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Surveillance System for Multiple Targets by Galvanometer Scanners

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Abstract: To prepare for terrorist and/or criminal attacks using unmanned aerial vehicles (UAVs), we have developed the Galvano Camera System. This system, which detects suspicious UAVs, is based on the high-speed and precise positioning technology of the galvanometer scanners. The proposed system is able to observe multiple moving objects simultaneously, using the high response of the galvanometer scanners, and display objects in a single monitor. We have proved the effectiveness of the system through field tests.

Keywords: Servo system, Sensor fusion, Target tracking, Cameras, Image processing

1. INTRODUCTION

In recent year, unmanned areal vehicles (UAVs) have been adopted for commercial use because of rapid development UAV's and peripheral technology. It is expected that UAV will be used for various purposes due to UAV's high mobility such as 3D survey at construction sites. On the other hand, some UAV related incidents have been reported. For example, the runway of airport was closed by witness information of UAV. The other case, the environmental protection group was collide with the UAV at the nuclear plant. These cases indicate that commercial UAVs are a security threat to important facilities, so we need to quickly establish a countermeasure for suspicious UAVs.

To deal with suspicious UAVs, we have two stages: first stage is detecting and monitoring the UAVs in the alert airspace, and second stage is removing the UAVs. In the first stage, some system which have a pan-tilt-zoom mechanism (PTZ) camera and wide-area surveillance device, such as microphone array or a RADAR, were proposed. At these systems, the operator visually checks suspected targets which are detected by wide-area surveillance device using the PTZ camera.

The PTZ camera consists of a camera with a zoom lens and a platform, and it has a wide range of motion; however, the camera and zoom lens are heavy so it is difficult to change the optical axis of camera quickly. Therefore, when a large number of suspected targets are detected by the wide-area surveillance device, it takes a lot of time to change the optical axis of the camera. As a result, the detection of the suspicious UAV is delayed. In addition, it is not possible to check the newly target while tracking the detected suspicious UAV. So it is necessary to install plural cameras depending on the alert airspace.

Meanwhile, Kobayashi (1998) and Yokoyama et al. (1999) propose to use fixed cameras to photograph an object in any position by rotating mirrors to change the reflection angle. Okuyama et al. (2013) suggests a method of photographing objects moving at high speed using a galvanometer scanner, a means of rotating mirrors which combines high responsiveness with positioning performance.

In this paper, we propose a camera system using a galvanometer scanner for the purpose of tracking and monitoring multiple targets simultaneously. The proposed system enables continuous imaging at multiple directions by adjusting the timing of the optical axis changing and exposure. In addition, since the reflecting mirror is completely stationary at exposure, image blurring does not occur. With the system which we proposed, the position of the target in the acquired image is identified, and the result is used for the next reflection mirror angle, thereby the proposed system enables the multiple target tracking. Finally, we verify the effectiveness of the proposed system by field tests using a prototype.

2. SURVEILLANCE SYSTEM FOR MULTIPLE TARGETS

2.1 System Configuration

Figure 1 shows the configuration of the multi-object simultaneous monitoring system proposed by the authors. In the proposed system, a camera, a galvano unit, used to the optical axis changing of the camera, and a zoom lens, placed between the camera and the galvano unit, are called "Galvano Camera". Also, the Galvano Camera, a controller, which controls the camera, the galvano unit, and zoom lens, an image processor, which creates the video from the acquired still image and identifies the position of the target in the acquired image, and a display compose the "Galvano Camera System".

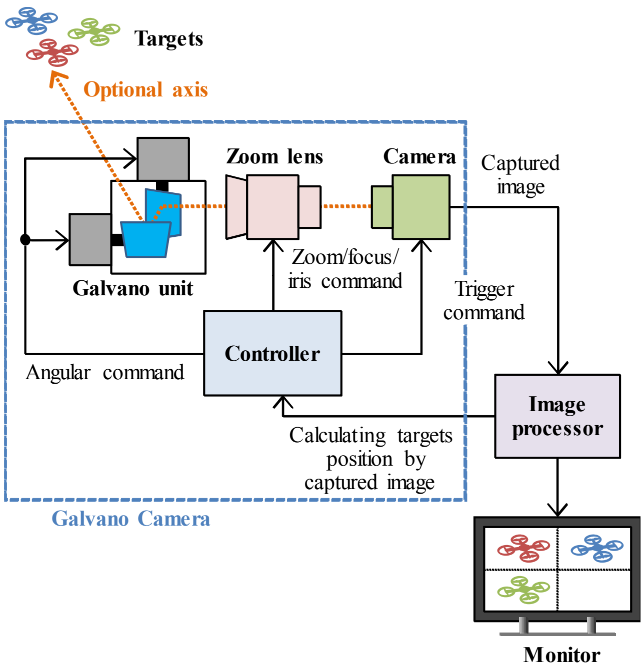

Fig. 1. Configuration of Galvano Camera System.

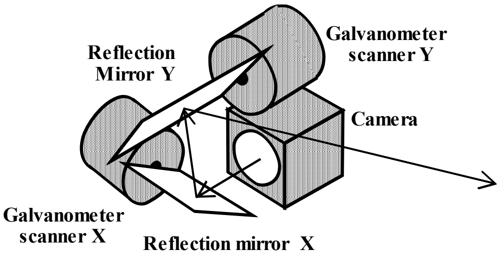

Fig. 2. Diagram of Galvano Camera.

The galvano unit used in this system consists of a pair of galvanometer scanners with a reflecting mirror at the tip and a drive amplifier. The scanning direction of the two galvanometer scanners are placed orthogonally. In the galvano unit, which arrangement is shown in Figure 2, the reflection mirror X is placed nearby the zoom lens in the horizontal deflection angle (azimuth), and the other is placed in the vertical deflection angle (elevation). The galvanometer scanner is one kind of direct drive motor, in which a load is directly attached to the tip of the rotating shaft, so it has high rigidly; therefore, it enables quick response. Then, Galvano Camera changes the optical axis of the camera faster than the PTZ camera. Also the camera and zoom lens, which are heavy parts, are fixed and only the light reflection mirrors are rotated, so the driving mechanism are compact.

2.2 Simultaneous monitoring of multiple targets

The proposed system enables simultaneous monitoring of multiple targets alternately by repeating the optical axis changing and exposure using galvanometer scanners which have high responsiveness. Now, we describe the flow for simultaneously monitoring three targets using the proposed system. Figure 3 shows a time-series and schematic diagram of the images acquired by the camera and the movement of the galvano unit. First, the position information of each

Fig. 3. Conceptual diagram of multiple target monitoring.

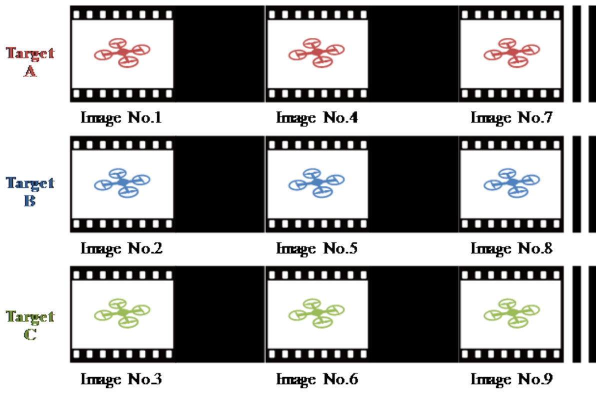

Fig. 4. Processed videos by Galvano Camera System.

targets is given to the system from the wide-area surveillance device, the controller calculates the rotation angle based on the direction of the first target A and drives galvanometer scanners. When the positioning is finished, the optical axis of the camera directs to the target A. Then, the controller outputs exposure trigger signal and the camera starts acquiring an image including the target A. Once the image acquisition is completed, the images of targets B and C are acquired in the same procedure. At this example, the system changes targets A->B->C->A->B->C sequentially and acquires images continuously.

Next, we describe the processing at the image processor. Figure 4 shows the video data correlating each target created by the image processor of this system. The image processor converts the images of the targets A, B, and C sent from the camera into three video data divided for each target. At the image processor, only the image including target A is connected in chronological order (image No.1->4->7) after colour tone correction processing which makes the image of target A clear. We obtain video data about targets B and C in the same procedure. At this time, the update cycle of each obtained video data is a product of the imaging cycle and the number of targets. The display divides the screen according to the number of targets and displays each video data. Through the above procedure, the proposed system displays the video data of targets A, B, and C simultaneously on the same display, so the operator can monitors three targets located in different directions.

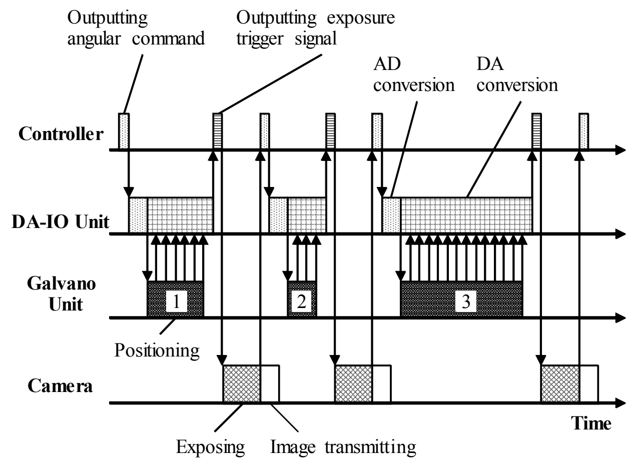

Fig.5. Timing chart of Galvano Camera System.

2.3 *Adjustment of operation timing*

When monitoring the multiple target with the proposed system, since the rotation angle depends on the positional relationship of the target, processing time of positioning is not constant. Therefore, when the imaging cycle is set too short, exposure of the camera may start while the optical axis is being changed, and there is a possibility that image blurring occurs in the acquired image. On the other hand, if the imaging cycle is set according to the maximum movement, the occurrence of image blur can be suppressed, but the image update frequency decreases.

In the proposed system, the frame rate can be maximized by suppressing the occurrence of image blur by adjusting the timing of the optical axis changing and exposure without overlapping. Figure 5 shows the timing chart of the controller, digital analogue input / output (DA-IO) unit, galvano unit and camera of the proposed system at three targets monitoring. The main processes are Analogue-to-digital conversion at DA-IO unit, Digital-to-analogue conversion at DA-IO unit, galvano unit positioning, camera exposure, and image data transfer. In this example, the rotation angle vary greatly, so positioning time is different for operations 1 to 3.

As the figure 5 shows, since the timing of each operation is adjusted in this system, the positioning of the galvano unit and the exposure do not overlap. Therefore, even if the time required for the positioning for each optical axis changing varies greatly depending on the positional relationship of multiple targets, image blurring does not occur.

3. METHOD FOR MULTIPLE IMAGE TRACKING

In this chapter, we explain how to detect and track targets from continuously acquired images. The proposed method is based on the background subtraction method, but differs from the conventional method in that it considers to the change in the optical axis of the camera by the galvanometer scanner and that it can track multiple targets simultaneously.

Figure 6 shows flows when tracking three targets in the image processor of the proposed method. Characteristically, a background model is provided for each target (S02), the

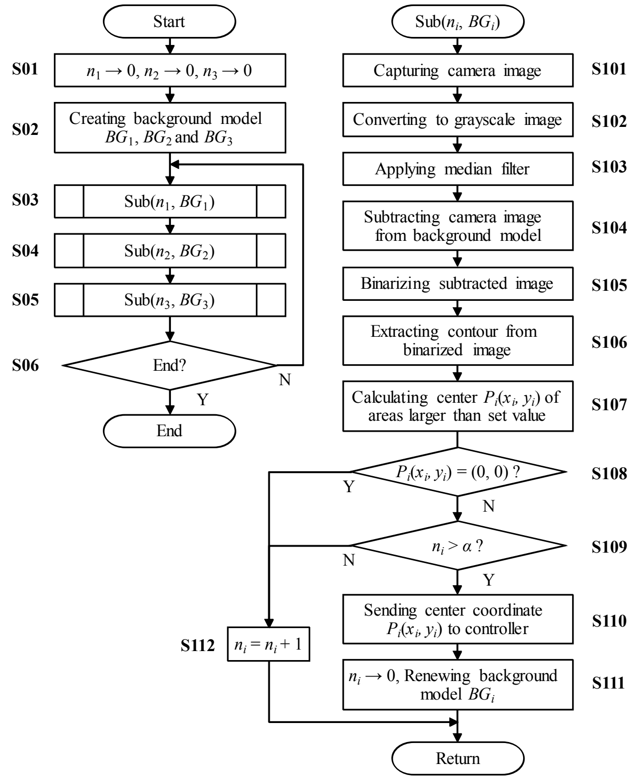

Fig. 6. Flow chart of detecting moving objects.

background model is updated whenever the optical axis changed (S111), and the optical axis change is not permitted until the set standby frequency α is reached (S109). Note that n_i is called the number of waiting times. First, the number of standby times and the background model for each target are initialized (S01, S02), and the process is repeated until the subroutine for each target is completed (S03, S04, S05). In the subroutine, an acquired image is converted into a grayscale image, and then a 5 × 5 pixel median filter process for noise removal is performed (S101 to S104). Next, the difference image between the post-filtering image and the background model is obtained, then the contour is extracted after binarization processing (S105, 106). The centre of contour P_i having a size larger than the specified value is calculated (S107). If P_i is at the centre of the image, the standby count is incremented by 1 and the process returns to the main routine (S108, S112). When P_i is not the centre of the image and the number of standby times is less than or equal to α, the standby number is incremented by 1 and the process returns to the main routine (S109, S112). If P_i is not the centre of the image and the number of standby times is larger than α, P_i is sent to the control unit, the number of standby times and the background model are initialized, and the process returns to the main routine (S109 to S111). As described above, the image processor of the proposed system derives the centre position of each target from the acquired image and sends coordinates to the controller. The controller drives galvano unit based on the target position.

Figure 7 shows a control block diagram of galvanometer scanner X in the proposed system. The control block diagram of galvanometer scanner Y is similar. In the diagram, $C_1(z)$ and $C_2(s)$ are the digital and analogue PID compensation, respectively.

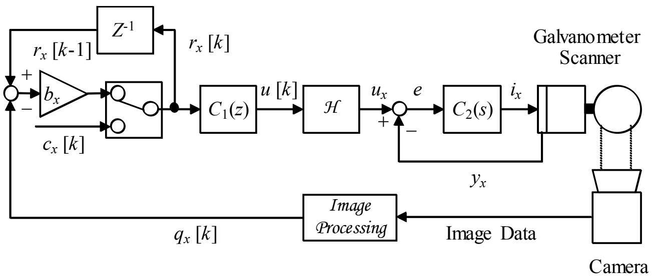

Fig. 7. Block diagram of Galvano Camera System.

This system can switch between two modes: a mode in which the angle command value is sent from the host (external command mode) and a mode where the angle command value is generated internally (tracking mode). Tracking mode is used after a moving object has been detected in the acquired image. A new angle command value r_x is created by comparing the position of the moving object in the image from the image processor with the angle command value one control cycle before. At this time, the angle command value is multiplied by the command magnification b_x. This is a value corresponding to changes in the zoom lens magnification. As described above, the proposed Galvano Camera System tracks multiple targets after capturing the target from the acquired image once.

4. EVALUATION TEST OF PROPOSED SYSTEM

4.1 System configuration of prototype

A prototype was produced for the evaluation of the proposed system. The proposed system consists of the Galvano Camera, control box, and control PC. The Galvano Camera is composed of a galvano unit, a drive amplifier, a DC fan for cooling the drive amplifier, a zoom lens, and a CMOS camera. The galvano unit used was a general-purpose product for laser markers (laser beam diameter: φ30 mm, movable range: ± 20 degrees in optical angle). The system control cycle is 1 ms, and the frame rate depends on the exposure settings.

4.2 Evaluation Test

We confirmed that the proposed Galvano Camera System can track and observe multiple targets simultaneously. The evaluation test was conducted at a golf course. The Galvano Camera System was placed on a hill about 5 m higher than the surroundings. We set three targets at the test field on different direction, a red balloon at point 1 (P1), a yellow balloon at point 3 (P3), and the volunteer walk around point 2 (P2). The distance from the observation point to each point is around 200 m, and the diameter of balloons are about 200 mm. The balloon is a 1.5 m long fish line attached to a general tripod. Then, we confirmed the frame rate and the presence of image blurring when tracking and observing three targets using the proposed system. The exposure time of the camera was 5 ms, and it was acquired with HD image quality (1280 × 720 pixels). Figure 8 shows images cut out from the video obtained in evaluation test as continuous still images every second. The shooting order is upper left (P1), upper right (P2), and lower left (P3). At this time, the azimuth (mechanical angle) of the galvanometer scanner ranges is 8.62 ~ 8.72 degrees at P1, 4.35 ~ 5.21 degrees at P2, and -7.72 ~ -7.67 at P3. Acquired images are reduced to 1/2 in length and width, and images in three directions are connected and displayed as a single screen. Also, the system does not occur image blurring. The frame rate at this time was 9 fps. The test results show that the Galvano Camera System is a technology that can simultaneously track and observe multiple targets. In addition, n order to evaluate the robustness of the algorithm adopted in the system, we are conducting tests at multiple locations with many obstacles, such as buildings and construction sites, and verifying its usefulness.

Fig. 8. Captured image of Galvano Camera System at test.

5. CONCLUSIONS

In this paper, we proposed a camera system using a galvanometer scanner for the purpose of tracking and observing multiple targets simultaneously. The proposed system adjusts the timing of the optical axis changing and exposure without overlapping; therefore, continuous imaging with the optical axis directed in a plurality of directions is possible. Further, tracking of multiple targets were achieved by the multiple image reference tracking method that determines the angle command of the reflecting mirror of each target based on the acquired images. Therefore, the proposed Galvano Camera System can automatically track multiple high-speed moving targets such as UAVs.

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