A Methodology for Building Single-Line Digital Road Networks Using GPS

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Accurate, up-to-date, single-line digital road network maps are a crucial foundation for many projects in the field of Geographic Information Management (GIM). Until recently, the best approach was to digitize the road network from paper maps or other stable print materials. A few years ago, the Queen's GIS Lab noticed the possibilities for mapping using GPS technology. While creating maps using GPS was not a new approach, creating accurate, single-line digital road networks using this technology presented a few challenges. To address these, the Queen's GIS Lab developed a methodology that includes selecting a GPS receiver, designing a two-pass method to log position information, and developing a software package called CalcRoad to process the data and generate the required single-line digital road maps.

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Selecting a GPS receiver

Factors such as the accuracy, memory capacity, and equipment configuration are particularly relevant to selecting a GPS receiver for mapping road networks. Accuracy limits are often dictated in a project by the amount budgeted for a GPS unit and by the authority for which the road network is being collected. Picking a unit in which the RMS (Root Mean Square) accuracy is five metres or less is an acceptable compromise since most road allowances are in the order of 10 metres. Today, this accuracy can be obtained relatively consistently without performing differential corrections.

The receiver must be able to collect as much data as possible before requiring a download to a computer. This eliminates the need for returning to a base station or taking a laptop into the field. Typically, less expensive GPS receivers can only collect a few hundred points, which is insufficient for logging an extensive road network. In general, a GPS receiver should have enough internal memory to collect up eight hours of continuous data or a maximum of 128 individual files.

Consideration must also be given to how the GPS receiver and antenna are mounted. An external antenna is required to ensure that all satellites in the current constellation are in view. The antenna is mounted on the passenger side of the car to ensure an accurate model of the width of the street by approximating the outer edge of the roadway. The buttons on the GPS must be easy to access for safety and convenience. The Queen's GIS Lab has experimented with voice-activated units to minimize concerns for safety but without consistent success. In general, it is recommended that both the driver and the navigator have full knowledge of the equipment and the methodology before mapping the roads; this ensures that the driver is concentrating on the driving.

The two-pass method

The Queen's GIS Lab developed the 'two-pass method' to ensure accurate coverage of all streets. While some researchers use a 'single-pass method', the two-pass method is quite logical, considering the task at hand. For example, in many instances (such as dead-end roads) the driver will have to return along the same street regardless of whether the GPS unit is recording data. Hence, the two-pass method maximizes the driving time that a single-pass method would waste. More importantly, the double coverage of each road provides redundancy and thus, a built-in data quality check.

The two-pass method requires that both sides of each road be driven, once in each direction. Whenever a one-way street is encountered, it is driven twice in the same direction. On the first pass, the antenna is attached to the right side of the vehicle and the vehicle is driven as close as possible to the right side of the road. With the antenna positioned on the left side of the vehicle, the vehicle is then driven next to the road's left side.

A separate data file is maintained for each direction. In addition, meticulous notes are kept in a field book identifying the file name, the street name, the direction in which it was driven, and in some instances, any changes in the road (such as direction or sharp curves). It is also useful to record a timestamp along with each notation in the field book. These time notations are a quick and easy way to coordinate separate files after the fieldwork is completed.

Streets are generally driven at the posted speeds, with slower driving necessary only when a road curves sharply and requires more points to properly define its route. Typically, the GPS receiver is set to record a position every three seconds, which provides consistent results while maximizing

the distance covered between downloads.

The two-pass approach delineates intersections by four distinct lines. The intersection is plotted in the centre of the square defined by the four road files. The single line that ultimately represents each street, therefore, passes directly through that point.

When "T" intersections are encountered, the vehicle is driven through the intersection to the other side of the road, the GPS receiver is turned off, the vehicle is turned around, a new file for the opposite side of the road is created, and the receiver is started again. If this process is too dangerous (for example, the traffic volume at an intersection is heavy), the vehicle is parked on the opposite side of the intersection and 30 to 50 points are collected. In this case, three files are created for a T intersection - one for each direction and one for the intersection points.

The region in which roads are being mapped is also an important consideration. For example, roads in rural areas can be heavily treed, particularly in cottage regions. Leaf cover can interfere with GPS reception - hence, it is preferable to map these roads in the early spring or late fall. If this is not an option, returning to a section of road at another time of day, in hopes that a different satellite configuration might permit better signal reception is often successful. Municipalities also present a unique challenge. Finding a time when traffic volume is at a minimum usually means that roads within a city core should be mapped during the night. Data for other roads, such as highways, suburbs, and rural roads that primarily run through agricultural areas, can generally be collected during daylight hours.

Running CalcRoad

The centreline of each road is calculated using CalcRoad, a program written by David Ball of the Queen's GIS Lab. CalcRoad is an add-on to Autodesk's AutoCAD™ and AutoCADMap™. Instead of manually "eye-balling" the centre between the two lines delineated by each road's file (one for each direction), CalcRoad automates this process. This not only reduces the amount of time required to determine the road's centreline but also provides a more accurate representation of that line. CalcRoad was developed as a result of various experiences with manually determining the centre between two lines that delineate each road.

CalcRoad requires two GPS files (one for each side of a road) and draws a polyline joining the points in the files. CalcRoad subsequently places regularly spaced points along these polylines. The spacing is user defined and usually ranges from 10 metres for curved roads to every 20 metres for straighter roads. For each newly created point on one side of the road, CalcRoad finds the closest point to it on the other side and calculates the midpoint between these two locations and stores it in memory.

Once this process is complete for every point in the selected section, the program draws a centreline using the stored midpoints. Finally, CalcRoad runs a line-simplification routine (similar to the Douglas-Puecker algorithm) based on a user-defined tolerance, eliminating unnecessary points from the centreline. This operation greatly minimizes storage requirements without affecting the overall length of the road segment. Typical tolerances, which determine when a point should be deleted or included, are in the order of 5 metres, the precision of the receiver.

To produce the final road network map, various CAD mapping tools are used to perform clean-up operations, including trimming and extending the lines at intersections to correct over- and under-shoots respectively. Typically, they are the result of the GPS receiver's accuracy or because of the tolerance levels used during the line simplification routine.

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Accuracy and precision

The Queen's GIS Lab conducted field tests to assess the precision of the two-pass method, mapping various intersections several times. In all cases, the plotted geographic co-ordinates for the intersections fell within ±4.5 metres of the first pass. As a check on accuracy, geo-referenced, single-line road network maps produced for Prince Edward County were overlaid on the region's Ontario Base Maps (OBMs) which were produced using stereo photogrammetry with aerial photographs. Where the OBM roads were up-to-date, the maps matched perfectly.

Conclusions

The two-pass approach has proven to be a safe and simple method for several reasons. First, the resulting centreline is an average produced by a larger sample size. Second, if the road were mapped using GPS and a one-pass method, the best way to accomplish this would be to drive down the middle of the road, a dangerous choice. Other options for the one-pass method include applying an offset, but this is difficult to consistently maintain. Finally, the combined approach provides built-in data quality checks and hence, is more accurate than driving a road only once, ensures a high level of precision with regard to the centre-points, and proves faster than digitizing the roads from paper maps.