OPTICAL TRACKING TELESCOPE COMPENSATION

James W. Gilbart

Due to the utilization of lasers with narrow beam widths in, for example, communication systems, the tracking telescopes used in support of these systems must be capable of precise positioning.

For example, in ATS-G, where laser beam widths of one to two seconds of arc are being used, an rms pointing error of less than three-tenths of a second of arc must be maintained in order to achieve a probability of transmitted error of less than 10^{-6}. Larger pointing errors result in increased power consumption and increased loss in the goodness of transmission.

In order, then, to minimize the effects of parameter variations such as inertial variations and bearing friction in the dynamics of a telescope, a control system design technique has been theoretically developed and implemented on a tracking telescope.

The control system design philosophy is illustrated in Figure 1, where it is evident that there are three different types of compensation. The first, termed open-loop compensation since it does not rely on feedback information from the telescope itself, provides 90 to 95

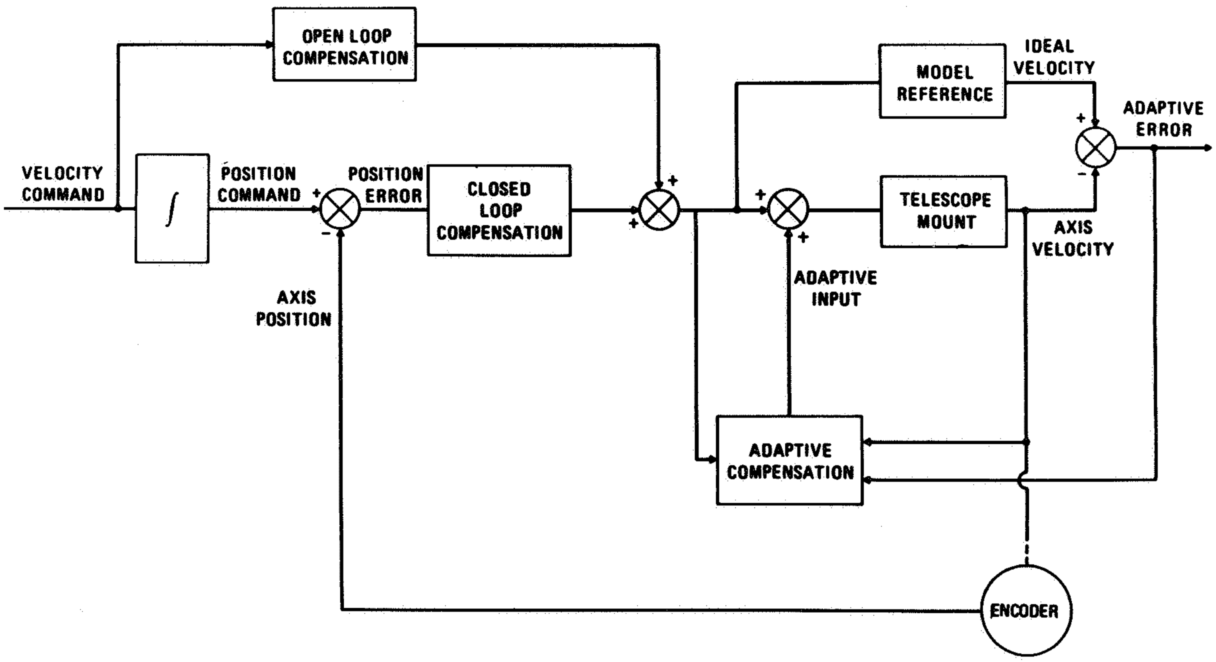

Figure 1. Design for one axis of tracking telescope.

percent of the drive signal to the telescope instantaneously, thus aiding in the high frequency response of the telescope and minimizing the effects of static friction in the bearings.

The second type of compensation is the conventional type, termed closed-loop compensation. Its primary function is to minimize the effects of disturbances such as wind gusts.

The third type of compensation, termed adaptive compensation, differs from conventional closed-loop compensation in that it incorporates self-learning or self-adjusting features; namely, self-adjusting parameters which track out unwanted parameter variations in the telescope. Adaptive compensation provides the precise input – the adaptive input – to compensate for these variations.

The goal of adaptive compensation is to force the adaptive error to zero, thus forcing the axis velocity to follow or track the ideal velocity. The ideal velocity is generated as the output of the model reference system, embodying the ideal or nominal characteristics of the telescope dynamics. Adaptive compensation is based on advanced control-theory techniques, namely, Liapunov stability theory. As far as we know, adaptive compensation has previously received application only in autopilots.

The next two figures summarize the field tests which were conducted on a tracking telescope made available at the Goddard optical site.

The command velocity for this test run (Figure 2) embodies the characteristics of a satellite in a 1000-kilometer orbit with a command rate varying from zero degrees per second on the horizon to 1.5 degrees per second directly overhead. The conventional system position error – the difference between the command velocity and the command

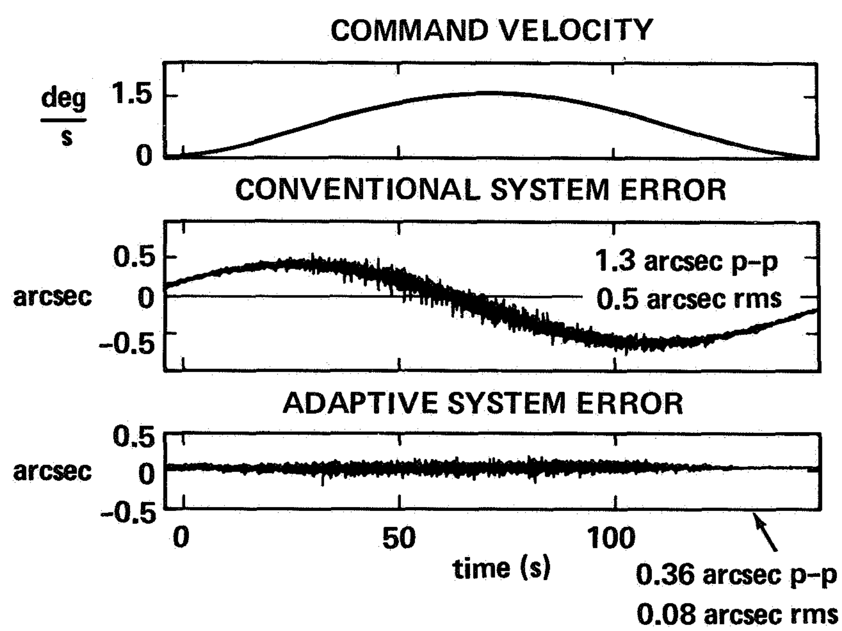

Figure 2. Tracking a satellite in a 1000-km orbit.

position – resulted from utilization of the cintrol system presently in use, and yields a peak-to-peak error of 1.3 second of arc or an rms error of 0.5 second of arc. The peaks in error occur at the points of maximum acceleration of the command velocity.

The adaptive system error, on the other hand, utilized in conjunction with the other forms of compensation, yields a peak-to-peak error of 0.36 second of arc, and an rms error of 0.08 of a second of arc, which represents more than a factor of six reduction in rms pointing error.

Furthermore, one can easily see that the low-frequency components of the error which were present in the conventional system design have been completely eliminated. The blurred signal which remains if spread out in time would indicate a nine- to ten-cycle resonance, which is precisely the structural resonance of the Y-axis, which has to be considered a fundamental limit in any control system design.

The same kinds of data are shown in Figure 3 for a command velocity which embodied the characterisitcs of what would be considered a worst-case satellite for an X-Y configuration. This is a satellite in an 80-kilometer orbit passing directly overhead. The entire pass is completed in a time period of less than two minutes; the command rate varies from zero degrees per second on the horizon to three degrees per second directly overhead.

In this example, the conventional system yields a larger peak-to-peak error, namely 3.6 seconds of arc; and an rms error of 1.3 second of arc. The combined compensation approach, utilizing the adaptive system, on the other hand, again completely tracks out the low-frequency error and yields a peak-to-peak error of 0.7 of a second of arc; and an rms error of 0.2 second of arc. This is again a reduction by more than a factor of six.

In summary, then, a model-referenced parameter adaptive control system, as it is correctly termed, has been utilized in conjunction with more traditional forms of compensation, in order to achieve a reduction of rms pointing error by more than a factor of six.

MEMBER OF THE AUDIENCE:

It appears that the adaptive errors are entirely very low frequency compared with any system resonance. Is that a fundamental limitation?

DR. GILBART:

Well, are you referring to the resonance which existed on the adpative system, the high-frequency signal?

MEMBER OF THE AUDIENCE:

No, I'm referring to the fact that in all cases it was the low-frequency components that you are removing by the use of the adaptive procedure.

DR. GILBART:

Yes, it will actually compensate for higher frequency errors. In this case, the only contribution to the error in the conventional system design was a low frequency error signal, plus a very high frequency error signal, namely, the nine- to ten-cycle per second resonance.

If the mount was an Az-El configuration and the satellite was overhead, there would be higher frequency components, and these components would be tracked out as well. But the nine- to ten-cycle oscillation represents a limit that cannot be corrected – to compensate for that resonance, higher frequency signals would have to be provided, but those signals would only drive the mount into further resonance.

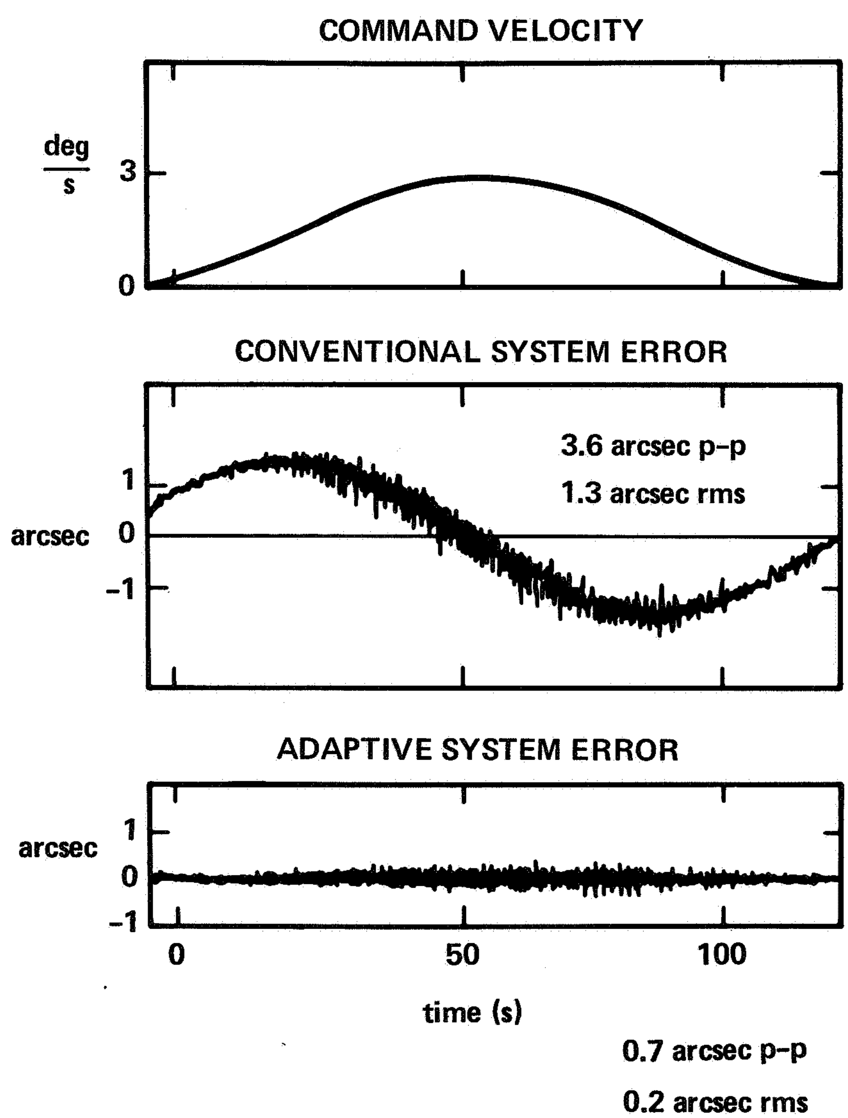

Figure 3. Tracking worst-case satellite.