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碩 士 論 文

透過行動裝置分享三度空間地理位置的資訊

Sharing Information of Three-Dimensional Geographic Locations
through Mobile Devices

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中 華 民 國 九 十 六 年 九 月

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Abstract (in Chinese)

本論文研製之現代人外出旅遊，可能對景點資訊不是非常了解。很幸運的，人們身邊有這行動裝置，例如行動手機內嵌數位相機及無線寬頻存取，當人們去參觀景點的時候，這些裝置可提供來存取地理位置資訊，作為一個便利的設備。本論文提議了一個系統，稱為 GLOBE(**GL**obe **O**n mo**B**il**E**)，包含一個行動裝置(GLOBE mobile)、一個嵌入式裝置(GLOBE client)以及一個伺服器(GLOBE server)。GLOBE mobile 是配備有全球定位系統(Global Positioning System, GPS)接收器、高度、方向與角度感測器的行動手機，它可以用來預估照片中物體在地球上三度空間(Three- Dimensional, 3D)的地理位置，而 GLOBE client 和 GLOBE server 可以來管理 3D 位置資訊 的相片，註解相片中的物件，聯結相片的資訊與旅遊筆記，在網際網路上與

人們分享他們的照片。因此，人們在旅行期間只要使用 GLOBE mobile 針對感興趣的物體進行拍照，即可藉由搜尋 GLOBE server 馬上獲得物體的資訊。此提議的系統幫助人們學習景點背後的資訊以及他們所參觀的物體，且也幫助使用者在旅行期間管理與分享資訊。

Sharing Information of Three-Dimensional Geographic Locations through Mobile Devices

Student: Cheng-Lung Lin **Advisors: Dr. Shiao-Li Tsao**

Degree Program of Computer Science
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Abstract (in English)

A procedure is People who travel to a place may not know well about the information of the sites. Fortunately, people may have a personal device such as a mobile phone which has a digital camera and broadband wireless accesses, and the device can serve as a convenient equipment to access the information of geographic locations when people visit the place. This paper presents a system, called the GLOBE (GLobe On moBilE), consisting of a mobile, a client and a server. The GLOBE mobile is a mobile phone equipped with GPS, height, direction, angle sensors which are used to estimate the three-dimensional (3D) geographic location on the earth of the objects in the photo. The GLOBE client and server can manage these photos with 3D location information, annotate the objects on the photo, associate the information and travel notes with the photos, and share their photos with people on the Internet. Therefore, people just use the GLOBE mobile to take a picture on the object that

they feel interested during a trip, and can immediately obtain the information of the object by searching on the GLOBE server. The proposed system helps people to learn information behind sites and objects they visited, and helps users to manage and share the information during a trip.

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首先誠摯的感謝我指導教授 曹孝櫟老師。老師熱心的教導，讓我學習到深厚的專業知識，灌輸我做學問該有的態度，教導我勇敢的面對問題，不斷給我的鼓勵，指點我正確的方向，使我在這幾年中獲益良多。本論文的完成，也感謝我的口試委員曾建超教授、彭文志教授以及鄭瑞光教授，因為有你們的指正與寶貴的意見，使得本論文能夠更完整而嚴謹。

兩年的日子裡，實驗室裡有共同的生活點滴與革命情感，學術上的討論、執行的計畫、競賽期間的熬夜與課程上的研究。感謝學長、同學以及學弟共同的砥礪，你們的陪伴讓兩年的研究生活變得絢麗多彩。感謝一正學長、建明學長以及宥霖學長給於我的幫忙，不厭其煩的指出我研究中的缺失，能在我迷惘時為我解惑。感謝誌謙、小暉、名杰、雅筑、彥筑，我們互相的鼓勵，恭喜我們順利走過這兩年。謝謝學弟建臻、家祥、小白、薪中以及冠儒給我的打氣與幫忙，你們所有的幫忙我將銘記在心。更要感謝當年保佑我的交大土地公，讓我有這難得機會進到交大唸書。感謝家人背後默默的支持，這更是我前進的動力，讓我這兩年的生活更有意義。最後，謹以此論文獻給我摯愛的爸爸媽媽。

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Chapter 1. Introduction

"Traveling thousands of miles is better than reading thousands of books," Chinese Proverb

When people travel to a place, they may not know very well about the facts, information, historical background, or knowledge of natural, geographic and historical sites they visited. They have to either carry heavy travel guides with them during a trip, or spend lots of efforts in studying books and surfing on the Internet in order to learn the information and knowledge of the sites before or after the visit. Fortunately, people have a personal device such as a mobile phone or a PDA (Personal Digital Assistant) which has a digital camera and broadband wireless accesses [9], and these devices can serve as very convenient equipment to access the information and knowledge of geographic locations on the earth at anytime when people visit the place [1][6].

In order to facilitate people to use mobile phones to gather information and knowledge of geographic locations they visited conveniently, some projects have utilized mobiles phones with camera functions and image recognition technologies to detect the object while people take a picture on it. For example, when people visit the Eiffel Tower in Paris and want to learn more about it, people can just use mobile phones to take a picture on the Eiffel Tower. The image recognition program on the mobile detects the object, retrieves the information from the database on the Internet, and then displays the information of the Eiffel Tower to the users. However, to 100% detect all objects correctly and to be able to detect all objects on the earth are very challenging. Instead of using image recognition technologies [1][8][12], some other projects propose to use the geographic location of a mobile which is equipped with a GPS (Global Positioning System) sensor as a key to query the information and knowledge of the sites where people locate or neighbor [1]. Unfortunately, the location of the mobile might not be able to accurately represent the location of the object in a photo which people take and feel interested. People may not be able to receive the information about the object they really need. For example, people who visit a park may see lots of mountains around them and want to know more about a specific mountain. When people use mobile phones to take a picture on the mountain, the GPS location of the mobile phone might not be able to locate the mountain that people feel interested.

In this paper, we propose a system, called the GLOBE (GLobe On moBilE) system, consisting of an embedded mobile device, called the GLOBE mobile, and a server on the Internet, called the GLOBE server. The GLOBE mobile is basically a mobile phone or a PDA with the extensions which are newly proposed and developed in this paper. People can use the GLOBE mobile to take a picture on any object on the earth, and the GLOBE mobile equipped with a number of low-cost sensors will report the GPS, height, direction, angle of the mobile and rough distance between the mobile and the object in the photo [2]. These parameters can be used to estimate the three-dimensional (3D) geographic location on the earth of the object in the photo. Besides the GLOBE mobile, we further develop the GLOBE server which helps users to manage their photos with 3D geographic locations, annotate the object on the photo, associate the information, travel notes, knowledge or web sites such as WiKi with the photos, and share their photos with friends or people on the Internet [3][4][5][7][10]. Therefore, we can construct a virtual terrestrial globe on the Internet which has tens of thousands of photos with the annotated information and knowledge contributed by huge number of Internet users.

Then, people just use the GLOBE mobile to take a picture on the object they see and feel interested during a trip, and can immediately obtain the information and knowledge of the object by searching on the GLOBE server using the 3D geographic location of the object in the photo [11][13]. The proposed system helps people to learn information and knowledge behind the natural, geographic and historical sites or objects whenever and wherever they visited. Also, the proposed system helps users to manage and share the information and knowledge of the sites they have visited and learned during a trip.

The rest of the paper is organized as follows. In Section 2, we introduce the system architecture and components of the GLOBE system. Section 3 presents the design details of the proposed GLOBE system. Section 4 discusses the preliminary experimental implementation and demonstrations. Finally, conclusions are made in Section 5.

Chapter 2. System Architecture and Components

2.1. Use case scenarios

People who use the proposed GLOBE system may have two possible usage scenarios. When people travel to a place, see any natural objects such as a mountain, river, star etc or geographic and historical sites such as a building, architecture etc. People can use the GLOBE mobile to take a picture on the object they feel interested. The GLOBE mobile which is equipped with GPS, height, direction and angle sensors can estimate the 3D geographic location of the object in the photo. The GLOBE mobile then uses the 3D geographic location of the object to search the terrestrial globe database on the GLOBE server through broadband wireless networks. The GLOBE server replies the query with a number of photos which are sorted by geographic locations between the query object and photos or accessing ranks of these photos. Users can see a number of similar photos immediately and can click any photo with the object they feel interested. Users can thus learn more information and knowledge related to the objects in the photos which are annotated by the original photo owners through the GLOBE mobile.

The other usage scenario of the GLOBE system is that people can share their photos, information, knowledge, comments etc. with their friends or other Internet users. Moreover, users who login the GLOBE server can annotate the photos they took, write travel notes and comments about the trip or sites they visited. Most importantly, the GLOBE server can automatically notify the user with more related photos in the terrestrial globe database when they browse their own photos. For example, users can search other photos with the same object they are interested but are taken by other users in different locations, from a different angle, at different years, times, dates or seasons. The more photos and information people shared or higher frequencies of the photos that other Internet users accesses will be rewarded by access speeds, access rights etc. Figure 1 illustrates the two usage scenarios of the proposed GLOBE system.

2.2. Architecture and components

We first describe the overall system architecture of the system. Figure 2 shows the overall system architecture of the GLOBE system and components. A GLOBE mobile is modified from a commercial PDA. Sensors can be connected to the GLOBE mobile via I^2C, UART, or Bluetooth. Currently, we use commercial GPS, 3-Axis accelerometer, and compass modules which offer Bluetooth connectivity to the PDA. The GLOBE client is based on eBox-2300 with a LCD. The GLOBE client is for users to manage, share their photos, annotates objects in the photos, searches and retrieves the photos and objects in 3D virtual terrestrial globe. The GLOBE server is a PC with a database and web services functions running Microsoft IIS 6.0 and SQL Server 2005. For outdoor usages, GLOBE mobiles access the GLOBE server via wireless networks. We currently use the 3G cellular network to access the GLOBE server. For indoor usages, the GLOBE mobile connects to the GLOBE client and then accesses the GLOBE server via broadband wired-line network.

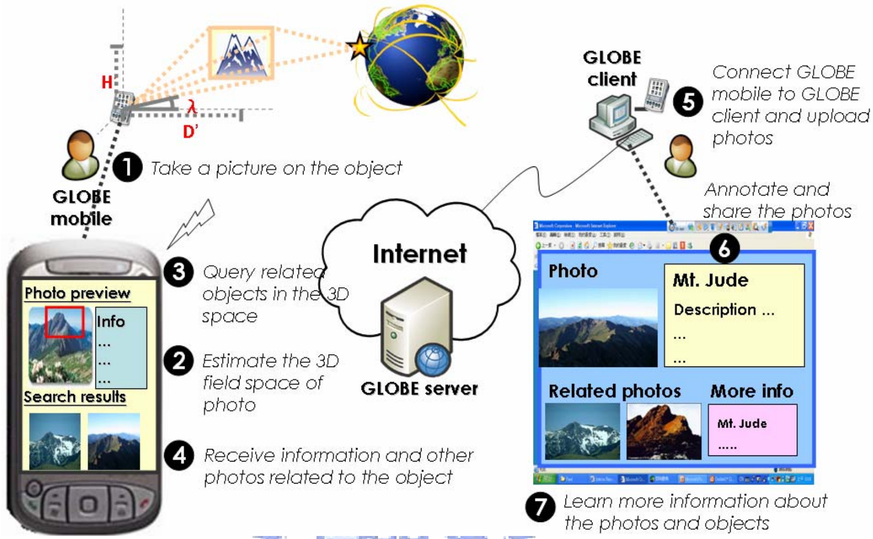


Figure 1. Usage scenarios of the proposed GLOBE system

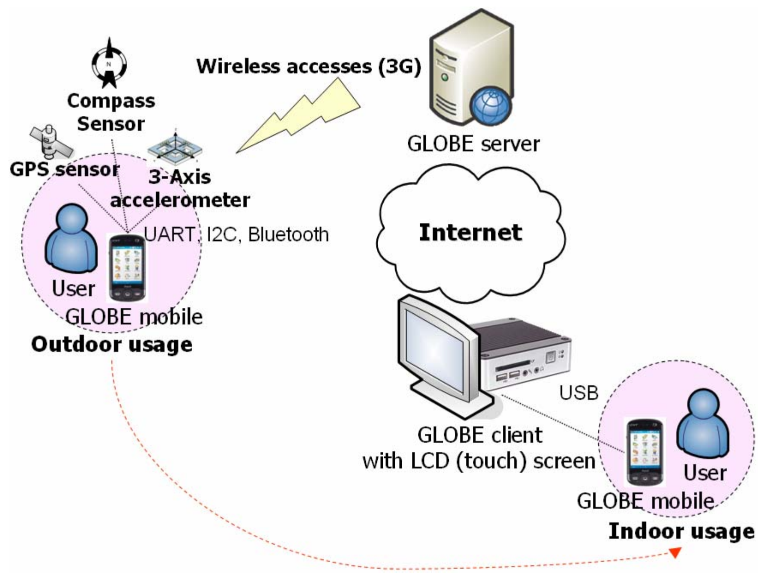


Figure 2. Overall system architecture of the GLOBE system and components

Chapter 3. System Design

3.1. GLOBE mobile

The design and implementation of the GLOBE mobile is first presented. Figure 3 shows the hardware and software architecture of the GLOBE mobile. While a user takes a picture, sensor data are collected. They are the location of the GLOBE mobile based on GPS sensor, the height above sea level of the GLOBE mobile based on GPS sensor, the direction and angle of the GLOBE mobile based on the 3-Axis accelerometer, and compass sensor. Besides the angle, height and location of the GLOBE mobile are estimated, and the parameters for the camera lens are also needed. The information for camera lens can be pre-configured based on the parameters of the camera lens or dynamically obtained by querying the camera module. The information are used to estimate the view angle of the photo, the rough 3D field space that a user took in a photo. Since the most of the camera cannot provide accurate focus distance, we do not use the distance between objects and camera in the current implementation. Only the view angle of the photo is used for estimating the field space of a photo. After the information of a photo is collected, these information are sent to the GLOBE server to compute the 3D field space of the photo, query the objects in the photos and other related photos. Figure 4 shows the message sequence chart between the GLOBE mobile and the GLOBE server. These procedures are to query possible objects in the photos, other related photos, and information about the objects. After the GLOBE mobile receives the responses, it draws the rectangles of the objects directly on the photo. Users can select the object they feel interested and retrieve the information about the object or other related photos. Users can learn more about the objects or sites they see and visit. The GLOBE mobile also combine with Microsoft Virtual Earth Mobile so that the user can also see the direction and estimated view field for this photo. If the GLOBE mobile does not have wireless connectivity, it also records the parameters of the sensors and camera lens for all photos. The users can search and retrieve the information and knowledge of the sites they visited while they come back home. We are now implementing pre-fetch download functions. The function supports users to plan their trip on GLOBE client, can pre-fetch all related information and objects before the trip. Then, even users do not have wireless accesses during a trip, they can also perform query on the local cache to learn the information about the objects they see.

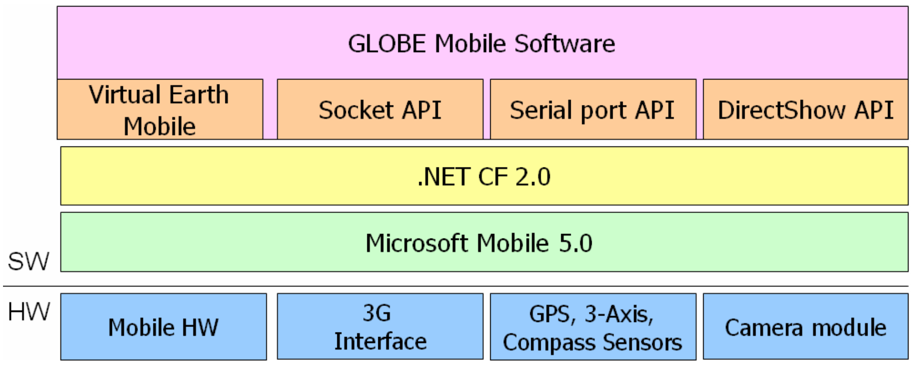


Figure 3. Hardware and software architecture of the GLOBE mobile

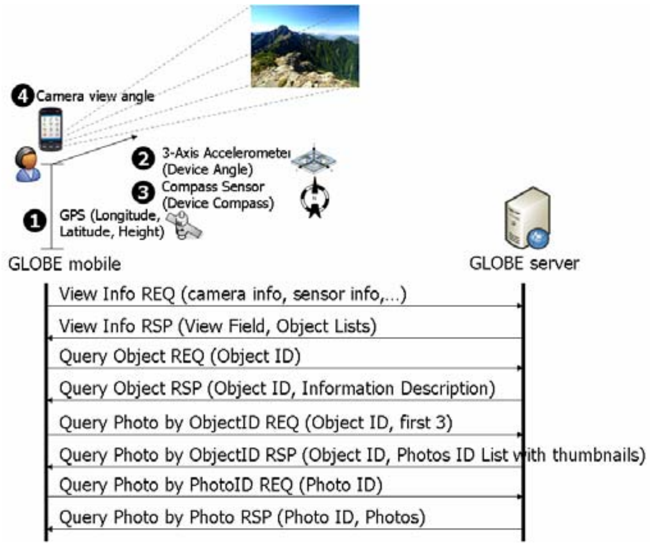


Figure 4. Message sequence charts between GLOBE mobile、client and server

The GLOBE system calculates the 3D geographic location of the object through the numeric values of longitude, latitude, angle, height, direction and distance, whose attributes will affect the accuracy of calculation (See Figure 5).

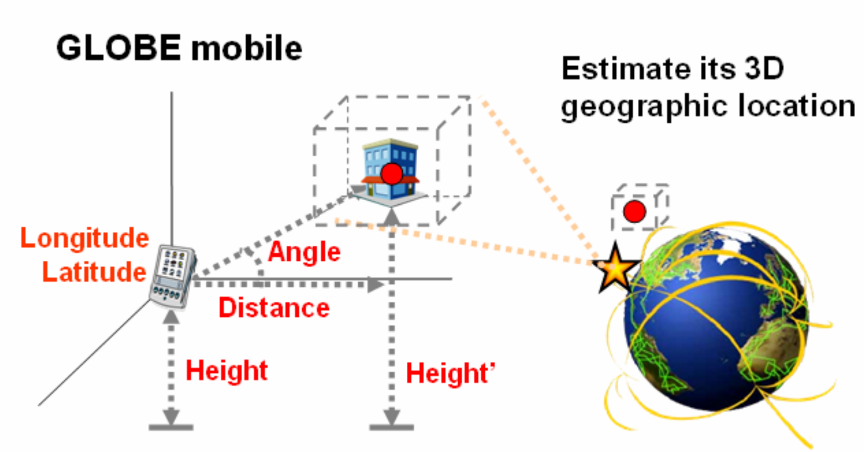


Figure 5. The function of calculation

■ The calculation of numeric value on angle: the accelerator obtains the angle by transforming the numeric value of the amplitude of vibration caused by three leaf springs on the axis of X,Y, and Z into angle-transformation formula. In real situation, when the three leaf springs on the axis of X,Y, and Z vibrate to a limited level, lower sensitivity , wider range of angle vibration, and increased errors will come to existence. For example, when the range of angle vibration is between 80 and 90 or 0 and 10, the errors will increase. Some adjustments need to be made to improve the accuracy. For software design, besides, in order to provide a more reliable and accurate system, the system software can do evaluation and modification by following the specification of the Figure 6, use resolution and sensitivity as the standard of data transmission and access, employ the switch-able g- range as the standard of determining the modified data, and provide wake-up timing to receive valid data.

Features	
Switchable g-Range	+/-2g, +/-10g
Resolution	4mg @ 50Hz bandwidth (digital 10bit)
Accuracy (inclination)	0.3°
Sensitivity (high-g,low-g)	51LSB/g, 256LSB/g
Cross Axis Sensitivity	0.2%
Power consumption	500 µA/600µA @ 2.5V_{DD} 5µA stand-by
Wake-up time	55ms
Operating Temperature	-40°C … +85°C
Package	MLF (6x6x1.45mm^3)
Programmable Interrupt	Zero-g detection (free-fall detection)
Interface	SPI
Mechanical shock	10,000g @ 50µs

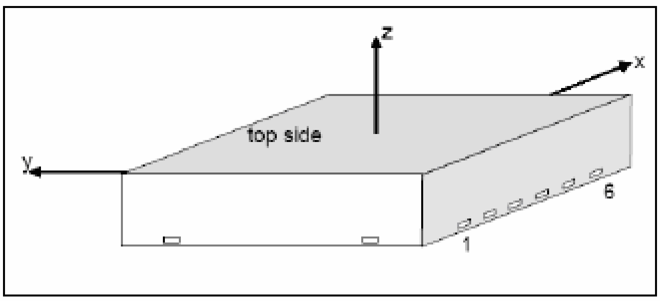


Figure 6. The specification of accelerator

■ The calculation of numeric value on height: the numeric value of height is the numeric value of height that the GPS receiver gets. Due to the quantity of detected satellite, the numeric value of height that the GPS receiver gets is often erroneous. In other words, when the number of detected satellite increases, the numeric value of height is much more accurate; as the number of detected satellite decreases, the numeric value of height is much less accurate. Therefore, the system employs the barometer as an auxiliary tool. When the detected satellite is numerous, we can transfer the measured height into barometric pressure and then obtain more accurate height by using the figure of altitude v.s. barometric pressure. This accurate height can also verify the number of detected satellite and the status of barometric pressure and altitude. The following Figure 7 offers the transformation between barometric pressure and altitude.

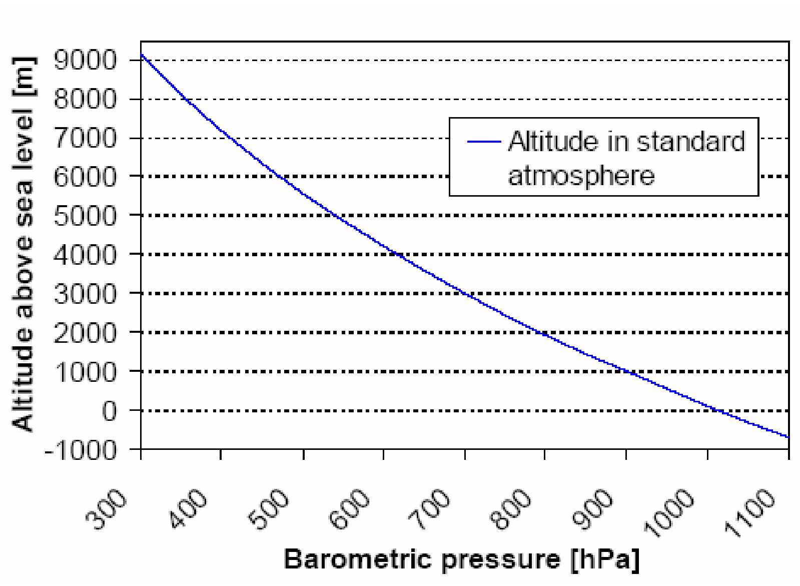


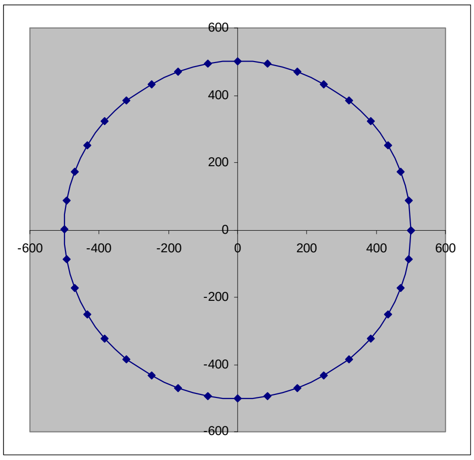
Figure 7. Altitude above Sea Level vs. Barometric Pressure

- The calculation of numeric values on latitude and longitude value: the GPS receiver's errors are caused by timing errors of the satellite and receiver, accuracy of the satellite's location, geometric distribution of the satellite, delayed errors of satellite signal passing aerosphere, and multi-layer effect of reflective wave. Therefore, in order to improve the accuracy of latitude and longitude, choosing a good receiver and better design technique on GPS such as AGPS is the first step (see Table 1). Furthermore, by using the number of the detected satellite as a standard of determining the latitude and longitude, the accuracy of data will increase.

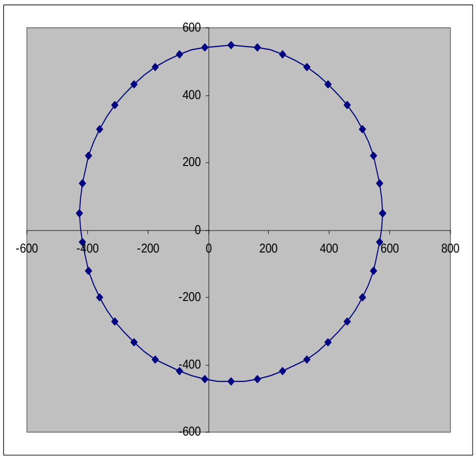
Table 1. GPS errors condition

Usage Environment	Outdoors outskirts		In-vehicle		Outdoors urban area		Indoors	
Sensitivity（ dbm ）	-130		-135		-140~-145		-145~-155	
	GPS	A-GPS	GPS	A-GPS	GPS	A-GPS	GPS	A-GPS
FFTT （ sec ）	45	4	45	5	X	10	X	20
Error（ m ）	<10	<10	<20	<15	X	<25	X	<30

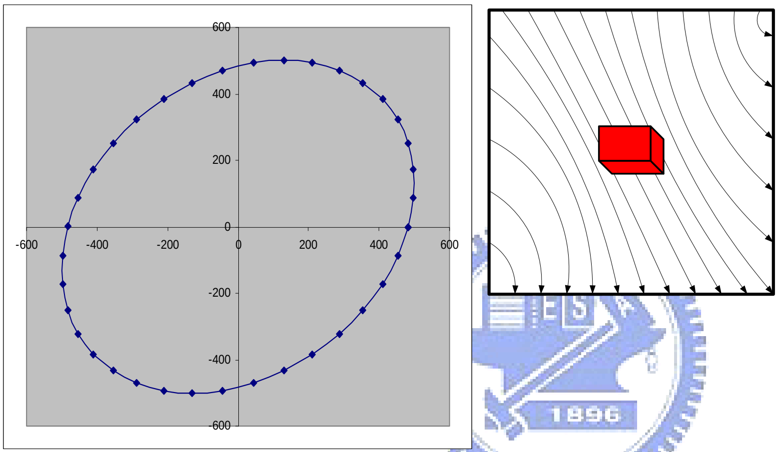
- The calculation of numeric values on compass: declination is the difference between magnetic North and true North. Inclination or dip angle is downward angle from horizontal of the local field 90° at the magnetic poles and 0° at the magnetic equator. Horizontal intensity defines the horizontal component of the total field intensity (combined X-Y fields). Vertical intensity defines the vertical component of the total field intensity (Z field). Magnitude and direction is the same everywhere. They free from interference Hard and Soft Iron effects. Turn the two orthogonal sensors in a circle while held in a single plane (Usually horizontal). Plot the X and Y sensor outputs on a plane. The result is a circle for X and Y describing Cos and Sin of the Azimuth or heading angle (see Figure 8 (a) for Calibration Plot in Undistorted Field), respectively. The heading is ArcTan(X/Y). A magnetic dipole source on the compass platform adds a constant vector to the Earth's field relative to X and Y sensors. Calibration circle is pulled off center (see Figure 8 (b) for Hard Iron Distortion). It is caused by permanent magnets, DC currents and batteries. We need to compensate by subtracting the X and Y offsets from the sensor readings. Besides, permeable objects on the compass platform attract and distort the local field effect changes and orientation (see Figure 8 (c) for Soft Iron Distortion). They will change calibration circle to an ellipse. It is caused by Nickel, Iron, other magnetic materials, SMT component plating, lead frames and RF shielding materials. We also need to compensate with X and Y scaling as well as rotation angle.



(a)



(b)



(c)

Figure 8. (a) Calibration Plot in Undistorted Field (b) Hard Iron Distortion (c) Soft Iron Distortion

Both hard and soft iron corrections usually are needed, especially true in watches and mobile phones due to battery and shielding proximity etc.

3.2. GLOBE client

The hardware and software architecture of the GLOBE client is shown in Figure 9. The GLOBE client implements below functions.

- GLOBE mobile detection and upload: while the GLOBE mobile attaches to the GLOBE client via a USB interface, the GLOBE client automatically enters the GLOBE system and synchronizes and uploads the trips and photos in the GLOBE mobile.

- Photos and objects annotation: the GLOBE client provides a tool for users to annotate the objects in the photos, add URL links to a photo or an object. The tools helps users to create objects in the photos and describes related information of the photos or objects or create reference links such as web sites or Microsoft Encarta link to the photos or objects.

- Photo and object search: the GLOBE client can communicate with the GLOBE server and search the related object and photos which users might feel interested or related to the photo the user took. The search at the GLOBE server is in 3D. The search results are based on hit ratios of an object and a photo and geographical relationship between the objects and photos.

- GLOBE server communications: It is the module for a GLOBE client to communicate with the GLOBE server using web services and SQL queries.

- Trip management: The function allows users to browse the path they traveled during a trip. Also it shows the locations, view fields of all photos that the users took during a trip.

- Photos management: The function allows users to move, upload, share and delete the photos.

- Extended search: The function is currently under development. It provides users to search a location from different view point, different view angle, and different time, season and ages.

- Interactive mode: The function is currently under development. It provides users to interactive with other GLOBE mobile and client users to exchange ideas and comments.

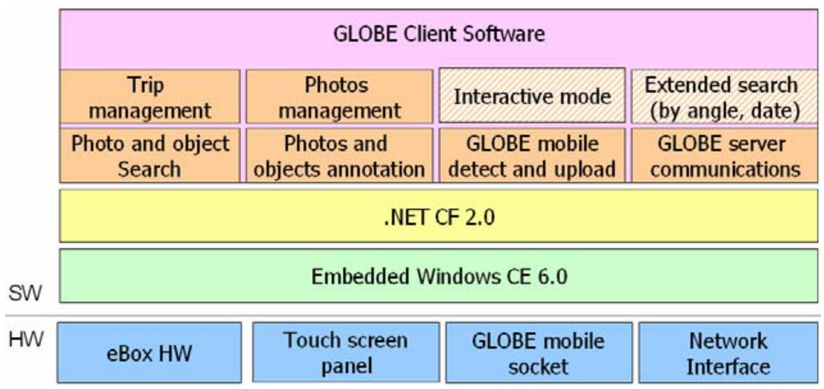


Figure 9. Hardware and software architecture of the GLOBE client

3.3. GLOBE server

The GLOBE server mainly maintains the photos, objects, information, and tags, and it also provides database search functions. While the GLOBE server receives the object query requests, it first calculates the 3D view space of a photo based on the camera and sensors parameters reported by the GLOBE client or mobile. Figure 10 shows the 3D field space of a photo. The GPS location of the GLOBE mobile can be used to determine its X, Y, Z positions which refer to world coordinates. The 3-Axis accelerometer and compass sensor can be used to decide the direction and angle that the camera directs. Then, the parameters of the camera lens can be used to identify the view angle. We use below equations to determine the view angle of a camera. The geometric representation of the angle-of-view formula is shown in Figure 11. For a lens projecting a rectilinear image, the view angle (α) can be calculated from the dimension (d), and effective focal length (f). The view angle is:

$$\alpha = 2\arctan\frac{d}{2f}$$

The effective focal length can simply to set equal to the stated focal length of the lens (F), the magnification factor (m) must be taken into account:

$$f = F \times (1 + m)$$

If the chosen dimension is to be the diagonal, then it can be calculated from the horizontal and vertical dimensions of the format through the use of the Pythagorean Theorem:

$$d = \sqrt{h^2 + v^2}$$

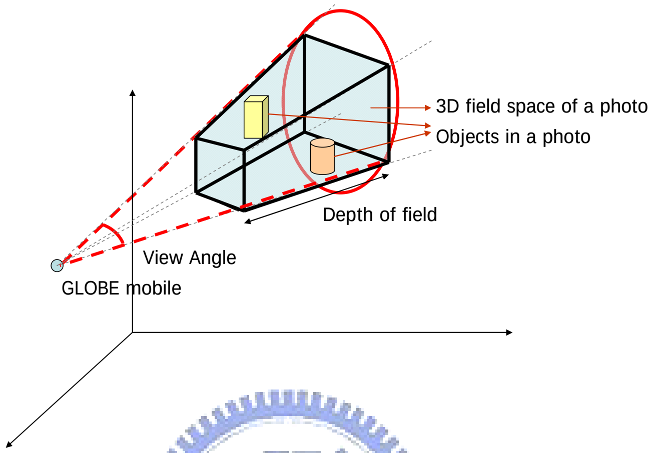


Figure 10. 3D field space of a photo

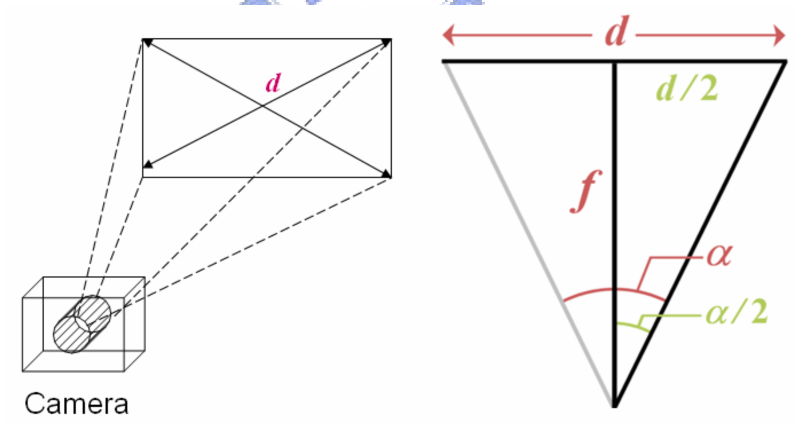


Figure 11. Geometric representation of the angle-of-view formula

In order to perform search, the GLOBE server has to convert the coordinates of the photos to the generic world coordinates. Therefore the 3D search can be done in a common coordinates. We apply vector space operations to convert the coordinates. In order to speed up the search, the photos are associated with a number of indexes which have hierarchies. We divided the earth into different view spaces and in different level of hierarchies. A search request will first check the view spaces that a photo covers and then the search is only applies to these objects in the same view spaces. That index and hierarchies search design can speed up the search. This is especially important if the server store tons of photos and objects. To determine if the object is in the 3D field space of a photo, the below equation is used.

$$\cos\theta = \frac{\vec{A} \bullet \vec{B}}{|A| * |B|} \geq \cos\frac{\alpha}{2}$$

Where is the view angle of the camera, A and B are the vectors of the photo and object. After the objects are detected, the GLOBE server translates the 3D space to 2D space since the GLOBE server only returns only rectangles of the objects to the GLOBE client/mobile. Therefore, the GLOBE server performs 3D to 2D translations and obtains all rectangles of the objects in the view space. Figure 12 shows the objects search and 3D to 2D translations. To avoid showing too many objects in a photo, a threshold is defined in filter small objects in a photo. Also, frequent access objects are returned to users first. Users may annotate the objects they found by using the tool on the GLOBE client. If more than two people identify the same object, the GLOBE server uses the intersection of the two vector spaces of the object that users identify as the new object locations. Figure 13 shows the concept. To reduce the design complexity, the 3D space of an object and a photo is described by a vector and a cubic box.

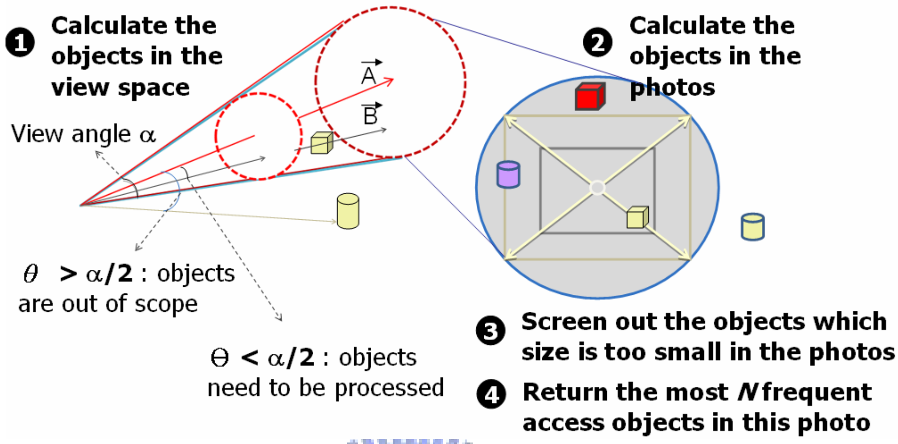


Figure 12. Objects search and 3D to 2D translations

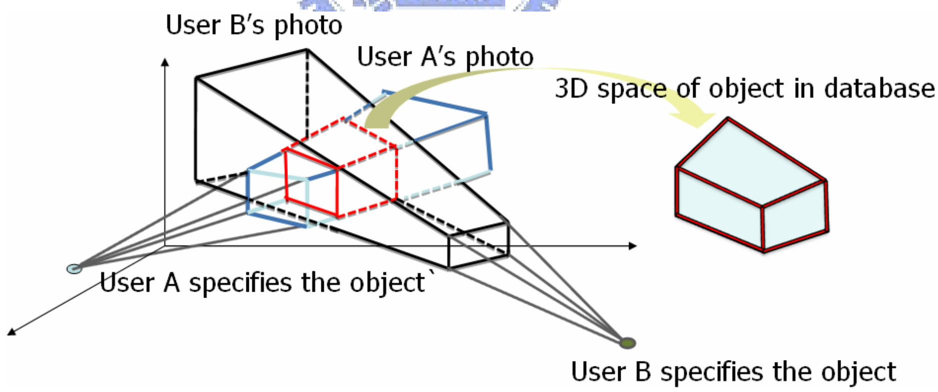


Figure 13. Identifying an object by two users and two photos

Suppose the embedded camera in the camera coordinate and the value is (0,0,0). We need to find the vector $\vec{v}$ for center of the camera lens. Set the horizontal angle θc and vertical angle ϑc. Figure 14 shows the view vector of the camera space. On the x-y domain, the $\vec{v}$ vector is: $< t\cos\theta c, t\sin\theta c, t\tan\vartheta c >$. Based on the methods of orbit determination we can translate the camera coordinate to world coordinate C = (Xc,Yc,Zc) according to the value of the longitude, latitude and height. The parameters of the world coordinate are:

X=(N+h)cosφcosλ, Y=(N+h)cosφsinλ, and Z=[N(1-e^2)+h]sinφ. In the above equations, $e^2=2f-f^2$, $N=\frac{a}{\sqrt{1-e^2\sin^2\phi}}$

Where φ,λ, h, f and a are logitude, latitude, height, flattening of the earth (f=0.006694) and earth equator radius (a=6378.1414 km) respecitively.

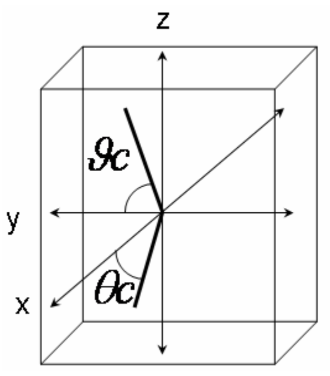


Figure 14. View vector of the camera space

First, we rotate y axle to $\frac{\pi}{2}-\varphi 1$ degree so that y axle aligns with the x-y domain. The equation is:

$$\vec{V}_y^{\,T} = \left\langle \begin{matrix} Xy \\ Yy \\ Zy \end{matrix} \right\rangle = t\left\langle \begin{matrix} \cos(\frac{\pi}{2}-\varphi 1)\cos\theta c - \sin(\frac{\pi}{2}-\varphi 1)\tan\varphi c \\ \sin\theta c \\ \sin(\frac{\pi}{2}-\varphi 1)\cos\theta c + \cos(\frac{\pi}{2}-\varphi 1)\tan\varphi c \end{matrix} \right\rangle$$

Then, we rotate z axle to $\theta 1$ degree so that the x-y-z domains are aligned. We have the equation as below:

$$\vec{V}_z^{\,T} = \left\langle \begin{matrix} Xz \\ Yz \\ Zz \end{matrix} \right\rangle = t\left\langle \begin{matrix} Xy\cos\theta 1 + Yy\sin\theta 1 \\ -Xy\sin\theta 1 + Yy\cos\theta 1 \\ Zy \end{matrix} \right\rangle$$

Finally, we rotate and move the camera coordinate to the origin of the coordinates. Figure 15 shows the procedure for translating coordinates. We thus can find the view vector of estimating object as:

$$\vec{V} = t\left\langle Xz - Xc' Yz - Yc' Zz - Zc \right\rangle = t\left\langle Xv' Yv' Zv \right\rangle$$

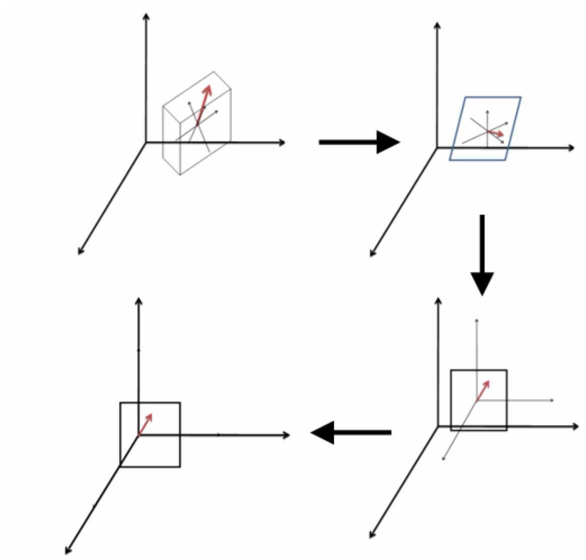


Figure 15. Procedure of translating coordinate

Chapter 4. Implementation and Demonstrations

4.1. Implementation

We have prototyped the GLOBE server, GLOBE client and GLOBE mobile. Demonstrations for using a GLOBE mobile and a GLOBE client to accessing the GLOBE server database are shown below. The GLOBE mobile also combine with Virtual Earth Mobile so that the user can also see the direction and estimated view field for this photo. Figure 11 shows snapshots of the current implementation. Figure 12(a) shows a user use a GLOBE mobile to take a photo on objects they feel interested. The GLOBE mobile queries the GLOBE server via a 3G network and obtains the possible objects in the photos. By clicking the object, the user can learn information related to objects. Figure 12(b) shows the same scenario but the user takes a photo at the same place but in different direction. That is to verity our 3D search engine is designed and implemented correctly and can search objects in the 3D virtual terrestrial globe. Figure 13 shows that the user comes back home attach his GLOBE mobile to the GLOBE client and starts to annotate his photos or learns more information about the sites the user visited.

Also, we compare the actual location and estimated location based on sensors' measurement results. We estimate the target based on measured parameters for four test cases, i.e. T1, T2, T3 and T4 through translating view vector of the GLOBE system. Figure 16 shows the relationship between the testing sites and the target sites and Table 2 shows the parameters of the sensors from four testing sites. The estimated results introduce certain errors because inaccuracy of the sensors. Table 3 shows the errors between actual location and estimated location. To reduce the error, we can add a pressure sensor to assist the measurement of heights of the GLOBE mobile which currently only relies on GPS. The estimated location can become more accurate if more than one sensors are used.

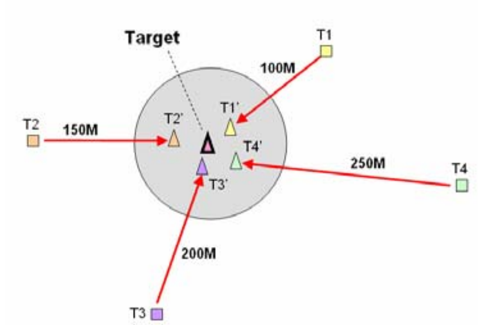


Figure 16. Relationship of the testing sites and the target

Table 2. Parameters of the sensors

	Target	T1	T2	T3	T4
Distance	0	100	150	200	250
Longitude	120.9983E	120.9991E	120.9982E	120.9953E	120.9979E
Latitude	24.7866N	24.7856N	24.7881N	24.7866N	24.7841N
Height	152.48	152.1497	147.2691	150.4664	163.3501
Direction		275	172	100	19
Angle		(0,0)	(17.9030,0)	(12.6200,0)	(-4.5110,0)

Table 3. Status and errors of the target and estimated location

	Target (T)	T1′	T2′	T3′	T4′
Longitude (E)	120.9983E	120.9980E	120.9982E	120.9981E	120.9990E
Latitude (N)	24.7866N	24.7857N	24.7880N	24.7869N	24.7856N
Height (M)	152.4800	-145.0450	111.96	79.5532	-152.0864
Δ E	0	-0.0003E (0.00025%)	-0.0001E (0.00008%)	-0.0002E (0.00017%)	+0.0007E (0.00058%)
Δ N	0	-0.0009N (0.0036%)	+0.0014N (0.0056%)	+0.0003N (0.0012%)	-0.0010N (0.0040%)
Δ Height	0	+297.5250	+40.5200	+72.9268	+304.5664

Chapter 5. Conclusions

The GLOBE (GLobe On moBilE) system which consists of GLOBE mobiles, GLOBE clients, and a GLOBE server was proposed in this paper. People can use the GLOBE mobile to take a picture on any object on the earth, and the GLOBE mobile equipped with a GPS sensor, a compass sensor, and a 3-axis accelerometer can estimate the 3D view field of a photo. The information can be sent to the GLOBE server so that objects with the three-dimensional (3D) geographic locations in the photo can be identified. Therefore, people just use the GLOBE mobile to take a picture on the objects they see and feel interested during a trip, and can immediately obtain the information and knowledge of the objects by searching on the GLOBE server using the 3D geographic locations of the objects in the photo. On the other hand, when users come back home, they can use GLOBE clients to annotate photos and objects in 3D virtual terrestrial globe, manage and share trips, photos, and objects with Internet users, and also learn more about the sites they saw during a trip. With contributions and shares from all Internet users, we can build a photo-based virtual terrestrial globe with objects and photos in 3D geographic locations. The proposed system helps people to learn information and knowledge behind the natural, geographic and historical sites or objects whenever and wherever they visited immediately and conveniently. Also, the proposed system helps users to manage and share the information and knowledge of the sites they have visited and learned during a trip. The GLOBE system realized the old Chinese proverb “Traveling thousands of miles is better than reading thousands of books," by using new technologies.

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