Mapping Ontario's Underground Utilities

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INTRODUCTION

One of the main problems that is surfacing in the construction process is the unknown location of underground utilities. The ideology of "out of sight, out of mind" cannot be tolerated any longer with underground utilities. This problem is leading to project delays, extra work orders, change orders, construction claims, contingency bidding, loss of service, property damage, and worst of all, injury and death (Anspach, 1996a). On April 24, 2003, seven people were killed in an explosion in Etobicoke, Ontario, due to a roadwork crew accidentally puncturing a gas main. It has been determined by the Ministry of Labour and the Technical Standards and Safety Association that the location of the gas main was erroneously delineated on the utility map by a number of contractors and sub-contractors. Just five days after the Etobicoke explosion, a worker was killed, and three more injured, in a gas main diversion project in Windsor, Ontario (Construction Safety Association of Ontario, 2003). North Carolina State University reports that excavating equipment that punctures buried utility lines causes a global average of one death per day (Bernold, 1994). Accurate mapping of underground utilities will eliminate many of these unnecessary injuries and deaths, and will improve underground construction practices that will yield lower costs, construction claims, and project delays. This paper will outline the on-going research activities at Ryerson University for implementing a photogrammetric solution for mapping utilities, and how to organize and display utility information to ensure that it accurately represents the buried infrastructure.

PROJECT MANDATE

Currently there are four main methods for mapping underground utilities: stand-alone Global Positioning System (GPS), Ground Penetrating Radar (GPR), Conventional Surveying (CS), and the Sub-Surface Utility Engineering (SUE) process. An in-depth analysis of each method can be found in Tulloch et al. (2005). Stand-alone GPS is a quick data acquisition system with a low cost, but it is only accurate to 1 meter when using broadcasted corrections. This method is commonly used to generate utility inventories for utility owners or municipalities. GPR generates meter level accuracy of the underground infrastructure while the data acquisition time and the cost is significant.

This application is desired if the underground utilities are not exposed, or the underground infrastructure is very dense. Conventional surveying is the most popular utility mapping method, since it obtains the desired accuracy needed for underground utilities and the cost is minimal. The disadvantage of this method is the time that is needed to acquire the spatial information. It is the most time consuming method of the four, which results in increased construction costs and delay times. An increasingly popular method in Canada is SUE, which is most commonly used in the engineering design stage of a sub-surface construction project. SUE can generate millimeter accuracy, but its costs are the greatest of the four methods presented in this paper. Figure 1 illustrates the relationship of each method with respect to time, accuracy, and cost, where data collection time is represented on the horizontal axis, the accuracy is on the vertical axis, and the cost is represented by the size of the bubble.

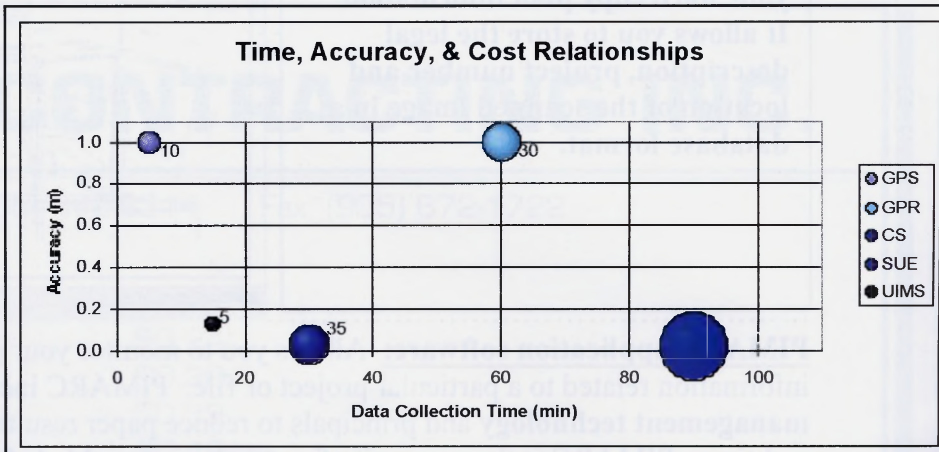

Figure 1. Time, Accuracy, Cost Relationships

Figure 1 also assists in setting the mandate for this project by depicting the gap between the data collection time, accuracy, and costs of the various mapping methods. The project mandate is to create a mapping system that obtains 1-20 cm level of accuracy, 95% of the time; collects the data in 15 minutes; and costs less than GPR, SUE, and CS. Two other objectives that govern the mandate are in place to ensure that the mapping system is user-friendly, and that the data can be easily transferred to various municipal and private sector computer applications, such as CAD products or asset management programs.

A PHOTOGRAMMETRIC SOLUTION

In any survey project it is a challenge to find the balance between the amount of survey data collected and mitigating the costs of the project. Mapping underground utilities is no different. To meet all of the objectives of this project's mandate, a photogrammetric solution is proposed. Figure 2 shows a flow diagram of how the utility information will be gathered, processed, displayed, and stored. The flow diagram has been divided into five sections, centered on a mobile GIS. The first section of the photogrammetric solution consists of uploading the Enterprise Stereo Model (ESM) and the municipality's existing utility database to a tablet PC. The ESM is a georeferenced model that contains the 3D coordinates of many of the municipality's topographical and structural features, such as manholes, catch basins, and fire hydrants. These features are used for control to reference the digital imagery. The next process of the photogrammetric solution involves downloading the information gathered from the two pieces of hardware; the digital camera imagery and the data stream from the stand-alone GPS receiver. The GPS receiver data stream (accurate to 3-5 meters) is used in a searching algorithm to gain the approximate location of the mapping system within the georeferenced ESM. Street intersections may also be used to identify the location of a local survey. The third step is to identify the control within the digital imagery, and pass this to the closed form exterior orientation algorithm that has been developed by Zeng and Wang (1992). This closed-form solution recovers estimates for the six exterior orientation (EO) parameters, and only requires the focal length of the digital imagery. Once estimates of the EO parameters are obtained, a traditional least squares photogrammetric bundle adjustment (Kenefick et al., 1972) can be performed to recover the true EO parameters and the interior orientation (IO) parameters. A relative and absolute orientation can be computed with known IO and EO parameters, which allows the digital imagery to be georeferenced.

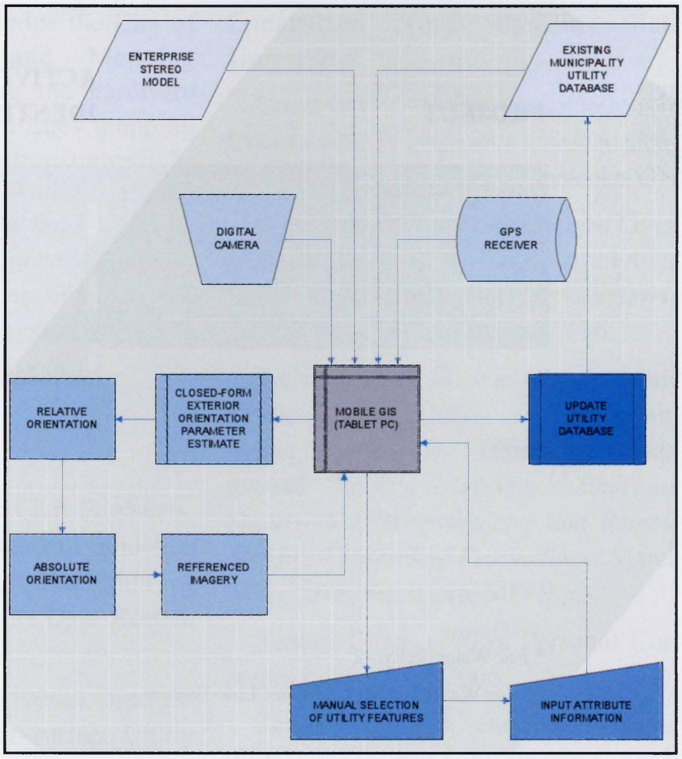

Figure 2. Photogrammetric Solution Flow Diagram

The fourth part of the photogrammetric solution requires the mapping system operator to identify the utility features from the referenced digital imagery. Since the imagery is georeferenced, coordinates for the utility features can be generated. Spatial information is only half of the solution, and must be augmented with attribute information of the utility. The operator will be prompted to input specific attribute information concerning the utility. The required attribute information for the mapping system is one area of research that is currently in progress at Ryerson University in conjunction with The City of Toronto. The last section of the solution involves an updating algorithm that will compare the results of the mapping system with the existing utility database. If there is a discrepancy, the utility database will be updated with the results from the mapping system.

PRELIMINARY RESULTS

The investigation of underground utility mapping at Ryerson University has been on-going for eight months, and will continue for one year. To date, the mapping system hardware has been assembled and the mapping software is currently being developed. The mapping system created at Ryerson University will be tested against all of the research objectives outlined in the project mandate, which includes the accuracy of the system, data collection time, data collection cost, user-friendliness of the mapping system, and data transferability to other computer applications. Out of the five research objectives, preliminary results have been accumulated for only the accuracy and the user-friendliness of the system.

The absolute accuracy of the mapping system will depend heavily on the accuracy of the control being used. The control used in this application is the ESM provided by the municipality. An accuracy assessment survey of the ESM was conducted using third order horizontal control. Forty-one topographical features were tied-in by conventional surveying methods, and coordinates were calculated for the features. The surveyed coordinates for the features were compared against the ESM coordinates. Preliminary results indicate that the mean difference between the ESM and the survey is 0.131 meters, which

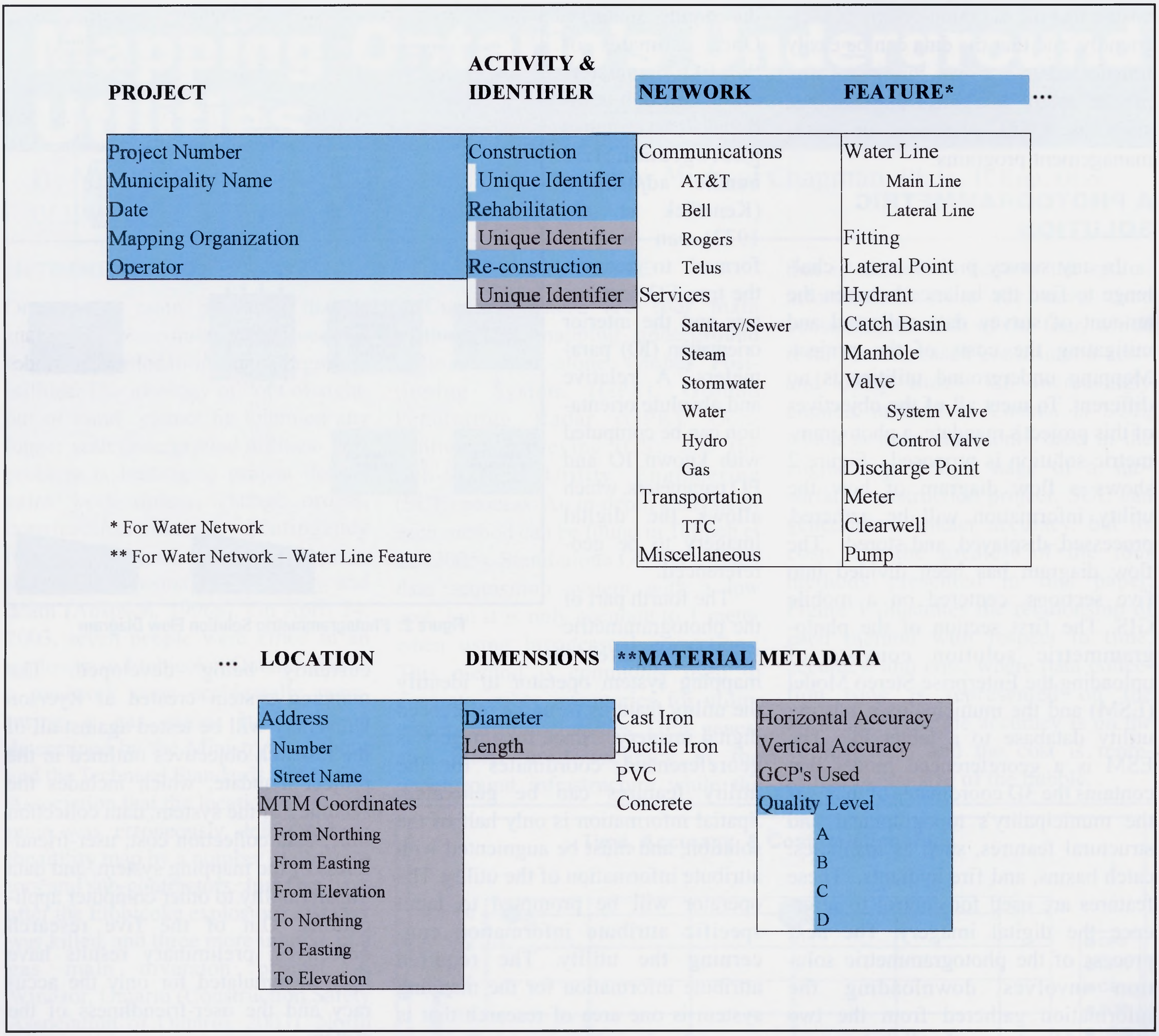

Figure 3. Mobile GIS Database

is below the 0.200-meter objective. The accuracy assessment of the ESM is ongoing and conclusive results will be available when the number of comparative features increases.

The second preliminary result that has emerged out of this research project is the user-friendliness of the mapping system. The flow diagram shown in Figure 2 illustrates the interaction that the operator will have with the mapping system when gathering sub-surface utility information. There are four tasks the operator must perform: capture the digital imagery and pass it to the tablet PC; identify the control points in the imagery and match them to ESM features; select the desired utility features in the georeferenced imagery; and input attribute information that describes each utility feature. The first three tasks are straightforward and should pose no difficulty to the operator, but the inputting of attribute information may create an area of uncertainty, especially if the operator is unaware of what attribute information is needed for various computer applications. Therefore, one requirement of this project is to research the various sub-surface data structures and data standards to determine what attribute information is a necessity, what information is beneficial, and what information is exhaustive. Much of this task compliments the research at the National Research Council (Vanier, 2005). Figure 3 outlines the data structure of the mapping system. The fields outlined in blue illustrate which information the mapping system will ask the operator to input. The fields in gray show the information that will be passed from the mapping system program into the database. To summarize, the operator will be prompted to fill all of the fields under the project menu, and identify whether the activity is a new construction, rehabilitation, or a re-construction. The type of unique identifier will depend on the activity. The operator will then be prompted to select the network that incorporates the utility, and to select the utility from a drop-down features list. The operator also must identify the street number and name closest to the utility using a predefined convention, identify the utility character (e.g., diameter and material), and input the quality level of the data (see American Society of Civil Engineers, 2003).

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Mark Tulloch is currently working towards his M.A.Sc. in the Department of Civil Engineering at Ryerson University under the supervision of Dr. Michael Chapman. Kevin Tierney is employed in the Survey and Mapping Services at the City of Toronto. The Ryerson University research team would like to acknowledge the City of Toronto's Survey and Mapping Services for supplying the hardware for the underground utilities mapping system. Comments and/or suggestions pertaining to this article, or this area of research, are welcome and can be directed to the authors at the following E-mail addresses:

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