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A Model of Telescope Mount Performance for Real-Time System Simulation

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FOR THE COMMANDER

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A MODEL OF TELESCOPE MOUNT PERFORMANCE FOR REAL-TIME SYSTEM SIMULATION

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ABSTRACT

A computer simulation of the performance of the first GEODSS telescope was developed for the purpose of remote Real-Time System software development and operator training. In order to prove useful, this simulation had to provide a realistic approximation to the performance of the actual telescope. The telescope model used for this simulation is derived from the equations for linear motion and makes use of the measured telescope rate maxima and acceleration and deceleration rates. This model yields a simulation system performance that quite closely matches the behavior of the telescope. Although the tuning of the telescope driving must be done with the actual telescope, this model has provided a reliable vehicle for most other Real-Time System software development.

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INTRODUCTION

The GEODSS Real-Time System that is located in New Mexico controls a 31-inch optical telescope with an equatorial mount. The main group of software development personnel are in Lexington at the Laboratory. Therefore, it was important to develop a reliable simulation of the telescope. Even at the site itself, a telescope-independent system is a useful tool for program checkout during the day when the Real-Time System is not in operation. Also, there are an increasing number of Air Force users of the system. It is thus helpful to have a simulation system available for the daytime training of system operators.

I. SPECIFICATIONS FOR THE SIMULATION SYSTEM

Two criteria dictated the design of the simulation system. First was the requirement that the simulation system appear as much like the Real-Time System as possible. That is, the simulation should involve as much of the same software as feasible and should appear the same to the system operator. The second criterion concerns the performance of the telescope. The telescope simulation should provide a reasonable approximation to the behavior of the actual telescope.

In order to minimize the differences within the software, the same telescope program was to be run for both the Real-Time and the simulated systems. The difference would consist of a simulation routine that would run in place of the telescope input routine.

The simulation of the telescope performance was to be more than just an insertion of the ephemeris rates and the predicted positions. Like the actual telescope, the simulated one would have inertia as well as fixed acceleration and deceleration rates and rate maxima. The basic dynamics of the telescope would therefore be accurately represented.

Such a simulation would allow, for example, detailed checkout of scan programs without the telescope. Scan patterns require stepping and stopping of the telescope. With a reasonably good representation of telescope behavior, most of the checkout could be done with the simulation system.

No attempt would be made to extend the precision of the modeling to include the finer details of mount dynamics. No oscillatory response would be modeled. There are many reasons for not constructing a precise model, the principal of which is that greater precision is not necessary for this application. Further, the continual changing of the number of auxiliary telescopes and cameras that must be driven by the GEODSS telescope mount makes the accuracy of a more detailed formulation difficult to achieve.

II. THE TELESCOPE MODEL

The telescope that this system is simulating is one that is driven by incremental encoders. That is, the telescope responds to rate commands on both the right ascension and declination axes and travels in the designated direction(s) when so commanded. As the telescope travels, the telescope position in right ascension and declination is updated. The computer is then able to read the updated position, which serves as the indication that the telescope is traveling at the commanded rate. The computer must therefore continuously monitor the telescope position in order to compute the correct rates for it. The computer cannot drive the telescope by sending out a commanded position to it.

From the standpoint of simulation, this means that the computer must frequently update the position of the telescope instead of reading that position from the mount. The computer simulation of telescope motion therefore consists of a program that calculates the updated position of the telescope based on the current and commanded telescope velocities and on the performance capabilities of the drives. The discussion of the mathematical model which specifies how the computer is to calculate these updated positions follows.

A. The Mathematical Formulation

The following formulation is given in terms of a single variable. That representation is sufficient for both axes because they are independent of one another. Both must be driven to reach a given location; but mathematically, there is no functional relationship between them.

The equations used are applications of the equations for linear motion. The drives for each axis function in a linear manner despite the spherical coordinate system in which the telescope is pointing.

The system responds to the input of a commanded rate v_c. Using the current velocity v_p and the current telescope position d_0, a new position and rate of the telescope axis are computed. The telescope performance constants for rate maxima and acceleration and deceleration are assumed to be given.

In order that the simulation system be as similar as possible to the Real-Time one, the telescope program must run frequently and regularly. Because this frequency may vary with the application, and because the formulation is a general one, it is here represented as $\frac{1}{n}$ seconds - where 'n' is the number of times per second that the telescope program is to run.

Because of the short time interval between runs of the telescope program, the telescope (real or simulated) may not be able to reach the desired rate within the present interval of $\frac{1}{n}$ seconds. Therefore, the time $\Delta\tau_n$ necessary to reach the commanded rate is first computed.

$$\Delta\tau_n = \frac{v_c - v_p}{a}$$

The quantity 'a' is the magnitude of the acceleration or the deceleration of the telescope, whichever applies in this case. For the first GEODSS telescope, the acceleration rate is approximately .5 degree per second^2, and the deceleration rate is slightly in excess of 2 degrees per second^2.

The quantity 'v_p' is the current, previously calculated rate of the telescope on this axis. This velocity is included in the calculation so that inertial effects will be correctly taken into account.

Last, 'v_c' is the commanded rate. That rate is assumed to be an attainable one for the telescope. If it is not, it will be reduced accordingly by the program.

The average velocity over the current time interval $\frac{1}{n}$ seconds is then computed. Two separate equations are used for this calculation. The selection of the appropriate one is made by determining if the telescope must accelerate (or decelerate) over the entire interval.

If the telescope is accelerating or decelerating over the whole interval, the average velocity is given by

$$v_{avg} = \frac{v_p + \frac{(v_c - v_p)}{|v_c - v_p|} \cdot a \cdot \Delta\tau}{2}$$

If acceleration or deceleration is occurring over part or none of the interval, then v_{avg} is computed in the following way:

$$v_{avg} = \frac{\Delta\tau_n}{\Delta\tau} \cdot \left(\frac{v_p + v_c}{2}\right) + \left(1 - \frac{\Delta\tau_n}{\Delta\tau}\right) \cdot v_c$$

where $\Delta\tau = \frac{1}{n}$.

Once the average velocity over the current time interval has been obtained, the new position d_n of this axis of the telescope is easily calculated. On the next cycle of the calculations, d_n will become d_o.

$$d_n = v_{avg} \cdot \Delta\tau + d_o$$

The velocity as well as the final position of the telescope must be computed. The velocity v_n of the axis at the end of the time interval will become v_p in the next cycle of the computations.

If the commanded velocity v_c was reached, there is no calculation involved:

$$v_n = v_c$$

If, however, the telescope was not able to reach the commanded rate due to acceleration or deceleration, the velocity must be computed. It is merely the sum of the previous velocity and the maximum change of velocity the mount can produce in that time interval.

$$v_n = v_p + a \cdot \frac{\left(v_c - v_p\right)}{\left|v_c - v_p\right|} \cdot \Delta\tau$$

B. The Addition of a Slew Rate

In addition to the variable rate drives modeled above, the telescope has a slew capability. On the first telescope, this consists of a separate motor on each axis which provides a single, fixed 'slew' rate of approximately 4 degrees per second. Because the variable rate drives only vary over the range ± .8 degree, the slew motors are used for driving the telescope long distances.

The changes necessary in order to incorporate a slew rate into this formulation are trivial. What is needed is a more complex method of determining the rate maxima and a selection among two sets of acceleration and deceleration constants. Neither of these changes affects the equations describing the motion of the telescope.

C. Application of this Model to the Second GEODSS Telescope

This model will also apply to the second GEODSS telescope. The rate maxima on that telescope are in fact adjusted to those of the first telescope so that they will perform in a similar manner. This allows the same software to be run on both telescopes. The acceleration and deceleration rates will be the major difference between them.

Given the rate maxima and telescope acceleration and deceleration rates, this model should be independent of a specific telescope. Once the insertion of the specific performance parameters of the telescope is done, a reasonable performance of the simulation would be expected regardless of the telescope used.

D. The Discontinuity in the Coordinate System

The discontinuity in the equatorial coordinate system occurs at the poles. The simulation program must handle this discontinuity correctly in order to effectively represent the telescope in all portions of the sky. Twelve hours are added to right ascension when crossing the pole. The sign of declination increments is also inverted at the pole.

III. AN ANALYSIS OF THE SIMULATION PERFORMANCE

In order to quantitatively analyze the performance of the simulation system, comparison data was taken on the behavior of the telescope and the simulation system for a number of cases. These cases include the exercise of the majority of normal system functions and should therefore provide reliable data on the effectiveness of the simulation. All of the data was taken on the first GEODSS telescope.

A. Satellite Tracking

In order to compare the two systems, the telescope was driven from a stationary position at the zenith to a synchronous satellite in the equatorial belt. The satellite was then tracked for a short time. Following that, the telescope was returned to the zenith. The process was then repeated for a faster satellite. A few seconds of error (which can be seen in the data presented in the table) were introduced into the measurements for the second case due to the motion of the satellite in right ascension between the time that the data was taken with the two systems. Especially considering that error, the agreement between the performance of the two systems is quite good. It should be noted that data for the second satellite is only available in the transit from the zenith to the satellite.

	zenith to satellite #1	zenith to satellite #2	satellite #1 to zenith
actual telescope	1 minute	1 minute 23 seconds	57 seconds
simulation	1 minute	1 minute 18 seconds	56 seconds

Neither the actual telescope nor the simulation routine was making use of slew rates at the time that this data was obtained.

Data was also taken on the tracking rates of the real and simulated telescopes with both slow and fast (near 100 arc seconds/second) satellites. For the simulated case, given reasonably stable target rates, it always tracks exactly at the predicted ephemeris rates to an accuracy of at least a tenth of an arc second.

The actual telescope does not track as accurately as does the simulation routine. Differences of a few arc seconds between the predicted and actual rates may at times be observed. The simulation program makes no attempt to model mount performance at this level of detail.

B. Scan Patterns

As the purpose of the GEODSS system is to find and track satellites, scan patterns are frequently used to find satellites. Along orbit scans are performed in conjunction with a satellite ephemeris to search ahead of and behind the orbital prediction. Also, box scans are performed to aid in such searches and for use in locating unknown satellites.

An analysis of the performance of the two systems in scan patterns was therefore done. As the telescope is repetitively driven a short distance and stopped, the scans afford a good opportunity to compare the performance of the two systems.

Both types of scans were run on both systems, and detailed data was taken on telescope travel. Both systems (particularly the simulated one) showed extremely consistent performances. A summary of the step and settle times of the telescope during these patterns is presented below for both cases.

The first table shows the step/settle times for two different step lengths in the box scan. The first step length is one field of view or approximately .7 degree. The second step length is the length of the scan line, which in this case was 2 degrees.

	.7 degree step	2 degree step
actual telescope	2-4 seconds (typically 3 seconds)	7 seconds
simulation	2 seconds	8 seconds

For the along orbit case, only one line is covered; therefore, only the step/settle time between fields of view is available.

	.7 degree step
actual telescope	2-5 seconds
simulation	4 seconds

The agreement on the scans is quite good. It is particularly good in view of the fact that the rate maxima on the telescope change periodically and that no adjustment of them was made in the simulation routine before the taking of the data.

IV. CONCLUSIONS

The data presented in Part IV shows very good agreement between the simulation prediction and the behavior of the actual telescope. Also, it reflects our experience with the simulation system. It has been a very useful and reliable tool for software system development. A sufficiently detailed representation of telescope performance is provided such that scan pattern development has been successfully done with it. The model of the telescope has therefore been shown to be reasonably accurate. It is simple, easily programmed and yet quite closely approximates the performance of the actual telescope. This model has consequently provided the basis for an effective simulation system.

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