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Adaptive Correction of Periodic Errors Improves Telescope Performance

Toomas Erm, Stefan Sandrock

Abstract— **As a further step to improve the tracking performance of telescopes, the intrinsic errors in the drive systems are analyzed. These errors fall into two categories, torque disturbances and sensor errors and they have different impact on the performance. Models for the errors are developed and algorithms for on line adaptive parameter identification are presented. The models can be used to significantly improve tracking precision and to monitor friction and unbalance of the elevation axis. The software is designed to allow for the adaptation of the process coefficients, or for the off-line modeling based on recorded process data. Finally, real test data are presented.**

I. INTRODUCTION

In this paper we present methods to deal with periodic errors that arise from imperfections in telescope drive systems. Common sources of these errors are torque ripple in motors, bearings and gears, tachometer ripple and interpolation error in encoders. All these errors have a spatially fixed frequency which due to the varying tracking rates of the telescope makes the temporal frequency vary. Since all data processing takes place in the temporal domain conventional filtering approaches can not be used to reduce the effects of these errors. Adaptive filtering can be used if the frequencies are outside the bandwidth of the control loops. Inside the bandwidth any filtering of this type will alter the phase of the response and make the control system unstable. We have developed a method to model the errors and estimate the model parameters, thus decouple the process of filtering errors from the control system.

II. MODELING THE ERRORS

Periodic error e can be modeled as

$$e = a\sin(n\varphi + \gamma)$$

where a is the amplitude, n the number of error periods per antenna revolution, φ the position of the axis and γ the phase of the error. This model is not well suited for estimation of the phase variable γ and is therefore re-written in a linear form of estimated variables a and γ, thus suitable for e.g. adaptive estimation.

$$e = a_1 \sin(n\varphi) + a_2 \cos(n\varphi)$$

Since the frequency $n\varphi$ is known, the two amplitudes a_1 and a_2 are left unknown. The estimation process depends on the origin of the error, i.e. disturbance or sensor error.

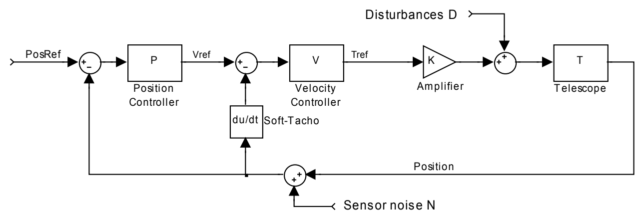

Figure 1. Typical control loop construction

The transfer function of the telescope T is approximated by the inertia to J and includes the position and velocity controllers implemented as PI controllers. The Soft-Tacho software performs a position differentiation. The transfer function G of the 3 inputs to the position can be described by the following relations:

$$G = \frac{PVK}{Js^2 + VKs + PVK} PosRef + \frac{1}{Js^2 + VKs + PVK} D + \frac{VKs + PVK}{Js^2 + VKs + PVK} N$$

where the first term is transfer function from position reference to actual position. The second term is the disturbance transfer function describing the effect of torque disturbances on the position and finally the third term relates the sensor noise to the position.

The algorithm uses a Kalman filter to estimate the parameters of the model which will compensate for the selected components, leaving the control loop free of errors.

III. PERIODIC DISTURBANCE CORRECTION

The disturbances have greatest impact on the performance when their frequencies fall outside of the control loop bandwidth. Fortunately this is not often the case due to the design geometry of the drive components.

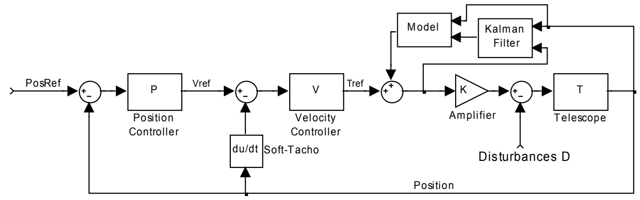

Figure 2. Estimation and compensation of disturbance errors

As seen in figure 2, the position and torque are used to drive the Kalman filter. The torque generated by the model is then added to the torque reference and relieves the torque reference of these components.

Toomas Erm, is with the Thirty Meter Telescope project, California Institute of Technology, Pasadena, CA 91125, USA (e-mail: term@astro.caltech.edu), Stefan Sandrock, is with the European Southern Observatory, Paranal, Chile (e-mail: ssandroc@eso.org)

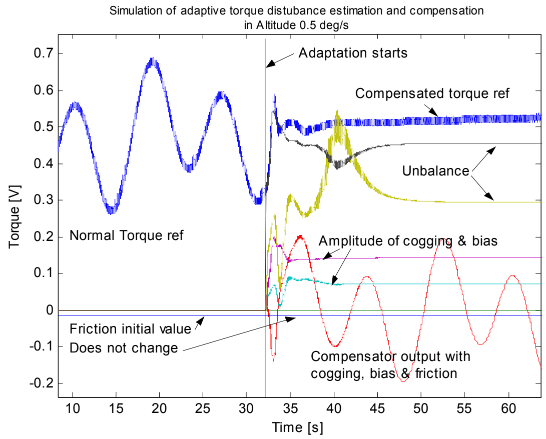

Figure 3. Simulation of the adaptive estimation of various disturbances

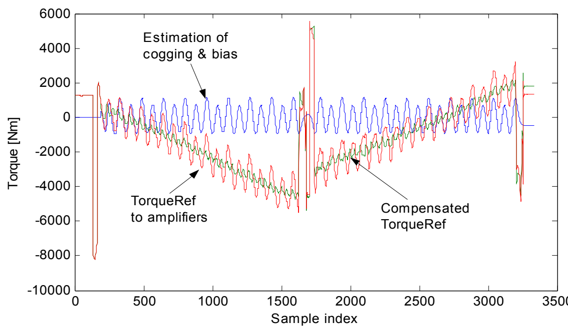

Figure 4. Estimation and compensation of the Bias and cogging torque at the VLT elevation axis

III. PERIODIC SENSOR ERROR CORRECTION

A position control servo can not be better than its encoder, or can it?

Sensor noise is difficult to detect, since the servo error is defined with respect to the sensor, i.e., the encoder in the position control. Thus, an error in the encoder enters the loop in the same way as a position reference, and the servo follows it. Periodic errors with a frequency that falls inside the bandwidth of the loops cannot be filtered out using a conventional filter.

Tape encoders exhibit periodic errors related to the lines on the tape. The temporal frequency of these errors are dependant on the speed and if the speed is high enough to make the frequency of the error to fall well outside the bandwidth of the control loop the error can be seen in the position error. Likewise if the speed is low enough to make the frequency to be within the bandwidth of the control system the servo can follow the error and no position error can be seen, but the telescope will be moving with the error.

The algorithm used for the torque compensation works also for the encoders if the frequencies of the errors fall outside of the bandwidth of the control loops. This is however of little interest since the error will not propagate through the control system and be visible on sky. When the error frequencies enter the loop bandwidth the position error is affected by the phase shift of the control loops and is distorted compared to the real error in the encoder. This means that the estimation of the model parameters is not correct and the correction is poor. To solve this problem an algorithm is used that compares the position reference (free from errors) and the position error. The assumption was used that during tracking the position error consists of encoder errors and noise. With this algorithm the model parameters are adjusted to obtain a minimum position error. The result is a slower convergence than the real Kalman filter.

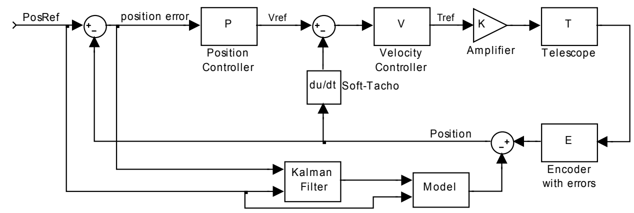

Figure 5. Estimation and compensation of sensor errors

The effect of the correction algorithm is shown below where simulated errors were injected after 15 seconds and are clearly visible. When the adaptation starts they disappear completely after a while. The slow rise and decay of the errors are due to the overlapping FFT technique used to visualize the process.

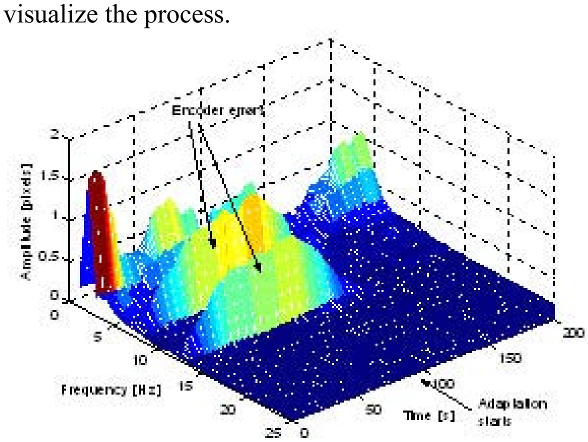

Figure 6. Real data showing encoder errors and their removal

IV. CONCLUSIONS

The methods presented in this paper provide a convenient way to suppress periodic errors with frequencies inside the control bandwidth. They can also serve as a useful tool for performance monitoring where parameter changes can be tracked over time. For more details about the software implementation see [1].

REFERENCES

[1] T. Erm, and S. Sandrock, "Adaptive periodic error correction for the VLT telescopes," *Proc. SPIE Large Ground-Based Telescopes*, Vol. 4837-106, 2002