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Overview on the development and applications of antenna control systems

A.A. Mulla[a,*], P.N. Vasambekar[b]

[a] Department of Electronics, Yashwantrao Chavan College of Science, Karad 415 124, India
[b] Department of Electronics, Shivaji University, Kolhapur 416 004, India

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ABSTRACT

During last three decades, the antenna control systems have been extensively developed, studied and applied in several satellite communication systems. While tracking the signal source, these systems play an important role in the alignment of antenna coordinates at receiving end. It is always needed to receive strongest, best quality and environmental effect free signal, transmitted by the transmitter. The speed, accuracy, power, cost and size are the important parameters of antenna control system. The number of control systems implement standard algorithms PI, PD, PID, PIDA, fuzzy, self-tuned fuzzy, LQG, H_∞, genetic, neural network and their combinations. Many researchers developed manual, differential, monopulse, electronic, auto-tracking, left-right, conical and step tracking methods to track signal source. In this paper the developments and applications of the antenna control systems are reviewed. The system performances of the implemented standard algorithms and tracking methods in antenna control system are discussed. The simulated and experimental results show that the advancements in algorithms have reduced major issues and increased performance of the systems. The performance is also improved with the combinations of tracking methods and/or algorithms.

1. Introduction

Satellite communication is one of the fast growing field of science and technology. It is useful to communicate the information over the globe. The antenna plays an important role of signal transmission and reception. The received signal quality (amplitude or strength) depends on the relative location of the satellite, antenna position (Gawronski, 2002) and antenna parameters. After design the antenna parameters become fixed. When the transmitted signal strength is fixed, the signal quality depends on the antenna position (in the form of coordinates). These coordinates are manually adjusted by operator/labor. The manual adjustments have limitations when the antennas are working on mobile vehicles, in antenna parameter measurement systems, in tracking or positioning systems, in antenna systems facing natural disturbances, in large size antenna systems, etc. To have lower pointing error, antenna should be aligned within one tenth of its beamwidth (Dybdal & Pidhayny, 2002). An automatic alignment of the antenna coordinates leads to receive the best quality strongest signal. The antenna control system consists of the electronic and mechanical components with control algorithm. The smallest possible pointing error, high speed, low power systems, etc. are the prime requirements of the system.

The tracking and positioning systems are the important categories of antenna control systems. A tracking system continually tracks a moving object without stopping its operation. It tracks a moving signal source or object, like communication satellite, spacecraft, etc. It can select the optimum signal strength for particular step by continuous tracking. In order to receive signal efficiently from the satellite, a receiving antenna should track the target satellite precisely. The receiving antenna system does it according to the predetermined search pattern.

In positioning system antenna tracks a moving object or it is in a moving mode (antenna mounted on mobile vehicle). When the strongest signal is obtained, it stops tracking and starts again when the signal goes below certain threshold level or adjusts the positioning coordinates by using sensors.

Keeping this in mind researchers developed various tracking and positioning methods and algorithms using modern technology. In many systems, the correct satellite position is found by,

i. Detecting the level of Automatic Gain Control (AGC) signal (Cho et al., 2003; Min et al., 2000; Myeongkyun Kim et al., 2013; Van Hoi et al., 2015a,2015b).
ii. RF detecting/sensing signal (Bolandhemmat et al., 2009; Brain et al., 1989; Gawronski, 2001).

* Corresponding author. Tel.: +919766633713.
E-mail address: mulla.1984@gmail.com (A.A. Mulla).

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iii. Using sensors (Edgar et al., 2007; Kocadag & Demirkol, 2015; Gawronski, 2002; Ito & Yamazaki, 1989; Ming et al., 2005; Myeongkyun Kim et al., 2013; Okumus et al., 2012; Soltani et al., 2011; Soltani et al., 2008; Tanaka et al., 1992; Tiezzi et al., 2012; Watanabe et al., 1996).

In this communication we focus on the necessity, applications, classification, basic elements and parameters/performance of the antenna control systems. Further various important aspects such as architecture, computation, algorithms, advantages and disadvantages of the reported antenna control systems are summarized.

2. Necessity

The following reasons support the necessity of antenna control systems.

(a) The drifting orbital positions of satellites due to some reasons like solar, lunar, oblate shape of earth, non-uniform earth gravity and radiation pressure. This small drift can affect the quality of the received signals from the satellite (Holleboom, 1987; Pirhadi et al., 2005).
(b) Every satellite has different look angles (azimuth and elevation) and certain polarization in a link. These angles are adjusted manually by labor/operator for every satellite with measurement of signal strength on TV, spectrum analyzer, field strength meter, compass or inclinometer. This manual antenna alignment is labor/operator sensitive, time consuming, different for different types of satellites and locations of receivers (Cesar et al., 2012).
(c) The receiving antenna systems are affected by some natural disturbances like torque (wind pressure), rain fall and some mechanical lacuna like gusts on the antenna structures, bearing, aerodynamic disturbances and internal uncertainties (Cho et al., 2003; Dimitrijevic & Antic, 1999; Hao & Yao, 2011; Hoque & Hassan, 2015; Yalcin & Kurtulan, 2009).
(d) The system sensitivity also depends on polarization of signal. The sensitivity reduces due to polarization mismatch. If signal polarization and receiving antenna polarizations are different, the system performance is degraded (Dybdal, 2004).
(e) The receiving antennas on mobile vehicles require a system which has capacity to track the satellite signals precisely and accurately when vehicle is in motion (Basari et al., 2010; Bolandhemmat et al., 2009; Brain et al., 1989; Chang & Lin, 2008; Kocadag & Demirkol, 2015; Cho et al., 2003; Densmore & Jamnejad, 1993; Edgar et al., 2007; Kim et al., 2006; Lin & Chang, 2011; Min et al., 2000; Ming et al., 2005; Myeongkyun Kim et al., 2013; Noordin et al., 2008; Soltani et al., 2008, 2011; Tanaka et al., 1992; Tiezzi et al., 2012; Tseng & Teo, 1995; Watanabe et al., 1996).
(f) For antenna parameter measurement, low cost, relatively simple, versatile and operator convenient automatic control systems are required (Anderson et al., 2010; Papaioannou & Langley, 1985).
(g) The narrow beamwidth antenna has important requirement of significantly improved pointing accuracy (Bolandhemmat et al., 2009; Lo, 1996).
(h) In high frequency band communications, to maintain precise communication link between spacecraft and ground station antenna, improved pointing precision is required (Gawronski, 2001).
(i) Advanced satellite communications with narrow spot beams require an automatic antenna pointing mechanism for maintaining spot beam coverage over the specified area (Gupta et al., 2012).

3. Applications

The applications of antenna control systems are listed below.

(a) The communication link between mobile vehicles (ship, car, train, bus, Yachts, etc.) and satellites (Basari et al., 2010; Bolandhemmat et al., 2009; Brain et al., 1989; Chang & Lin, 2008; Cho et al., 2003; Densmore & Jamnejad, 1993; Edgar et al., 2007; Kocadag & Demirkol, 2015; Kim et al., 2006, 2013; Lin & Chang, 2011; Min et al., 2000; Ming et al., 2005; Noordin et al., 2008; Soltani et al., 2008, 2011; Tanaka et al., 1992; Tiezzi et al., 2012; Tseng & Teo, 1995; Watanabe et al., 1996).
(b) Radiosonde tracking in a radio theodolite system (Bhuiya et al., 2010).
(c) Telemetry receiving antenna tracking system (Payne & Haider, 1993).
(d) Tracking weather satellites (Kalliomaki & Tiuri, 1970) and
(e) Tracking GEO and non-GEO satellites (Cheng et al., 2012; Pirhadi et al., 2005; Taheri et al., 2014)
(f) Automatic control system for antenna parameter measurement (Anderson et al., 2010; Papaioannou & Langley, 1985)
(g) Systems used in adverse weather conditions (high rain fall, wet snow), atmospheric water vapor pressure and temperature gradients (Holleboom, 1987; Kuramoto et al., 1988; Rama Rao et al., 1994)
(h) Continuous spacecraft tracking (Gawronski, 2002)
(i) Mobile satellite internet terminal and television reception system (Bolandhemmat et al., 2009)
(j) The radio-telescope antenna positioning system (Isa & Basher, 2005)
(k) Field measurement in different conditions for geostationary satellite with vehicle mounted antenna system (Basari et al., 2010)

4. Classification

The antenna control systems can be designed with following two technologies.

(a) Mechanical steering
(b) Electrical (or Electronic) steering

Both the technologies are used in directional antennas in communication links.

(a) Mechanically steered systems use motors and other mechanical parts to rotate the antennas. The energy consumption in these systems is higher and the moving parts require more care and service (Cheng et al., 2012; Kalliomaki & Hilton et al., 1989; Kalliomaki & Tiuri, 1970; Tanaka et al., 1992; Van Hoi et al., 2015a).
The mechanical steering can be achieved in following two ways.
    (i) Closed loop
    The system is in the closed loop (Gawronski, 2001) when the control unit receives the control signal from antenna feedback path presented in Fig. 1. In this system receiving antenna tracks the satellite by using detected satellite signal. The received satellite signal always suffers from shadowing and blocking effects of varying signal level. The system therefore requires extra action and time to search and recover.
    (ii) Open loop
    In the open loop system the feedback path presented in Fig. 1 is absent and the control unit receives control signals from positioning sensors like gyroscope. It is more suitable for a land to mobile-satellite services