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Parameter identification for a two-axis gimbal system and its kinematic calibration

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Abstract: The main difference between robots and gimbals is the range, in which the objects are working. Robots usually operate in a limited space, whereas joint limits in typical industrial gimbals are much wider. The main position error for serial-chain robot comes from linear and angular tolerances imposed on joints. On the other hand, in gimbals, the linear errors could be largely omitted. Gimbal systems used for tracking or positioning need to have a high positioning accuracy and good repeatability. Additional requirements should be met for applications, in which a gimbal system is mounted on moving platform introducing extra disturbances. It is hard to achieve a well-designed gimbal system in practice that will successfully work in military or commercial applications. A number of features should be taken into account in the simplest case such as geometrical tolerances, system biases, friction, and dynamic parameters. Kinematic calibration of a line-of-sight system is a first step to achieve good enough performance. In this paper a systematic procedure for kinematic calibration of a two-degree-of-freedom spatial line-of-sight system is presented. Numerical results are shown to improve a nominal kinematic model of a system with non-orthogonal, imperfect joints to the extent possible by simultaneously alleviating sensor noise.

Keywords: kinematic calibration, gimbal, dynamic, line-of-sight, stabilization

1. Introduction

Consider a two axis gimbal system shown in Fig. 1. Assuming that a reference frame π_0-is a mechanical base body, π_1 is a coordinate frame attached to a first body, and π_2 is a coordinate frame attached rigidly to a second body, we introduce two joint angles: azimuth θ_1 and elevation θ_2 . Using the orientation of the axes shown in Fig. 1, we can write a simple relation that transforms a line-of-sight (LOS) expressed in π_2 to the quantity read in π_0 frame.

$$\boldsymbol{LOS}^{(0)} = \boldsymbol{Rot}_z(\theta_1) \cdot \boldsymbol{Rot}_x(\theta_2) \cdot \boldsymbol{LOS}^{(2)} \tag{1}$$

Unfortunately, in real systems, the equation (1) should be supplemented to capture inherent kinematic errors existent in the structure. Non-orthogonality between mechanical base and azimuth axis of revolution should be taken into account. There is also a bias between azimuth and elevation axes and noticeable bias between line-of-sight and elevation axis. In tracking or positioning gimbal systems, there is a need to describe those non-orthogonality conditions and exploit measurement data to improve kinematic model. The relation (1) becomes more complex as it should capture various, potentially random, error sources that influence the accuracy of the parametric model.

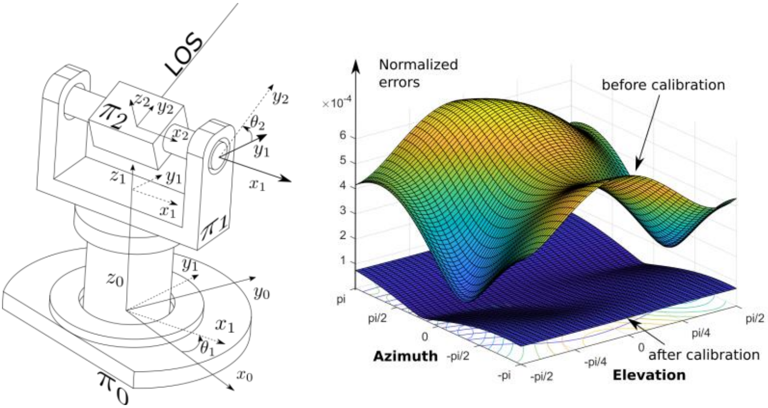

Fig. 1 Two-axis gimbal system and the results of kinematic calibration

2. Methodology and Results

The main idea of parameter identification for kinematic calibration is to create a model of a gimbal system, which minimizes the design errors stemming from various issues e.g. non-orthogonality of revolute axes. Various techniques might be used to achieve these objectives [1]-[3]. Because of random character of the errors, a number of simulation scenarios has been created to evaluate the performance of the model. The prepared sample test cases take into account the accuracy of acquired data for calibration, the amount of data available in the batch, and the predicted magnitude of geometric error tolerances. Variant of least-squares algorithm as employed as a workhorse for computations to facilitate comparisons. A series of numerical results confirmed the usefulness of the proposed methodologies in the above-mentioned aspects for a broad range of sampled points taken from the workspace of a gimbal system. Partial simulation-based results are depicted in Fig. 1, where a normalized kinematic error is provided for two test cases: before and after kinematic calibration. The plot demonstrates that the devised corrections yield a reduction of the normalized errors with respect to the ideal kinematic model of a gimbal system for a broad range of joint angles sampled from the workspace.

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