DEVELOPMENT OF DIGITAL SURFACE MODEL AND FEATURE EXTRACTION BY INTEGRATING LASER SCANNER AND CCD SENSOR WITH IMU

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TS SS-3: Mobile Multi-Sensor Mapping Systems

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ABSTRACT:

Three dimension data are in great demand for the various applications such as 3D GIS, navigation, digital archive, simulation, computer games, and so on. In order to represent space in details, it is indispensable to acquire 3D shape and texture together. However, there still lacks a reliable, quick, and handy method of acquiring three dimension data at higher resolution. In this research, we propose a combination of a digital camera and a small (cheap) laser scanner with inexpensive IMU (Inertial Measurement Unit) for unmanned air vehicles.

3D shape is acquired by laser scanner as point cloud data, and texture is acquired by CCD sensor from the same platform simultaneously. Positioning data is acquired by GPS (Global Positioning System) and IMU. All the sensors are synchronized with movement or attitude of the platform. In this paper, a method of integrating all the sensors is focused. All the sensors are tightly fixed on the platform to establish rigorous geometric relationships. Calibration of laser scanner and CCD camera is conducted to know relative position and attitude of each sensor against GPS and IMU. Through Kalman filter, an optimal estimate of the sensor position and attitude is estimated from GPS and IMU. Bundle block adjustment is conducted using continuous CCD images. The result of bundle block adjustment aids Kalman filter by initialization of position and attitude.

Using this measurement system, a procedure for automated construction of digital surface model is developed using these sensors. This paper proposes a new method of rendering objects with rich shape and detailed texture. Sensor position and attitude for mapping are basically acquired by GPS/IMU and their errors are complemented by digital camera images using tie point. In case of real time mapping, colored point cloud model is produced as a quick view.

Feature extraction is conducted by range data and image data. Geometric shape which is acquired by leaser scanner represent features. Texture information, which is acquired by digital camera, details those features. That is, more detailed extraction is possible using both 3D shapes and colors. It is possible to extract not only man-made object but also natural object such as people and vegetation.

1. INTRODUCTION

1.1 Background

Three dimension data is in great demand for the various applications such as 3D GIS, car navigation, pedestrian navigation, digital archive, simulation, computer games, and so on. In addition, targets of 3D data acquisition are now spreading to the 3D modelling of moving objects. In order to represent 3D space and moving objects in details, it is indispensable to acquire 3D shape and texture together efficiently (Zhao, H., Shibasaki, R., 2000). However, there still lacks a reliable, quick, cheap and handy method of acquiring three dimension data of objects at higher resolution and accuracy in outdoor and moving environments(Nagai, M., Shibasaki, R., etc., 2003). In this research, A combination of a digital camera and a small (cheap) laser scanner with inexpensive IMU and GPS for mobile platform are proposed. Using mobile platform is very important for acquiring data effectively(Zhao, H., Shibasaki, R., 2001). That is, it is necessary to consider the method to get to develop the high precision positioning. In this research, the way of direct geo-referencing is achieved automatically from mobile platform using all the sensors without any ground control points. (Here, direct geo-referencing means geo-referencing which do not require ground control points with accurately measured ground coordinate values.) Therefore, after the accurate trajectory of the platform with attitude changes are determined through the direct geo-referencing, 3D shape of objects is determined by laser scanner as 3D point cloud data, while texture is acquired by CCD sensor from the same platform simultaneously. In this paper, a method of direct geo-referencing of range data and CCD images and integrating all sensors for constructing textured 3D model from the mobile platform are focused.

1.2 System Design

In this research, laser scanner and digital camera with IMU and GPS are used to develop digital surface model(Kumagai, H., Kubo, Y., 2002 and Kumagai, H., Kindo, T., 2000). 3D shape is acquired by laser scanner as point cloud data, and texture is acquired by CCD sensor from the same platform

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simultaneously. Positioning and attitude data is acquired by GPS (Global Positioning System) and IMU (Inertial Measurement Unit). List of sensors which is used in this research is shown in Table 1.

Sensors	Model	Specification
Digital Camera	Canon EOS D60	3072×2048 pixels Focus length 24.0mm
Laser Scanner	SICK LMS291	Angular resolution: 0.25° Max. Distance: 80m Observation Angle: 100º
IMU	Tamagawaseiki TA7572	Range Angular Velocity ±200°/s Accuracy Angle ±0.1° Angle Velocity ±0.05°/s Acceleration ±0.002G
GPS	Ashtech G12	Accuracy Differential 40cm Velocity Accuracy 0.1(95%)

Table 1. List of sensors

All the sensors are tightly fixed on the mobile platform to have constant geometric relationship and they are controlled by common laptop PC to synchronize the laser scanning and taking images with the movement or direction of the platform. Figure 1. shows the system design of this research. In this system, two laptop PCs are used. There two laptop PCs are synchronized by 1 pps (pulse par second) data of GPS. Table 2 shows the frequency of data acquisition.

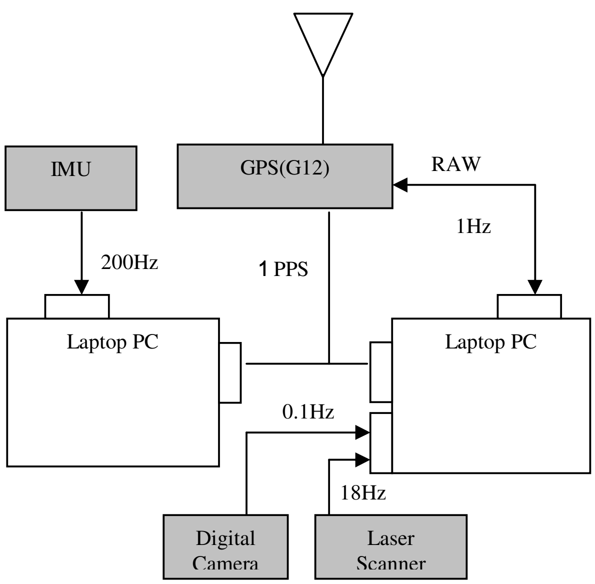


Figure 1. System design

Sensors	Frequency
Digital Camera	0.1 Hz
Laser Scanner	18 Hz
IMU	200 Hz
GPS	1 Hz

Table 2. Frequency of data acquisition

1.3 Platform

In this research, all the measurement tools are loaded on a unmanned helicopter, RPH2, which is made by SUBARU. It is shown in Figure 2. And Table 3 shows the main specification of RPH2. And all the sensors are tightly fixed under the unmanned helicopter. When the experimental measurement is conducted, the unmanned helicopter flies about 1.8m/s of speed for getting enough resolution of data.

Figure 2. SUBARU RPH2

Weight	330 kg
Pay load	100 kg
Motor	83.5 hp
Main Rotor	Diameter 4.8m

Table 3. Specification of RPH2

2. 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 unmanned helicopter 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.

2.1 Interior Orientation

Calibration for digital camera is conducted to decide interior orientation parameters, principal point (x_0, y_0), focus length (f), and distortion coefficient (K_1). 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 interior orientation are shown in Table 4.

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

Table 4. Interior orientation parameter

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.

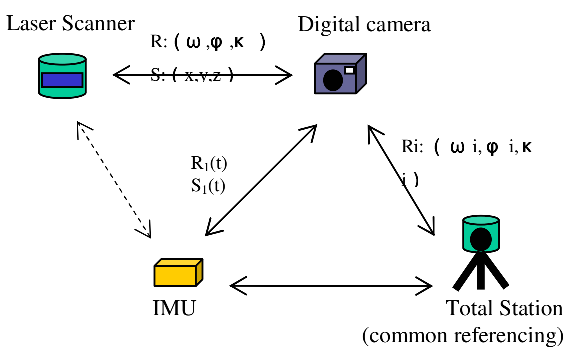
$$x_u = x' + x' (K_1 r^2) \tag{1}$$

$$y_u = y' + x' (K_1 r^2) \tag{2}$$

where $x' = x - x_0$, $y' = -(y - y_0)$, $r^2 = x'^2 + y'^2$
(x, y): image coordinate

2.2 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. Figure 3 shows the concept of calibration to decide exterior orientation parameter.
For laser scanner calibration, the solar cell is used. The solar cell connect to an earphone. If the solar cell receive laser beam from laser scanner, the earphone beep. In this way, the center of laser beam is measured for calibration even though laser beam is invisible.



where R: Rotation Matrix
S: Shift Vector

Figure 3. Concept of calibration for exterior orientation

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).

$$X^{world}_{laser} = (Ri*R)\, x + (Si+S) \tag{3}$$

$$X^{world}_{image} = f(Ri, Si, f, x_u, y_u) \tag{4}$$

Where f( ): collinearity condition equation

3. CONSTRUCTION OF DSM

3.1 Integration of Positioning Sensors

The positioning and attitude of sensors are decided by integration of GPS, IMU, and images. One of the main purposes of this research is to integrate all sensors and to develop the high precision positioning system in all circumstances.
Figure 4 shows the algorithm for deciding attitude, velocity, position using only IMU.

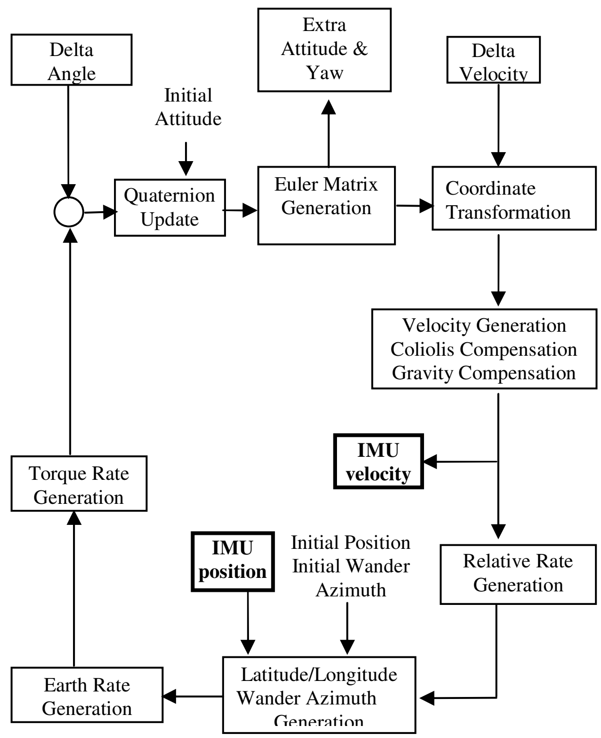


Figure 4. Pure navigation block diagram

IMU has a rising quality, but it is still affected by systematic errors. Through Kalman filter operation, an optimal estimate of the sensor position and attitude are determined from GPS and IMU. Meanwhile, relative orientation of CCD image is determined by bundle block adjustment. Bundle block adjustment is a non linear least squares optimization method using tie-points of inside block. GPS and IMU allow automatic setting of tie-points and they reduce the number of tie-points and searching time of tie-points by the limitation of searching area. GPS, 1Hz, and IMU, 200Hz, with Kalman filter which has high frequency is necessary for geo-referencing of range data, which frequency is 18Hz. But accuracy is low because of miss alignment, drift error, or effect of PDOP. On the other hand, CCD images are taken every 10 second and geo-referencing is computed by bundle block adjustment which has very high accuracy of mapping. But frequency of computation is very low. That is, because of different frequency and accuracy, these two different methods of geo-referencing, Kalman filter and Bundle block adjustment.
Therefore, the combination of bundle block adjustment and Kalman filter is proposed in this research. The result of bundle block adjustment aids Kalman filter by initialization of position and attitude. In this research, the result of bundle block adjustment is treated as true positioning values. IMU and GPS

are initialized for Kalman filter using the result of bundle block adjustment. That is, after every bundle block adjustment that is every 10 second, GPS and IMU and their errors are complemented. Figure 5 is the strapdown navigation algorithm for integrating IMU and GPS with the result of bundle block adjustment..

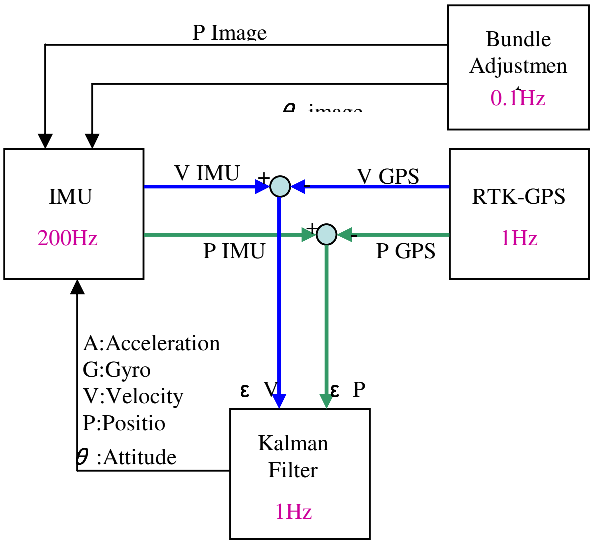


Figure 5. Strapdown navigation algorithm

3.2 Geo-referencing

While measuring, the platform, including all sensors, is continuously changing its position and attitude with respect time. For direct geo-referencing of laser range data, corrected position and attitude data is used. Geo-referencing of range data is determined by 3D Helmert's transformation which is computing rotation matrix and shift vector 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 with time by Kalman filter and Bundle block adjustment in this research.

$$X^{world}_{laser} = (R_1(t)*R)\,x + (S_1(t)+S) \quad (5)$$

$$X^{world}_{image} = f(R_1(t), S_1(t), f, x_u, y_u) \quad (6)$$

Where f( ): collinearity condition equation

Therefore, geo-referencing of range data and CCD images is done directly to overlap exactly with high accuracy and high resolution.

3.2 Construction of DSM

The point cloud data which is acquired by laser scanner is geo-referenced by corrected IMU data. This data presents with world coordinate system. Image data are overlaid on geo-referenced point cloud data. The integrated point cloud data shows a good matching with image data because IMU data was corrected by there image data using by the result of Bundle block adjustment.

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.

4. 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, texture..

4.1 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(Manandar, D., Shibasaki, R., 2002). 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. Figure 6 shows the feature extraction procedure of the acquired data. At first, range data used to group all the feature by common characteristics. Then, segmentation is conducted using color and edge of images. Image data has higher resolution than range data. Finally, range data and image data is integrated for detailed extraction.

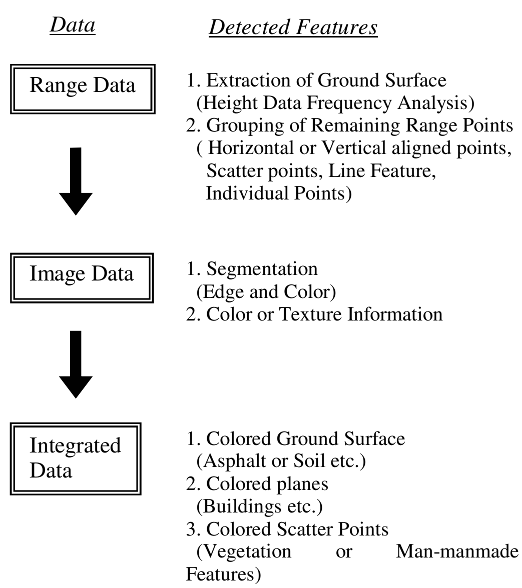


Figure 6. Feature extraction procedure

4.2 Feature Extraction Results

Finally, feature extraction is conducted. Range data and image data are used for feature extraction. List of extracted feature is shown in Table 5. In this research, only several main features are extracted, because the test site of this research is limited.

But there is every possibility of extracting using by 3D shape and texture information. As a feature, various features have to be attempted to extract. Also, application to use this detailed extraction has to be considered such as earthquake disaster, volcanic eruption, urban mapping, etc.

Detected Feature	Distinctive Feature
Concrete Ground Surface.	- ground surface - gray color (concrete color)
Grass Ground Surface	- ground surface - green color (vegetation color)
Manmade object (complex shape)	- Scatter Point - not green color (not vegetation)
Manmade object (Box shape)	- Artificial Shape - not green color (not vegetation)
Natural vegetation	- Scatter Point - not green color (not vegetation)
Wall	- Vertical Plane - gray color

Table 5. Extracted Features

5. CONCLUSION

In conclusion, all the sensors, laser scanner, digital camera and IMU, GPS 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 rigorous geometric relationship is used for constructing DSM and integrating digital camera images. In this paper, we propose a new method of direct geo-referencing by the combination of bundle block adjustment and Kalman filter. Because of the aiding Kalman filter by bundle block adjustment, geo-referenced range data and CCD images are overlap correctly. 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 unmanned helicopter. This paper focus on how integrate these sensors with mobile platform.

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