Location-Based Sabo Infrastructure Monitoring

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Abstract. Although we often generate a three-dimensional (3D) geometrical model as a base map in infrastructure asset management, it is difficult to acquire details of asset attributes in 3D measurement. Therefore, we focus on field-based investigation and inspection using mobile devices, and aim at assisting investigators in Sabo infrastructure monitoring with location-based applications. In this paper, we propose and evaluate our location-based investigation application as follows. First, we propose an inspection flow suitable for field-based monitoring. Second, we develop an HTML5-based Web GIS application for field-based investigation. Third, we clarify the most suitable combinations among location, angle, azimuth, elevation, image, movie, and voice data acquired with mobile devices. We conduct an experiment in a sediment-retarding basin consisting of dikes, bridges, and debris barriers, and explore some issues in Sabo infrastructure monitoring using mobile devices.

Keywords. Sabo infrastructure management, Mobile device, Construction information modeling

1. Introduction

Infrastructure asset management is a framework for achieving sustainable infrastructure, such as roads, bridges, railways, and water treatment facilities. Generally, management focuses on the lowest life-cycle cost in a process of construction, maintenance, rehabilitation, and replacement. Based on this framework, a 3D geometrical model based on construction information modeling (CIM) is often generated. Moreover, asset attributes, such as deterioration, condition, and age are acquired. To check the position of structures and structural elements and collect data related to these structures in frequent monitoring, there is a need to refer to maps, engineering drawings, databases, and technical documents (Garrett et al. 2002). Reliability, completeness, efficiency, and cost are significant indices in monitoring. Reliability, completeness, and efficiency can be satisfied using terrestrial LiDAR, a vehicle-borne mobile mapping system, and aerial photogrammetry is performed using an unmanned aerial vehicle. However, with these approaches it is difficult to satisfy the cost index. In the current state, it is also difficult to acquire details of asset attributes with 3D measurements. Therefore, we focus on ground investigation and inspection using mobile devices (Kamada et al. 2013). Field-based inspection requires some location-based applications, such as geo-tagged image acquisition (photography), database interface, and navigation (Hammad et al. 2006). Mobile devices, such as tablet PCs, smart phones, and global positioning system (GPS) cameras, have the potential to assist inspectors in infrastructure asset monitoring because of their built-in sensors and components that include cameras, assisted GPS receivers, gyro sensors, Wi-Fi, microphones, speakers, vibrators, and large storage. We aimed to assist investigators in infrastructure asset monitoring with location-based applications. In this paper, we propose and evaluate our location-based investigation application.

2. Methodology

A conventional flow for infrastructure inspection is shown in Figure 1.

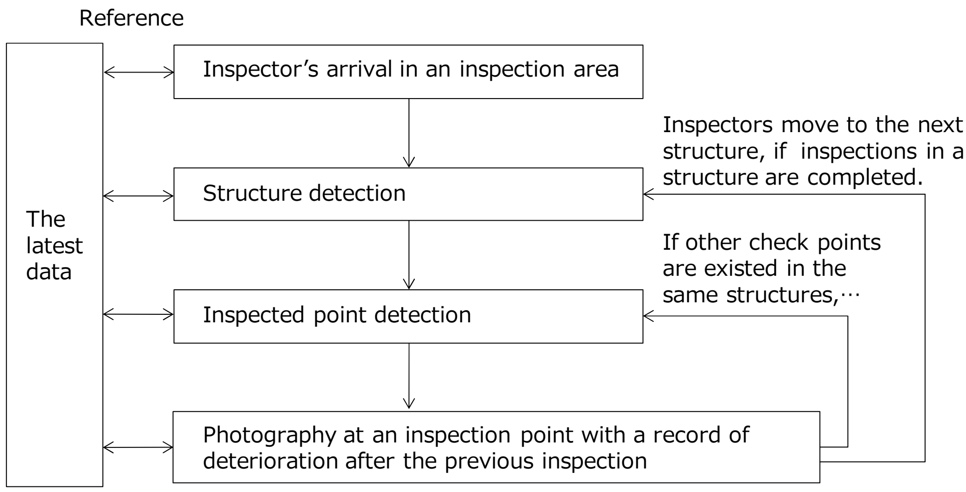

Figure 1. Infrastructure inspection

During infrastructure inspection, we generally refer to the latest inspection documents to determine an inspected position, as follows. First, the structure to be inspected is detected after the inspector's arrival in the inspection area. Next, an inspected point is detected in the structure. Then, the condition of the inspected point is recorded and compared with the latest inspection. After that, a geo-tagged photo is captured at the inspected point. Based on these operations, we propose a location-based approach to assist infrastructure inspection.

2.1. Mobile inspection application

The functions and performance of infrastructure inspection assistance with a mobile device, such as a tablet PC equipped with GPS, are summarized in Table 1. Category A indicates essential functions and category B indicates additional functions. In addition, specific objects and actions for mobile inspection applications are classified according to function, as shown in Table 2. Additionally, we propose a data model for our Web GIS-based mobile inspection application to satisfy the above-mentioned functions, as shown in Figure 2. An inspection work is subdivided into several activities, such as geotagged image acquisition, adding a postscript to a photo, and adding a postscript to an engineering drawing. Geotagged data generated from these works are managed with Extensible Markup Language to automate file export using an inspection template prepared by municipalities and a combination of managed data, such as maps, images, and movies, using position data as a retrieval key in inspection navigation. Acquired GPS data are mainly used for the management of location and time data. The location data included represent the position of structures, camera position data, and camera azimuth and rotation data.

Table 1. Summarized functions and performance for an infrastructure inspection using a mobile device

Category A	・Display of maps, drawings, images, movies, and technical information ・Input of characters, lines, and shapes ・Adding a postscript to technical documents
Category B	・Documentation compatible with various template sheets ・Display of various types of maps and drawings (tiff, shp, sxf, dwg, etc.) ・Navigation in facility area ・Measurement (distance and area, etc.) ・Change detection ・User intuitive operability

Table 2. Specific objects and actions for a mobile inspection application

Photography - Position - Date - Azimuth - Photographer - Rotation	Map - Zooming - Azimuth - Camera position - Current position	Drawing memo - Circle - Text - Line - Color - Rectangle - Zooming
Photo memo - Circle - Text - Line - Color - Rectangle - Zooming	Documentation - Pull-down - Text - Radio button - Sound	Failure alert - Pop-up display

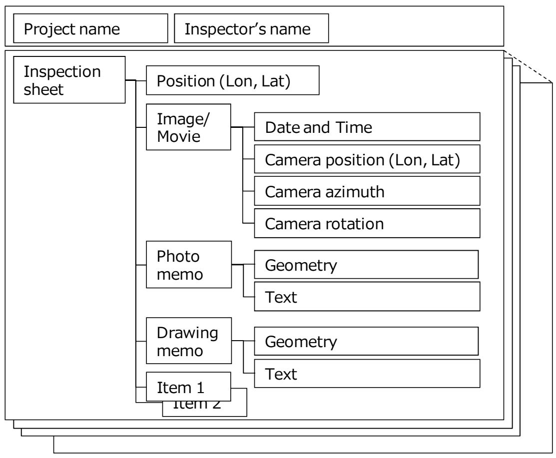

Figure 2. A data model for our mobile inspection application

2.2. Location data management

The required positioning accuracy is dynamically changed by each inspection work. For example, a closed photograph requires the same position (with approximately 1 cm accuracy) and direction (with approximately 1 degree accuracy) in the latest inspection to achieve automation of image registration for detection of any change in an infrastructure inspection (Nakagawa, Katuki, Isomatu and Kamada, 2013). On the other hand, inspection point detection requires lower positioning accuracy, from approximately 10 cm to 1 m. Moreover, in structure detection, positioning accuracy is allowed to be approximately 10 m. In addition, 100 m positioning accuracy is sufficient for an inspector's arrival in an inspection area. Thus, a definition with several steps or spatial resolutions is effective in location data management. In this research, these steps are represented as levels of details (LODs), such as LOD1: address, LOD2: structure, LOD3: inspection point, and LOD4: photography, as shown in Table 3.

Table 3. Details of LODs for a positioning in inspection works

Levels of details	Content	Required accuracy	Approach
LOD1 **Address**	Inspector's arrival in an inspection area	100m	- Map - GPS (single positioning) - GPS tablet - GPS camera
LOD2 **Structure**	Structure detection	10m	
LOD3 **Inspection**	Inspection point detection	10 cm – 1 m	
LOD4 **Photo management**	Documentation - Photography - Drawing	- 1 cm - 1 degree	- Movie (geo-tagged) - GPS tablet

Positioning from LOD1 to LOD3 requires from 1 to 100 m accuracy. Thus, single GPS positioning is suitable for position data acquisition. However, LOD4 requires 1 cm accuracy with precise positioning, such as a real-time kinematic GPS (RTK-GPS). Generally, low-cost inspection restricts the use of expensive devices such as an RTK-GPS. In low-cost inspection, the performance of satellite positioning is generally improved by assisted-GPS, differential GPS and multi-GNSS positioning using GPS, GLONASS, and QZSS. Data fusion of GPS and dead reckoning also improves the performance of positioning. However, although these approaches improve availability, they have almost no effect on positioning accuracy improvement (Inaba et al. 2013). In this research, satellite positioning was assumed to have 1m accuracy, even if we could apply improvement approaches to positioning accuracy. Thus, a navigation approach using movies was applied in LOD4 (precise positioning). This approach assists inspectors to determine a position in a photography using a movie that was captured in the latest inspection and the attached approximate position data acquired with GPS.

3. Methodology

The control of erosion and sediment is called Sabo. We conducted an experiment involving the daily and annual Sabo infrastructure inspection work in a sediment-retarding basin consisting of dikes, bridges, and debris barriers in Fukushima, Japan (see Figure 3). In this study area, we prepared 40 checkpoints for infrastructure inspections. At each checkpoint, we acquired inspection data for our experiments, as shown in Table 4. Each experiment included inspection navigation, log browsing, recording, location data acquisition, and photography using our mobile inspection application. A conventional paper-based inspection was also conducted in parallel.

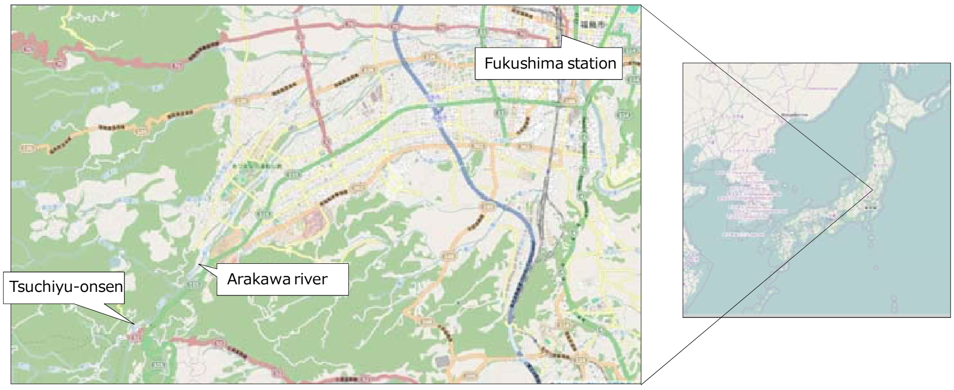

Figure 3. Study area

Table 4. Abstract of experiments

[1] Preliminary survey using moblie deveices	
Date	19th – 20th, Dec., 2013
Contents	Activity classification in a conventional paper-based SABO inspection
	Environment survey for GPS positioning and Wi-Fi connection
Devices	GPS camera (EXILIM EX-20G, CASIO)
	GPS tablet (Xperia Tablet S, SONY)
[2] Demonstration using our mobile application for SABO inspection	
Date	30th – 31th, Jan., 2014 and 10th - 12th, Sept., 2014
Contents	Verification of our mobile application
	Issue extraction in mobile inspection
Devices	GPS camera (EXILIM EX-20G, CASIO)
	GPS tablet (YOGA Tablet 8, Lenovo)
	GPS tablet (Xperia Tablet Z, SONY)

Screenshots of our mobile application are shown in Figure 7 and Figure 8. This application consisted of several functions such as real-time browsing of position and rotation data, GPS logging, camera capture, Google Maps, and information postscripts. Moreover, this application was coded with HTML5 so that it was not affected by operation systems (OS) and browsers. In these experiments, our application used the Firefox browser (ver. 27.0) on an Android OS (ver. 4.1.2). The data acquired with the mobile device were managed on a local storage device and shared on a server through asynchronous communication.

Camera capture

GPS logger

Inspection log viewer
in Google Maps

Figure 4. Developed mobile inspection application

A GPS (Holux) mounted omni-directional camera (QbiC / ELOMO) was also used in our experiments to verify the possibility of precise navigation in the infrastructure inspection, as shown in Figure 5.

Figure 5. A GPS mounted omni-directional camera (left image) and captured movie with position and rotation data (right image)

4. Discussion

4.1. Integrity of location data

In this research, we focused on a mobile application for infrastructure inspection, and location data management for inspection navigation. In fact, the availability of an application using location data depends on the integrity of the location data (Yabuki, 2013), and the integrity of the location data strongly affects location data browsing, and inspection recording and log browsing. Here, to improve the integrity, we focused on a combination of acquired data, such as location, photo, movie, and voice data. We classified five combinations among these data types, as follows.

a) Position (latitude and longitude)

Although inspection navigation is difficult without height data, we confirmed that numerical height information was not necessary in order to detect a position. The inspection navigation could be conducted with an approximate height position, such as an upper part, lower side, or façade of a structure.

Several minutes were required for detection of the previous inspection position. The most suitable procedure for the detection of the previous inspection position in our experiment was as follows. First, an approximate position was determined using a map. Second, the fine position was determined with a GPS data reference. However, the numerical value of the GPS data was unstable in fine position detection.

b) Position (latitude and longitude) , azimuth, and elevation angle

Several minutes were required for detection of the previous inspection position. The most suitable procedure for the detection of the previous inspection position in our experiment was as follows. First, we referred to longitude and latitude to detect the position. Second, we referred to the azimuth angle using magnetic sensor data taken from a tablet PC. Third, we referred to an elevation angle using gyro sensor data taken from the tablet PC.

c) Position (latitude and longitude) , azimuth, elevation angle, and photograph

We determined the position for inspection with position, azimuth, and elevation angle data. Moreover, we could reconfirm the position with a photo taken in the previous inspection. However, when a difference existed between the position determined from position, azimuth, and elevation angle data and the position estimated from a geotagged photo, inspectors were unable to determine the true position for the inspection.

d) Position (latitude and longitude) and movie

We did not conduct an experiment related to video capture, which provides the shortest capture time and efficiency for navigation. However, we confirmed that an effective approach for inspection navigation was to capture a movie that shifted from a position that was far from an inspected point to one that was close. Moreover, we confirmed that a movie was a better approach than a picture for change detection in infrastructure inspection when an inspection point was in a complex environment, such as craggy places and Sabo sites.

e) Position (latitude and longitude), movie, and voice

Although this approach was the easiest, movie and voice data should be browsed from first to last to detect an inspected point. Moreover, this combination required a conversion application from voice to text. The quality of navigation depended on the inspectors in the previous inspection. Thus, to improve the stability of the conversion, general rules were required for the voice input.

4.2. Performance of operation using tablet PC

We have qualitatively confirmed that automation of location and time data recording is more reliable than manual paper-based recording in infrastructure inspection. On the other hand, paper-based recording offers an advantage for documentation in an outdoor location, because text input with a mobile PC is time-consuming work. Moreover, we confirmed that raindrops worsen the performance of the touch interface, even when a waterproof tablet PC is used.

Position data acquisition depends on single GPS positioning. Although our study area consisted of open-sky environments and structures, GPS positioning was insufficient for positioning in LOD3 (inspected position detection) in an area surrounded by mountains or under a bridge. On the other hand, we have confirmed that geotagged movie was effective in estimating the LOD3 and LOD4 position data. Even if position data included a positioning error caused by low dilution of precision and multipath transmission, an inspection position could be detected using movie guidance. Moreover, we could also focus on geotagged omni-directional camera data to detect an inspected position.

However, although we used Google Maps as the base maps in our experiments, there was a difficulty in managing the frequent map updates. Therefore, in future, we will prepare a more reliable base map using GPS log data and an open source map such as OpenStreetMap.

In addition, we confirmed that inspection work using a tablet PC held with both hands was dangerous on bad roads, in riverbeds, and in craggy places. Therefore, we propose to use hands-free applications using wearable devices and voice-guided applications with geofencing techniques (Nakagawa, 2013) to improve safety in inspections using a mobile device.

5. Summary

New inspection approaches, such as 3D scanning, are expensive. However, an inspection approach using mobile devices has an advantage in terms of cost performance as well as conventional approaches. In this paper, we proposed and evaluated our location-based investigation application based on CIM. Through our experiment, we explored several issues in infrastructure asset monitoring using mobile devices. Integrity in positioning should be improved to achieve more reliable and effective inspection works. Therefore, we proposed an LOD definition for positioning data management in inspection works. Moreover, we proposed combinations of several types of data acquired with a mobile device in inspection works to improve reliability, completeness, and integrity in positioning. In addition, we clarified that a conventional location-based navigation system is sufficient to provide position data for an inspection in LOD1 and LOD2. In LOD3 and LOD4, we showed that a combination of position, movie, and voice data was the most suitable combinations among location, angle, azimuth, elevation, image, movie, and voice data acquired using mobile devices.

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