Fuzzy Control of Data Link Antenna Control System for Moving Vehicles

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Abstract: The tracking antenna system must be always pointed to target moving vehicle. Especially, for an antenna mounted on a movable vehicle, it needs the stabilized antenna system. In this paper, two types of fuzzy controller were derived and applied to a data link antenna system and the altitude control of unmanned helicopter, respectively. A simplified Fuzzy-PID controller was designed for 2-axes antenna stabilization and tracking system and the performance was verified by simulations and experiments. Computer simulations were performed by Matlab and SIMULINK. A 2-Axes antenna (SeaTel 1898 model) was selected as test platform of this research. The antenna was modified by using two Blushless Direct Current motors and an embedded DSP controller. To verify the performance of designed antenna servo control system, the performance of the conventional PID controller and that of the Fuzzy-PID controller, designed by the same PID control gains, were compared.

Keywords: Data Link Antenna, Stabilization, Tracking, Fuzzy Controller

1. Introduction

The performance of stabilization and tracking system mainly depends on the servo control system that driving the antenna pedestal. However, the outdoor antenna servo system is subject to significant torque disturbances from wind pressures and gusts on the antenna structures, as well as bearing and aerodynamic frictions. This control system should provide a sharp directivity in spite of the environmental disturbances and internal uncertainties. To solve these problems, several stabilization and tracking controllers were introduced but it is important that new needs and short life cycle design are implemented in these controllers. The more flexible and rapid prototyping design is necessary for these embedded control system. Therefore, the implementation of a real-time controller is necessary for the precise generation of the reference signal and robust tracking performance. With recent advances in embedded controller and digital control theory, high performance techniques were developed. The communication antenna accuracy might be improved by the use of a high performance controller and better control law.

A fuzzy-PID controller was designed for a 2-axes antenna stabilization-tracking system and the performance was verified by simulations and experiments. To verify the designed antenna servo control system, the performance of the conventional PID controller and that of the fuzzy-PID controller, designed by the same PID control gains, were compared.

Computer simulations were performed by Matlab and Simulink. A 2-Axes antenna (SeaTel 1898) was selected as test platform of this research. To verify the performance of the designed fuzzy controller for tracking antenna system, simulation block was designed and tested by several environmental disturbance conditions.

2. Antenna System

2.1. The Structure of Antenna System

Generally, antenna system is composed of three parts, ACU(Antenna Control Unit), PCU(Pedestal Control Unit), SAP (Stabilized Antenna Pedestal). ACU controls SAP by transferring control command for azimuth and elevation angles of SAP and calculate position of the moving vehicle. In figure 1, general structure of antenna system was represented.

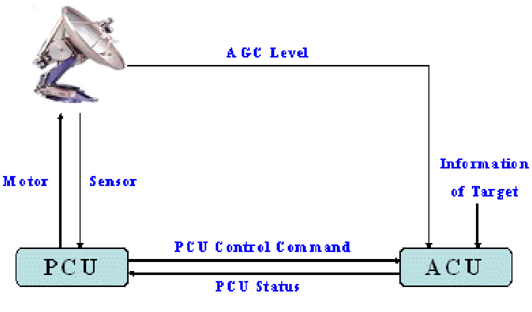

Fig. 1. Structure of the Tracking antenna system.

SAP is mechanical part that directly controls the azimuth and elevation angle of the antenna for pointing a moving vehicle. PCU controls SAP using azimuth and elevation angle value form ACU.

2.2. The Pointing Angle

The coordinate of moving vehicle is consist of altitude φ (center angle is TOA, T is a perpendicular fall point) and latitude λ. Also, the coordinate of the considering point P is consist of altitude l (center angle is POB) and latitude ψ. The latitude difference between moving vehicle and point P was represented as L. Center angle BOT has value of ς and center angle POT(angle between moving vehicle and point p view form center of mass) is to be ϕ. Put the distance between moving vehicle and point P as *R*, the distance between moving vehicle and center of earth as *r*, and the radius of earth as RE, the elevation angle is equal to equation (1) and azimuth angle is equal to equation (2).

$$E = \sin^{-1}\left\{\frac{\cos\phi - \left(\frac{R_E}{r}\right)}{\frac{R}{r}}\right\} \tag{1}$$

$$a = \sin^{-1}\left(\frac{\sin L \cos\varphi}{\sin\phi}\right) \tag{2}$$

2.3. Stabilization Algorithm

An antenna system mounted on a vehicle, having disturbance motion, becomes unstable owing to vehicle's roll, pitch and yaw motion. If this antenna system was used for data link between moving vehicles, the disturbance bring to pointing error and disable to communicate between moving vehicles. Thus, for continuous communication between moving vehicles such as satellites and unmanned aerial vehicles, an antenna system having at least more than 2-axes is needed. A SeaTel 1899 model was used for this study. This antenna can stabilize 2-axies tracking and stabilization. Detailed specification of the antenna was represented in table 1. Stabilization is the process of de-coupling the vehicle's motion from the antenna. If we consider the dynamics of moving vehicle such as ships and aircraft, the vehicles are affected by not only desired motion but also other disturbance motion. Put the 3-directional motion of a vehicle as longitudinal, lateral and vertical direction as X, Y and Z axis, respectively with respect to center of mass, the disturbance motion of vehicle can be described by the combination of rotation motion of each axis. The rotational motion with respect to X, Y, Z-axis is called Roll, Pitch, Yaw(RPY). When the antenna is mounted on a moving vehicle such as ground vehicle, ship and so on, a stabilization system must be equipped to compensate the roll, pitch and yaw motion of the vehicle. Stabilization allows the antenna to remain pointed at the satellite while the vehicle turn, rolls or pitches under it. To accomplish this, the Pedestal Control Unit (PCU) on the antenna pedestal assembly senses the motion and applies drive to the appropriate motors in opposition to the sensed motion. Figure 2 is the coordinate system for these compensations.

Table 1. Specification of Antenna System. (SeaTel898)

Gain		12.2 GHz (34.4 dB)
Azimuth	Turn Rate	12°/sec
	Turn Range	680°
Full Elevation Range		10°~80°

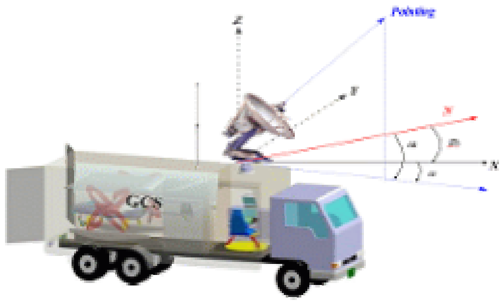

Fig. 2. The Coordinate System.

2.4. Tracking Algorithm

For Antenna tracking, the basic tracking method used in this research is the so-called step-tracking algorithm. Figure 3 shows the schematic illustration of the step tracking moving method. The step tracking operation begins when the antenna is commanded to make an initial one-step turn in any direction, after which the level of the receiving signal is compared with the previous level before the turn. If the signal level has increased, the antenna continues another one-step turn in the same direction. If the signal level has decreased, the turn of the antenna is reversed. By these step-by-step turns, the receiver antenna can track the point of maximum signal level. Since this method uses only the feedback information of the electric field intensity, it has advantages of an economic hardware configuration and relatively simple control software.

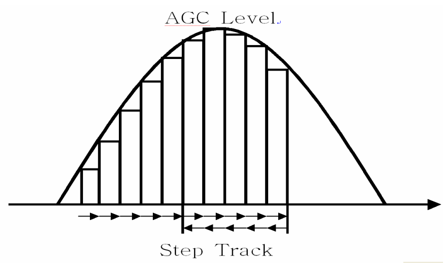

Fig. 3. Step-Tracking Moving Method.

3. Controller Design

A fuzzy-PID Controller was designed for the tracking antenna control system. In figure 4, the input membership function for error, error rate, and error acceleration were represented. EN, EP, RN, RP, AN and AP are error negative, error positive, error rate negative, error rate positive, error acceleration negative and error acceleration positive, respectively.

The Fuzzy control Rules for control block 1 are shown as followings,

R1: IF Error is EP and Error Rate is RP,
THEN Output is OP
R2: IF Error is EP and Error Rate is RN,
THEN Output is OZ
R3: IF Error is EN and Error Rate is RP,
THEN Output is OZ
R4: IF Error is EN and Error Rate is RN,
THEN Output is ON

Similarly, the Fuzzy control Rules for control block 2 are shown as followings,

R1: IF Error Rate is RP and Error Acceleration is RP,
THEN Output is OPM
R2: IF Error Rate is RP and Error Acceleration is AN,
THEN Output is ONM
R3: IF Error Rate is RN and Error Acceleration is AP,
THEN Output is OPM
R4: IF Error Rate is RN and Error Acceleration is AN,
THEN Output is ONM

In figure 5, the output membership function of control block 1 was represented. ON OZ, and OP are output negative, output zero, and output positive, respectively In figure 6, the output membership function of control block 2 was represented. OMN and OPM are output middle negative and output positive meddle, respectively.

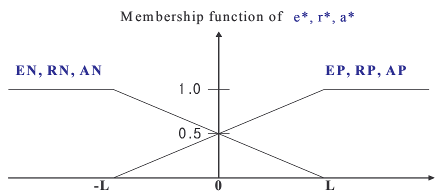

Fig. 4. Input Membership Function.

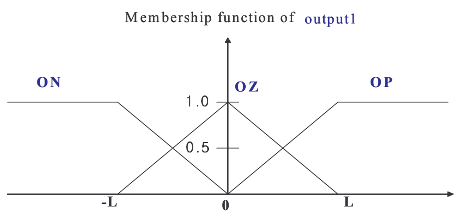

Fig. 5. Output Membership Function for Block 1.

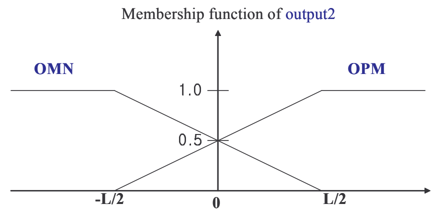

Fig. 6. Output Membership Function for Block 2.

4. Simulations

The fuzzy-PID controller for data link tracking antenna system was design and the performance was verified with computer simulations. Matlab and Simulink were used for these simulations. A Fuzzy rule based controller was designed and the performance was tested with several environmental conditions. In figure 7, Simulation block diagram of Matlab and Simulink was shown. For the availability test for the designed fuzzy-PID controller, the comparison with conventional PID controller was performed. The conventional PID controller has fixed control gains but fuzzy-PID controller has variable PID control gains. Figure 8 shows the step response of fuzzy-PID control system and PID control system. This result shows that the fuzz-PID controller is better performance than conventional PID controller. Figure 9~10 shows the response of tracking antenna system with sine environmental disturbances. Solid blue line is response and error of fuzzy-PID controller and dashed red line is those of conventional PID controller. The resultant performance of fuzzy-PID is also superior then the conventional PID controller in two cases. Thus results are due to the variable gain of fuzzy-PID controller and early adaptation of error. The final steady state PID control gains are all same for two controllers. In all cases, from these simulations, it is verified that the performance of fuzzy-PID controller is superior then conventional fixed gain PID controller.

4. Conclusions

A data link antenna system mounted on a vehicle such as ships and aircraft, becomes unstable owing to vehicle's roll, pitch and yaw motion. These disturbances bring to pointing error and disable to communicate between moving vehicles. The stabilization is a process of de-coupling the vehicle's motion from the antenna. The tracking allows an antenna to communicate continuously for movable target vehicles without interruption.

In this research, a stabilization algorithm and a tracking algorithm were tested by computer simulations for a 2-axes data link antenna system. By using coordinate transformation, the compensated angle calculation algorithm was derived and to increase performance of the antenna system, a fuzzy-PID control algorithm was used. The performances of conventional PID controller and the fuzzy-PID controller were compared in both computer simulations and real field experiments. The used fuzzy-PID controller showed superior performance to conventional-PID controller and satisfied the performances of general purpose data link antenna system in all cases of simulations.

Acknowledgement

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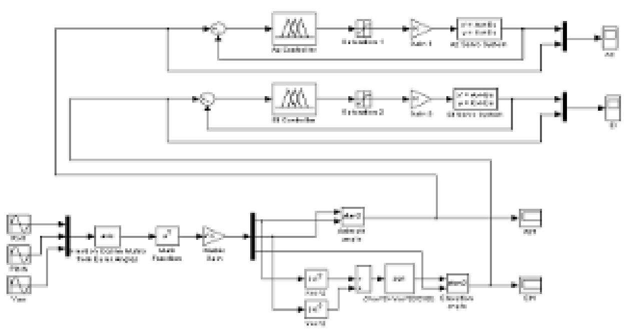

Fig. 7. Simulation Block Diagram of Matlab and Simulink.

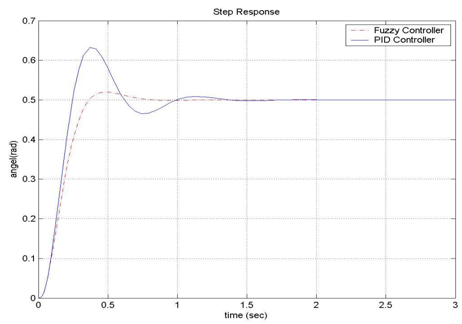

Fig. 8. The Step Responses of PID Controller and Fuzzy-PID Controller.

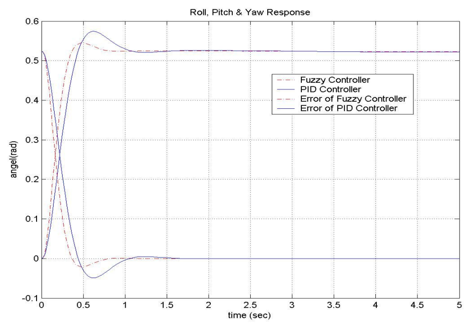

Fig. 9. The Responses of Controller with the Roll, Pitch and Yaw Motions of the Vehicle. (6 Seconds)

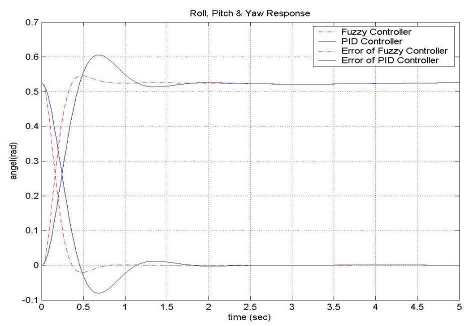

Fig. 10. The Responses of Controller with the Roll, Pitch and Yaw Motions of the Vehicle. (2 Seconds)