Comparison of Precision of GPS Coordinate Data by Obtaining Measure

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Introduction

Due to the remarkable improvement in the quality of the coordinate information together with widespread diffusion of reasonable-price electronic devices, GPS（Global Positioning System）has acquired in recent years wider acceptance among social lives. Disaster prevention is known as one of the fields that provide a wide spectrum of concerned issues which extend from drawing ups of hazard maps to prior and *ex post facto* assessments of the damages caused by various disasters.

U.S. Census Bureau has practiced address canvassing operations in 2009 where field canvassers have collected GPS coordinates of respective residential units by clicking handheld PC devices armed with ArcPad software. Together with i-Phone, digital cameras are now enjoying wider popularity as easy access measures to capture location information. Although such disaster-related researches have mostly relied on digital maps provided by private firms and compact digital cameras loaded with GPS software, information regarding the positioning rules adopted in maps and precision of censing technology given by the camera used for observations seem not to be obvious to the public users.

The aims of this paper are twofold: first, to identify some remarks when one uses digital maps and mobile devices in order to capture coordinate information, and second, to clarify and assess by empirical study the possible observation errors in data obtained through digital camera.

1. Obtaining the latitudinal and longitudinal information

This paper will discuss two measures to obtain latitudinal and longitudinal information: one is to obtain coordinate information through addresses-based conversion and another is to capture them by using GPS terminals. Following paragraphs will portray a quick sketch on the obtaining process and some pending problems regarding these two measures will be raised.

(1) Obtaining latitudinal and longitudinal data through address-based conversion

Direct capturing of GPS coordinates for huge number of dwelling units, business sites and social facilities are quite labor intensive and time consuming operation. In

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order to obtain tens of thousands of location information through these mobile terminals, however, we need huge number. Relevant data required, for example, for compiling hazard maps are usually converted from existing address files. In order to obtain latitudinal and longitudinal information, web-based matching services are provided by Google Maps[5], Yahoo! Maps[6], CSV address matching services[13] and Portal Cyber Japan[14]. These services are provided free of charge and user can make access to the coordinate information with relatively unsophisticated programming steps. As these digital maps are mostly provided by private firms, contents are sometimes amended due mostly to their own accounts with no particular explanation. It is also probable that providing services are occasionally suspended abruptly. Even in cases when services are provided by the government or by other public authorities, services sometimes are stopped due to the budget cuts and other reasons. Central and local governments are major users of hazard maps. Although stable and reliable positioning of the features is required especially for the hazard maps used for the administrative purposes, the above stated issues may yield difficulties. The second subchapter will address some examples for these difficulties.

(2) Capturing coordinate data by means of GPS terminals

In recent years compact digital cameras furnished by GPS capturing software (hereinafter simply referred to as GPS cameras) are supplied to the market at reasonable prices. Mobile smart phones with varied GPS-based services are now enjoying growing popularity among public. These mobile terminals are now widely applied as convenient tools to capture latitudinal and longitudinal information [2]. PC application software which can display photo snapshots from GPS cameras and smart phones are also on sale.

In case of smart phones, a special user contract should be concluded to make the GPS function available. Reasonable price mobile terminals with an appropriate function are required for public use including analyses of disasters and for other academic purposes.

High-quality apparatuses for professional users, of course, give fairly good estimates with observation error of less than some cm in terms of precision. One of the blocking walls, however, which now disturbs wider use of reasonable price GPS terminal, is that they usually suffer from unavoidable observation errors which is termed “final 10 meters problem”[4].

In case of smart phones, positioning data received from satellites is usually adjusted with the location information given by local telecommunication stations, which is regarded to improve significantly the direct observation results. In case of disastrous incidents like earthquakes and floods when radio waves from telecommunication stations are unavailable due to the widespread suspension of electric power, observation results by smart phones will lessen the accuracy to the levels almost comparable to GPS cameras.

As described above, due to the “final 10 meters problem” from which electronic tips for positioning GPS carried by GPS cameras and smart phones now suffer, latitudinal and longitudinal coordinates of the real features captured by these tools may more or less differ from those displayed on the digital maps. Thus, among well organized academic papers on disaster analyses there are some which carry results adjusted by particular PC software[1][3]. The third subchapter will discuss the assessment of the observation errors.

2. Obtaining latitudinal and longitudinal data from digital maps

This subchapter will discuss two web-based obtaining of latitudinal and longitudinal data based on address matching: piecewise obtaining and program-based one.

(1) Piecewise obtaining by direct input of addresses on digital map

Web services provided by digital map businesses respond latitudinal and longitudinal data in varied manners. Some softwares return positional data in response to the given addresses, others display the data in URLs which correspond to addresses. There often occurs the different positioning on maps or different latitudinal and longitudinal data are displayed depending on the employed software. Maps in Figure 1 illustrate the searched results by three groups of web services. Google Maps[5], Yahoo! Maps[6], Mapion[7] and goo Maps[8] compose the first group, which are based on maps offered by ZENRIN Co. Ltd.[15]. Chizumaru[9] falls in the second category which is based on maps offered by SHOBUNSYA Co. Ltd.[11]. MapFan[10] provides matching services based on maps from Increment P Corporation[12].

Figure 1 (a) Google Maps (ZENRIN)

Figure 1 (b) Yahoo! Maps (ZENRIN)

Figure 1 (c) Mapion (ZENRIN)

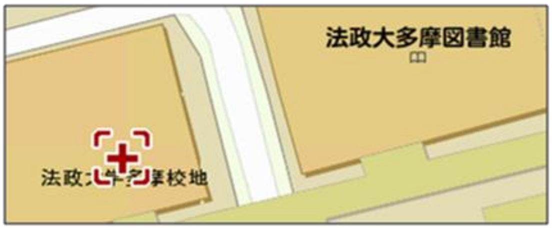

Figure 1 (d) goo Maps (ZENRIN)

Figure 1 (e) CHIZUMARU (Shobunsha)

Figure 1 (f) MapFan (Increment P)

A. Comparison among the same digital maps

Six maps in Figure 1 shows the searched results for the address "4342 Aihara, Machida-shi, Tokyo" where Hosei University Tama Campus is located. As Figure 1(a)-(d) illustrate, so far as the identical digital maps are employed, the same address indicates the identical position on the map even in cases when service providers are different. Reproducibility of pointing on maps is also ascertained in other cases as well. Figure 1(e) and (f) give different positioning from those shown as Figure 1(a)-(d). These facts suggest that possible difference is derived from digital maps on which respective service providers are dependent.

B. Difference in notation of angle and geographical coordinate systems

Table 1 compares the searched results given by web service provider.

Table 1 Obtained latitudinal and longitudinal information by web service provider

No.	Web services	map	Notation of angle	Geo. Co. System	latitude	longitude
1	Google Maps	ZENRIN	degree	World GCS	35.615093	139.297398
2	Yahoo! Map	ZENRIN	degree	World GCS	35.61506244	139.29739242
3	Mapion	ZENRIN	degree	World	35.61182778	139.30058333

				GCS		
4	goo Map	ZENRIN	d,m,s	Not mentioned	35°N36m42.580s 35.611828	139°E18m2.100s 139.300583
5	CHIZUMARU	SYOBUNSHA	d,m,s	Tokyo Datum	35 °N36m41s 35.611389	139°E18m8s 139.302222
6	MapFan	IncrementP	d,m,s	Not mentioned	35 °N36m43.5s 35.612083	139°E17m55.3s 139.298694

referred address: 4342 Aihara Machida-shi Tokyo

As for notation of angle, degree is described by decimal, while degree, minute and second (abbreviated in the table as "d,m,s") by sexagesimal measurement. For reference, although SI units (the International System of Units) given for angle is given by radian, this unit notation is not used in the geographical coordinate system.

Japan now has two geographical coordinate systems: world and Japanese geographical referencing systems. The former is known as international standard of geographical referencing system whose Japanese version is now termed "Japanese Geodetic Datum 2000." As for the transition of the systems from former Japanese system which was called "Tokyo Datum", to the world system see note (1) at the tail of this paper.

As notation of angle and geographical coordinate system are convertible automatically by means of relevant software, we can disregard the difference of the applied geographical referencing systems. The notation of angle and geographical coordinate system are convertible automatically by means of relevant software.

C. Inconsistency of latitudinal and longitudinal data supplied by the identical digital map

As maps in Figure 1 illustrate, the searched address is plotted on maps. Their latitudinal and longitudinal data are also displayed as concomitant information. The first two columns from the right in Table 1 show the obtained coordinate data. As observations 4, 5 and 6 in Table 1 are originally given in degree, minute and second as for the location information, for the sake of reference, the relevant cells for these 3 cases carry degree notation also in the second line.

As observations from 1 through 4 in Table 1 show the searched results based on ZENRIN map, the displayed maps indicate the same spot. However, the obtained latitudinal and longitudinal figures can enjoy coincidence only to the second decimal place. The range of discrepancies in distance between observations 1 and 2 and that between observations 1 and 3 are 3.427 and 463.182 meters, respectively. As is obvious from these observations, the digital map-based searched results of addresses will indicate the same spot. The same spot in maps, however, do not necessarily offer identical latitudinal and longitudinal figures. As for the significant decimal place, the above example displays maximum distance of 463.182 meters. This topic will be further discussed in the third subchapter.

(2) Program-based obtaining information through Google Geocoding

Users also can obtain latitudinal and longitudinal data by submitting programs compiled of functions provided by web map services. Users, for example, prepare CSV files in advance which give a list of addresses and by feeding them in sequential order they can obtain location information on the map i.e. plots and their latitudinal and longitudinal figures.

As explained above, when users wish to obtain latitudinal and longitudinal data by direct input of addresses on digital map, addresses are processed one by one. The largest advantage of programming-based procedure is that a considerably huge number of addresses can be processed en bloc. It should be noted here, however, that Google Geocoding has a setting of maximum number of coding that can be processed by day. See note (2).

As an example of geocoding, this paper examines Google Geocoding on which most digital camera businesses in Japan are dependent. Table 2 shows the obtained results from two samples of addresses "4342 Aihara Machida-shi, Tokyo" and "1-8-6 Shinkawa, Chuo-ku, Tokyo."

Table 2 Latitudinal and longitudinal data obtained through Google Geocoding

addresses	Obtained date	latitude[degree]	longitude[degree]
4342 Aihara, Machida-shi, Tokyo	July, 2010	35.6152469	139.2953124
	February, 2011	35.6150636	139.2973928
1-8-6 Shinkawa, Chuo-ku, Tokyo	July, 2010	35.6779361	139.7831772
	February, 2011	35.6779361	139.7831772

The observed figures seem to tell two facts. Firstly, as for the first address, the obtained latitudinal and longitudinal figures are different from those in Table 1. This fact suggests that the mixed procedures for obtaining latitudinal and longitudinal information for a set of addresses may produce inconsistency in terms of the captured coordinate data.

Secondly, as latitudinal and longitudinal figures in Table 2 show, the obtained results may differ by date of data capturing operations, although the same tool was employed in the operations. Figure 2 illustrates approximately 190m of discrepancy in terms of distance between the indicated points for the same address by differed date of operation. Although the detailed examination still to be done on the factors which generate possible discrepancies, it would be worth recording the date and time of capturing data together with coordinate information.

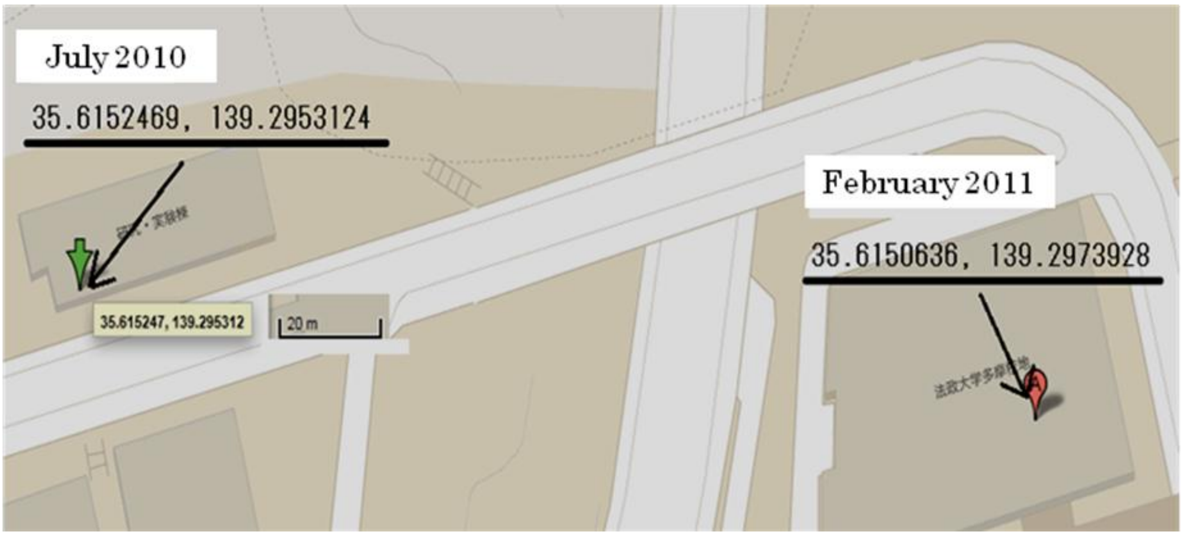

Figure 2 Discrepancy of distance by repeated operations (moved by 189.567m)

3. Possible errors in location information captured through reasonable-price digital compact cameras

Due to the convenience in recording itinerary and keeping memories of spots experienced in the sight-seeing tours, GPS cameras now enjoy expanding market recently. While only two camera manufacturers offered tools loaded with GPS software in March 2010, six businesses (Panasonic, CASIO, SONY, Canon, HOYA(PENTAX), Fuji Film) offer them to market one year later. As stated in 2(2), Together with smartphones, GPS cameras now became one of the handiest and most convenient tools for capturing location information.

This subchapter will discuss possible observation errors and raise some remarks on the use of GPS cameras. The information on the observation operation is as follows:

Employed tool: Panasonic LUMIX DMC-TZ10 released March 2010

Geographical coordinate system: world geographical referencing system (WGS84 same with Google)

Date and time of observation: 13:00 March, 4^{th}, 2011

Weather condition: clear

As referred to above, ordinary electronic geodetic GPS chips suffer from “final 10m problem” in terms of data precision for the time being. User manuals for the GPS cameras, however, carry only a limited description on the possible observation errors. While those for two brands suggest the hundreds of meters of possible errors, others have no mentions at all. Captured coordinate data are significantly affected by the place and conditions where the cameras took snapshots. It often happens that one cannot capture the relevant information due to the shadowing effect by the neighboring lofty buildings. Figure 3 illustrates observation failure because of the neighboring 5-floor apartment house.

Figure 3 Example of observation failure due to the shadowing by the buildings

At regions with latitudinal condition almost comparable to Japan, differences of 0.0001 in latitudinal and longitudinal degree correspond to about 11 and 9 meters, respectively. These figures suggest that observation errors of about ±10 meters are almost equivalent to the difference of ±1 degree at the forth decimal place.

According to the Japanese Construction Law, every building sites must face the road at least 2 meters in widths (Sub-section 1 of Section 43). In order to distinguish the location of the buildings applicable for drawing hazard maps, allowable observation errors are recommended to be less than 1 meter. Most academic researches including those in the field of science dealing with the prevention of disasters are based on the coordinate figures captured by reasonable price mobile terminals furnished with GPS geodetic chips. Taking the actual size of the buildings into consideration, further examination is to be done to judge if observation results with 10m of possible errors are actually applicable to identify features.

As for the required number of ciphers at decimal place, as have already discussed in 3(1)C, one unit difference in the third decimal place gives 463.183 meters. If one considers the possible size of error of about 10m, a maximum number of ciphers should be fourth decimal place.

Figure 4 illustrates another coordinate capturing practice at a shrine in Tokyo. In this case, field operator failed to capture figures at façade of the feature, he could rather succeed at sides. The first map gives geodetic codes captured at left side of the façade (35.722139 in latitude, 139.713447 in longitude), while the second displays the results captured at its right side (35.722186 in latitude, 139.713475 in longitude). By inputting coordinate data onto Google Maps, operator could get relevant spots which are marked by arrow on maps. Actual photoshot spots marked in "×" and the pointed head of each arrow are somewhat distances. Displayed maps in Figure 4 seem to suggest two facts. Firstly, the shifting of photoshot spots has accompanied corresponding shifts in position of arrows, although the generated shifts are not the same scale. Secondly, latitude and longitude give different results in terms of discrepancies. Discrepancies in latitude are much larger than those in longitude.

(a) left side of the façade (b) right side of the façade

Figure 4 Results of geodetic survey practices

Figure 5 shows the result of another capturing practice at a multi-floor apartment house also in Tokyo.

Figure 5　Geodetic survey of multi-floor apartment house

The arrowed head point in Figure 6 and figures in Table 4 give a set of portrayed results obtained by inputting the captured coordinates (35.71346 in latitude, 139.73006 in longitude).

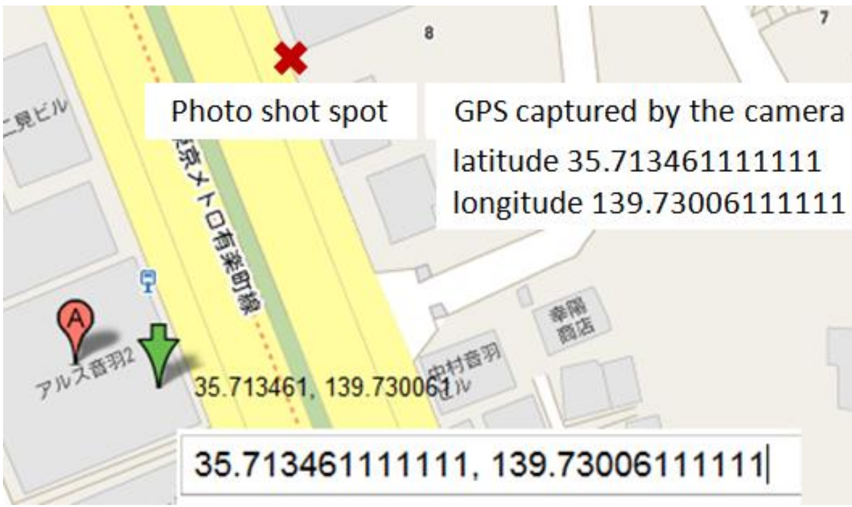

Figure 6　Google mapping of the surveyed results

Table 4　Comparisons of figures by geodetic survey and Google Geocoding

Addresses	Data sources	latitude[degree]	longitude[degree]
1-8-3 Otoba, Bunkyo ward, Tokyo	GPS camera	35.713461	139.73006
	Google Geocoding *	35.714159	139.730285
1-22-18 Otoba, Bunkyo ward, Tokyo	Google Geocoding *	35.713584	139.72995

Google Geocoding *　: coordinate figures obtained through address-based Google Geocoding

The right arrow in Figure 6 shows the result of Google Geocoding. The Google Maps points to another apartment house at opposite side of the road. Due to the difference in latitude, map seems to have chosen other apartment house marked by the arrow (A).

Although GPS cameras and Google Maps adopt the same geographical referencing system, they indicate the location point more or less differently. In order to assess probable size of gaps in positioning, two stages of examinations were practiced.

In the first place, the survey precision of GPS chips in cameras was examined. Japanese latitudinal and longitudinal standard (Figure 7) was chosen as an observation point to assess the errors which may arise in geodetic operation. Table 5 gives standard figures.

Figure 7 Japanese latitudinal and longitudinal standard

Table 5 Coordinate information of Japan latitudinal and longitudinal standard

latitude	35°N39m29.1572s	35.65809922 [degree]
longitude	139°E44m28.8759s	139.74135442 [degree]

Survey operation was repeated ten times at this particular point. The captured figures are listed in Table 6.

Table 6 Captured figures in repeated practices [in degree]

No.	latitude	longitude
1	35.65805278	139.74145556
2	35.65805556	139.74140278
3	35.65806111	139.74146389
4	35.65807222	139.74143333
5	35.65807500	139.7414667

No.	latitude	longitude
6	35.65807778	139.74137500
7	35.65808889	139.74140833
8	35.65810833	139.74133889
9	35.65811667	139.74136667
10	35.65815000	139.74125833

As figures in Table 6 shows, discrepancies are within one unit at the fourth decimal place for latitude as well as longitude. Table 7 carries means, maximum values and standard deviations in meters calculated out of disparities from the true values for 10 respective cases.

Table 7 Observation errors [in meters]

	mean	Maximum value	Standard deviation
Latitude	1.5	5.7	3.4
Longitude	-3.4	9.0	5.5

According to the Table 7, although standard deviations of observation errors are not ignorable, their maximum divergence is shorter than 10 meters. When one considers the size of errors which GPS geodetic chips furnished in reasonable price terminals can possibly generate, the observation result can be judged to be within expected scope.

Concluding remarks

This paper discussed measures to capture latitudinal and longitudinal information widely used in various researches, among others, the performance of GPS cameras and Google Maps in obtaining coordinate data and indication on maps together with a quick review on the type and size of concomitant errors. Followings are the obtained remarks.

(1)Web geocoding by address matching

When one obtains coordinate information through web-based address matching, it is of vital importance to record together with coordinate information the following items: (a) name of the web service, (b) applied digital maps, (c) notations, (d) geographic coordinate system and (e) date and time of capturing data.

(2) Capturing coordinate data through GPS cameras

GPS camera applied for this study is loaded with GPS chip with maximum observation error of ±10 meters which stands ±1 unit at the fourth decimal place in degree. Accuracy of the captured data depends substantially on property of the furnished electronic chips. Significant number of figures for terminals applicable to research purposes is required to be more than 4 at the decimal place. Comparative studies among GPS cameras and other handy terminals and by time and climatic conditions are still to be practiced.

(3) Errors caused by camera-based data capturing and Google Maps

As observations in tables 6 and 7 tell, maximum size of errors is less than 10 meters. Since actual size of the buildings are considered to be large enough, one can well expect that in most cases locations indicated by captured GPS coordinates may correspond to features on digital maps. However, capturing practices in this study identified an interesting fact that captured latitudinal and longitudinal figures are more or less different from those on the digital maps despite the identical coordinate system applied. This issue is also left for future examination.

(Notes)

(1) Geographical coordinate referencing systems

"Standard of the Survey" stipulated in Japanese Surveying Act (Sub-section 2 of Section 11) was amended from Japanese to world geographical coordinate referencing system which was put in forth on 1st April, 2002. Between the two systems there exist some divergences. Latitudes, for example Tokyo and its environs, expressed in Japanese system will increase its figure by about 12 seconds in the world system, while longitudes by -12 seconds. These discrepancies in angles give approximately 450 meters of divergence to the Northwest direction. The free converting software is already available.

(sources)

http://www.gsi.go.jp/LAW/jgd2000-AboutJGD2000.htm (6 March, 2011)

http://www.gsi.go.jp/LAW/G2000-g2000-h3.htm (6 March, 2011)

(2) Geocoding

Geocoding denotes data processing procedure to convert addresses into geographic coordinates (latitude, longitude). With the assistance of coordinate information, one can plot marker on the map. By means of Google Geocoding API(#), users can make direct access to geocoder via HTTP requests. One can also convert coordinate information to addresses through "reverse geocoding" procedure.

Google Geocoding API provides geocoding services up until 2,500 per day. In case of Google Maps API Premier, users can process 100,000 requests per day. These limitations may be altered without any notices in advance. In addition, a maximum frequency of requests are also stipulated to defend the services from dishonest users. For continuous requests beyond 24 hours and detected illegal users, Geocoding API services are to be suspended temporary. For the repeated violation of the limits set for request, further access to the Geocoding API are blocked.

(#)Geocoding API

Geocoding API are only applicable in combination with Google Maps. Use of Geocoding without displaying on the map is not allowed.

For further information on the use of Geocoding API : http://code.google.com/ intl/ja/ apis/maps/documentation/ Geocoding/#Geocoding

(source)Google Maps API Web site

http://code.google.com/intl/ja/apis/maps/documentation/javascript/v2/services.html#Geocoding (6 March, 2011)

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※ We confirm all URLs on March 10, 2011.