Global Positioning System Advanced Targeting System

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BIOGRAPHY

Paul Guggenbuehl received a BS in electrical engineering from California State University, Chico. He joined the Naval Air Warfare Center Weapons Division in 1987. His worked included navigation system integration onboard the AV-8B weapons platform including Miniature Airborne GPS Receiver (MAGR) integration. In 1994 he joined the GPS/INS Branch at the NAWCWD. He continues work on various GPS systems including aircraft and weapon-borne GPS systems.

Matt Boggs received his BS in Electrical Engineering from New Mexico Institute of Mining and Technology. Matt has been a member of the GPS/INS Branch since 1989 and has been involved with design and implementation of missile hardware-in-the-loop simulation, navigation error analysis, antenna measurement techniques and GPS jamming efforts. Matt is currently focused on antenna and electromagnetic measurement techniques.

ABSTRACT

With the advent of GPS guided munitions, the need for more accurate absolute target position information has increased dramatically. A highly accurate target location can reduce the number of weapons required to inflict the appropriate damage, and reduce collateral damage around a target area. Of equal concern, protection of military personnel operating a targeting device requires a large standoff from the target location.

In response to these requirements, NAWCWD's GPS/INS Branch was tasked to develop a prototype targeting device capable of targeting at large standoff range with minimal target location error (TLE). The result of this effort was the GPS Advanced Targeting System (GATS). GATS. is a "man portable targeting system" using commercial off the shelf technology (COTS) that permits targeting with an error in single digits (meters). The system uses Global Positioning System (GPS) to locate the shooter or FAC, an attitude determining system to get angle and azimuth relative to the target, and a laser range finder for range to the target. This system is a developmental prototype that is being used to demonstrate the technology.

DESIGN GOALS

As part of the sponsor's tasking, the following design goals were outlined:

- Minimum standoff range of 10 km
- Near-Precision Guided Munition (PGM) grade TLEs
- Man-portable
- Use of WGS-84 coordinate frame
- Compatibility with existing rangefinding equipment

Accurate determination of target position from a standoff location is dependent on the ability of the system to determine pointing angles relative to its coordinate frame. If pointing angle can be accurately determined, integration of ranging information (from a range finder), pointing angle and sensor position is a relatively straightforward process.

With these basic design goals in hand, a survey of potential sensors for attitude determination was made. Sensors investigated include the following, combined with apparent strengths and weaknesses:

Sensor	Pro	Con
Manual (survey techniques)	Simplistic, inexpensive	Equipment operational limitations, accuracy constraints
Flux-gate Magnetometer	Rapid results, compact, inexpensive	Accuracy degraded due to limited resolution and magnetic field variations
Inertial Multisensor	Very Accurate	Initialization of sensor required, more costly, high power consumption
GPS based interferometer	Good accuracy, rapid results, moderate price	Array size

Table 1. *Potential Attitude Determination Sensors*

In discussion with the sponsor, it was determined that the requirement for the targeting system to have autonomous operation, coupled with operational requirements, eliminates the manual mode.

Use of an inertial multisensor requires a ground-alignment mode lasting several minutes and a velocity initialization input. Upon completion of ground-alignment, the system would be switched to a navigation mode for target location. Inertial units have limitations due to their drift over time; this limitation can be addressed by adequate characterization and application of appropriate gyro bias terms. A final limitation of the inertial multisensor for this application stems from the need to initialize with a velocity input; this input usually requires a velocity beyond the capabilities of a foot-powered operator.

The final sensor, a GPS based interferometer, has many advantages over potentially competing sensors. Highest among these advantages are the lack of requirement for a ground initialization, a long term stability of the system's output.

ERROR ANALYSIS

To identify the most appropriate method for determining pointing angle and the corresponding sensor required, the overall system target location error must be addressed. The target location error will dictate the aiming accuracy required of the target system. For this, we choose the single-sigma target location error:

(1) $$\sigma_{tl} = ((\sigma^2_{t} + \sigma^2_{standoff}\,(\sigma^2_{misalign} + \sigma^2_{az} + \sigma^2_{el}) + \sigma^2_{range})^{1/2}$$

where:

σ_{tl} = Target location error [m]
σ_{t} = Targeteer position error [m]
$\sigma_{standoff}$ = RU standoff range from target [m]
$\sigma_{misalign}$ = Antenna-to-RU misalignment error [mRad]
σ_{az} = Azimuth pointing error [mRad]
σ_{el} = Elevation pointing error [mRad]
σ_{range} = Laser rangefinder range error

In order to determine the required targeting system pointing accuracies, metrics must be assigned to the remaining error terms. All of the the terms shown below in Table 2 are based on "typical" values seen empirically in previous tests carried out by GPS/INS Branch.

Error Term	Typical Value
σ_{RU}	2.0 [m]
$\sigma_{standoff}$	0-10.0 km
$\sigma_{misalign}$	1.0 [mRad]
σ_{range}	5.0 [m]

Table 2. *Error Term Values*

Classes of sensors as seen in Table 1 can be specified to indicate accuracy. For this study, only a high-end flux gate magnetometer was investigated, with a 10.0 mRad pointing accuracy in both azimuth and elevation.

Using the error equation of (1), a MATLAB routine was written to explore the effects of various sensors' impact to TLE vs. standoff range. An example plot of this study is seen below in Figure 1.

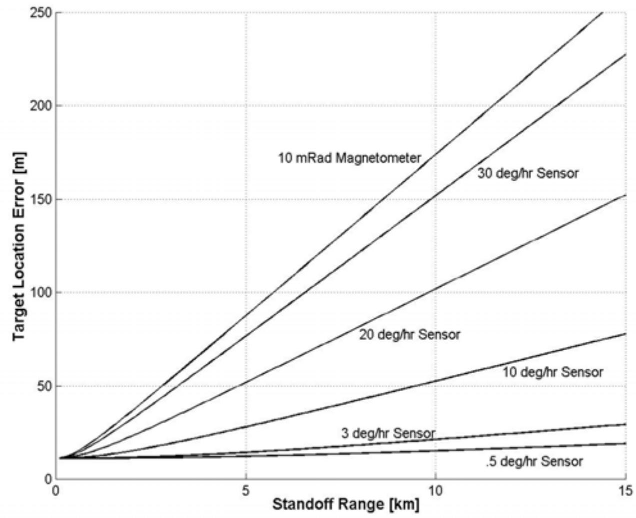

Fig.1 *TLE vs. Standoff Range of Magnetometer and Inertial Multisensors at 60 s of Drift*

Upon further analysis, it was realized that the GPS interferometer's performance could be optimized by using more than a single data point attitude solution. By using data from the interferometer that is of a fairly coarse data spacing, attitude data recorded is poorly correlated between data points. This assumption is additionally made more valid when the sponsor's proposed concept of operation is included to allow multiple measurements over a broad period of time, with potential measurements from varying positions. The net impact of this analysis is that the interferometer's performance may be enhanced through use of averaging techniques to negate error sources over the span of the poorly correlated data. The impact of this may be seen below in Figure 2.

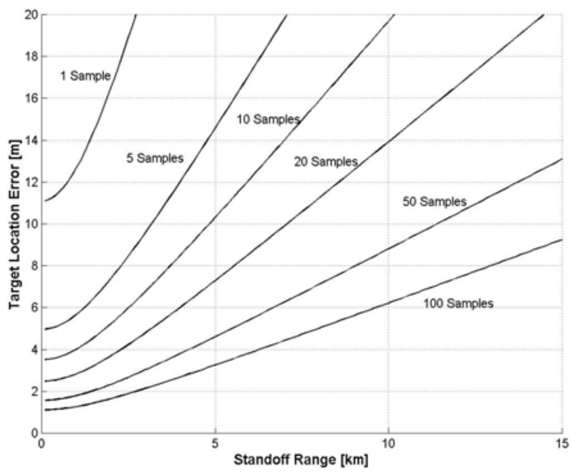

Fig. 2 *Impact of Multiple Datapoints on GPS Interferometer Performance*

With the preceding analysis in hand, the decision was made to determine system pointing through use of a GPS interferometer device utilizing an averaging technique on collected attitude data.

SYSTEM IMPLEMENTATION

Demonstration of the GATS concept was carried out through use of COTS components. Use of COTS and civilian-grade components allowed the rapid prototyping and demonstration of the system.

System Architecture

GATS consists of four basic major components: the GPS interferometer, the laser rangefinder and a controller PC. The system's components are interconnected as seen in the block diagram seen below in Figure 3.

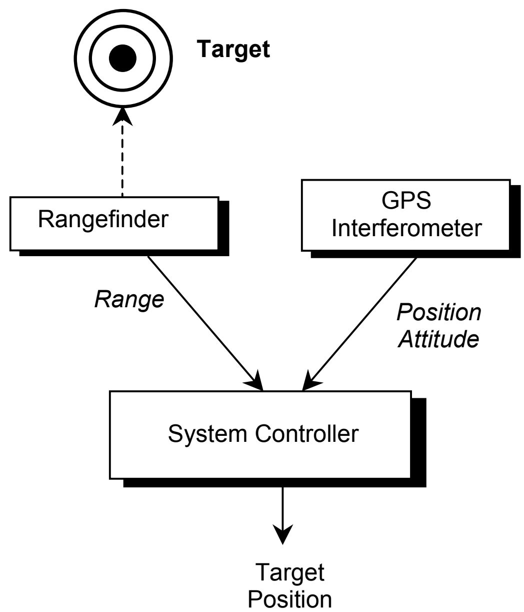

Figure 3. *GATS Architecture Block Diagram*

Components

The GATS system uses a GPS receiver for both attitude determination (azimuth and elevation) and positioning. The receiver used in the engineering prototype is the Trimble Vector, a six-channel C/A code receiver. The receiver's four antenna are arranged on an aluminum structure as an array. The array is constructed so that the distance from the master antenna to the other 3 antennas is accurately known. Each antenna provides a separate input to the receiver. The cable line bias is characterized for each cable from each antenna to the receiver. The receiver uses interferometer measurements to calculate position (standard GPS measurements), pitch, roll, and azimuth. The receiver operates from a 12 VDC power supply.

A Litton MELIOS eye-safe laser range finder is used for ranging. This system was selected due to its similarity and compatibility with rangefinding hardware in current use by the sponsor. The MELIOS used for the GATS program has a 20 kilometer range, with a range resolution of 5 meters. A RS 232 communication link is utilized by the GATS for data communications and operation with a computer. The MELIOS is powered either by a 28V battery and has a 500 cycle laser discharge life.

The Laser Range Finder is located at the center of the antenna matrix. The range finder and antenna array is mounted on a tri-pod and pointed at the target. Continuous attitude, positioning, and ranging data is recorded. Figure 4 illustrates the prototype GATS and its major components.

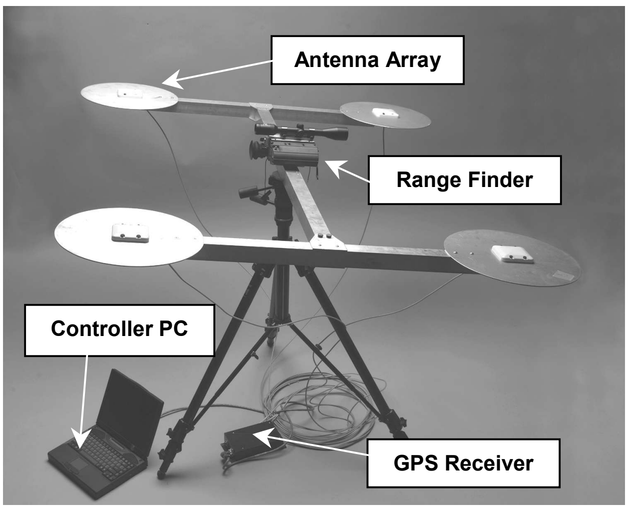

Fig. 4 *Prototype GATS*

Figure 4 illustrates the prototype GATS late in its development; included with the system is a sport-shooting grade spotting scope to counteract the MELIOS viewfinder's minimal optical gain. An additional feature of the prototype system is the large groundplane discs on each antenna element. This features were designed to counteract possible multi-path effects; in testing, this feature was demonstrated to not significantly affect performance and can be minimized in future versions.

TESTING

GATS was extensively tested during its development, both to validate work on the system and also as part of product refinement with the system sponsors. In these tests, GATS was deployed with other targeting systems, and also targeting against known target locations from a known targeting location. Figure 5 shows the GATS system in such a test.

Fig. 5 *Field Test of GATS*

Test Configuration

Late in the development of the GATS system , the system was tested and evaluated as part of a larger sensor evaluation program in conjunction with NAWCWD's Weapons Engagement Office (WEO). In this test series, the GATS would be located in an arbitrary location (based primarily on line-of-sight to available targets). The GATS system would "self-survey" itself to find its position, and then the system operator would be instructed to obtain target positions of various targets. Each of the targets were previously surveyed by NIMA for NAWCWD WEO; the target position was not given to the GATS operator until well after the targeting event had taken place, thus eliminating any possible "coloring" of targeting data due to *a priori* target location knowledge. Targets in one test series were arranged relative to the target location.

In this test series, the GATS was setup on a surveyed position on a hilltop location, with vertical elevation approximately 400 feet above the surrounding valley floor. Approximately 15 targets were located within line of sight of the hilltop, with ranging distance varying from several hundred meters to over 14 km away. In each targeting case, the NAWCWD WEO observer would verbally describe a target and the feature (such as a window or doorway) that the targeteer was to locate. The test took place over 4 different days with two different operators, in varying weather conditions. Wind was of a concern because of the airfoil-like qualities of the antenna ground planes. Because the observation point was elevated it was sensitive to prevailing weather conditions. The gusty winds buffeted the array around on two of the testing days. Examples of targets were towers, buildings, laser tracking stations, and actual simulated targets.

Testing Methodology

The targets used for the GATS assessment were chosen to provide a clean line-of-sight between the hilltop and the target. Many of the targets offered aimpoints on vertical surfaces neat normal to the collection line of sight. However, some of the aimpoints are at the top center or a top edge of cylindrical or dome shaped objects making laser ranging more difficult.

The 15 GATS aimpoints were each surveyed relative to the hilltop benchmark by NIMA surveyors using conventional surveying methods. The aimpoint coordinates were provided in WGS-84 and were reported to have an absolute accuracy better than 1m. The survey data also provided an accurate range, bearing and elevation angle from the benchmark to each aimpoint. (In general, the accuracy of these relative measurements is better than the absolute aimpoint coordinate accuracy.)

There targets were grouped into three general categories based on range from the hilltop benchmark, close (0 to 3 kilometers), medium (4 to 7 km), and far (11 to 14 km).

The prototype GATS configuration was used to collect data and derive the aimpoint coordinates. For each collection, the operator aimed the GATS frame at the target and a member of the assessment team viewed the target to ensure that the aimpoint had been properly selected. Once the GATS frame was properly pointed, the GPS determined target position using its recorded position and attitude data , and processed by the system software.

Component Errors

The primary components in the overall target location error are self survey errors (GATS measurement of its own location), ranging errors and pointing errors.
The current GATS software computes and uses an average self position for each target coordinate computation. For each target, GATS records 1-Hz GPS position data to a file. For each of the 15 targets the self-survey measurements were compared to the hilltop benchmark.

The range measurements were made by taking 5 to 20 laser shots at each target. The averages of these were compared to the true range data. The pointing measurements were made with the GPS unit recording the averages of the pointing angles to the target. These measurements were compared to the truth data in the surveyed location of each target. A geodetic calculator was used to compute the angles to each target with the truth data.

Test Results

Following conduction of the test, targeting information determined by the GATS was given to the NAWCWD WEO for comparison and analysis to the known, surveyed NIMA target locations. The resulting errors are summarized below in Table 3 and Figure 6.

Target	Range Err [m[	Radial Err. [m]
1	0.86	31.5
2	1.66	39.0
3	16.76	36.0
4	0.41	29.0
5	1.50	49.5
6	405.14	18.5
7	0.07	33.3
8	45.06	31.5
9	118.31	30.0
10	3.89	27.0
11	2.17	36.5
12	3.08	23.5
13	4.45	34.0
14	14.52	19.3
15	5.11	27.0

Table 3. *Realized Targeting Errors: Ranging*

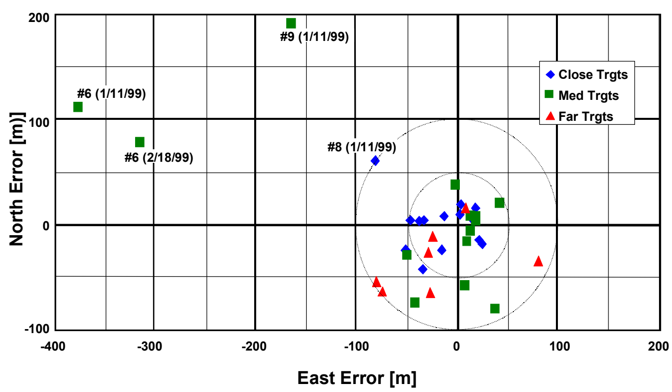

Fig. 6. *Realized Targeting Errors*

The majority of the targets demonstrated average CEP errors as follows:

- Long-range target error: 51.0
- Medium-range target error: 36.0 m
- Short-range target error: 19.9 m

As seen in Figure 6, four targeting runs on two designated targets resulted in gross errors. This is largely due to the targets providing poor laser reflectivity for the range finder: Target 6 was a lattice tower, while Target 6 was the small, hemispherical roof askania dome. The large errors demonstrated in these four cases are primarily the result of poor quality ranging data. Additional error sources are the result of wind buffeting on the antenna array structure. These wind effects were later minimized through the application of a low-pass filter to the attitude data.

Observations

Many considerations for the missionization of a GATS-type of system were seen through the development and testing phases of the GATS demonstrator. Concerns such minimizing visible exposure, portability, and robustness to environmental effects (especially wind) must be addressed in such an effort. Additional attention must be made to providing the operator sufficient optical gain in the system's sighting scope to provide adequate resolution to see long-range targets. Finally, the impact of training of system operators has a big impact on system TLE: operators with background in target shooting used the system, they demonstrated much lower typical TLEs than their counterparts.

CONCLUSION

This paper provides the background and considerations for the design and implementation of GATS, a GPS-interferometer based remote targeting system. Example test data from a series of tests against surveyed targets is provided to illustrate the potential of such a system, even when COTS hardware is utilized. The GATS prototype proved to meet design goals as originally outlined, given its COTS hardware components. Use of current-technology components (such as modern laser rangefinders) will allow a GATS derivative system to provide higher quality targeting (e.g. to precision guided munitions grade) information from a man-portable targeting system.

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