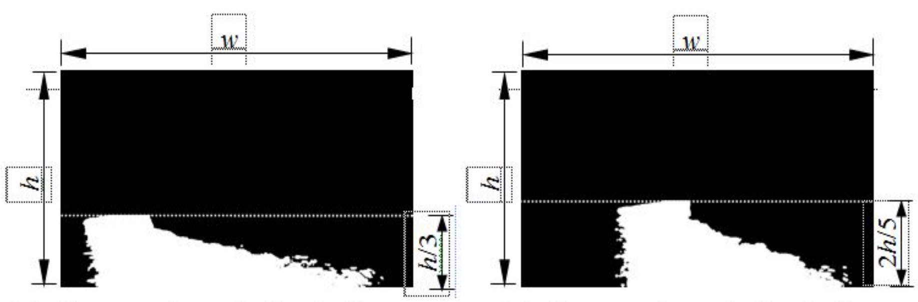


Figure 3: HSV Image Converted from the Original Photo Image

Figure 4: Binary Image Converted from the HSV Image

River Area Determined Using the Lower Parts of the Binary Image

There are three states in the flying motions of the multi-rotor drone, namely hovering, turning and moving forward. In the binary images in all three states, the river area was shown in the bottom half side. Then, the river area when the multi-rotor drone is moving forward become higher than hovering and turning state. Under the trial and error, the river area in hovering and turning state was determined as the bottom part of one-third of the whole binary image. While, the river area in the state of moving forward was determined as the bottom part of two fifths of the whole binary image as shown in Figure 5.



(1) River area determined at the bottom part of one third of the whole binary image (in hovering and turning state)

(2) River area determined at the bottom part of two fifths of the whole binary image (in moving forward state)

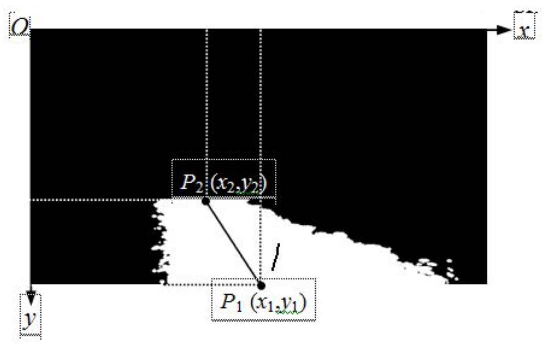
w : width of the image [pixel] h : height of the image [pixel]

Figure 5: River Area Determined Using the Lower Part of the Whole Binary Image

Flying Direction Determined by Finding the Center Points of the Upriver Area

Figure 6 shows the flying direction visualized by a line drawn from $P_1(x_1,y_1)$ to $P_2(x_2,y_2)$ in the river area. The O-xy is the coordinat frame of the image. $P_1(x_1,y_1)$ represents the current position of the multi-rotor drone and $P_2(x_2,y_2)$ represents the end point of the flying direction of the multi-rotor drone. The flying direction was determined by finding the center point of top side of the river area, namely upriver side. The flying direction was then determined using a line drawn from the center point of bottom side of the whole binary image to the center point of top side of the river area. The original and binary images with flying directions for the three different states of the multi-rotor drone are shown in Figure 7.

***O-xy* :** Coordinate frame of the image



$P_1(x_1,y_1)$: current position of the multi-rotor drone

$P_2(x_2,y_2)$: the end point of flying direction of the multi-rotor drone

Figure 6: Flying Direction Visualized by a Line Drawn from P_1 to P_2 in the River Area

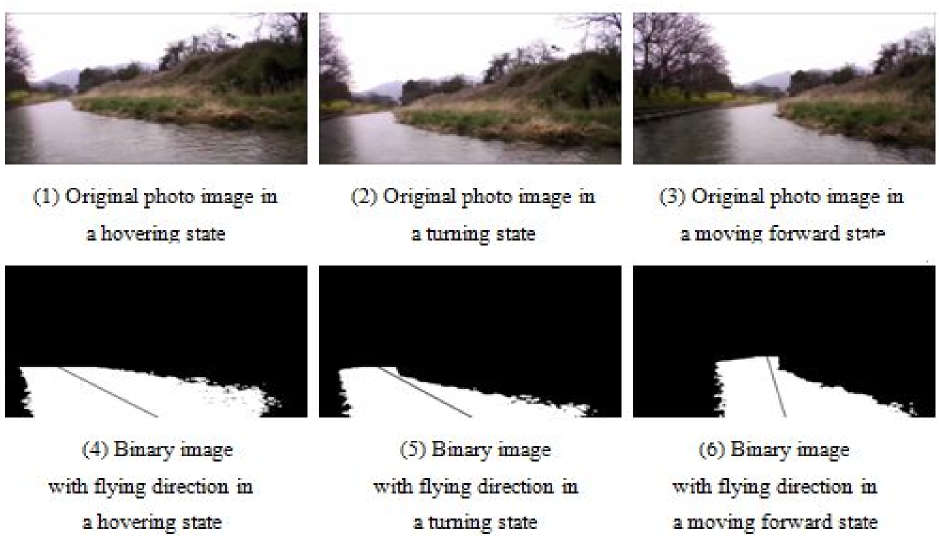


Figure 7: Original Photo and Binary Images with Flying Directions in Three Different States of the Multi-Rotor Drone

ALGORITHM FOR AUTONOMOUS FLIGHT ALONG A RIVER

The algorithm for the autonomous flight along a river consisted of four consecutive stages, namely segmentation of river scenes, flying to the center of the river, flying along the river, and flying to the riverside.

Segmentation of River Scenes

Figure 8 shows the algorithm of the 1st stage of the autonomous flight, namely the segmentation of river scenes. It is most important to detect exactly the course of the river for flying autonomously along the river. Therefore, an algorithm to segment accurately the river areas from the river scenes is required. Original photo images of the river scene are captured by the single-lens camera on the multi-rotor drone. Then, the original images will be converted into HSV images. Furthermore, the river area is determined by detecting the sky reflection area on the HSV images. Finally, the river area with flying direction is shown in the binary images. The frame rate of the camera is 30 [fps]. Therefore, the frame rate in the algorithm needs to be regulated to approximately 10 [fps] as it takes a lot of time to perform the image processing. The frame rate can be regulated so as to accord the each duration of a flying motion of the drone.

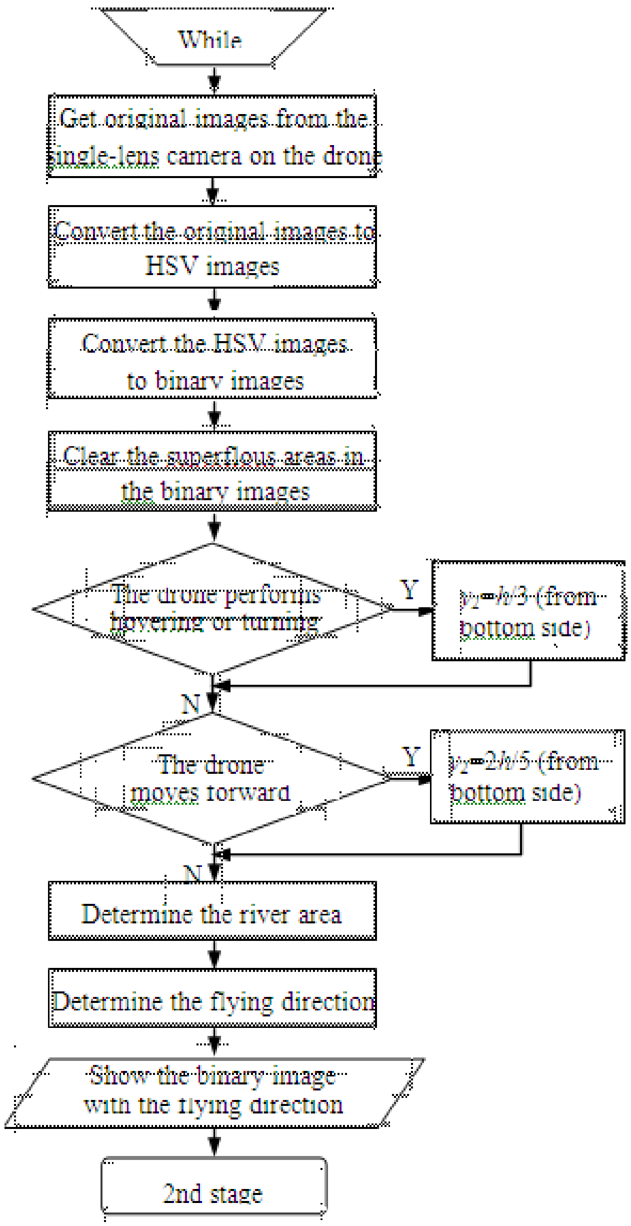


Figure 8: Algorithm for the 1st Stage (Segmentation of River Scenes)

Flying to the Center of the River

Figure 9 shows the algorithm for the 2nd stage of the flight, namely flying to the center of the river. In this stage, the multi-rotor drone is controlled manually. Firstly, the drone takes off the ground at a riverside and flies up to the altitude of 0.8 [m] from the ground. Then, the altitude of the drone is increased up to 2.5 [m]. After that, the drone flies to the center of the river and then turn to face the upriver side.

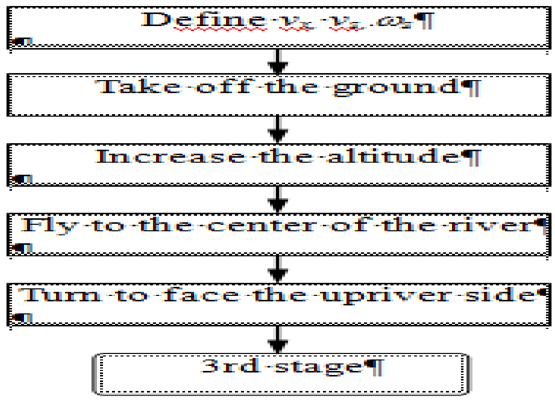


Figure 9: Algorithm for the 2nd Stage (Flying to the Center of the River)

Flying along the River

Figure 10 shows the algorithm for the 3rd stage of the flight, namely flying along the river. In this stage, the multi-rotor drone autonomously flies along a river based on the result of the image processing with a linier velocity in x-direction (v_x) and an angular velocity in z-direction (ω_z). Once the drone face toward the upriver side, the manual control mode is changed to autonomous control mode. In this mode, the value of v_x is fixed while the value of ω_z is determined using a proportional controller. The value of ω_z is depended to the x-coordinate of the end point coordinates of the flying direction, namely x_2. After that, a certain range of ω_z is enforced to zero in order to avoid unstable condition of the drone. Furthermore, the drone autonomously flies along the river with the v_x and ω_z.

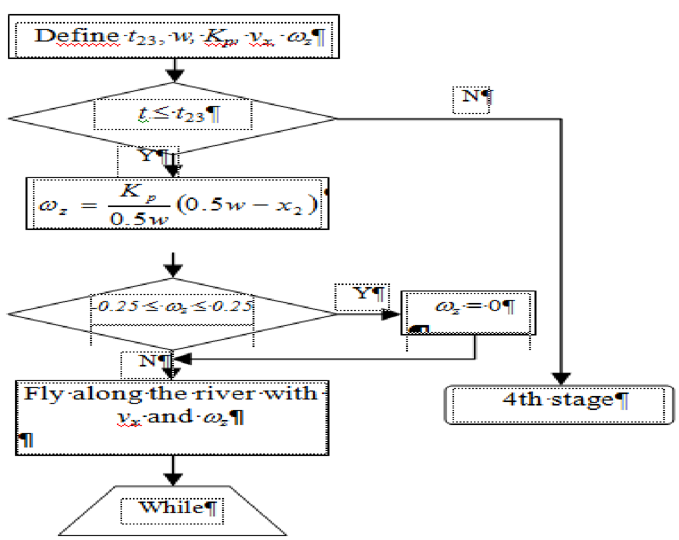


Figure 10: Algorithm for the 3rd Stage (Flying Along the River)

Flying to the Riverside

Figure 11 shows the algorithm for the 4th stage of the autonomous flight, namely flying to the riverside. In this stage, the multi-rotor drone autonomously turns to face the riverside with a fixed v_x and ω_z and then flies to the riverside with the v_x. Finally, the drone lands on the ground at the riverside to complete the autonomous flight.

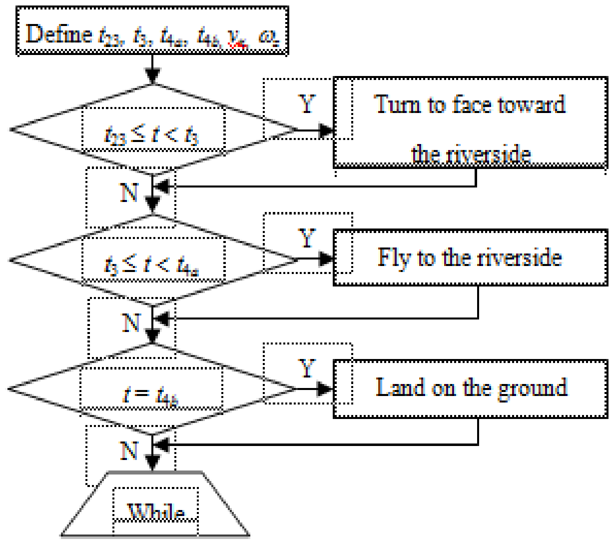


Figure 11: Algorithm for the 4th Stage (Flying to the Riverside)

FLYING EXPERIMENTS USING A MULTI-ROTOR DRONE

Method

In order to perform the autonomous flight along a river, we carried out flying experiments performed by the AR.Drone 2.0 (Parrot) as the multi-rotor drone using a single-lens camera and the image processing installing on a PC. The photo image of the multi-rotor drone is shown in Figure 12.

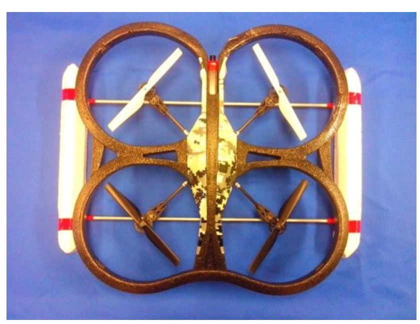


Figure 12: Photo Image of the Multi-Rotor Drone (AR. Drone 2.0 (Parrot))

Figure 13 shows the configuration of the multi-rotor drone. The two cameras, namely front and bottom cameras are mounted on the drone and they are connected to the main microprocessor. Then, the microprosessor is connected to the wireless connection (Wi-Fi) chipset. The drone and the PC are connected each other through the Wi-Fi as shown in Figure 14. Furthermore, we installed the program having the algorithm for the autonomous flight developed by authors inside the PC. The multi-rotor drone performs the autonomous flight while the PC performs the image processing. Original images of river scenes are captured by the single-lens camera (front camera) mounted on the drone. After that, the images data are automatically send to the PC. Then, the PC carries out the image processing to find the flying directions. Furthermore, the PC automatically generates and then sends flying motion commands to the drone so that it can perform the autonomous flight.

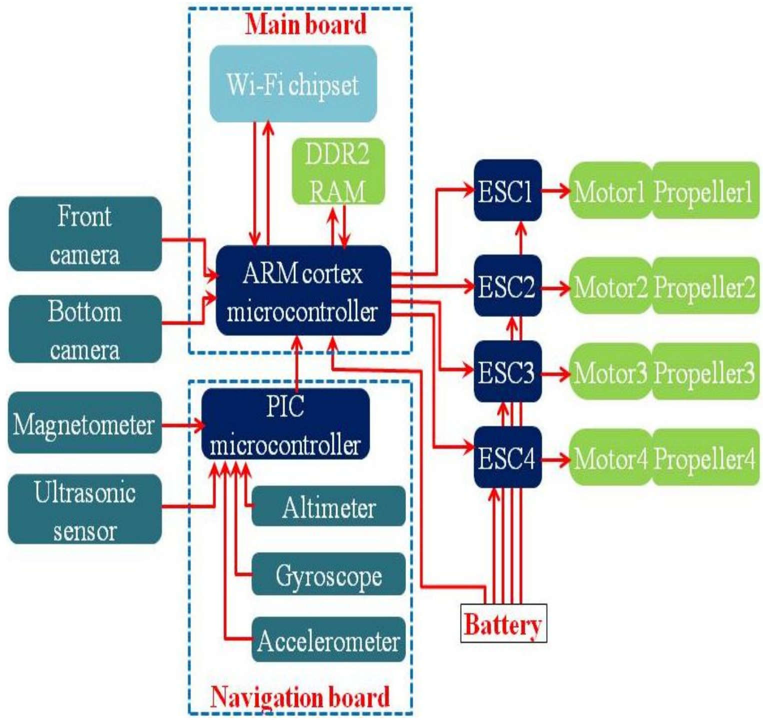


Figure 13: Configuration of the Multi-Rotor Drone (AR. Drone 2.0 (Parrot))

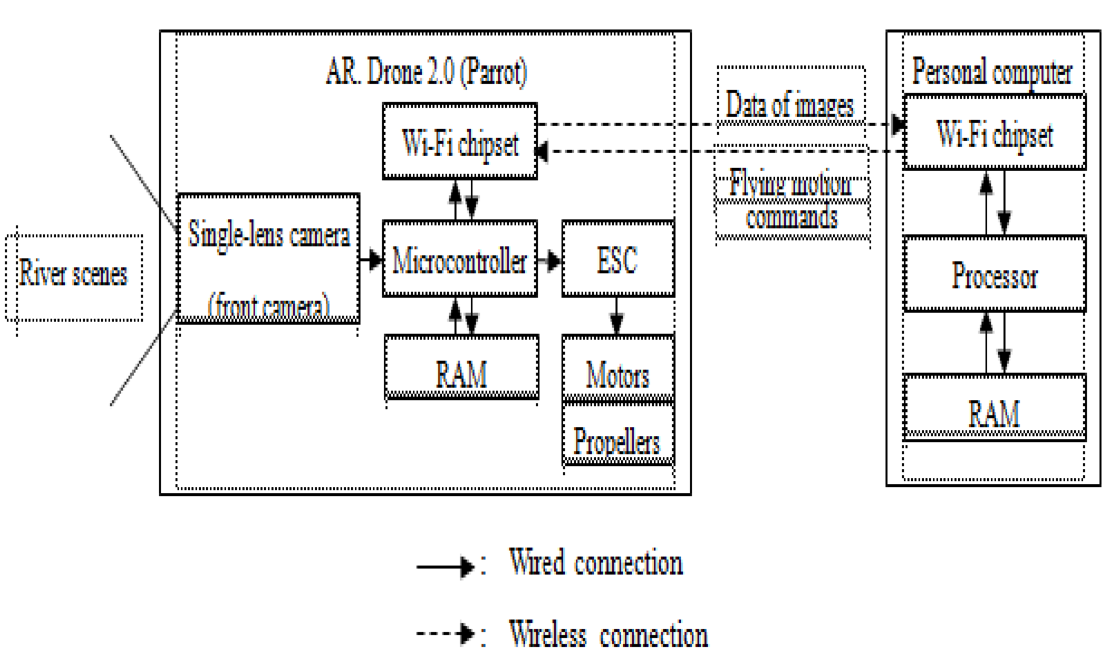
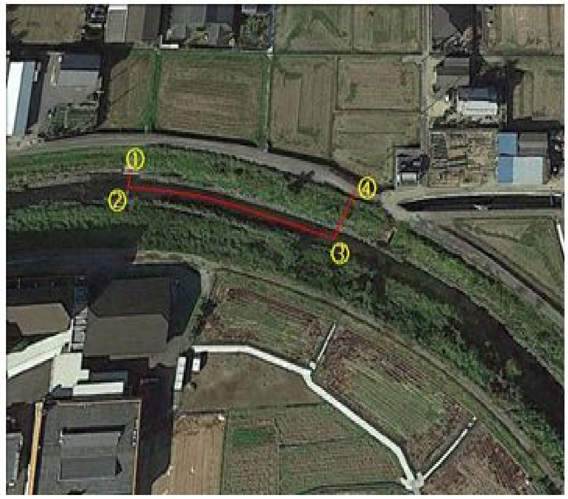


Figure 14: Signal Flow

Figure 15 shows the path and the three consecutive stages of the autonomous flight performed by the multi-rotor drone on a curved river. The three stages consist of flights from the start position to the center of the river (Stage 1), along the river (Stage 2) and from the center of the river to the end position (Stage 3). The algorithm is made so that the multi-rotor drone firstly takes off the ground at the riverside, then flies to the center of the river, then fly along the river, and finally lands on the ground at the riverside.



: Flight path (The distance from ② to ③ is 90 [m])

① : Start position

④ : End position

① – ② : Stage 1 (Manual flight from the start position to the center of the river)

② – ③ : Stage 2 (Autonomous flight along the river)

③ – ④ : Stage 3 (Autonomous flight from the center of the river to the end position)

Figure 15: Flight Path and Three Consecutive Stages of the Autonomous Fligh Performed by the Multi-Rotor Drone in the Flying Experiment for the Curved River

RESULTS

Figure 16 shows the photo images of the multi-rotor drone captured by a person standing on the ground in the flying experiment for the curved river from ① to ② (Stage 1). At this stage, the drone was controlled manually using the PC. At the beginning of this stage, the multi-rotor drone took off the start position at the riverside as shown in Figure 16(1). The drone increased its altitude and performed hovering over the start position at the height of 0.8 [m] as shown in Figure 16(2). After that, the drone increased its altitude up to 2.5 [m] and then flew to the center of the river as shown in Figure 16(3). After reached the center of the river, the drone turned to face toward the upriver side. At this position, the manual control mode was changed to autonomous control one and the PC started the image processing. Figure 17 shows photo images of the multi-rotor drone captured by the person standing on the ground, photo images of the river scene captured by the single-lens camera mounted on the drone, and binary images converted from the photo images of the river scene in the flying experiment for the curved river from ② to ③ (Stage 2). At this stage, the drone autonomously flew along the river using the single-lens camera and the image processing proposed by authors. In the experiment, the drone could autonomously fly along the river as far as 83 [m]. Finally, the drone landed on the grass at the riverside.

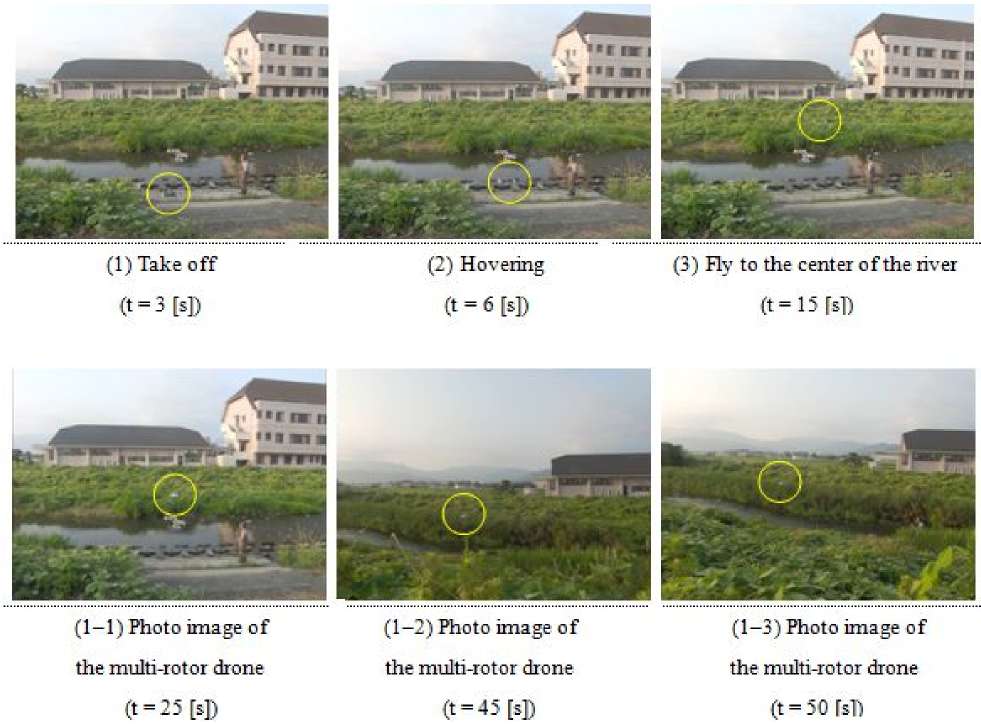


Figure 16: Photo Images of the Multi-Rotor Drone Captured by the Person Standing on the Ground in the Flying Experiment for the Curved River from ① to ② (Stage 1)

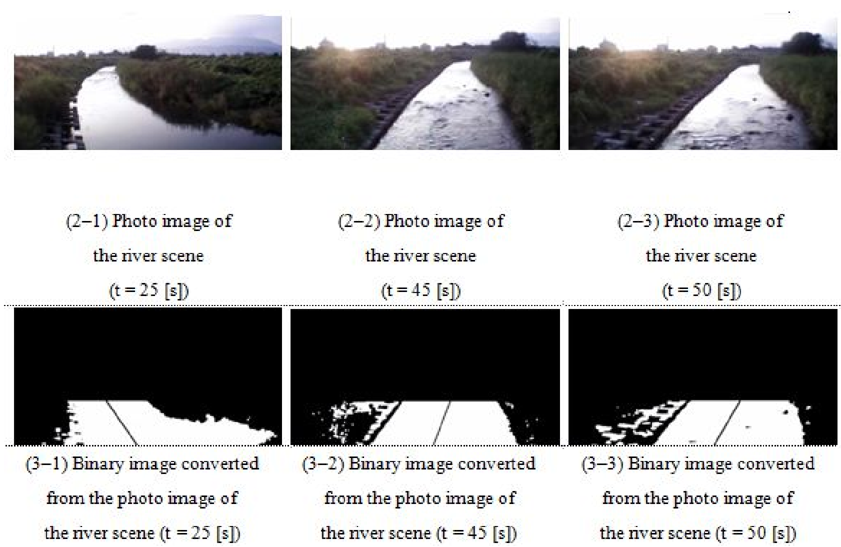


Figure 17: Photo Images of the Multi-Rotor Drone Captured by the Person Standing onthe Ground, Photo Images of the River Scene Captured by the Single-Lens Camera Mounted on the Drone, and Binary Images Converted from the Photo Images of the River Scene in the Flying Experiment for the Curved River from ② to ③ (Stage 2)

CONCLUSIONS

Firstly, the algorithm to perform an autonomous flight along a river had been developed in this research. Then, the experiments in which the multi-rotor drone performs the autonomous flight along a curved river using a single-lens camera and the image processing proposed by authors. The experimental result shows that the drone could autonomously fly along the river for the distance of 83 [m]. In future, we will measure the 3D coordinates of the path of the river using a GPS and an image processing. Finally, we will create a 3D map of the path of the river using the 3D coordinates data.

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