ADDITION OF VIDEO TO TELEMETRY TRACKING SYSTEM UPGRADES SPATIAL DATA TO RADAR-QUALITY

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ABSTRACT

Traditionally telemetry trackers have not been required to provide precision space-position data. Such data, when needed, has required expensive radar or optical support. Currently, an increasing number of flight test operations have need of precision spatial data, in conjunction with telemetry data reception, in areas where no radar or optical support is available. To meet this need, EMP has carefully combined existing technologies to upgrade the angle output data accuracy of telemetry trackers to the level expected of precision radars. A TV Boresight Camera and video Tracking Error Detector combined with the EMP Model ACU-6 microprocessor-based Antenna Control Unit provide the means to automatically measure and store all of the systematic bias errors inherent in a telemetry tracking system. The resulting error model is used to provide real-time-data-correction for each error parameter. Video tracking provides correction for dynamic tracking errors in real time. Calibrations utilize boresight and stellar targets. The design goal to reduce dynamic angle data error to <10 arc seconds, RMS*, appears to be reasonable.

INTRODUCTION

For several decades the derivation of precision space-position data has been in the realm of expensive radar systems or theodolite complexes, both of which limited testing to a specific geographical location. Telemetry tracking systems were designed solely for the purpose of receiving telemetry data. This allowed substantial latitude in the design of the pedestal and shaft-position sensors. For example, several milliradians of backlash in the

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* In Accordance with radar convention, a zero-mean error distribution is assumed (radar is properly aligned) and the RMS error is in fact the standard deviation of the distribution, which is also called its 1-sigma value or simply sigma (σ).

drive train was of little consequence and the angle data, although not precise, was adequate for the purpose. On the positive side, the leniency certainly resulted in greatly reduced costs for the tracking systems. Presently, however, there is need on several test ranges for accurate spatial data in conjunction with telemetry tracking operations in the absence of radar support. EMP has met the challenge by combining computer technology with that of video tracking to provide Real Time Data Correction and upgrade the telemetry tracker's shaft-angle data output to near-radar-quality at a relatively low cost.

The modification, which can be added to most automatic tracking telemetry antenna systems, is comprised of a TV Camera mounted on boresight, an Automatic Video Tracking Error Detector and an EMP Model ACU-6 microprocessor-based Antenna Control Unit. Many systems are already equipped with boresight TV cameras which may be utilized and/or ACU-6 units that may require additional PC cards and programming.

The sensitive and very accurate TV Video Tracker and the computing capability of the ACU-6 are used to automatically measure the various static errors in the system and store the results in memory. The error corrected parameters are used in subsequent real time computations. The video Tracker corrects dynamic errors associated with the r-f tracking loop by modifying the angle position data words, also in real-time.

Determination of the position of a target vehicle in space (space position) is by triangulation involving at least two tracking systems. A three station solution is preferred. A single station solution is made possible by the addition of either laser or r-f range measuring circuitry.

REAL TIME DATA CORRECTION

This paper presents a method for calibrating and error correcting elevation-over-azimuth tracking pedestals using boresight and stellar targets. The approach is to generate an error model and then make adjustments in real time.

Consider, first, the present angle data output capability and the potential capability of the typical telemetry tracking antenna system now operating in the field. The most common shaft angle sensor is a synchro transmitter with an accuracy of six minutes. Some systems utilize two-speed synchro packages (1:1 and 36:1) or precision synchros (20 second) for increased accuracy. The instrument accuracy is unimportant since the synchro error, like other system errors, is included in the error model and corrected in real time. The angular resolution of the output data is determined by the synchro-to-digital converter. A sixteen bit converter provides a resolution of about 20 arc seconds.

Substantially higher resolution can be achieved by use of direct-coupled, optical, shaft encoders. For example, a 20 bit optical shaft encoder provides a resolution of 1.24 arc seconds. The addition of an Automatic Video Tracking Error Detector and a TV Optical Boresight Camera with a 20 inch focal length and a standard pickup area of 2/3 inch (1 degree field of view) makes a subsystem with a resolution of 1.7 arc seconds a possibility. While tracking an r-f signal, the antenna may not always be pointed directly at the target vehicle due to servo acceleration lag or various other factors. At these times the TV Tracking Error Detector generates delta x and delta y error signals which are added to or subtracted from the Telemetry Tracking Antenna System's angular position data in real time, thus providing REAL TIME DATA CORRECTION.

CALIBRATION

The elimination of various errors inherent in target track data reduction are compensated for by real time correction from firmware in the ACU-6 Antenna Control Unit. A Calibration Data Area is provided in the ACU-6's non-volatile, battery backed BRAM and contains operator examinable, known error magnitudes. These errors are typically determined during the installation and then stored for retrieval each time the system software is invoked. Many of the biases can be assumed constant unless a hardware replacement or site relocation is performed. Others must be determined prior to each mission to assure that high accuracy data is obtained.

The TV optical Boresight is a tool for providing the Calibration Data Area. An automatic star calibration program is provided to enable the operator to completely calibrate the optics system which is the reference for the TV-tracker and other platform instrumentation systems. The following pedestal errors are determined by observing a number of well defined targets (minimum of three). Measurements are taken in normal and plunge mode to resolve the error components:

a. Azimuth encoder bias
b. Elevation encoder bias
c. Nonorthogonality (also termed Inclination error.)
d. Skew (also termed Collimation error)
e. Droop

Before running a star calibration the operator should run a mislevel slew, and set current weather conditions using the appropriate variables. In addition, azimuth and elevation biases should be roughly determined.

The system accuracy is a function of the individual instrument accuracy. The angular accuracy is determined by the TV-optical performance. Target space position information relative to time for a two axis tracking pedestal network is obtained by numerical solution of measurement data from two or more sites. The accuracy of the target space position information relative to time is a function of the individual measurement accuracies, the number of sites used in the solution, and the relative geometry of the sights and target.

The optical axis collimation and encoder zero reference coefficients can be refined by regression analysis after each mission using dynamic star track error determination in the replay mode. However, the possible lack of target opportunities at the time of specific need due to meteorological obscuration compel consideration of alternate means for sensor axis collimation and encoder zero reference checks. The relative optical axis positions are expected to remain stable over time intervals of hours but have a tendency to drift and deteriorate over longer periods and intervening tracking systems shutdowns. The sensor axis alignment coefficients can be adequately monitored and updated by the results of suitable sensor boresight target (BST) lock-on procedures in the normal and plunge pedestal attitudes. The simplicity and independence of the quasi-static measurements of sensor axis coefficients by BST lock-ons present an attractive alternate or back-up for the more dynamic, but weather dependent star track measurement techniques.

The initial boresight alignment of the optical head relative to the pedestal can be accomplished using the collimated boresight target as a reference. The lens is focused at a point near the hyperfocal distance. Conventional optical tracking system boresight orientation technique applications exist that can be simply adapted.

The optical/r-f boresight target permits accurate and precise determination of the optical head instrumented line of sight (LOS) axis collimation (orthogonality) coefficient which is the primary optical reference for the error model determination process. The automated boresight procedure is conducted in two phases:

(1) Electronic reticle skew alignment and scale factor determination.

(2) Normal - Plunge lock-ons

Electronic Reticle Skew Alignment and Scale Factor Determination

The TV electronic reticle skew and scale factors are determined by an automated scan routine controlled by the ACU-6. The right-left reticle skew and scale factor procedure (Figure 1-a) is as follows:

(1) Lock on the boresight optical target in normal position.
(2) Allow for settle time.
(3) Lock the pedestal in elevation.

(4) Drive the pedestal in azimuth ± 3/4 of a degree.
(5) Compute the right-left scale factor (F_A) (arc seconds per bit) and display on the monitor.
(6) Compute the right-left reticle up-down delta at ± 3/4 of degree points and display on the monitor in the units of arc seconds.
(7) Enter the right-left scale factor in units of arc seconds per bit, mils per bit and decimal degrees per bit and skew in units of arc seconds, mils and decimal degrees into ACU-6 memory for further utilization.

The up-down reticle skew and scale factor procedure (Figure 1-b) is as follows:

(1) Lock on the boresight optical target in normal position.
(2) Allow for settle out time.
(3) Lock the pedestal in azimuth.
(4) Drive the pedestal in elevation with the computer ± 3/4 of a degree.
(5) Compute the up and down scale factor (F_E) (arc seconds per bit) and display on the monitor.
(6) Compute the up-down reticle skew right-left delta at the ± 3/4 of a degree second points and display on the monitor in units of arc seconds.
(7) Enter the up-down scale factor in units of arc seconds per bit, mils and decimal degrees per bit and skew in units of arc seconds, mils and and decimal degrees into ACU-6 memory for further utilization.

Normal-Plunge Lock-on

A boresight subroutine for computer aided track (CAT) performs all essential boresighting, control and computation functions with a minimum of effort required from site personnel. The CAT mode operation is considered necessary to attenuate the optical track noise effects of atmospheric shimmer, bearing stiction and other sporadic disturbance expected during track. In the case of abnormally unfavorable BST track conditions, repetition of the data collection over an extended period (perhaps several minutes) is indicated.

The correlation of the BST lock-on measurements with the azimuth and elevation coordinates is illustrated in Figures 2 and 3 respectively. The azimuth and elevation encoder reference corrections are indexed to the lens optical standard.

S_A, SE	= Known true position of boresight target
B_A, B_E	= Pointing axis lock-on encoder coordinates (see Figures 2 and 3)
B_A	$= [N_A + (P_A + 180°)] /2$
B_E	$= [N_E + (180° - P)] /2$

$A_z = (S_A - B_A)$ = Azimuth encoder reference corrected coefficient

$A_b = (B_A - N_A)$ = Collimation

$E_z = (S_E - B_E)$ =Elevation encoder reference correction

The normal-plunge lock-on procedural steps are as follows:

(1) Lock-on the boresight tower optical target in normal position in CAT mode.
(2) Allow for settle out time.
(3) Collect data (n =>100).
(4) Compute (N_{ao}, N_{Eo}) averages.
(5) Compute standard deviation (σ) for each axis.
(6) Delete points > 2σ from mean for each axis.
(7) If the number of points edited exceeds 10%, double the data collection time and repeat.
(8) Compute new values of N_{Ao}, N_{Eo} after editing.
(9) Lock on the boresight tower in the plunge position in CAT and repeat Steps 2 through 8.
(10) Compute the mean encoder coordinate values (normal/plunge) for azimuth and elevation.
    a) Azimuth Mean (B_{Ao}) of the boresight target.
    $B_{Ao} = [N_{Ao} + (P_{Ao} + 180_o)] /2$
    where:
    N_{Ao} = Average azimuth reading in normal BST lock-on position after editing
    P_{Ao} = Average azimuth reading in plunge BST lock-on position after editing
    b) Elevation Mean (B_{Eo})
    $B_{Eo} = [N_{Eo} + (18^\circ - P_{Eo})] /2$
    where:
    N_{Eo} = Average elevation reading in normal BST lock-on position after editing
    P_{Eo} = Average elevation reading in plunge BST lock-on position after editing
(11) Compute BST encoder reference corrections for azimuth and elevation offset of MEAN from that of the survey coordinates of the BST.
    a) $A_{Zo} = (S_A - B_{Ao})$ = (Survey BST - B_{Ao})
    b) $E_{zo} = (S_E - B_{Eo})$ = (Survey BST - B_{Eo})
(12) Compute the LOS misalignments for azimuth and elevation.
    a) $A_{bo} = (B_{Ao} - N_{Ao})$ = optical LOS collimation error correction coefficient

b) In consideration of term: $(B_{Eo} - N_{Eo})$.
This term results from pedestal mislevel and if non-zero requires that the azimuth axis be physically leveled (made vertical) since hemispherical mislevel cannot be removed based upon the observation of a single point.

(13) Record (in units of arc seconds).

a) A_{zo} Azimuth encoder reference correction.
b) E_{zo} Elevation encoder reference correction.
c) A_{bo} Optical LOS collimation error correction coefficient.
d) K_{do} Optical LOS droop character correction coefficient.
e) N_{ao} and σN_{Ao}.
f) N_{eo} and σN_{Eo}

(14) Enter the correction coefficients in ACU-6 memory.

A prime objective of the error determination system design is to specifically define an accurate track system error model in an expeditious and timely manner. Accuracy in this case means that the systematic error sources of the entire data system must be predictable within a small residual root sum square error. The ultimate residual systems RMS error that can be achieved with the automatic error determination concept will best be evaluated by on-site experiments.

A systems design angle accuracy goal sigma of ± 10 arc seconds or better appears to be reasonable. This value reflects the scatter of residual systematic errors remaining after the pedestal angle output data are corrected for all known systematic errors. The achievement of this goal for the complete system is possible since the basic assumption of the measurement effort rests on the well defined positions of the stars whose coordinates are known to a practical accuracy of less than 0.5 arc second.

On-site data processing is designed to allow for a completely localized error model determination with a minimum of human intervention. Star ephemeris positions are used as an absolute angular standard. The design utilizes a pedestal mounted primary electro-optical sensing system which relates optical-sensor and pedestal errors to the celestial star field absolute standard.

The preferred mode of operation is a real time designation of the pedestal mounted sensor optics to the reference star using ephemeris angle pointing accuracies of less than 0.5 arc seconds sigma. The optical sensor measures the off-axis angular position of the star image and furnishes a digital representation of the angular error sensed.

When using stars (or point sources) as targets the data collected for systematic error determination is applicable to the electro-optical sensor and pedestal errors.

The heart of the error determination mode of operation is the comprehensive software package design which mechanizes the functions required to automate the error model determination process.

CONCLUSION

Telemetry Tracking Antenna Systems can be given the capability to provide very precise space position data by the addition of optical shaft encoders, video trackers and the application of real time data correction. Inclusion of range measuring equipment provides single station solution capability. At the sacrifice of some precision, digitized synchro data can be utilized in lieu of optical encoders and still produce results which will exceed the requirements of the majority of operations at a very nominal cost.

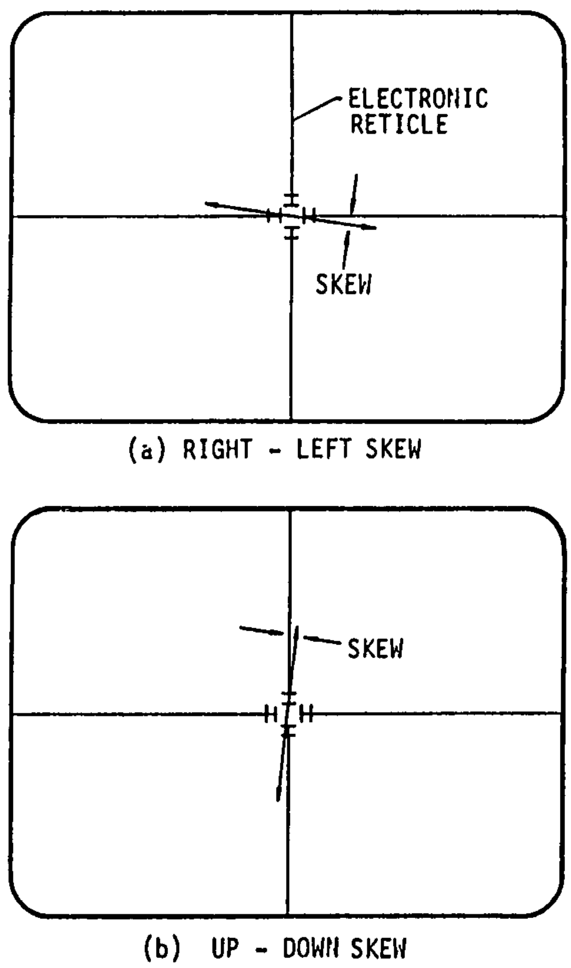
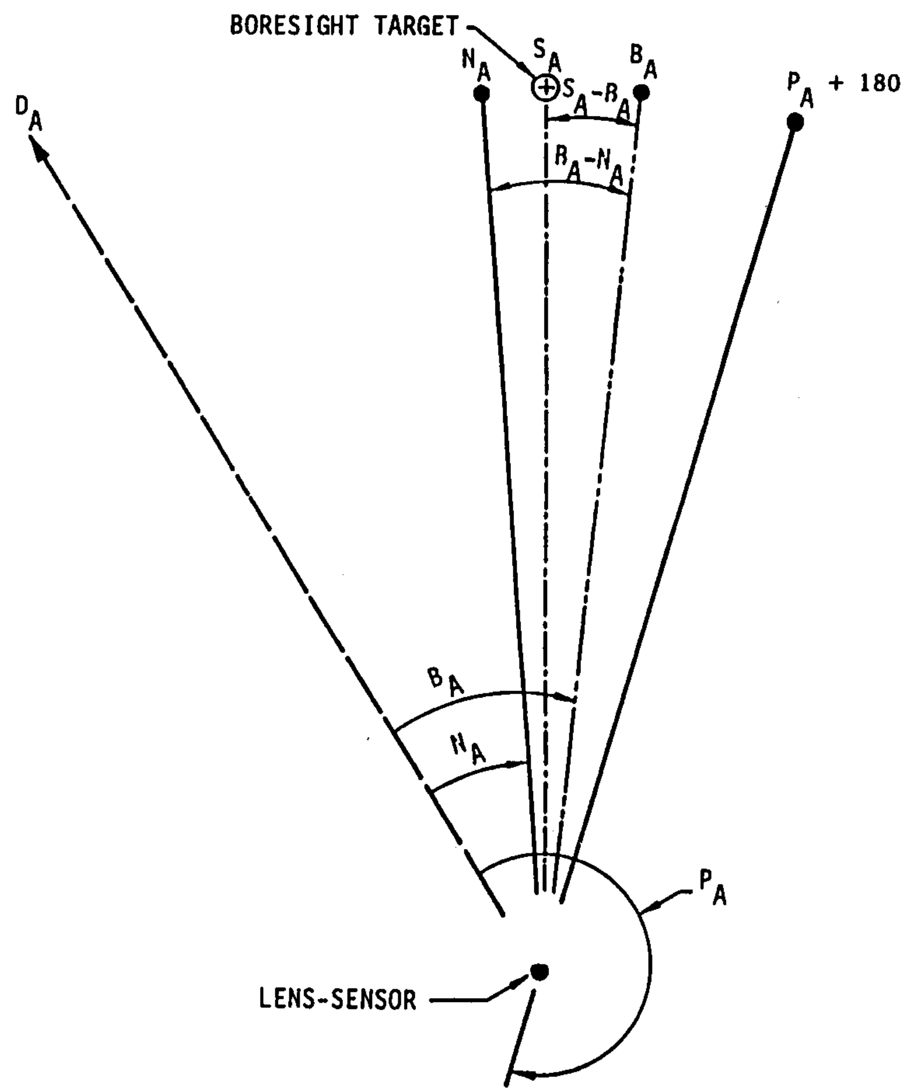


FIGURE 1. ELECTRONIC RETICLE SKEW AND SCALE FACTOR DETERMINATION SCANS



S_A = BST AZIMUTH REFERENCE (SURVEY) COORDINATE

N_A, P_A = COORDINATES OF AZIMUTH ENCODER DURING LOCK-ONS IN NORMAL & PLUNGE

B_A = BST LOCK-ON AZIMUTH POINTING AXIS ENCODER COORDINATE

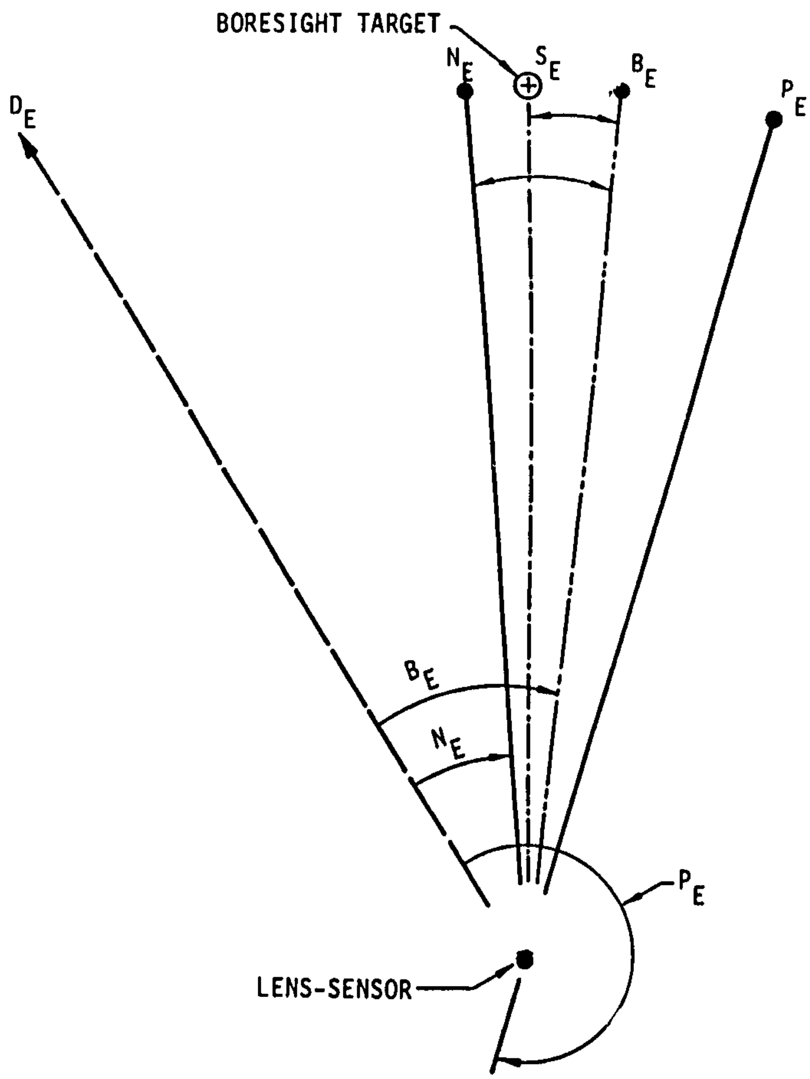
$S_A - B_A = A_Z$ = AZIMUTH ENCODER ZERO REFERENCE CORRECTION

$B_A - N_A = A_b$ = AZIMUTH COLLIMATION ORTHOGONALITY CORRECTION COEFFICIENT

D_A = AZIMUTH ENCODER ZERO READOUT COORDINATE DIRECTION

RELATIONSHIP OF BST LOCK-ON MEASUREMENTS
AZIMUTH COORDINATE

FIGURE 2.



S_E = BST ELEVATION REFERENCE (SURVEY) COORDINATE

N_E, P_E = COORDINATES OF ELEVATION ENCODER DURING LOCK-ONS IN NORMAL & PLUNGE

B_E = BST LOCK-ON ELEVATION POINTING AXIS ENCODER COORDINATE

$S_E - B_E = E_Z$ = LOCK-ON ELEVATION ENCODER ZERO REFERENCE CORRECTION

D_E = ELEVATION ENCODER ZERO READOUT COORDINATE DIRECTION

<u>RELATIONSHIP OF BST LOCK-ON MEASUREMENTS</u>
ELEVATION COORDINATE

FIGURE 3.