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Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 6-A: A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions

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Purpose of this document

This document describes the process of planning a data collection mission. This will involve a review of where unpaved roads are in the collection area, a review of possible obstacles to flight operations, and the creation of a flight trajectory. This document is likely to be updated during the course of the program, based on user feedback, and the advice of domain experts.

Motivation

In order to be able to collect aerial road condition data, either from a manned or autonomous platform, one must know what needs to be collected (which roads are ready for inspection in a given area), what might interfere with that collection (obstructions to either flight or observation), and how best to collect the needed data. This process could be complicated, tedious, and expensive if conducted in the traditional manner. We are proposing to provide tools to assist the planner in this task, and in making a plan as quickly, and efficiently, as possible.

Mission Planning Sub-tasks

Asset Definition

We are only interested in measuring the condition of unpaved roads. While most people tasked with planning a collection mission will already know which roads are unpaved, having a visual way of locating possible target roads is useful. The planner will want to have a convenient way of displaying at least the following information as map overlays:

- Unpaved roads, and possible classification as gravel or bare-earth
- Conditions, if known, as of last inspection
- Date of last inspection
- Date and type of last remediation
- Public comments

Based on these (and possibly other) factors, the mission planner will select an area for data collection. The section below entitled "***Deriving an unpaved roads network as a major mission planning input using high-resolution aerial imagery***" describes in detail how an unpaved roads network can be created to define the asset that will be assessed by this project's sensor and platforms.

Flight Safety and Effectiveness Inspection

Before choosing a flight plan, the site needs to be evaluated for safe flight operations, as well as suitability for aerial collection. For example, the presence of high-voltage towers and distribution lines, the location of restricted airspaces, etc., will restrict the possible flight paths. Also, the presence of visual obstructions (trees, shadows, etc.) may make certain areas difficult (or impossible) to evaluate from the air.

This process needs to be defined separately for manned and unmanned collections; there are different requirements if the collection is to be performed by a manned sensor.

Manned Mission:

Although planning can be performed by anyone, a licensed pilot will need to review and approve any plan, to ensure that FAA regulations are followed, and adequate safety margins are included.

Unmanned Mission:

Unmanned collections take place at a lower altitude than manned flights, and have a larger number of possible obstructions (e.g. small radio towers, which would not be an issue for a manned platform, will be a possible obstruction for a small UAS).

Flight Trajectory Planning

The flight trajectory will be created by a tool called the Ground Station Control program, commercially available software that the project team has been evaluating. The trajectory will be based not only on the location(s) of the roads, but on the outcome of the previous flight-safety site assessment. The program has the ability, once programmed with a flight-plan, to automatically take-off, fly the mission, and auto-land. At any time, however, the operator can input flight adjustments using a joystick, or the safty-pilot can resume full manual control if needed.

The Ground Station Control program uses maps obtained from Google Earth to assist the user in accurate flight planning. An example of its use is given below.

First, the user brings up the tool, and selects the general area where a data collection is wanted. The typical view is shown below in Figure 1:

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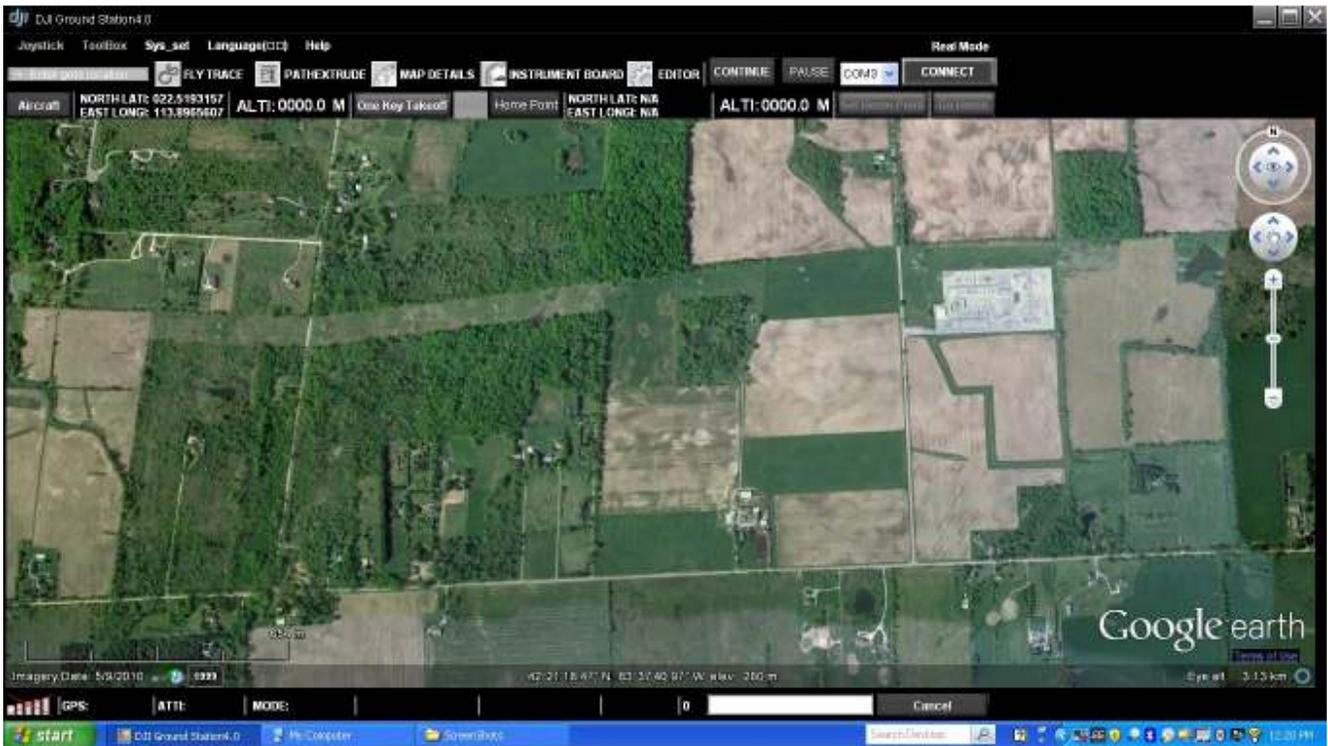


Figure 1: Typical view of opening screen in Ground Station program

Along with the usual Google Earth screen controls, there are a number of functions related to creating a flight trajectory and in-flight operations. The first thing a user will likely want to do is input a flight-plan consisting of a series of waypoints and associated flight parameters (altitude, speed, etc.). The screen showing an editing session in progress is shown below in Figure 2:

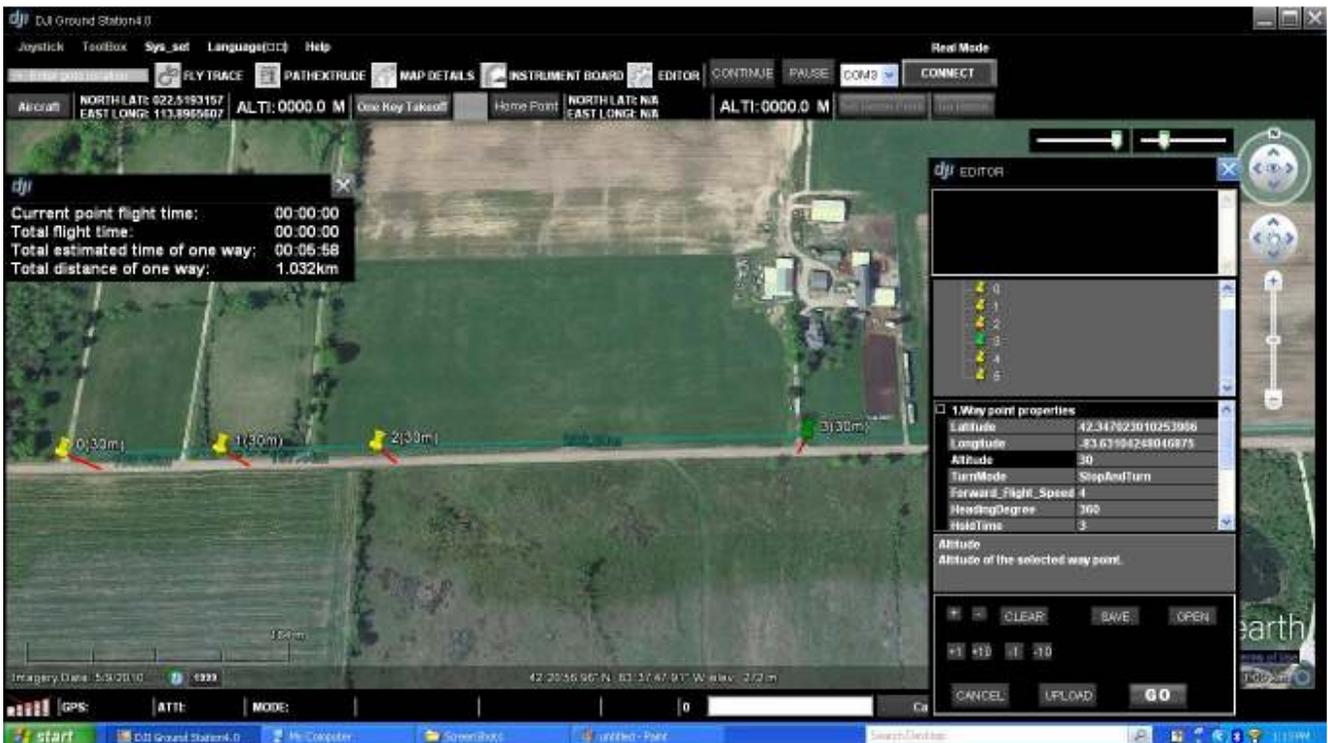


Figure 2: Editing session in the Ground Station program

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For each waypoint, the user may select the altitude, loiter, speed to next waypoint, and type of turn (e.g. “stop and rotate to next heading”, or “smooth curve”, among others). The waypoint is shown as a “pushpin” icon in space, with a red vertical line descending to the ground directly below it. This gives the user some visual feedback concerning the overall height of the trajectory, and is useful where the terrain has changing altitudes. Also shown, on the left, is a summary of the current mission. During planning, only the estimated time and distance are shown; during a flight, the actual flight time is also displayed.

A completed mission is shown below. The flight begins on the road at the left of the screen, proceeds down the road at an altitude of 30m for just under a kilometer, leaves the road to the south, and proceeds back to the starting point at an altitude of 50m.

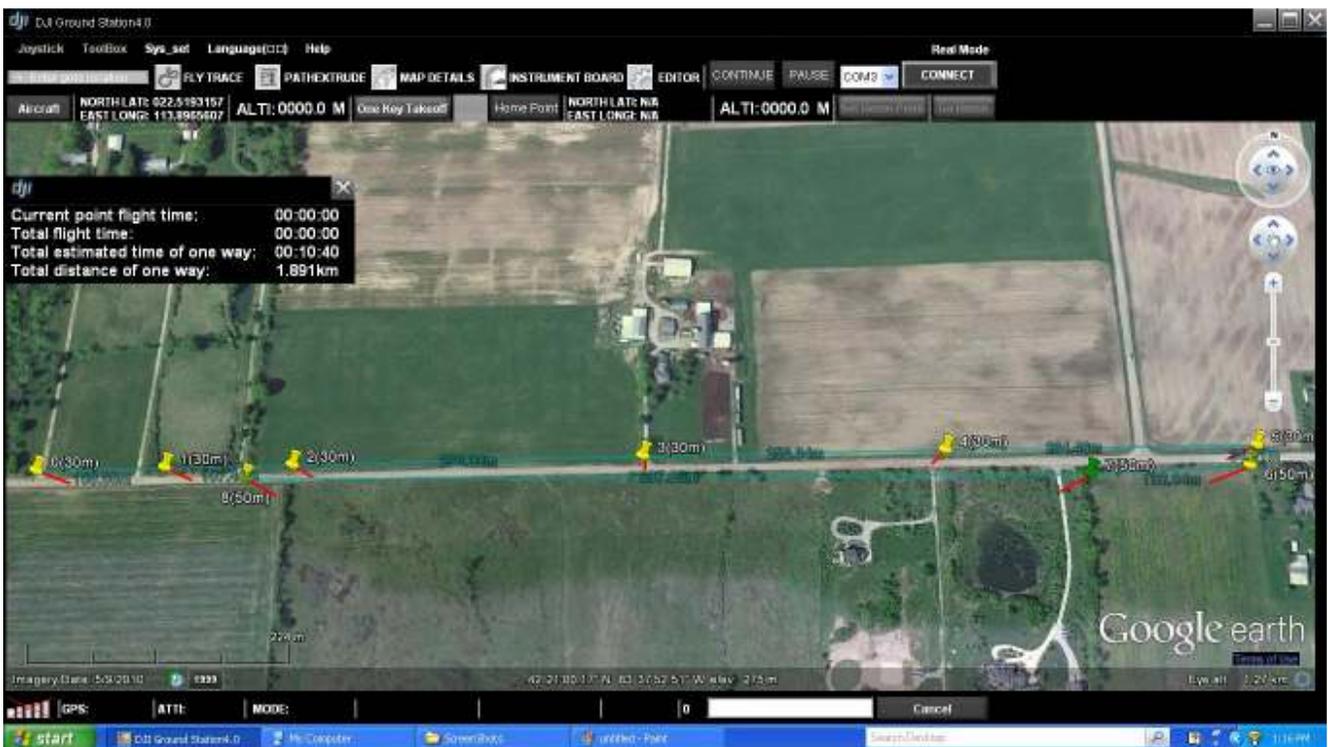


Figure 3: Complete flight path, looking down

It is possible to view the flight path from any angle and altitude, to help visualize the trajectory. An example of an alternate view is shown below:

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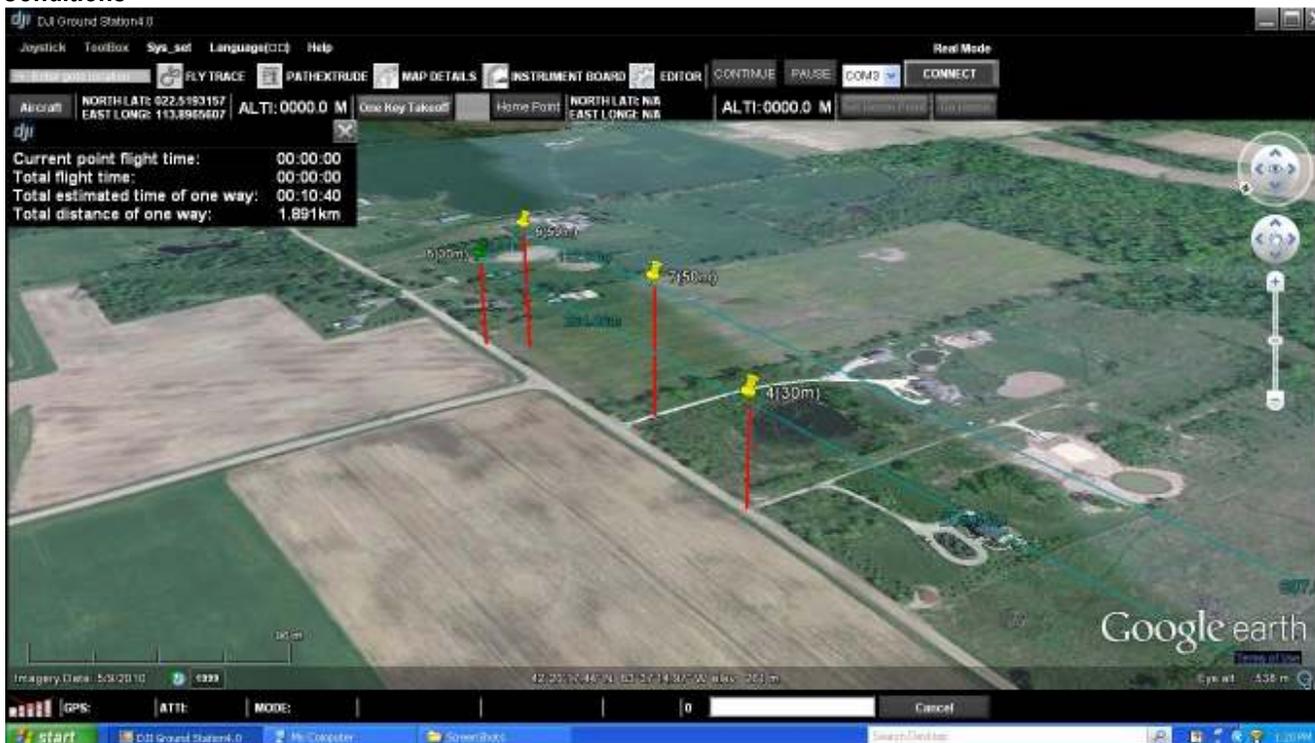


Figure 4: Oblique view of flight path

Once the flight path is chosen (which may be done anywhere), the user should inspect the actual location for possible obstructions that were not shown on the Google Earth images. In particular, communications towers and power distribution infrastructure change regularly, and the current Google Earth imagery may well be out-of-date.

The flight plan is loaded into the autopilot, and the mission is ready to begin.

Deriving an unpaved roads network as a major mission planning input using high-resolution aerial imagerylight Trajectory Planning

Overview of deriving an unpaved roads network

The mission of Task 6.2 from the project's Statement of Work was to derive an unpaved road network as a major input into the project's mission planning system from high resolution aerial imagery. The method should produce a roads network that would be easily adaptable to other mission planning systems as well. Through one of the project's cost-share partners at the Southeastern Michigan Council of Governments (SEMCOG), 30 cm spatial resolution aerial photography that covered the 7-county SEMCOG region in Southeast Michigan was made available for use for mapping of unpaved roads. The goal was to create an unpaved road network since the status of roads as unpaved vs. paved does not currently exist as part of the Michigan Framework Roads Network GIS layer and has been indicated as a priority by SEMCOG, Michigan's Transportation Asset Management Council (TAMC), and local government agencies such as the Road Commission for Oakland County (RCOC), all cost-share partners on this project. The final form was a road type layer that will form a major mission planning

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input for route definition and flight path analysis. Any deployed system (manned or unmanned) needs to know which roads it will be flying over, and understanding which ones are unpaved and in need of sensing by this project's system or systems is a basic requirement. By using a combination of Trimble's eCognition software and ESRI's ArcGIS software, a methodology to extract unpaved roads was derived by the project team and the status of a sample area of roads in two Michigan Counties was added to the Michigan Framework Roads Network attribute table. The classification was also able to demonstrate the ability to pull out unpaved roads that were not in the Michigan Framework Roads Network, which is helpful when not all unpaved roads were included in existing GIS layers.

Study area and aerial imagery data

The 30-cm aerial imagery included four different bands in the red, green, blue and infrared portion of the electromagnetic spectrum that were used to identify the unpaved roads within southeast Michigan. The classification was first applied to the northern rural region of Oakland County (Figures 5 and 6).

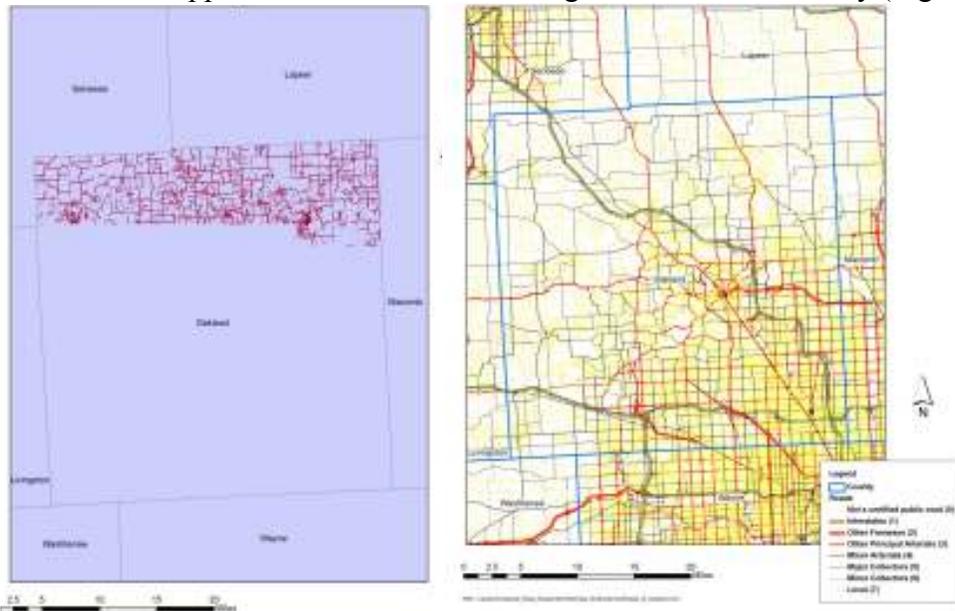


Figure 5. The location of unpaved roads classified in northern Oakland County from the SEMCOG 4-band aerial imagery and the existing Michigan Framework Roads Network for the area.

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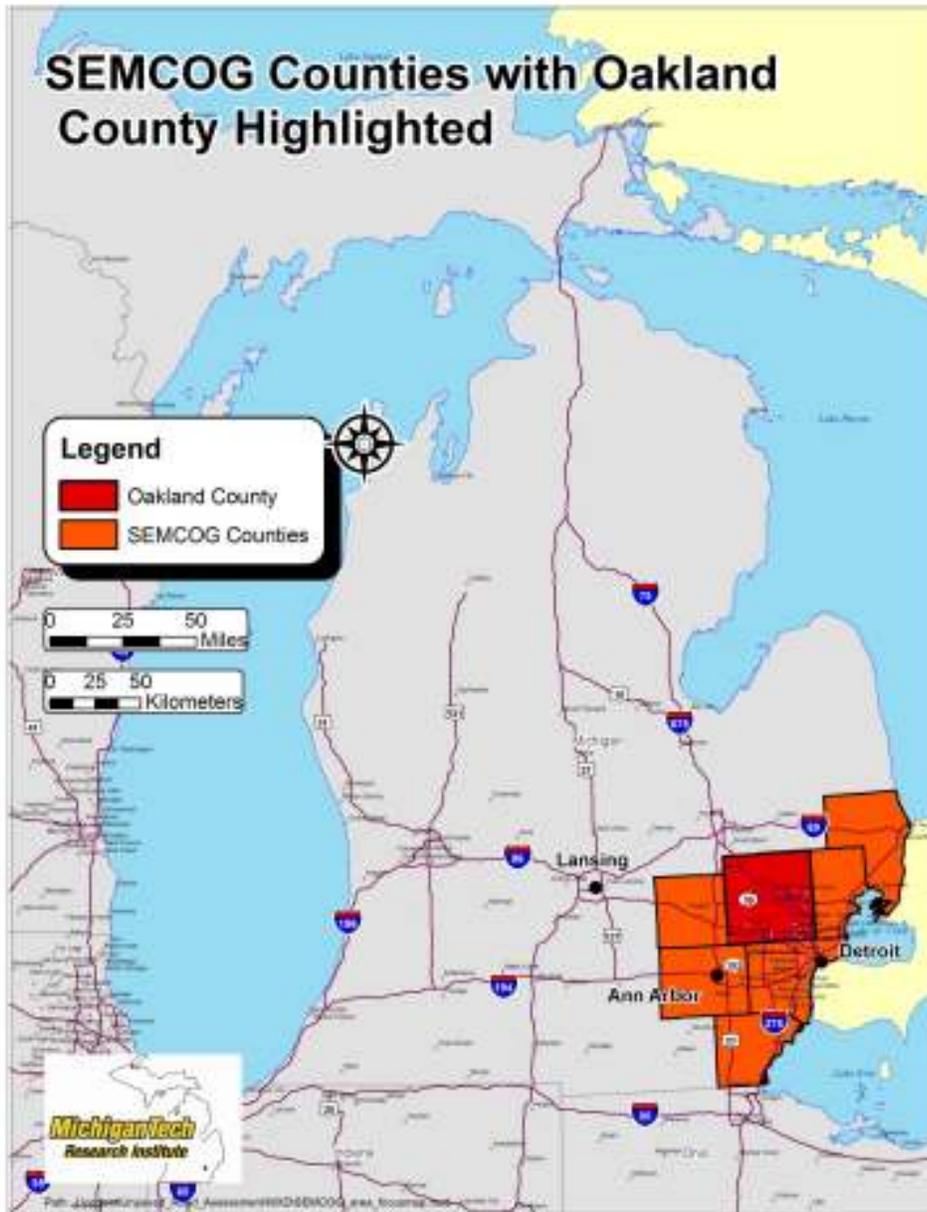


Figure 6: The Oakland County, Michigan initial unpaved roads asset mapping area in a regional context.

The methodology applied to the aerial images for Oakland County included segmentation in Trimble’s eCognition object-based image classification software, applying the classification in eCognition, and then importing the unpaved road polygons into ESRI’s ArcGIS for further analysis.

Methodology

Principal Component Analysis

Before applying the segmentation and classification of the unpaved roads, the images were mosaiced into 2x2 squares in ArcGIS and then a principle component analysis was performed on each mosaic. Principal component analysis (PCA) is based on an orthogonal transformation of the data to convert a set of data of possibly correlated variables into a set of values of linearly uncorrelated variables called

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principal components (Joliffe 2002). The first principal component has the largest variance and accounts for as much of the variability as possible. Each succeeding component has the highest variance under the rule that it be orthogonal to (i.e., uncorrelated with) the preceding components. In this case, the principal component analysis was applied to the 4-band aerial mosaic imagery and three principle components were chosen as the output. The first principle component was used to mask out shadow regions from trees over the unpaved roads and could also be used to detect bare soil areas (Nobrega et al. 2008).

Segmentation to Detect Roads Network

Using Trimble's eCognition software, the aerial images were segmented using the object-based image analysis software to segment objects contained within the aerial images (roads, trees, lakes, fields and houses). The 4-band aerial images, principal component analysis (3 principal components) and a thematic layer that was a 30-foot buffer around the center line of the Michigan Framework Roads Network were imported into eCognition for the segmentation. The process involved a chessboard segmentation, a multi-resolution segmentation using a compactness of 10 and a shape and compactness of .9 and .1, respectively. The final segmentation piece was combining objects that had a maximum spectral difference of 5 between neighboring objects. The result was an image with the roads as objects of the segmentation that were then classified within a rule set in eCognition (Figure 7) from applied thresholds.

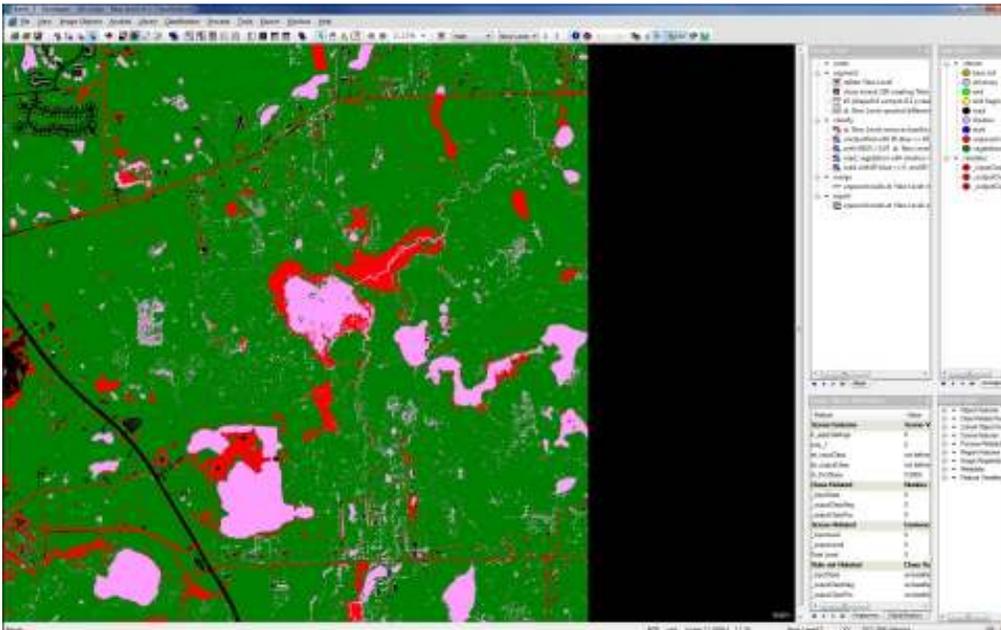


Figure 7. An example for the same mosaic in Figure 8 of the image classification and segmentation in eCognition.

Classification of Unpaved Roads

A rule set was developed in eCognition to classify the unpaved roads and to also classify objects that were not unpaved roads in order to extract the polygons for analysis in ArcGIS. This same rule set is also applicable through any computer programming language (i.e. MATLAB, IDL or Python), but without the added capability that eCognition has to extract "objects" from a set of geospatial images.

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The first part of the classification development and the rule set was to pull out any areas that would be considered an impervious or semi-impervious object by taking the mean of the infrared channel minus the mean of the blue channel and calling anything that was greater or equal to 65, our imposed threshold, an impervious or semi-impervious object (this idea is based on input from Nobrega et al. 2008). Then the normalized data vegetation index was applied to aerial imagery to pull out the vegetation, where values that were greater than 0.07 were labeled vegetation, including any thing that was previously defined as semi-impervious or impervious. From the vegetation and roads values, objects with a value greater than -130 were classified as a shadow from the mean of the blue value in the object minus the first principle component (Nobrega et al. 2008). The last part of the classification was to identify objects as unpaved roads by taking the mean infrared band minus the mean of the blue and anything greater than zero, in addition to the mean of the infrared value minus the mean of the green value. When this value was greater than 2.5, then these objects were called unpaved roads, only for the objects already defined as impervious or semi-impervious. Figure 7 above, is an example of this process and the red, unpaved road polygons were exported to ArcGIS for further analysis and to label roads in Michigan Framework Roads Network as unpaved based on the above analysis methods. There was also minimal manual editing in ArcGIS for places where old asphalt, which is spectrally similar, was also called an unpaved road.

Labeling the Michigan Framework Roads Network in ArcGIS

The unpaved roads polygons that were detected and classified in eCognition were imported as a standard ESRI shapefile into ArcGIS (Figure 8). These polygons were set to the same projection as the Michigan Framework Roads Network and then intersected with a 30 foot buffer layer around the Michigan Framework Roads Network. The features were intersected in order to remove areas such as bare soils in a field that were being labeled as unpaved roads due to their spectral similarity. The first goal was to label the unpaved road in the attribute table and to calculate the percentage coverage of the eCognition polygons overlaid onto the Michigan Framework Roads vector. Only those road types that were National Functional Classification types 4, 5, 6, or 7 were assessed to see if the eCognition-based methods called them unpaved as they can be either paved or unpaved. Types 4, 5, 6, and 7 cover: Minor Arterials (4), Major Collectors (5), Minor Collectors (6), and Local (7) roads while Interstates (1), Other Freeways (2), and Other Principal Arterials (3) are nearly always paved and were excluded from further analysis. This was accomplished by converting the eCognition unpaved road polygons that were intersected with the Michigan Framework Roads Network into a line feature with the Polygon to Line tool. The line features and also the polygons of unpaved roads from eCognition were segmented due to tree cover, so unpaved roads are detected only where there are no trees or shadows.

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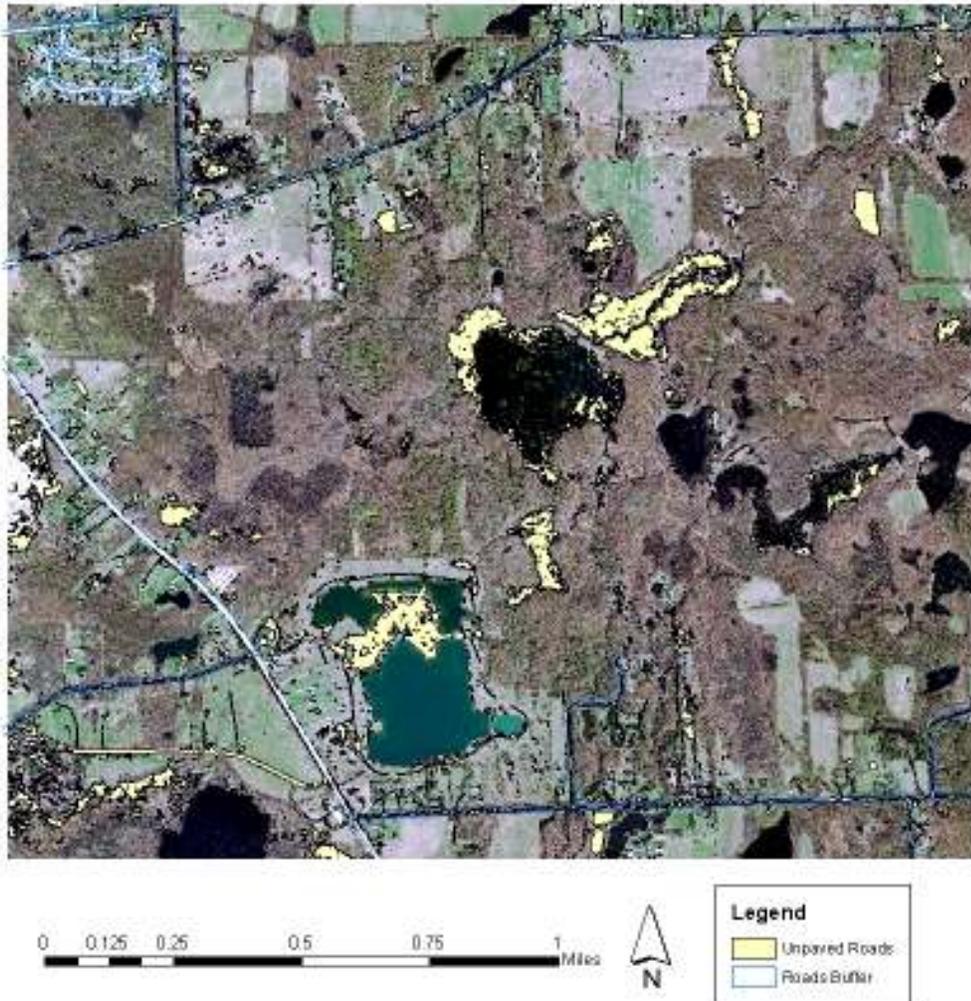


Figure 8. A 2x2 mosaic showing the initial unpaved roads polygons (yellow) and the Michigan Framework Roads Network 30 foot buffer that was intersected to get rid of polygons that were spectrally similar to unpaved roads but were not near the roads network.

The next step was to take those segmented unpaved roads from eCognition that were converted into a vector or a line feature and to open the attribute table. The length was recalculated for each line segment using the ArcGIS Calculate Geometry function. Using the LRS_LINK from the Michigan Framework Roads Network as a unique identifier, the total length for each eCognition unpaved road segment based on the LRS_LINK was calculated by using the Summarize tool after highlighting the LRS_LINK column for both the unpaved roads attribute table and the Michigan Framework Roads Network attribute table. The result was a sum of the segments along the each LRS_LINK or each part of the road. The final piece was taking that sum of the length along the LRS_LINK identifiers and dividing it by the length of the road within the Michigan Framework Roads Network to get the percentage of the road that was unpaved. NFC roads 4, 5, 6, and 7 were labeled as unpaved roads if they were a certain percentage of the total road length; >50% appears to be a valid rule for labeling roads as unpaved but can be adjusted depending on tree-coverage. An example of the appended attribute table is in figure 9. The end result is an example area of the Michigan Framework Roads Network that now contains information on whether or not the road is unpaved for the project's initial

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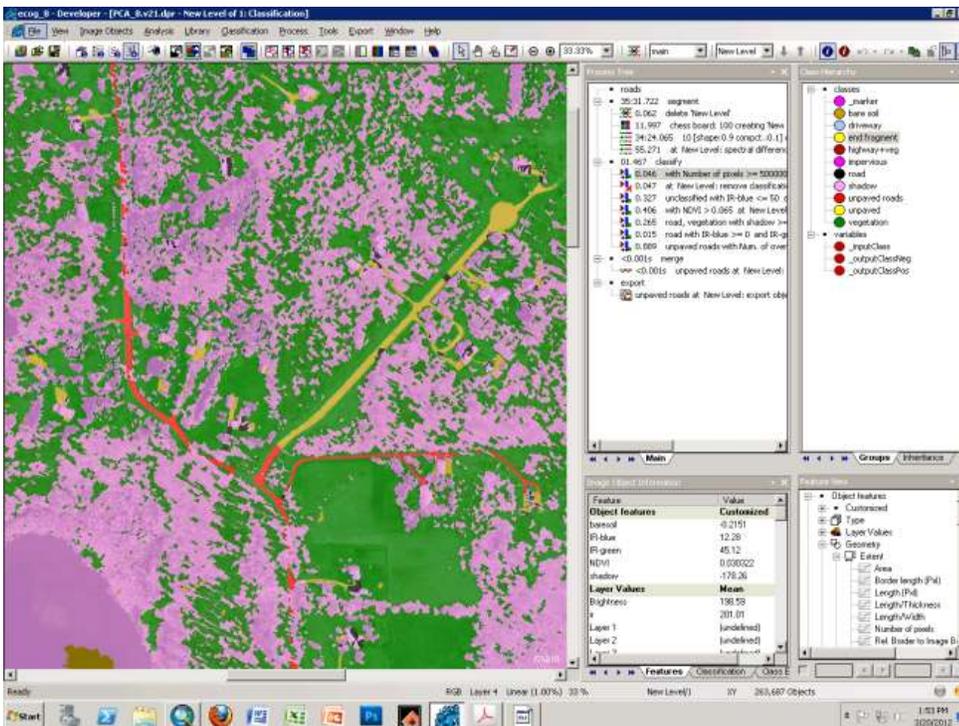


Figure 10. An example where the unpaved roads were identified outside of the Michigan Framework Roads Network with the eCognition rule set. Red is the unpaved road from the Michigan Road Network and brown is the road that was not part of the network.

Masking Michigan Framework Roads Network and classifying and detecting those regions with increased accuracy

Upcoming improvements also involves taking the existing Michigan Framework Roads Network and only classifying the 30 foot buffer around the NFC 4, 5, 6, and 7 roads. This will allow us to increase the accuracy by tuning the threshold values for the unpaved roads classification. Then a Receiver Operating Characteristic (ROC) curve will be plotted to compare the probability of detection and the probability of a false detection based upon how well the algorithm is classifying unpaved roads (Hand and Till 2001). The ROC curves will help tune the road detection algorithm by finding the best segmentation settings as well as aiding in the classification rule sets in eCognition, to improve the accuracy of threshold values for pulling out the full extent of the unpaved roads. This analysis will continue over the next quarter and will build upon the mapping of unpaved roads for Oakland County and other southeast Michigan regions, such as Monroe County where relatively few trees exist in the more agricultural area (Figure 11 shows an example).

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Figure 11. A "no-trees over roads" example image that will be the beginning basis of the ROC curves for detection and classification of unpaved roads under ideal conditions, improving the accuracy of the thresholds used to map the unpaved roads in eCognition. The purple areas are the polygons from eCognition, the blue is the 30-foot Michigan Framework Roads Network buffer.

References

- Hand, David J. and Robert J. Till. 2001. A simple generalization of the area under the ROC curve for multiple class classification problems. *Machine Learning*, Vol.45(2): 171-186.
- Joliffe, I.T. 2002. *Principal Component Analysis*, Second Edition. Springer, 487 pgs.
- Nobrega, R.A.A., C.G. O'Hara, J.A. Quintanilha. 2008. An objected-based approach to detect road features for informal settlements near Sao Paulo, Brazil. Chapter 6.4 in "Object-Based Image Analysis: Spatial Concepts for Knowledge-Driven Remote Ssensing Applications", 19 pgs.