3D Modeling and Visualization Based on Laserscanning

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Abstract
The paper describes an approach using the ground-based laser-scanning technique for data fusion, object modeling, and visualization. A ground-based mobile mapping system has been developed, upon which multiple sensors including CCD, DGPS and laser scanner have been integrated to provide near-continuous positions of the platform in space and simultaneously to collect spatial information in object space. The objectives of this system are for mapping road, surveying bulk of accumulation, and other related applications. Two practical applications of the system are introduced in this paper. Finally some conclusions and further research work are provided.

I. INTRODUCTION

There are lots of methods available to acquire geographic information, such as direct surveying in the field, digitizing from existing maps, and photogrammetry. In recent years, great progresses have been made in the laser distance measurement technique, which has characteristics of automation, high precision, high speed, and cost-efficiency. Along with the development of laser techniques, 2D and 3D LS (Laser Scanners) without reflector are invented for large area data acquisition. These developments realize automatic collection and transformation of measurement data (only distance value, by which coordinates can be evaluated). 3D objects can be described as a range image that is made up of enormous discrete points called points cloud.

Range images acquired by a range sensor can be used to solve 3D object reconstruction issue that is an obstacle in stereopsis from optical images. This is the main reason why laser scanning technology has gained a broad attention.

Due to the use of different mounting platforms, laserscanning technology can be divided into airborne laserscanning and ground-based laserscanning. In the past ten years many corporations and research institutes have devoted significant efforts to technology research and system development. In Canada, the University of Calgary has integrated airborne LS with other sensors and has conducted numerous experiments in 1998[1]; In the Netherlands, the Survey Department of Rijkswaterstaat has been investigating the feasibility of extracting topographic information from laser measurements since 1988 [2]. A few commercial companies have offered their airborne surveying systems, for instance, SAAB system developed by TopEye, Sweden, ALTM System developed by Optech, Canada, and Fli-Map system developed by John Chance, U.S.A., and so on. Airborne laserscanning systems have been applied mainly to acquire swiftly large area data [3,6,7,8,9,10]. The ground-based LS, which characterizes high speed and convenience, has an important function in building 3D spatial objects. The ground-based LS is divided into 2D scanning and 3D scanning. The University of Tokyo of Japan integrated 2D laserscanning system with other sensors and experimented in 1999 [4,5]; In China, Wuhan Technical University of Surveying and Mapping has investigated ground-based laserscanning technology since 1999 [13]. SICK Optic-Electronic Co. Ltd. and IBEO Lasertechnik GmbH of Germany have rather matured industrial products respectively. Moreover, Cyrax system developed by Cyra Technologies, Inc. of U.S.A. is a typical ground-based 3D Laserscanning system. Cyrax is a portable, and auto-scanning laser system that makes it possible to quickly map and model large, complex sites and structures with a good level of detail and accuracy. Laserscanning ground-based is mainly applied to rebuild 3D city models and to acquire local geographic information [4,5,11,13].

In this paper, our research is mainly focused on the integration between ground-based LS and other sensors. The system we developed is an Integrated Mobile Mapping System combining DGPS, CCD, and laserscanning system. The system supports data fusion, modeling and visualization. The main problems solved in the system are as follows:
- Multi-source data acquisition

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- Multi-source data registration and fusion
- Modeling and reconstruction
- Visualization and interactive operation.

II. PRINCIPLES AND OBJECTIVE

Overview

In the fields of engineering and surveying there are increasing demands for the synchronous acquisition of geometric information and texture character of spatial objects. Creation of truly 3D and realistic models of spatial objects is a research direction. How to swiftly acquire geometric information and texture character of spatial objects, and to transform them into digital signals, with which computer can deal for engineering design, management and monitoring, is a very crucial technology. Building 3D visual models is also very important and is paid greater attention.

The application system that we developed is based on a mobile platform upon which multiple sensors measurement systems have been integrated. The system integrating DGPS, a CCD camera and a LS can realize data collection, object measurement, 3D-object reconstruction and visualization. In this system, DGPS acts as the positioning sensor and clock controller. Shown in Figure 1, the CCD camera and the LS are fixed on the platform and are aligned to be coaxial. LS range images are used to reconstruct the scene structure by indirect measurement of 3D-object coordinates. In general LS generates the model using a vast number of unstructured points. As a result the topology of the object is completely lost. Once the geometry of CCD image is built, the images can be mapped to their real positions to form 3D realistic models.

Data acquisition

The platform we used, e.g., a car or other land vehicles can run approximately at a speed of 30Km per hour. The measurement of the object points is based on two basic components, the absolute position of the platform and the relative position between the platform and the object. In this system, an absolute positioning sensor we employed is the kinematic differential GPS, which determines the trajectory of the platform with a high accuracy up to cm level. The LS surveys the distance between the platform and the object up to 14, 400 times per second. The pulsed laser beam moves along the track of platform through the forward motion of the scanner. The precision of distance measuring with laser scanning can reach a centimeter level.

The CCD camera, that is aligned with the LS, has a field of view smaller than the scanning width, and is operated with an electronic shutter. This feature provides good suppression of background light and prevents movement blur in the image. Each frame of image is marked with time and frame number in order to allow synchronization with the other data. The acquired digital images are transmitted into the computer through a image capturing board in real time.

Geometric model

Shown in Fiugre.2, point O" is the center of LS; point O is the projection center of CCD. In this coordinate system point O is taken as the origin of the coordinate system, x-axis positive direction coincides with progressive direction, and OO" as Y-axis, and the zenith direction as Z-axis. In a certain clock, coordinates of the CCD image can be described as (x, y, -f), in which f represents focal length of CCD, x is a constant and varies with time. The projection equation between discretional object point P and the corresponding image point according to Wang [12] is as follows:

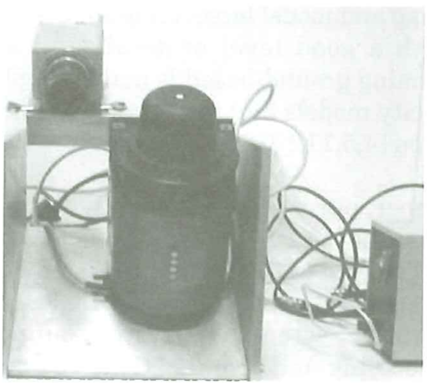

Figure 1. Intergrated sensors

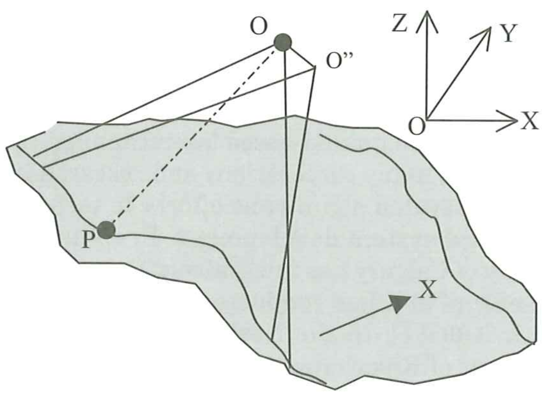

Figure 2. Coordinate sketch map

$$x = -f \frac{a_1(X_p - X_O) + b_1(Y_p - Y_O) + c_1(Z_p - Z_O)}{a_3(X_p - X_O) + b_3(Y_p - Y_O) + c_3(Z_p - Z_O)}$$
$$y = -f \frac{a_2(X_p - X_O) + b_2(Y_p - Y_O) + c_2(Z_p - Z_O)}{a_3(X_p - X_O) + b_3(Y_p - Y_O) + c_3(Z_p - Z_O)} \quad (1)$$

Where, $a_1, a_2, a_3, b_1, b_2, b_3$ c_1, c_2, c_3 are determined by CCD stature parameter and (X_o, Y_o, Z_o) by DGPS.

As mention above, LS describes objects using distance and angle information. See Figure 3, assumed that the distance value OO" is r, the following equation can transform directly LS coordinates (ρ_1, θ_1) into the coordinate system shown in Figure 2:

$$\rho_2 = \sqrt{\rho_1^2 + r^2 - 2\rho_1 r \sin\theta_1}$$
$$Y_p = \rho_2 \sin\theta_2 = \rho_1 \sin\theta_1 - r \quad (2)$$
$$Z_p = -\rho_1 \cos\theta_1 = -\rho_2 \cos\theta_2$$

According to Equation (2), the 3D coordinates of P can be determined, where X-coordinate varies with time. Then the texture information extracted from the CCD images can be pasted onto the DEM generated from range images. Subsequently, 3D visual models, and some of fundamental measurements such as mapping profiles, bulk of stack, etc, can be built.

System architecture

The system consists of four components: data acquisition, data processing, data management, and application. The hardware elements of the systems are a LS, real-time navigation sensor DGPS, a CCD camera, PC monitors and data software. Figure 4 shows a schematic diagram of the system.

III. ALGORITHM

In the system GPS acts as a positioning sensor and clock controller that controls the acquisition of CCD

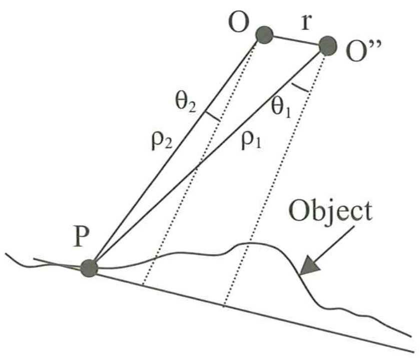

Figure 3. Coordinate transformation

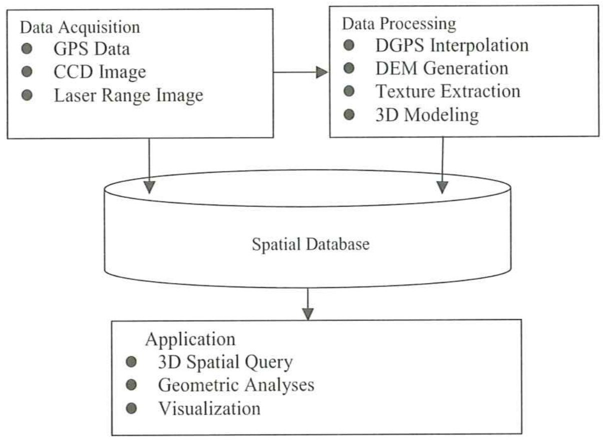

Figure 4. Schematic structure diagram of system

images and laser range images. The basic steps are as follows. Firstly the multi-source data are collected; then TIN (triangle irregular net) and DEM are generated by using GPS data and laserscanning data; subsequently textures from CCD images are extracted; finally textures are pasted onto the corresponding DEM points to build 3D visual models.

Calibration

Before the outdoor surveying, integrated multi-sensors are calibrated firstly. The calibration process of determining the precise interior geometry of CCD and LS is essential to produce accurate 3D information. Optical measures and mathematical means are used. Through calibration, the exterior and interior stature elements and relative position of CCD and LS are determined. After calibration the CCD images are georeferenced.

Data processing

Data filtering

The LS directly measures the distance from LS to object using pulse transmission. It is inevitable to avoid errors in raw data because of noises caused from vegetation and mobile objects such as foot passengers, vehicles, trees and so on. Taking DEM as digital images, erroneous points can be eliminated validly from DEM by using a low pass filter that preserves low frequency components and screens high frequency ones. Of course, it is at the cost of losing some of information.

Data compression

The applications of laser technology are to be confined whether spatial information needs to be described using dense grid and auxiliary data. On one hand, it needs to preserve object features from the original information; on the other hand, it is supposed to leave out unimportant data as much as possible. In our system data compression of LS is mainly performed in post-processing. In fact, we compress enormous CCD images data caused in the course of surveying by software before recording.

Data fusion

First, according to GPS clock make CCD images and range images synchronization and unify profile (see Figure 5). Second, project and paste CCD image pixel P1 onto DEM P2 (i.e. P1's spatial position), thus the 3D image of P2 is generated. The basic principle is in the following: the projection center O, P1 and P2 are in a beeline; the position P2 can be calculated by evaluating intersection between beeline and DEM. According to this method the geometric coordinates of every pixel can be computed by using a simple interpolation. Once the coordinates of the pixels are calculated, the position of the texture can be defined. The process is repeated until the whole image is completed. As a result the four-dimension information is formed. The 4D information includes 3D geometric position and corresponding texture character.

3D Modeling and visualization

Having generated TIN (triangle irregular network) from 3D point clouds, the first step is to interpolate the TIN into a regular grid DEM; and then to extract texture character from CCD images. Subsequent step is to match and fuse between CCD images and DEM. The final step is to rebuild 3D models and realize the 3D dynamic display such as simulating driving, flying and so on.

IV. APPLICATIONS

The laserscanning is a promising technology and has been used widely. The original data of the system are the LS range data, the CCD image, and attribute data.

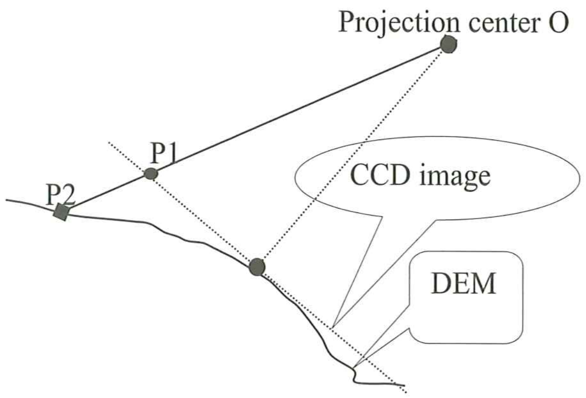

Figure 5. Projection transform

Spatial database, which carries out the management of multi-source data, can be formed. Excepting for modeling 3D objects, the database can be used to realize information inquiry, analysis of data and visualization of 3D models.

The following two cases show practical applications of our system, where how to cope with CCD images are still under investigation.

Surveying bulk of accumulation

The chosen trial zone was a field coal-stack of a certain power-generating Plant located in Hubei Province, China. The size of the coal-stack is 50m×260m. The system is mounted on the travelling crane that can run along the stationary rail. The CCD camera was not used in this case. With the movement of the travelling crane, the system scanned the coal-stack and obtained real-time trace of the platform. Based on the original data, the digital surface model of coal-stack can be generated. The bulk of coal-stack can be calculated within 5 minutes. This method is very fast, efficient, and with high precision.

Figure 6 shows the simulative map of coal-stack produced by using Open-GL, in which the color is simulative. In the system the interactive operation of the model can be realized.

Rebuilding 3D levee

In China the levee length of Changjiang River extends to thousands of kilometers. The prevention or control of flood is an arduous task. How to evaluate and monitor in near real-time the security of levee needs rapidly updated 3D digital levee models. The system attempts to utilize laserscanning technology to acquire DEM of the levee. In this case the system is mounted on an automobile. Using this technology surveying the levee with 10 kilometers long only needs half an hour. Figure 7 shows a grid-net model of the levee that spans 1 kilometer. Figure 8 is the real levee CCD image captured.

Other potential applications

The following applications with the system are under investigation:

Detection of roads

The DGPS system, which excepting for acting as system clock, can be used to measure the centerline of the road in real time and control the scanning of CCD and LS sensors. Therefore, 3D models of the cement lines can be reconstructed, and the visualization of them can be realized. It is expected that the system

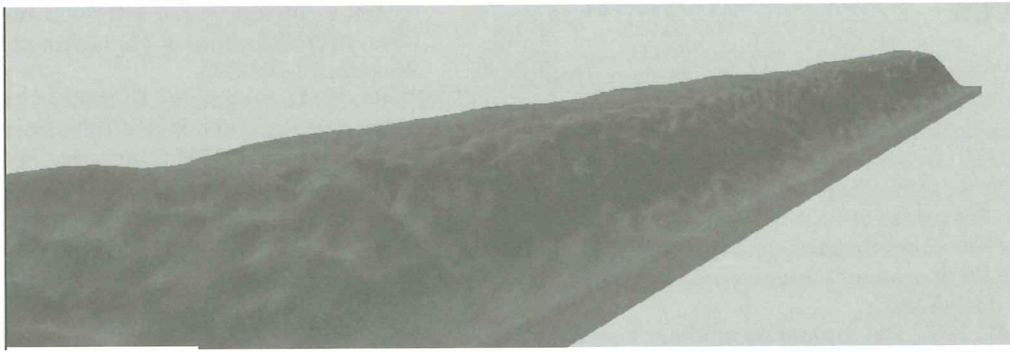

Figure 6. 3D coal-stack map

can replace the classical surveying methods and can accomplish the detection of roads efficiently. This technology is promising.

Deformation analysis of the levee

We attempt to apply the system to perform deformation analysis of the levee. The surface information of the levee can be collected automatically using this system. Using the DGPS dynamic positioning data, the measurable 3D models of the levee can be formed. Therefore, the following work can be conducted: 1) analyses of 3D deformation of the levee; 2) simulative analyses of flood. According to analysis results, the security factor of the levee can then be determined.

V. CONCLUSIONS AND REMARKS

This paper introduces a method to rebuild and visualize 3D objects by using laserscanning. In the system the range images provide fine 3D surface data while optical images show detailed texture information. Rebuilding 3D models by fusing the range image and the optical image provides a means to solve the modeling difficulties that are encountered by traditional methods.

The further investigations are required in the following fields:

- *Calibration*. The accuracy of generated DEM as well as pixel value and coordinates interpolation is dependent on the calibration. Calibration needs to be done in both static and dynamic cases.
- *Mosaic*. It is desirable to generate a mosaiced image. How to mosaic images and to correct deformations caused by moving of the platform needs a further research.
- *Extraction of Theme Information*. The methods that extract thematic information of spatial objects (such as structure, road, etc.?from range images are to be investigated in the future.
- *Information Inquiry*. The main problems are focused on querying information directly on truly 3D images.

Moreover, how to extract texture information and paste them onto the corresponding DEM point with high accuracy and reliability is also an investigative content in the future.

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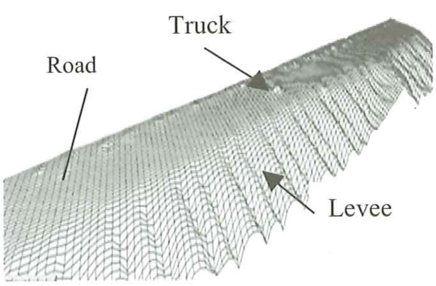

Figure 7. Grid-net of the levee

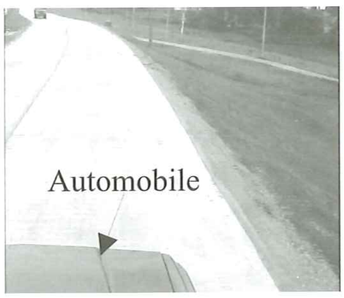

Figure 8. Real levee map

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