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Satellite Tracking Control System Using Fuzzy PID Controller

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Abstract: This paper presents the results of study, design and manufacture of a searching and satellite auto-tracking system used for mobile receiver. This system applies both the traditional proportional integral derivative (PID) control and the fuzzy PID control methods. Firstly, the PID controller was designed by Ziegler-Nichols tuning method to obtain control parameters. Then, a fuzzy controller was applied to tuning online parameters of the PID controller. In order to apply for mobile satellite receiver, the tracking control system has been designed, fabricated on a PCB board. Simulated and experimental results indicate that the system performances obtain from applying the fuzzy PID controller was better than traditional PID controller.

Keywords: Satellite tracking system, step-tracking algorithm, PID controller, Fuzzy controller, satellite communication.

1. Introduction

In the mobile satellite communication, received systems are mounted on the movable device such as ship, train, car or airplane. In order to receive continuous signals, antenna system must be steered in both the azimuth and elevation angle to track a satellite. Tracking capabilities depend on the beam width of the antennas and the speed of mobile motions. Thus, high gain and directional antennas with narrow beams need to track the satellite both in elevation and azimuth directions. In the fact that, antennas should track the satellite only in the azimuth directions because the elevation angles to the satellite are almost constant. The satellite tracking system shown in Fig.1, which consists of a satellite antenna, a low-noise block-down converter (LNB), a set-top box tuner, antenna control unit (ACU) and mechanical system.

Research and development of the antenna tracking system is widely processed [1-8]. Mobile system uses different tracking algorithms and control methods to lock on the satellite such as the

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traditional PID controller was applied for antenna tracking system [4], the step tracking algorithm with H∞ controller was used for the tracking loop design [6], the both traditional PID and PD-type fuzzy control methods were used for mobile satellite antenna tracking system with parameter variations effect [7-8].

This paper describes the development of a satellite received system which has been capable of searching and satellite auto-tracking used for Vinasat-1 system, which is configured to provide both fixed and mobile communication services with eight C-bands transponders and 12 Ku-band transponders. The satellite is positioned at 132^0 east.

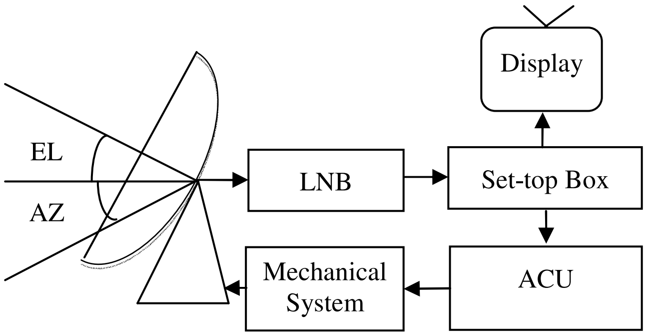


Fig 1. Diagram of the satellite tracking system.

This system applies the step-tracking algorithm and the fuzzy control method. Firstly, The tracking system uses the conventional PID control method to obtain the key parameters of antenna tracking and stable loops. However, due to the nonlinear characteristics of the DC motor, the PID controller couldn't work exactly in operating process. So a fuzzy controller was applied to tuning online parameters of the PID controller.

The organization of this paper is as follows: the first section is introduction. The second one is for searching method and satellite tracking algorithm. The third one is that designing a traditional PID controller and fuzzy PID controller. The design and fabrication of the satellite tracking control system are given in section 4. The last part is the conclusions.

2. Searching method and satellite tracking algorithm

2.1. Satellite searching method

There are two types of satellite searching method: Mechanical and electrical. In the mechanical method, both elevation and azimuth angles of transmitter are controlled by pressing azimuth up and down keys or elevation right and left keys to drive a motor system. For electronic method, searching system is done automatically by rotating the antenna according to the elevation and azimuth angle, which was calculated by software program.

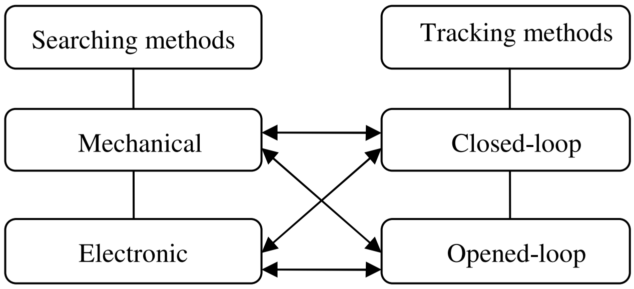


Fig 2. Satellite searching and tracking methods.

To perform the process of finding a satellite, we must base on the parameters of the satellite and ground station. A ground station is located at a known point on the surface of the Earth and defined by latitude δ, and longitude λ. Geostationary satellite is determined by longitude λ_G and altitude above ground. These parameters can calculate the azimuth angle (angle measured east from north in the horizontal plane) and elevation angle (angle between the line of sight to the satellite and the local horizontal plane) of the line of sight (LOS) to the geostationary satellite [9]. Base on these parameters the system can control automatically or manually the ground station antenna to capture the satellite.

2.2. Step tracking algorithm

There are two tracking algorithm, namely an opened-loop method and closed-loop method. The opened-loop uses information of mobile position from GPS receiver and angle sensors. In contrary, the closed-loop method utilizes the satellite signal to track it such as the step tracking algorithm. The diagram of step tracking algorithm is shown in Fig.3.

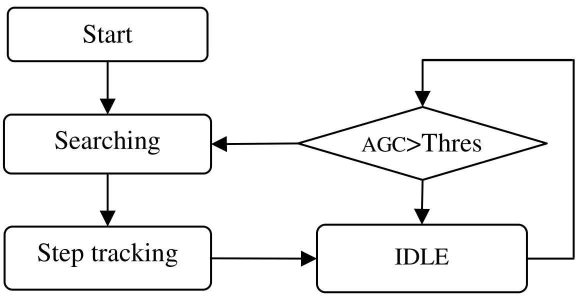


Fig 3. Diagram of step-tracking algorithm.

Firstly, the control system operates in the manually or automatically search mode via parameters of ground stations and satellites. Then the system switches to step-tracking mode. In this mode, the control system will perform tracking process until AGC signal level is over the threshold level and tracking state keeps the idle stage. When the receiver system moves, if the AGC signal level drops between the threshold level, tracking system will move to searching mode.

When the step tracking mode starts, the antenna control system sets initial threshold step, then the received signal level will be used for comparing with the signal level before moving. If the received signal has increased, the antenna continues one-step shift in the same direction. If the received signal level has decreased, the antenna moves in the opposite direction. By step-by-step turns, the receiver antenna can track the point of the highest signal level.

This algorithm has the advantages of simple system configuration and low cost because this algorithm uses only feedback about the received signal level to the control facility.

3. Design of PID controller and fuzzy PID controller

3.1. Design of PID controller

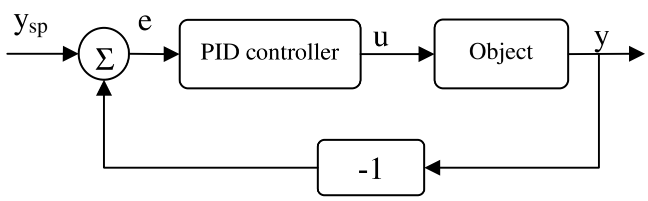


Fig 4. Diagram of PID controller.

The structure of PID controller is shown in fig 4. Where u is control signal and e is control error signal ($e = y_{sp} - y$). Control signal is the sum of three components: proportional, integral and derivative and is defined as follows:

$$u(t) = K_P\left(e(t) + \frac{1}{T_I}\int_0^t e(\tau)d\tau + T_D\frac{de(t)}{dt}\right) \quad (1)$$

Transfer function of the PID controller:

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_P + K_I\frac{1}{s} + K_D s \quad (2)$$

$$G_{PID}(s) = K_P(1 + \frac{1}{T_I s} + T_D s) \quad (3)$$

Table 1. Parameters of the DC motor

Parameter	Description	Value
R	Armature resistant	2.96 Ω
L	Armature inductance	150 mH
J	Moment of inertia	42.3e-6 $Kg.m^2$
b	Viscous-friction coeficient	48.6e-6 Nms
K_t	Torque constant	13.5e-3 N-m/A
K_b	Back EMV constant	13.5e-3 V-sec/rad

The controller parameters are K_P, K_I (or T_i), K_D (or T_D). These parameters affect the setting time, overshoot, steady-state error of the system. There are many methods to calculate these parameters, the most popular method is the Ziegler - Nichols.

To calculate the control parameters K_P, K_I, K_D we have to determine transfer function of the control object. Parameters of the DC motor are shown in table 1 [10].

Transfer function of the control object are calculated by the following famula:

$$G_V(s) = \frac{13500}{6.345.s^2 + 132.498.s + 326.106} \quad (4)$$

Due to the effects of noise and measurement errors as well as non-linear nature of the engine, lead to the calibration parameters of the PID controller is difficult to achieve good value. Therefore, a fine-tuning process is performed by a fuzzy controller before applying to the system controller.

3.2. Fuzzy PID controller

The structure of the fuzzy PID controller is shown in Fig.5. Fuzzy controller will perform optimizing control parameters of PID controller based on the current parameters of the classical error (e) and the rate of the change of error (de/dt). Therefore, the input of the fuzzy controller includes control error signal e(t) and its derivative de(t). The outputs of the fuzzy controller are three PID parameters: K_P, K_I, K_D [11].

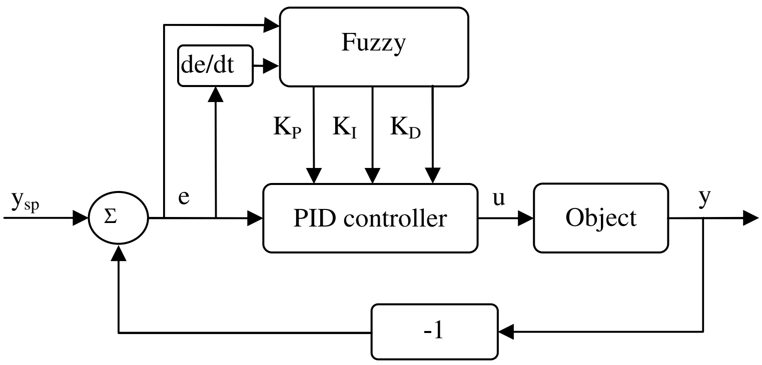


Fig 5. Block diagram of fuzzy PID controller.

Here, we use Mamdani model for the fuzzy controller as shown in Fig.6.

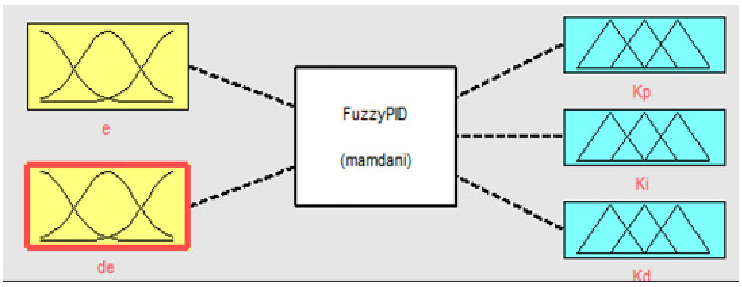


Fig 6. Model of fuzzy PID controller.

The Membership functions of the input fuzzy are used triangular shapes as shown in Fig.7. The input variable “e” is divided into five overlapping fuzzy sets: NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small), PB (Positive Big), and input variable “de” is also divided into five overlapping fuzzy sets: DF (Decrease Fast), DS (Decrease Slow), MT (Maintain), IS (Increase Slow), IF (Increase Fast).

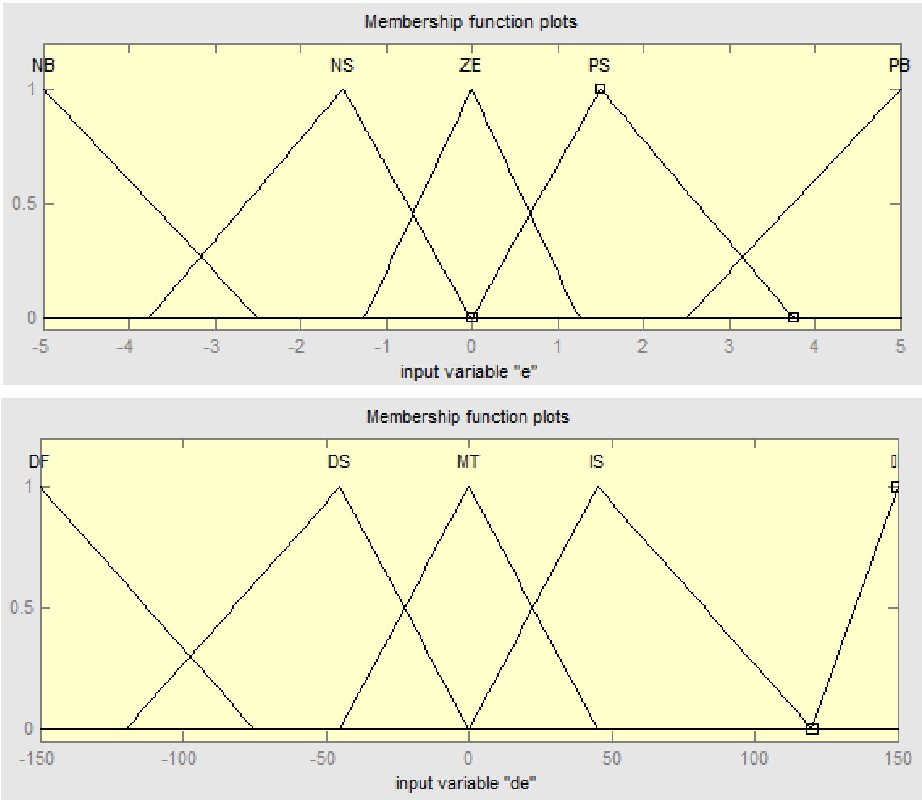


Fig 7. Membership functions of input variables.

The outputs of the fuzzy controller are divided five sets: S (Small), MS (Midium Small), M (Medium), MB (Medium Big), B (Big). Membership functions of the fuzzy output are also used triangular function. Each fuzzy variable has value between 0 (non-member) and 1 (full-member).

The rules relate the input and output variable using If-Then statements. The result of rules shown in Table 2:

Table 2. Fuzzy controller cross reference rules

de(t)/e(t)	NB	NS	ZE	PS	PB
DF	S	S	MS	MS	M
DS	S	MS	MS	M	MB
MT	MS	MS	M	MB	MB
IS	MS	M	MB	MB	B
IF	M	MB	MB	B	B

The simulink model of the fuzzy controller is shown in Fig.8.

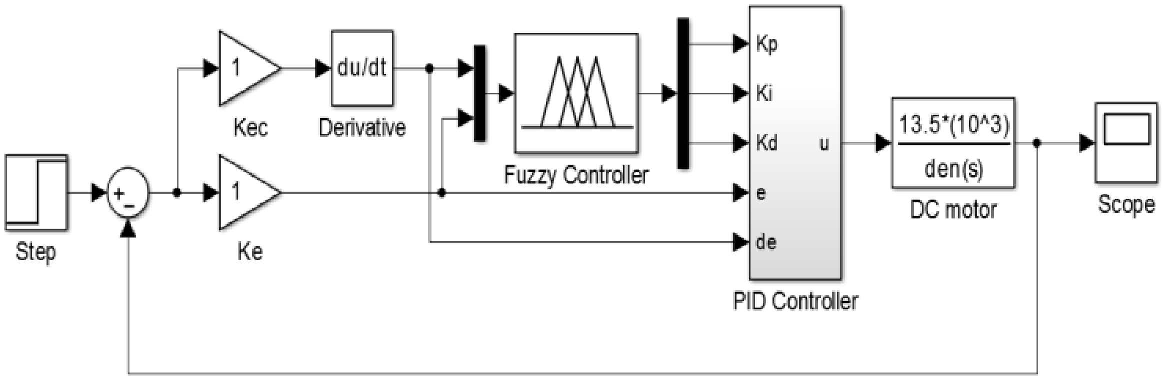


Fig 8. Simulink diagram fuzzy PID controller.

The simulated results of PID controller and fuzzy controller are shown in Fig.9. From the figure, the result shows that the response of PID controller is oscillatory and long setting time, which can damage the system. But the response of fuzzy PID controller is better than PID controller.

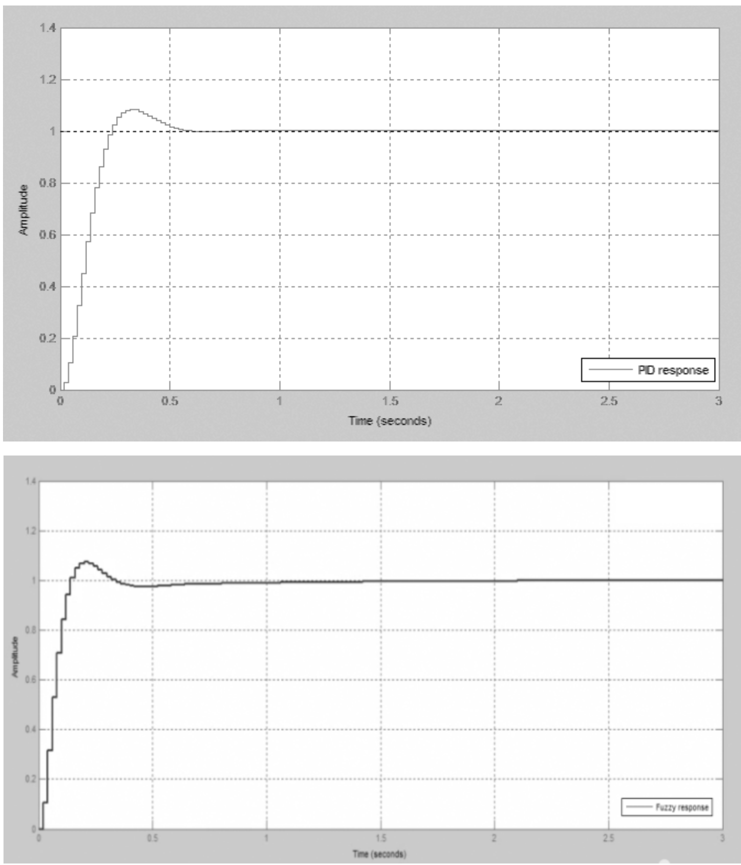


Fig 9. The step response of the PID controller and the fuzzy PID controller.

4. Building tracking control system and experimental results

The architecture of the tracking control system is shown in Fig.10. The microcontroller receives signals from inputs such as keyboard, AGC, and encoder and send to computer. Besides microcontroller also receives signal from computer to control mechanical system tracking the satellite antenna when the receiver moves.

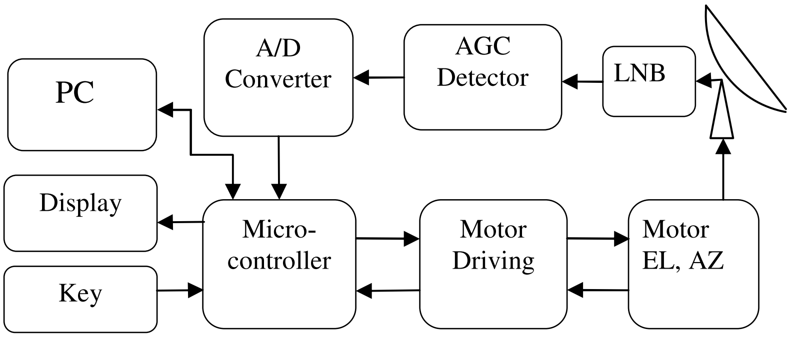
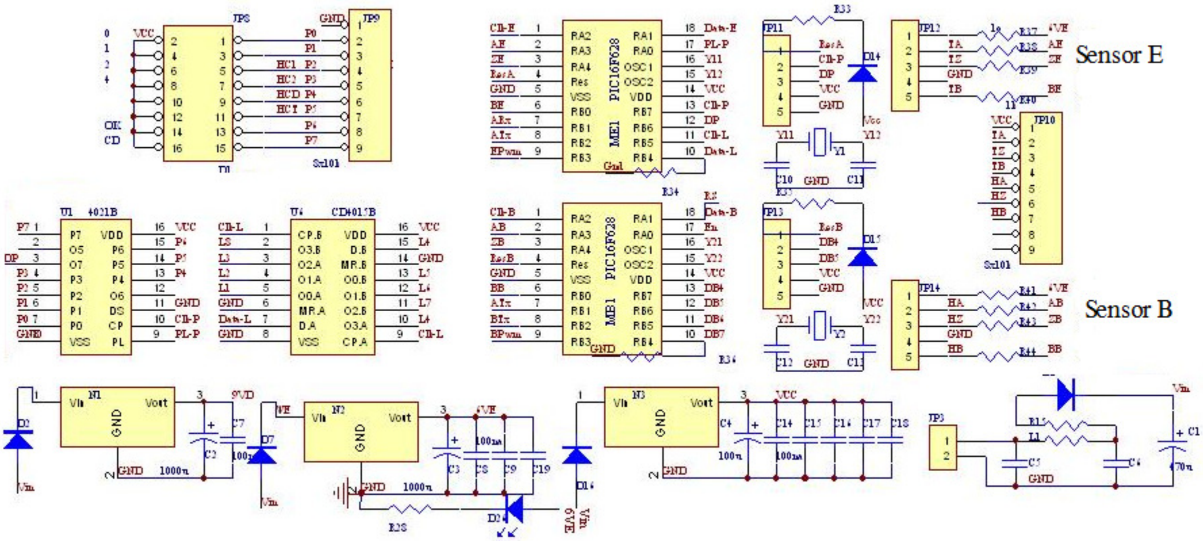


Fig 10. Block diagram of experiments configuration.

Control Center is done by software installed in the computer. Software performs receiving the sensor signal from the microcontroller, then perform to calculate incorrect azimuth, elevation angle. After that, software implements control process using the step tracking algorithm with fuzzy PID controller.

To obtain the AGC signal level, the AGC detector provided the proportional signal level of AGC voltage. This AGC signal passed through the A/D converter to convert digital signal. Because the AGC signal range is very narrow, A/D converter must have a high accuracy with 12 bit resolution.



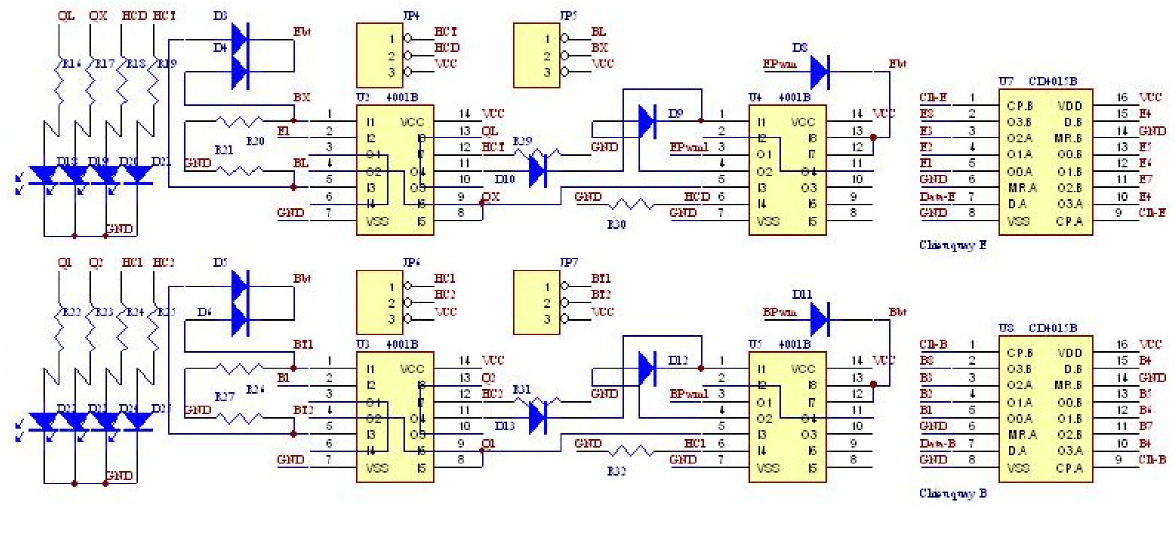


Fig 11. Electronic scheme of the tracking system.

To calculate the elevation and azimuth angle of antenna, microcontroller read the latitude and longitude value of ground station from the GPS receiver and angle value from sensors. By comparing between the angle value of GPS and sensors, system controls the motor driving rotating new position.

The electronic scheme of tracking system is shown in Fig.11. Motor driving circuit uses power transistor 2SC2581 and A1106, which installed in the form of H-bridge. System uses PIC16F628A that is 8 bit microcontroller.

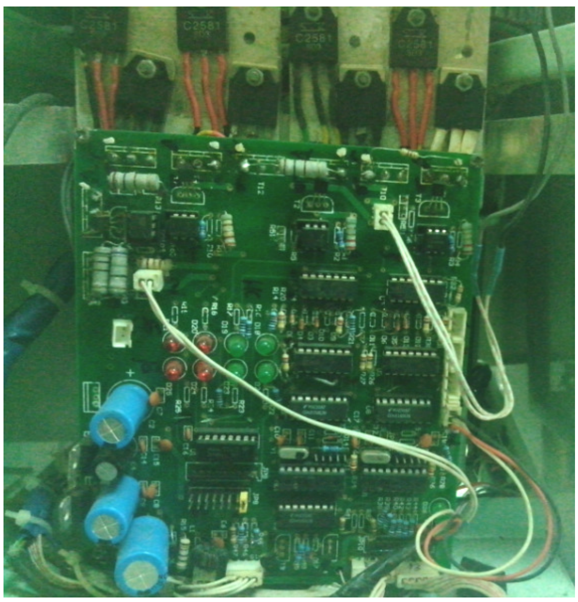


Figure 12. Electronic scheme of the tracking system.

In order to confirm a performance of tracking algorithm and fuzzy controller, the parabola antenna with a diameter of 60cm is used for Vinasat 1 satellite. Mechanical system use two 24V-DC servo motors with speed of 1500 rpm, elevation range of rotation is from 0^0 to 90^0 and azimuth is from 0^0 to 355^0. The completed tracking control system is shown in Fig.13.

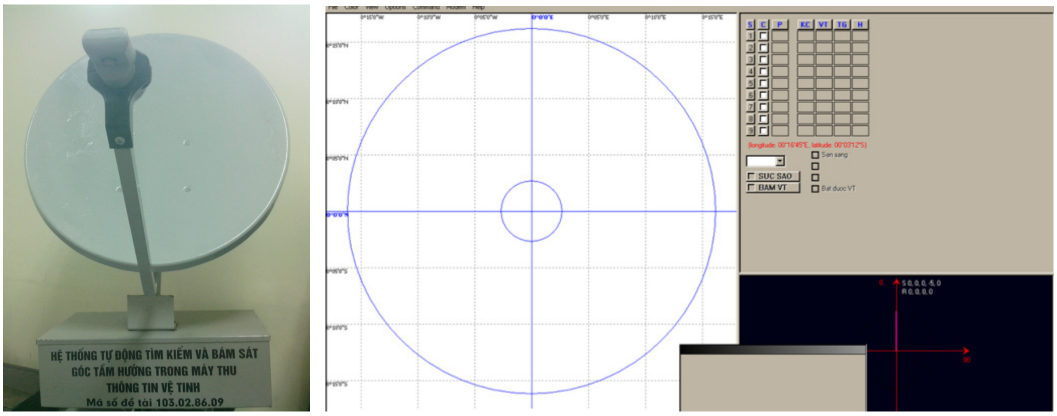


Fig 13. Tracking control system and control software interface.

Fig.14 indicates variations of the AGC voltage versus time when using the PID controller and fuzzy PID controller. At the point of 10s, the time to reach the focus item is observed 0.7s in case of PID controller and 0.4s in case of fuzzy PID controller. The results show that the AGC level curve is flatter than in case of PID controller.

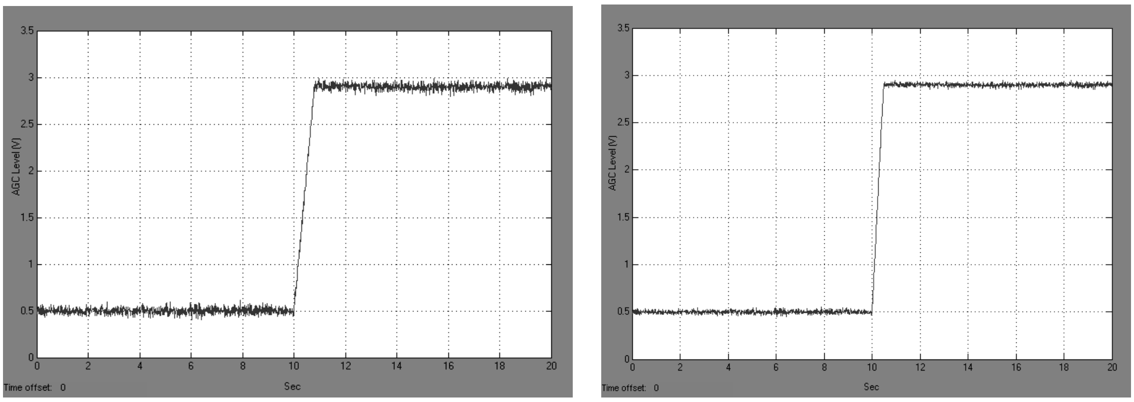


Fig 14. AGC level with PID controller and fuzzy PID controller.

5. Conclusions

This paper presented the study, design and fabrication of the searching and satellite auto-tracking system used for mobile satellite receiver. The paper applied fuzzy control method to design selt-tuning fuzzy PID controller with two inputs and three outputs. The result shows that the fuzzy PID controller has a better performance in response time, small overshoot, small steady state error.

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