Free Space Optical Communications System Pointer

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Abstract

Free Space Optical (FSO) communications pointing problems will be described and a solution presented. Conventional systems used in sea, land, and space are illustrated. Our integrated approach investigates three major problems areas: kinematics, structure, and dexterity. Their interrelationship will be discussed.

Introduction

FSO/RF communication systems offer the potential of much higher bandwidth, unencumbered by FCC or ITU restrictions. FSO/RF communication is also covert with low probability of intercept, jam-resistant, resistant to EMI and co-site interference, low power, low weight, small size, and low cost. FSO/RF communications systems acting as advanced, next-generation Airborne Communications Nodes also offer the potential for significant logistics savings. In Desert Storm, the deployment of Army Signal Units required 40 C-5 sorties and 24 ships. By being largely self-deployable, a UAV-based Airborne Communications Node could reduce the number of airlift sorties required for communication support by half or more.

Office of the Secretary of Defense reports that *"The key trend for future communications systems is increasing data rates brought on by migration towards higher RF frequencies and the emerging dominance of optical over RF systems. Laser-based systems will offer data rates two to three orders of magnitude greater than those of the best future systems. The advantages of optical communication were demonstrated in 1996 when a ground-based laser communication system (lasercom) provided data rates of 1.1 terabits/sec at over 80 nm [nautical mile] range. Airborne and space borne Tbps lasercom systems will certainly be possible by 2025. Although lasercom will shortly surpass RF in terms of data rate, RF will continue to dominate at the lower altitudes for some time into the future because of its better all weather capability."*

The Pointer Problem

A key component of any practical, covert laser communication system regardless of space, sea, mobile or man-portable system will be the advanced, light weight, low cost antenna pointing and tracking mechanism (Figure 1). The optical community is only beginning to look at this element of the overall problem of FSO. Such a system requires a mechanism that is (1) easily manufacturable and therefore inexpensive; and that has (2) high slew rate; (3) high accuracy; and (4) wide, singularity-free range of acquisition. Ross-Hime Designs, Inc. (RHD) believes that it has developed a new, innovative mechanism that can meet these demanding requirements. RHD proposes that a Free Space Communication System Sensor Pointer be based on the Omni-Wrist III. The Omni-Wrist III is a revolutionary, patented, low-cost, lightweight, compact, rugged, high-dexterity pointing device for space, land, and sea-based communication applications [2-5]. It is a major advancement over conventional azimuth/elevation mounts because it offers 180 degrees of unimpeded (singularity-free), hemispherical movement; low manufacturing costs; and a streamlined design integrating pivots into the body of the device. These features combine to produce a reliable, high-performance pointing device capable of greater precision than existing designs.

Ross-Hime Designs has won a NAVY SBIR Phase I for "Low Cost Submarine UAV Communication System and Data Link." According to Mark Rosheim "The key aspect of our approach will be to reduce

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the lifecycle cost of an airborne line-of-sight TCDL data-link and increase the range of the data link to be limited only by the UAV altitude, up to a distance of 322 km (200 mi)." A bi-product of this contract is the new plastic Omni-Wrist III shown here. Benefits expected to arise from the SBIR include: high capacity multimedia data exchange, jam-resistant communication, small transmit/receive aperture, low power and weight and resistance to EMI and co-site interference.

The test and evaluation Omni-Wrist III unit (Figure 2) addresses technology gaps in existing approaches to sensor pointing. Typical precision solutions have involved the use of either a distributed axis system or a gimbal. Both of these types of conventional azimuth/elevation mounts suffer from slowed response times and/or limited range of motion, or from singularities (voids in the work envelope). The first type of design has a sensor mounted on a fork for elevation (pitch) that in turn is mounted on a rotating base for azimuth (yaw). Such a design requires the positioning of two independent systems, which increases response time by introducing unnecessary path optimization calculations into every pointing operation.

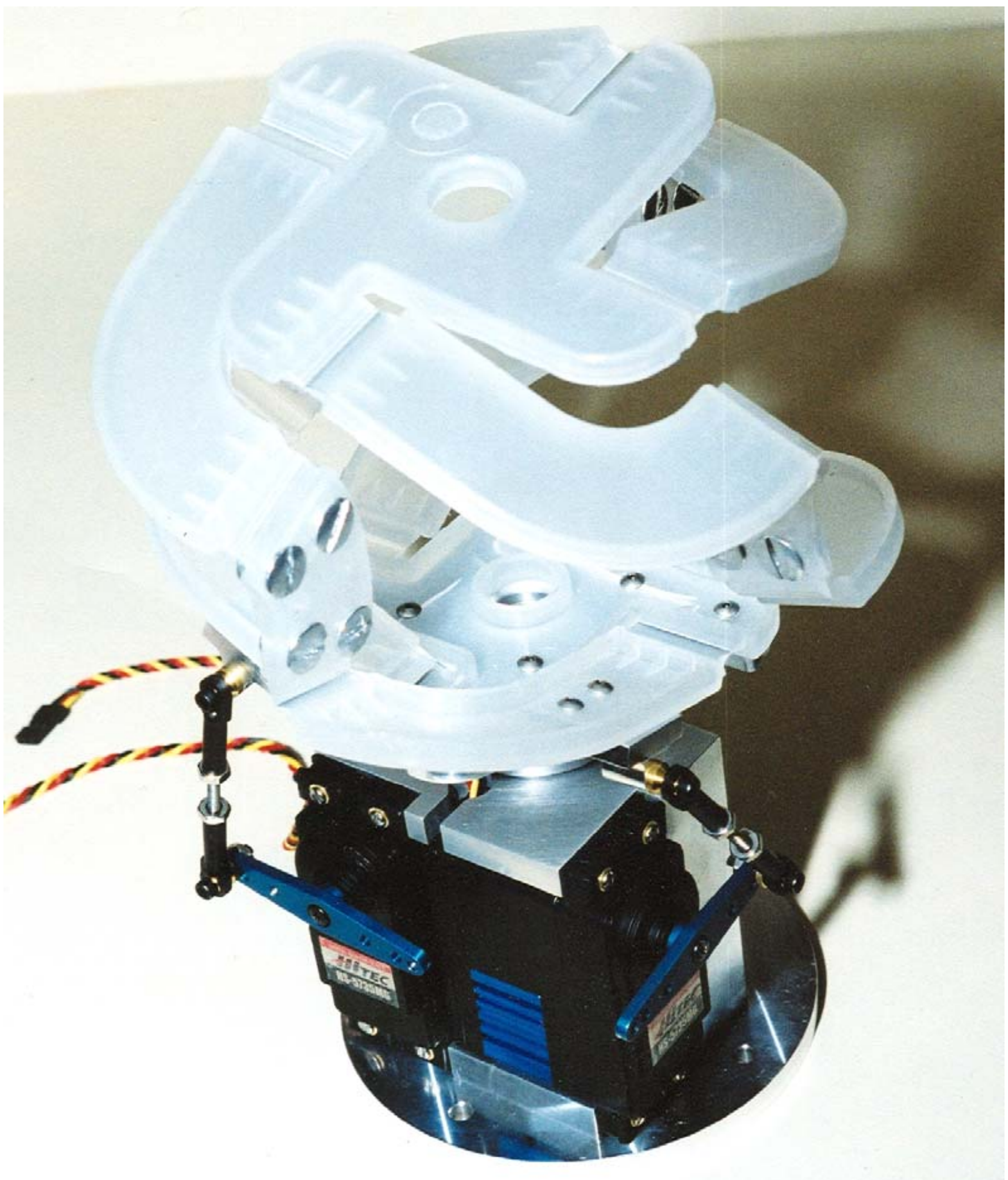

Figure 1. Advanced UAV Antenna Pointing System

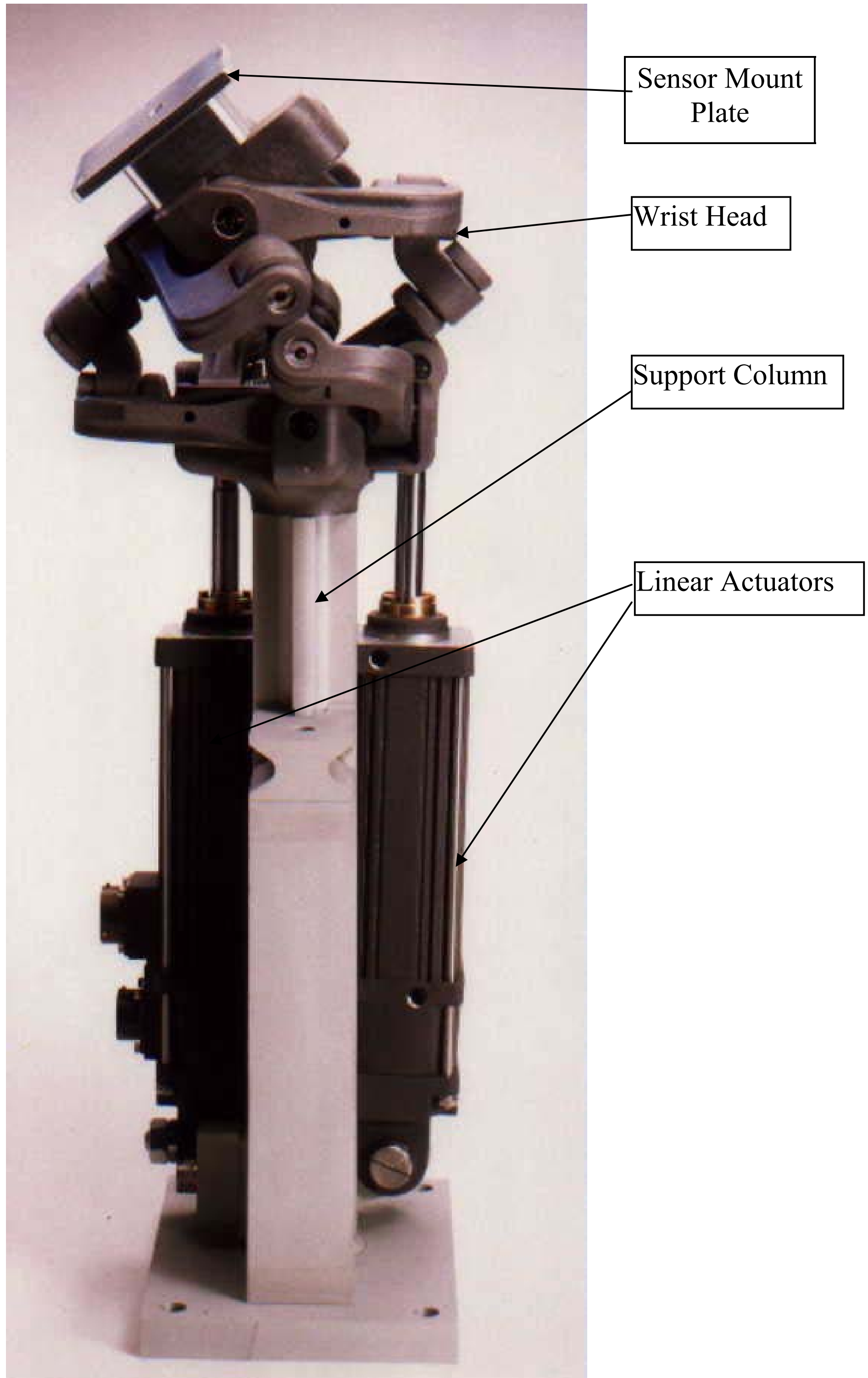

Figure 2. Omni-Wrist III Pointer

Presently two forms of precision antenna pointing systems dominate the ground-based and space-based markets (Figure 3). Schaeffer Magnetic, Inc., Chatsworth, California “Biaxial Drive” represents the most common design, also know as an azimuth and elevation or yaw-pitch type drive [6]. Schaeffer’s system is composed of two harmonic drives powered by DC motors with redundant winding and electronics. Wiring for electronics, motors and antenna is integrated within the structure. The simple mechanical design is very stiff and rugged. Although compact and precise, within limits, this design has a singularity (it jams) when the antenna is pointed straight up. Yaw becomes roll and the resultant singularity degrades precision and complicates control. This is particularly evident when tracking high speed objects or in the case of ship pointing systems where the ship is pitching and yawing due to rough seas. Another popular packaging variation is manufactured by Wescam, Inc, Toronto, Canada this spherical sensor platform appears to be based directly on the ball turret from World War II bomber aircraft (Figure 4).

The second common antenna pointing system is represented by the "APS" manufactured by the Honeywell Space Systems Group, Phoenix, Arizona [1]. Two perpendicularly mounted actuators produce ±110 degrees each. Singularity is mitigated when the antenna is pointing straight up because of the perpendicular orientation of the two actuators. However, singularity or gimbal lock occurs when the pointing system attempts to move in circumduction (a combination of pitch and yaw motion) at the extremes of its range of motion. Example: when the pointer is tracking along the horizon the upper actuators must toggle over each other in a saddle shaped profile making precision pointing impossible. The Honeywell design lacks stiffness because the orientation of the joints creates longer lever arms that could cause deflection under high inertia loading. As in the Schaeffer system two harmonic drives with redundant motor windings and electronic power the system. Complex flexible cables (a major design problem) are found in both designs.

KVH Industries has received a license for its sales of certain of its stabilized satellite communications antenna products that include robotic wrist actuator technology under U.S. Patent No's. 4,723,460, 4,729,253 and 4,686,866 originated by Mark E. Rosheim.

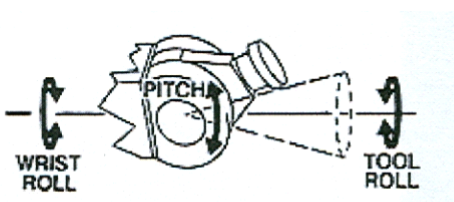

Figure 3. Schaeffer Kinematics

From the above one may conclude that aside from improvements to motor speed reducers, i.e., Harmonic Drive devices, the fundamental kinematics and structures for sensor pointers has not been advanced since W.W.II. They are still predominantly simple azimuth/elevation devices or variations on the simple gimbal. Singularity-ridden, they are unable to maintain a lock within the full hemisphere which is required for horizon-to-horizon tracking.

To answer the growing need for improved singularity-free pointers that complement the growing sophistication in optics and control, Ross-Hime Designs, Inc. sensor pointer was developed under Phase I and Phase II SBIR contracts for the Ballistic Missile Defense Organization. By way of contrast it uses a new, innovative, unique, patented, double universal joint that reduces response time by enabling a single calculation to drive the motion of the joint. RHD has designed and built a number of gimbal system for the robotic industry since 1987. Over 6,000 have been used in the RF antenna pointing industry over the last eight years. The main advantage is singularity-free motion and ruggedness. Flexible cables are eliminated as the motors are stationary. Pure circumduction without gimbal lock about its extreme range of motion is possible through its unique double universal joint design making horizon-to-horizon as well as zenith tracking practical. This singularity-free motion is unique to Omni-Wrist III creating a hemispherical range due to the unique patented structure and kinematics [3-5]. The double universal joint has orthogonal axes like the compass gimbal. The range of motion problem is solved by adding a second joint. Simplicity is maintained by phasing the two

Figure 4. W.W.II Ball Turret

joints together mechanically rather than powering each gimbal independently. What is often unappreciated by designers and engineers is the radical transformation that a gimbal must go through to achieve a perpendicular orientation of the output in any direction from the mechanism centerline. While it is common to make pointers with stock actuators and components they invariably have singularities. This is a result of either their kinematics, structure or both.

Table 1. Preliminary Free-Space Communications Sensor Pointer Performance Goals

Load capacity	4.5 kg (10 lb)
Output Speed	60 deg sec
Unit weight	9.1 kg (20 lb)
Accuracy	0.06 deg > 3.6 arc minutes >216 arc seconds
Range of motion	180 degrees Hemisphere (2π steradians)
Dexterity	Singularity-Free
Construction	17-4 Stainless Steel, Engineering Plastic
Physical Envelope	Cylinder, 20.3 cm (8") Diameter X 45.7 cm (18") high

Test Results

This section presents a summary of the test results for the Omni-Wrist III Sensor Mount. A detailed report was included in a paper presented at the SPIE Conference in Seattle, July 2002 [2]. Two test methods were used to determine the pointing accuracy. A Coordinated Measuring Machine (CMM) was initially used and a second test method utilized an attached laser pointer to determine the repeatability of the pointing accuracy. In this last test, the Omni-Wrist III Sensor Mount was exercised through various deflections.

CMM Test Results

The CMM was capable of high precision measurements of any point on the Omni-Wrist III Sensor Mount. The tip of the Sensor Mount was used for these measurements. As the Sensor Mount was exercised the position of the tip was precisely determined. These positions were then compared with expected values and the various errors were calculated. The Sensor Mount was placed within the CMM and exercised at two azimuth settings, (0 and 45 degrees). At each of these positions the declination angle was changed from 0 to 81 degrees in several steps. All told there were 58 separate positions. The pointing error was less than 0.05 degree (180 arc seconds).

Laser Pointer Test Results

Figure 5 shows the Omni-Wrist III Sensor Mount attached to its mount that was anchored to the wall. A laser pointer was attached to the Sensor Mount at the center hub. The central hub also incorporated the means to attach various weights. We used regular bar bell weights for the testing. Weights of 2.1 and 2.8 (4.6 and 6.1 lb) were the primary values used.

The Omni-Wrist III Sensor Mount was exercised through many different sequences. Two home positions, (Dec = 0, Az = 0) and (Dec = 89, Az = 180) were used. The test sequences consisted of large angle deflections, small and medium angle deflections, and multiple angle movements. A weight of 2.1 kg (4.6 lb). was attached to the Sensor Mount for most of the tests. For all the tests only one of the tests produced an average repeatability error greater than the goal of 216 seconds of arc. In general the reproducibility error was less at the home position (0, 0) than at (89, 180). At (0, 0) the actuators are retracted and the Sensor Mount movements were more certain than when the actuator positions were at their extremes. Speed tests indicated that an angular deflection greater than 160 degrees/second could be accomplished - much faster than the goal of 60 degrees/second.

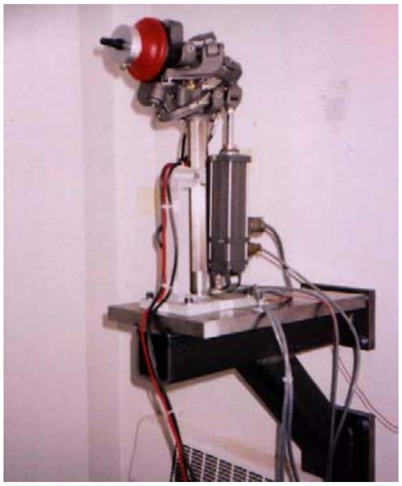

Figure 5. Omni-Wrist III Test Setup

Table II shows the positions used in the tests. Figures 6 and 7 plot the test results. Each value represents the average of at least three repetitions. Figure 8 is a plot of the resultant [SQRT(x^2 + y^2)] pointing error. The median pointing error was 60.84 arc seconds.

Table II

Home Position Dec = 89; Az = 180

Test #	DEC	AZ
1	0	0
2	45	90
3	45	270
4	45	0
5	75	180
6	75	45
7	80	170
8	89	90
9	89	270
10	45	45
11	80	0
12	89	135
13	89	225
14	15	315
15	30	315
16	89	45
17	35	315
18	40	315
19	50	315
20	60	315
21	70	315
22	80	315

Home Position: Dec = 0; Az = 0

Test #	DEC	AZ
1	89	0
2	89	45
3	89	90
4	89	135
5	89	180
6	89	225
7	89	270
8	89	315
9	45	0
10	45	90
11	45	45
12	45	135
13	45	180
14	45	225
15	45	270
16	45	315
16	45	315

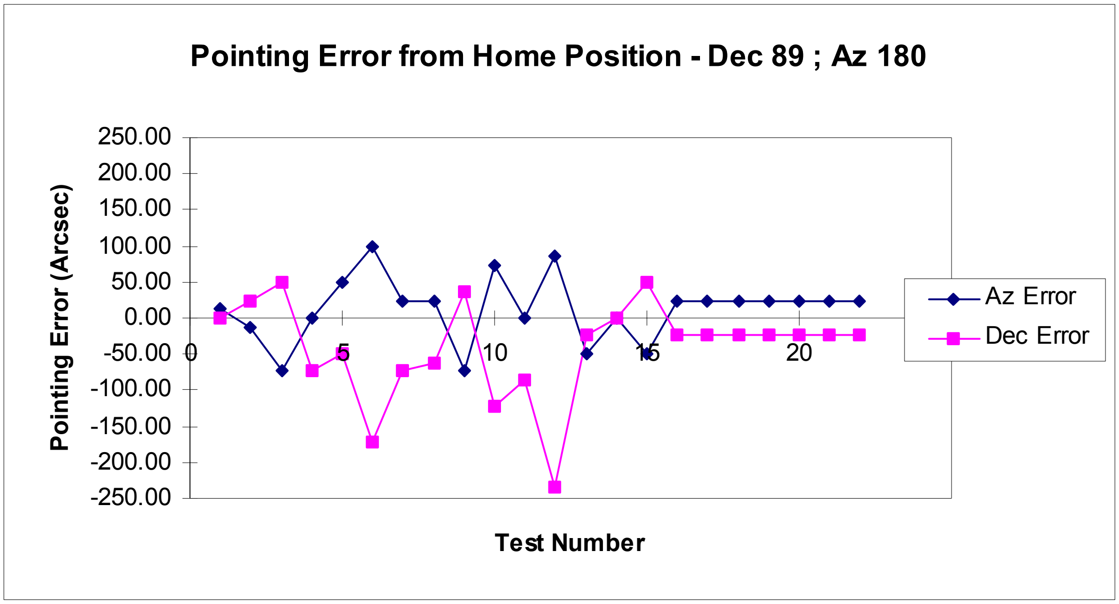

Figure 6. Azimuth and Declination Pointing Errors for the Omni-Wrist Sensor Mount

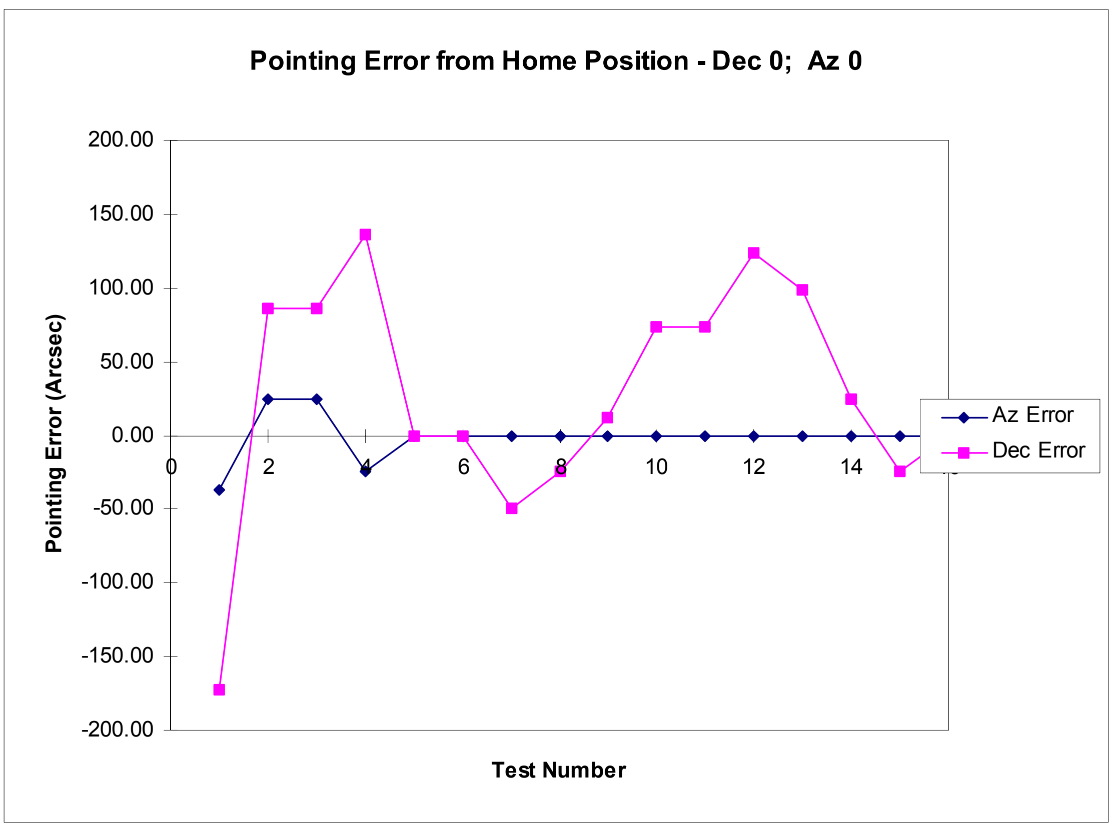

Figure 7. Azimuth and Declination Pointing Errors for the Omni-Wrist Sensor Mount

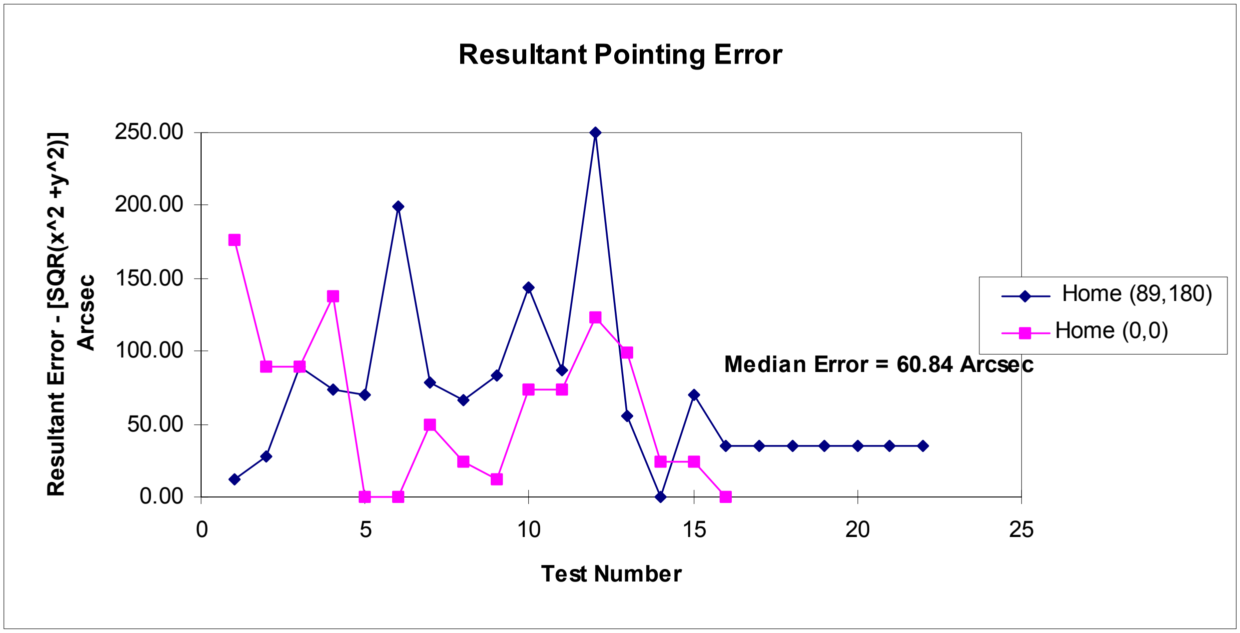

Figure 8. Resultant Pointing Error for Omni-Wrist Sensor Mount

Conclusions

A background on the pointer problem was presented with a discussion of desired capabilities. These capabilities include (1) full hemispherical range that is singularity free, (2) ease of control through single computation, (3) high slew rate, and (4) low cost. Historical sensor mount designs that persist to this day were related. The Omni-Wrist III Sensor Mount was presented as a candidate with advanced horizon-to-horizon tracking capability. The value of singularity-free motion was presented with test results.

References

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