Mobile Digital Imagery Mapping
2500kms Roadway Asset Inventory
Snohomish County, Washington, U.S.

Jon WARREN, U.S.A

Key Words: Mobile Digital Imagery Mapping, Roadway Asset Mapping

Snohomish County Mobile Mapping Project, Snohomish County, Washington

The Asset Maintenance Management System (AMMS) committee, of Snohomish County Public Works, was looking to develop a roadway asset collection and management system to provide geographic based location and attribute data for the county's roadway facilities. The goal was to collect, identify and inventory the assets within the County's right of way and those under their current maintenance program.

David Evans and Associates (DEA), of Bellevue, WA., USA was the prime consultant, with **GeoAutomation, Geocopia**, and **Transcad,** as team members for the project. **DEA** provided the project and contract management, data research, survey control, mission planning, field data collection, and QA/QC. **GeoAutomation**, of Belgium, provided the computations and processing of the tracks and poses for the imagery geographic positions, and data extraction and mapping support. **Transcad, Ltd of Cairo, Egypt,** provided the data extraction of the mapping features. **Geocopia**, of Montreal, Quebec, provided the training, instructional personnel, and vehicle, with the 14 cameras and 17 computers, for recording and processing 37 terabytes of imagery.

DEA was responsible for mapping and collection of roadway attributes for: pavement markings (lane stripping, crosswalks, turn arrows, etc...), above ground utility facilities, signs, guardrails, barriers, planter strips, retaining walls, curb, gutter, sidewalk, ADA ramps, traffic signals, and luminaires. Deliverables included: ESRI based GIS feature data sets, post-processed data, detailed images, and software to view and extract data (x, y, and z values of each unique pixel), and a positional control and accuracy statement of within 0.3m. The average accuracy was within 0.2' in x, 0.2' in y, and 0.2' in z values.

The **GeoAutomation**® system is very unique technology that utilizes digital imagery and pixel matching of 14 cameras, recording images at a rate of 22 images per second per camera, providing a constant 360 degree view, on a mobile vehicle platform at traffic speeds. This provides the ability to perform roadway asset inventory mapping (sub 30cm) or Design Grade (sub 2cm) accuracy mapping, from your desktop computer, without endangering personnel in traffic. The mapping from your desktop computer can be accomplished by the DEA Team, and/or by the client's staff, because it does not require any significant training or interpretation of millions of points of lidar data. They also provide the software to view, extract, and populate into other CAD based software programs (ESRI, AutoCad, and Microstation). The system is simple to use and the images are only 250KB of data.

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I would like to begin with an outline to provide you with the flow and direction of this paper.

1. INTRODUCTION

Jon Warren, P.L.S., WA., U.S.A.

- Senior Associate/WA. Region Survey Manager, David Evans and Associates, Inc.
- Licensed Professional Land Surveyor, WA.
- 40 years of Experience in Surveying
- 30 years as P.L.S. in Washington state, 18 years in private sector and 12 years as the Snohomish County Surveyor
- Currently the President-Elect of NSPS, formerly of ACSM
- Member of the National Society of Professional Surveyors (NSPS) and the Land Surveyors Association of Washington (LSAW)

2. CREATION OF GEOAUTOMATION

Studiebureau Patrick Casier, here further named SPC, is an engineering company specialized in topography, cartography and water management. Since 2003 the government of the Flemish part of Belgium asked to create a large scale map of all cities and villages in the Flanders. AGIV (Agency for Geographical Information in the Flanders) wanted to realize this in less than 10 years. The job concerned aerial photography/photogrammetry for the inner areas and topography for the public domain. To realize this, many surveyors and apparatus were needed (GPS and tachymeters) and a lot of manpower.

SPC worked also some weeks a year in an archeological site in Turkey, named Sagalassos; they created there the digital map of the site as well the grids where the archeologist operated. This site was managed by the archeology division of the University of Leuven. On this site operated as well the department of electrical engineering (ESAT). They created 3D views of all monuments on this site based on technology developed by the Vision department at the same university applied till then for the medical field. SPC and the University started discussing if their technology could also be implemented for mobile mapping.

End 2006 SPC and ESAT started some tests and the results were so good. GeoAutomation was born as a spin-off from the university, Patrick Casier and some people PhD's who were involved in the development of the technology. In February 2007 the company started and the first tests with a mobile van were executed in July of that year. 2 months later the production for AGIV started and were directly successful.

With this technology the SPC capacity of workload raised tremendously; without buying more GPS and tachymeters nor more employees we were able to more than triple our production and turn over.

The **GeoAutomation**® system is very unique technology that utilizes digital imagery and pixel matching of 14 cameras, recording images at a rate of 22 images per second per camera, providing a constant 360 degree view, on a mobile vehicle platform at traffic speeds. This provides the ability to perform roadway asset inventory mapping (sub 30cm) or Design Grade (sub 2cm) accuracy mapping, from your desktop computer, without endangering personnel in traffic. The mapping from your desktop computer can be accomplished by the DEA Team, and/or by the client's staff, because it does not require any significant training or interpretation of millions of points of lidar data. They also provide the software to view, extract, and populate into other CAD based software programs (ESRI, AutoCad, and Microstation). The system is simple to use and the images are only 250KB of data.

3. ASSET MANAGEMENT

Cities, Counties, States, and many agencies own and maintain several forms of infrastructure. This can be several hundres miles of roadway network and all the accompanying accoutrements like pavement markings (lane stripping, crosswalks, turn arrows, etc...), above ground utility facilities, signs, guardrails, barriers, planter strips, retaining walls, curb, gutter, sidewalk, ADA ramps, traffic signals, luminaires, and all above and below ground utilities (water, sewer, storm, energy, and communication). It can be their water system, with manholes, catch basins, valves, hydrants. It can be power, with poles, transformers, and the like. All of these items, including pavement, are physical assets that have some value. They cost something to purchase, to maintain, and to replace.

3.1 Why?

3.1.1. Citizen Response / Customer Service
In order to help you understand and accurately respond to citizen questions and concerns.

3.1.2. Public Welfare (FEMA)

To assist in the rapid response to public safety concerns and in the event of a disaster, municipalities with an accurate inventory of their assets, will receive funds for replacement much faster than the town that is trying to remember where they all were.

3.1.3. Fiscal Responsibility

There is a responsibility to maintain assets purchased with public funds that the public relies on for every day activity, safety and service.

3.1.4. Infrastructure Sustainability

Just to know the condition of the infrastructure and know that it is safe and serviceable.

3.1.5. Federal Audit Requirements(GASB34)

There is an annual valuation of the assets required by the Federal government, these items do depreciate.

3.1.6 Institutional knowledge / Succession Planning

Being able to pass the information on: There was a city that had a car run into a fire hydrant with the anticipated result. The city as builts indicated the shut off valve was about three feet from the hydrant and the responding crew started digging. The valve was actually 30m away. It took them nearly eight hours to find the guy, not the drawing, document, or file, but the guy who remembered where that valve had been installed. They made the front page of the paper, complete with a picture of old faithful blowing a geyser of water 10m into the air for eight hours.

3.2 Strategic Management of Physical Assets

3.2.1 Physical assets have a life-cycle

You have a $20 valve. After fifteen years, it’s starting to get old and failing. After the cost of the flood it is $50,000. An asset inventory and management program could have helped prevent the failure. They are installed, used, maintained, and eventually disposed of and/or replaced, and all of these stages costs money. Strategic management of the asset allows for planning, budgeting, extending the life (maintenance), and an orderly removal or replacement of the asset, before the critical failure occurs. Most things have a life expectancy and being able to keep track of when you are nearing the end of that life expectancy allows you to plan for the orderly inspection, repair, and replacement of that particular piece of infrastructure, in turn minimizing your cost and preventing the catastrophic failure.

3.3 What do you want to do and know?

3.3.1 What is it?

- Asset identification, history, construction, inspection, maintenance, and repair costs

3.3.2 Work Management

- Work orders, maintenance schedules, labor, materials and equipment costs.

3.3.3 Monitor Performance

* Utilize the information when work orders are created and to post information to field crews via a tablet, and to keep track of how it's doing.

3.3.4 Share the information across your enterprise system

- One important function is to share this information with Legal, Public Works, GIS, Law Enforcement, Assessors office, and accounting, anyone in your organization who will at some time need information about an asset.

3.4 GIS as the catalyst

- Asset Maintenance Management System (AMMS)

  The vast majority of AMMS share a commonality of Geographic Information System integration, providing a graphic map interface with location and information about the asset. This overarching system is an Asset Management and Maintenance Software or AMMS. Having the geo-location and other attribute information for your assets is the best first step or update to your process. Remember the fire hydrant story… a guy in the field with a tablet and access to current, accurate information about the valve would have really helped out. You can start with your critical infrastructure and add on as you have the time and budget.

4. GEOAUTOMATION – AUTOMATED INFRASTRUCTURE MOBILE MAPPING SYSTEM (AIMMS)

GEOAUTOMATION VEHICLE (4.1)

There are a number of ways to approach to collect the asset information:

- Field survey and inspection. If done properly, it is very precise, but most costly and time consuming.
- Aerial mapping is great for large areas, building footprints, basic location of objects, but unless you spend a great deal of money, you aren't going to get small features like valves, Fire Hydrants, ADA facilities, monuments, and the like.
- LiDAR: static and mobile mapping creates a very rich data set and detail, but it is very large data and needs special skill sets and tools to derive the benefit from that data.
- Video van recording- aka Google Street View- typically gives you a coming and going view of what is in the right of way, but positional accuracy is not sufficient for recovery.
- GeoAutomation: This technology is based on photogrammetry, a proven science that has been enhanced by the advancements in computer and digital camera technology.

  There are advantages and disadvantages to each method, DEA can directly perform three of these: field survey collection, static and mobile LiDAR, and GeoAutomation, and we have strong relationships to provide aerial. Because this is based on photogrammetry, the mapping accuracy of the data we collect is better and more reliable than video, and likely more cost effective than aerial and field survey.

- **Overview of the system**

The process behind this is acquiring imagery, controlling it, georeferencing it, collecting map data and providing it to the user. Sounds a lot like photogrammetry… because it is. This is essentially automated terrestrial photogrammetry, so we know that the science behind it is solid.

Overlapping imagery is acquired by the vehicle, typically along with GPS. The imagery is Georeferenced using the GPS, ground control, or both, to create a 3D geospatial construct from which map data is collected as point features, line features, shapes, or polygons, even full point clouds if that is what you want.

4.1 Hardware

4.1.A

4.1.B

4.1.C 4.1.D

4.1.A Open passenger side camera door displaying the three camera for the up, direct, and down views.

4.1.B Multiple cameras are mounted in rigid frame superstructure within the protection of the cabin. The cameras are small, but very powerful and high-definition.

4.1.C The crew compartment is comfortable and allows the two man crew to navigate the route, monitor all 14 camera images, and the GPS solution during the driving collection process.

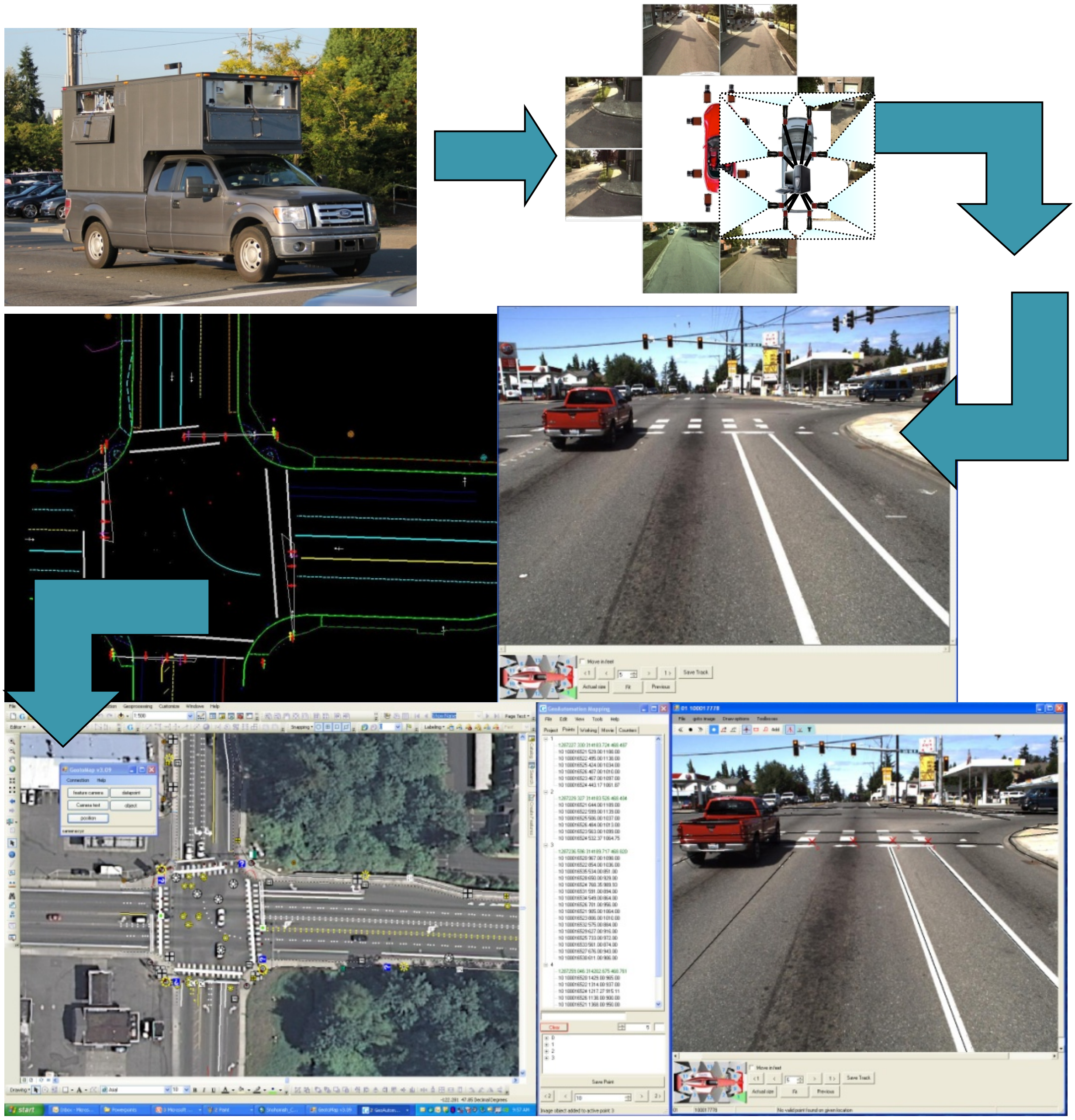
4.1.D The imaging system runs off of substantial on-board power, enough for a day's operation, which is necessary to operate the cameras and the rather substantial server with removable SSD drives used to store and collect the imagery.

4.2 14 Cameras | 22 Frames p/s | 360° View

The truck is equipped with 14 high-definition cameras: two each fore and aft looking straight, two fore and aft looking obliquely CROSS mounted, two on each side looking 90 degrees, and one on each side looking 90 but angled upward to catch tops of poles, second stories, etc…

Combined these simultaneously firing cameras capture a 360 degree view at every exposure station as the vehicle is moving at normal speed. Normal speed is dictated by speed limits in the areas of most of the assets is going to be between 40 and 65 kilometers (kph) per hour. We can go at 95 kph on a highway, because the cameras can fire at 22 frames per second and are adequate for that kind of data capture. The system collects a great deal of imagery, giving YOU multiple views of any given object. 22 Frames per second gets a picture, 14 simultaneous pictures, about every 70cm at 40 kph. Assuming an overlap of more than 90%, you aren't going to miss anything.

4.2 WORKFLOW



The mission is planned and the vehicle collects the imagery, which is then processed and bundled with the control to create a 3 dimensional image construct from which CAD features can be extracted and recorded into a familiar environment. The imagery and mapping end up on the desktop of the user, where additional features, attributes, and information can be added to the mapping. The user can utilize the interface to view the collected imagery to see the asset and its surrounding environment.

4.3 High Resolution Cameras

These high resolution 2 megapixel cameras produce very high resolution images. The imagery on the left is the capture from the collection system, on a low light and overcast day. The image on the right is a screen capture is an example of the high-resolution cameras providing the detail and light enhancement to view in detail from far away. You can still clearly see detail in the sign, the bolt heads on the signal pole base, the pedestrian signal actuator, all from about 25m across this intersection. The camera does pick up a lot of information and detail, but if you were mapping that pole and actuator, you wouldn't do it from this image, you move up to a much closer view. This is an example of the capabilities of the high-resolution cameras.

4.4 GEO-Referencing

4.4.1 <u>On Board, dual frequency GPS</u>

- Not Required, but typically the first source of control
- Ground control points where necessary, depending on the required accuracy
- GPS or total-station coordinates for high accuracy
- Photogrammatry derived points for lower accuracy
- Post photo ID of control actually preferable

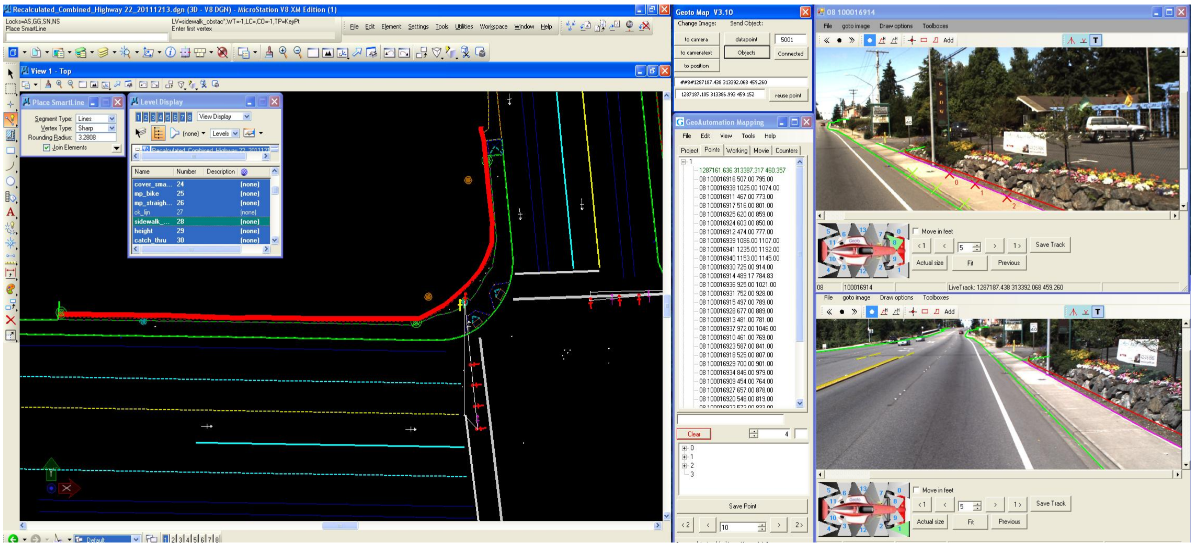
On-board Dual Frequency GPS receiver is collecting during the mobile data collection process. The system uses US GPS and GLONASS, so there are several satellites visible at all times, except when blocked by vegatation, buildings, and/or terrain. A recent collection in the Southwest was tracking 22 satellites. The GPS will be our first line of control, most of the time. The beauty of the system is that it doesn't have to rely on the GPS. The system can function with only ground control points which makes it possible to use in places were a GPS or an IMU can't function…heavy vegetation areas, deep urban canyons, inside tunnels! GPS is our first line of control, and where the GPS is inadequate or fails, we can add post photo identified ground control to support the imagery. Depending on the accuracy needed for your application, ground control can come from field survey, aerial photography, existing mapping, or other sources.

4.5 Accuracy Expectations

Accuracy	Control	Application
Dependent on ortho	Ortho Photo	Video drive through; Online street views; Asset inventory
3cm - 30cm	On Board GPS or 100m spacing	Asset management; Data collection; GIS applications
2cm	30m spacing	Detailed Design Mapping; Public works infrastructure; Curb and gutter
1cm	20m spacing	Pavement overlay design; Volume calcs; Tie–ins

This table represents the kind of control spacing requirements that are necessary to for a specific end product accuracy.

4.6 Desktop Mapping

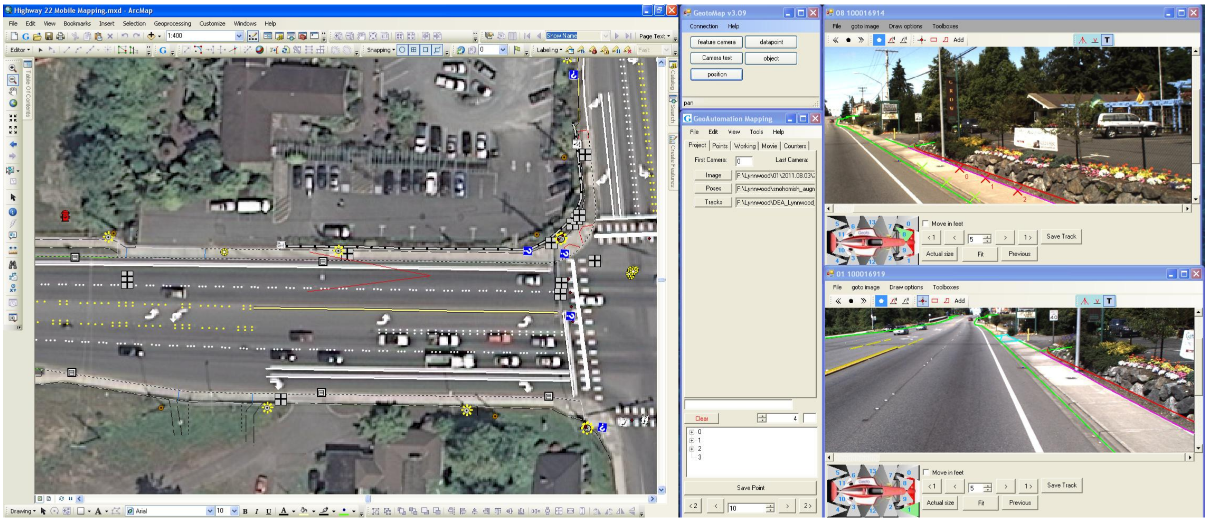


4.6.1

Once you have controlled the imagery, the desktop interface is extraordinarily easy to use. The image viewing software, that is part of the deliverable, becomes a pointing/selection device. It isn't necessary to view it in stereo, eliminating the need for good stereo vision, the system is automatically comparing features in multiple images to collect the point you have identified. The software plugs directly into ESRI Arc products, AutoCAD, Microstation, and a handful of other CAD packages. Collection takes place in the CAD or GIS environment, using the tools that you are already familiar with in that environment. If you are collecting a curb line, then it is using the complex line or line function in Microstaion.

The two panels on the right are the GeoAutomation viewing panes. Features and line work collected there go directly into the CAD drawing, open on the left. Features that have been collected can be superimposed back into the collection side, which you can see represented by the line work there. You can also superimpose your existing line work into the images, assuming the same projection and units, which makes it easy to check your existing data for position, correct feature code, attribute checking, and so forth. The center pane is showing the number of images that the system is using extract the feature.

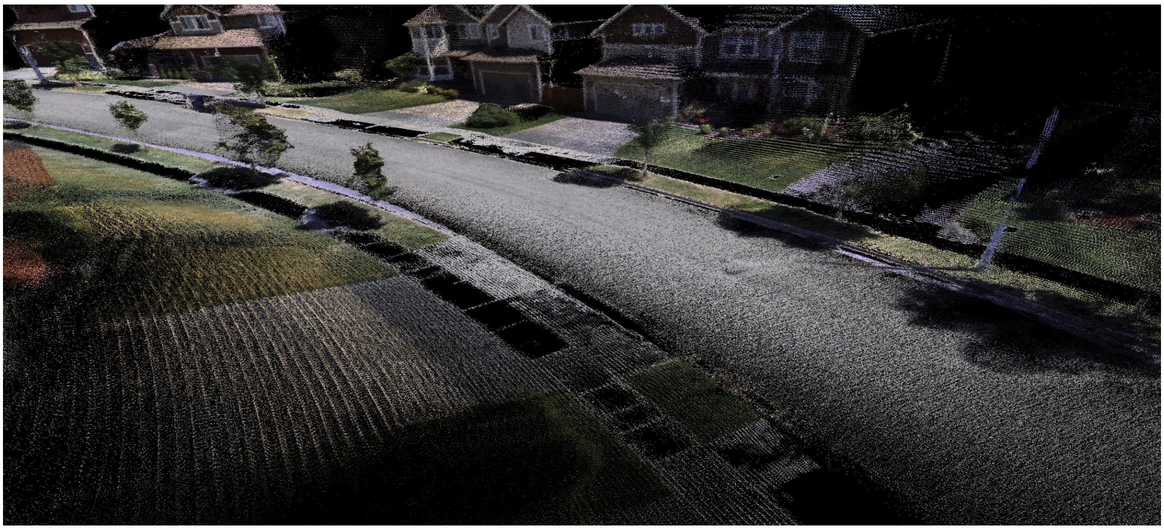
4.6 Desktop Mapping (continued)



Here is the same desktop, but connected to ArcGIS. The red triangle in the middle of the GIS window, is associated with the active camera view and showing you where you are looking. When you start toggling through the 14 cameras, represented on the little race car, the triangle will move around and show you what your view angle is. By pointing to a location in the GIS window, you can have the AIMM imagery catch up to you and show you the view from that point. If you move off to a different location in your base map, hit a point, the viewer will display the imagery from that new location. Handy for doing desktop recon.

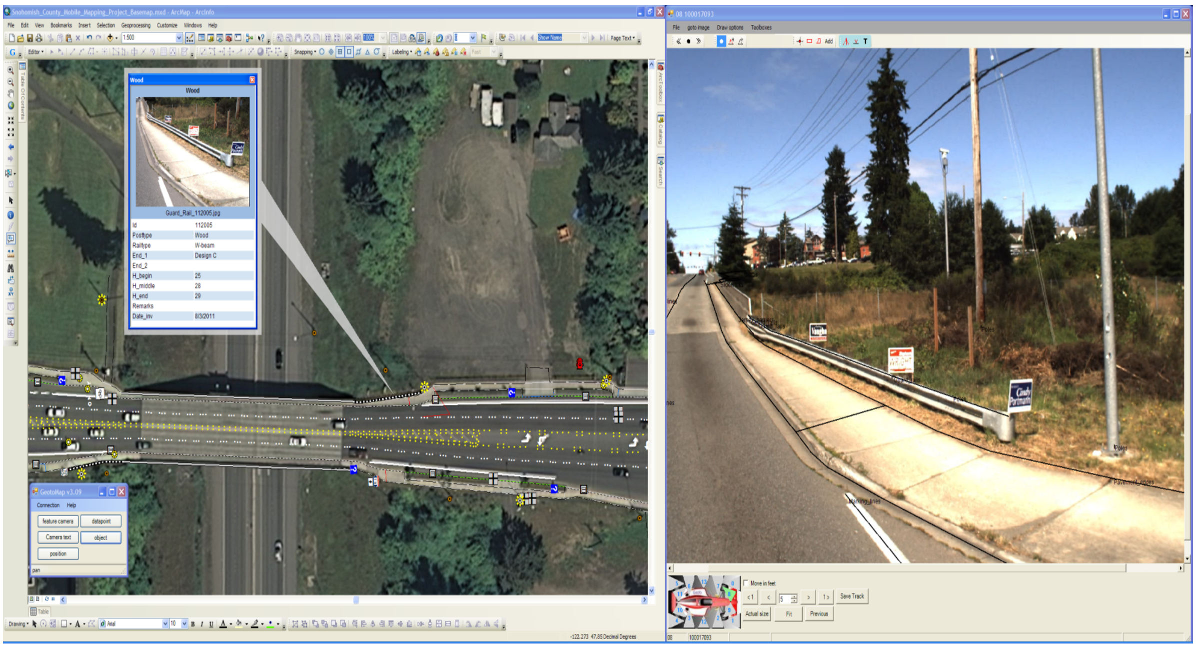
If you happen to not have connectivity to your CAD or GIS, say you are in the field with no license for that software, you can collect the point in “data collector” mode. The feature can be picked in the AIMM imagery, the xyz reordered, a text identifier added to it, then that text file can be saved and imported into the CAD or GIS at a later date.

4.7 Point Cloud Generated From Images



As part of the normal operations of this system, it is auto-correlating pixels in adjoining images to define a precise X, Y, Z location for all identified pixels. This process allows for the development of a very robust point cloud generated from every usable pixel. With pixel sizes less than a centimeter, with 100 cm on a side, a point density of 1000 points per meter can be generated. This is a really robust data set.

4.8 Transportation Infrastructure



Curb, gutter, sidewalk, luminaire poles, guardrail (condition, material, posts, and type of cap), are easily seen in the imagery and captured as line features in the GIS file and given attributes. Overhead Traffic signals, Traffic Cameras, signal arm, and all of the features associated can be collected at once, or as needed.

4.9 Water Infrastructure

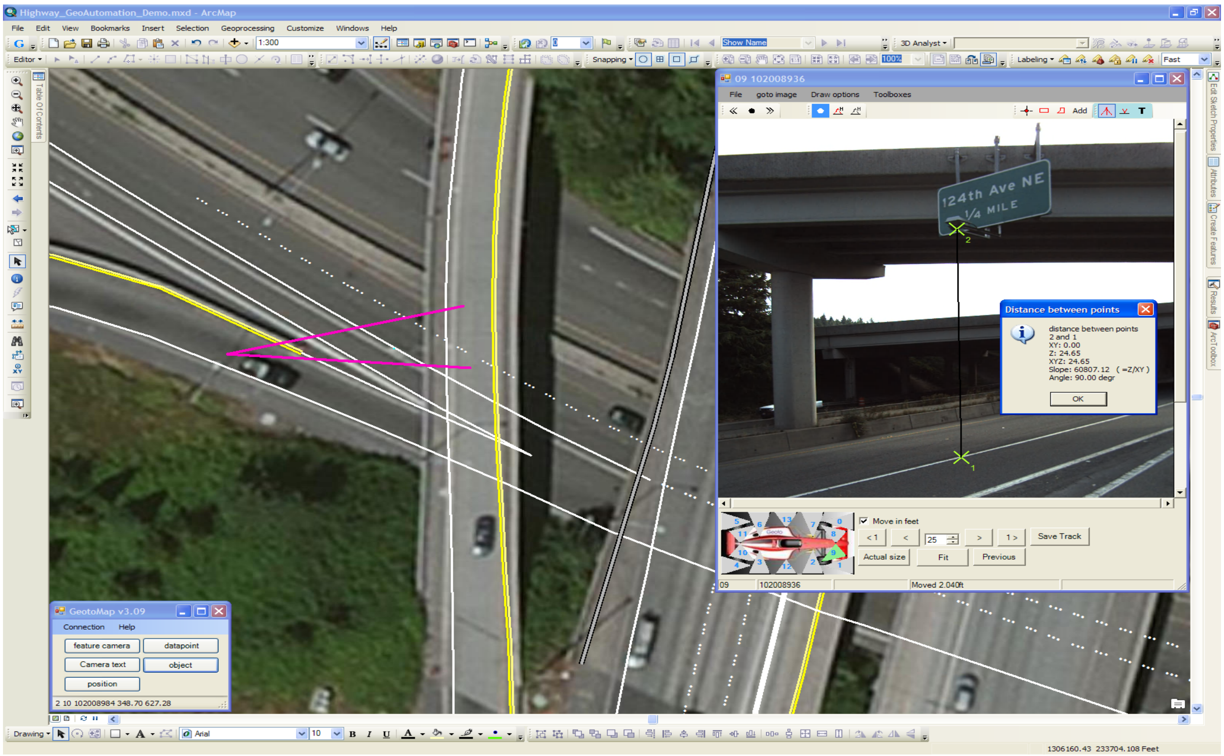
4.10 Pavement Condition

Pavement conditions can be assesed and located for future review and inspection. This can be very useful to significantly reduce field trips for viewing and locating.

4.11 Power Infrastructure

Power lines, poles, transformers, light arms and more can be located and tagged individually and stored with pertinent information. In this case, we connected lines from connection point to connection point, but not the conductor itself.

4.12 Feature Clearance Measurement



We can make precise distance and height measurements without having to interact with a CAD or GIS, in this case a clearance measurement.

5. SNOHOMISH COUNTY, WA., USA - MOBILE MAPPING PROJECT – 2500kms

5.1 Project Management

DEA managed the project tasks and was the central point of communication for the project team. DEA's management of the project included, schedule, communication, safety, and QA/QC. DEA facilitated a project "kick off" meeting with project team staff and key county staff. DEA participated in a monthly to weekly project meeting and provide meeting minutes to facilitate communication of:

1. Project status and coordination of major milestone deliveries
2. Project issues and/or questions with county and DEA team members

Deliverable: Monthly progress report/meeting minutes

5.2 Survey Control

DEA utilized the Washington State Reference Network (WSRN), to provide primary positioning of the GeoAutomation system. In areas that were not covered by the WSRN, DEA used a local base station for post processing the data. When a local base station was established, DEA used static GPS procedures to position the point into the WSRN coordinate system.

Deliverables: GPS report

5.3 PRE-Mission Planning

DEA established data collection routes by graphically plotting the proposed routes and coverage areas into Google Earth. These routes were then scheduled into a weekly data collection plan. We attempted to identify known construction zones and optimal collection times based on the area traffic, GPS windows and any other relevant factors.

*Deliverable: Planned route trajectories. *kmz files*

5.4 Field Data Collection

DEA collected approximately 2500kms of Snohomish County roadway using a GeoAutomation® mobile imagery mapping system. This system did traverse the county roadways and collect asset inventory items indentified, within 15m of the vehicle at the project accuracy requirement of +/- 30cm at a 95% confidence level.

The data collection task included the following sub-tasks: Safety Assessment: Mobile image collection: Route completeness and Imagery review:

5.4.1 <u>Safety Assessment</u>

The data collection was achieved under normal driving conditions during daylight hours and favorable weather. DEA conducted a daily route safety meeting prior to collection. The safety meeting included accident and emergency protocols, local environmental concerns such as weather, street conditions, school zones, events and construction. DEA was also responsible for gathering all related information, and coordinated with the County on any known county related data that could impact the data collection phase, such as: county roadway construction and maintenance project locations and schedules; and other county known data that could impact the project.

5.4.2 Data Collection

Field Data Collection will be will phased in manageable area zones:

Phase 1 - Zones 1-4 – Southwest County
Phase 2 - Zones 1-4 – Southeast County
Phase 3 - Zones 1-4 – Central County
Phase 4 - Zones 1-4 – North County

The establishment of Washington State Plane Coordinates, NAD83 (2011) horizontal datum, and elevations (NAVD'88) vertical datum, did utilize the Global Positioning System (GPS), and was based on the Washington State Reference Network (WSRN), therefore DEA will track the GPS PDOP real-time and log areas of low GPS reception. DEA did review the data coverage on a daily basis for completeness of collection and line of site issues.

DEA did post process the imagery based on the initial GPS positions. If the GPS positioning didn't meet the accuracy requirement of +/- 30cm at 95% confidence then DEA did supplement those areas with ground control positions and complete a bundled GPS and ground control adjustment. The ground control was stationary (non-movement) physical features identifiable in the images. The ground control was located with either RTK GPS or total stations as applicable. Some large areas, pre-identified as low probability of GPS signal strength, were controled with pre-data collection photo ground control points.

5.4.3 QA/QC of Imagery Accuracy

The Data Collection QA/QC did provide the County with useable digital imagery of the collection of all the county roadways. It did not contain the symbols and/or the GIS shapefiles that was included in the final product delivery. DEA did perform an accuracy check survey of a representative geographic sampling of all the county roadway miles.

Deliverable: Post Processed Imagery, and a Positional accuracy statement and control report

Snohomish County did perform quality checking on a random sampling of imagery collected on roadway miles utilizing the following methods and criteria:

- Visual verification of imagery using GeoAutomation software
  - Images were clear and features recognizable
  - No excessive obscuring of assets
- Statistical sampling of all roadway miles to determine they are covered
  - Calculated representative image volume and compared to actual
  - Reviewed file size for excessively small or large files
  - Reviewed coverage tracks for completeness

The GeoAutomation technology is designed to compensate for random defects in individual imagery frames based on camera positioning, overlap and rate of capture. The County did consider the imagery product to be acceptable unless there were entire sections where all frames from cameras oriented in a given direction of capture appear defective or missing. Review was completed within thirty (30) days of delivery and DEA did was notified in writing of any areas of imagery coverage deemed unacceptable.

5.4.4: Data Extraction Training

DEA did train Snohomish County GIS staff to extract data from the GeoAutomation imagery data. A typical GIS specialist did learn to extract data in about 4 hours of instruction. DEA also provided a tutorial and documentation for basic data extraction tasks. DEA did provide 4 hours of instruction for up to 12 county staff at the Snohomish County Training Center and a 4 hr follow up session to answer any questions and provide further instructions, if necessary, to be sure all is working well.

5.5.1: Feature Extraction

Feature extraction was accomplished by the GeoAutomation® software. GeoAutomation is an ESRI ArcGIS extension and therefore provides a direct link with the GIS database. Technical functionality of the software includes the ability to import data from existing GIS databases; measure heights, widths, distances and clearances; digitize accurate x, y, z locations of assets and features; and collect points, lines and polygons. An example of a simple feature extraction is the user selects a pixel in the images and the coordinate of that pixel becomes the feature in the GIS database.

5.5.2: QA/QC Processed Data

During the post processing, quality was achieved by comparing the processed data to the random features collected by RTK/GPS measurements. The data/product was reviewed by DEA for completeness and accuracy. There was a targeted review of roadway asset inventory items by staff in the field and office for completeness and accuracy of the attribute and position data. The verification of features extracted and attribute annotation was achieved by back checking each shapefile against the County's aerial imagery.

DEA did field verify a representative sample of assets and geographic sample areas of each of the 4 phases to ensure consistency, completeness, and quality of deliverables.

The accuracy of the back check of existing features in the GeoAutomation imagery of several thousand points fell within an average range of 3 to 5 cm.

The County did perform quality checking on a random sampling of spatial data (shapefiles) collected on roadway miles in each delivery. Review shall be completed within 30 days of delivery and DEA will be notified in writing of any errors discovered. Each asset data layer (GIS shapefile) was reviewed utilizing the following methods and criteria:

❖ Feature verification

- Feature counts of the extracted data layers were generated and compared against feature counts from county data. Where county GIS data existed for a given asset type, visual comparison was also be made between the two asset layers comparing feature density
- Spatial location of extracted features was compared to county GIS data for proximity.
- Random audits for each asset type were performed using GeoAutomation software to look for missed assets.
- Spatial location of extracted features was compared to visible locations in county aerial imagery.
- Field verification of asset locations were via RTK/GPS for conformance to required accuracy standards.

6. CONCLUSION

We, the team of **DEA**, **GeoAutomation**, **Transcad**, and **Geocopia**, were able to accomplish the mapping and attributing of 2500 kms of Snohomish County Roadway, accurate to sub 30cm in urban and rural conditions, involving work stations in 4 different countries (U.S.A, Belgium, Egypt, and Canada), all within an effective working time frame of 16 months. I believe the determination and cooperation of this multi-country team, and the amazing and unique capabilites and simplicity of the **GeoAutomation** Mobile Digital Imagery Mapping System, are an excellent example of what made this a successful project, unlike any of it's kind in the world.