MOBILE MAPPING FOR 3D GIS DATA ACQUISITION

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ABSTRACT:

This paper presents technologies of mobile mapping for acquiring of large scale three dimensional GIS data based on the results of a cooperative research conducted at the Department of Geomatics Engineering, the University of Calgary and supported by Geofit Inc. and Natural Sciences and Engineering Research Council of Canada (NSERC). The mapping platform is a vehicle equipped with GPS, INS, CCD cameras and a computer system. With GPS providing positional data and INS providing orientational data, the acquired images are accurately geo-referenced. Large scale, three dimensional spatial databases can be constructed by extracting geometric and attribute information from these images.

The developed prototype system combines the technologies of integrated GPS/INS, digital imaging, close-range photogrammetry, advanced computer graphics and object-oriented database management technologies. It is expected to have a variety of applications including highway mapping, city planning, automatic vehicle navigation, utility mapping, etc.

1. INTRODUCTION

Due to the large volume of spatial data involved in GIS databases, automation of data acquisition is a very important issue in terms of time, budget and feasibility. This is especially true when 3D GIS data acquisition is concerned, where field survey is usually carried out because map digitizing is often insufficient. Spatial data collection has been not efficient until Global Positioning System (GPS) technology has been applied. GPS provides a unified reference frame for databases. However, GPS surveying gives object positions on a point to point basis. To obtain 3D coordinates of an object, this direct measuring method requires that a GPS receiver is mounted on the point. Obviously this is not an efficient and feasible way of acquiring large volume 3D databases. An indirect method of data acquisition using GPS is to use GPS to control cameras and then to obtain 3D coordinates through controlled or geo-referenced images.

The technique described in this paper is an indirect measurement method that combines an Inertial Navigation System (INS) with GPS receivers. INS can provide highly accurate absolute orientation data. These two systems work in a complimentary way. With sophisticated data processing, both positional and orientational data can be obtained with a high accuracy. Using such a configuration, the navigational information of the cameras is constantly updated while the vehicle is in motion. The images taken are, therefore, associated with geo-referencing data. By applying digital photogrammetry, any objects appearing in multiple images can be extracted with a reasonable 3D accuracy.

Recent developments of the system including optimal acquisition of 3D object coordinates, automation of feature extraction, object-oriented modeling, distributed computing architecture and animation of extracted 3D data are also discussed. Some results are given in the end of the paper.

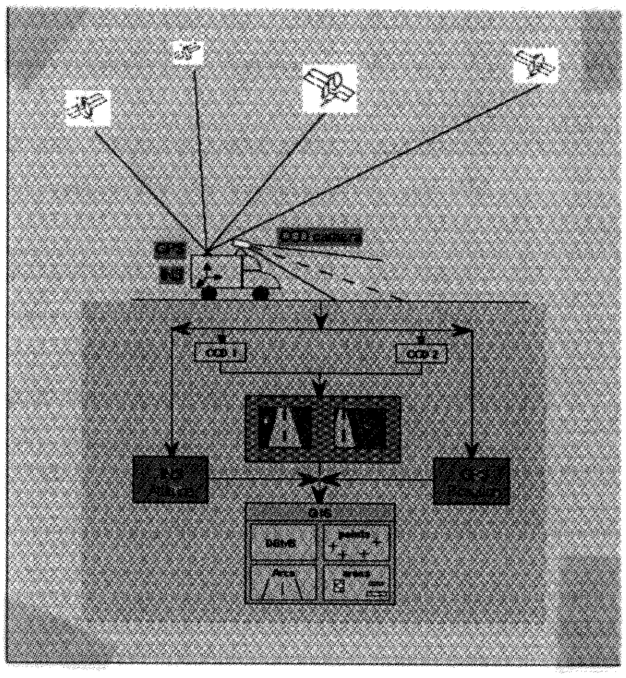

Figure 1: Configuration of the mobile mapping platform

2. ACQUISITION OF GEO-REFERENCED IMAGE DATA

The data acquisition platform is named VISAT (Video, Inertial system and SATellite), with its system architecture shown in Figure 1. The number of cameras can be as many as eight in the present configuration. High precision positioning is achieved by applying differential GPS, with an additional receiver located at a control point with known coordinates. The INS installed inside the van supplies the angular orientation parameters of the van in a three dimensional coordinate system. It also provides interpolated positions, corrects GPS cycle slips, and is used as a back-up during GPS outages.

The integration of GPS and INS technologies is especially advantageous in situations where GPS signals cannot be received completely. For example, in downtown areas the GPS signals are obstructed by high buildings. In these situations, INS data can be used to compensate for the loss of GPS positional information. This ensures that the acquired images can be oriented geometrically at any time with a sufficient accuracy.

Before each prolonged use of the mobile platform, a calibration procedure is necessary for determining the relative positions of each of the components, such as INS, GPS antenna and cameras. These parameters might change slightly over time because of the vibration caused by the movement of the platform. The on-board computer records the images and the associated navigational data. The data are downloaded onto the office computer server on which image data are preprocessed and managed.

The data recorded in real time are not directly usable. First of all, the GPS data need to be processed because of the differential mode configuration. This procedure ensures navigational accuracy of the images. Secondly, some images may have poor quality. In addition, to make the objects in images clearly discernible against the background, some image enhancement work is needed. Filters are carefully chosen to avoid any pixel shift due to the processing.

3. DATA PROCESSING ON VISAT-STATION

The platform for geometric information extraction is named VISAT-Station. Basically, it consists of a SUN SPARC series workstation with two monitors, running MOTIF. One monitor is used for the so called MultiView subsystem, where stereo images and graphic user interface elements are displayed. Most of the interactive procedures are conducted on this screen (see Figure 2). The other monitor is used for the OverView application, with the base map and P-lines (i.e. route of the van) displayed. Whenever an object is measured, its projection on the base map is shown on the OverView screen. The main purpose of OverView is to give the user a reference for the measured data using a base map. For high-end applications, we can have more than one monitor for MultiView, or even several workstations networked together in case of time-critical surveying in which several operators can simultaneously carry out measurements of data from the same van run. For low end applications, OverView and

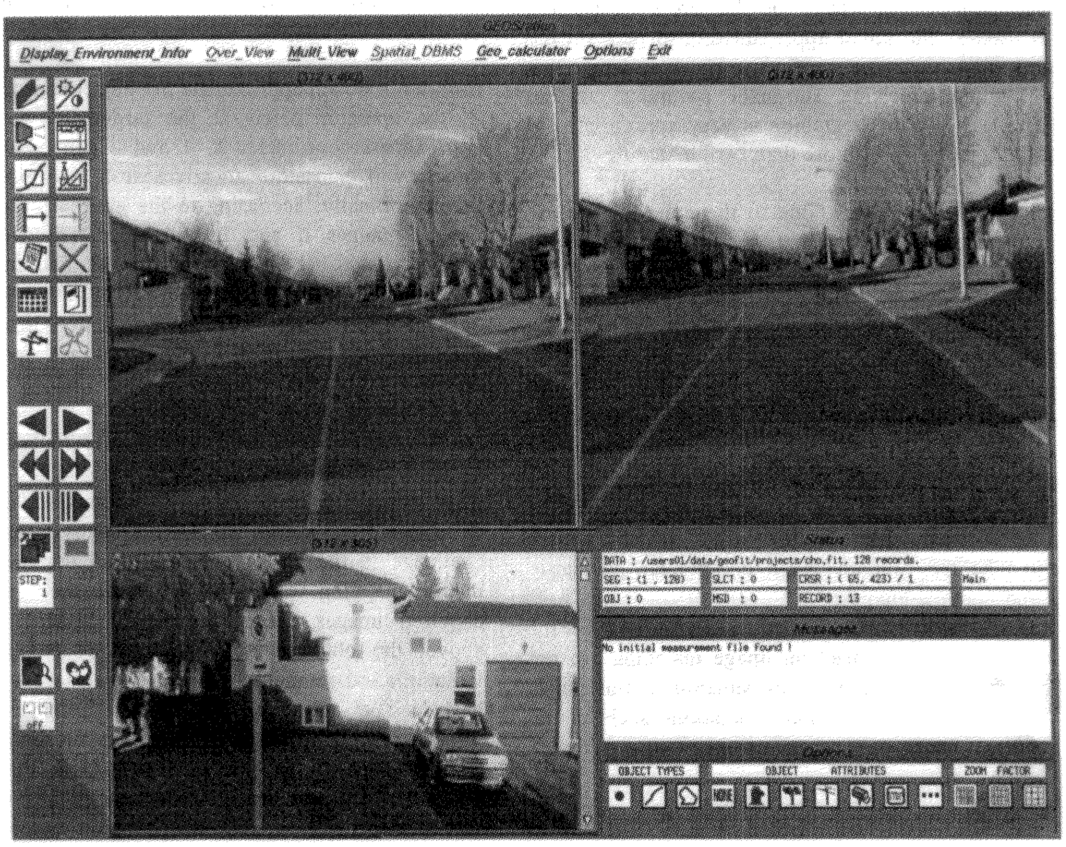

Figure 2 : User interface of MultiView

MultiView can share a single screen or OverView may be disabled.

During measurement, 3D coordinates are obtained through triangulations. Currently, the operator specifies a point in the first image, the points in other images needed for the triangulation can be obtained either through manual interactions or through the automated image matching. Each time the first point is chosen, the corresponding epipolar lines in other displayed images are shown to give the operator a reference. Up to six points can be used to perform the triangulation using the least squares for an optimal solution. Tests have shown that the positional accuracy of object points is up to 30 cm within a 50m object range.

For the purpose of automation, image matching techniques are used for measuring conjugate image points. To this end, two area-based single-point matching methods have been implemented: cross correlation and least squares matching. In the cross correlation process, a small window is used to find the maximum correlation coefficients along the corresponding epipolar line(s). Therefore, two-dimensional searching is replaced by one-dimensional operations in the images. This significantly reduces the amount of computational time. Since geo-referencing errors and other errors may exist, the search is performed in three adjacent lines centered on each epipolar line. This feature improves the matching reliability and accuracy. In most situations, the object distance is within a certain range. The searching range is, therefore, reduced in order to minimize computation time. Furthermore, the pair of target and search windows are normalized to have the same mean gray level. This technique does not require precise initial approximation. The result of the cross correlation algorithm is used as the initial approximation to perform the least squares matching (i.e. refinement). Following this procedure, a high precision sub-pixel accuracy can be achieved. The least squares matching is very appropriate for performing multi-image (i. e. more than two) matching.

In close-range photogrammetry, due to the consideration on the wide coverage of objects and high accuracy in 3D determination, the cameras have considerably large differences in orientation. This in turn results in large difference of geometry in stereo images because of the short distance between cameras and objects. This effect is very troublesome to area-based matching techniques. As such, feature based matching has to be employed in this case.

Image intensity and its changes (edges) are dependable factors for algorithms to determine 3D positions. In the current approach, area-based and feature-based matching are combined to take the full advantage of epipolar geometric constraints and multiple images.

Although automation tools based on image matching are not dependable tools for all objects for all situation at this point, they are reasonably reliable in some situations such as the extraction of street lines.

4. OPTIMAL ACQUISITION OF 3D OBJECT COORDINATES

3D object coordinates can be uniquely intersected by two georeferenced digital images that overlap the object. The precision of the coordinates depends on not only the quality of georeferenced digital images but also the space geometry formed by the target point and the two camera exposure stations. According to an error analysis, if only the measurement errors of two image coordinates are taken into consideration, the optimal object coordinates will be obtained by using two image stations i and j respectively, with the following criterion (Li et al, 1995):

$$RMS^2 = (D^2_i + D^2_j) / \sin^2(C_{ij}) + H^2_{ij} / (\sin^2(A_i) + \sin^2(B_j)) = minimun,$$

Where, D_i is the distance between camera station i and the target P, D_j is the distance between camera station j and the target P, C_{ij} is the space angle at the intersection of lines $\overline{iP}$ and $\overline{jP}$, H_{ij} is the distance between point P and baseline $\overline{ij}$, A_i is the space angle at the intersection of line $\overline{iP}$ and $\overline{ij}$, and A_j is the space angle at the intersection of line $\overline{jP}$ and $\overline{ij}$.

Point matching techniques are used to automatically search all images that cover the desired target from a sequence of images. If approximate coordinates X, Y and Z of the target are known, the 3D coordinates can be projected onto all selected images. A sequential matching technique will find out precise position of the target in each image within constrained searching areas. Otherwise, the target will be identified as invisible in the image.

In order to obtain approximate 3D object coordinates X, Y and Z, the operator points at the target in two images. The approximate coordinates X, Y and Z can be calculated. The system will then automatically search all visible images and records. Finally, according to the optimal criterion, the two optimal images (i and j) will be determined. The image coordinates (x_i, y_i), and (x_j, y_j) are modified automatically by point matching techniques and are used to intersect the optimal 3D object coordinates X, Y and Z. The coordinates are further employed to form GIS entities and are recorded in the database.

5. AUTOMATION OF INFORMATION EXTRACTION

The increasing need for the automation of information extraction from mobile mapping systems poses a significant challenge in the current research and commercialization of mobile mapping technologies, due to the large volume of captured images needing to be processed. As mentioned above, the obtained terrestrial images exhibit large scale variations and geometrical discrepancies across images, which have to be accounted for in the automatic process of information extraction. This increases the complexity of the task substantially. In the current system development, an object-directed and user-guided strategy has been proposed and applied to the system design of the automated or semi-automated functions of information extraction. The automatic extraction algorithms are designed to be tailored to the specific objects. The user takes the responsibility of object recognition and activates an object-directed algorithm for object extraction. Guided by the user supplied information, the scene- and image-domain knowledge can be incorporated into an object model and, thus, a model driven automated algorithm can be employed in the object extraction process. The motivation of this strategy is to accommodate a friendly environment of interaction between two important agents in the system: human user and computer machine. A number of object extraction algorithms have been developed. Aside from the single-point based multi-image matching algorithm which is described and used in the previous sections for object point measurement, the following algorithms have been developed:

5.1 Road Centerline Reconstruction

Road centerline information marked by the lane markings is very important to the generation of a road network information system. It can be used to compute road inspection parameters (longitudinal profile and surface deformation). A global method to the automatic reconstruction of 3D road centerlines from image sequences has been successfully implemented to deal with the diversified appearances of lane markings on roads (Tao et al., 1996). In this method, the reconstruction is considered as a problem on "*shape from image sequences.*" The problem is to synthesize road centerline information available from successive images into a 3D shape model. Firstly, a 3D physically-based shape model of road centerlines is set up using the vehicle trajectory determined by the combined GPS/INS navigation data. In order to synthesize the constraint information coming from object assumptions and image sequences into the model, the model is defined as an active and deformable 3D curve (3D snake). Cubic B-splines are employed to define this deformable 3D curve model of the road. The physically-based deformation mechanism has been incorporated into the model such that the model can be progressively deformed under the action of internal and external constraint forces. The extracted 3D points of road centerlines from image sequences can act as external energy which forces the model to deform towards its desired position. A novel feature extraction and matching algorithm is developed to obtain these 3D points of road centerlines from image sequences based on the exploited stereo-motion constraints. Internal energy arises from smoothness constraints representing the natural characteristic of the shape of road centerlines. It maintains the a priori assumptions about the shape of the model. Under a combination of the actions of internal and external forces, the model will be deformed incrementally towards the final state in which forces from different sources are balanced. The model resulting at the end of an input sequence represents a 3D road centerline shape. Various tests have demonstrated that this method functions very reliably even in situation where the road conditions are far from ideal (Tao, 1996).

5.2 Road Boundary Extraction

It is by no means easy to set up an unified model of road boundaries dealing with a large variety of scenarios. However, the features of road boundaries varies relatively smoothly. After comparisons of different algorithms, a matching based boundary tracker is developed. If an starting point along a road boundary is initiated by the user, the tracker will follow this boundary automatically in the image sequence. The least squares matching method is employed in the following process. Considering the large distortion of road boundaries in the image which seriously causes the matching-based line following method to be corrupted, an object space matching tracker is proposed. With the knowledge of the known orientational parameters of images and the height of camera station, the image window of road boundaries can be rectified onto the ground plane. After the rectification, the geometrical discrepancies along the same boundary are reduced to a great degree and the object space based least squares matching algorithm can be introduced for the boundary following. In order to verify the tracking results from single images, stereo matching method is also applied. In this sense, when the matching tracker moves one step, the least squares matching algorithm is applied along the boundary within a single image and between two stereo images. Finally, a Hough transfer algorithm is employed to smooth the tracked points and eliminate blunders.

5.3 Vertical-linear Object Detection

Road corridor environments contain many vertical-linear objects, such as traffic signs, power lines, telephone lines, electronic poles, etc. The vertical line detection algorithm is designed to assist the user to recognize and position such objects. A further application of this kind algorithm is to realize the automated recognition of road related structures and infrastructure. The implementation of the vertical line detection consists of four modules: (a) vertical edge filter; (b) local linking of vertical edges; (c) Minimal Description Length (MDL) edge segment representation; and (d) vertical segment matching. Again, using the ground plane constraints, a vertical low-pass filter is applied to detect the vertical edge points whose angle is perpendicular to the normal of the ground plane. A straight line controlled point linking method is then used. Several rules about the knowledge of vertical-linear objects, such as edge direction, contrast and shape, are defined to restrict the linking process. To facilitate the line based feature matching, the MDL method is applied to the parametric representation of line segments. Consequently, the line segment can be matched using the correspondence of the feature set of line segments.

6. DATABASE GENERATION AND DATA VISUALIZATION

Geo-referenced images yield 3D information by measurement interaction. However, this system is not simply a survey data processing platform that is limited to photogrammetric functions. Instead, it is integrated with capabilities to allow the construction of 3D objects. In recent research (Qian, 1996), objects are treated as semantically meaningful entities that are more than lists of 3D coordinates, although at the low level the 3D geometry of objects is constructed vertex by vertex. The spatial relationships between the vertices are also described. In the current implementation, a wire frame model is used to describe 3D geometric structures. In a general 3D information system, geometry is only one aspect of an object, in addition to its rich descriptive information. Close-range images give intuitive impressions of object types although practically we need some additional information to give a complete description of object. In this system, users can define various object types using object-oriented features.

Because of the distributed architecture of the software system, it provides a multi-user measurement environment which facilitates data sharability and teamwork. After generating the database, data query and addressing can be expedited by using 3D data visualization techniques. Figure 3 shows the area in Laval, Quebec, Canada, where the sample data set was collected in 1994. Figure 4 is a geo-referenced image and a view of the extracted 3D objects at the same location.

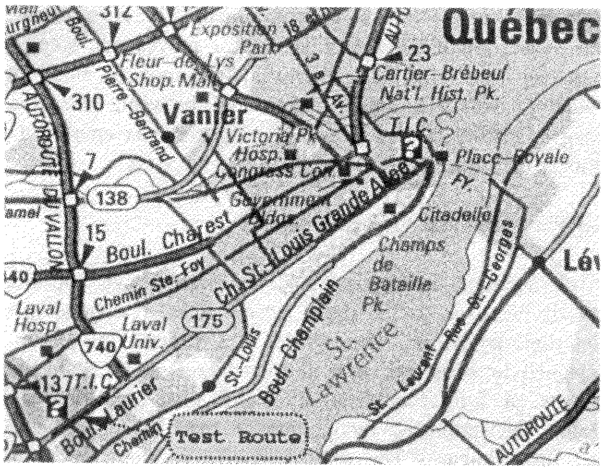

Figure 3: The test area

7. CONCLUSIONS

The purpose of developing this system is to enable fast, accurate and efficient object measurement from images from a moving vehicle. Instead of time-consuming measurements in the field, they can be performed using georeferenced stereo images in the comfort of the office. It makes the data recording procedure highly streamlined and automated. With strong referencing in the data processing, quality checking is very easy because objects are presented visually on-line. Assisted with automated image matching techniques, the interactive procedure requires much less effort, attention and professional skills. By integrating GIS databases in the system, the measurement data is effectively and consistently managed. Not only does the system create a comfortable surveying environment, it drastically reduces costs as well.

8. ACKNOWLEDGMENTS

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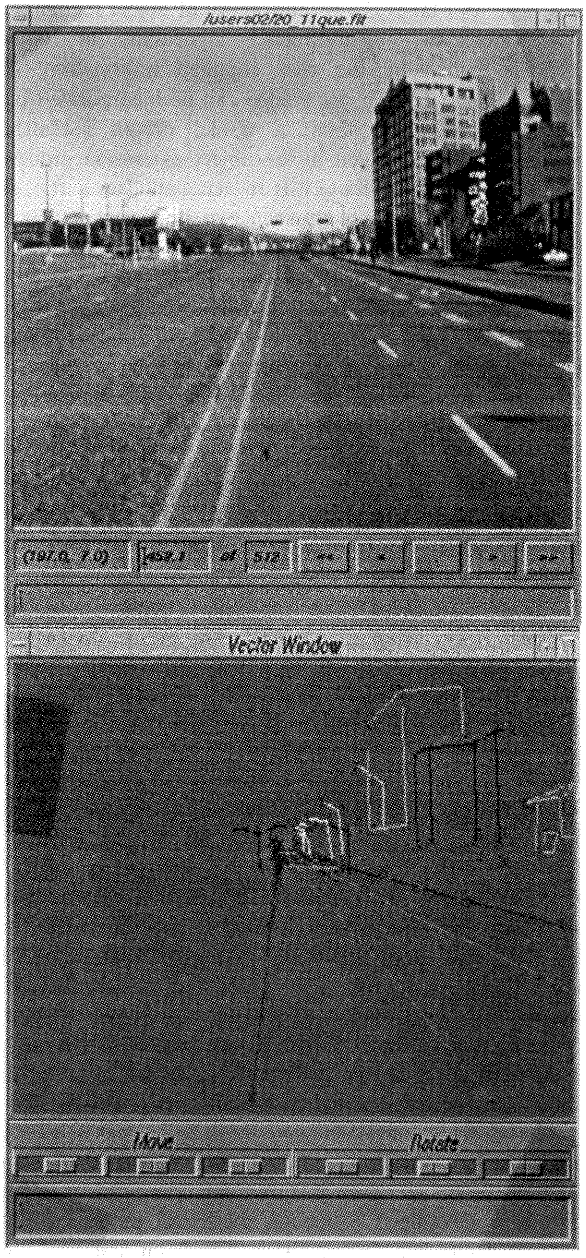

Figure 4: Geo-referenced image and extracted 3D visualization

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