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Antenna pointing system for satellite tracking based on Kalman filtering and model predictive control techniques

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Abstract

The present work proposes a new approach for an antenna pointing system for satellite tracking. Such a system uses the received signal to estimate the beam pointing deviation and then adjusts the antenna pointing. The present work has two contributions. First, the estimation is performed by a Kalman filter based conical scan technique. This technique uses the Kalman filter avoiding the batch estimator and applies a mathematical manipulation avoiding the linearization approximations. Secondly, a control technique based on the model predictive control together with an explicit state feedback solution are obtained in order to reduce the computational burden. Numerical examples illustrate the results.

Keywords: Conical scan; Antenna pointing control; Satellite tracking

1. Introduction

The antenna pointing control system presented in this work is a proposal for a university ground station. It is considered that the antenna will communicate with a satellite orbiting with an altitude between 400 and 800 km for imagery purpose. The image is received by a highly directional antenna with 2.6 m diameter. The present work deals with the pointing control system of the this antenna. An estimation of the satellite trajectory is known, so an initial reference for the antenna pointing is set. The problem is that the prediction may diverge from the real trajectory, for example, due to the gravitational force of other bodies (Kelecy and Jah, 2010). Besides that, some phenomena like atmospheric temperature gradient may cause the radio frequency (RF) beam to refract, causing a point error as well. Also, wind forces and manufacturing imperfections may disturb the control system (Gawronski et al., 2000; Gawronski, 2008). All these events cause pointing deviation, as illustrated in Fig. 1, and sensor calibration procedures for improving the pointing accuracy, as described in Bandikova et al. (2012) and Lee and Yeom (2015), are not always sufficient. Despite that, the control system must be able to point the antenna correctly.

In order to have a satisfactory beam pointing, the pointing deviation is estimated during the communication. RF sensing techniques are used for this purpose allowing to estimate the spacecraft position relative to the beam (Dang et al., 1985). There are two main classes of RF sensing techniques, monopulse based techniques (Nateghi et al., 2009; Nateghi and Mohammadi, 2010; Bayer et al., 2012) and scanning based techniques (Besso et al., 2010). Monopulse techniques can estimate the pointing error using one single sample of the received signal, while scanning techniques add harmonic movements to the antenna

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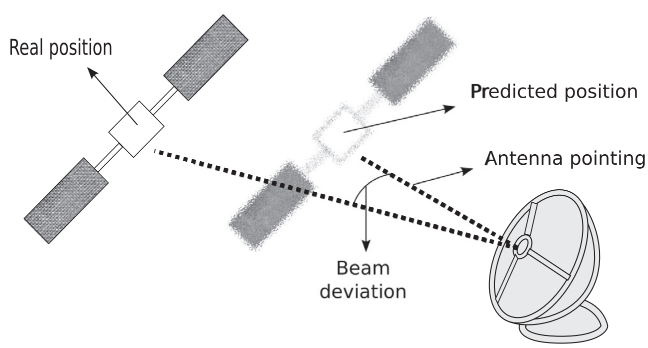

Fig. 1. Illustration of a possible beam deviation problem.

path and analyze the variation of the received signal through time (Hawkins et al., 1988). Monopulse techniques are more precise, but are also more expensive, and in this case a scanning technique will be used in order to provide low cost solutions. Scanning techniques often employs batch estimation to estimate the pointing deviation by analyzing the received signal sequence, making them slower than monopulse techniques (Gawronski and Creparo, 2002). The performed estimation can be used by the controller to reduce the pointing deviation error.

Scanning techniques simply add harmonic movements to the original antenna reference becoming simpler and cheaper compared with other methods. These movements cause a variation of the received signal. The analysis of the received signal allows to estimate the beam pointing deviation. Among the scanning techniques, such as conical, Lissajous, and Rosetta, the conical is a good design choice due to the simplicity without loss of performance (Gawronski and Creparo, 2002). The classical conical scan (CONSCAN) is developed based on the hypothesis that two variables are constant during the scan period, the satellite position and the transmitted power. Considering this hypothesis, the beam deviation can be estimated using the least mean square (LMS) technique, a batch estimator.

In this work, a new control system architecture for a ground station antenna is proposed with two main contributions:

1. A new Kalman filter (KF) based on the CONSCAN method;
2. A controller based on the model predictive control (MPC) technique.

The first one is related to the beam pointing deviation, and the second one to the control law itself. By using the KF in a recursive way it is possible to estimate the pointing deviation without considering the hypothesis of the classical CONSCAN approach, that is, the satellite does not move during the scan period and the carrier power does not vary. The new results are similar to the ones of the monopulse based techniques, and a preliminary result was presented in Souza et al. (2013). Concerning the controller, by using an explicit state feedback solution for the MPC, it was possible to reduce the computational burden of the optimization problem compared to the classical approach. The MPC method is largely applied to tracking problems and can be used when the model and the reference is known a priori. In this case, the control law is obtained by solving an optimization problem that minimize the system output tracking error during a predictive horizon. The main drawback of the MPC is the heavy computation, what is overcome in the present work by using a simplified version of the MPC. Numerical simulations illustrate the quality of the proposed method.

The work is divided as follows: the beam deviation estimation technique is described in Section 2, the control law is presented in Section 3, the simulations are presented in Section 4, and the conclusions are presented in Section 5.

2. Estimation of the beam pointing deviation

2.1. Conical scan

The theory about the CONSCAN presented here is based on Gawronski and Creparo (2002). The CONSCAN consists in the addition of harmonic movements in both axes, azimuth and elevation, making the antenna to perform a circular pattern while follows the spacecraft, as represented in Fig. 2. This movement is circular, with radius r and angular velocity ω.

In Fig. 3, the frame of reference is presented. The origin represents the original antenna path, $\mathbf{s}_k$ the spacecraft position, $\hat{\mathbf{s}}_k$ the estimated spacecraft position, $\mathbf{a}_k$ the antenna position during the scan, and $\mathbf{e}_k$ is the difference vector

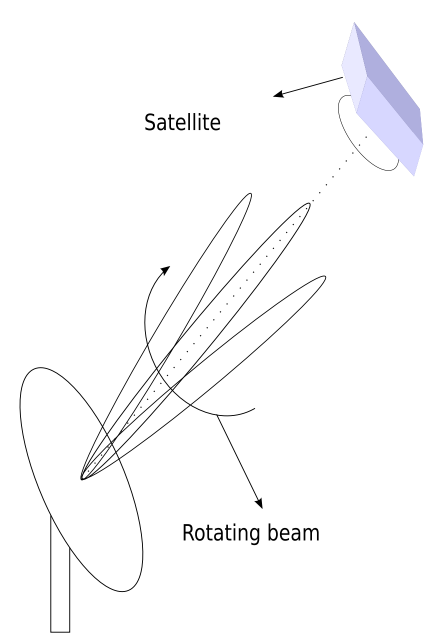

Fig. 2. Illustration of the CONSCAN movement.

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