Error Analysis of the Mobile Phone GPS and its Application to the Error Reduction

YUKI ODAKA*[1], YUSUKE IN*[2], MAYUKO KITAZUME *[1],
MASAKAZU HIGUCHI*[3], SHUJI KAWASAKI*[4], and HITOMI MURAKAMI*[5]
*[1] : Masters Student of Science and Engineering
*[2] : Undergraduate Student of Information Science
*[3] : Postdoctoral Researcher of Information Science
*[4] : Visting researcher
*[5] : Professor of Information Science
SEIKEI University
3-3-1 Kichijojikitamachi, Musashino-shi, Tokyo, 180-8633
JAPAN
dm106207@cc.seikei.ac.jp

Abstract: - In recent years, study of location identification by mobile phone has been attracting a lot of attention. Especially, GPS contents of mobile phone are increasing for the purpose of various kinds of applications, such as games, navigations and etc. So far, many investigations have been carried out for GPS performance by conventional GPS devices, but few people study mobile phone GPS performance. In this paper, we measured and examined the performance of mobile phone GPS using various types of terminals of different venders under some environments. As for the performance improvement, we propose an efficient method and evaluate it for the results including distance errors and direction errors of GPS. The reduction methods for such errors applying to the group characteristics of mobile phones are also described.

Key-Words: - Mobile phone GPS, distance errors, direction errors, noise reduction, impulse noise

1 Introduction

Currently, mobile content using GPS is rapidly increasing, and the mobile phone GPS has become a required feature for navigation, providing location information in case of emergency, disaster, etc. In this regard, we measured and accumulated quantitative data of mobile phone GPS error characteristics under various conditions [1] - [3]. Compared to the previous research results on mobile phone GPS, it is revealed that under certain conditions, significant errors can result. Additionally, we examine the mobile phone GPS error characteristics under a variety of conditions.

In particular, the characteristic combination of multiple models (hereinafter referred to as the group characteristics) are explored and based on the results, methods of error reduction are examined.

2 Overview of Experiments

In this study, using eight mobile phones of five different types from four venders, GPS measurements were taken every minute. Three experiments described below were carried out. The number and configuration of mobile phone models shown in Table 1 were used in the experiments.

Experiment 1: Error characteristics by mobile phone direction

Experiment 2: Out of sync error (impulse noise) analysis

Experiment 3: Group characteristics of mobile phone GPS error

As a method of calculating the error, the difference between the measured and the true value of measurement point was calculated by employing the Hubeny formula [4]. For the determination of the true value, the value from Google map service was used as reference.

Table 1: The composition of the 8 mobile phone terminals of 5 different types used in experiments

Mobile Phone Type	①	②	③	④	⑤
Vender	A	B	C	C	D
Units	1	1	1	3	2

As will be discussed shortly, Experiment 1 uses terminal 1-A (mobile phone type 1 by vender A), while Experiments 2 and 3 use all the 8 terminals of 5 different types.

3 Experiment 1 : Error characteristics by mobile phone direction

By considering the user convenience, the GPS antenna is generally placed around the top end of the display. Thus, when GPS measurements are taken by the mobile phone, in order to determine whether the measurement directions has any effect, for a fixed time the antenna direction is changed from North, South, East and West. These measurements were performed under clear sky conditions. Next, based on the results, we carried out verification and evaluation using the average error and error variance diagrams. The results of the experiment are shown in Table 2 and Figure 1.

From the above results, it can be seen that there is a noticeable difference in some maximum error values, but the values for the average error and error variance are not so different and are actually very close. It is apparent that the direction characteristics do not exist and it can therefore be confirmed that the orientation of the antenna does not affect the GPS measurements taken by the mobile phone users.

Table 2: GPS error for the 4 directions

Direction	East	West	South	North
Average Error (m)	13	14	14	12
Maximum Error(m)	62	56	49	122
Minimum Error (m)	0	0	1	0
Variance (m^2)	94	109	99	97

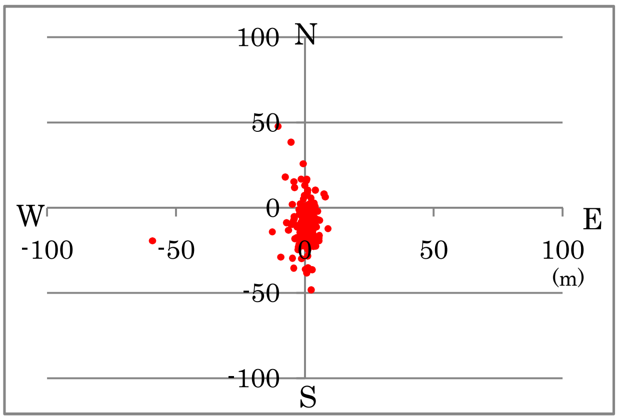

Fig.1: Error variance diagram for the Eastern direction (For other directions, the Western, Southern, and Northern, almost same figures are obtained.)

4 Experiment 2 : Out of sync error (impulse noise) analysis

4.1 Impulse noise characteristics

As mentioned above, we have carried out mobile phone GPS measurements, but in most of the results rare occurrences of error of some several hundred meters to some several thousand meters have been identified. Such a large error significantly decreases the utility of the GPS. We named such an error 'out of sync error' or 'impulsive noise.' In this experiment, we investigate the indoor and outdoor impulse noise characteristics of the different mobile phone types using 8 terminals (shown in Table 1) under the same environmental conditions and for the same length of time. The measurements for each vender's mobile phone are recorded. Furthermore, we also consider a method of impulse noise reduction.

In order to find the cumulative probability distribution, measurements taken over a period of 24 hours were integrated and from these measurements impulse noise occurrence rate was determined. From these observations, an error greater than or equal to 100 meters was defined as impulse noise. A representative part of the results for impulse noise characteristics are shown in Figures 2 and 3.

The cumulative probability distribution results suggest that the percentage of impulse noise for outdoors and indoors in terms of the time rate is 0.2% and 3.5%, respectively. For outdoors, the occurrence frequency was as low as 0.2%, but for indoors, due to multipath and other error factors, the occurrence frequency was comparably more than 10 times high.

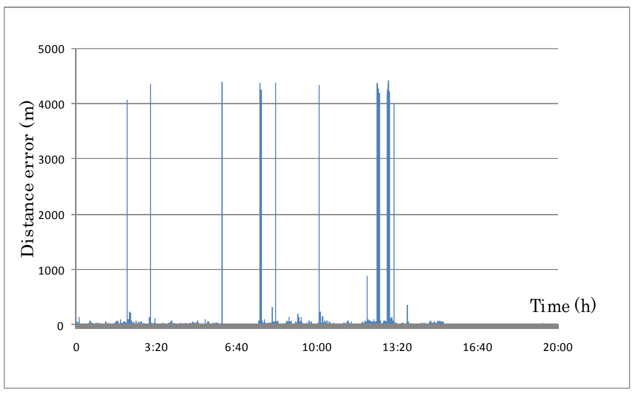

Fig.2-1: Indoor impulse noise measurement results of terminal ④-C-1 (same terminal type as ④-C-2).

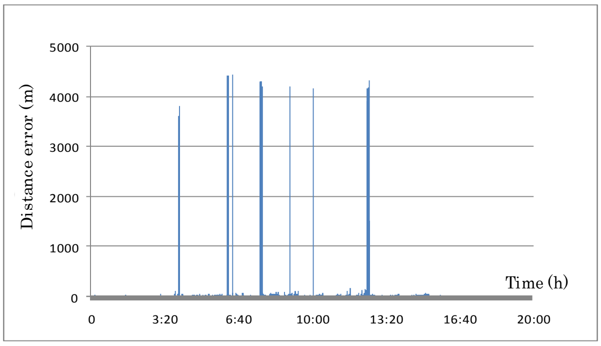

Fig.2-2: Indoor impulse noise measurement results of terminal ④-C-2 (same terminal type as ④-C-1).

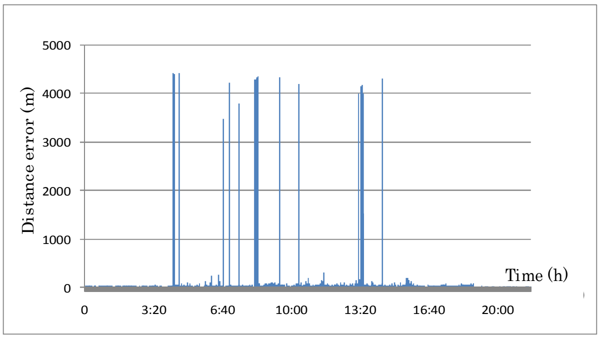

Fig.3-1: Indoor impulse noise measurement results of terminal ④-C-3.

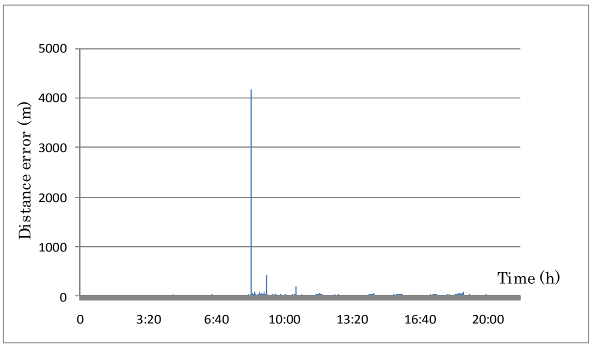

Fig.3-2: Indoor impulse noise measurement results of terminal -C.

As shown in Figures 2-1, 2-2 and 3-1, for mobile phones from the same vender, the impulse noise characteristics are almost the same. It can be confirmed from Figures 3-1 and 3-2 that even for the same maker, different mobile phone types have different impulse noise characteristics. The notation, X-Y-Z denotes a mobile phone type X, by vender Y and Z is the unit number. We can also recognize from Figures 2-1, 2-2 and 3-1 that once impulse noise occurs, the chances of it recurring continuously are high.

4.2 A Method for Impulse Noise Reduction

We consider an N-point moving average method for impulse noise reduction. The noise reduction effectiveness for N=3 and N=5 are shown in Figures 4-2 to 4-3. Figure 4-1 is for the basic measurement error result, while Figures 4-2 and 4-3 are the results obtained from Figure 4-1 when N is set to 3 and 5 respectively.

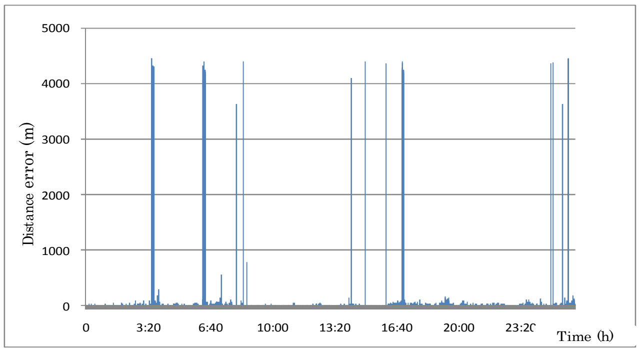

Fig.4-1: Indoor impulse noise measurement results of terminal ④-C-3.

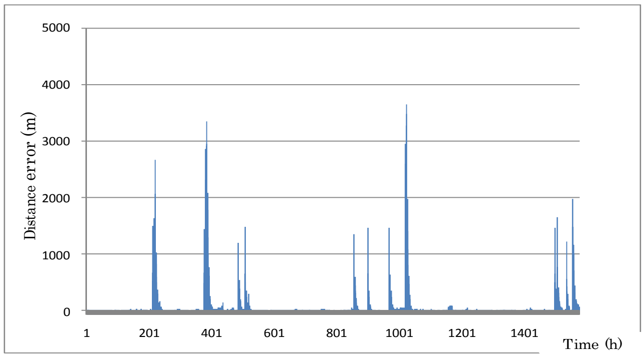

Fig.4-2: Indoor impulse noise measurement results of terminal ④-C-3 in Figure 4-1 when the 3-point average method is applied.

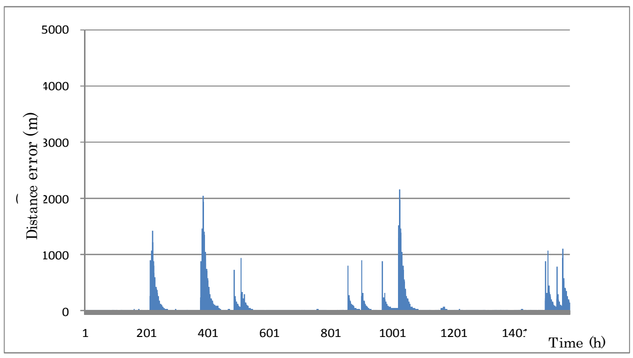

Fig.4-3: Indoor impulse noise measurement results of terminal ④-C-3 in Figure 4-1 when the 5-point average method is applied.

By applying the N-point moving average method, the maximum value of the impulse noise can be reduced significantly as shown in Figures 4-1 to 4-3. By increasing the value of N, it is possible to further reduce the impulse noise values but the error spreads in time. For this reason, if the impulse noise occurs continuously, the effectiveness of the moving average method is small.

4.3 Formulation of the GPS error characteristics

Based on the outdoor measurements data obtained using 8 mobile phones, the GPS error distribution was formulated. The following method was employed. First, the probability of GPS error frequency and distance error were found separately and then a graphical representation of their relationship was obtained. Next, the approximate curve was assumed to fit the gamma probability distribution function shown in Equation (1) and then the parameters α and β of the gamma distribution function were determined by the least squares method.

$$f(x,\alpha,\beta) = x^{\alpha-1}e^{-x/\beta}(1/\beta^{\alpha}\Gamma(\alpha)) \qquad (1)$$

The method of calculation by the least squares method is as follows. Say, the GPS error x_k [m] has a probability of y_k, then the difference between y_k and $f(x_k,\alpha,\beta)$, denoted by $d_k = (y_k - f(x_k,\alpha,\beta))^2$, is calculated for k=1, 2, 3, …, 100. The values of α and β that minimize S, defined below, are obtained.

$$S = \sum_{k=1}^{100} d_k = \sum_{k=1}^{100} (y_k - f(x_k,\alpha,\beta))^2$$

The partial derivatives of S with respect to α and β are calculated, and then the simultaneous equations $\partial S/\partial\alpha = 0$, $\partial S/\partial\beta = 0$ are solved to get values of α and β. The result is shown in Fig. 5.

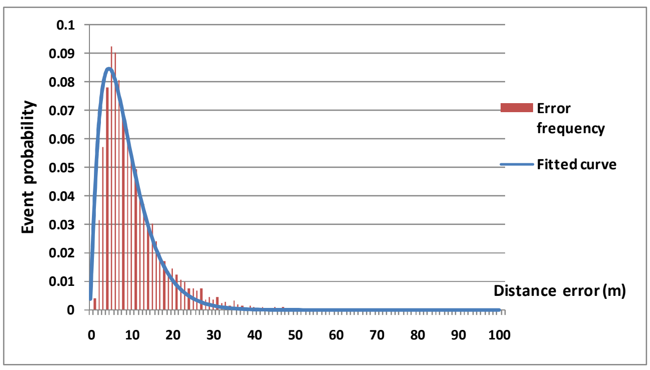

Fig.5: The frequency of errors and gamma distribution fitted curve (Outdoor example)

By using this least squares method, the outdoor GPS error characteristic parameters α, β in Equation (1) were 2.1 and 4.3, respectively. On the other hand, the indoor parameters α, β were 1.6 and 9.1 respectively.

5 Experiment 3: Group characteristics of mobile phone GPS error

5.1 Verification and evaluation of group characteristics

As a way of using GPS in the future, the following two scenarios can be envisaged. First, many mobile phone owners can use their mobile phones at the same time, in the same place. Second, a large number of GPS-equipped sensors can be densely placed in close vicinity. Based on this situation, the correlation between multiple GPS measurements can be calculated. The method employed uses terminals from a single maker to investigate the difference in characteristics between the different mobile phone types. Also the characteristics from different mobile phone makers are investigated. As in the previous two experiments, 8 terminals of Table 1 are used but the measurement time is extended. All the terminals are placed with a circle of 1m radius.

In order to find out if there is correlation between GPS errors, the cross-correlation coefficient over the same period for each GPS error in the preceding experimental results was examined. Table 3 shows the results.

Table 3: The correlation coefficients of distance error and direction error between mobile phones.

		Indoors		Outdoors	
	Combination	DSEC	DREC	DSEC	DREC
[1]	1-A & 2-B	0.15	0.21	0.16	0.2
[2]	1-A & 3-C	0.16	0.22	0.06	0.13
[3]	1-A & 4-C-1	0.32	0.33	0.1	0.26
[4]	1-A & 4-C-2	0.11	0.13	0.2	0.29
[5]	1-A & 4-C-3	0.11	0.14	0.21	0.3
[6]	1-A & 5-D-1	-0.01	0	0.12	0.29
[7]	1-A & 5-D-2	0.1	0.12	0.09	0.09
[8]	2-B & 3-C	0.09	0.08	0.11	0.22
[9]	2-B & 4-C-1	0.05	0.1	0.26	0.41
[10]	2-B & 4-C-2	0.05	0.1	0.15	0.12
[11]	2-B & 4-C-3	-0.03	0.05	0.26	0.39
[12]	2-B & 5-D-1	-0.01	0.04	0.16	0.33
[13]	2-B & 5-D-2	-0.03	0.02	0.09	0.22

[14]	3-C & 4-C-1	-0.01	0.01	0.05	0.14
[15]	3-C & 4-C-2	0.22	0.23	0.03	0.2
[16]	3-C & 4-C-3	0.01	0.01	0.02	0.08
[17]	3-C & 5-D-1	0.01	0.02	-0.01	0.1
[18]	3-C & 5-D-2	0	0.01	-0.03	0.12
[19]	4-C-1 & 4-C-2	0.35	0.36	0.39	0.46
[20]	4-C-1 & 4-C-3	0.4	0.42	0.28	0.4
[21]	4-C-1 & 5-D-1	-0.01	0	0.14	0.34
[22]	4-C-1 & 5-D-2	-0.03	0	0.09	0.16
[23]	4-C-2 & 4-C-3	0.34	0.35	0.34	0.44
[24]	4-C-2 & 5-D-1	-0.01	0	0.16	0.3
[25]	4-C-2 & 5-D-2	-0.01	0	0.09	0.17
[26]	4-C-3 & 5-D-1	-0.01	0	0.2	0.31
[27]	4-C-3 & 5-D-2	-0.01	0	0.07	0.2
[28]	5-D-1 & 5-D-2	0.09	0.08	0.15	0.07
	Average	0.09	0.11	0.14	0.24

Key: DSEC: Distance Error Correlation, DREC: Direction Error Correlation

Each cross-correlation, the indoor distance error and direction error [5] had average values 0.09 and 0.11, respectively. The correlations between some models of the same type were shown to be high. In addition, the average outdoor distance and direction errors were 0.14 and 0.24, respectively. These values are even higher than those for indoors. As with outdoor results, some indoors correlations between terminals of the same type were slightly higher.

From the results, it can be confirmed that models from the same vender showed slightly high correlation in distance and direction errors. But among the other models, even for the same GPS chip (in all the experiments the chip is from Qualcomm), the correlation is nearly zero. For each vender's terminals, the GPS positioning error is thought to be highly dependent on the antenna's location, structure and sensitivity.

5.2 Estimation of the true value of measurement points

As mentioned in the results for mobile phone GPS error's group characteristics in Section 5.1, correlation coefficients between terminal models have been confirmed to be generally low. Using this nearly zero cross-correlation and multiple mobile phones to reduce the measurement error, the true value of measurement points was estimated. The true value estimation method is defined below.

As the method of estimating the true value, the GPS error can be expressed as a sum of measurements as shown in Equation (2). The estimate at a point is denoted by $\hat{f}(x)$ such that

$$\hat{f}(x) = F(x) + \sum_{i=1}^{N} n(x_i)/N \qquad (2)$$

$F(x)$ The true position,

$n(x_i)$ Noise at terminal i,

N The number of devices used in the measurement of GPS error.

Using the fact that the mobile phone GPS error correlation coefficient is small, the amount of noise error $\sum_{i=1}^{N} n(x_i)/N$ used to determine the error in Equation (2) is closer to zero.

Based on these concepts, first, the average GPS error for one terminal that would become the basis, and different combinations of true value measurements from terminals two to eight are obtained. The results are shown in Figure 6. In this figure, the average estimate from the ${}_8C_n$ (n = 2 ~ 8) combinations of terminals, the maximum estimate and the minimum estimate are shown.

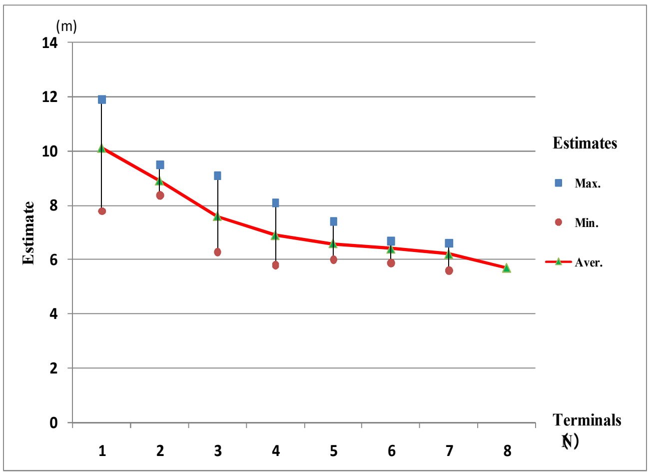

Fig.6: The relationship between the number of terminals, N, and the estimated error.

These results indicate that the higher number of terminals N, the higher the possibility of reducing the GPS error. Then we compared the average distance error for the 8 terminals before and after estimation. Table 4 and Figure 7 show the results.

Table 4: The error before estimation (average of 8 terminals) and after estimation.

	Before Estimation	After Estimation
Average Error (m)	15	6
Maximum Error(m)	46	41
Minimum Error (m)	4	0
Variance (m^2)	35	37

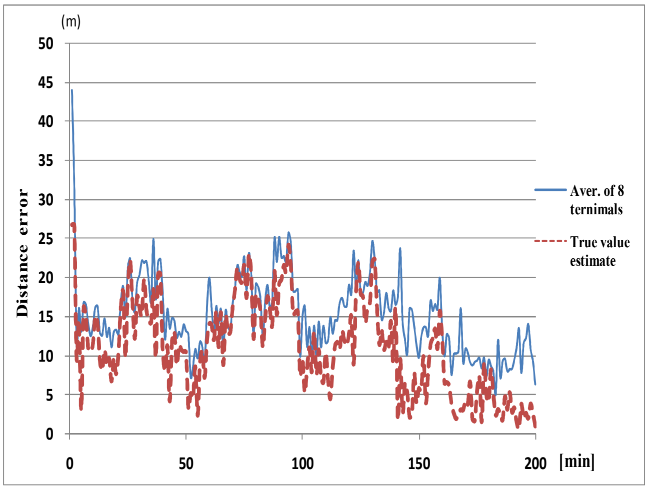

Fig.7: Comparison of the average distance error between the true value estimation method and that of 8 mobile phone terminals.

Through estimation of true value using 8 mobile phone terminals, it is possible to reduce the GPS measurement error to less than 40% when compared to the error obtained by using only one mobile terminal.

6. Conclusions

The results of the experiments can be summarized as follows.

1. The GPS error characteristics are independent of the orientation (N, S, E, W) of the mobile phone.
2. Sync (impulse noise) is rarely encountered, but causes very large errors when encountered. In clear sky conditions, the time rate of occurrence is about 0.2%, but in indoor conditions where the GPS satellites are hard to see, the occurrence rate increase to about 3% to 4%. The amount and timing of its occurrence is highly dependent on the type of mobile phone terminal.
3. Impulse noise reduction by the N-point moving average method (N=3-5) is very effective.
4. The GPS error distribution is well approximated by gamma distribution.
5. As for the group characteristics between multiple GPS mobile phones, the cross-correlation between the distance and direction errors is small. Using this property, by a simple addition GPS error from multiple terminals, it is possible to estimate the true value of measurement points. For example, when using eight mobile phones, the GPS error can be reduced to below 40% of that produced by a single mobile phone.

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