A new technology tracker for the Pluto mission spacecraft

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ABSTRACT

A star tracker for a mission to the planet Pluto is described. Low mass, low power and high levels of performance are required at the lowest possible cost. These goals are achieved for the FY94 baseline Pluto mission by a modified, commercially available star tracker, the HD- 1003, from Hughes Danbury Optical Systems. The Pluto mission, the spacecraft design, the star tracker and its performance are discussed,

Keywords: Star trackers, low mass, low power, Pluto, high performance, programmable

1. INTRODUCTION

A star tracker for a mission to Pluto is described with background on the planet and the spacecraft. The work performed is part of a continuing mission development activity at the Jet Propulsion Laboratory on a small spacecraft for a Pluto flyby. Pluto is the only remaining planet of the solar system which has not yet been visited by a robotic spacecraft, The mission challenges are daunting. Two, 3-axis stabilized, 180-kg spacecraft with 10-year flight times are planned in a budget-constrained era. The spacecraft, each with redundant engineering hardware, are to complete fast flybys of Pluto and its moon, Charon, following direct trajectories from Earth. The science package includes visible and infrared imagers, an ultraviolet spectrometer, a radio occultation experiment, and a Russian atmospheric constituent probe or Drop Zond.[1] The FY94 baseline described is called the Pluto Fast Flyby (PFF) spacecraft.

The attitude control subsystem provides the required precision pointing during the encounter phase. Sensing for open loop pointing is provided by the star tracker. The FY94 baseline includes a version of the Hughes Danbury Optical Systems (HDOS) HD-1003 star tracker modified for minimum power and mass.

2. THE PLUTO-CHARON SYSTEM

Pluto has a very elliptical, 248-year orbit. Since 1979 it has been inside the orbit of Neptune and will remain there until 1999, when it will again be the farthest planet from the Sun. It reached perihelion in 1989. For several years around perihelion, Pluto has a tenuous atmosphere, which eventually collapses as it moves further from the Sun. By 2020 it is expected that its atmosphere will have condensed. Because of the present existence of an atmosphere, and the fact that the planet has not yet been explored, Pluto is a candidate for a near-term flyby mission. Pluto is the smallest planet. It has a diameter of 2,300 km, which is two third's that of the Earth's moon. Charon has a diameter of about one half of Pluto's and a 6.4-day orbit, which is the same as Pluto's rotation period. The pair can be regarded as the only true double planet in the solar system.

3. THE PFF SPACECRAFT AND CONSTRAINTS

A diagram of the FY94 baseline PFF spacecraft is shown in Fig. 1. The wet mass of the spacecraft is 180 kg, while the dry mass is 158 kg. The power available from the radioisotope thermoelectric generator at encounter is projected to be 78 watts. The design of the spacecraft components accommodates 22 krad (Si) of total ionizing radiation. Imaging of one side of the planet will be done by each of the two spacecraft during the near encounter phases. Mosaics will be taken with a maximum image motion compensation rate of 1 mrad/sec. The Pluto and Charon pointing requirements are knowledge of 1.5 mrad (3σ), position control of 2.0 mrad (3σ), rate control of 10 μrad/sec (30).

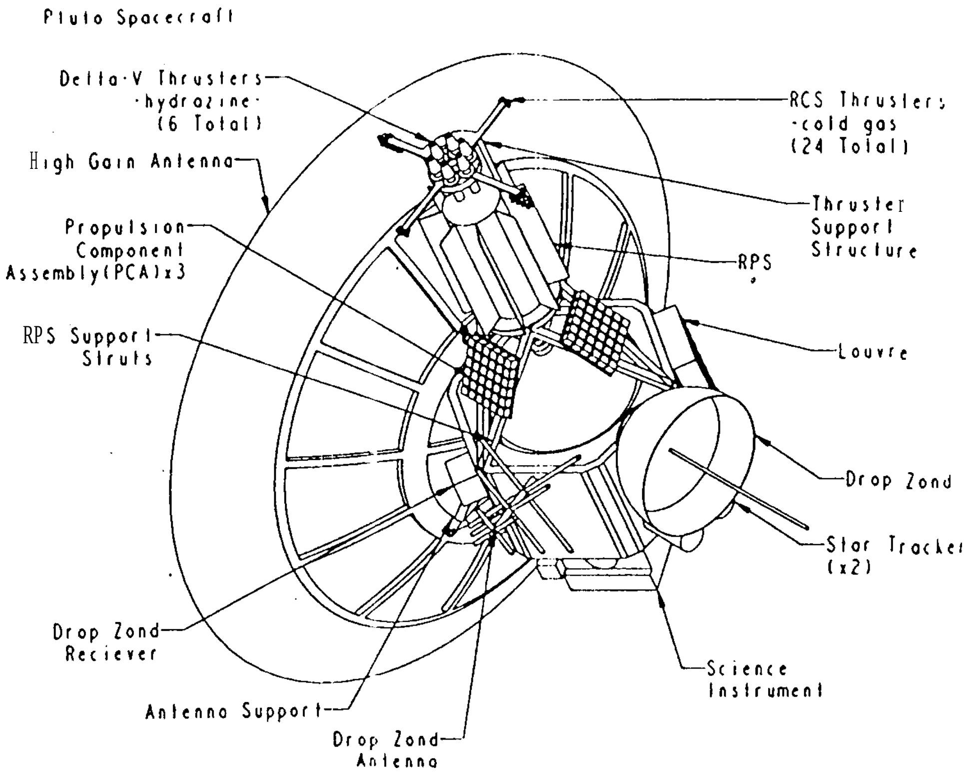


Fig. 1. The FY94 baseline Pluto Fast Flyby spacecraft.

4. ATTITUDE DETERMINATION COMPONENTS

The PFF spacecraft carries sun sensors, inertial reference units (IRUs) and star trackers for attitude sensing. Because of the mass and power constraints, an IRU was selected (Honeywell GG1308 ring laser gyro), which can only deliver rate determination of 33 μrad/sec (3σ) after a 100-second integration, so that the IRU cannot bc used to control the spacecraft rate to the required 10 μrad/sec (3σ).[1] However, data from onc PMT can be used to meet the requirement within 15.4 seconds using typical Pluto encounter star fields.[1] Therefore, the star tracker is the key precision-pointing sensor. Since no standard tracker was available to meet the need, JPL let a contract to HDOS for an assessment and demonstration of the necessary technology as part of the FY94 Micro-Spacecraft and PFF Advanced Technology Insertion program. The effort was called the planetary micro-tracker (PMT) program.

5. PMT REQUIREMENTS AND DESIGN OVERVIEW

The requirements and performance of tbc PMT for the Pluto Fast Flyby Mission arc summarized in Table 1. They were met (with the exception of mass) by modifying the HD-1003 star tracker assembly (STA) currently in development at HDOS.[2] The HD- 1003 S1'A is the product of, and directly benefits from, over 20 years of successful HDOS star tracker development efforts. The result, shown in Fig. 2, is a small, lightweight, reliable, radiation hardened, low power and low cost design that can track up to six stars simultaneously with an overall 2-axis accuracy better then 28 μrad (1 σ) at update rates to 10 hz. All of the parts utilized in the HD- 1003 STA are space qualified and are sufficiently radiation hardened to support missions of at least ten years in space in a wide variety of orbits, The design is also somewhat modular in that it can support a range of spacecraft mounting and thermal interfaces as well as various data buses.

For the application to the PMT, three-axis inertial position reporting (pitch, yaw and roll about the PMT boresight) was incorporated. In addition, even higher accuracy was achieved while lowering weight and power. This was accomplished by virtue of the more benign radiation and thermal environment of the mission, the lower update rate requirement (2.5 hz), and the availability of secondary power from the spacecraft bus and other factors, The result is a design whose performance is predicted to be 17.7 μrad (1σ) in pitch and yaw, and 255 μrad (1 σ) in roll at the end of the mission.[3] At the same time, the tracker mass has been reduced from 3.2 to 2.0 kg and the peak power has been reduced from 11 to 3.5 watts. An exploded view of the PM1' is shown in Fig. 3. A functional block diagram is shown in Fig. 4.

Table 1. Summary of PMT Requirements and Performance

PARAMETER	REQUIREMENT	PERFORMANCE
Functionality	Star Tracker	Star Tracker
Angular Error -2 axis –3 axis Mv=6, EOL, = 0.3 deg/sec	30 µrad, 1 σ/star/sample 275 µrad, 1 σ/2 stars/sample	17.7 µrad, 1 σ/star/sample 255 µrad, 1σ/2 stars/sample
Sky Coverage	>97%	>97%
Tracking Update Rate	2.5 Hz	2.5 Hz
Sun Exclusion Angle	<45 degrees	<45 degrees
Output Data	10 bits	10 bits
In-Flight Re-Programming Capability	Yes	Yes
Acquisition Probability	>97% for at least 4 stars	>97% for at least 4 stars
Target Tracking	Support target limb tracking	Support target limb tracking
Tracking Rate	Up to 0.3 degrees/sec	>0.3 degrees/sec
Mission Duration	10-15 years	> 15 years
Sun Exposure	Up to 30 minutes	>30 minutes
Mass	≤ 1.5 kg	2.0 kg
Power	≤ 6W Peak	3.5W Peak
Reliability	TBD	106 hrs MTBF
Cooling	Passive preferred	Passive

The pMT consists of a lightweighted, bright-object hood; wide field-of-view, color-corrected optics; a low-noise, frame-transfer CCD; signal and data processing electronics; and, an integrating structure.

The bright-object hood is designed to attenuate out-of field sources, of which the Sun is the most significant, in order to preserve dynamic range and minimize the contribution of noise caused by background light. Otherwise, out-of-field sources could cause background noise to rise above the necessary level required for optimum star acquisition and centroiding accuracy. The hood consists of a lightweighted, baffled, aluminum structure that is thermally isolated from the optics. The hood length and internal baffle geometry reduce solar illumination caused background light levels sufficiently when the Sun is more than 45 degrees from the optical axis.

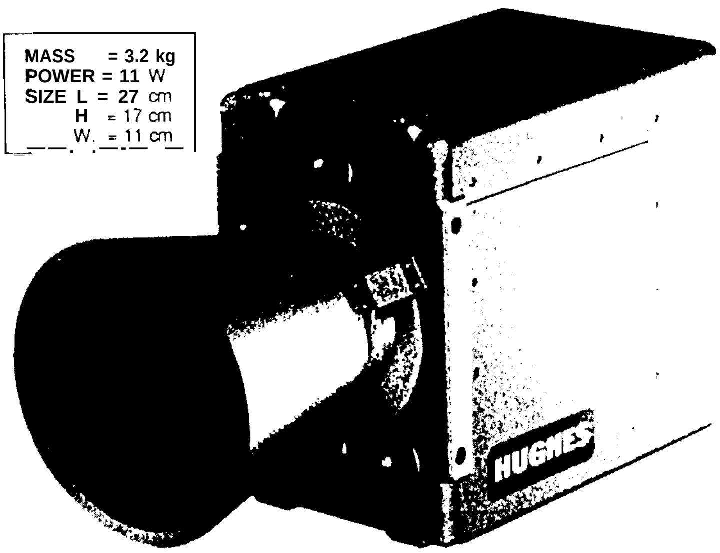


Fig. 2. Hughes 1003 Star Tracker assembly.

The optics consist of a refractive imaging system with an 8 x 8 degree square field of view. Its design produces an image with the necessary encircled energy (which is typically 2 to 3 pixels in diameter), color- correction, and lack of distortion in order to acquire and track stars as dim as Mv=6 with the specified accuracy.

The focal plane incorporates a 1024 x 512 pixel, 3-phase frontside-illuminated CCD operating in the frame transfer mode and incorporating multi-pinned phasing (MPP) technology in order to minimize dark current. The device has the necessary quantum efficiency, noise, charge transfer efficiency, uniformity, dynamic range, and speed to satisfy the PMT requirements over the mission life and radiation and thermal environments.

The CCD output drives the signal processing circuitry which is used to capture and digitize the image data. The circuitry includes a correlated double sampler to reduce noise, a IO-bit A/D converter, and the necessary clock drivers to support the CCD modes. The circuitry has been implemented as Class S Application Specific Integrated Circuits (ASICs) developed by Hughes using a radiation-hardened process line. l'he CCD and the signal processing circuitry are all controlled by a dedicated state machine which is synchronized with the system clock and frame update rate. The dedicated state machine resides within a custom, radiation-hardened gate array, as does most of the digital data processing circuitry.

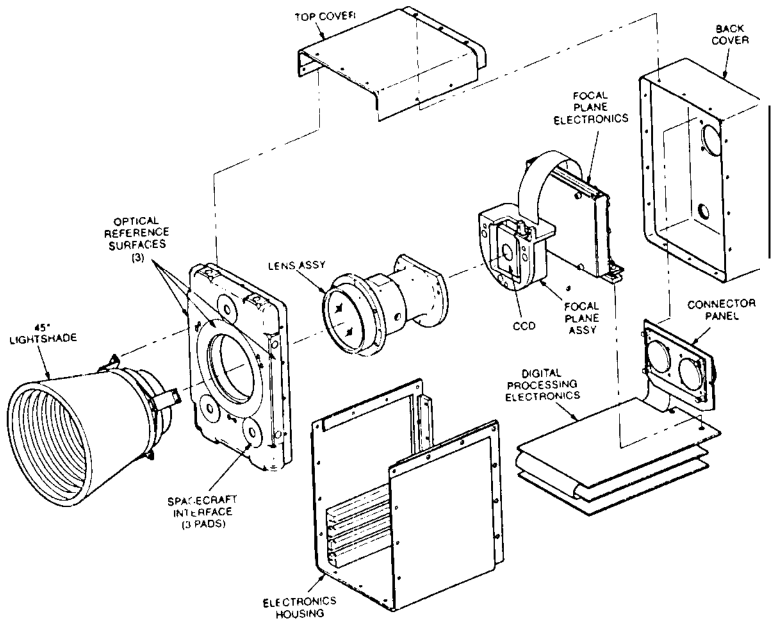


Fig. 3. Exploded view of PMT

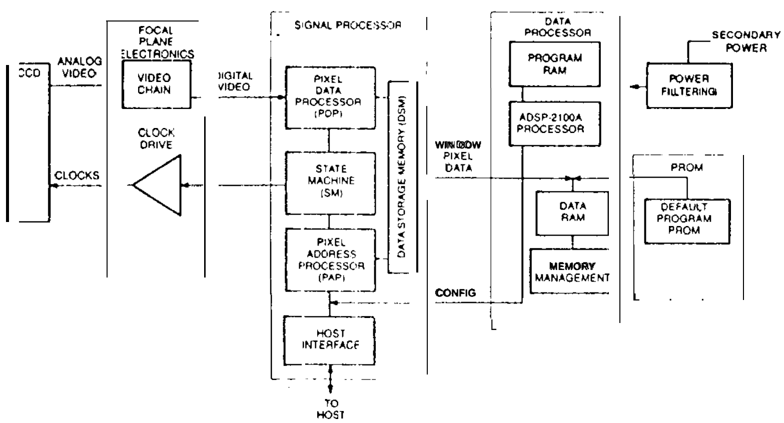


Fig. 4. Functional block diagram of PMT.

The digital data processing circuitry filters and thresholds the raw pixel data in order to minimize the volume of traffic handled by the microprocessor. Logic is used to divide [he output into small track windows that can be accessed so that six stars can be tracked simultaneously. Digitized pixel data within each track window is stored in temporary memory buffers where it is accessed by the microprocessor. It in turn, calibrates, centroids, and formats the pixel data and filters out unwanted proton and debris-induced noise. Resultant centroid and magnitude data for up to six stars is generated at the required update rate. This data along with housekeeping and status data is provided in a format consistent with the RS-422 communications bus.

The mass and power reductions from the HD- 1003 were largely accomplished by eliminating unnecessary radiation shielding, the de/de converter and the thermoelectric cooler. These changes were enabled by reduced radiation environment of the PFF mission relative to the HD- 1003 design environment, the availability of secondary, regulated power, and by the usc of passive CCD cooling. Power reduction was also aided by the reduced frame rate of 2,5 Hz and by timing adjustments which were made in order to reduce peak power.

6. PMT PERFORMANCE

The performance requirements and capabilities for the PMT are summarized in Table 2. The predicted performance is based upon models whose fidelity has been verified by comparing their predicted values to measured acceptance data on production trackers. Referring to Table 2, columns 1 and 2 are the specified requirements. Column 3 is the predicted worst case performance based on a set of dimmest stars at end of life. Column 4 represents a more realistic estimate of performance considering actual star brightness and separation statistics obtained by "flying" the mission and looking at real star distributions. Finally, the last column shows what could be achieved if a means of in-flight calibration existed so that low spatial and temporal frequency boresight errors could be calibrated out. The error budget for the PMT at Pluto encounter is shown in Fig. 5.

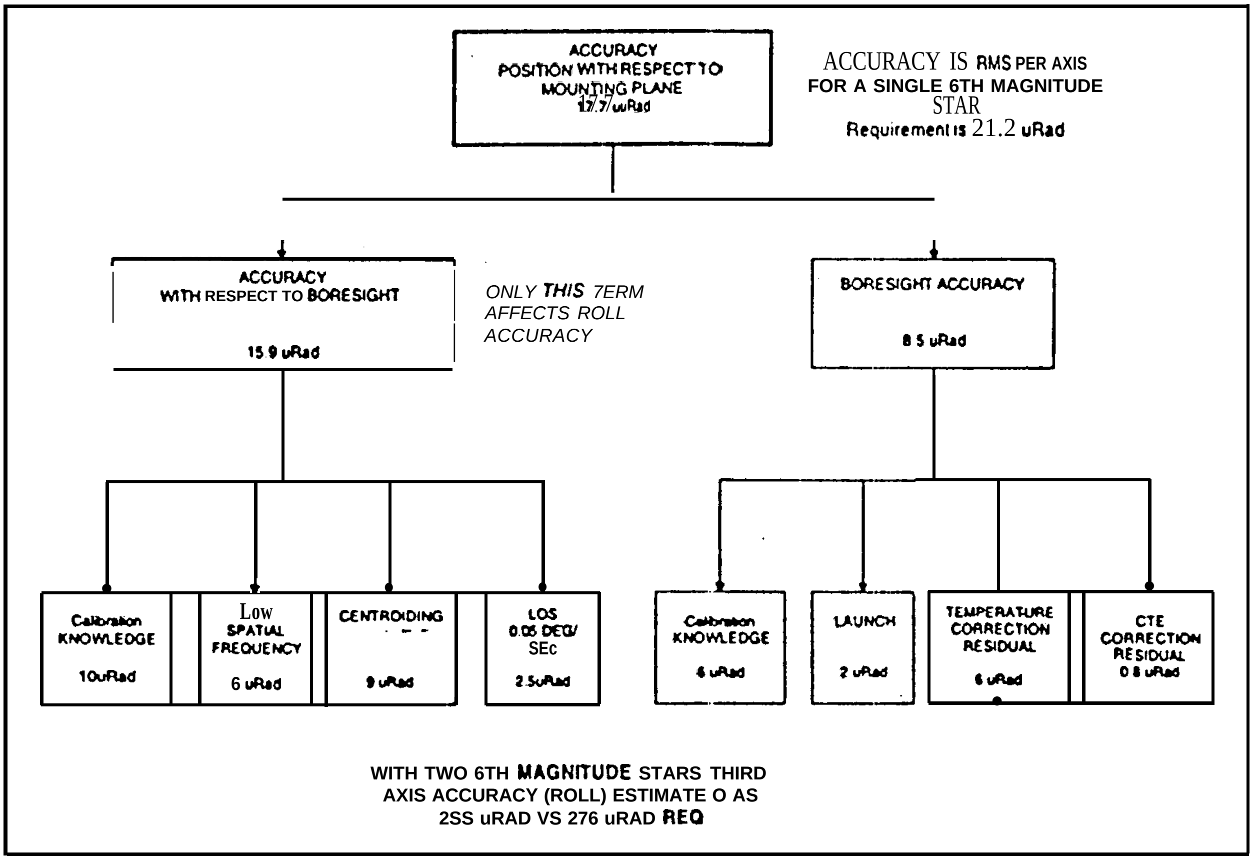


Fig. 5. Error budget for PMT at encounter,

Table 2, Performance Analysis Results

Axis	Requirement	Expected Performance	Scenario Performance	Scenario Performance with Calibration
Roll	275 (2 stars)	255 (2 stars)	105	105
Pitch	21.2 (1 star)	17.7 (1 star)	10.29	5.8
Yaw	21.2 (1 star)	17.7 (1 star)	9.9	5.2

Note: Pitch and yaw are given as 30 μrad for two axes, all values are μrad, 10.

In addition to its excellent star tracking performance, ways to utilize the star tracker to support planetary tracking were investigated. A relatively simple approach that would allow the tracker to be used as a limb tracker, if needed, was developed. Fig. 6 shows the limb tracking algorithm that was developed and demonstrated.

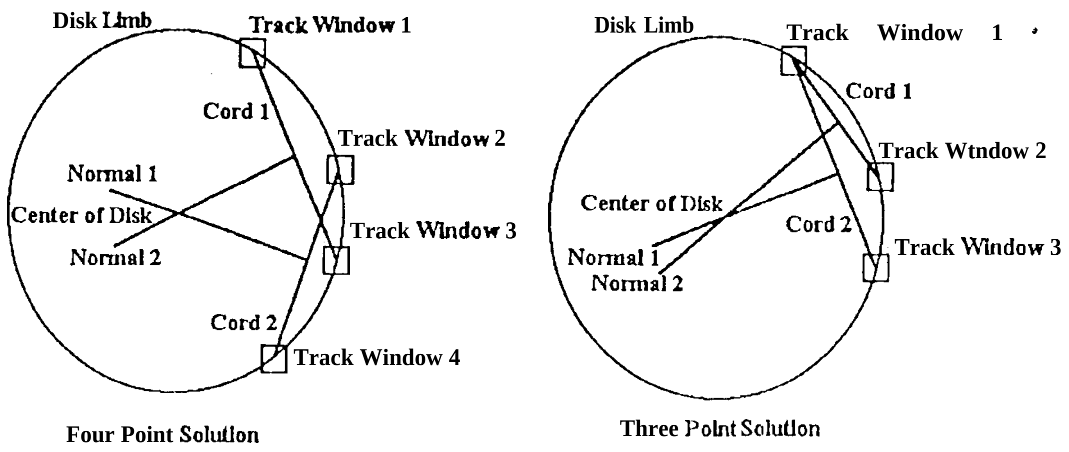


Fig. 6. Limb tracking algorithm, intersection to cord normals.

7. PMT BREADBOARD RESULTS

The existing STA breadboard was modified to demonstrate and quantify the star tracking performance of the PMT. The functions demonstrated included acquiring and tracking multiple stars, acquiring and tracking planetary limbs, and extracting 3-axis performance data (pitch, yaw, and roll) within the accuracy limits of [he breadboard. The breadboard, shown in Fig. 7, consists of a computer-controlled scene simulator, a set of flight optics, the flight CCD, and all the necessary signal and data processing hardware and software to acquire and track up to four stars simultaneously. The breadboard modifications incorporated the necessary algorithms to provide 3-axis position data (pitch, roll, and yaw) from the star centroid and magnitude data, and to input and track planetary limb features. The end-to--end breadboard performance results were calibrated and the test data was correlated with values predicted for our flight design and with data measured on operational star trackers. The results showed that the predicted capabilities for the Pluto design can be achieved with margin. For example, Fig. 8 shows that measured pitch, yaw, and roll, spatial and temporal frequency errors are well within the predicted values.

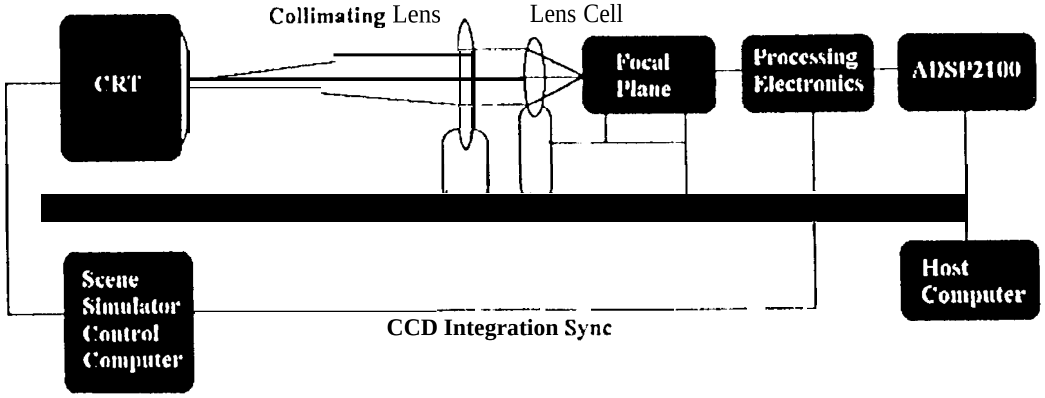
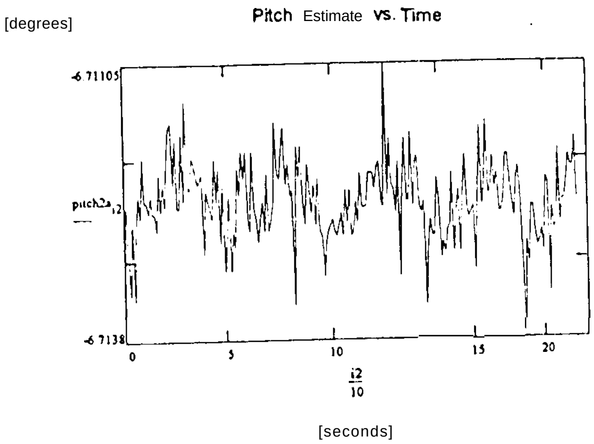


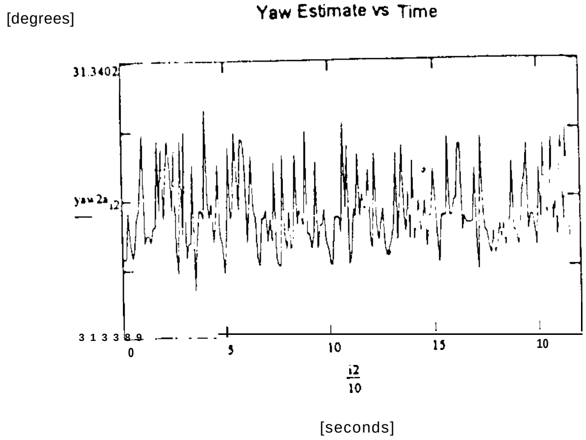
Fig. 7. STA breadboard.



Statistics

pitchm = -6712	[degrees] mean pitch estimate
σpitch = 1 423	[arcsec] 1σ pitch error
Δpitch = 9901	[arcsec] peak-peak pitch error

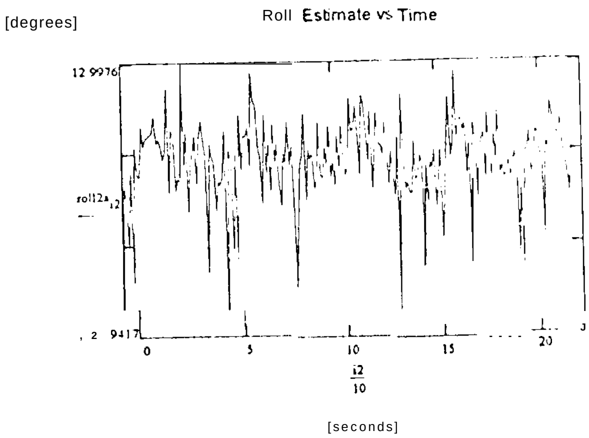
(a) Pitch performance



Statistics

yawm = 31 339	[degrees] mean yaw estimate
σyaw =0999	[arcsec] 1σ yaw error
Δyaw =4 744	[arcsec] peak-peak yaw error

(b) Yaw performance



Statistics

rollm = 12 978	[degrees] mean roll estimate
σroll = 32 631	[arcsec] 1σ roll error
Δroll = 201 108	[arcsec] peak-peak roll error
σrollest = 35 764	[arcsec] estimated roll error

(c) Roll performance

Fig. 8. Measured pitch, roll and yaw spatial and temporal performance for case 2 with 2 stars tracked at a 3.1 degree separation.

8. CONCLUSIONS

A **baseline design** for [he **PMT** has been developed and demonstrated using the existing HDOS HD-1OO3 STA breadboard. The design can be readily implemented by incorporating relatively minor changes to the existing HD- 1003 production star tracker. These changes include eliminating unnecessary radiation shielding, reducing the volume and mass by virtue of elimination of the de/de converter and the thermoelectric cooler, replacement of the communication bus, and software modifications to incorporate the necessary algorithms to perform planetary limb tracking and to accommodate the new bus, The result is a very low mass and power design that meets all of the PMT performance and life requirements (except mass) with margin.

9. ACKNOWLEDGMENTS

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10. REFERENCES

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