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Line of sight stabilization controllers tuning from high-level Modulation Transfer Function specifications

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Abstract: A method to tune the parameters of the controller of an inertially stabilized platform is presented. This platform carries an electro-optical system. The image quality is obviously influenced by the movements of the platform: the Line of Sight (LoS) of the imager has to remain fixed in an inertial frame. The more the LoS controller manages to counter the movement of the platform, the better the image quality will be. The motion Modulation Transfer Function (motion MTF) measures the amount of blur brought into the image by the motion of the platform. It represents the contrast over spatial frequencies. Up to now, it has mostly been used as a validation tool for controllers already tuned from derived low level and conservative considerations. The proposed methodology aims to tune LoS controllers using directly the motion MTF as a criterion in the design procedure.

Keywords: Line of Sight motion compensation, Inertial platform, Modulation Transfer Function, Parameter optimization

1. INTRODUCTION

1.1 MTF and image quality

The image quality of an electro-optical system depends on various factors such as optical design, transmittance of the atmosphere or Line of Sight (LoS) stabilization among others (Holst (2008)). The Modulation Transfer Function (MTF) of an electro-optical system is the global measure of the contrast of the image over spatial frequencies. The closer to 1 the MTF is, the better the image quality. The system MTF is the product of elementary incoherent MTFs related to the phenomena contributing to the image quality degradation as spatial frequency increases, see (1) (Holst (2008)):

$$MTF_{system} = MTF_{motion} \times MTF_{optics} \times ... \qquad (1)$$

In the LoS stabilization field, the quantity of interest is the motion MTF. The performance on LoS controllers is usually specified in terms of motion MTF: a given level of motion MTF has to be reached over given spatial frequencies. In Fig. 1, a motion MTF curve associated with random motion is displayed. The contrast varies from 0 to 1 and the spatial frequencies are given in cycle per pixel, one cycle being the transition from white to black in the image.

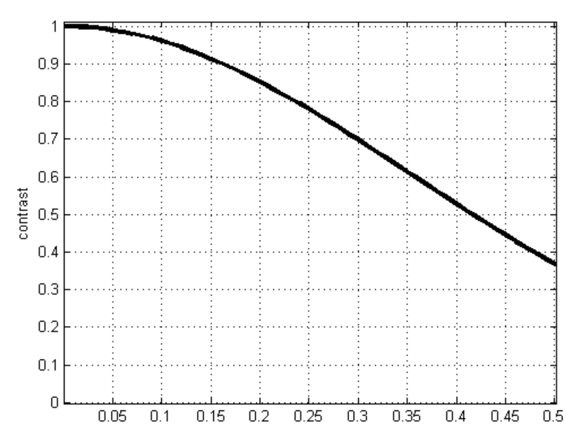

Fig. 1. Motion MTF curve over spatial frequency

1.2 Usual design of LoS controllers

Some general methods have been applied to tune LoS controllers (Ghaeminezhad et al. (2014)), (Roshdy et al. (2012)). These methods aim at decreasing the stabilization error but no indication is given as to the acceptability of the solution found regarding the image quality specification. In most industrial applications, the high-level specification on MTF is usually rephrased as a low-level

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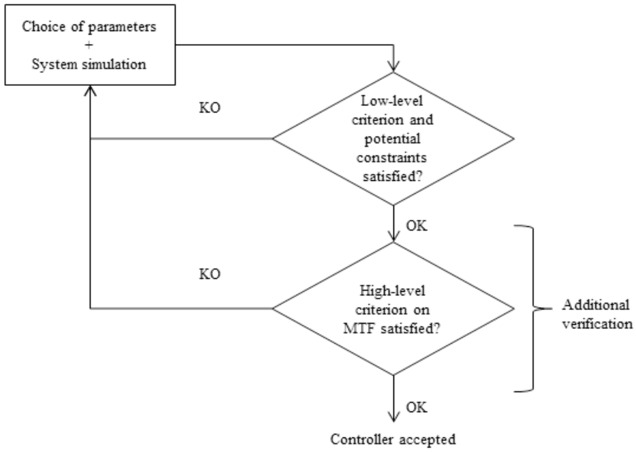

Fig. 2. Current tuning process of the controller (two-step approach)

specification on the RMS level of the position error for practical reasons. Indeed the RMS level of the position error is a more common control specification, more easily linked with the parameters of the LoS controller. However, there is no strict equivalence between high-level and low-level specifications. In particular, in order to allow the rephrasing from one specification to another, the position error is supposed to be a white noise (ECOM (1975)). As a matter of fact, this hypothesis proves wrong: platform mechanical resonant modes or external perturbation spectral characteristics can be found in the position error spectrum. Moreover this approach is a two-step method. Once the low-level specification is met, a validation test on the high-level specification has to be carried out. This validation test requires an experienced engineer and sometimes experimentations, which are time-costly. Fig. 2 sums up the usual tuning process of the controller. As the tuning process is performed in two steps, it is non-optimal.

Considering all these aspects, the usual tuning methodology may therefore lead to conservative results. As the demand on stabilization performance increases, it might then appear impossible to reach the given specifications. The goal of this work is to consider the high-level specification to tune the controller so as not to encounter such difficulties and to save time and thus cost by avoiding an extra final validation test.

1.3 MTF used as an optimization criterion

As with motion MTF and controllers, the use of the optical MTF to assess optical systems is widespread and the design goals of optical systems are generally specified in terms of optical MTF. Nevertheless, the design of optical systems using MTF as an optimization criterion as in Rimmer et al. (1991) is not very common because MTF calculation is more time-consuming than low-level optical merit functions (Yabe (2002)) and less easily linked with optical parameters. In Anderson (2010), a PI controller was tuned by maximizing the area under the MTF curve using evolutionary algorithms. The obtained PI controller yields better results in terms of MTF than the initial PI. However the optimization method employed needs numerous evaluations of the cost function (Sandou (2013)). Assessing a cost function including MTF implies simulating the inertial stabilized plant and evaluating the MTF using data from this simulation. Both operations imply non-negligible execution time. Moreover, when the model of the system is made more complex to better approximate reality, the simulation time goes up. Finally, the number of evaluations increases with the number of controller parameters. Whereas evolutionary approaches are powerful to tune controllers with complex criteria (Feyel (2008), Sandou (2013)), it seems difficult to use them to tune a complex controller with a MTF criterion in an industrial framework, due to high computational times. Following the path of Anderson (2010), the method presented here aims to employ the motion MTF to tune a LoS controller. However, the controller tuned here comprises more parameters. In order to limit the simulation time, the initial point is supposed to be an admissible, quickly tuned, existing controller, tuned with usual low-level criteria. The goal is to show an improvement in the performance by using a MTF-based criterion.

The paper is organized as follows. In section 2, the problem is defined. In section 3, the optimization method is described and in section 4, numerical results are displayed. Section 5 concludes with the results and deals with future works.

2. PROBLEM DEFINITION

2.1 The considered plant

The system is an Inertially Stabilized Platform (ISP) whose role is to hold the LoS of an imager relative to inertial space. ISP applications are numerous and include surveillance, missile guidance and astronomical telescopes among others (Hilkert (2008)). The ISP considered here consists of two orthogonal gimbals allowing two rotations in pitch and yaw, see Fig. 3. This system is naturally mass-stabilized: the rotations in pitch and yaw are supposed to isolate the imager from the external movements of the platform base in order to hold the LoS steady in an inertial frame. However, in spite of a careful mechanical design, torque disturbances appear. A feedback loop is necessary to counter these disturbances and keep the direction of the LoS inertial. In order to meet this purpose, a gyrometer which measures the absolute rate is used as feedback signal for each rotational axis. Both the imager and the rate gyro are mounted directly on the inner gimbal. For sake of simplicity, the movements in pitch and yaw are considered to be decoupled. Thus, only rotation in pitch is studied in the sequel.

The block diagram in Fig. 4 shows the model of the system used for the study (in what follows, s is the Laplace variable): ω_{ref} is the absolute rate reference input. For our stabilization application, it is set to 0. θ_{LoS} is the angular position of the system. Its desired value is taken equal to 0 here. T_d is modelled as a Dahl friction torque disturbance. The Dahl model is a good representation of the friction phenomon observed in the studied system while requiring less coefficients to identify than a LuGre model for example (Olsson (1998)). ω_d is a rate disturbance caused by the flexibility of the structure which amplifies part of the vibrating environment. The motor back-EMF is included in the model, though not mentioned in Fig. 4.