High speed dynamics characterization, system identification, and control to optimize the dynamic behavior of an electromagnetic deformable mirror for ophthalmic applications

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Purpose

The purpose of this study is to design and validate a linear quadratic (LQ) control to improve the temporal performance of the electromagnetic deformable mirror (DM) mirao52-e (Imagine Eyes, France), which has been shown to be very well suited for ophthalmic applications [1]. The control is developed using a high speed adaptive optics (AO) test bench with a sampling frequency of 10 kHz.

Methods

The dynamic response of the DM membrane was measured using a high-speed, open-loop AO test bench with a sampling frequency of 10 kHz. The test bench employs a wavefront sensor (WFS) capable of measuring large aberrations with high accuracy, with a maximal frequency of 60 Hz: HASO-eye (Imagine Optic, France). The test bench's high sampling frequency was made possible thanks to stroboscopic wavefront measurements of the DM response, during repetitive DM signal application. The same test bench has previously been successfully used to develop a model reference control for a single DM actuator [2].

In the current study, the actuators were classified in distinct groups based on the actuator geometry. The step response of the mirror membrane was studied for each group and system identification methods were used to create state-space models of the membrane's responses to different actuator excitation.

Based on these models, LQ controls were developed with varied optimality criteria. The controls were designed and simulated using the Matlab and Simulink software packages. Experimental evaluation and validation were carried out with the high speed test bench.

Results

The designed controls were implemented both for the distinct groups of actuators separately, and when combining actuators for different groups to correct for current ocular aberrations such as astigmatism and defocus. There was a good correspondence between simulated and measured data.

The dynamic behavior of the DM experiences a significant improvement in terms of stability when using the LQ control, relative to operation without the control. The most efficient strategy proved to be discrete time LQ control, developed by discretization of continuous-time state-space models of the DM response. The discretization better respects the characteristics of the DM electronics, giving a more performing control strategy.

Figure 1 shows examples of simulations and measurements of the DM step responses when stimulating a peripheral actuator, using continuous- (A) and discrete- (B) time LQ control.

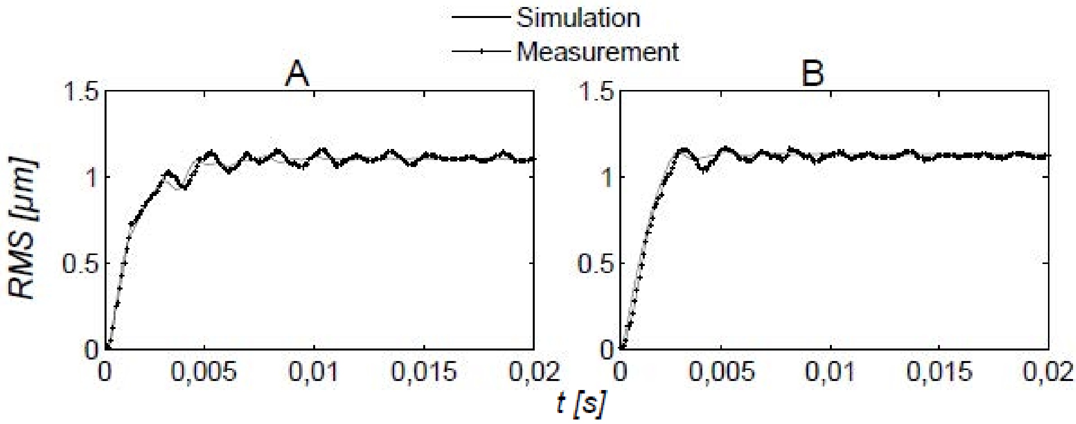

Fig. 1. Simulation and measurement of the DM's step response for a peripheral actuator when controlling the DM dynamic behavior by continuous- (A) and discrete- (B) time LQ control, respectively.

Conclusions

The presented method allowed dynamic characterization of a DM at a high sampling frequency (up to 10 kHz) when using a high precision WFS. Thanks to precise measurements providing detailed knowledge of the DM dynamic behavior, accurate modeling of the DMs' dynamic response was conducted. Powerful controls were implemented to adjust and improve the temporal performance of the DM.

It should be noted that such DM models can also be integrated in a complete AO loop, to respect the effect of DM dynamics in closed-loop operation. Thereafter, the global performance of the AO system can be optimized using the LQ approach [3].

References

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