A Low Cost and High Accuracy Optical Boresighting and Alignment System Using Video Cameras

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ABSTRACT

This paper describes a novel optical boresighting and alignment system used to mechanically align antennas on a compact antenna range at the North Island Naval Air Depot in San Diego, CA. The antenna range has a 5-axis (roll/upper slide/azimuth/elevation/lower slide) positioner used to measure various airborne antennas for production testing. The video alignment system implemented on this range uses two video cameras outfitted with telephoto lenses, one on the roll stage and the other on an antenna-mounting fixture. The system has been demonstrated to yield an accuracy of ±0.005 degrees. Prior to the start of testing the positioner is commanded to a "0" position and the cameras focus on a fixed optical target to provide the operator with a quick visual confirmation that the positioner is accurately aligned prior to testing. The video alignment system described has numerous advantages over other mechanical alignment techniques, is low cost, easy to use, and can be adapted to a variety of testing configurations.

Keywords: Alignment, Antenna Measurements, Boresight. Video

1.0 Background

The US Navy contracted with Nearfield Systems, Inc. (NSI) to provide a system upgrade to the Compact Automatic Test System (CAATS) test range located at the North Island Air Depot in San Diego, CA. The range is a combination compact and tapered range that was relocated from Alameda, CA approximately 4 years prior. The system upgrade consisted of a new fully motorized 5-axis positioner (roll/upper slide/azimuth/elevation/lower slide), automated measurement software, and range integration and testing services. The range is used for post-repair verification testing of various airborne antennas.

Currently, about 7 antenna types are tested on the range but 3 are most common. Each antenna type requires a different positioner configuration. Since most of the testing is done on single units or in small batches, range setup and verification of the antenna's mechanical alignment required a high percentage of the overall test cycle time. To improve the range throughput NSI and US Navy personnel established a goal of designing and implementing a general purpose and highly accurate boresight alignment system. This system is used by the range operators to provide an independent (of positioner encoders) means of verifying the positioner alignment for their various test configurations. The design goals of the independent measurement system:

1. Have the ability to accommodate various antenna types without lengthy setup time
2. Require only one operator
3. Verified from the control room without entering the chamber
4. Not interfere with or affect the quality of the measurements
5. Be reliable – not require expensive calibration procedures
6. Have high accuracy – the system was specified to be accurate to ±0.005 degrees
7. Be easy to calibrate
8. Be cost effective

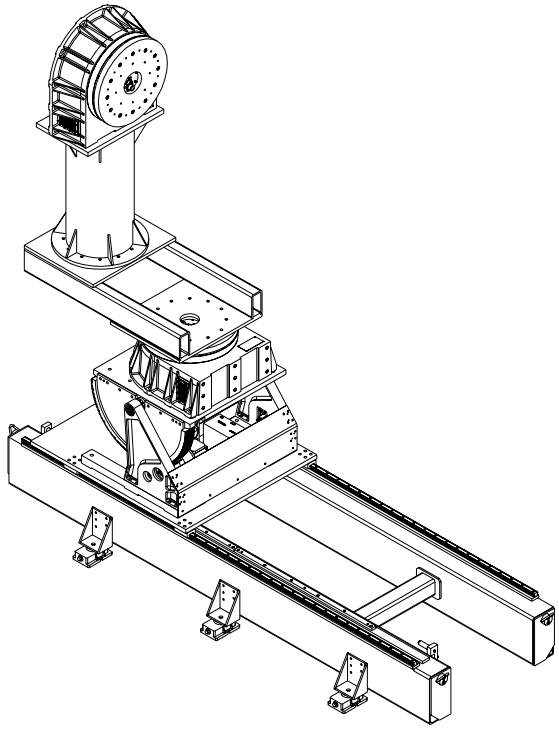

Figure 1- NSI 5 Axis Positioner (Roll/Slide/Az/EL/Lower Slide)

2.0 System Description

To meet these goals, NSI delivered an independent video measurement system that consists of two high-resolution video cameras with 500mm lenses and precision mounts, an illuminated optical target, a video switcher, and monitor with crosshairs. One of the cameras is mounted on an adjustable bracket located on the rear of the roll positioner and points along the roll stage axis. The video and electrical signals are routed through sets of slip rings in the positioner and lead to a video switcher and high resolution rack mounted black and white monitor that is located in the range control room. The monitor has crosshairs on the screen for target centering.

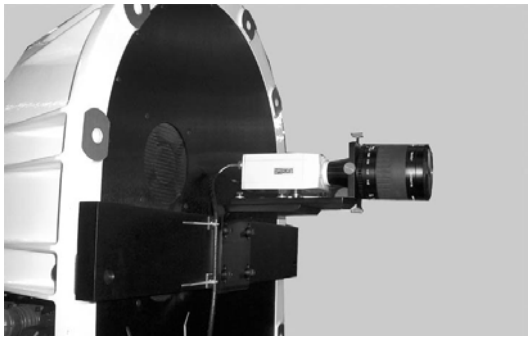

Figure 2- Roll Axis Camera Mounted to the Rear of the Stage

The roll stage camera is attached to rigid anodized aluminum "L" bracket mount. The mount is attached to an aluminum bar that spans the rear of the roll stage and places the center of the imaging sensor of the camera on the stage's rotation axis. Both the stage and the mounting bar have machined surfaces on their respective mating surfaces. Vertical slots on the "L" bracket and horizontal slots on the mounting bar allow for fine-tuning adjustment of the camera to laterally position the imaging sensor on the axis of rotation of the roll axis. Angular adjustment is achieved through 4 setscrew adjustments that permit approximately two degrees of azimuth and elevation adjustment of the camera on the mount.

A second camera, identical to the one on the rear of the roll stage, is mounted perpendicular to the customer's precision antenna test fixture and uses the same optical target to verify the fixture is aligned on the range. Only one camera other will be used depending on which type of antenna is being tested. Booth cameras use the same optical source for targeting.

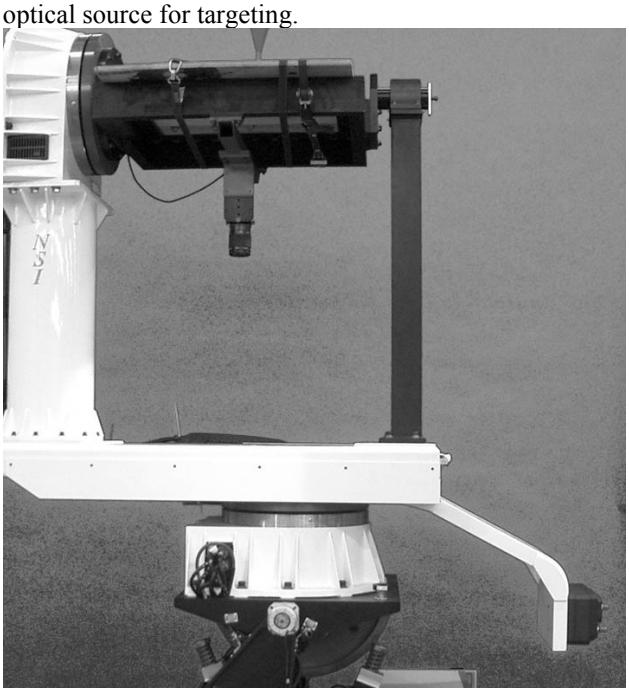

Figure 3- AUT Mounting Fixture Shown With Video Camera (pointed downward)

3. Installation and Alignment

As part of the system installation and alignment the nominal "0.0" position of the positioner was set so that the face of the roll stage was aligned to be perpendicular to the range centerline. To establish the range centerline NSI determined the mechanical center of the Scientific Atlanta Roll/Az/El stage before it was removed from the chamber. The mechanical coordinates of the original

stage were used to define the electrical centerline of the chamber. The installation of the new NSI Roll/Slide/Az/El/Lower Slide positioner was set to match the original range centerline coordinates. All position measurements and alignments were done with a Faro Laser Tracker.

An illuminated optical target was placed on the electrical range centerline and mounted to the chamber wall in the tapered portion of the chamber. It was located approximately 10 meters from the positioner. The target was constructed using a yellow light emitting diode enclosed in a plastic enclosure about 3cm x 4cm x 2cm. A small 0.8mm hole in cover plate provides an optical point source for targeting. The enclosure is mounted on a short tube that has an adjustable mount for affixing to the chamber floor or wall and providing about 2cm of lateral (X&Y) adjustment. Height is also adjustable permitting easy installation. The targeting assembly was nested in the chamber's anechoic material to minimize its reflective cross section. The unit is powered by a wall-mounted transformer and requires low voltage power minimizing fire risk. A photo of the optical target unit is shown in Figure 4.

Figure 4- Optical Target Mounted in Chamber

After the roll stage was aligned to be mechanically perpendicular to the range centerline, NSI used the laser tracker to locate the stage axis of rotation and transfer it to the rear of the stage for precision alignment of the camera. The roll stage camera mount was adjusted to place the optical target, an illuminated dot, at the center of the cross hairs on the video monitor. When the positioner is at "0.0" the dot should be at the intersection point of the crosshairs. Once aligned, the attachment screws were locked down on the mount and the cross bar was match drilled and pinned with bull nosed locating pins with mating steel inserts to enable the camera mount assembly to be removed and reattached without the need for realignment. This was necessary to permit service access to the rear of the roll stage.

Alignment of the camera on the Antenna Under Test (AUT) mounting fixture was less straightforward. The AUT fixture is a square aluminum weldment designed to accommodate mounting various antenna types. The fixture is supported by the face of the roll stage on one end and by a support strut that is attached to the base of the upper slide unit on the other end. All fixture mountings use precision-machined surfaces with steel locating pins and sleeves to enable range operators to remove and reattach the fixture without the need for external alignment tools. The second fixture camera is mounted on the rear of the fixture by means of a removable bracket. The bracket also uses locating pins for easy assembly. The fixture camera is used to verify the alignment of the bracket on the range prior to the start of antenna testing.

Calibration of the optical system is easily verified on a periodic basis by the use of optical instruments, either a laser tracker or traditional optical tools. Permanent tooling ball locations were installed on the range by NSI during the installation provide a quick and reliable reference that can be used to verify system alignment and for system mechanical calibration.

4. Operation

The camera alignment system has become a useful tool in the setup and testing of various antennas on the range. Some of the ways the camera system is used are:

1. Prior to antenna testing - Verification that the multi axis positioner system is at mechanical "0".
2. Prior to testing – Verification that the AUT test fixture and mounts are properly attached and aligned.
3. Diagnostic tool for backlash correction verification – the NSI measurement system uses backlash correction to achieve the ±0.005 deg. pointing accuracy. The camera verifies the backlash correction is properly calibrated and operational.
4. Diagnostic tool to verify encoder operation – a high-resolution incremental optical encoder is incorporated into the azimuth and elevation axes. The optical system is used to cross check the operation of the encoder.

The Navy has been successfully using the optical alignment system as a cross check to verify system performance prior to testing.

5. Summary

The video alignment system as designed by NSI for the US Navy has shown to be a valuable tool in verifying the correct setup and alignment of antenna on the CAATS range. Since the monitor is located in the instrumentation rack in the operator control room it is very easy for the operator to glance at the video monitor to verify alignment before and between tests. Additional uses and benefits of a video optical alignment system are being explored as more complex testing is being done.

6. References

Dan Slater Near-field Antenna Measurements, *Artech House, Norwood, MA*, 1991

7. Acknowledgements

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