Development of an Advanced Global Field Survey System (GFSS) for Terrestrial Monitoring and Mapping with a Demonstration for Agricultural Cropland Mapping in Asia

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Abstract

Field survey databases always play a critical role in terrestrial monitoring and mapping. This study develops an advanced GFSS as a tool for conducting field studies and builds a field survey database. The GFSS allows users to use Apple's iPhone or iPad to collect field survey data, including photos, locations, and the user-defined data. The field survey data gathered with an iPhone or iPad are synchronized with a GPS Photo database on a server and can be shared with other users. Existing field survey data can be imported to the GPS Photo database and the data in the GPS Photo database can be extracted to various formats. As a demonstration, the GPS Photo database was utilized to assess the accuracy of the irrigated area maps of Vietnam, Laos, and Myanmar, which were derived from the Global Irrigated Area Map that was released by the International Water Management Institute in 2007.

Introduction

Field survey databases play a critical role in terrestrial monitoring and mapping. For example, a field survey database is an essential input for the design and training of the algorithms of the agricultural cropland mapping applications; this data is also vital in verifying the accuracy of the agricultural cropland mapping results. A basic field survey database for terrestrial monitoring and mapping applications includes time, latitude, longitude, and a description of the object of monitoring or mapping, such as the soil temperature, the main species of plant, or the type of irrigated area. To build such a field survey database, a user must carry out field studies with necessary devices (such as a GPS device and camera), enter the data collected into a computer, and convert it to a database.

A great deal of open field survey data exists at research institutes and on the Internet. For many years, surveyors at research institutes have been collecting a lot of field survey data. Because the field survey data are used for various purposes, they are often not well-organized in databases to be effectively used by the terrestrial monitoring and mapping applications in the form of computer software, such as agricultural cropland mapping applications (Siebert *et al.*, 2005; Thenkabail *et al.*, 2009a, 2009b, and 2011). There are also open geographical data sources on the Internet such as Alexandria (Alexandria, 2004) and GeoNames (GeoNames, 2007). Although these data sources are well-organized to be used by computer software, they are mainly updated by ordinary users, who are not professionals in the field of terrestrial monitoring or mapping, so the data is not reliable enough to be used (Ying, 2003; Greg *et al.*, 2004; Popescu *et al.*, 2009). Consequently, building a well-organized field survey database, which not only contains new field data but also includes the existing field survey data, is a very meaningful work.

Nowadays, mobile devices are the first priority for surveyors when selecting a device to work with. Today's mobile devices not only serve as key computing and communication mobile devices but also come with a rich set of embedded sensors, such as accelerometers, digital compasses, gyroscopes, GPS, and cameras (Lane *et al.*, 2010). However, there are only a few software packages for mobile devices that can be used to collect field survey data. The most widely known free software packages for this purpose are GIS4Mobile (GIS4Mobile, 2011) and ArcGIS® (Esri, 2011). With GIS4Mobile, the user can take photos of the objects of interest and input information to describe them. However, GIS4Mobile does not support working with polygons, which is the one of very important features required by the field studies. Furthermore, the user's device must connect to the Internet to capture, save, and modify data. This will be impossible in the regions where Internet connection is not available. With ArcGIS®, although it is a good software package for monitoring and mapping applications, the user's device must also connect to the Internet to work and the user has to buy and install ArcGIS® Server software package in order to get the field survey data out from the user's device. Therefore, a free software package that runs on mobile devices without Internet connection and can be used effectively to collect field survey data for the terrestrial monitoring and mapping applications is necessary.

To build a better field survey database for terrestrial monitoring and mapping applications as well as to provide a

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Photogrammetric Engineering & Remote Sensing
Vol. 78, No. 8, August 2012, pp. 875–884.

0099-1112/12/7808–875/$3.00/0

tool to conduct field studies, this study develops an advanced Global Field Survey System (GFSS) that includes a field survey database for terrestrial monitoring and mapping applications named GPS Photo database and three software packages: the GPS Photo database software running on Windows™, Linux, and Mac; the Field Survey software running on Apple's iPhone (Apple iPhone, 2010) and iPad (Apple iPad, 2010), and the Field Survey Server software running on a Linux server. Using this GFSS, the user can create a new GPS Photo database or convert existing field survey data to the GPS Photo database. The GFSS allows the user to use Apple's iPhone or iPad as a tool to collect field survey data including photos, locations, and user-defined data. The field survey data on the iPhone or iPad is synchronized with the GPS Photo database on the server and can be shared with other users. The GFSS helps the user to add existing field survey data such as photos, locations, and other information to the GPS Photo database. The data in the GPS Photo database can be extracted to various formats to provide the inputs for the terrestrial monitoring and mapping applications.

System Design

The GFSS has two requirements: to provide a tool for field studies and to build a GPS Photo database for terrestrial monitoring and mapping applications. Figure 1 shows the design of the GFSS, which allows the user to use an iPhone or iPad as a tool to collect data such as photos, location information, and user-defined data. The GFSS helps the user to send data to the GPS Photo database on the server from the user's mobile device or from computers, permitting the user to manage the database (add, modify, or remove data). The user can synchronize with the data on the server when his device connects to the server through a Wi-Fi or 3G network. The GFSS can also be used to convert the existing field survey data to the GPS Photo database, share data among users, as well as to receive requests from the user, process the results, and send them back in the proper formats.

GPS Photo Database

GPS Photo database (Van and Takeuchi, 2010; Van *et al.*, 2011) is a field survey database for terrestrial monitoring and mapping applications. Every item in the GPS Photo database contains information about one place of interest. This information is divided into two categories: the basic category includes photos, location information, and land-cover information, and the extension category includes user-defined data. Photos are taken to show the visual characteristics of the place of interest. Location information is used to specify the position of the user at the time the data was collected as well as the position of the place of interest. The location information includes the latitude, longitude, altitude, and postal address. Information about the distance and bearing angle from the user to the place of interest is also included in the database. The land-cover type indicates the land-cover type of the place of interest at the time the data was collected. Because the land-cover definition depends on the user, organization, or country, the GPS Photo database allows the user to define an object in accordance with some different customizable land-cover classification definitions. One of the default sets of land-cover classification definitions is the International Geosphere-Biosphere Program, which includes 17 land-cover classes (IGBP, 2006). The user can also add new land-cover classification definitions to the database. The extension category allows the user to add user-defined data, which depends on the particular field survey. Figure 2 is an example of an item in the GPS Photo database displayed on the iPad and the iPhone with the basic category such as time, latitude, longitude, altitude, IGBP land-cover type, and extension category such as main species, average height, average diameter of the plant at the place of interest.

In this study, the GFSS uses SQLite, a free database management library (SQLite Team, 2010), to manage the GPS Photo database. This database management library was integrated into the operating system of the iPhone and iPad, and it is straightforward to install on Windows™ and Linux environments as well.

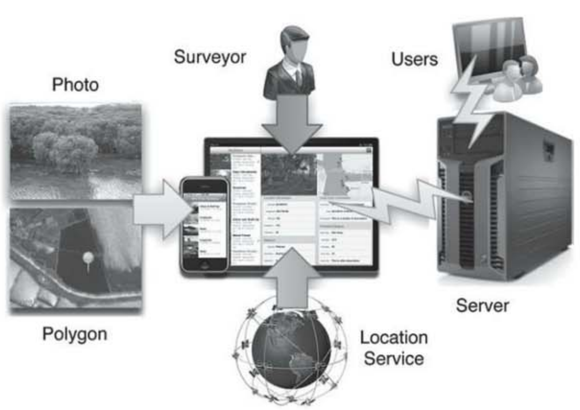

Figure 1. Design of the GFSS.

Hardware

In this study, we selected Apple's iPhone or iPad as the devices for which to develop the Field Survey software. The first reason is that the iPhone or iPad includes a touch screen, which allows the user to interact with the device directly and quickly. Second, these devices include many sensors, such as a gyroscope, compass, accelerometer, proximity sensor, and other more conventional features that can be used to provide information such as front- and back-facing cameras, GPS, and with Wi-Fi and 3G network connectivity. The GPS, which allows the device to determine its location, enables the use of new location-based applications such as local search, mobile social networks, and navigation with 10-meter precision. The compass and gyroscope also assist in determining location, providing the device with increased awareness of its position in relation to the physical world and enhancing location-based applications. These features make the devices ideal sensing tools in the field. Third, the iPhone or iPad is programmable with computing and communication resources offered by applications of third-party programmers. Fourth, a lot of the populace are using the iPhone or iPad for personal reasons; this is a big advantage in integrating and spreading the software to users.

Nowadays, the Linux operating system is widely used. The benefits of Linux reach far beyond the abilities of other systems. The main benefit of Linux is that it is stable, usually free, and a very efficient operating system. A big advantage of this is that the Linux operating system is an excellent solution for businesses and companies. Since Linux is more stable and customizable than other operating systems, it makes the system especially suitable for running servers, which cannot afford to have downtime. Because of these advantages, a Linux server was selected to store and maintain the GPS Photo database.

(a) (b)

Figure 2. An item in database displayed on (a) the iPad, and (b) the iPhone.

Software

The GFSS includes three software packages: GPS Photo database, Field Survey, and Field Survey Server. The GPS Photo database software, running on Windows™, Linux, and Mac, is used to convert the existing field survey data (photos, GPS, and other information) to the format required by the GPS Photo database. The Field Survey software, running on iOS (Apple, 2011) on the iPhone and iPad, serves as a tool for field studies and as an interface between the user and the GPS Photo database. The Field Survey Server software serves as a database management application on the Linux server.

GPS Photo Database

For many years, research institutes have been collecting field survey data. Surveyors use cameras to take photos, GPS devices to get information about the latitude, longitude, and altitude, and notebooks to store all information about the place of interest. The collected data normally is not entered into a well-organized database to be used by terrestrial monitoring and mapping applications. For this reason, the GPS Photo database software was developed to convert this data to the GPS Photo database. Figure 3 shows how to convert the field survey data taken using a normal camera and a GPS device to the GPS Photo database.

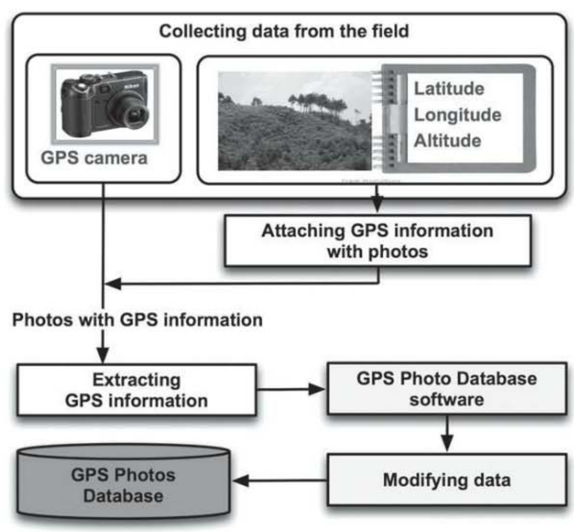

Figure 3. Converting field survey data to the GPS Photo database.

In the first step, GPS information, including latitude, longitude, and altitude, is added to the photo file using the free EXIF Pilot software (EXIF Pilot, 2003). In the next step, EXIF information is extracted from the photos using the free EXIF-O-Matic software (Rahulbotics, 2003). Based on the extracted information, the GPS Photo database software creates records and adds them to the GPS Photo database. The user can modify the information in the database if necessary.

Field Survey Software

The Field Survey software was developed to work on the iOS operating system of Apple's iPhone and iPad. With the Field Survey software, the user can use the iPhone or iPad as a tool for field studies to collect data. The software also allows the user to interact with the GPS Photo database on the iPhone or iPad and the server.

Tool for Field Studies

The user can use an iPhone or an iPad with the Field Survey software installed to take photos, get location information, specify the land-cover type, and edit user-defined information regarding the place of interest. Every time the user takes the photo using the built-in camera of the device, the Field Survey software automatically retrieves the latitude, longitude, and altitude values of the user's position. The GPS location service inside the device can locate the position of the user with 10-meter precision. The position of the user is normally different from the position of the object in the photo; therefore, specifying the position of the object is important. For this reason, the user needs to touch the device's screen to specify the position of the object in the photo.

Figure 4 shows the user's position and the object's position in the Field Survey software. After taking a photo, the user can assign the land-cover type and enter user-defined information about the place of interest. In Figure 5, the user selects the irrigation type for the place of interest to use in the cropland mapping applications. When the device is connected to the Internet, the user can upload the data to the server and share it with other users.

With GFSS, maps can be displayed offline on an iPhone and an iPad. In order to display maps offline, the user selects and downloads them from server to the user's device. This feature allows the user to work with the maps even in the regions where the Internet connection is not available.

Normally, the user collects data for one geographical point whose position is specified by latitude and longitude.

Figure 4. Specifying the object's position on a map.

Figure 5. Selecting the irrigation type.

However, in many situations, all the points in the same region share the same data, which means that the data for a position can be used for all the points inside that region. For example, in the paddy field shown in Figure 6, the data collected for one position can be used for all other positions in this paddy field. In this case, the user can apply the collected data for the whole region by selecting a polygon that represents the region of interest. Figure 7 shows the place of interest specified by a polygon. After specifying the polygon on the map, the user can edit the related information about the region as he does when updating the information for a new photo.

Figure 6. A homogenous region of a paddy field.

Interacting with the GPS Photo Database

As a database management application, the Field Survey software allows the user to display data on an iPhone or an iPad, add data to or remove it from the GPS Photo database, and synchronize the database on an iPhone or an iPad with the database on server.

In the Field Survey software, the database is displayed in two view modes: the map view mode and the detail view mode. Figure 8 shows the map view mode and Figure 9 shows the detail view mode of a database on an iPad.

The map view mode shows the data on a map, which provides the traditional view to the user. Each item in the database is displayed as an annotation with a corresponding classification identifier. The user can select an annotation to see the detailed information about the corresponding item. The Field Survey software also lets the user overlay the custom maps in the map view mode. In Figure 8, the cropland map derived from the ALOS AVNIR2 data for the Khammouane Province in Laos is overlaid with the annotations of places visited.

The detail view mode displays the data for every item in the database. This view mode presents the data with a photo, a map, and tables. In this view mode, the user can edit any information in the GPS Photo database, such as changing the photo, relocating the positions of objects of interest, modifying the polygon representing the place of interest, etc. Figure 10 shows the interfaces on an iPhone while the user is editing the data in the detail view.

The user can change the values of latitude, longitude, and altitude as shown in Figure 10c, select the land cover type as in Figure 10d, and enter a description as in Figure 10e. The Field Survey software can synchronize the database on an iPhone or an iPad with the database on the server. This feature also enables users to share data. Whenever the user's device connects to the server, all the changes made using the device will be synchronized to the server.

Figure 7. Selecting polygon for a homogenous region of a paddy field.

Figure 8. Map view mode on an iPad.

As the interface between the GPS Photo database and the user, the Field Survey software provides data from the GPS Photo database based on the user's requests. The user can search for items in a certain region specified by the distance from a center position or by the name of the region. The user can also search for items based on the time their data were collected or based on the land-cover type of the items. Figure 11 shows a location within 100 kilometers of a position (N20°58′48″, E106°54′05″) in the Quang Ninh Province in Vietnam. The results of a search can be saved in a new database so that the user can work only with the items being searched.

Another important feature of the Field Survey software is data extraction. The data in the database or the results of a search can be extracted in various formats. Data can be extracted in text format to be used by other software. Data can also be represented in Google's KML (Google, 2011) and Esri's Shapefile formats (Esri, 2010), which can be used in Google Earth® and ArcGIS®. Furthermore, the detailed information about an item can be provided to the user in the form of a report. Figure 12 shows the database for presented in Google's KML format.

Field Survey Server Software

The Field Survey Server software runs on a Linux server. It has three main functions: to manage the GPS Photo database on the server, to synchronize the GPS Photo database with the database on the user's device, and to update the land-cover classification data.

When the user interacts with the GPS Photo database on the server from an iPhone or iPad, the software on the server receives the request from the user and implements operations such as adding new data to or removing data from the database. When the user sends a synchronization

Figure 9. Detail view mode on an iPad.

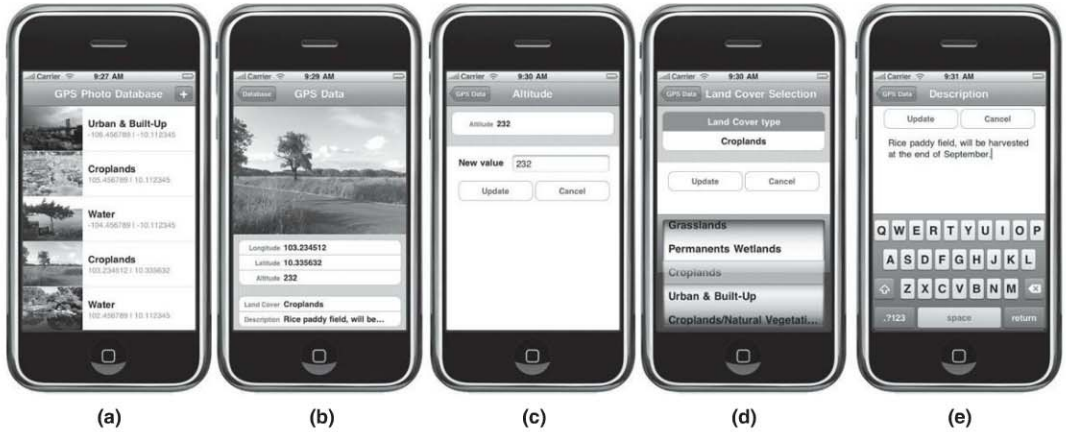

Figure 10. Editing data in the GPS Photo database on an iPhone: (a) GPS Photo Database, (b) GPS Data, (c) Altitude, (d) Land Cover Selection, and (e) Discription.

Figure 11. Items within 100 kilometers from the center point.

request to the server, the software on the server compares the database on the server with the database on the user's device and synchronizes the two databases.

The user can also send a request to the server to generate or update maps. Based on the satellite images and the GPS Photo database on the server, the Field Survey software on the server will call to another software package to generate or update the maps. Afterward, the user can download the results and overlay it on the map on his device.

Accuracy Assessment for the Global Irrigated Area Map

The GPS Photo database, which has been updated since 2008, contains the field data that were collected in Myanmar, Laos, and Vietnam. As a demonstration for agricultural cropland mapping, in this study, the GPS Photo database is used to assess the accuracy of the irrigated area maps of Laos, Myanmar, and Vietnam. These irrigated area maps are derived from the Global Irrigated Area Map (GIAM), which was provided by the International Water Management Institute (IWMI). The GIAM has been produced since 1999

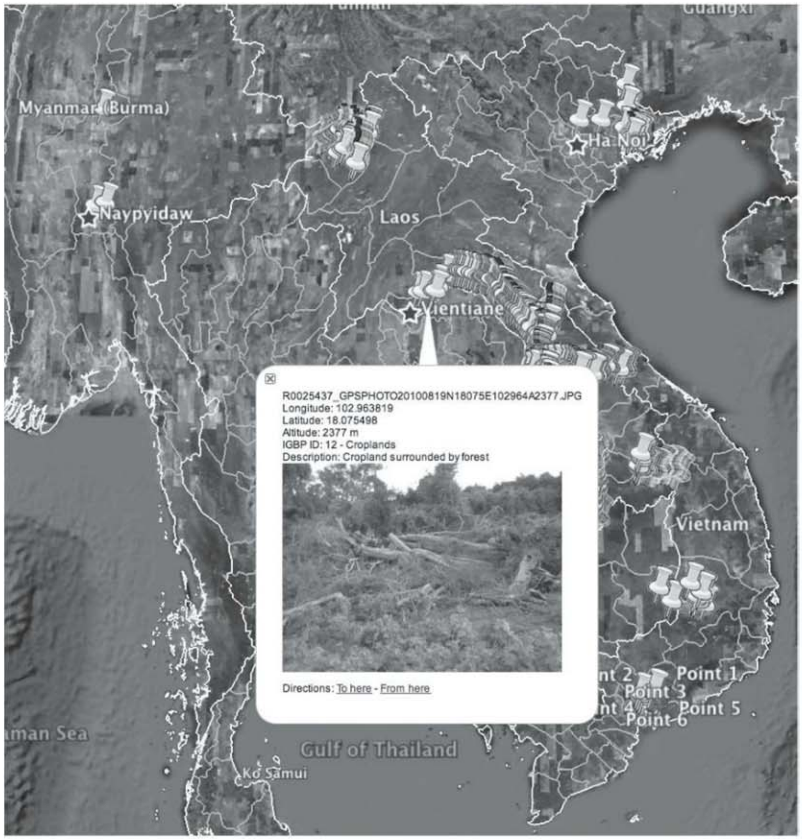

Figure 12. Database in the KML format.

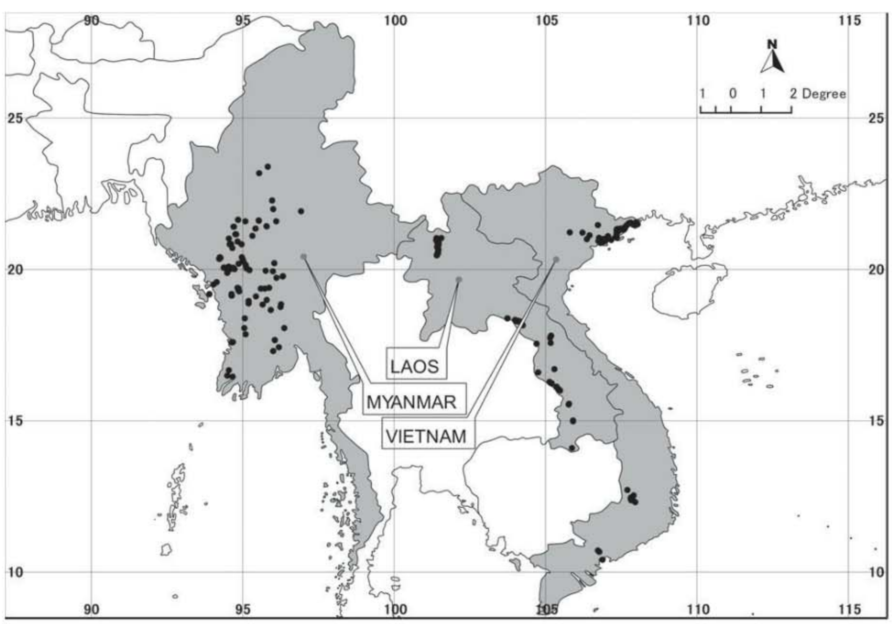

Figure 13. The distribution of the ground dataset extracted from the GPS Photo database.

through the use of multiple satellite sensors and secondary data. The latest version of GIAM, 2.0, was released in 2007. The accuracy of the GIAM was assessed by using a ground dataset with 1,971 points, 1,005 of which were irrigated locations. This ground dataset provided an accuracy of 79 percent in mapping irrigated areas with errors of omission of 21 percent and commission of 23 percent (Thenkabail *et al.*, 2009a).

Accuracy Assessment through the Use of the GPS Photo Database

Accuracies were determined based on a ground dataset extracted from the GPS Photo database for the entire irrigated areas (all of the irrigated area classes in the GIAM was put together). Nearly 6000 ground data points in the GPS Photo database and the GIAM were processed to generate the ground dataset for accuracy assessment. The total number of ground data points is 96 for Laos, 97 for Myanmar, and 98 for Vietnam. The number of irrigated ground data points is 26 for Laos, 16 for Myanmar, and 25 for Vietnam. The non-irrigated ground data points were not considered in accuracy assessment. The distribution of the ground data points is shown in Figure 13.

Point-based accuracy and error estimates (Congalton and Green, 2009; Foody, 2002) were established based on:

$$\text{Accuracy of irrigated area class} = \frac{\text{Irrigated Ground data points classified as irrigated area}}{\text{Total number of ground data points for irrigated area class}} \times 100$$

$$\text{Errors of omission for irrigated area class} = \frac{\text{Irrigated ground data points falling on non-irrigated area class}}{\text{Total number of irrigated area ground data points}} \times 100$$

$$\text{Errors of commission for irrigated area class} = \frac{\text{Non-irrigated ground data points falling on irrigated area class}}{\text{Total number of non-irrigated ground data points}} \times 100$$

Table 1 details the accuracies and errors. According to the assessment result, the irrigated area map of Laos is the most accurate map among three irrigated area maps. It has the highest accuracy (81 percent) and the lowest amount of errors of omissions (19 percent). Especially, the irrigated area map of Laos has very low errors of commission (0.03 percent, only two non-irrigated ground data points fell on irrigated area class), it means that the non-irrigated areas were mapped well for Laos. The lower level of accuracies and much higher errors of omission and commission of the irrigated area maps of Myanmar and Vietnam when compared with those of Laos are the result of the intermixing between irrigated and non-irrigated areas in a large area (the irrigated area of Lao is less than 300,000 hectares, while the irrigated areas of Myanmar and Vietnam are greater than 4,000,000 hectares (Thenkabail *et al.*, 2009a)).

Discussion

The fundamental issue related to accuracy assessments at such large scales as 1- or 10- kilometer resolution pixel size is the generating the ground dataset from the GPS Photo database. In many cases, the ground data that is collected in a portion of a pixel of a 1 km × 1 km area includes both irrigated and non-irrigated portions. Therefore, it is not always possible to determine the exact percentage of the area that is irrigated. For this reason, there must be the irrigated and non-irrigated ground data points that were unrepresentative.

Another issue is the distribution of the ground data points. Some parts of the GPS Photo database were created by converting the existing field data of the research institutes in Laos, Myanmar, and Vietnam to the format of the GPS Photo database. Therefore, the distribution of the ground data points depends on the purpose of the field surveys at those research institutes, which leads to the situation that there are many ground data points in some places, and there are no ground data points in other places. In this case, the advanced GFSS of this study, which includes the software package on the iPhone, iPad and the user-defined data feature of the GPS Photo database, will be the solution: it helps a surveyor to collect any kind of field data in any location to enrich the GPS Photo database. Consequently, the ground dataset would be better for accuracy assessment and other purposes, not only for agricultural cropland mapping applications such as irrigated area mapping, but also for the terrestrial monitoring and mapping applications.

Conclusions

The GFSS developed by this study is dedicated to terrestrial monitoring and mapping applications. It converts the iPhone and iPad to a tool for field studies with which the user can take photos, collect location information, and user-defined data. The offline map display feature allows the user to do the field works at the region where Internet connection is not available. The database on the user's device can be synchronized with the GPS Photo database on server and shared with other users. The user can also add existing field survey data to the GPS Photo database.

This GFSS has been used in many monitoring and mapping projects in Laos, Myanmar, and Vietnam since 2008. The GPS Photo database that was created by this system contains nearly 6,000 photos and very useful information for terrestrial monitoring and mapping applications. As a demonstration, the GPS Photo database was used to assess the accuracy of the irrigated area maps of Laos, Myanmar, and Vietnam, which were derived from the GIAM. The result shows that the irrigated areas of Laos were well mapped with 81 percent accuracy and small incidence of errors, while the irrigated area maps of Myanmar and Vietnam revealed the lower level of accuracies with 63 and 68 percent, respectively, and the higher level of errors of omission and commission. There were the difficulties in generating the ground dataset for assessment at 1- or 10-kilometer scale as well as in selecting a good distribution of the ground data points based on the ground data points, which were converted from the existing

Table 1. Accuracy and Errors of GIAM Version 2.0 for Laos, Myanmar, and Vietnam

Country name	Total irrigated ground data points (number)	Correctly classified irrigated ground points (number)	Accuracy of irrigated areas (percent)	Errors of Omission (percent)	Errors of Commission (percent)
Laos	26	21	81	19	0.03
Myanmar	16	10	63	37	14
Vietnam	25	17	68	32	30

field survey data of the research institutes. The advanced GFSS of this study, especially the Field Survey software on an iPhone, iPad and the user-defined data feature of the GPS Photo database, is a good solution to solve that problem. It also emphasized the importance of the advanced GFSS of this study, not only for agricultural cropland mapping, but also for terrestrial monitoring and mapping.

In the future, the Field Survey software will be developed to run on other mobile operating systems such as Android (Google Android, 2011) and Windows Phone (Microsoft, 2011). A website will also be built to enable the user interact with the GPS Photo database through web. Field Survey software on iOS is being verifying by Apple, and it will be available for download from Apple's App Store (Apple App Store, 2011) in 2012.

Acknowledgments

This study was funded by Japan Aerospace Exploration Agency (JAXA). The study was conducted within the framework of the project entitled "SAFE - Space Applications for Environment". The authors would like to acknowledge the following agencies and institutions for their contributions: Earth Observation Research Center (JAXA, Japan), Forest Protection Department (Ministry of Agriculture and Rural Development, Vietnam), Forest Inventory and Planning Institute (Ministry of Agriculture and Rural Development, Vietnam), Space Technology Institute (Vietnam Academy of Science and Technology, Vietnam), Remote Sensing Center (Water Resources and Environment Administration, Laos), and Forest Department (Ministry of Forestry, Myanmar). The authors would also like to acknowledge the support of Dr. Prasad S. Thenkabail, research geographer of US Geological Survey.

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