Development of Digital Surface Model and Feature Extraction by Integrating Laser Scanner and CCD sensor

Masahiko Nagai, Ryosuke Shibasaki, Huijing Zhao, Dinesh Manandhar
Center for Spatial Information Science, The University of Tokyo
Cw-503, 4-6-1, Komaba, Meguro-ku, Tokyo 153-8505, Japan
Tel: 03-5452-6417 Fax: 03-5452-6414
nagaim@iis.u-tokyo.ac.jp

Abstract: In order to present a space in details, it is indispensable to acquire 3D shape and texture simultaneously from the same platform. 3D shape is acquired by Laser Scanner as point cloud data, and texture is acquired by CCD sensor. Positioning data is acquired by IMU (Inertial Measurement Unit). All the sensors and equipments are assembled on a hand-trolley. In this research, a method of integrating the 3D shape and texture for automated construction of Digital Surface Model is developed. This Digital Surface Model is applied for efficient feature extraction. More detailed extraction is possible, because 3D Digital Surface Model has both 3D shape and texture information.
Keywords: Laser Scanner, Digital Camera, IMU, Digital Surface Model, Feature Extraction, Sensor Integration.

1. Introduction

Three dimension data are in great demand for the various applications such as 3D GIS, car navigation, digital archives of remains, simulations, computer games, and so on. In order to represent space in details, it is indispensable to acquire 3D shape and texture together. Also, in order to represent space effectively, it is indispensable to use mobile platforms. A lot of research efforts have been made to the development of mobile mapping system with integrating of geo-referencing sensors and mapping sensors (e.g. [1], [2], [3]). However, there still lacks a reliable, quick, and handy method of acquiring three dimension data at higher resolution. In this paper, a combination of mapping sensors, a digital camera and a small (cheap) laser scanner, with geo-referencing sensors, inexpensive IMU, is proposed. Development of accurate digital surface model and detail feature extraction is conducted using inexpensive and handy measurement tools.

2. System Design

In this research, laser scanner and digital camera with IMU are used to develop digital surface model and to extract features. 3D shape is acquired by laser scanner as point cloud data, and texture is acquired by CCD sensor from the same platform simultaneously. Positioning and attitude data is acquired by GPS (Global Positioning System) and IMU (Inertial Measurement Unit). All the sensors are tightly fixed on the platform to have constant geometric relationship and they are controlled by a common laptop PC to synchronize the measured data with the movement or direction of the platform. In this research, all the measurement tools are loaded on a hand-trolley for mobile mapping. And they are tightly fixed as shown in Fig.1. When the experimental measurement is conducted, the hand-trolley is pushed by hand to measure the side objects. Table 1 shows the list of sensors and their characteristics which are used in this research. All of them are all-purpose measurement tools.

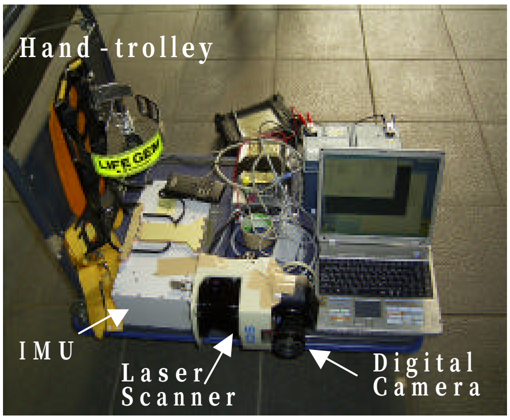

Fig. 1. Sensors on a hand-trolley

Table 1. List of sensors

Sensor	Characteristics
Digital Camera	Canon EOS D-60 Pixel size: 3027 x 2048pixels CCD size: 22.7mm x 15.1mm Lens: EF24-85mm F3.5-4.5 USM
Laser Scanner	SICK LSM291 Angular resolution: 0.25° Max. Distance: 80m Observation Angle: 100°
IMU	ZUPT interval: 30sec CUPT interval: 6min.

3. Sensor Calibration

Calibrations of sensors are necessary due to two reasons; to know the image distortion and to know relative position and attitude of each sensor against IMU. All the sensors are fixed on the hand-trolley to establish rigorous geometric relationships. The purpose of calibration is basically to integrate all the sensors and positioning devices to a single coordinate system, so that captured data can be integrated and expressed in terms of a single world coordinate system.

1) Interior Orientation

Calibration I is conducted to decide interior orientation parameters of digital camera, principal point, focus length, and distortion coefficient. Control points for camera calibration are taken as stereo images several times. Camera calibration is performed by the bundle adjustment using control points. Interior orientation parameters which are computed in this Calibration I are shown in Table 2.

Table 2. Interior orientation parameters

x_0	1532.9966 pixels	f	24.6906 mm
y_0	1037.3240 pixels	K_1	1.5574E-008

x_0, y_0:principal point. f:focus length. K_1:distortion coefficient

In order to estimate appropriate lens distortion for digital camera, lens distortion mode is shown in Eq. (1) and Eq. (2). These equations consider only radial symmetric distortion.

$$x_u = x' + x' (K_1 r^2) \quad (1)$$
$$y_u = y' + x' (K_1 r^2) \quad (2)$$
$x' = x - x_0$, $y' = -(y - y_0)$, $r^2 = x'^2 + y'^2$
(x, y): image coordinate

2) Exterior Orientation

Calibration of digital camera and laser scanner is conducted to estimate exterior orientation parameters, positions and attitude. This needs shift and orientation between each of sensors and IMU, which is computed from calibration. At first, rigorous geometric relationship between laser scanner and digital camera is established. This relationship is strongly fixed at all times. Then, geometric relationship between digital camera and IMU is established. That is, geometric relationship between laser scanner and IMU is theoretically established. Fig. 2 shows the concept of calibration II.

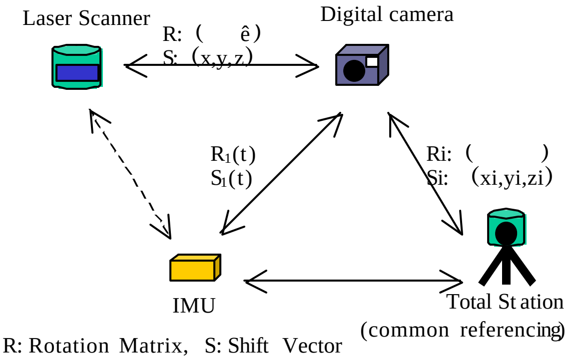

Fig. 2. concept of Calibration II

Geo-referencing of laser scanner data and digital camera image is done by computing the rotation matrix, R, and shift vector, S with IMU. All the points scanned by the laser scanner, x, and digital camera, (x_u, y_u), in terms of local coordinate system is converted to world coordinate system as given by Eq.(3) and Eq.(4).

$$X^{world}_{laser} = (Ri*R)\,x + (Si+S) \quad (3)$$
$$X^{world}_{image} = f(Ri, Si, f, x_u, y_u) \quad (4)$$
f( ): collinearity condition equation

4. Construction of DSM

Laser scanner, digital camera, IMU has different coordinate system. All the coordinate systems are converted to world coordinate system in order to have compatibility of data overlaying and sharing with the existing database. The hand-trolley is continuously moving and the position and attitude of the hand-trolley is changing with respect time. Geo-referencing of laser data and digital camera image is converted by computing rotation matrix, R, and shift vector, S, with the respect time of IMU data and calibration parameters. All the points scanned by the laser scanner, x, and digital camera, (x_u, y_u), in terms of local coordinate system is converted to world coordinate system as given by Eq.(5) and Eq.(6). t is the time function. Rotation matrix, R(t), and shift vector, S(t), is changing with time because of drift of IMU. However, IMU is corrected by ZUPT (Zero velocity updates) and CUPT (Coordinate updates) in this research. So, $R_1(t)$ and $S_1(t)$ are constant all the time as well as R and S because the sensors are rigidly fixed on the platform.

$$X^{world}_{laser} = (R_1(t)*R)\,x + (S_1(t)+S) \quad (5)$$
$$X^{world}_{image} = f(R_1(t), S_1(t), f, x_u, y_u) \quad (6)$$
f( ): collinearity condition equation

Fig. 3 show the point cloud data which is acquired by laser scanner at Institute of Industrial Science of the University of Tokyo. This data presents with world coordinate system. The integrated laser data shows a good matching between the different sensor data indicating that the calibration result.

The DSM is a 3D model of the object surface that is manipulated using a computer. It is comprised of 3D measurements that are laid out on a grid. These measurements are the 3D point cloud data, which is derived from laser scanner.

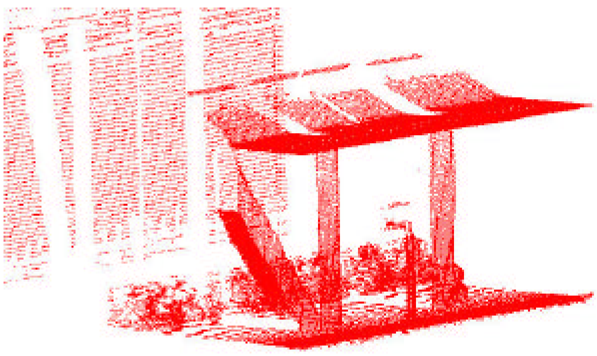

Fig. 3. Point cloud data with world coordinate system

5. Feature Extraction

Feature extraction is conducted by range data and image data. Geometric shape, which is acquired by leaser scanner detect features. Texture information which is acquired by digital camera details those features. That is, more detail extraction is possible using both 3D shapes and colors.

1) Feature Extraction Procedure

Feature can be detected from both range data and image data. In range data, there are some basic information to divide into several groups, ground surface, horizontal plane, vertical plane, scatter points, and line feature. Usually, natural feature like trees or weeds have scattered range points where as the man-made features follow some geometric patterns like horizontal and vertical aligned points. However, for detailed extractions, this is not always true. Some man-made features which have very complicated shape such as bicycles or decorated object has scattered range points. In this point of view, image data is used to complement range data for further details. Fig. 4 shows the feature extraction procedure of the acquired data.

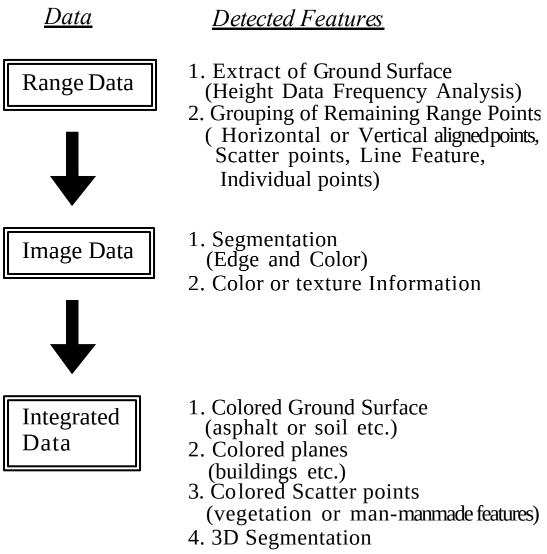

Fig. 4. Feature Extraction Procedure

2) Feature Extraction Results

Finally, feature extraction is conducted at ground floor of Institute of Industrial Science of the University of Tokyo. Range data, which is shown in Fig. 3 and image data, which is integrated to this Fig.3 are used for feature extraction. There are no special features existing, but still some features can be extracted. List of extracted feature is shown in Table. 3.

Table 3. Extracted Features

Detected Feature	Distinctive Feature
Concrete Ground Surface.	- ground surface - gray color (concrete color)
Concrete Ceiling	- parallel to ground surface - gray color (concrete color)
Parking place for Bicycles.	- Scatter Point - not green color (not vegetation)
Wall	- Vertical Plane - gray color (concrete color)
Pillar	- rectangular shape from ground surface to ceiling - gray color (concrete color)

6. Conclusion

In conclusion, all the sensors, laser scanner, digital camera and IMU, are integrated to construct digital surface model. Calibration of laser scanner and digital camera is conducted to know relative position and attitude of each sensor against IMU. This is one of the key points of this research. This rigorous geometric relationship is used for constructing DSM and integrating digital camera images. Feature extraction from range data and image data is more effective than feature extraction from image data alone.

In this paper, all the sensors and equipments are assembled on a hand-trolley. This paper focus on how integrate these sensors with mobile platform. There are numerous researches are necessary as future study, and they are specified in the following:

1. IMU drift error has to be modeled, so that the platform can be operated continuously without ZUPT and CUPT.
2. Various features have to be attempted to extract.
3. Other platforms have to be attempted, for example, unmanned helicopter, some vehicles and vessels.
4. Application to use this research has to be considered such as earthquake disaster, volcanic eruption, urban mapping, etc.

References

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