PRECISE POSITION AND ATTITUDE GEOREGISTRATION OF VIDEO IMAGERY FOR TARGET GEOLOCATION

Dr. Alison K. Brown, *NAVSYS Corporation*
14960 Woodcarver Road, Colorado Springs CO 80921

ABSTRACT

In this paper, an autonomous georegistration system, the GI-Eye, is described that provides the precise location and attitude of digital video imagery data. This "smart camera" approach significantly simplifies and streamlines the process required to extract the precise target locations from digital video images, improving the timeliness targeting data in the battlefield. The autonomous georegistration system relies on a differential integrated GPS/inertial solution to provide the precise position and attitude of the camera. Using NAVSYS' proprietary precise calibration and alignment algorithms, the video georegistration system is able to determine the direction of pixel coordinates to an accuracy of 1 milli-radian. This enables target coordinates to be determined to an accuracy of 1 meter at distances of up to 1 km from the camera location. Test data from the system is presented showing the 3-D targeting performance using the GI-View PC-based software analysis tool.

INTRODUCTION

In a dynamic battlefield environment, there is a core need to be able to rapidly process imagery data from airborne surveillance sensors and extract target coordinates in a timely fashion. Previous image-based targeting system implementations have used stereo photogrammetric techniques to determine the 3-D relative position of image features to the camera location. These require intensive data-processing to resolve for position and rotation angle changes between the stereo images and also rely on known reference points from a database to establish the absolute location of target features.

NAVSYS has developed a GPS/inertial video product, the GI-Eye, which provides precise position and attitude data to automatically georegister the video imagery collected. The system is designed for installation in a ground-based or airborne vehicle. The GI-Eye is based on NAVSYS commercial-of-the-shelf (COTS) software package called InterNav[1]. This package allows optimal integration of GPS and inertial instruments with the minimum of non-recurring effort, enabling semi-customized systems to be delivered to provide the most cost effective solutions for a particular application.

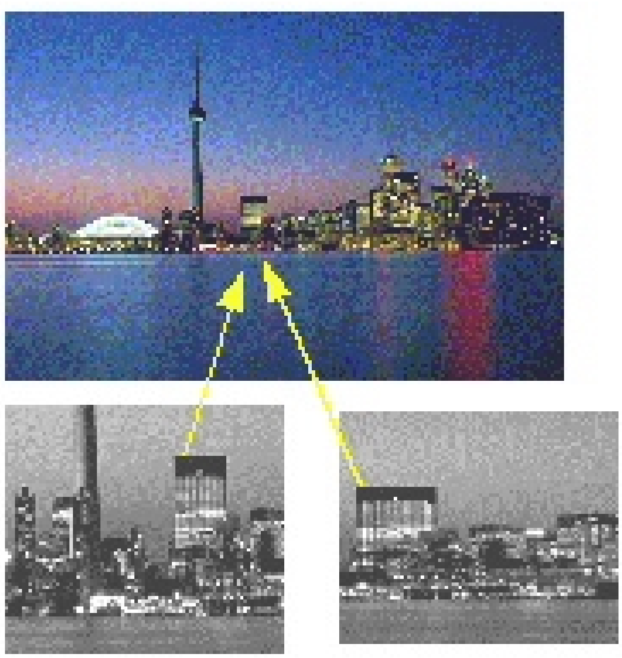


Figure 1 Passive Video Triangulation

The companion GI-View data analysis tool is used to locate target coordinates from the images collected using a passive video triangulation technique, as illustrated in Figure 1. This software runs under Windows 95 of Windows NT in a portable PC or laptop, enabling rapid and accurate location of target coordinates without the need for any known registration points within the image.

The GI-Eye system enables rapid data collection for generating maps, target coordinates, or the location of any features of interest in an area. The GPS and inertial components provide accurate positioning information while the video augmentation provides the capability to create a 3-D precise target position by acquiring successive images from different observation points or by cooperative targeting by separate observers. This allows for rapid and cost-effective geo-registration and target location. The system design and operation are described in the following sections of this paper.

GI-EYE OVERVIEW

Extracting coordinates from video imagery has historically required significant processing to determine the relative position and orientation of stereo image pairs (through photogrammetry) or the use of expensive fixed-base stereo vision systems. The GI-Eye GPS/inertial video camera system enables high accuracy 3-D coordinates to be extracted from the video data without requiring the use of photogrammetric processing or stereo cameras. This is achieved through the use of three proprietary technologies developed by NAVSYS: precise attitude determination using our InterNav GPS/inertial alignment software; precision camera calibration using in-house developed algorithms; and optimal estimation of the feature coordinates using our GI-View software analysis tool.

The precision to which any object can be located from a pixel coordinate is a function of the accuracy to which the camera location and attitude is known. The integrated GPS/inertial system will provide meter level positioning accuracy when operating with differential GPS corrections. To provide high accuracy target locations, the camera attitude must be known precisely. The target location error scales with the attitude error (in milliradians) and the distance to the target (in km). For example a 1 milliradian azimuth error (0.57 degrees) will result in 1 meter of error for targets at a distance of 1 km from the camera. To achieve this level of attitude performance using conventional alignment techniques has previously required the use of expensive, high accuracy inertial navigation systems. NAVSYS' proprietary GPS/inertial alignment algorithm enables inexpensive inertial measurement units (IMUs) to be used to provide this same level of performance at significantly reduced cost[2].

The GI-Eye system is designed to use a commercial digital camera installed on a base-plate with the inertial and GPS sensors (Figure 2). Before the digital images can be used to extract target coordinates the camera must be calibrated for optical misalignments and distortion in the lens. NAVSYS have developed a proprietary calibration technique that enables the camera errors to be calibrated and reduces the residual attitude errors derived from the pixel coordinates to less than 0.3 mradian. Calibration results are shown later in this paper.

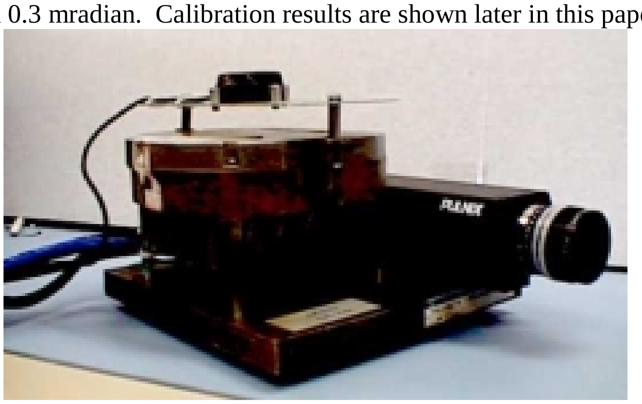


Figure 2 GPS/Inertial/Video Sensor Assembly

The extraction of the feature coordinates from the georegistered imagery is performed using the GI-View software. This operates using NAVSYS' proprietary GI-Locate optimal estimation algorithm. With conventional photogrammetry or stereo imaging systems, an image pair is used to determine the distance to an object. Just as a person uses two eyes to judge distances, every object "seen" in the stereo image pair can be triangulated to a three dimensional coordinate and then transferred to a point coordinate (latitude, longitude and altitude). When collecting a continuous video data stream, features are generally visible in many more than two images from the GI-Eye system. The GI-Locate algorithm is designed to select images where any feature is in view and automatically cue the operator to pick the pixel locations from the common images. The use of multiple video images enables the GI-Locate algorithm to optimally estimate the feature 3-D location, providing much higher performance than conventional stereo imaging.

The GI-View software uses the Microsoft Access data-base software for data management to facilitate data archival and interfacing with other software utilities, such as GIS data management programs. The relational database architecture embedded in Access provides a simple and effective interface for recording feature attribute data and customizing data management for a particular application. The standard macro generation, query and report generation features within Access also facilitate customizing the user interface and searching and exporting of key data.

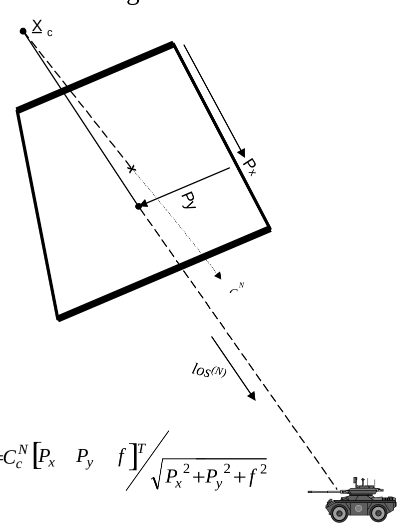
GI-EYE SYSTEM CONFIGURATION

The GI-Eye sensor assembly includes the GPS antenna, inertial measurement unit (IMU) and camera mounted on a precision base-plate to maintain high accuracy alignment between the sensor components (Figure 2). The sensor assembly is designed to facilitate installation on any vehicle and does not require any field calibration or set-up procedures. Customized packaging is also available for specific vehicle or aircraft installations.

A Pentium computer is used to provide the GI-Eye operator interface and perform the real-time data processing and data archiving for the GI-Eye system The GI-Eye sensor data can either be recorded for post-test analysis, or relayed in real-time to a remote site for data analysis. DGPS corrections can either be applied in real-time to correct for GPS errors, or can be applied post-test when analyzing the video data. The GI-Eye performance specification and physical characteristics are listed in Table 2 at the end of this paper.

GI-VIEW TARGETING ALGORITHM

NAVSYS have developed an optimal estimation technique to estimate the target location from the GI-Eye sensor data and automatically calibrate for GI-Eye sensor errors, such as inertial alignment or calibration errots. The principle of operation of the GI-View target location algorithm is illustrated in Figure 3.



$$los^{(N)} = C_c^N \begin{bmatrix} P_x & P_y & f \end{bmatrix}^T \Big/ \sqrt{P_x^2 + P_y^2 + f^2}$$

Figure 3 GI-View Target Location

The estimated line-of-sight to the target in the navigation (North, East, Down) frame can be computed by transforming the pixel derived line-of-sight vector in camera axes to the navigation frame using the inertial attitude data.

Equation 1 $$l^{(C)} = [p_x \quad p_y \quad f] / \sqrt{p_x^2 + p_y^2 + f^2}$$

where p_x and p_y are the target pixel coordinates derived from the image data, and f is the focal length of the camera (in pixel units). The alignment between the camera frame and the inertial body frame is fixed and is defined by the matrix C_C^B. The direction cosine matrix derived from the inertial data to transform from body to nav frame coordinates can be used to compute the line-of-sight from the camera location to the target location in navigation frame coordinates.

Equation 2 $$l^{(N)} = C_B^N C_C^B l^{(C)}$$

Since the camera location is known (x_C), the target coordinates can be calculated through a least squares solution from multiple image data. The target location error is observed through the following equation for each camera image.

Equation 3 $$x_T{}^{(N)} = x_C{}^{(N)} + R\ l^{(N)} \qquad R = |x_T - x_C|$$

GI-VIEW CAMERA CALIBRATION

To reduce costs, the GI-Eye uses an off-the-shelf commercial digital camera to collect the target imagery. However, any errors in the camera alignment to the inertial (C_C^B) or in the camera optical parameters, such as the focal length or lens radial distortion, will introduce errors in the computed line-of-sight to a target from the pixel coordinate data (see Equation 1 and Equation 2).

These errors are illustrated in Figure 4. To observe the errors caused by camera (pre-calibration) images were collected for a target at a known location. Using Equation 3, the predicted pixel coordinates in the image were calculated using the inertial position and attitude data and the published camera data. These are shown compared with the actual location of the target as observed from the digital image data. The difference between the actual and predicted pixel locations results in a error of around 5 mrad RMS – which would result in very inaccurate target coordinates if not corrected.

NAVSYS has developed a calibration procedure to estimate and correct for the camera misalignment and optical errors. This procedure is built into our GI-View software and does not require any special test equipment or training, to enable rapid calibration of the system in the field and installed in different configurations. In Figure 4, the results of the same test data shown in Figure 5 is plotted, but with the camera calibration parameters applied. Post-calibration, the residual errors from the digital video pixel data reduces to within 0.3 mrad.

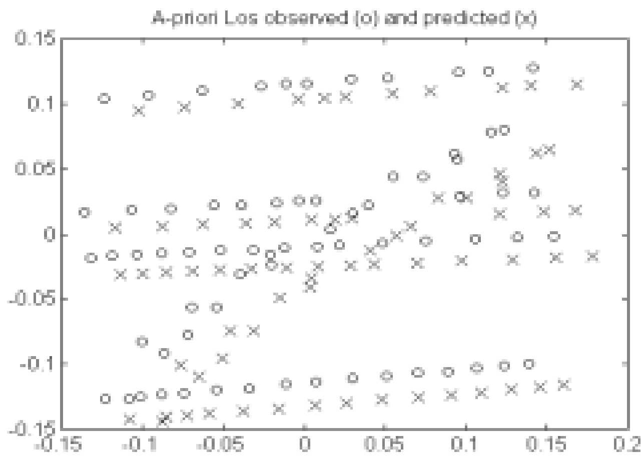


Figure 4 Pre-Calibration Pixel Coordinate Errors (~5 mrad RMS)

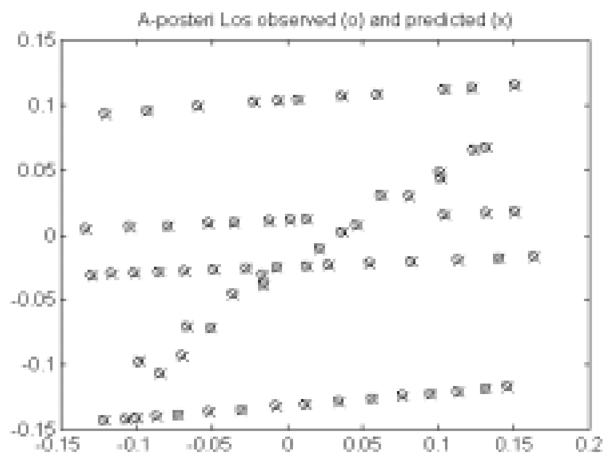


Figure 5 Post Calibration Pixel Coordinate Errors (~0.3 mrad RMS)

GI- VIEW USER INTERFACE

The GI-View software runs on conventional PC workstations or laptop computers and provides a simple "point-and-click" user interface to minimize operator training time.

Image processing and enhancement tools are included in the GI-View software to facilitate location of corresponding target locations in different images. A target (or "Object") can be entered into the Objects database by selecting **New Object** from the menu (Figure 6) and selecting the target of interest from any image through a simple point-and-click interface.

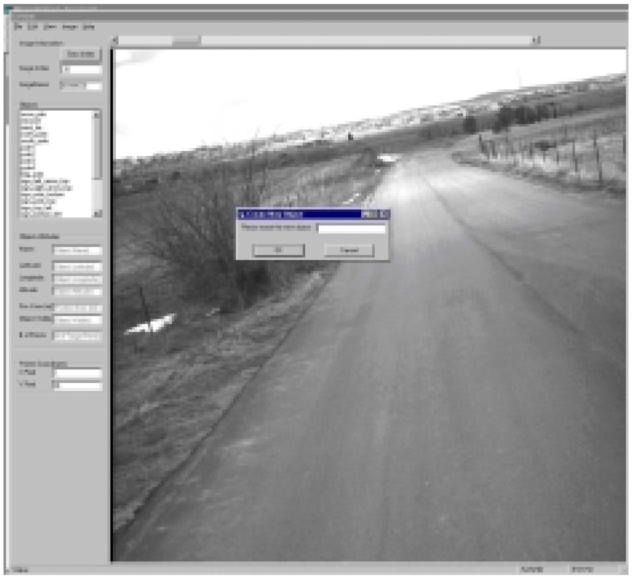


Figure 6 Adding target using "New Object"

Once a target has been selected, the user is cued as to the probable locations of this target in any other images by plotting a line across the images where the target may be in view (Figure 7).

Figure 7 Epipolar Line to Target Area

Once the target location in a second image has been entered (point-and-click), the GI-View software automatically calculated the target 3-D coordinates (latitude, longitude and altitude) and enters these into the Objects database. The target coordinate accuracy can be further improved by selecting more target locations in other images (point-and-click). The likely location of the target is indicated in each image by a circle (Figure 8). As more information is added to compute the target location, an estimate of the final solution accuracy is calculated and loaded into the Objects database with the updated coordinates.

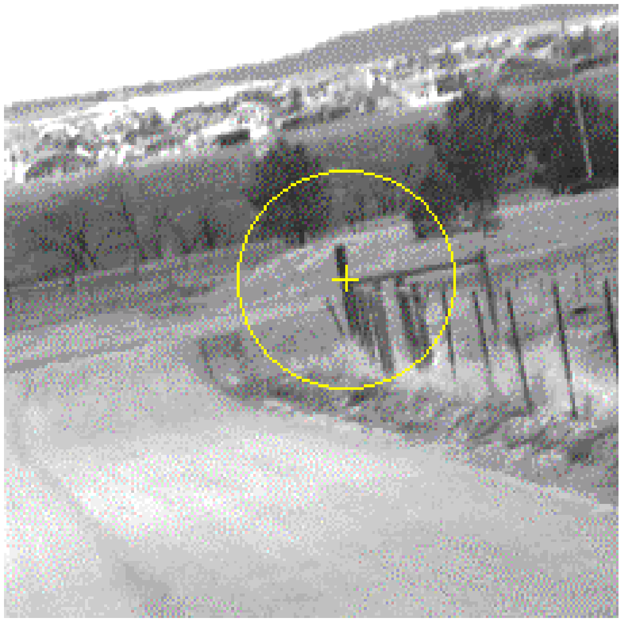


Figure 8 Target circled

The GI-View software uses Microsoft Access for data management to facilitate data archival and interfacing with other software utilities, such as GIS data management programs. The relational database architecture embedded in Access provides a simple and effective interface for recording feature attribute data and customizing data management for a particular application. The standard macro generation, query and report generation features within Access also facilitate customizing the user interface and searching and exporting of key data.

GI-EYE TARGETING TEST DATA

The accuracy of the GI-Eye system has been tested by “targeting” markers placed at surveyed locations. The GI-Eye system was mounted in a test vehicle and driven around the targets to collect image data. The target coordinates computed from the GI-View software was compared with the surveyed target location based on kinematic GPS solutions. The results of this testing is shown in Table 1.

Table 1 Test Data

OBJECT NAME	North error (m)	East error (m)	Down error (m)	Range from camera (m)
obj0410_4	-0.5315	0.9831	-0.7672	409
obj0410_5	-0.0558	-0.7364	-0.4439	412
obj0410_6	-1.2798	1.3979	-0.5007	562

CONCLUSION

Automatic construction of three-dimensional (3-D) target coordinates supports many commercial and military applications. Military users can use this data for real-time targeting by reconnaissance and Special Forces Units, or for mission visualization and rehearsal activities. For example, in planning hostage rescue missions or tactical operations.

Data has been presented in this paper with the GPS/inertial sensors providing georegistration data for a high resolution video camera. The precise positioning and attitude determination, which makes autonomous georegistration possible, is also applicable to simplifying data analysis and multi-sensor data fusion from a variety of other sensors such as imaging, electro-optic or synthetic aperture radar. NAVSYS is currently working with NSWC

Dahlgren under a Cooperative Research and Development Agreement (CRADA) to transition this technology for use in other remote sensing applications. NAVSYS is also under contract to ONR to develop a man-portable version of the GI-Eye for use as a targeting device for Forward Observers.

Commercial applications for the GI-Eye system also exist for Geographic Information System (GIS) applications where the rapid data collection and precise location capabilities facilitate populating feature attribute databases. Examples include, locating roadway signage, utility resources or mapping rights of way. Recently, NAVSYS provided a system to a mining company for use in generating a 3-D model of the mining construction area from the video data.

The ease of operation of the GI-Eye targeting system and the high accuracy targeting data provided make this system an excellent solution for both military and commercial geographic data collection operations. The GI-Eye sensor assembly is designed to facilitate integration into a wide variety of different platforms (ground based, airborne) and a man-portable configuration will shortly be available. The GI-View software has been developed using COTS tools and is based on the Windows operating system to facilitate integration with other data analysis and visualization tools. NAVSYS offers the GI-Eye system as an off-the-shelf product and also provides packaging and integration services for specialized applications.

REFERENCES

[1] "Multi-Application GPS/Inertial Navigation Software," I. Longstaff, L. Burton, D. Tieben, C. Koop, ION GPS '96, Kansas City, MO, September 1996

Table 2 GI-Eye Performance and Component Specifications

GI-Eye System Characteristics	
Time Accuracy	250 nanoseconds (1-PPS output)
Position Accuracy:	
DGPS (post-test):	1 meters CEP
DGPS (real-time):	< 3 meters CEP
SPS (no DGPS)	100 meters SEP
Azimuth Accuracy:	1-3 mrad (1-sigma)*
Dynamics:	
Velocity:	1000 m per second
Acceleration:	4g (sustained trackng)
Host Computer:	Rack mounted, Pentium computer
Internal Interface Cards:	GPS, DGPS, IMU, frame grabber
Storage Capacity:	>6 Gbyte Hard Drive (3 1-hour data sets at the peak data rate)
GI-Eye Interfaces	
Operator console:	RS-232 interface to optional remote terminal
1-pps:	Precise time sync output
Analog video:	30 frame/sec RS-170 analog output
Digital image data files	
Peak data rate:	1 frame/2 secs (programmable log rate)
Data format:	Bitmap file format (1024x1024 pixels)
Georeference data files	Time, position & attitude data for each image (ASCII format)
Post-Test analysis data files	GPS & IMU raw data for post-processing with DGPS corrections
GI-View Software • Viewer for GI-Eye image data with built-in image enhancement • Displays GI-Eye location in map format with image view overlaid on the projection • GI-Locate algorithm computation of image locations from selected pixel coordinates	
GI-Locate Performance^{+}:	
Relative Location Accuracy:	0.1-0.3 m (range to target<100 m)*
Absolute Location Accuracy:	1-3 m (range to target <1000 m)* <3 m (range to target <1000 m with high accuracy DGPS option)*
Data export:	Access Database File format Access report generation for GIS data interfaces
Requires:	Pentium PC with Windows NT 4.0
Inertial Measurement Unit	
Fiber-optic Gyros:	1-10 deg/hr
Accelerometer:	200 μg to 1 mg
Data interface:	Serial Data Bus
Data output rate:	100 Hz fixed
Weight:	1.54 lbs
Size:	3.5 inches D x 3.35 inches

Video Camera	
Camera:	High resolution mono-chrome (CCD)
Imager:	1”(9.1mmx9.2mm) progressive scanning)
Pixel:	1024(H) x 1024(V)
Digital data Interface:	10-bit, RS-422 digital signal output
Analog data Output:	RS-170 for monitoring
Lens:	Specify desired field-of-view when ordering system
Precision mounting base-plate:	
Camera/IMU alignment	< 1 mrad (w/calibration)
Compact Geared Tripod Head	Pan 360°, Tilt ± 30° to -90° and side-to-side ± 30° to -90°
GPS Receiver Characteristics	
Acquisition time:	
Time to First Fix:	2 min (cold start)
Re-Acquisition:	5 secs to valid position (warm)
Position Update Rate:	5 Solutions per second
Differential GPS Real-time DGPS receiver (Standard) Direct broadcast from geostationary satellite transponder Wide area differential GPS service precise positioning throughout the continental U.S. and much of Canada and Mexico Nominal accuracy is 1 to 3 meters (1 sigma horizontal) Post-test DGPS Reference Station (option) GPSCard Performance Series Receiver RTCM 104 Rel. 2.0 differential GPS output Correction accuracy: 0.1 meter Requires PC compatible laptop or desktop computer	
GI-EYE Miscellaneous	
Power:	12 VDC or 28 VDC 1200 watts max
Operational temperature:	+10°C to +45°C
Storage temperature:	-25°C to +60°C
Shock:	4.2 G
Vibration:	1.5 G
Approx. dimensions:	29”Hx30”Dx19”W
Weight:	106 lbs.
System customization: Call for details on our customization services to facilitate GI-Eye integration and operation	
Calibration services: Available for custom camera installation and alignment	

* Dependent on camera motion when data is taken
+ Object of interest must be large enough to be distinguished to one-pixel from image data.