Method of Event Location Identification Using GPS and Camera Function of Mobile Phones

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Abstract: - In recent years, network applications with location-awareness have been attracting a lot of attention as a technical element for ubiquitous computing. Among such applications, those for environmental issues especially requires, for the sake of immediate detection and providing solutions, a high precision of auto-detected location information of relevant places. In order to realize the precision, technical challenges will be evaluation of the precision of GPS information and how to improve it. So far, these issues have rarely been studied, however. In this paper, we consider especially mobile applications on mobile phones, first to evaluate the precision of GPS information on mobile phones, and second to study how to improve the precision. According to these results, we discuss the possibility of applying location information on mobile phones to the environmental issues and future technical problems.

Key-Words: - GPS, Mobile Phone, Pattern matching, Correlation Coefficient

1 Introduction

The ICT (Information and Communication Technology) is expected to provide solutions to three major social problems in Japan today, aging with declining birth rate, security and safety, and environmental issues. Among the ICTs, a special attention is put on mobile phones, since they are the most widespread network terminal devices so that more than a hundred million people use in Japan.

A mobile phone enables one to get a useful and convenient information whenever and wherever. It is thus an important tool for construction of a ubiquitous network.

In recent years, mobile phones are equipped with GPS (Global Positioning System) normally and, in addition, 88% with cameras. Most of the cameras equipped in mobile phones have high qualities similar to single digital cameras, with pixels three millions to three and half or even five.

The camera of mobile phones has the merit that, one can send images taken by it immediately to other mobile phones or personal computers by attaching to an e-mail. Moreover, the images can have the location information from GPS as well as time information [1].

While the location information is today a very important information for mobile applications, it involves certain errors. So far we have examined that the indicated location can have errors more or less depending on locations [2~4]. As we mention later, even the errors include in location information obtained by mobile applications performing error correction at cellular stations with those cellular stations that perform error correction, the resulting location errors are at least 30[m] in the outdoor and around 100[m] or sometimes 1000[m] in the door [5~6].

In order to make the location information as more useful content, the indicated location must be more accurate. In the circumstance of emergencies or disasters, a more accurate precision of location is necessary. Also, to provide a solution for environmental pollution mentioned above, much more precision is required.

In this paper, we examine how precisely the mobile GPS can identify the true location, with indicating the error precision. Also, we construct a system that correct mobile GPS information and evaluate the performance of the system. In the system, to obtain a more precise location than that indicated by just GPS, we perform the pattern matching[7~10] for a image taken by mobile phone with corresponding images in the database.

2 Experiment1: Measurement of GPS Error

First, we measured the GPS errors in order to estimate the degree of the errors, at Musashino city in Tokyo. The major GPS systems in mobile phones are presently two ways. One is basic GPS measurement system which measures the location using just a GPS satellite. The other one, called DGPS, performs an error correction at cellular stations. In the experiment, we measured errors at Seikei university in Musashino city using two mobile phones each with the basic GPS or DGPS, and, also for reference, a conventional GPS receiver.

The location measurement was done at seven places in the university, indoor or outdoor. We measured about 50 times at each place. Tables 1 and 2 list statistics of the measured errors at each place by using GPS and DGPS, respectively. The Figures 1 and 2 show the histograms of the errors at place 4 by using GPS and DGPS respectively.

Table 1 Measurement Statistics (DGPS A): Average Maximum, Variance, Standard Deviation (m)

DGPS A	①	②	③	④	⑤	⑥	⑦
Average	28	19	26	84	52	51	46
Maximum error	120	80	110	500	100	130	140
Minimum error	3	5	1	20	5	15	5
Variance	756	192	477	4976	700	601	735
Standard Deviation	27	14	22	71	26	25	27

Table 2 Measurement Statistics (GPS B): Average, Maximum, Variance, Standard Deviation (m)

GPS B	①	②	③	④	⑤	⑥	⑦
Average	18	21	62	431	232	478	97
Maximum error	50	600	90	1150	640	1100	650
Minimum error	3	5	5	55	15	25	5
Variance	151	288	15822	57851	40003	84653	25259
Standard Deviation	12	17	126	241	200	291	159

Description of each place is as follows.

1. Outdoor, with the sky obstructed by trees.
2. Outdoor, with the sky not obstructed.
3. Outdoor, surrounded by building; tends to have multi-pass
4. Indoor, center of the first floor in a building with six stories
5. Indoor, beside a window of the first floor of the same building as 4
6. Indoor, center of the sixth floor of the same building as 4
7. Indoor, beside a window of the sixth floor of the same building as 4

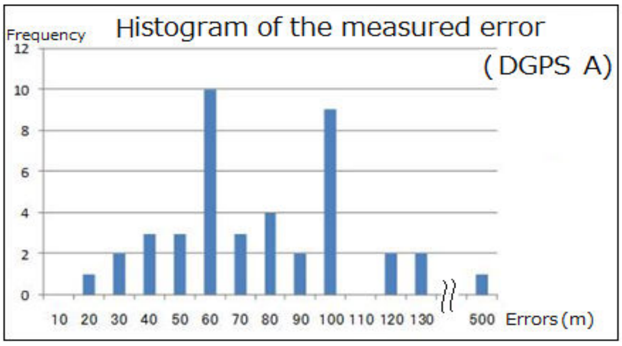

Fig. 1 test results at location4

(the mobile phone with DGPS)

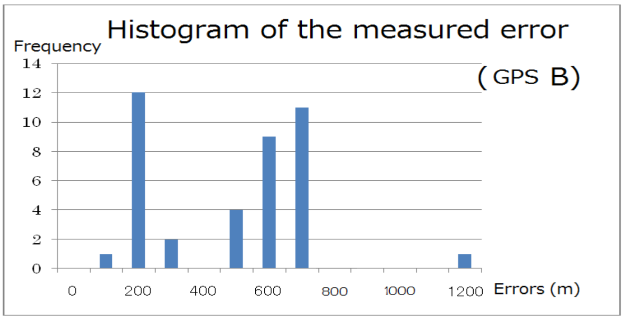

Fig. 2 Test result at location4

(the mobile phone with GPS)

As seen from Tables 1 and 2, and Figures 1 and 2, the mobile phone with DGPS presents less errors than that with basic GPS. Both of two terminals once have an enormous error due to synchronazation loss.

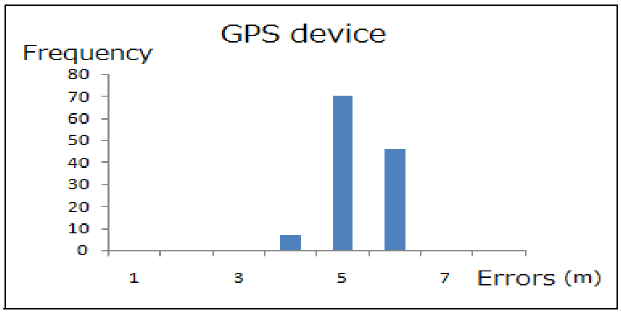

Fig. 3 Error histogram of a conventional GPS device

Figure 3 shows the histogram of the errors measured by the reference a conventional GPS receiver at place 2. When the measurement place is outdoor without obstacles in the sky, a conventional GPS receiver can detect the location with more finer precision than mobile phones. When the measurement place was indoor or close to a building, however, the measurement itself was not available. Henceforth, we performed our experiments by using only the mobile phone with DGPS.

3 Experiment2: GPS Measurements at Several Places in Japan

Figure 4 depicts how GPS satellites look like at the same time at several places in Japan. It seems that we can say almost the same number of satellites are observed at the same position in the sky, wherever in Japan.

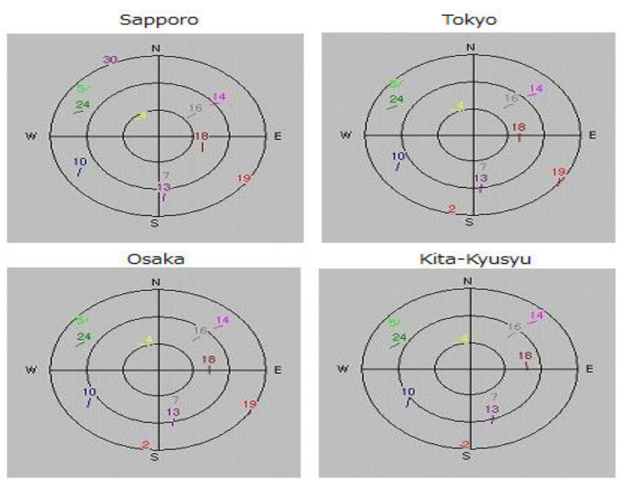

Fig. 4 The View of Satellites at Several Places in Japan

In order to confirm the independence of places, for GPS result we further performed a next measurement in the same way as experiment1 at the following five places in japan:

1. Yokohama, Kanagawa.
2. Nikko, Tochigi.
3. Uruma, Okinawa.
4. Naha, Okinawa.
5. Sapporo, Hokkaido.

In the measurements, for each place, we observed the errors of GPS information every minutes. All of observations were done at the fourth or fifth floor of a building.

Figures 5 and 6 indicate the measurement results at the two places of the five, and Table 3 lists the observation statistics.

Table 3 Measurement Statistics of Location Errors.

	Yokohama	Nikko	Okinawa (middle)	Okinawa (Naha)	Sapporo
Average	84	84	75	41	260
Maximum	1213	436	7087	146	3136
Minimum	1	11	1	3	9
Variance	9038	4694	161270	405	40298
Standard Division	95	69	402	20	201
Data	989	1022	899	1131	1005

Fig. 5 Distribution of Identified location, at Nikko, Tochigi

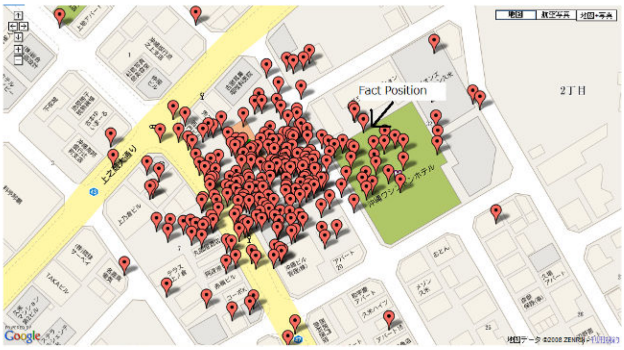

Fig. 6 Distribution of identified location, at Naha, Okinawa

Despite the anticipation from Figure 4, the location errors vary depending on places. Sometimes the errors were so large that we had maximum errors like 3000[m] or 7000[m]. This factor is due to the synchronazation loss of the mobile phone and is different from the location error itself. In our measurement, synchronazation loss were observed with frequencies within 5% at all places.

As can be seen from Figures 5 and 6, every place have a particular bias of error. In order to analyze the bias, we set fact position to the origin on the x-y plane and plot the error to the plane. We obtain standard deviation σ_H,

$$\sigma_H = \sqrt{\sigma_x^2 + \sigma_y^2} \quad \ldots(1)$$

where σ_x^2 is standard deviation of x-direction, and σ_y^2 is standard deviation of y-direction,

$$\sigma_x^2 = \frac{\sum_{k=1}^{n}(x_k - \bar{x})^2}{n} \quad \ldots(2)$$

$$\sigma_y^2 = \frac{\sum_{k=1}^{n}(y_k - \bar{y})^2}{n} \quad \ldots(3)$$, respectively.

For each the five place, we analyze the bias and distribute of the errors. Figures 7 and 8 are distributions of the errors in Figures 5 and 6, respectively. The measurement errors, as seen from the figures, tend not to distribute uniformly but with particular biases.

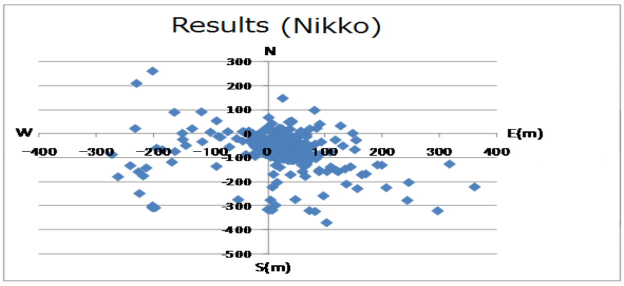

Fig. 7 Test results in Nikko

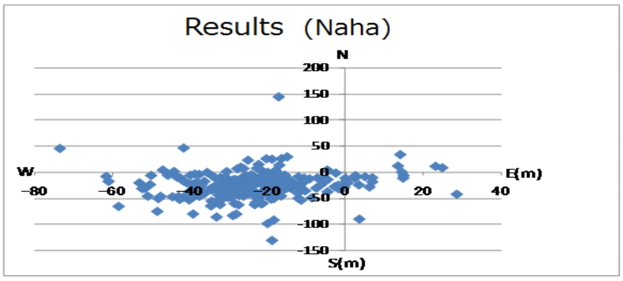

Fig. 8 Test results in Naha

The bias was observed at every place and the direction on the plane and magnitude of the error depend on the places. This may be guessed to be due to the positions of the cellular stations and measurement places. Also, we considered that biases of particular directions occur by multi-pass at those places that are indoor or close to building[11~12].

4 Experiment 3: Reproducibility of Error

As far as we consider usual usage in daily life, GPS may be of practical use even in erroneous environments if only the errors are reproducible. Hence we measured location errorsin the section, biases and synchronization loss inside or roof of buildings in Seikei university, to confirm the reproducibility.

In this measurement, we received GPS information every minutes and then plotted frequency and distribution of the magnitude and biases in Equation(1).

4-1. Experiment 3-1: Outdoor reproducibility

The measurement was done on the roof of a building without obstacles in the sky.

In order to confirm whether GPS errors vary when seasons change or not. We performed the measurement three times on 16th, Oct. 2008, 6th, Jan. 2009 and 11th, Jan. 2009. The statistics of results are shown in Table 4 and their histograms in Figures 9, 10 and 11.

Table 4 Measurement statistics on the roof

	2008/10/16	2009/1/6	2009/1/11
Average	91.00	99.92	97.25
Maximum	0.90	0.92	1.31
Minimum	17.39	15.42	14.95
Variance	267.24	218.45	171.27
Standard Deviation	16.36	14.81	13.10

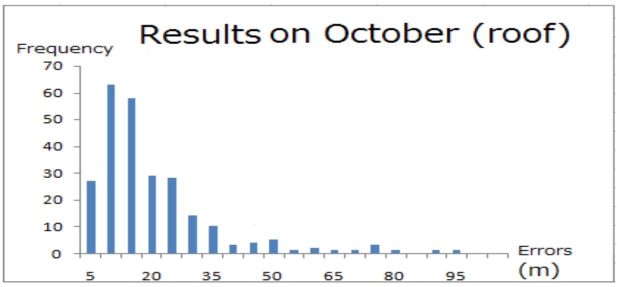

Fig. 9 Frequency of errors of GPS device on October

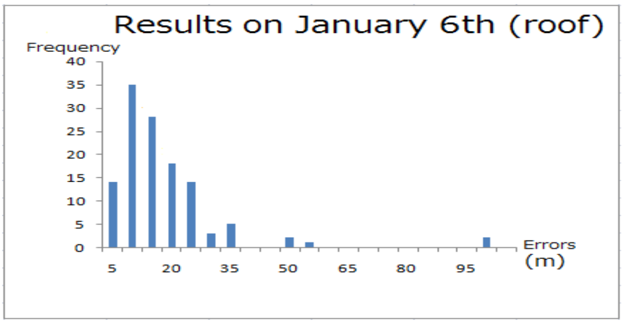

Fig. 10 Frequency of errors of GPS device on January 6th ~ 7th

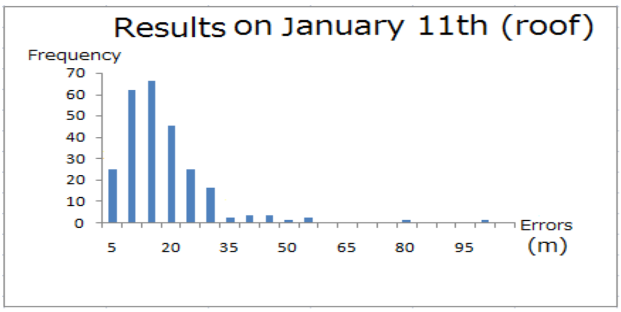

Fig. 11 GPS test results on the roof on January 11th

The table and figures suggest that, as far as there's no obstacles in the sky, the statistics are almost the same. Thus we may consider in this case that GPS information on the roof is reproducible.

4-2. Experiment 3-2: Indoor reproducibility

Next, we performed the measurement at place 6 in experiment1, in which the building is likely to cause large errors, to see whether the GPS errors have reproducibility or not. The measurement was done for three consecutive days.

Table 5 Indoor test results

	First	second	Third
Average	353.98	278.83	345.55
Maximum	0.41	1.72	0.26
Minimum	52.18	63.09	48.10
Variance	1826.25	2496.93	1763.60
Standard Deviation	42.77	50.01	42.01

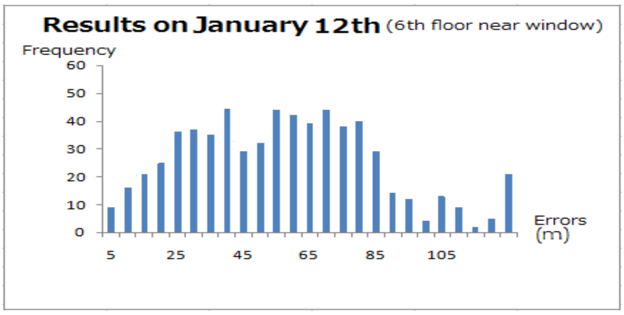

Fig.12 Test results in location6 on the January 12th

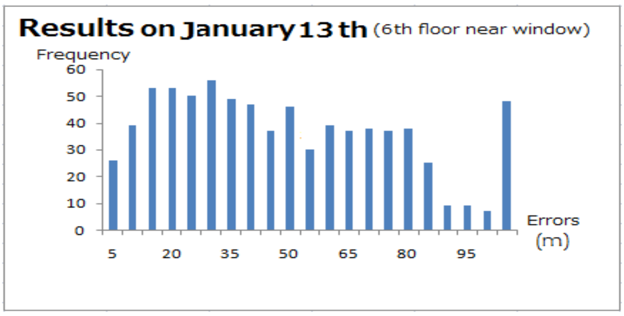

Fig.13 Test results in location6 on the January 13th

Table 5 lists the statistics of results and Figures 12 and 13 the histograms of results of the first and second trials, respectively. In the figures, the GPS errors are from 50 to 60m in average. The bias in Equation (1) is plotted in Figures 14 and 15.

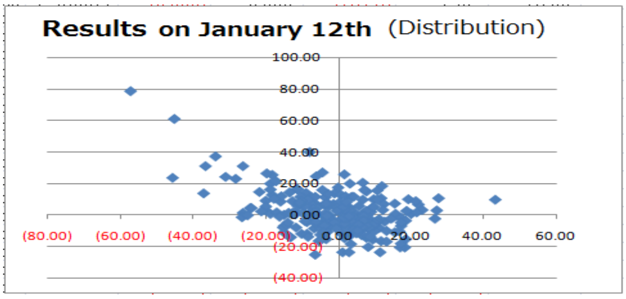

Fig. 14 Distribution of errors in Figure 12

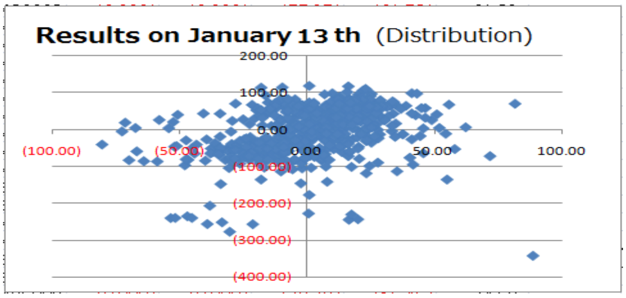

Fig. 15 Distribution of errors in Figure 13

The difference of errors in the figures are within 10[m] and the direction of biases are mostly the same. The difference of mean error may be due to the small difference of GPS satellite's periodicity, since the small difference causes multi-pass that presents different values at every clock-time, so that the errors as in the two are observed even at the same place.

By the measurement, it turns out that synchronazation loss may rarely cause severe errors and that the mobile phones with DGPS identify 90% of locations with errors less than 100[m].

5 An Application with Image Processing

As seen so far, we may say that errors of GPS information are at most 100[m]. Though the precision is sufficient for our daily life, it is not sufficient for use in the problems of environmental pollution. Therefore, in order to make the more precise location identification, we constructed an error correction system that performs a pattern matching between pictures taken by a camera of mobile phone and images in database. In the experiment here, we evaluate the performance of the location correction method based on pattern matching. [13~17].

6 Experiment 4: Pattern matching

Let a picture be taken by camera of mobile phone at a place where an environmental problem has occurred. We call the picture the input image. We will perform the pattern matching between the input images and database images. To obtain more precisely, we calculate the correlation coefficient of two images by the following Equation (4), to evaluate the similarity:

$$\text{Correlation} = \frac{\sum_{n=1}^{N}\sum_{m=1}^{M}(f(m,n)-\bar{f})(g(m,n)-\bar{g})}{\sqrt{\sum_{n=1}^{N}\sum_{m=1}^{M}(f(m,n)-\bar{f})^2}\sqrt{\sum_{n=1}^{N}\sum_{m=1}^{M}(g(m,n)-\bar{g})^2}} \quad \cdots (4)$$

where,
N: number of pixels in vertical direction of images
M: number of pixels in horizontal direction of images
f: input image by camera of mobile phone
g: movie stored in the database, respectively.

We performed the pattern matching trials for every input image at 20 spots in Seikei university with corresponding 20 videos in the database. The possible matching trials are thus 400 cases. As the database images, we used a image in every five frames, in order to make the operation fast. This reduction was done according to a pre-experiment result to determine an appropriate reduction rate of frames without changing the correlation coefficients [7].

The following is the pattern matching process we use in this section.

Step1: Transforming the input images and database movies into monochrome images
Step2: Making the two images into binary.
Step3: Performing edge detection on the input image and frames of a candidate video

source. Calculating the sequence of correlation coefficients: Firstly with the input image as it is, in order to determine frame-time intervals of video frames with high peak values of correlation coefficients. Secondly with the input image enlarged along a sequence of magnification ratios, in order to determine the vertical height of the scene in the input image.

Step4: Enlarging the input images in order to analyze them in detail, using Equation (5) in Figure 16, and then performing the pattern matching (see step5 for more detail).

$$\hat{u}(x,y) = \sum_{i=0}^{M-1}\sum_{j=0}^{N-1} u(i,j)\varphi(x-i, y-j) \quad \cdots (5)$$

$\hat{u}(x,y)$: interpolatetd picture element; $u(i,j)$: picture element; $\varphi(x-i, y-j)$: two-dimentional interpolation function

Here, φ(x) and φ(y) are

$$\varphi(x,y) = \phi(x)\,\phi(y)$$ where,

Φ: one-dimensional interpolation function

Step5: Identifying the location from a peak of the correlation coefficients as follows.

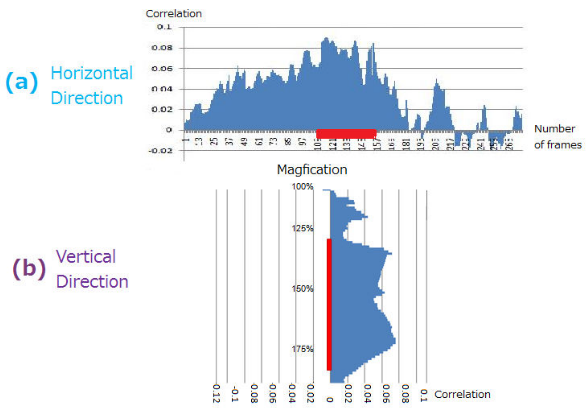

Fig. 16 An example in which correlation coefficient has peaks (vertical or horizontal direction)

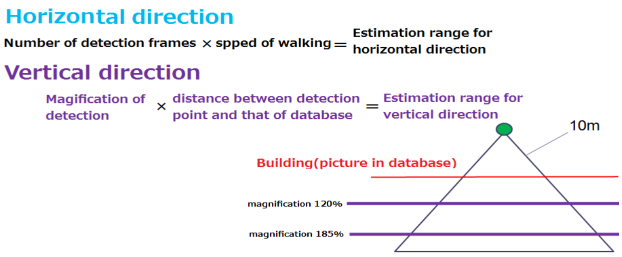

Fig. 17 Estimation example of location precision

Figures 16 and 17 explain how to estimate the location precision by correlation coefficient of input images and database video sequences. The database video was shot with panning a video camera. Figure 16 (a) plots, for the horizontal axis frame-time, the correlation coefficients of an input image with frame image at each frame-time.

It contains a portion, indicated by red, of frame-time interval on which the correlation coefficients presents the largest peaks. On this interval of peaks, we judge that the input image coincides with the database video.

The distance given by the product of the peak interval length and the panning speed may then be the horizontal width of the identified place:

$$\text{Horizontal Width} = (\text{Peak} - \text{Interval length})[s] \times (\text{Panning speed})[m/s]$$

Then, we obtain the horizontal location precision by distance obtained by the time-length of the red interval and the panning speed. Since 1 frame-time is 1/30[s], the horizontal width in the example of Figure 17(a) is 40[frame] × 1/30 [s] × 1.5[m/s] = 2[m]. For vertical range, Figure 17 plots the correlation coefficients with respect to magnification of the input image.

Here we have detected the peaks with threshold 0.1. The threshold was determined according to a preliminary experiment that we would mention later. We determine the vertical height of the identified image by the product of magnification ratio of the peak interval (indicated red) in Fig.16(b) and the distance 10[m] between camera and objects.

Vertical Width = (Maximum ratio in peak values −Minimum ratio in peak values) × Distance between detectionpoint and that of database[m]

In the example of Figure 17, the vertical height is thus estimated as (1.85-1.20)×10[m] =6.5[m].

Before these pattern matching, we have performed a preliminary experiment on the panning speed, in order to investigate whether the correlation coefficients change depending on the speed or not. Specifically, we tried the panning speed 0.5, 1.0 and 1.5[m/s] and observed the difference of correlation coefficients respectively. Figures 18 and 19 indicate the results of 0.5 and 1.5[m/s].

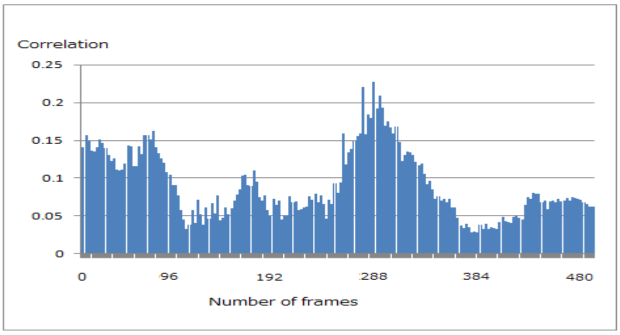

Fig. 18 Correlation coefficients with panning speed 0.5[m/s]

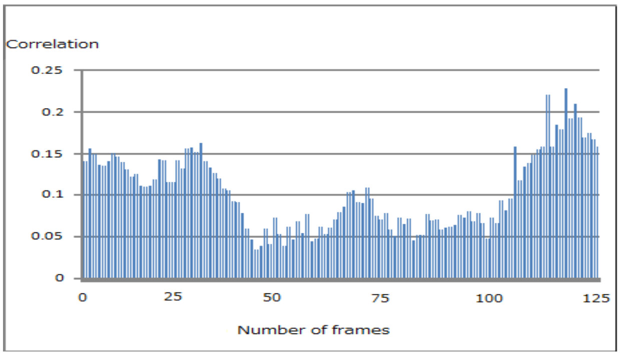

Fig. 19 Correlation coefficients with panning speed 1.5[m/s]

Specifically, we tried the panning speed 0.5, 1.0 and 1.5[m/s] and observed the difference of correlation coefficients. From Figures 18 and 19, we observe that the difference of correlations are small so that the difference of mean and maximum values are at most 0.02. This is true for various values of the panning speed.

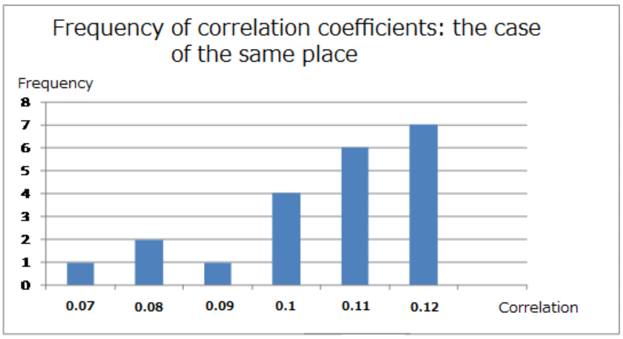

Fig. 20 Frequencies of difference of mean and maximum values of correlation coefficients: the case that the input image and database video are the same place

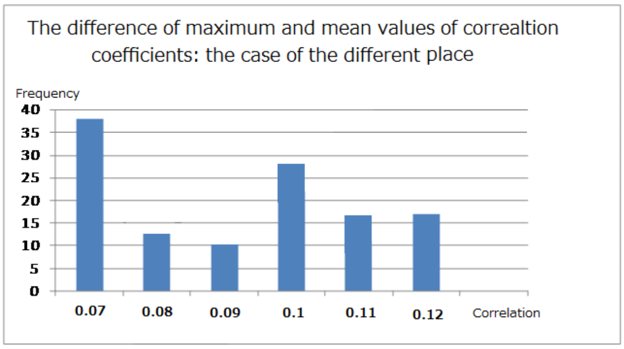

Fig. 21 Frequencies of difference of mean and maximum values of correlation coefficients: the case that the input image and database video are different places

Sometimes the sequence of correlation coefficients does not have peaks, or are noisy to tell a distinct peak. We have thus set a threshold 0.1 of the difference of maximum and mean to detect a peak.

The value 0.1 comes from the fact that, in Figures 20 and 21, it is a change point of the distributions, while correlation coefficients larger that 0.1 have significant mass of distribution.

7 Results

Figures 22 to 25 are a part of 400 trials of the pattern matching. Each of the trials is either the case that input image and database video sequence present the same place or different. Below we discuss the case of the same place in subsection 7-1 and different place in subsection 7-2, respectively.

7-1. The case of the same place

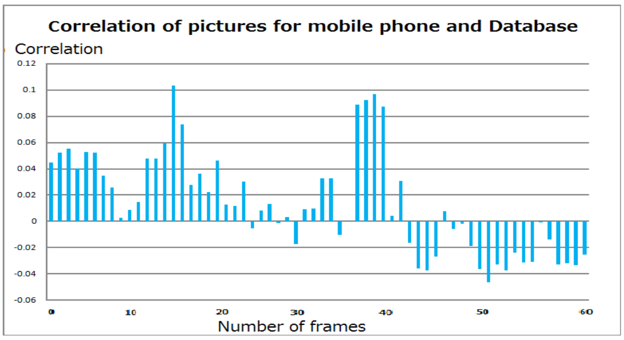

Fig. 22 Correlation of images presenting the same place

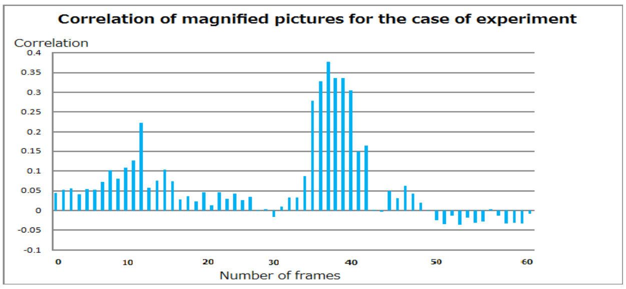

Fig. 23 Correlation with input image enlarged in Fig. 22

The maximum values in Figures. 22 and 23 are 0.103 and 0.376, respectively. The increase of the maximum may thus imply that the location identification with input images enlarged gets better precision.

7-2. The case of different places

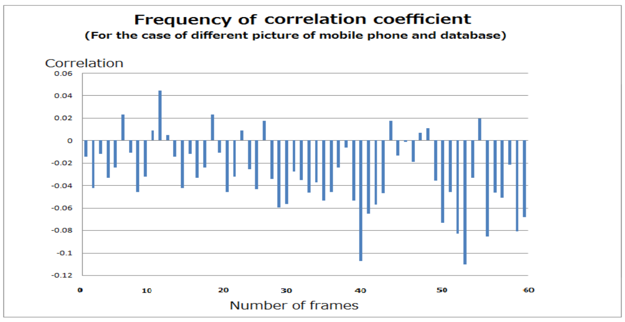

Fig. 24 Correlation of images presenting different places

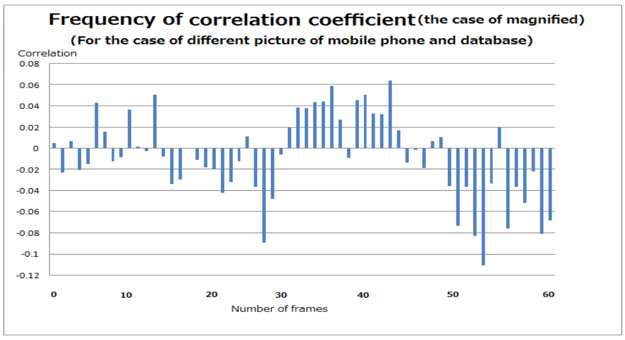

Fig. 25 Correlation with input image enlarged in Fig. 24

Here the correlation is taken for the two images presenting different places. The correlations are much worse than the case of the same place as anticipated, with mean -0.02 and maximum 0.05 at best with input image enlarged.

8 Summary and Conclusion of the Pattern Matching

We can summarize the results in Section 7 as follows.

8-1 The case that difference of maximum and mean of correlations larger than 0.1

In this case, we can identify the location within error range of 400[㎡] for 85[%] of the trials.

Fig. 26 Identified area of 400[㎡] in case of difference of average and maximum correlation more than 0.1

8-2 The case that mean of the correlations more than 0.1

In this case, we can identify the location within error range of 30[㎡] for 8[%] of the trials.

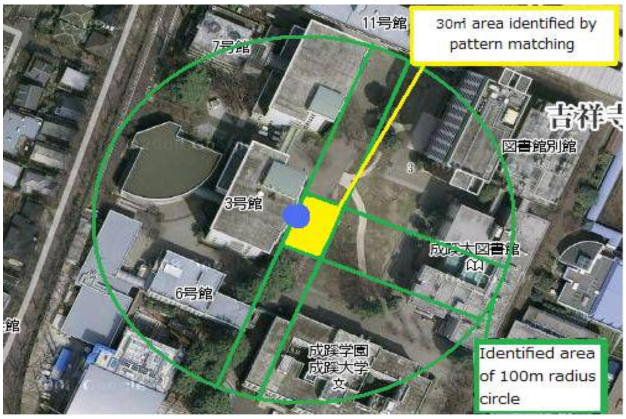

Fig. 27 Identified area of 30[㎡] in case of difference of mean of correlations is larger than 0.1

Figures 20 and 21 are relative frequency of the correlation coefficients. Since the input image and video are of different places, the correlation must have not present peaks. In the experiment here, however, actually we had peaks 50 times out of 330 trials. These 50 trials may be considered misdetection.

In order to reduce the misdetection, we have set a threshold on the difference of maximum and mean of the correlation coefficients, which is designated A in Table 6.

Then, it turned out that, by setting A=0.1, we could reduce the misdetection, as well as missing of correct detection. Therefore, we have set the threshold of A=0.1.

Table 6 Correct/Wrong

A	correct	wrong
0.08	15 (75%)	33 (8%)
0.09	15 (75%)	27 (7%)
0.10	15 (75%)	23 (6%)
0.11	12 (60%)	9 (2%)

8-3 The case that mean of the correlations less than 0.1

For those input images either with their places not in database, or without significant peak, or the difference of maximum and mean is less than 0.1, the identification precision is worse than in subsections 8-1 and 8-2. The common range of the errors is within the circle of radius 100[m].

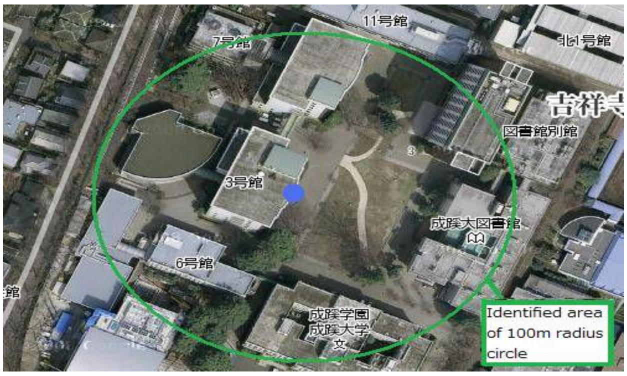

Fig. 28 Identified circle of radius 100[m] by GPS

The result here is summarized in Table 7.

Table 7 Summary of the result

Test condition	Ratio of peak existence	Ratio of correlation more than 0.1 as well as peak existence	Others
Different places mobile phone and database	13%(50)	0%(0)	87%(330)
Same place of mobile phone and database	85%(17)	75%(15)	15%(3)
() is the number corresponding to the ratio			

9 Concluding Remarks

Using GPS attached to mobile phones, we have conducted experiments of comparison of precision of GPS-alone system and DGPS and comparison of location-dependent error characteristics and reproducibility at several places in Japan. We observed how precisely the location identification is done as well.

As the main part of the paper, we constructed and evaluated a GPS precision improvement system. The system, according to GPS information of error range, searches the best similar image to an input image, in database. Then it performs a image matching through observation of correlation peak, to estimate the vertical and horizontal range of distance of the input image.

As described in subsection 5-3, we observed that it is possible to make the location identification more precise than the original GPS information that indicates the error range as circle of radius 100[m], i.e. the range of area $10^4 * \pi$ [㎡]. In fact, our system has gained the precision up to the area of 400[㎡] at 85% of places and 30[㎡] at 75% of places.

We may consider that suggests a capability of the method of correlation matching on edge-extracted images to improve the precision of location identification.

10 Future Problems

It may be necessary to consider in more detail the precision of GPS antenna or cameras for each of the mobile phones. Also, analysis of relationship between GPS radio wave and cellular stations, is essential.

The location information will undoubtedly make human life more convenient and give solutions to existing problems. For an ICT society in near future, a more sophisticated and detailed location information is indispensable.

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