Multi-Rigid-Body Dynamics and Stabilization Of Two-Axis Line-Of-Sight System With Platform-Induced Disturbances

Łukasz Rówienicz, Paweł Malczyk

Division of Theory of Mechines and Robots
Institute of Aeronautics and Applied Mechanics
Faculty of Power and Aeronautical Engineering
Warsaw University of Technology
Nowowiejska 24, 00-665 Warsaw, Poland
[lukasz.rowienicz.dokt, pawel.malczyk]@pw.edu.pl

EXTENDED ABSTRACT

1 Introduction

Inertially stabilized platforms are used in many places ranging from civil to military applications. Usually, a high-quality mechanical design is required for such line-of-sight (LOS) systems to support control systems in high-performance tracking accuracy and disturbance rejection. There are many types of disturbances acting on LOS systems, which may affect LOS pointing performance. LOS stabilization disturbances from sources such as friction, mass imbalance, and platform vibrations must be accounted for and appropriately suppressed to increase the system pointing performance [1].

This paper presents a multi-rigid-body dynamic model of a two-axis LOS system described in joint coordinates. Some significant imperfections of LOS systems have been implemented in Matlab/Simulink environment. Firstly, the angular rates of the base-body are embedded in the model. Secondly, LuGre friction torques [2] are implemented. Thirdly, mass imbalance and geometric errors in terms of non-orthogonal axes are also taken into account. The overall goal of this work is to investigate the system's behavior with internal and external disturbances and select dominant drivers that impact on LOS performance and accuracy. A second minor objective of this talk is to devise a possible control strategy to reject disturbances acting the system.

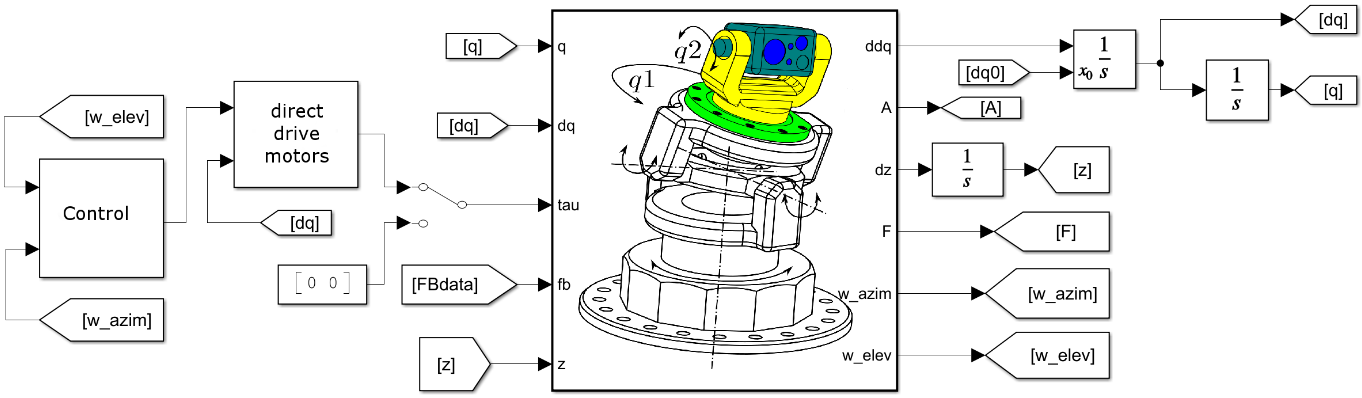

Figure 1: Two-axis (azimuth-elevation) LOS system with floating base-body, motors, and joint velocity stabilization

2 Two-axis rigid body dynamics and stabilization

A model of a spatial two-degree-of-freedom LOS system has been implemented in Matlab/Simulink as shown in fig. 1. The equations of motion for the system are generated by using Newton-Euler formalism in terms of spatial operator algebra given in [3] and used in [4]. The implementation is ready to be used for multi-degree-of-freedom LOS systems as well, in which fine- and coarse-grain stabilization is simultaneously used.

In addition to serial chain dynamics of the LOS system, driving constraints imposed on the base-body are considered to simulate platform-induced disturbances, which are expressed in terms of angular rates. The general form of the two-axis LOS system is ultimately expressed in joint coordinates $\mathbf{q}$ (presented in fig. 1) and takes the following form:

$$\mathbf{M}(\mathbf{q}) \cdot \ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q}, \dot{\mathbf{q}}) \cdot \dot{\mathbf{q}} + \mathbf{B}(\mathbf{q}, \dot{\mathbf{q}}) + \mathbf{F}(\mathbf{q}, \dot{\mathbf{q}}) = \boldsymbol{\tau} \quad (1)$$

where $\mathbf{M}(\mathbf{q})$ is called a mass matrix, $\mathbf{C}(\mathbf{q}, \dot{\mathbf{q}})$ represents centrifugal and Coriolis terms, $\mathbf{B}(\mathbf{q}, \dot{\mathbf{q}})$ embraces all quantities, which are responsible for transferring the platform's motion to outer bodies of the LOS system. Moreover, $\mathbf{F}(\mathbf{q}, \dot{\mathbf{q}})$ contains external forces/torques exerted on the bodies (e.g., gravity), and $\boldsymbol{\tau}$ represents the control forces/torques generated by electric motors.

3 Implementation in Matlab/Simulink

The Simulink model shown in fig. 1 consists of a few additional features that help a designer to investigate the dynamic properties of the LOS system working in different mission scenarios. The entry [FBdata] allows for changing the platform's motion type to capture the effect of the perturbation on short- and long-term bias errors. The LuGre friction torque is recorded in [F] output port, and the state [z] represents the average bristle deflection, which is updated every instant. The quantity [A] is a rotation matrix that corresponds to the last body in the chain, which transforms a pointing vector, which should be co-aligned with the desired LOS vector, to the global frame. The symbols [w_azim] and [w_elev] denote the angular (joint) velocities related to elevation and azimuth angles represented in local coordinate frames. A model shown in fig. 1 contains electric motors as well it implements PD (proportional-derivative) velocity control loop to isolate the pointing vector from platform vibrations.

4 Preliminary numerical results

Figure 2 presents the preliminary numerical results for two cases. The first scenario assumes that the stabilization works for an idealized case, in which there is no internal (friction, mass imbalance, gimbal axes non-orthogonality) disturbances. In the second simulation case, the mentioned imperfections are added, and the pointing accuracy is investigated for the same platform vibrations and PD controller parameters.

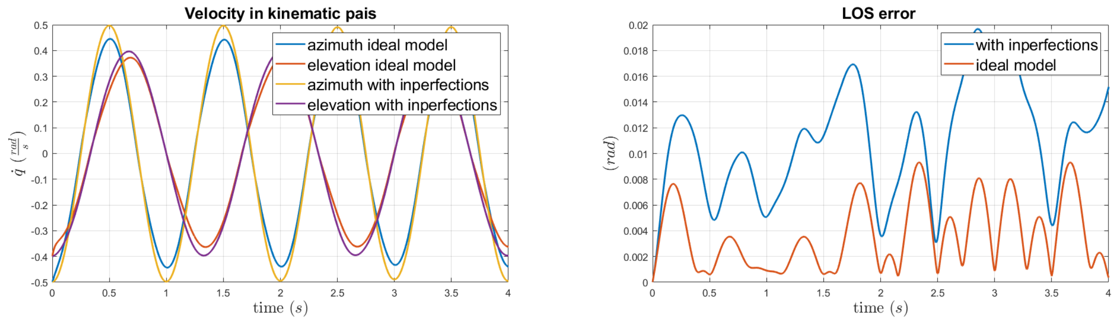

Figure 2: Leftmost figure: joint angular velocities for and ideal and imperfect model, Rightmost figure: LOS errors expressed in terms of the measure $\varepsilon(t) = \left\| \frac{\sqrt{2}}{2} log(\mathbf{A}(t)^T \cdot \mathbf{R}_{ground}) \right\|_F$ proposed in [5], where $\mathbf{R}_{ground} = \mathbf{I}$ is the identity matrix denoting the orientation of the ground

The results in fig. 2 show an inevitable degradation of the LOS performance when internal disturbances are activated. Even though the joint angular velocities shown in the leftmost figure are not significantly affected by the activated disturbances, there is a significant impact of the deficiencies on the pointing errors. In this work, we will present possible control architecture that would isolate or attenuate base-body disturbances and minimize bias errors with sufficient inner loop stability.

References

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