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Application of position and inertial-rate control to a 2-DOF gyroscopic platform

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ABSTRACT

This paper presents a control application for the inertial stabilization of a gyroscopic platform with two degrees of freedom (2-DOF). The purposes of this application are, first, to control the angular positions of the platform in the absence of inertial disturbances and second, to control velocities measured in an inertial frame, while rejecting the disturbances associated with moving components. With regard to the first objective, a switching-control strategy is proposed in order to reduce the effects of friction as the main source of undesirable non-linear behaviors. Regarding the inertial-rate control, a master–slave control structure is suggested to achieve the desired specifications. Simulation and experimental results are presented, showing the performance attained on a real platform.

1. Introduction

In this paper, we discuss the design and implementation of a control strategy for a gyroscopic platform whose position and inertial velocity in the presence of perturbations need to be regulated. There are some applications that require accurate positioning and low velocity tracking. In these cases, friction phenomena usually have significant effects, leading to follow-up errors and the appearance of limit cycles. These errors need to be compensated for or reduced to fulfill the specifications in each case.

Some related applications can be found in the literature. In Guesalada [7], a controller for a positioning servo that takes into account friction phenomena is presented. A gain-scheduled control of systems with dynamic friction is proposed in Vivas et al. [16]. Switching controllers for tracking systems is proposed in [13,9]. Also, with respect to control systems we can find in other applications such as control of hard disk drive servo systems [15], control of an orbital Earth observing system [11], control of a two-axis sun following device [12,14], etc.

The problem of inertial stabilization is also an important issue in the field of aeronautical and navigational systems, among others. There are many applications in which a variable orientation relative to an inertial frame needs to be controlled. Some examples are automatic aircraft control, torpedo steering mechanisms [4], gaze stabilization for visual servoing [10], planetary gear transmission systems [6], humanoid robot control [17] and amusement devices. In all of these cases, inertial stabilization requires measurement feedback from a gyroscopic sensor located on the mobile platform, which usually provides the velocity of a body with respect to the inertial frame.

This paper deals with the design and implementation of control structures for an industrial two-degree-of-freedom (2-DOF) platform, which rests on a base plate whose orientation can be arbitrarily modified. This allows us to emulate the disturbances in the intended final environment, such as the platform on board a ship, for instance. Cameras that need to be stabilized in the presence of different kind of perturbations are mounted on this type of platforms.

This control application was implemented in two different operation modes:

- *A non-inertial position control mode* in which the angular positions are the controlled variables. For this mode, a switching control strategy is proposed in order to reduce the undesirable consequences of the non-linear friction effects. One of the most noticeable effects on the controlled system due to friction is the presence of a limit cycle around the steady-state position values. The switching strategy consists of using a particular control law suitable for large displacements and switching to another control law when the platform angles are close to their reference values. This second controller is intended to reduce the steady-state error, that is, the amplitude of the mentioned limit cycle.
- *An inertial rate control mode*, where the inertial velocities of the platform are to be controlled. In this mode, we propose a master–slave control structure, combined with a gain-scheduling strategy. The inner control loop attempts to reject

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for appropriate tracking performance of velocity references.

As a matter of fact, the proposed control techniques in this paper was part of some work developed under contract for a industrial company, that incorporate this controller in the control of a radar platform. Due to the character of this work, this application of the controller cannot be published, and only simulation and application in a small platform are permitted for publication.

The remainder of the paper is organized as follows: In Section 2, descriptions of the physical platform and the corresponding model used for controller design are given. The strategies followed for controller design in both operating modes are presented in Section 3. Section 4 gives some simulation results with the proposed control structures. Section 5 presents some details about the hardware implementation of the control system as well as some experimental results from the real platform. Finally, in Section 6, the paper ends with some conclusions about the study presented.

2. System description

The system considered in this paper is the industrial 2-DOF platform shown in Fig. 1a. It consists of two main structural units: the *base*, whose position is determined by the *azimuth angle* ψ, and the *main body*, whose coordinate is the *elevation angle* θ. These angles are both depicted in the platform scheme presented in Fig. 1b. Each revolution axis is equipped with a current controlled DC brushless motor with a brake and gear reduction. Additional mass can be added in the elevation axis in order to modify the system behavior.

Two optical fiber gyros are available for the inertial control. The gyros are located in the elevation axis, so the inertial velocity measure for the azimuthal axis is modified when the elevation axis moves. This dependency can be overcome by a projection of the measure in the orientation axis with

$$\dot{\psi}_i = \frac{\dot{\psi}_{ig}}{\cos(\theta)} \tag{1}$$

where $\dot{\psi}_{ig}$ is the gyro measurement, θ is the elevation angle and $\dot{\psi}_i$ is the modified measurement.

Besides this, two pistons arranged in a quadrature fashion, independently driven by two velocity-controlled electrical motors, were included in the system. This allows us to introduce some disturbances with respect to the orientation of the base plate holding the 2-DOF platform.

Fig. 2 shows a schematic diagram of the 2-DOF platform. The platform orientation and elevation rates ($\dot{\psi}$ and $\dot{\theta}$, respectively) can be driven by means of two input torques: τ_ψ for the orientation axis and τ_θ for the elevation axis. Nevertheless, the available input signals being considered in this work are actually voltage signals. Thus, henceforth τ_ψ and τ_θ have to be understood as such and measured in volts.

Some dynamic behavior is involved in the gyro measures. The angular velocities of the non-inertial base plate, $\dot{\psi}_c$, $\dot{\theta}_c$ and $\dot{\phi}_c$ (orientation, elevation and yaw, respectively), implicit in the gyro measures, are considered as disturbances to be rejected in the regulation of the inertial platform velocities ($\dot{\psi}_i$ and $\dot{\theta}_i$).

Prior to the controller synthesis stage, it is necessary to obtain a model of the platform. The dynamic equations of the system can be obtained from Lagrange's equations of motion. In particular, the Lagrangian of the system under consideration is given by

$$L = T - V = \tfrac{1}{2}(\dot{\psi}^2(I_{zz_1} + I_{xx_2}\sin^2(\theta) + I_{zz_2}\cos^2(\theta)) + I_{yy_2}\dot{\theta}^2) \tag{2}$$

where T and V are the kinetic and potential energy, respectively. I_{zz_1} stands for the moment of inertia of the first joint along its own axis (Z direction), I_{xx_2}, I_{yy_2}, I_{zz_2} are the moments of inertia of the elevation axis, along directions X, Y and Z, respectively.

Taking into account that the load of the elevation axis is concentrated along the shaft, the potential energy can be considered invariant and hence may be discarded from the equations. From the Lagrangian formulation, the following dynamic model of the 2-DOF platform derived:

$$\begin{cases} \tau_\psi = \ddot{\psi}(I_{zz_1} + \sin^2(\theta)I_{xx_2} + \cos^2(\theta)I_{zz_2}) + \dot{\psi}\dot{\theta}\sin(2\theta)(I_{xx_2} - I_{zz_2}) + F_\psi(\dot{\psi}) \\ \tau_\theta = \ddot{\theta}I_{yy_2} - \tfrac{1}{2}\dot{\psi}^2\sin(2\theta)(I_{xx_2} - I_{zz_2}) + F_\theta(\dot{\theta}). \end{cases} \tag{3}$$

Functions $F_\psi(\dot{\psi})$ and $F_\theta(\dot{\theta})$ introduce friction torques in the orientation and elevation axes, respectively. A static, asymmetric

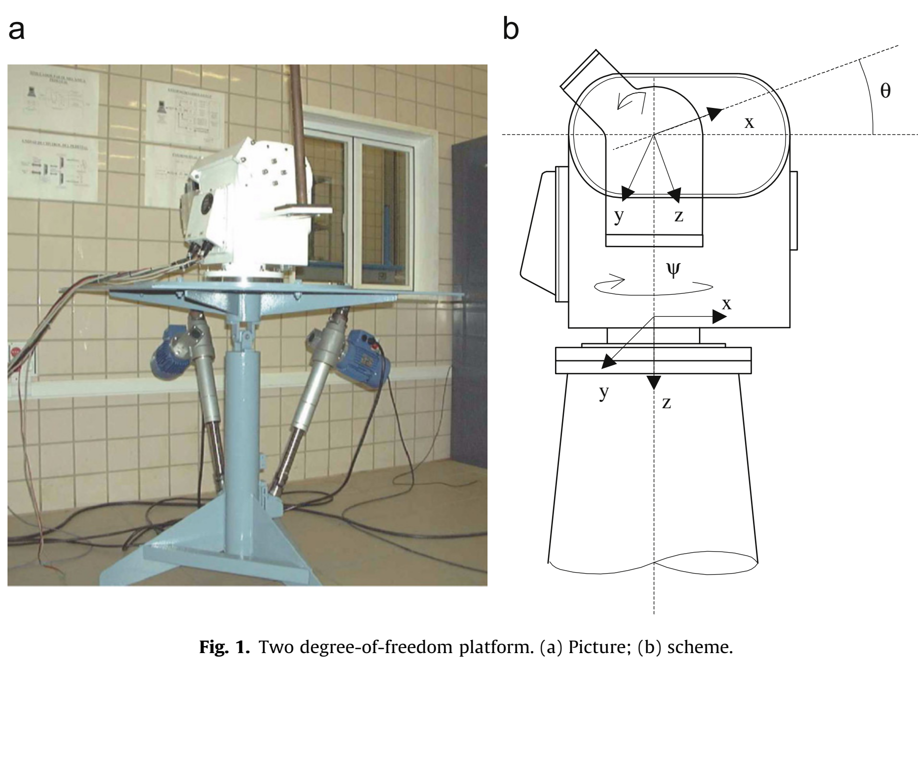

Fig. 1. Two degree-of-freedom platform. (a) Picture; (b) scheme.