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A Simple Autonomous Hovering and Operating Control of Multicopter Using Only Web Camera

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Abstract—In this paper, an autonomous hovering control method of multicopter using only Web camera is proposed. Recently, various control method of an autonomous flight for multicopter are proposed. But, in the previous proposed methods, a motion capture system (i. e., OptiTrack) and laser range finder are often used to measure the position and posture of multicopter. To achieve an autonomous flight control of multicopter with simple equipments, we propose an autonomous flight control method using AR marker and Web camera. AR marker can measure the position of multicopter with Cartesian coordinate in three dimensional, then its position connects with aileron, elevator, and accelerator throttle operation. A simple PID control method is applied to the each operation and adjust the controller gains. Experimental results are given to show the effectiveness of our proposed method. Moreover, another simple operation method for autonomous flight control multicopter is also proposed.

Keywords—autonomous hovering control, multicopter, Web camera.

I. Introduction

THERE have been attracting a big attention that the utilization of the radio control helicopter is expected in various fields such as the monitoring of the disaster points such as landslides, facilities check of the infrastructure including a bridge (Fig. 1), and environment monitoring or the dispersion of the pesticide. In the previous, a single rotor type helicopter has been used in such a situation. But, in general, the radio control helicopter of single rotor type has difficult operation, and an expert technique is required for the operation. To overcome this difficulty, the radio control helicopter of four rotor type has been developed widely in recent years. Four rotor type helicopter (from now on, we call it as "multicopter") has a superior characteristics such as hovering properties and vertical takeoff and landing, and the spread advances because the operation is simpler than two rotor type. Compared with two rotor helicopters, the operation of multicopter is simple, but the steering multicopter is still difficult, and training of the operation is also necessary. To utilize a multicopter in more various fields, an autonomous flight control system of multicopter is required.

To realize an autonomous flight of multicopter, we have to make a dynamic model of multicopter and design a control system. A dynamic model of multicopter has been widely developed for the autonomous control of a multicopter[1], [2], [3], [4], [5], [6], [7]. The dynamic model of multicopter is described by nonlinear system, and its construction is complicated. Thus, it is difficult to apply for the practical applications.

In this paper, to solve those problems in the previous researches, we propose a control method that met the real use of multicopter and show that autonomous hovering control is achievable with a simple and easy method. The three dimensional positional information is measured by attaching a simple marker to multicopter, and produce a control input by a controller using this information. Furthermore, a position detection method and equipments of the operating systems are very simple and cheap apparatus in a proposed method, therefore, it can be easily to apply to the practical systems. Moreover, we also propose a prototype manipulation method of multicopter which are only moving a Web camera in the right and left and changing a volume of flame on a monitor screen.

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II. Problem Formulation

For an autonomous flight control method of multicopter, a lot of dynamic models and control methods has been proposed. It is well known that a coordinate system which is given in Fig. 2 is defined, a feedback controller makes each torque τ_θ, τ_ϕ, τ_ψ corresponding to roll, yaw, pitch or lifting power f_1, f_2, f_3, f_4 from dynamics of multicopter. In the actual multicopter, for example, APM flight controller (http://www.3drobotics.com/apm/) is mounted and it receives PPM signal transmitted by radio controller and the appropriate rotation speed of each rotor and the control signal to a motor

Fig. 1: Flight under the bridge (four rotor helicopter in the red oval)

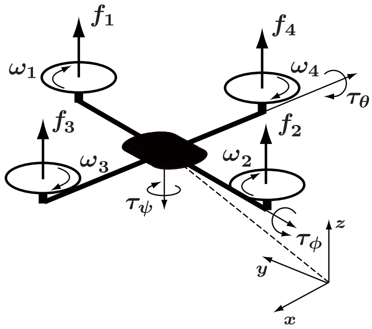

Fig. 2: Schematic diagram of the multicopter

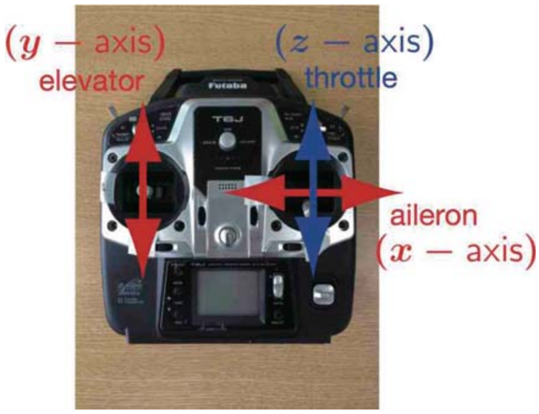

Fig. 3: Radio control transmitter

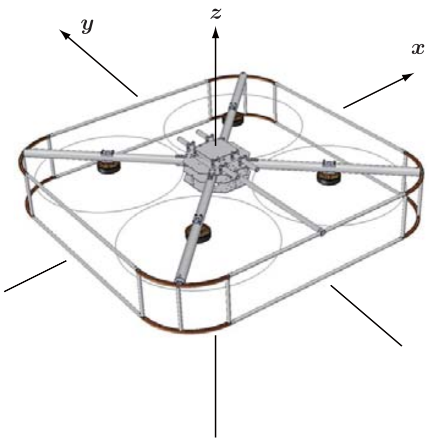

Fig. 4: Axis of multicopter

are calculated. Therefore, when we operate a multicopter, we give appropriate values of the aileron, elevator, throttle with a lever which is shown in Fig. 3, these operations cope with the x, y, z axial direction which is shown in Fig. 4. However, for the practical situations, we do not transmit the values of torque corresponding to roll, yaw, pitch to each rotor from radio controller. Therefore, we operate aileron, elevator, throttle corresponding to the x, y, z coordinate to control a multicopter via transmitting the PPM signal using radio controller. In other words, when we control the positioning of the multicopter, it

Fig. 5: Front view of multicopter

is necessary to make a control input for multicopter to operate aileron, elevator, and throttle corresponding to the position of x axis, y axis, and z axis of the multicopter.

III. Proposed Method

For an autonomous flight control of multicopter, it is often used a high–performance position measurement devices such as OptiTrack (https://www.naturalpoint.com/optitrack/). This measurement system can measure the position of multicopter precisely, but it can only apply to the limited environment. Therefore, it is very hard to apply the OptiTrack system in a real environment. On the other hand, position measurement of multicopter is necessary to realize an autonomous flight.

To solve this problem, in this paper, we use a simple position measuring system to measure the position of multicopter and carry out the autonomous flight control. We attach an AR marker to the multicopter which is shown in Fig. 5 (enRoute, PG400), and measure a position of multicopter by reading AR marker using a Web camera (Logicool ®HD Pro Webcam C920t). From this captured image using Web camera, we recognize the x, y, z coordinates and positions of the AR marker by the programming of processing. Based on these coordinates, we give the reference position of each coordinate and realize an autonomous hovering control of the multicopter. We define the reference position as $r_i(t)$ $(i = x, y, z)$, then we can get the error signals for each position as $e_x(t) = r_x(t) - x(t)$, $e_y(t) = r_y(t) - y(t)$, and $e_z(t) = r_z(t) - z(t)$.

Using these error signals, control inputs for aileron, elevator, and throttle is given by the following PI–D control method as follows:

$$u_a(t) = k_{Pa}e_x(t) + k_{Ia}\int_0^t e_x(\tau)\mathrm{d}\tau - k_{Da}\frac{\mathrm{d}x(t)}{\mathrm{d}t} \quad (1)$$

$$u_e(t) = k_{Pe}e_y(t) + k_{Ie}\int_0^t e_y(\tau)\mathrm{d}\tau - k_{De}\frac{\mathrm{d}y(t)}{\mathrm{d}t} \quad (2)$$

$$u_t(t) = k_{Pt}e_z(t) + k_{It}\int_0^t e_z(\tau)\mathrm{d}\tau - k_{Dt}\frac{\mathrm{d}z(t)}{\mathrm{d}t} \quad (3)$$

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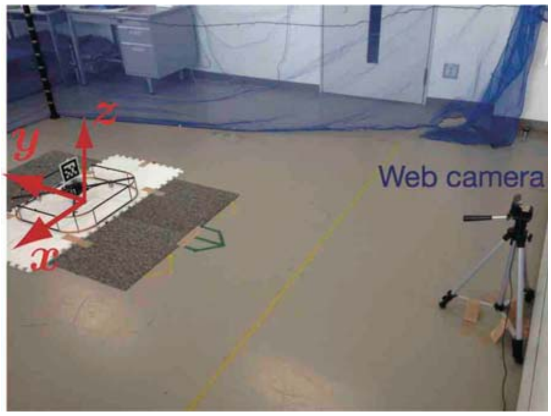


Fig. 6: Experimental situation

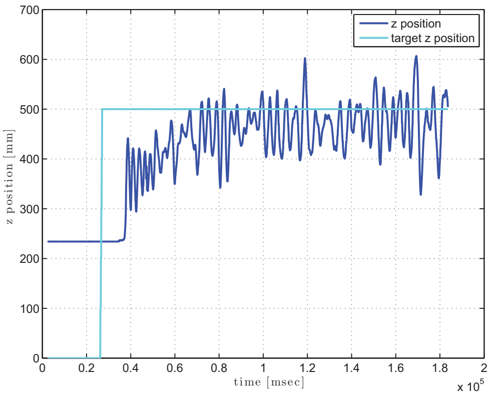


Fig. 7: Experimental result (z–axis)

IV. Experimental Result

The experimental environment is shown in Fig. 6. We get a position of the multicopter with the captured image which we acquired with a Web camera. Then, we calculated control inputs $u_a(t)$, $u_e(t)$, $u_t(t)$ of aileron, elevator, and throttle from Eqs. (1), (2), and (3), respectively. Each control input is converted into the PPM signal using processing programming. These PPM signals are transmitted to the multicopter using a radio controller module (RCSD–01, LABOAR) with Arduino. The aforementioned method is naturally expanded method that a human steers helicopter using radio controller, and autonomous hovering control is enabled without changing the present system.

In the experiment, the multicopter took off from a landing situation, and the desired positions were set to 0.5[m], i. e., $r_x(t) = 0$, $r_y(t) = 0$, $r_z(t) = 0.5$. Fig. 7 depicts the time history of the altitude of multicopter. The AR marker is attached to height of the 0.22[m] from the floor, therefore, the initial value of altitude is 0.22[m]. Fig. 8 shows the $x - y$ positions of multicopter. As we can see these figures, a good autonomous hovering control was given by using our proposed method.

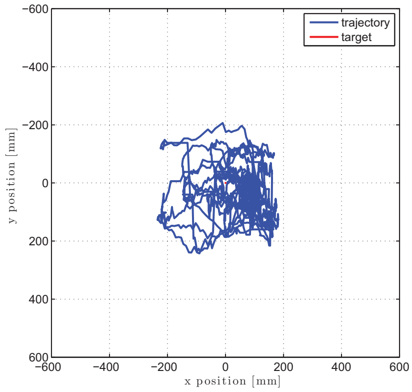


Fig. 8: Experimental result (x–y axis)

V. Novel Operation Method of Multicopter

In the previous sections, we showed a simple autonomous hovering control of multicopter. On the other hand, there have been paid much attention to control a position and posture of multicopter using GPS signal, position recognition with laser range finder, and so forth.

Recently, the bridge monitoring systems are considered to watch the situation such as the aged deterioration of the bridge. It have already been proposed the observation method which hanging a video camera from on the bridge or using a telescope with a camera. Using a video camera which attached to a multicopter, the observation of the state of bridge is also planned. Fig. 9 shows such a situation. The position of the multicopter can not measure by GPS in the bottom of the bridge, therefore, we can not control the multicopter based on GPS. To control the position and posture of the multicopter where it can not use GPS, the operator (a person) should manipulate the proportional radio controller. But, it is well known that the operation skills of multicopter are very difficult, therefore, there is a limit to make it widely available. Furthermore, it is difficult to operate multicopter to see the video image from a video camera because we can not see it directly. To solve these problems, the development of the method to easily operate a multicopter is needed.

VI. Basic Ideas

To achieve a manipulation method of multicopter only using video image which is hanging from on the bridge, first of all, we control the movement of an omnidirectional mobile robot which put on the floor using only a Web camera. Fig. 10 shows the omnidirectional mobile robot and captured video image from a Web camera. The three colors LED as color markers are attached to the omnidirectional mobile robot and recognize the position and posture of the robot using captured image from Web camera. Our proposed method can control a mobile robot so that the central location (the center marker) of mobile robot comes to the center of the camera image. Moreover, we make that the size of the frame on the screen is changed. Resizing this frame, our proposed method can move a mobile robot in the front-back direction (the direction that robot approaches a camera, and goes away), because of the

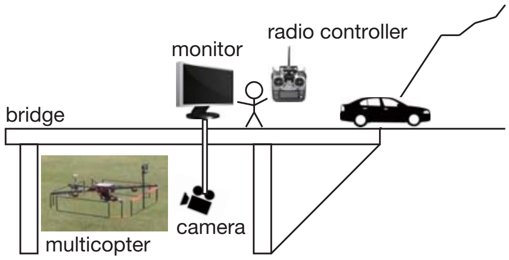


Fig. 9: Schematic diagram of conventional bridge monitoring

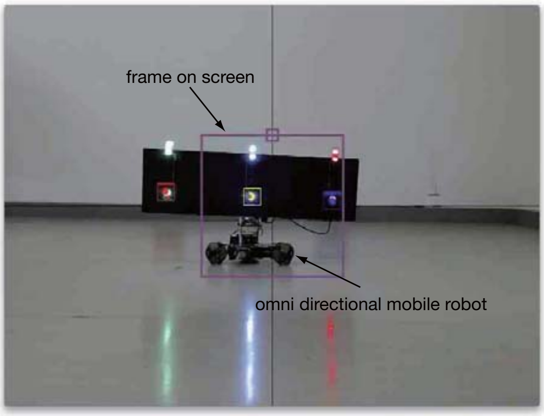


Fig. 10: Omnidirectional mobile robot and captured screen of Web camera

red and blue marker adjust with the both ends of the frame of the screen, respectively. Using our proposed method, the mobile robot can move right, left, front, and back direction with moving a camera in the right and left, and resizing the frame in the screen.

VII. Problem Formulation

To realize the idea of manipulation method of multicopter, first of all, we consider to control a position and posture of mobile robot moving on the floor, using an image which is provided from a Web camera. Three LED tape different in the color in the equal space as a color marker to omni mobile robot with a wheel which is shown in Fig. 10 are attatched.

We made an application to recognize the position of the color marker which is called color tracking method, using an image which is provided from a Web camera.

Fig. 11 shows the screen display window that width is w and height h. Moreover, we draw the red square that size can resize on the center of the window. We define the control objective that the marker of the middle which is three color markers accords with the center of the window. Moreover, the control objective is that the side of right and left of a red square follows the marker of both ends. Then the control objective is achieved, the state of the window would be shown as Fig. 12. Using this proposed method, if we turn a Web camera in a horizontal plane,we can move a mobile robot in the direction of right and left. Moreover, when we changing the size of

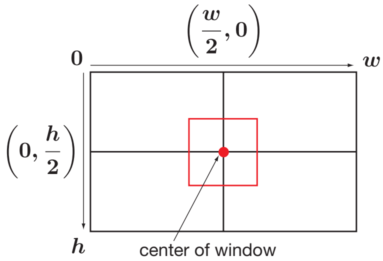


Fig. 11: Screen display

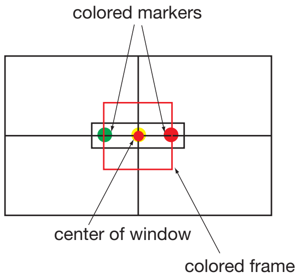


Fig. 12: Control Objective

the red square on the window, we can make a move that the mobile robot approaches, and goes away.

VIII. Motion Control of Mobile Robot

To establish the motion direction of the mobile robot based on an error to be provided from the position relations of a window and the marker to move a color marker attached to a mobile robot car to the center of the window, error signals should be defined. In addition, a marker of mobile robot keeps posture, that is, it is always necessary for a marker to turn to the front of a Web camera. The position relations of a window and the marker in some situation is shown in Fig. 13(a). The position of the marker of the middle as (x_1, y_1), and the distance of the color of both ends as ℓ_1 are defined. Moreover, a side of length of a red square is ℓ_2 is defined and this length is variable. From these definitions, the errors from a central marker to the center of the window are the lateral direction e_x and the lengthwise direction e_y, and they can be described as follows:

$$e_x = x_1 - \frac{w}{2} \tag{4}$$

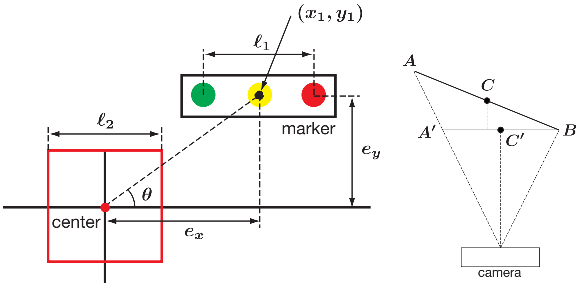
$$e_y = \ell_2 - \ell_1 \tag{5}$$

Velocities of mobile robot for the direction x and y are given as follows:

$$v_x = K_{px} e_x \tag{6}$$

$$v_y = K_{py} e_y \tag{7}$$

where K_{px} and K_{py} are transformation coefficients of position to velocity. Based on the value of e_x and e_y, the azimuth of the mobile robot is determined. In the case of $e_x \geq (\leq) 0$, there is the marker on the right (the left) side of the window center, and, in the case of $e_y \geq (\leq) 0$, there is the marker in the near (the far) from a Web camera. If the center of the



(a) error of center position (b) posture

Fig. 13: Definition of position and posture of marker

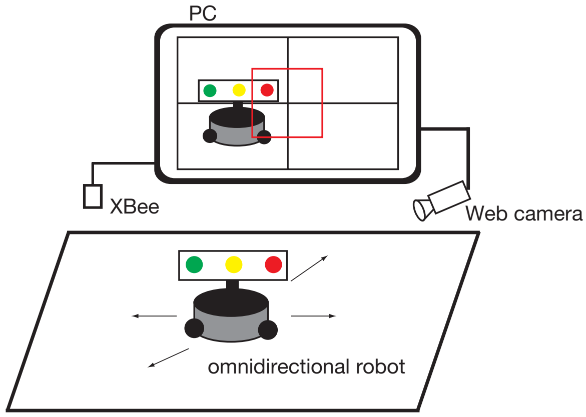


Fig. 14: Experimental enviroment

window is defined as the origin, then the relation of marker and the window can be given as follows:

$$\tan\theta = \frac{e_y}{e_x}, \tag{8}$$

therefore, the angle θ is given as follows:

$$\theta = \tan^{-1}\frac{e_y}{e_x}. \tag{9}$$

Therefore, $\theta + \pi$ becomes the direction that a mobile robot should go.

From the position relations of the three-color marker on the window, the posture of mobile robot is decided. When a mobile robot inclines for a camera when we assume three colors of a marker carrying every to mobile robots A, C, B from the left, we can show the position relations of the marker in Fig. 13(b). But, as for the marker, A is reflected in the position of A' because the marker reflected in the plane in a window. Then, the center of A' and B becomes C' on the window, and the between C and C' has a gap. A gap of this C and C', we can control the posture of the mobile robot based on this value.

IX. Experimental Results

Fig. 14 shows the experimental environment. A Web camera (Logicool c920) is connected to a PC, control system and image processing are programmed by processing (ver. 1.5.1). A mobile robot has three DC motor, and each motor is

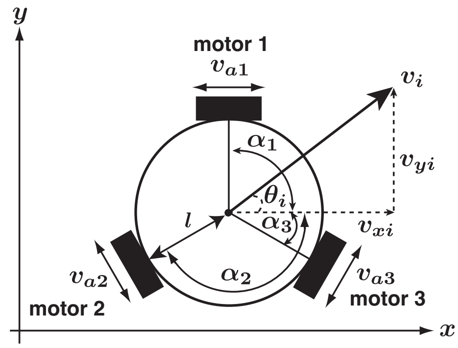


Fig. 15: Kinematic structure of mobile robot

driven by Arduino Fio with XBee via dual motor driver (TB6612FNG/sparkfun) [8]. The posture of mobile robot is recognized by the Processing program via Web camera, we can get the x, y positions and azimuth of the robot. Based on the measurement position data of the mobile robot, control input for robot is determined by Eq. (6), (7), and (9). Using XBee, these informations are transmitted to mobile robot from PC. Fig. 15 shows the kinetic structure of omnidirectional mobile robot where $\alpha_1 = \frac{\pi}{2}$, $\alpha_2 = -\frac{5}{6}\pi$, and $\alpha_3 = -\frac{\pi}{6}$, and the radius of the mobile robot is l = 0.11[m]. From the calculated values as the velocity v_x, v_y and rotational velocity $\dot{\theta}$, the rotational velocity of each omni wheel is calculated by the follows:

$$\begin{aligned}\begin{bmatrix} v_{a_1} \\ v_{a_2} \\ v_{a_3} \end{bmatrix} &= \begin{bmatrix} \sin\alpha_1 & -\cos\alpha_1 & l \\ \sin\alpha_2 & -\cos\alpha_2 & l \\ \sin\alpha_3 & -\cos\alpha_3 & l \end{bmatrix} \begin{bmatrix} v_{xi} \\ v_{yi} \\ \dot{\theta}_i \end{bmatrix} \\ &= \begin{bmatrix} 1 & 0 & l \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & l \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & l \end{bmatrix} \begin{bmatrix} v_x \\ v_y \\ \dot{\theta} \end{bmatrix}. \end{aligned} \tag{10}$$

We put the mobile robot in the arbitrary position and posture in the screen of the camera, then we can get the window screen as Fig. 10. The mobile robot began moving, and the marker of the middle accorded with the center of the window. Besides, the mobile robot moved that the side of right and left of a red square equaled the marker of both ends. Figs. 16, 17, and 18 show the error signals e_x and e_y, and angle θ, respectively. These figures show that error signals and angle θ converge to almost zero This means that the control objective is achieved. Therefore, a good control performance was achieved by using our proposed control manipulation.

X. Conclusions

We proposed an autonomous hovering control method of multicopter and it could be done by a simple and easy method. The three-dimensional positional information of multicopter was measured by using an AR marker, and produce a control input by a controller using this information. The experimental result has checked that proposed system could autonomous hovering control of multicopter.

Moreover, we proposed a novel manipulation method of mobile robots using Web camera. It was confirmed that the

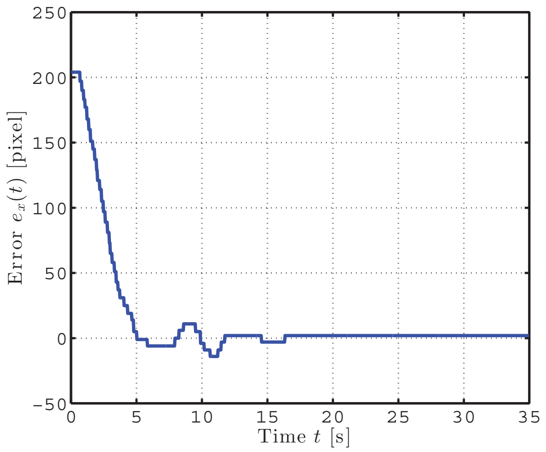


Fig. 16: Error of x–axis

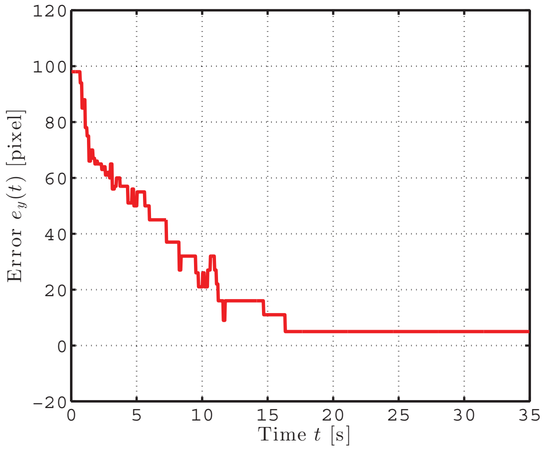


Fig. 17: Error of y–axis

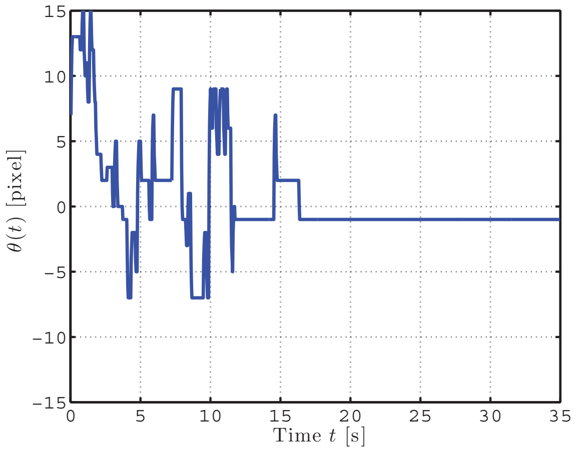


Fig. 18: $\theta(t)$

mobile robot could move right, left, front, and back direction with moving a camera in the right and left, and changing the size of the frame in the screen. If we can apply this manipulation method to a multicopter, we can easily operate multicopter only training a camera on a multicopter and resizing the frame on the monitoring screen. Our future research will be devoted to realize of these methods.

Acknowledgment

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