Appendix H – BVRCS (BridgeViewer Remote Camera System) Training Session and How to Manual

Bridge Viewer Remote Camera System Demonstration

Michigan Tech Research Institute
3600 Green Ct.; Suite 100
Ann Arbor, Michigan 48105
Lake Superior Conference Room
November 20, 2014; 9:30 am – 11:30 am

9:30am – 9:45am: Introductions and Brief Overview of Events

9:45am – 10:00am: Overview of BVRCS Equipment and Software

- GoPro Hero 3 cameras
- Garmin GPS Unit
- GeoJot+
- ArcMap

10:00am – 11:15am: Demonstration of BVRCS Data Processing, Visualization, and Mapping

11:15am – 11:30am: Conclusions and Questions

Overview

Assessing bridge infrastructure deterioration has developed into a challenging task due to decreasing funds for the maintenance and replacement of structurally deficient highway bridges in the United States. Through a research grant provided by Michigan Department of Transport, the Michigan Tech Research Institute (MTRI) is currently assessing bridge infrastructure and assessment through the use of remote sensing technology such as high resolution photogrammetry and photo inventory tools such as the Bridge Viewer Remote Camera System (BVRCS). The BVRCS uses two GoPro Hero 3 cameras attached to the right and left edges of a vehicle hood, images were collected as the vehicle traversed the bridge. The BVRCS costs less than $1,000, can be mounted to any vehicle, and deployed to multiple sites without any additional costs.

www.mtri.org

Bridge Viewer Remote Camera System (BVRCS)

A "How To" Manual

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Background

The Bridge Viewer Remote Camera System (BVRCS) is a dual camera system that can be mounted to any vehicle to collect a photo inventory of a bridge deck and other bridge elements. This system was developed as a low-cost technology to capture location-tagged photos that can be used as a reference for assessing the current condition and comparing changes over time. Currently, bridges are inspected by field crews visiting bridges and taking photos of only major problems that are found during inspections. The purpose of the BVRCS is to capture a location-tagged set of photographs of a bridge so that inspectors can easily and inexpensively review a bridge at a later point and over time as more photo inventories are taken, while working from the office. This is intended to optimize field time and enable review of high-resolution photos of a bridge, especially its deck. This system would allow inspectors to simply drive across each lane of the bridge deck with minimal disruption to traffic while keeping the inspector safe and collecting the photo inventory. There are companies with dedicated equipment that will deploy their vehicles to take a photo inventory. Their systems take either HD video or use cameras somewhat similar to BVRCS. The main difference however is that the cost per deployment can be expensive. BVRCS costs less than $1,000 to put together from inexpensive components and can be mounted to any vehicle for deployment to multiple bridges without additional cost.

The Michigan Tech Research Institute (MTRI) has successfully deployed the BVRCS on multiple road and bridge segments. These demonstrations were conducted during different bridge condition assessment projects for funding agencies such as the United State Department of Transportation (US DOT) Office of the Assistant Secretary for Research and Technology (OST-R) (formally the Research and Innovative Technology Administration, RITA) and the Michigan Department of Transportation (MDOT).

This document serves as an instruction manual for use of the MTRI developed BVRCS. It includes the equipment necessary for deployment, approximate costs of equipment, set-up, data collection, and data processing procedures.

Require Equipment and Software

Equipment List

Two GoPro Hero 3 cameras (with micro-SD memory cards)
Two GoPro camera mounts
A Garmin GPS Unit (GPSMap 78sc, or similar unit)

Computer Software

DNRGPS
GeoJot+ Version 2
ESRI's ArcGIS

The GoPro Hero 3 camera is capable of capturing both still imagery and recorded videos (Figure 1). Weighing 2.6 oz (74 grams) (4.8 oz (136 grams) with housing), this small but versatile camera is idea for active sporting events and outdoor use. Images captured by the camera are wide-angle (narrow field of view lens can be installed) and can automatically take up to 3 frames per second. Likewise, videos are recorded at 1080p and capture audio. Wi-Fi is built into the camera and allows for Smart Remote or cell

phone (via a downloadable app) remote control. Additionally, the camera is waterproof up to 40 meters (131 feet) when placed into the waterproof housing. Images and video are stored on a micro-SD card. Purchase of the GoPro Hero 3 and accessories (some of which are sold separately) will cost $199.99 through www.gopro.com.

Figure 1: The GoPro Hero 3 camera; Wi-Fi button (red circle), power and mode button (green circle) and record/capture/select button (orange circle).

Camera mounts used in the BVRCS were created using replacement parts purchased for $19.99 through www.gopro.com and a slotted metal bar and magnet (Figure 2).

Figure 2: GoPro Hero 3 camera mount.

In order to determine the location of each image taken by the GoPro, a GPS unit is required and the Garmin GPSMAP 78sc unit is recommended (Figure 3). The unit cost $349.99 and is available through

www.garmin.com/en-US. Any other GPS unit that is capable of producing a track log should suffice for these purposes.

Figure 3: Garmin GPSMap 78SC unit.

Methodology

Prior to placing both GoPro cameras onto the vehicle's hood, each should have a fully charged battery inserted into the back and the camera (Figure 4) and must have their settings configured to capture two still frames per second. After turning on the camera, use the mode button to change the mode to time lapse (icon is a camera and clock) (push the mode button three times) (Figure 5). The camera should indicate that 12MP images will be taken in half-second intervals. If the settings are not set to these options, they can be changed by using the mode button to access the camera's settings (push the mode button four times).

Figure 4: Battery insert on the back of the GoPro.

Figure 5: Camera settings should be set to capture 12 MP images at 0.5 second intervals.

In order to setup the track log, use the “Page” button to navigate to the Main Menu. Select Setup by using the “Enter” button. Scroll down to the Tracks menu and press “Enter”. The first option “Track Log” should be highlight. Press “Enter” and scroll down to “Record, Do Not Show” or “Record, Show on Map”. Press “Enter”. Immediately, the GPS unit will start collecting data.

After setting up the track log, take a picture of the GPS with both GoPro cameras. Make sure that the image will contain the GPS unit’s clock. This is a vital step in order to match images captured by the camera to GPS points taken within the track log.

After configuring the GoPro cameras and GPS unit, place the two mounted cameras onto the hood of the vehicle and push the record button. Place the camera in front of each GoPro camera if this has not already been done. The vehicle can then be driven across each lane of the bridge at a moderate speed while the GoPros and GPS unit collect required data. At the completion of the data collection, press the record button on both cameras, which will stop any additional imagery from being collected. Lastly, on the GPS unit, navigate back to the Main Menu and select Track Manager. Current Track should be highlighted, press “Enter”. This will open a new menu with Save Track highlighted. Press “Enter” again and name the file. After naming the file, use the arrows to navigate to Done and press “Enter”. The track log is now saved.

Data Processing

Upon completing the data collection, data processing should occur within a day or two. The following step-by-step process describes how to use the different processing softwares, link images to GPS data, and visualize / map collected data.

1. **Download imagery from each GoPro.**

   This process will require a micro-SD card reader. Typically, a micro-SD card reader comes with the micro-SD card when purchased from most major retailers. Although the exact cost of the package depends on the size of the micro-SD card, most are not too expensive and range between $40 - $80.

   If there are multiple bridge crossings during the data collection, try to keep a list of each run’s time and direction. This will assist in separating the data after it is downloaded. MTRI typically

label each GoPro as either “right” or “left” and use that information when naming files that contain raw imagery.

2. **Download GPS data from the Garmin Device.**
   MTRI uses a program developed by Minnesota’s Department of Natural Resources called DNRGPS (Figure 6). This program was created to transfer data between Garmin handheld devices and GIS software. Different versions for available releases of ArcMap are available at (www.dnr.state.mn.us/mis/gis/DNRGPS/DNRGPS.html).

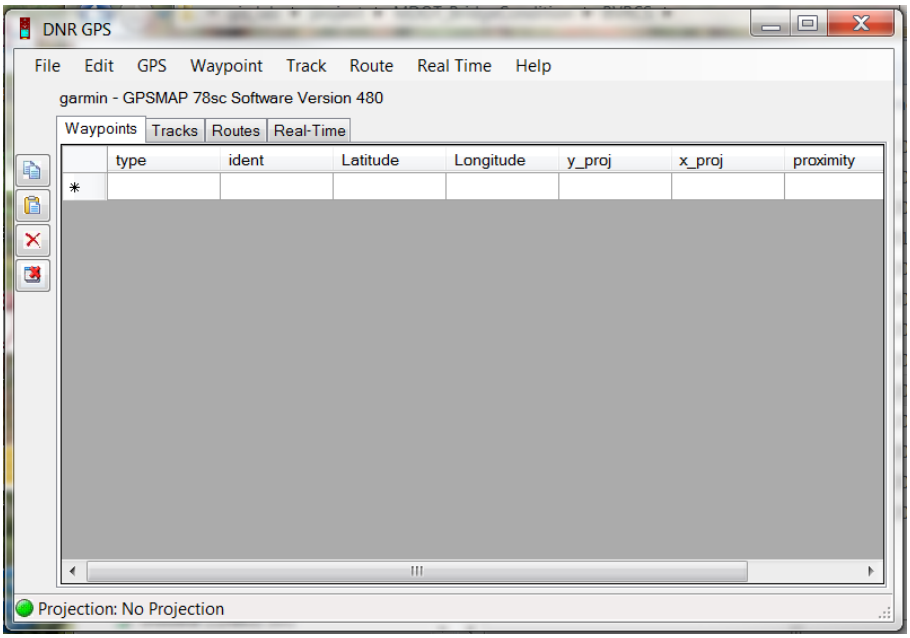
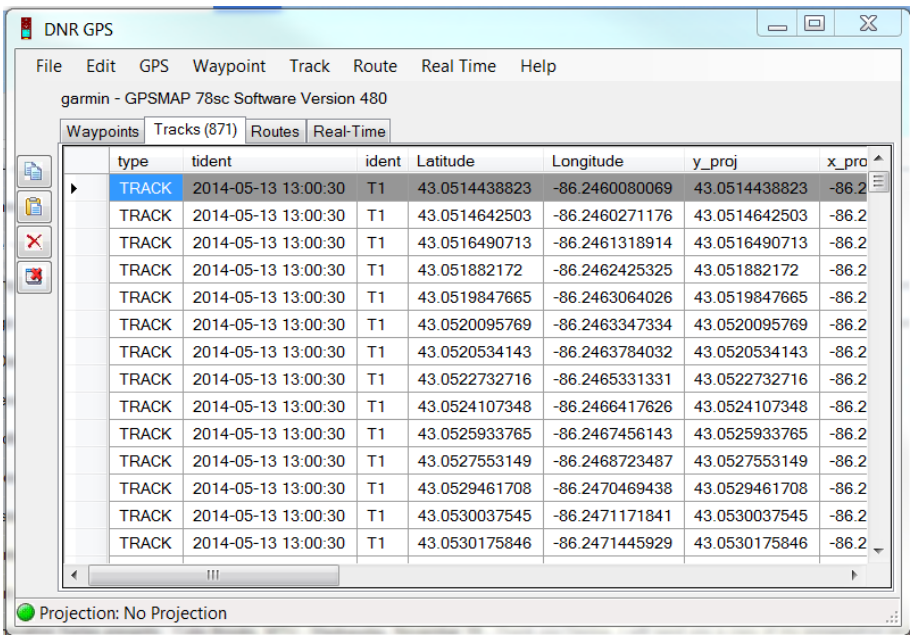


Figure 6: DNRGPS software layout.

Using a USB cord, plug the GPS unit into the computer and select “Track → Download” from the menu bar (Figure 7). Select the track that was created during the data collection. Next, select “File → Save To → ArcMap → File” and change the “Save as Type” to ESRI Shapefile (.shp). Name your output file and location.



type	tident	ident	Latitude	Longitude	y_proj	x_pro
TRACK	2014-05-13 13:00:30	T1	43.0514438823	-86.2460080069	43.0514438823	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0514642503	-86.2460271176	43.0514642503	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0516490713	-86.2461318914	43.0516490713	-86.2
TRACK	2014-05-13 13:00:30	T1	43.051882172	-86.2462425325	43.051882172	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0519847665	-86.2463064026	43.0519847665	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0520095769	-86.2463347334	43.0520095769	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0520534143	-86.2463784032	43.0520534143	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0522732716	-86.2465331331	43.0522732716	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0524107348	-86.2466417626	43.0524107348	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0525933765	-86.2467456143	43.0525933765	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0527553149	-86.2468723487	43.0527553149	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0529461708	-86.2470469438	43.0529461708	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0530037545	-86.2471171841	43.0530037545	-86.2
TRACK	2014-05-13 13:00:30	T1	43.0530175846	-86.2471445929	43.0530175846	-86.2

Figure 7: A loaded GPS track dataset.

3. Link Images to GPS Data Using GeoJot+

GeoJot+ is a software program designed to simplify the photo-capture to mapping and reporting processes required for many data analyses (http://www.photomappingsoftware.com/). Developed by Geo-Tactical Solutions, the program is available for free (short-term demonstration period), but ranges between $220 and $330 for the essential and team plans, respectively. Licenses for the software must be updated yearly. GeoJot+ creates outputs that are usable within other geo-spatial software such as Google Earth, ArcGIS, and GeoSuite. For the purposes of BVRCS, GeoJot+ outputs will be imported into ArcMap to allow for visual analysis of GoPro captured imagery. The ability to view GeoJot+ output imagery in ArcMap does not require an activated license. However, in order to link up GoPro images and GPS coordinates collect by a GPS unit, a GeoJot+ license is required.

3.A. Assign a Working Folder

After obtaining a GeoJot+ license and downloading the software, each new project is assigned a working folder (Figure 8). Click on “New Project” and create a working folder. As a suggestion, use a name that describes the bridge and camera location (i.e. Merriman_Right, or Merriman_Left). Additionally, verify the location of the folder. Click OK.

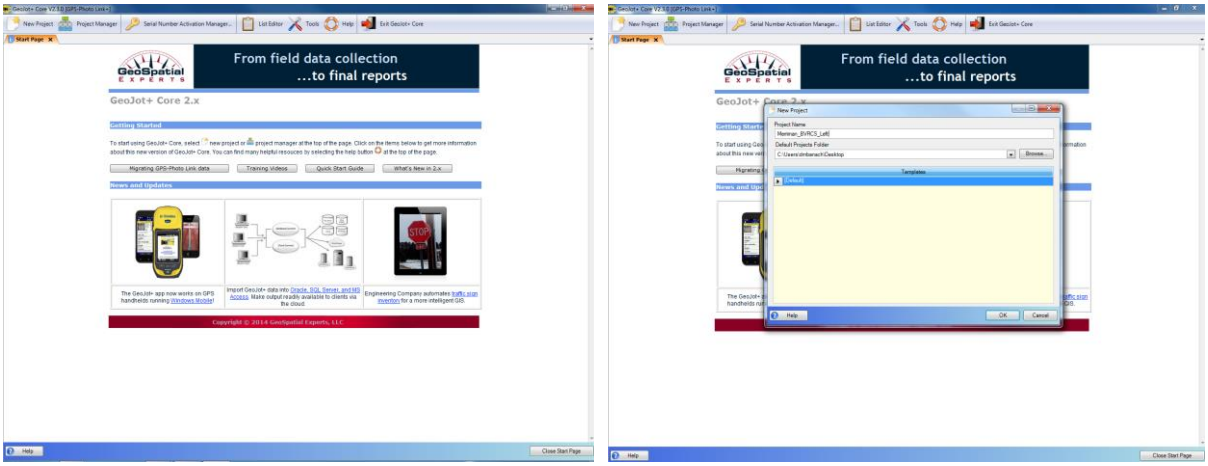


Figure 8: The GeoJot+ homescreen (left) and new project window (right)

3.B. Import imagery into folder

After creating the new folder, the GeoJot+ project page is displayed (Figure 9). The project page is where all of the GeoJot+ processing will occur. Automatically, Tab 1 (Import Photos) is selected. Within Tab 1, click on "Import Photos" and navigate to the folder location where the raw imagery is located. Select (check box) each image that will be included (Figure 10). Select OK. This will create a new folder in your working folder that includes all imported imagery. Additionally, each image will appear in the Tab 1. Each image will include a red X near the bottom left corner, indicating that it does not contain GPS coordinates.

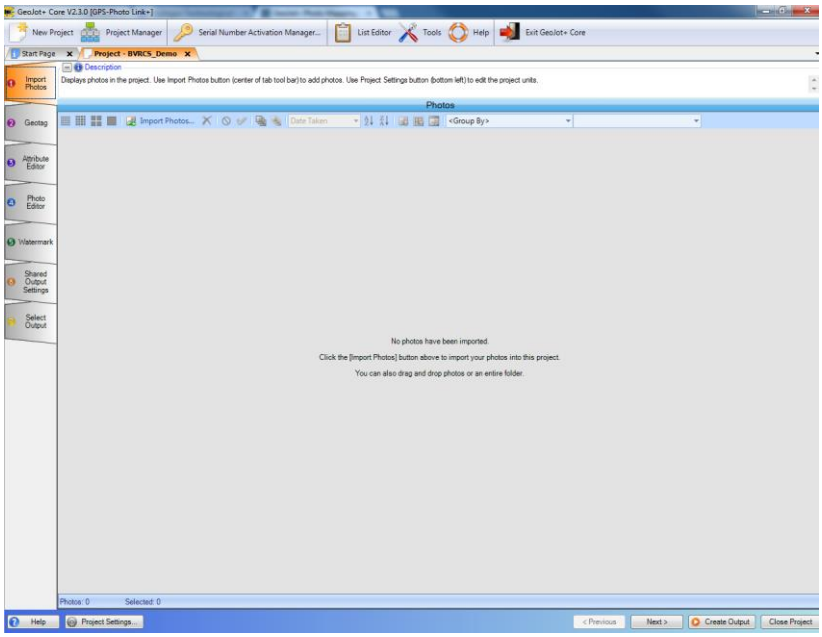


Figure 9: GeoJot+ work area display.

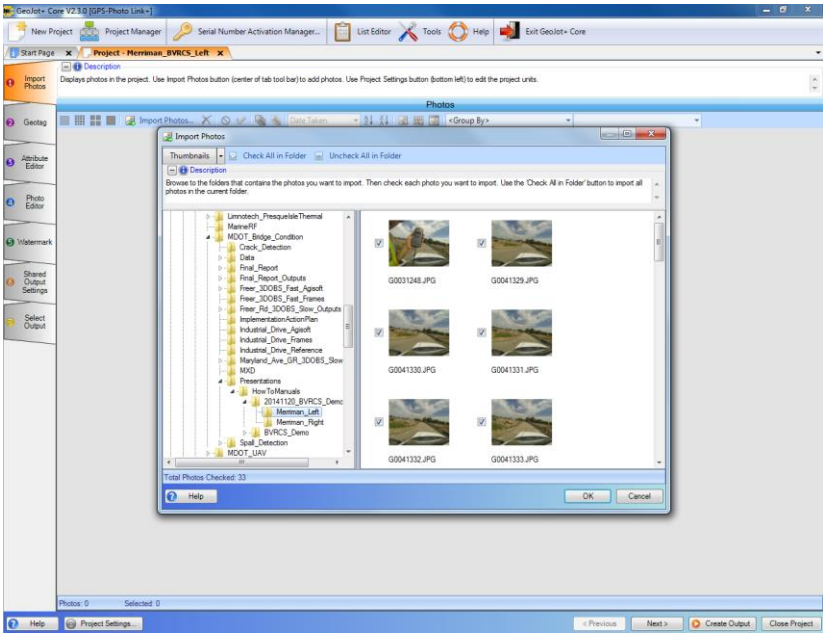


Figure 10: The Import Photos window is where images can be selected for further processing

3.C. Geotag Wizard

Next, select Tab 2 (Geotag). This will display a table that includes the count of GPS and non-GPS tagged photos and the overall percentages (Figure 11). The full (100%) count of images should be non-geotagged. Click on “GeoTag Wizard”.

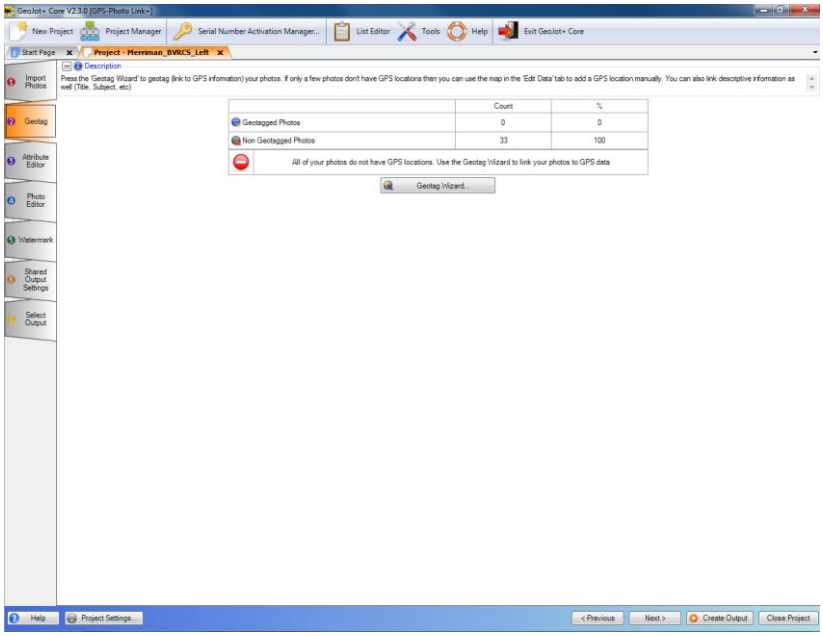


Figure 11: Tab 2 (Geotag) contains the Geotag Wizard

The first window to open in the GeoTag Wizard is the “Geotag Data Source”. Since we have already downloaded the GPS data from the Garmin device, keep the selection on “Use GPS Fire (Shape File, CSV, GPS, NMEA, LOG)” (Figure 12). Click Next.

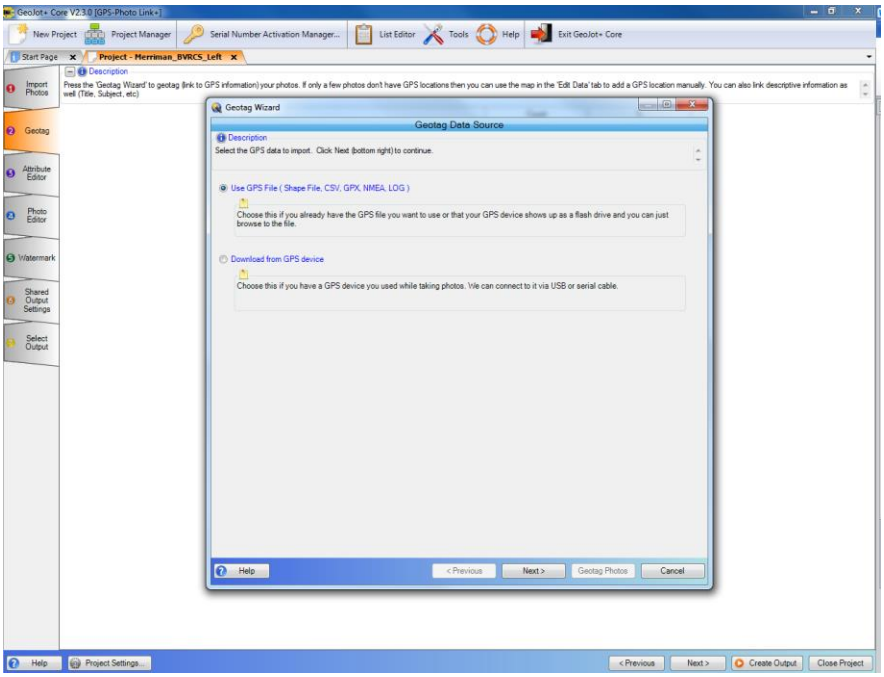


Figure 12: Geotag Data Source window within the Geotag Wizard.

The next window in the Geotag Wizard is “Import GPS Data File”. Navigate to the downloaded GPS data (in shapefile format) (Figure 13). Click Next.

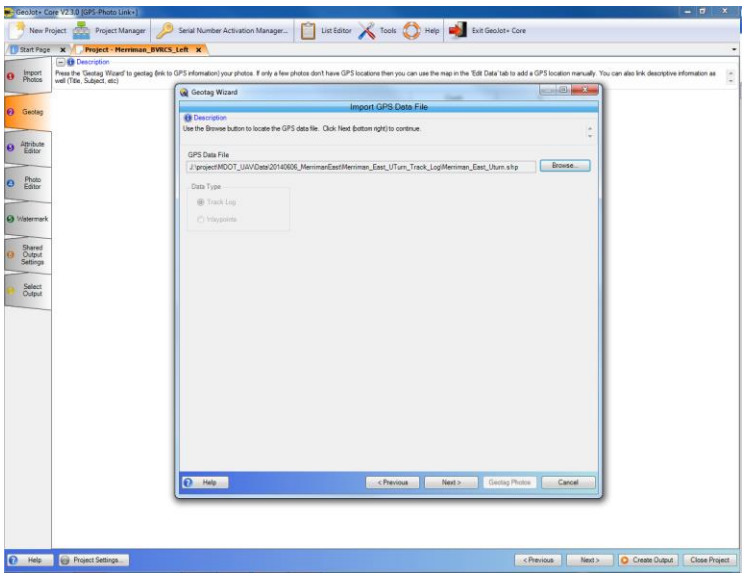


Figure 13: The Import GPS Data File window within the Geotag Wizard.

Next in the “Select Field from Data Source” window, verify that the Elevation geospatial attribute corresponds to the altitude column. Additionally, verify that the Date attribute corresponds to the date column, and Time attribute to time. The data source datum should remain at WGS 84. Lastly, verify that the unit for each attribute is correctly labeled (Figure 14). Click Next.

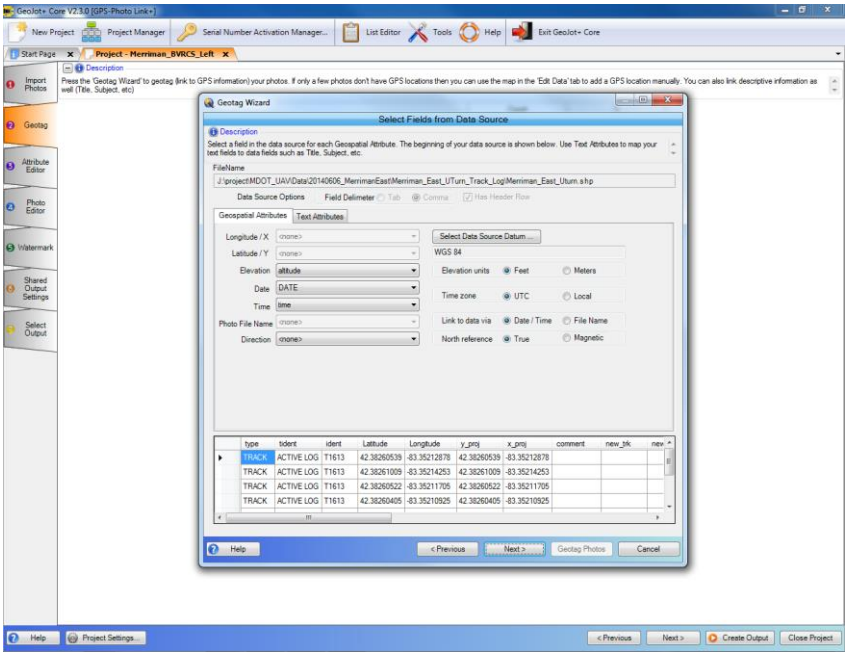


Figure 14: The Select Fields from Data Course window within the Geotag Wizard.

In the “Time Synchronization” window, use the selection labeled “Use a photo of the GPS receiver to manually enter the data and time of the GPS receiver”. Uncheck the “GPS position match threshold” box and keep the “Time Matching Type” at “Interpolate between points” (Figure 15). Click Next.

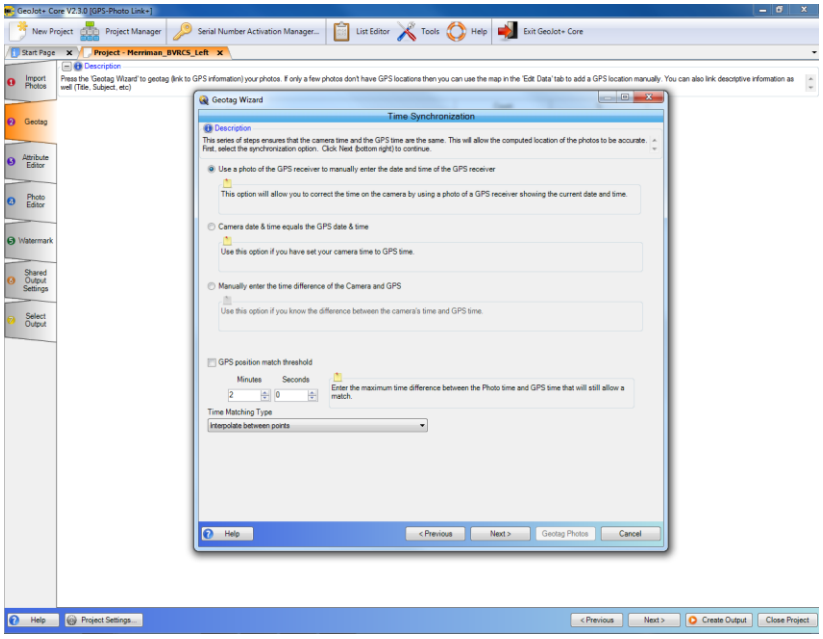


Figure 15: The Time Synchronization window within the Geotag Wizard.

In the "Photo of GPS Device" window, find and select the photo containing the GPS device and time. Enter the GPS time and date EXACTLY as it appears into the "GPS Date & Time" box. GeoJot+ will automatically calculate the offset. Additionally, leave the Time Zone as Local Time (Figure 16). Click Next.

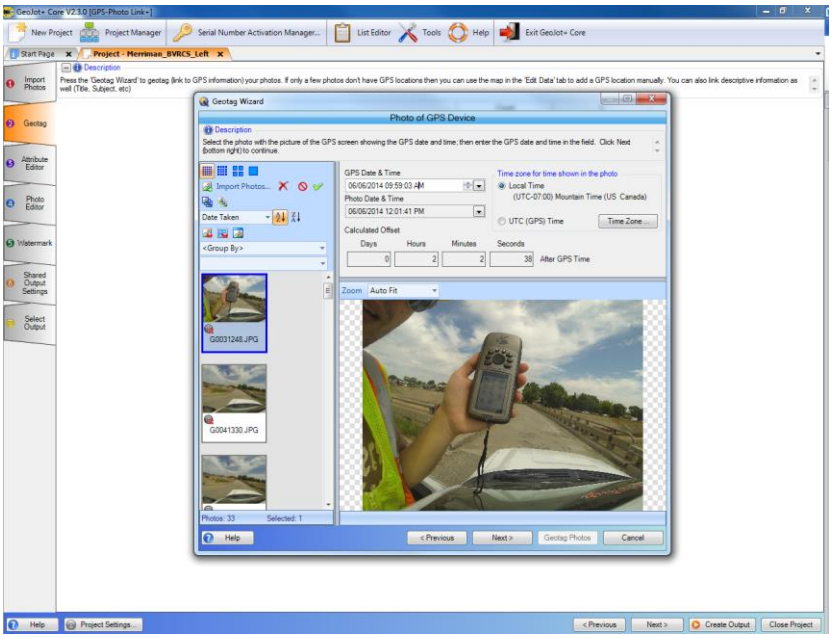


Figure 16: The Photo of GPS Device window within the Geotag Wizard.

Lastly, in the “Time Mating Options” window, leave the check box unchecked (Figure 17). Click Geotag Photos.

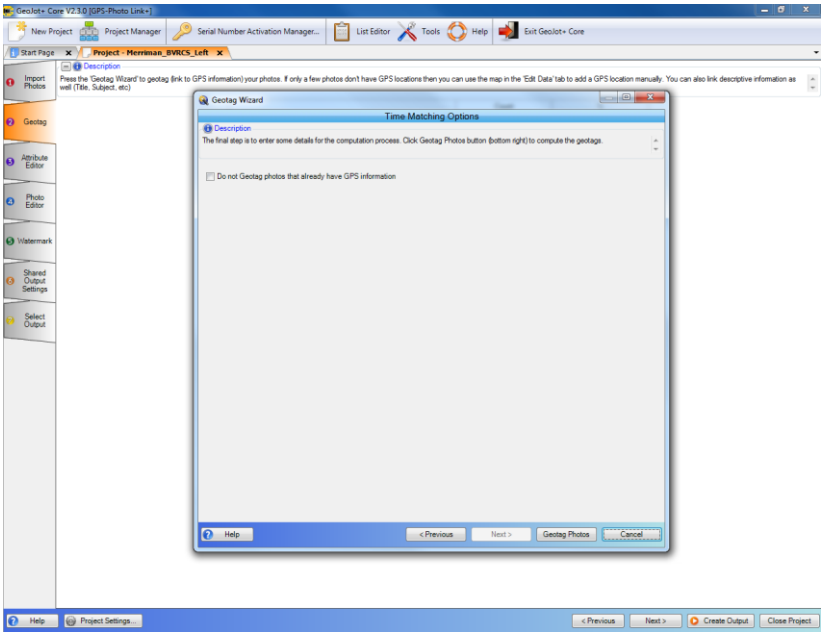


Figure 17: The Time Matching Options window in the Geotag Wizard.

GeoJot+ then syncs GPS data to each image taken by the GoPro. Processing time depends on the number of photos. Successful geotagging will produce a box indicating the 100% of the photos were linked to GPS positions (Figure 18). Click OK. In Tab 2 (Geotag), the table should now read that 100% of the image count is now geotagged. Additionally, Tab 1 will now show all photos with a green checkmark where the red x was previously.

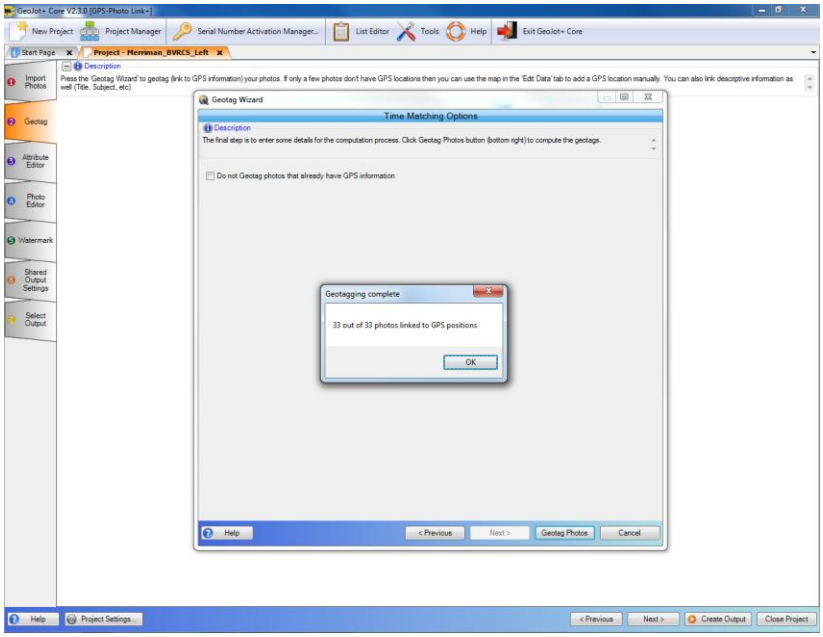


Figure 18: Geotag results from the Geotag Wizard should indicate 100% synchronization.

3.D. Watermarking Photos

Click on Tab 5 (Watermark). Only one photo will be displayed, but the selected attributes and their locations will be applied to each photo. Attributes can be selected (or deselected) using the check boxes on the left side. MTRI typically selects the following attributes to display and their locations (Figure 19):

- Filename (Row-Top 1, Column-Center, Show Name-No, Display Order-1);
- Date Stamp (Row-Bottom 2, Column-Right, Show Name-No, Display Order-1);
- Elevation (Bottom-1, Column-Center, Show Name-No, Display Order-1);
- Latitude (Bottom-2, Column-Left, Show Name-No, Display Order-1);
- Longitude (Bottom-1, Column-Left, Show Name-No, Display Order-1);
- Time Stamp (Bottom-1, Column-Right, Show Name-No, Display Order-1)

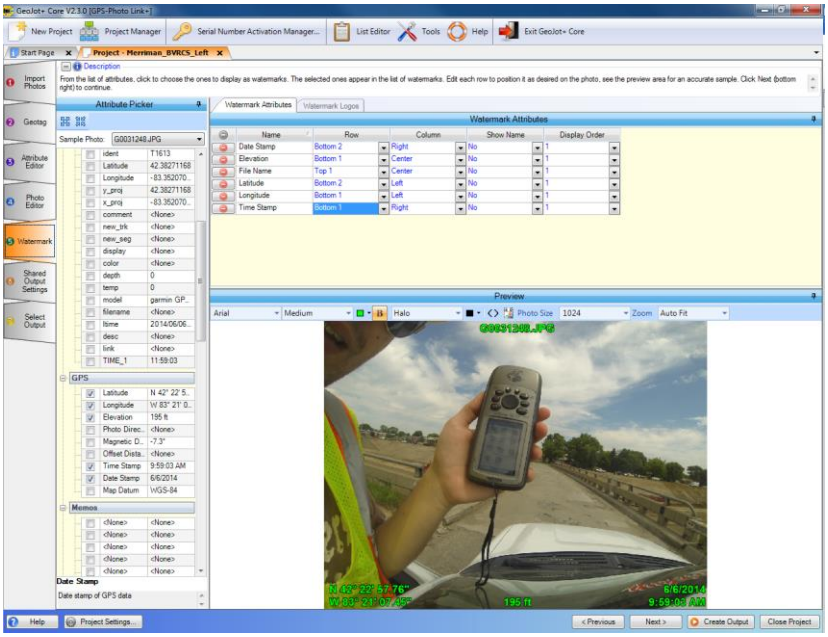


Figure 19: Selected attributes to be watermarked on each photo.

3.E. Select and Create Outputs

Navigate to Tab 7 (Select Outputs) and choose the desired outputs. MTRI typically creates a shape file, and Google Earth output (Figure 20). Each selection can further have their options changed. Upon selecting the outputs, click Create Output.

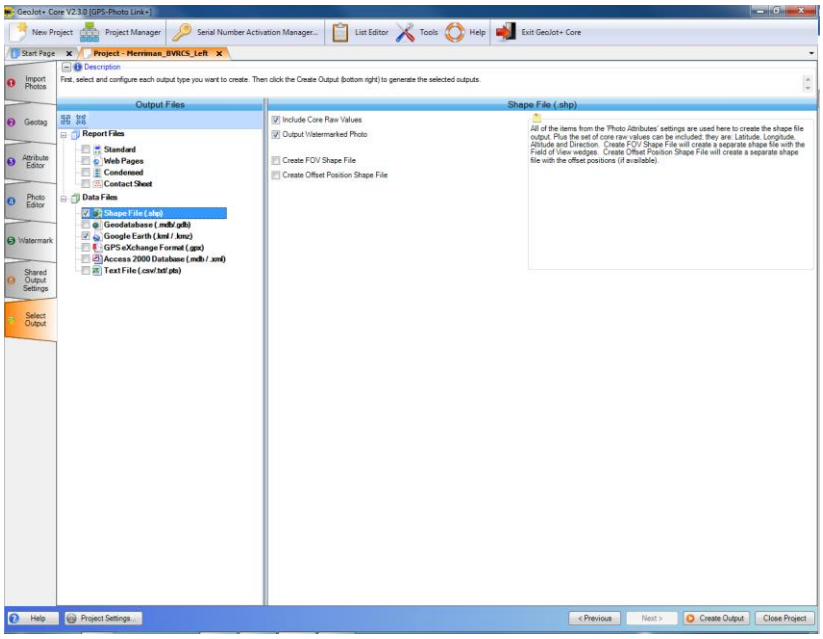


Figure 20: Selection of different output options.

GeoJot+ will then create the outputs that were requested. Processing time depends on the number of photos and outputs (Figure 21). Upon successful completion, an output folder will be created within the working folder and the progress window will show a message that says “Done”. Click Ok and GeoJot+ will return to its home screen.

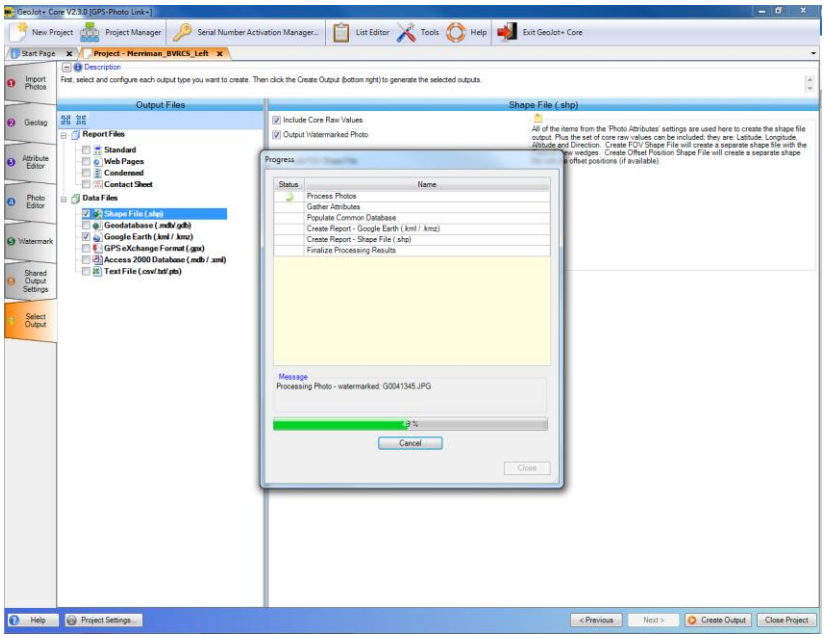


Figure 21: GeoJot+ processing the photos and creating the requested outputs.

Repeat Section 3 for the other GoPro camera.

4. Mapping and Visualization in ArcMap

After successful geotagging of photos from the GoPro cameras, open ArcMap and import both shape files that were previously created within GeoJot+ and a basemap. The shape files will be located in the output folders. Upon adding the shape files to ArcMap, points should appear along the study bridge (Figure 22). Due to using only one GPS unit while collecting data, both the “left” and “right” images will appear on top of one another. Therefore, slight manual interpolation must be used to create a visualization / map.

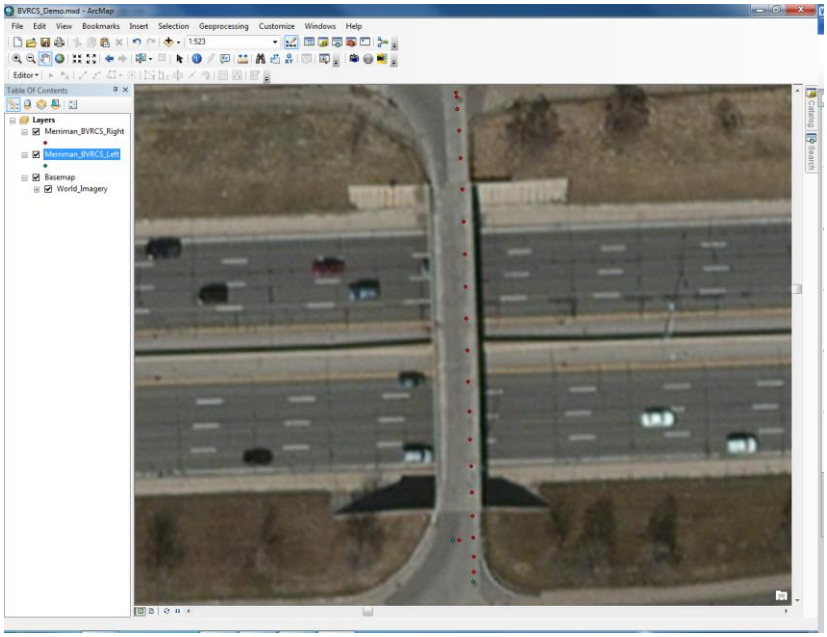


Figure 22: GPS points created by GeoJot+ based on the input GPS coordinates and inputs

Right click on the BVRCS layer that needs to be manually moved. For this example dataset, the "left" GoPro imagery must be moved to the left side of the bridge. Right click on the "left" dataset and select "Edit Features → Start Editing". If a warning window pops up, click on "Continue". Right click on the "left" dataset again and click on "Selection → Select All". This will highlight each point. By moving the mouse over one of the highlighted points, the cursor should change into a symbol that includes four arrows. This will allow the user to manually move all of the selected points to the desired location. Click and hold the left mouse button and move the left points to the left side of the bridge (Figure 23). Click the Editor Toolbar and select "Save Edits" and then "Stop Editing" (Figure 24). The symbology for each image can now be changed to a desired symbol. MTRI typically uses large different colored circles for each camera.

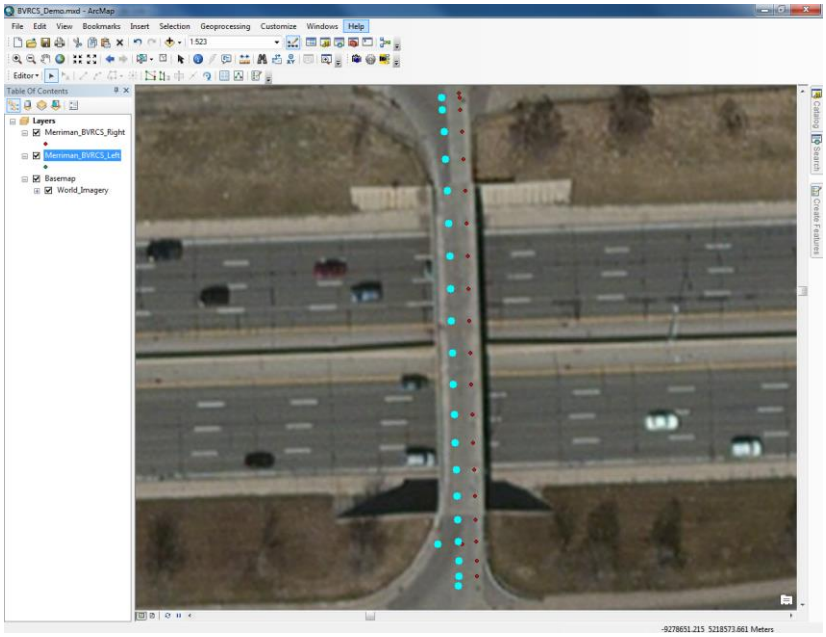


Figure 23: The left camera coordinates and images are manually moved to represent more realistic data.

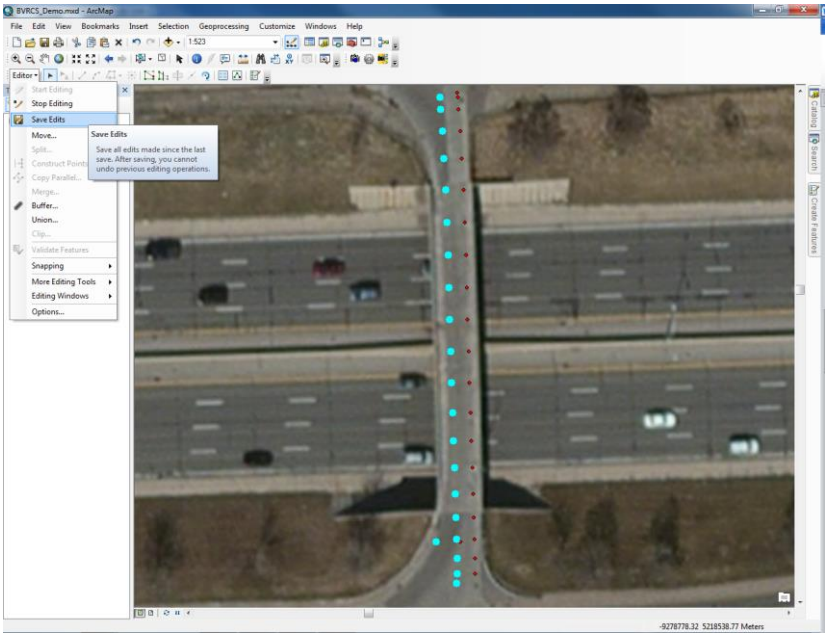


Figure 24: When editing a data layer, it is vital to separately save the edits using the Editor toolbar.

Additionally, points that are either not on the bridge or not required within the visualization can also be deleted from the dataset (typically the GPS photo is deleted). This is done by right clicking on the dataset and starting an edit session (as previously described). Next, right click on the dataset layer and select “Open Attribute Table”. Select the photos that will be deleted (will

turn light blue) and click on the X at the top of the attribute table (Figure 25). As before, make sure to save all edits.

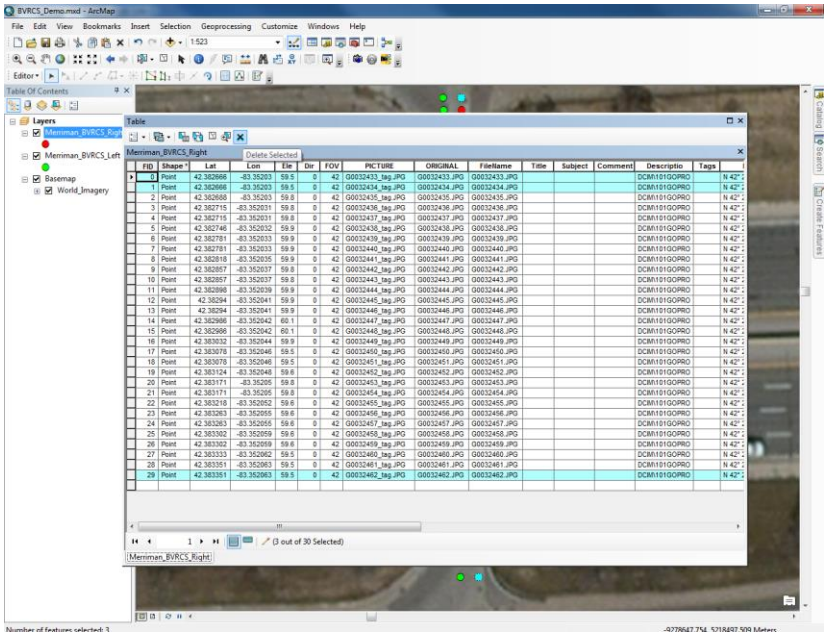


Figure 25: Certain unnecessary points can be deleted.

The visualization should now have a “left” and “right” dataset with points that are directly across from one another. Additionally, the symbology for each dataset should be clearly visible and different from one another (Figure 26).

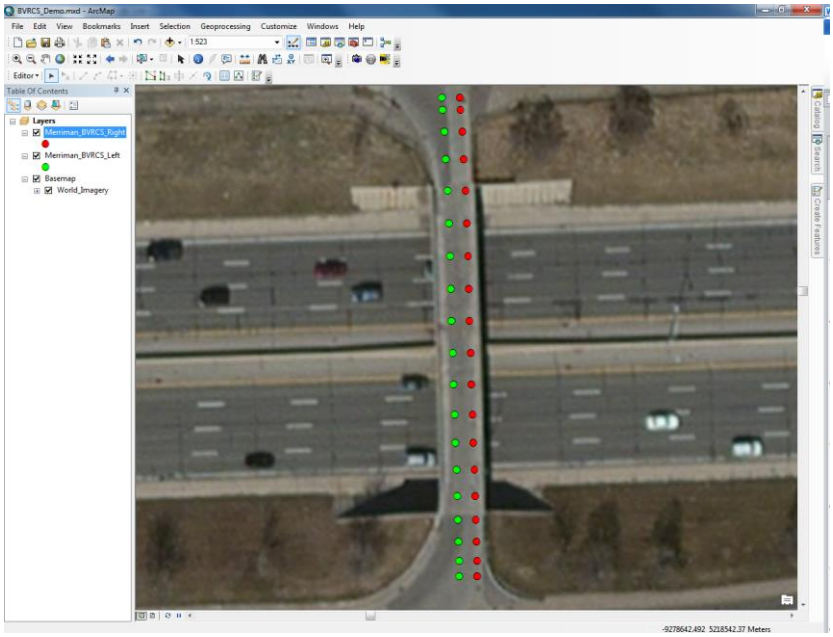


Figure 26: Each GoPro is represented by a different group of points along the bridge.

5. Hyperlinking Within ArcMap (using GeoJot+ hyperlinks)

GeoJot+ contains a hyperlink tool within ArcMap that allows the user to hover over a point, allowing the image that corresponds to each point to appear within ArcMap. Additionally, this tool does not require the user to have a paid GeoJot+ license. To use this tool, the computer must have GeoJot+ downloaded and the GeoJot+ toolbar activated within ArcMap.

To activate the toolbar, right click in the empty toolbar space within ArcMap and select GeoJot+ Core (Figure 27). The GeoJot+ tools bar contains three icons; View Photo (camera), Setup (Gear), and Run GeoJot+ Core (GeoJot+ icon) (Figure 28).

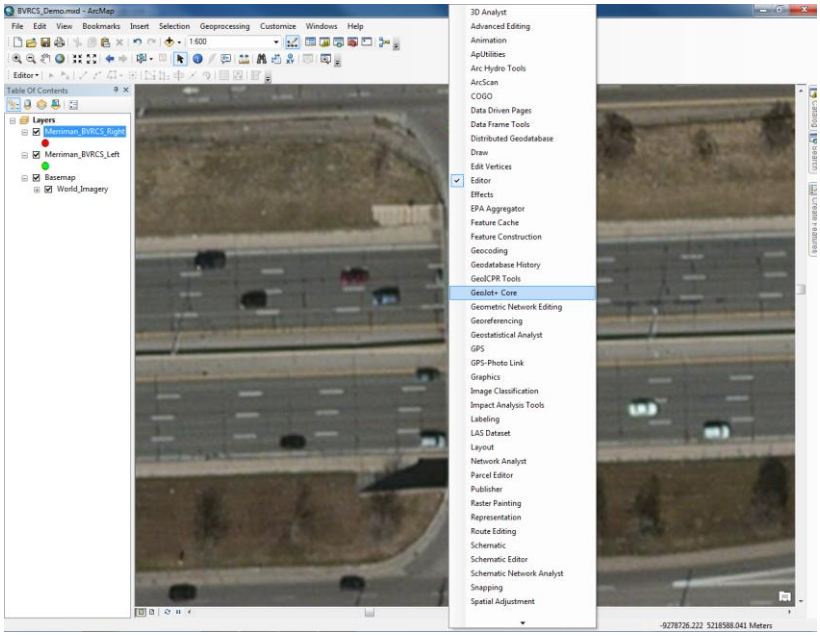


Figure 27: Turning on the GeoJot+ Core Toolbar.

Figure 28: The GeoJot+ Core Toolbar.

To hyperlink the photos using GeoJot+, select the Setup icon. Select the data layer that is being hyperlinked. Uncheck the “Not a photo layer (no processing) option. Next, change the “Click filename field” and “Popup filename field” to PICTURE. In the “Fields shown in popup window” select the following five options; Lat, Long, Ele, TimeStamp, and DateStamp. Change the “Popup Photo Size” to Large and leave the three check boxes below it checked. Lastly, change the “Attribute List Size” to 5 and leave “Show Field Names” selected (Figure 29). The exact selected and number of fields can change depending on the user’s preference. Click OK. Repeat for all data layers.

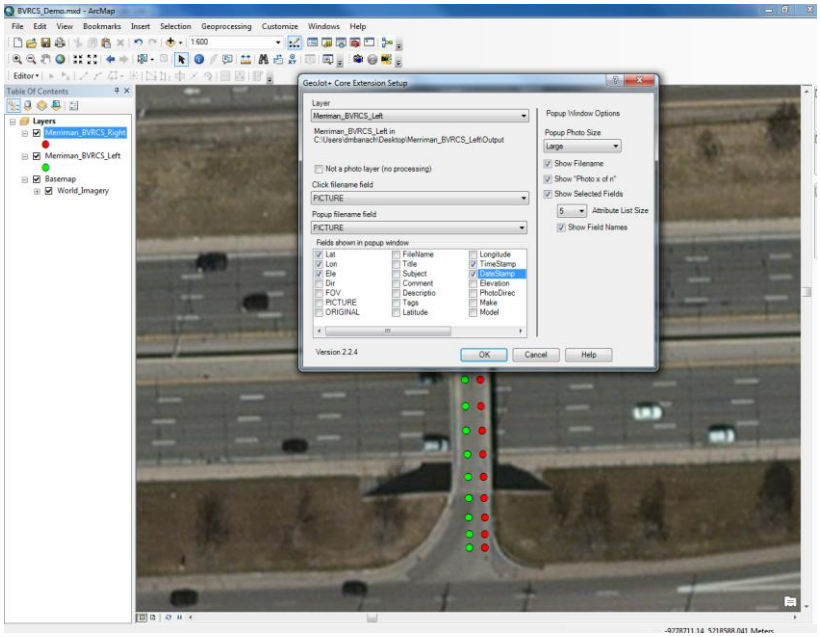


Figure 29: Hyperlink setup using GeoJot+ Core.

Next, select the “View Image” icon from the GeoJot+ toolbar. The cursor will change to an arrow and camera. By hovering over each point, the corresponding image(s) will appear (Figure 30). Pay close attention to the number of photos that occur at each point. Due to the fact that each GoPro collects two photos per second, but the GPS unit only collects one point per second, GeoJot+ places two photos at each GPS point. Manual interpolation and moving of images within ArcMap is possible, if desired. Each image can be viewed by clicking the right or left arrow in the popout window.

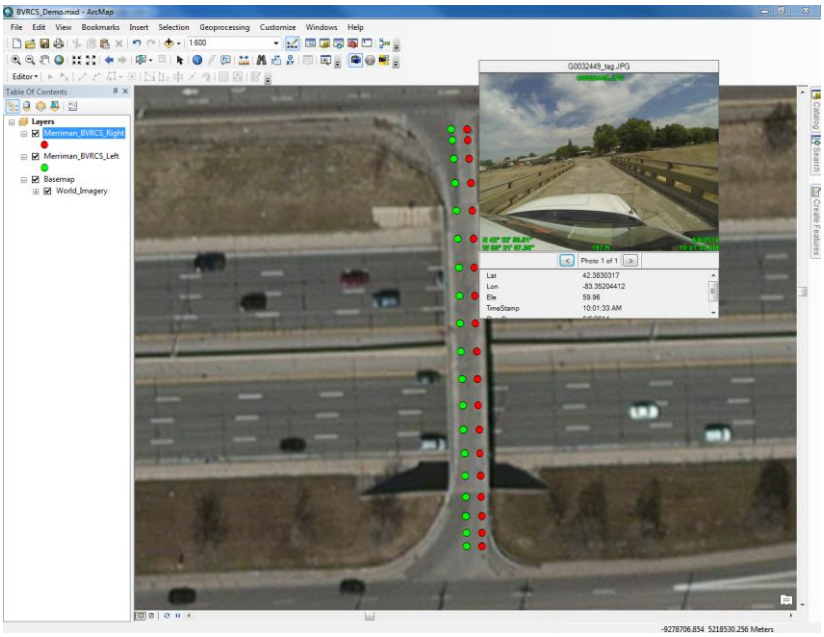


Figure 30: An example of a successful hyperlink using GeoJot+ Core.

6. Hyperlinking Within ArcMap (using ArcMap hyperlinks)

Hyperlinking capabilities also exist using ArcMap. However, in order to use it, an additional field must be created within each dataset layer. Open a dataset's attribute table. Click on the first icon (Table Options) and select "Add Field" (Figure 31). Name this field "HYPRLNK" and change the type to Text. Additionally, change the Field Properties Length to 150 (Figure 32). Click OK.

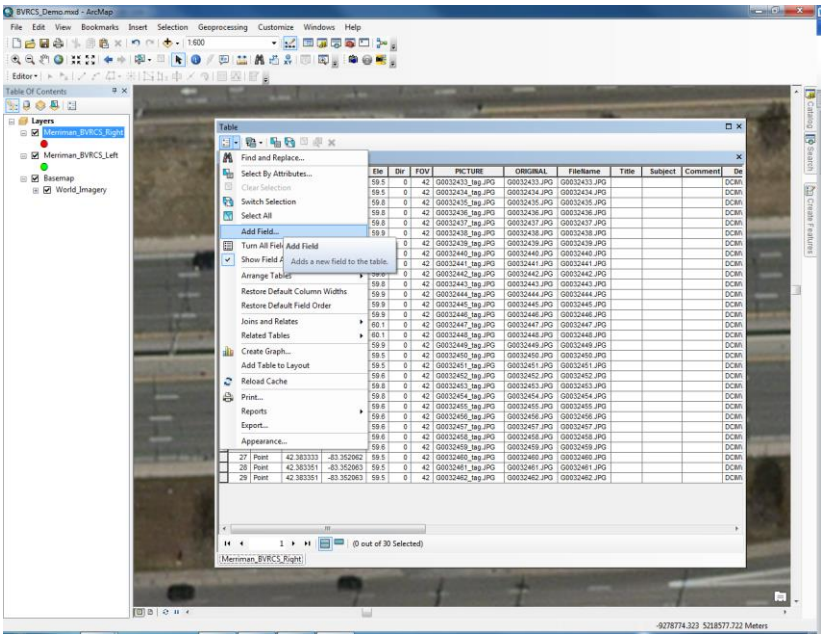


Figure 31: Adding a field within a data layer's attribute table.

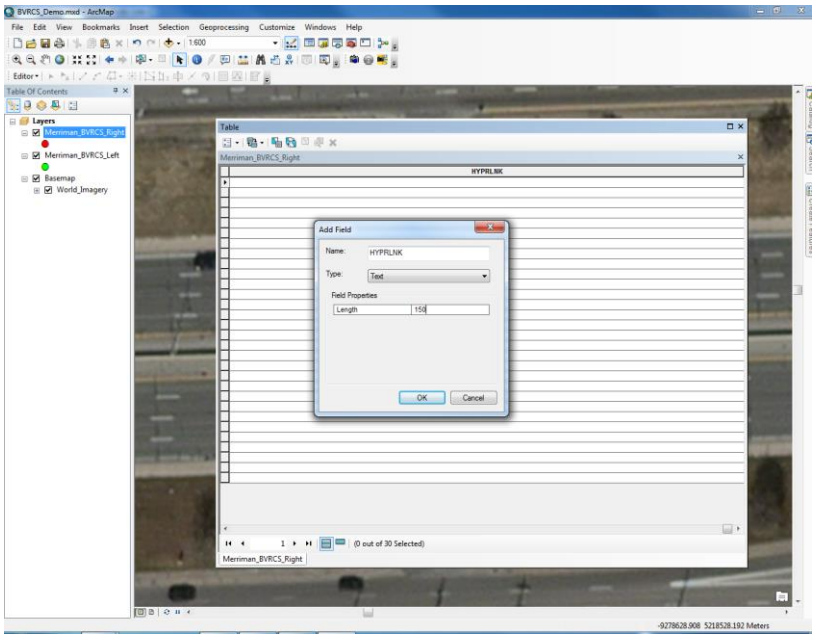


Figure 32: Using the Add Field tool within a layer's attribute table.

Start an edit session on the data layer. Copy and paste the first photo's file location into the new field. Repeat this process for each photo within the data set (Figure 33). Save the edits. Repeat this for the other data set.

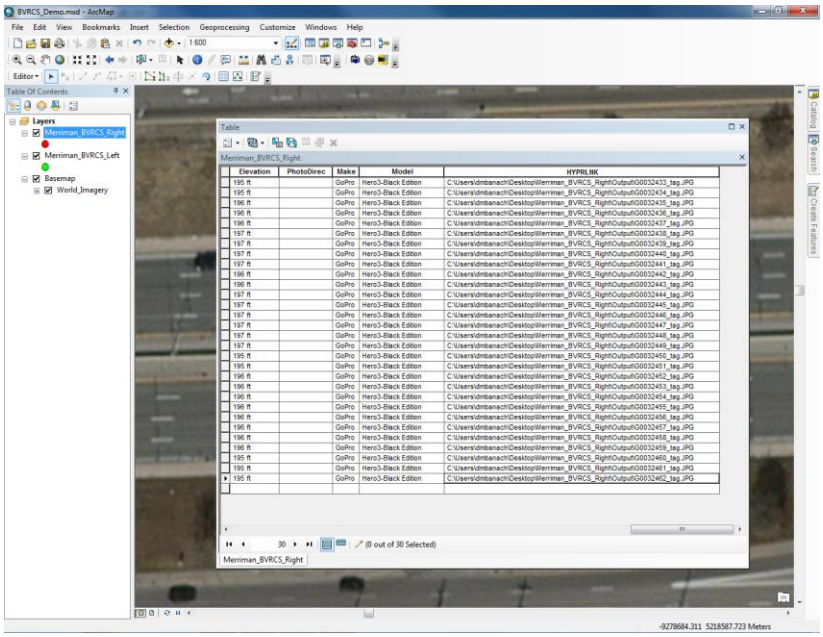


Figure 33: Hyperlink file locations setup within the attribute table.

Next, right click on either data layer and select "Properties". Click on the "Display" tab and check the box under Hyperlink and next to "Support Hyperlinks using field:" (Figure 34). Change the fieldname to HYPRLNK. Keep other options the same. Click OK and repeat for the other dataset.

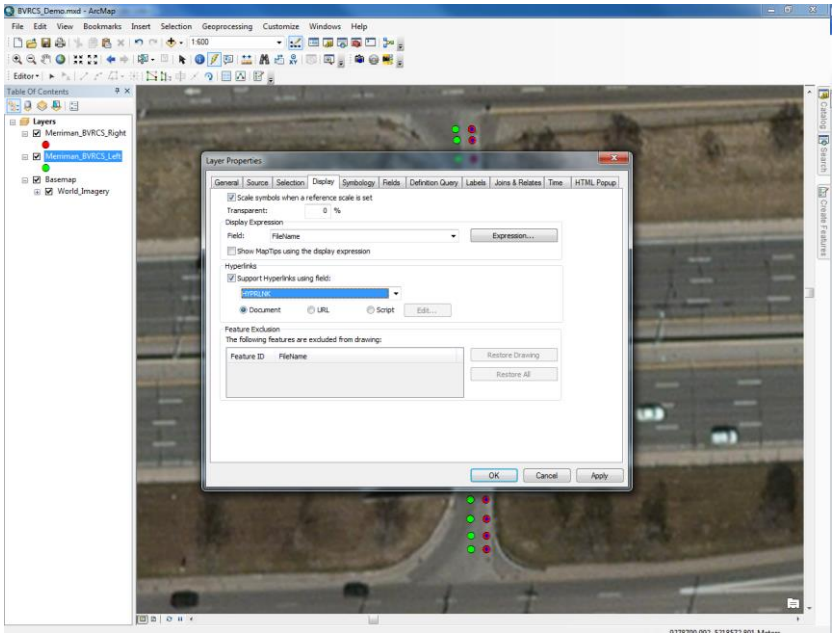


Figure 34: Setting up hyperlink capabilities within ArcMap.

Select the Hyperlink tool (lightning bolt on the Tools toolbar). Blue dots should appear on each point on the bridge. Click on a blue dot to select the image that corresponds to each location. Since some locations contain multiple images, the user must select which image to view). Click on Jump. A popup window containing the image will then appear (Figure 35).

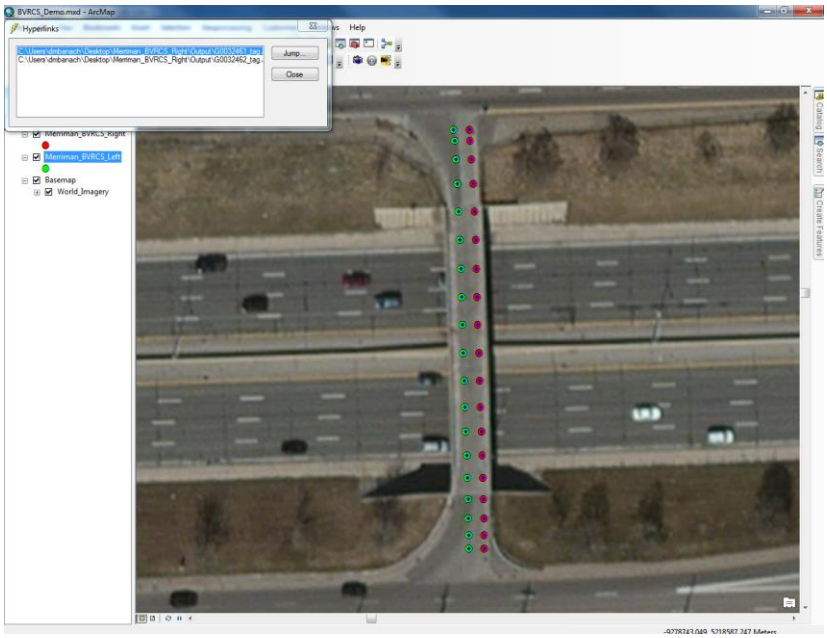


Figure 35: Hyperlink dots appear on top of each GPS location.

Conclusions

This "How to" manual provides users with an overview of the BVRCS. The system's components (equipment and software), data processing methods, and hyperlinking capabilities have been established through a step-by-step guide. Through using the BVRCS, local, state, and federal department of transportations (DOTs) can gain a better understanding into a bridge deck's condition that is more up-to-date than typical Streetview imagery available through Google. Additionally, this imagery is high enough resolution to allow the user to visually assess bridge distress features such as spalls (potholes). With the minimal costs associated with BVRCS (less than $1,000 for the cameras and GPS unit) and short setup and collection times (less than 30 minutes), DOTs can easily use the BVRCS for bridges within their areas of concentration.

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Appendix I - Implementation Action Plan

Based on the results of this project, the following Implementation Action Plan is meant to direct the Research Advisory Panel and other MDOT personnel in applying changes within department policy or practices. This guide provides an overview of the project and the problems it focused on changing. Additionally, the outcomes and potential values to MDOT are reviewed. Recommendations on how MDOT can incorporate remote sensing technologies for condition assessment are provided.

Project Title: Evaluation of Bridge Decks using Non-Destructive Evaluation (NDE) at Near Highway Speeds for Effective Asset Management

Project Number: Contract no. 2010-295, Auth. no. Z7, Research no. OR10-043

Principal Investigator: Theresa (Tess) M. Ahlborn, Michigan Technological University

Project Manager: Eric Burns, MDOT

Research Manager: Michael Townley, MDOT

Description of Problem

With approximately 4 million miles of roads, 117,000 miles of railroad, and 600,000 bridges, the transportation infrastructure system in the United States is vast and complex (Landers 1992). With millions of people relying on the transportation network, the reliability, safety, and security of these infrastructure components is critical for the economic well-being of the country. Maintenance reports have indicated that nationwide, approximately 25% of bridges are structurally deficient or functionally obsolete, with repair costs estimated to be $140 billion (AASHTO 2008). MDOT has previously reported that 12% of the state's 11,000 bridges are structurally deficient. To efficiently monitor and assess bridges and other transportation related components, such as roadside assets, pump stations, and traffic conditions, new advancements in technologies that can minimize costs and periods of inspection, as well as improve the public's mobility, need to be assessed and incorporated into structural health monitoring strategies.

Current bridge assessment techniques, including coring, conductivity, pavement sounding using acoustics (i.e. chain dragging and hammer soundings) and ground penetrating radar, can be tedious, time consuming, labor intensive, operator dependent, and cost prohibitive. These tests often include visual inspections or interpretations, creating results that are operator dependent. Additionally, these tests often require lane and road closures, which increase safety concerns for both inspection teams and drivers. Therefore, any advancement in technology could greatly enhance transportation asset inspection and maintenance procedures.

Advancements in the field of remote sensing can provide transportation agencies with ready, rapidly deployable systems capable of collecting surface and subsurface condition information for concrete bridge decks. For the purposes of this research and demonstration project, optical and thermal sensors were used to collect data on potential spalls, delaminations, and cracking, and to create photo inventories. The overall goals for this project were to demonstrate and enhance remote sensing capabilities to meet the needs of MDOT, often at resolutions higher than what is currently available, and to improve and combine multiple systems onto a single vehicle. Data collection at near-highway speed for the top of deck assessment and proof of concept testing for the underside of the deck was conducted for surface and subsurface evaluation. By successfully completing these objectives, MDOT has the capability to enhance their inspection methods, potentially creating a less-costly assessment procedure and a safer working environment for assessors and the general public.

Major Discoveries

Results from laboratory studies and field applications have shown that several non-destructive, remote sensing technologies are capable of providing condition assessment of both the top and bottom of concrete decks for highway bridges. The following is a review of the major accomplishments and discoveries made with each system. An integrated, single platform system was developed for application on the top riding surface of concrete bridge decks at near highway speeds while an additional technology was investigated for use on the underside of the deck.

Top of Bridge Deck

BridgeViewer Remote Camera System (BVRCS)

Through the use of BVRCS, the project team has successfully demonstrated the use of a low cost deployable system that provides visual analysis of bridge deck conditions, which can occur during an active bridge inspection. With imagery being collected as a vehicle is driven across the bridge, multiple bridge decks can be assessed per day without additional costs after the initial setup. Although higher resolution imagery can be obtained using more expensive cameras, GoPro imagery has proved to provide imagery with a resolution high enough to discern spalls and patchwork on a bridge deck at 45 mph and above. The fact that distress features can be located using GoPro imagery indicates that using a vehicle with cameras attached to the vehicle's hood can provide a quicker assessment methodology than visual inspection. The Michigan Tech Research Institute (MTRI) has proven that transportation agencies, such as MDOT, can have access to an up-to-date photo inventory of a bridge deck and distress features by incorporating the BVRCS in bridge deck assessments.

3D Optical Bridge-evaluation System (3DOBS)
3DOBS was upgraded to address two main objectives. The first is to increase the speed of the collection vehicle and the second was to increase resolution for crack detection. This was accomplished with two new cameras as this was not possible with a single camera with current technology. The Red Epic allowed a version of 3DOBS to operate at speeds up to 45 mph over bridge decks with imagery resolution similar to that of the original 3 mph prototype developed under the USDOT/RITA project *Bridge Condition Assessment Using Remote Sensors* (Ahlborn et. al, 2012). This would allow for the collection vehicle to collect the necessary imagery without closing traffic lanes or the entire bridge. A Nikon D800 was used for crack detection but at speeds less than 5 mph. With the increased resolution, bridge deck cracking can be classified down to 1/32nd in. After the imagery was collected, it was processed using Agisoft PhotoScan to generate georeferenced orthoimagery and digital elevation models (DEMs). These data sets are useful to transportation agencies for locating and characterizing deck spalls and cracking.

System Integration
Optical imagery can assist in the assessment of the surface condition of concrete bridge decks while thermal imagery can assist with detection of subsurface anomalies such as delaminations. Recognizing that combining technologies will enhance the inspectors ability to assess a bridge element, 3DOBS, passive infrared (IR) thermography, and BVRCS were combined onto a single vehicle for bridge condition assessment. A new vehicle mount was developed to hold both 3DOBS and the thermal camera system owned and operated by BridgeGuard, Inc. Dual mounting allows for the simultaneous collection of optical and thermal imagery as the vehicle travels at near-highway speed. A Trimble GPS antenna was also attached to the mount so the imagery can be referenced to the same location in a GIS. The GPS data is also used for the referencing of BVRCS by using its track log. Eight separate layers of data are generated from the collected imagery, including orthoimagery, DEM, hillshade of the DEM, LAS point cloud of the bridge deck, thermal mosaic, detected spalls, detected cracks, and potential delaminations. As imagery from each system is processed it is similarly referenced and can easily be displayed together in a GIS. Combining technologies can be used in decision support systems for asset management.

Underside of Bridge Deck and Fascia

Active IR Thermography
To address the limitations presented by passive IR thermography, specifically on the underside of a bridge deck where the presence of solar radiation is limited, an active IR thermography proof of concept test was conducted to quantify delaminations on the Franklin Street bridge in downtown Grand Rapids, MI. Using a portable infrared heater and two thermal imaging cameras, including a high resolution FLIR SC640 and a compact lower resolution FLIR Tau 2, delaminations were successfully detected on the bottom of the bridge deck and a pier cap by actively heating the test areas using heat times of 5 minutes and 15 minutes. A simple visual analysis method was developed and provided a quantified area of each subsurface defect through a correlation of thermal and optical images. In addition, the feasibility of using this technology for delamination depth prediction was investigated and confirmed by using a laboratory developed analysis method based on thermal contrast between areas of delamination and areas of sound concrete.

The results of the active IR thermography field application have led to the consideration of several improvements to the test set-up and methodology prior to implementation of this testing technique by bridge inspectors. Compared to conventional non-destructive testing methods commonly used such as hammer sounding, active IR thermography testing requires a longer inspection time, which is dependent on the depth of delaminations within the test area. In the current study, test areas of approximately three feet by three feet were investigated. Following a 15 min. heat time, a 35 min. observation time was necessary to completely define delaminations of variable depth. Similarly, a 25 min. observation time was necessary after testing conducted with a 5 min. heat time. Also taking into account equipment set-up time and calibrations, the active IR thermography test method takes longer to conduct than hammer sounding. With further development of this technology could prove useful for detailed inspections.

How the Information will be used in MDOT

Integrated System on Top of Bridge Deck

Remote sensing technologies have the potential to allow MDOT to assess bridge deck condition without the need to close traffic lanes or have inspectors exposed. With 3DOBS, BridgeGuard, and BVRCS combined on the same vehicle, a complete understanding of the bridges condition could be quickly obtained. Already, staff from MDOT Survey Support has expressed interest in being able to use and share the types of high-resolution imagery and digital model data that can be produced from these cameras. MDOT Bridge Management team members, including inspectors and bridge managers, are logical consumers of the bridge condition data derived from optical and thermal data sources, as the percent spalled and percent delaminated for concrete bridge deck surfaces are already information that is needed in current bridge inspections. Data collected with these technologies can be used to assign NBI ratings to bridges decks while at the same time keeping inspectors safe and creating repeatable and objective results.

MDOT may choose to purchase equipment and software for its own use in some areas, such as BVRCS. The MDOT Survey Support staff may want to process imagery data sets in-house using software tested in this project to create custom products needed by MDOT. However, implementation for more service-type data needs, such as bridge inspections using combined 3DOBS and thermal IR, may be more suited to collection and processing via third-party vendors, especially where MDOT is already working with the private sector.

For BVRCS, MDOT can purchase the individual components of BVRCS for a small cost. Each GoPro (Hero 3) camera currently costs approximately $300 and the GPS device also costs approximately $300. Additionally, other small parts needed for the mounting system will bring the overall total to approximately $1,000. Besides providing inspectors with a photo inventory of the entire bridge deck, BVRCS can also be used for inspection preparation. By using up-to-date imagery of the bridge deck, inspectors will have a better idea into what type of equipment is needed for individualized inspections, and if traffic control will be required. Although other photo inventories such as Google Street View provide imagery similar to what BVRCS can produce, agencies have control over when the images are produced or when updated imagery

will be collected. BVRCS allows for total control over updates of critical infrastructure based on transportation agency schedules and needs.

Implementation of the BVRCS requires little training to collect and process data. A "How To" manual has been written and provides step-by-step instructions that indicated how to collect, processes, and map / visualize collected data. Training sessions were suggested during an October 2014 project meeting in Lansing, Michigan and in November 2014, MDOT personnel visited MTRI in Ann Arbor, Michigan where they were briefed about BVRCS and received a full data processing and visualization demonstration. As needed, additional training sessions could occur.

It is recommended that remote sensing technologies such as these optical and thermal options be integrated into the bridge inspection program to assist in the evaluation of the top surface of concrete bridge decks. To attain full implementation of integrated optical and thermal imagery, it is recommended that MDOT begin by conducting a pilot study to demonstrate the usability and productivity of the system. It is recommended that a pilot study of up to 20 bridge decks in the seven MDOT regions be performed to provide further education on how the system operates and understand the repeatability of the method. Bridges should include a range of deck surface ratings and deck sizes. It is also recommended that future discussions be held with MDOT to determine how to best use the information captured from these combined technologies. Some questions to be addressed include whether such a system should be used until the deck has reached a specific condition state which then triggers a maintenance alert, how does the data correlate to ride quality, can deterioration curves be generated from time-history data, how can MDOT regions and counties use the information for condition reporting or load rating, and how does MDOT best use this information to prioritize preservation.

Underside of Bridge Deck and Fascia

Given the current state of the active IR thermography test method, the appropriate application of this technology must be identified. With limited laboratory and field test data, it is first and foremost recommended that additional research and investigations be conducted prior to implementation as a commonly used condition assessment tool by bridge inspectors. The proof of concept testing successfully identified several areas for improvement. Test equipment, procedures and analysis methods require refinement to produce repeatable results. One of the comparisons made from the results of the active IR study on the underside of the Franklin Street bridge was between a high resolution FLIR SC640 thermal camera and a lower resolution FLIR Tau 2 camera. Understanding that inspectors are likely to use different thermal cameras than were used in this research with respect to resolution, it is important that any new testing procedures or analysis methods consider such difference to ensure repeatability. Further study using the technique on vertical surfaces such as pier caps and fascia beams is needed beyond the proof of concept testing demonstrated here.

It is recommended that active IR thermography be used in detailed inspections after which general scoping inspections have already been conducted but owners and end users will be ultimately responsible for making such an application decision. For wide spread use and applications other than detailed inspections, inspection times using active IR thermography

should be reduced through additional research before it can be deemed a deploy acceptable technology.

It is further recommended that training sessions be provided to bridge inspectors so they can gain a better understanding of the thermal camera within their department and how its features and capabilities affect delamination detection. As lower cost and smaller thermal imaging cameras are manufactured with higher resolution, repeatability of active IR thermography testing will become achievable by inspectors statewide.

Value Added to MDOT

Top of Bridge Deck

Through careful evaluation and conducting multiple tests in various locations, the project team has demonstrated how 3DOBS, passive IR thermography, and BVRCS can provide quality data on the condition of concrete bridge decks. These systems also have the capability to provide repeatable collects of the same bridge for change detection over time. MDOT is now gaining access to advanced technologies that can provide cheaper and safer ways of collecting critical operations and maintenance information.

Processing optical and thermal imagery provided from 3DOBS and BridgeGuard, Inc., respectively, data was able to produce spall and delamination detections that are comparable to current visual and sounding techniques. Results from these analyses indicated that using a near highway speed system to collect data will produce quality outputs, which in turn will create safer working conditions by reducing the time onsite workers need to spend on highly traveled roads. Additionally, the area and percent spall or delamination can be automatically calculated. All of these outputs are provided as GIS layers that can be displayed together thereby allowing for a more complete understanding of the deck condition. To conduct this type of analysis, MDOT will need to acquire the appropriate cameras and train qualified staff to process the imagery. It is recommended that future work in this area include training for MDOT personnel to better understand the processing steps involved with the optical and thermal imagery, independent of whether implementation is in-house or through a third-party service. In addition, this type of imagery and analysis would diminish costs associated with bridge inspections, such as lane closures and potentially also the amount of personnel time needed to conduct a traditional inspection (i.e. labor costs).

By incorporating BVRCS into bridge deck assessments, MDOT can quickly obtain temporally accurate imagery of bridge decks and store the information into photo inventories. These inventories can be accessed and prove especially beneficial prior to the next scheduled bridge assessment (typically every two years for bridge infrastructure). The photo inventory can be used as a visual comparison between each inspection and help determine if immediate actions are required for the infrastructure. This photo inventory can also include photos that are watermarked with information pertaining to the location (latitude and longitude), date, time, and elevation (among other options) of each image. Additionally, by incorporating a GPS device and geotagging the GoPro imagery, MDOT can create a map within GIS software (ESRI's ArcMap)

to help visualize where each photo was taken as the vehicle drove across the bridge. Within the GIS software, hyperlinks can be set up to allow the user to select certain locations on the bridge where data exists, allowing a pop-up window to show which photos were taken at each point. Having geotagged imagery can make post-assessment reviews easier for the bridge inspector. Overall, by using BVRCS to collect a photo inventory, MDOT will have an up-to-date understanding of the bridge deck that can help identify locations of distress features and potential future actions that need to take place, leading to more effective asset management for concrete bridge decks.

Underside of Bridge Deck and Fascia

The application of active IR thermography for a proof of concept field demonstration has shown that this remote sensing technology is acceptable for detecting and quantifying delaminations on the underside of a concrete bridge deck and the side of pier caps. Through this testing application, limitations including inspection time, environmental factors and analysis methods were identified and provide insight for the advancement of active IR thermography testing. While conventional inspection techniques such as hammer sounding are capable of delamination detection over a relatively short inspection time, further research and development of this technology may allow for more accurate estimates of delamination area than traditional inspection techniques. In addition, further reducing the inspection time of this technology will improve the cost effectiveness of deployment and make it a contending inspection technique for bridge health monitoring. As with technologies deployed for the top deck surface, implementation of active thermal IR testing can lead to enhanced inspections, resulting in more informed decision-making regarding timing for maintenance and repair.

Implementation Plan Checklist

The following checklist provides a summary for MDOT on understanding the type of results achieved during this project and the items or actions necessary to implement these results.

Results achieved through this research (check all that apply)		Items/Actions needed to implement results (check all that apply)	
X	Knowledge to assist MDOT	X	Management decision
X	Manual change	X	Funding
X	Policy development or change	X	Training
X	Development of software/computer application	X	Information technology deployment
X	Additional research needed	X	Information Sharing
	Project produced no usable results		Other (specify)
	Other (describe)		