逆 GPS の実験的研究

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はしがき

逆 GPS 方式ポジショニングシステムは、本報告者が発明人の一人であるポジショニング方式である。また、その原理も広く認知され始めているが、実験的検討はほとんど行われていない。そこで、超音波をキャリアとした実験、電波をキャリアとしたシミュレーション、実験を行った。

超音波を媒体とした場合では、単一パルス時よりも更なる測位範囲拡大を狙い送信信号をスペクトル拡散化し相関受信を行うハードウェア実験装置を作成し、実験を行った。その結果、単一パルスでの実験と比較して、約 4 倍のレンジ（64 倍の空間）に測位範囲を拡大できた。

電波を媒体とした場合では、まず詳細なパラメータを含む回路を検討し、シミュレーションによりその性能評価を行い装置作成の目処を立てた。また、5 つ以上のアンテナを用いたポジショニング精度の向上法の提案を行った。次に、普及を考慮して市販の無線通信モジュール“GIGA WAVE”を利用した実験システムを設計し実験を行った。その実験により、送受信モジュールは受信シンボル復調タイミングの精度の大幅向上が必要であることが明らかになり、また、その際に伝搬遅延時間差を検出する相関器出力は振幅変動や雑音の影響を受けにくく、遅延時間差によってのみ変化するような回路である必要があることがわかった。この問題をクリアするため、位相連続 FSK (CP-FSK) を変調方式とするポジショニングシステムに改造を行った。

まず、有線ケーブルを利用した 10m×10m×3m の仮想的な 3 次元空間で測定評価実験を行い、測位精度が 40cm～90cm の結果を得た。さらに誤差の大きさが GDOP に対応していることを確認した。無線での実験では、有線と同様の 10m×10m×3m の実フィールドでの実験を行い、測位精度が 80cm～2m の結果を得た。

今後は、種々の電波環境下でのポジショニング精度の点からの性能評価や提案した測位精度向上手法の無線信号での性能評価実験を行う予定である。

研究組織

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研究発表

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著　者　名	論　文　標　題
Jun' ichiro MORIYA	A study of Inverse GPS based positioning system

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学会等に発表している印刷物を添付。

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A study of Inverse GPS based positioning system

Jun'ichiro Moriya, Takaaki Hasegawa

Abstract—**This paper describes the carrier-level simulation for hardware experiments of the Inverse GPS based positioning system. Moreover, parameters of the positioning system are studied using this simulator. The positioning system consists of a delay time difference estimation subsystem and a position calculation subsystem. This paper shows the block diagram of the delay time difference estimation subsystem and decides on several parameters, for example frequency conversion into the intermediate frequency, aimed at 2.4GHz wireless LAN signals. After that, the bandwidth of band-pass filters for correlation and convergence time for position estimation for hardware implementation are discussed. An improved scheme of position estimation using more than five antennas is proposed.**

Index Terms-The Inverse GPS, IEEE802.11b, Wireless LAN, Positioning, Spread Spectrum

I. Introduction

Recently, extensive studies have been carried out on ITS[1] and ubiquitous computing [2] on highly location-dependent information etc. Moreover, popularity of mobile phones with the GPS [3] receiver, mobile terminals and car navigation increases needs about location information, such as tracking of the person (for example, a child or an elderly person), pedestrian navigation, logistics through use of position information, E911 regulation. Therefore, LBS (Location Based Services) become a large market as increased needs about location information. Location information of human and object is essential requirement for Awareness Enhancement [4] that brings improvement of safety and efficiency in ITS and economic activation. Location information and positioning technologies are becoming important for implementation of location-dependent systems and services.

There are varieties of technologies that can obtain location information, such as the GPS [3], the Pseudolite [5], Active Bats [6], Cricket [7], PNCMM [8], M-CubITS [9], and AirStation [10] etc. There is the Inverse GPS scheme (IGPS) [11] that differs from those positioning technologies. This may become basic technology applicable to various positioning fields, such as ITS, ubiquitous computing, positioning of a wireless LAN terminal, and this system's principle is becoming to be recognized widely. An example of the Inverse GPS applications is positioning in a local place or positioning of a mobile terminal in the place that is unavailable for the GPS. However, some experiments with ultrasonic waves [12], [13] were not carried out thoroughly. Therefore, knowledge of system implementation and accuracy are still unknown.

In this paper, a career-level simulator is built for hardware designing as a preliminary stage for hardware experiment of the Inverse GPS based positioning system. Moreover, parameters of this system are studied using this simulator.

The remainder of this paper is organized as follows: Section II provides the Inverse GPS scheme. Section III describes concrete processing of the delay time difference estimation subsystem for a 2.4GHz Wireless LAN signals. System parameters are discussed in Section IV. An improved scheme of position estimation using more than five antennas is the subject to Section V. Conclusions and future works are presented in Section VI.

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II. The Inverse GPS scheme

A. The GPS [3] *and The Inverse GPS scheme* [11]

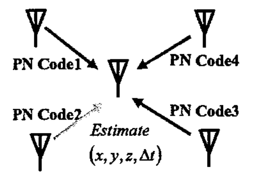
As shown in Fig.1, the GPS receives different pseudo noise signals from four satellites. The position of a receiver can be obtained by solving quaternary simultaneous quadratic equations like equations (1), where x, y, z and Δt are unknown quantities. Δt is the time difference between the accurate system time of satellites and time of an inexpensive receiver.

As depicted in Fig.2, the Inverse GPS scheme has the reverse relation between transmission and reception of the GPS. Delay time differences τ_{21}, τ_{31} and τ_{41} between antennas are estimated. The system estimates the position of the transmitter by solving quaternary simultaneous quadratic equations like equations (2), where x, y, z and τ_1 are unknown quantities.

B. The Inverse GPS based positioning system

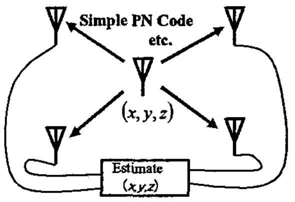
In Fig.3, the system consists of a delay time difference estimation subsystem and a position calculation subsystem. The former subsystem estimates delay time differences from received signals. The latter subsystem calculates the position of the transmitter from the estimated delay time differences. The former subsystem is explained in detail in Section III.

The principle of the delay time difference estimation uses the early/late gate [14] used for the discriminator of spread spectrum signals. The position calculation subsystem estimates the coordinate (x, y, z) of the position of the transmitter using equation (2) and τ_{21}, τ_{31}, and τ_{41} obtained by the delay time difference estimation subsystem. Appropriate arrangement of antennas is necessary, because the solution becomes indeterminate if receiving antennas are in a plane.



$$\begin{aligned}\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}&=c(\tau_1+\Delta t)\\ \sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}&=c(\tau_2+\Delta t)\\ \sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2}&=c(\tau_3+\Delta t)\\ \sqrt{(x-x_4)^2+(y-y_4)^2+(z-z_4)^2}&=c(\tau_4+\Delta t)\end{aligned} \quad (1)$$

Fig.1 Principle of the GPS.



$$\begin{aligned}\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}&=c\tau_1\\ \sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}&=c(\tau_1+\tau_{21})\\ \sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2}&=c(\tau_1+\tau_{31})\\ \sqrt{(x-x_4)^2+(y-y_4)^2+(z-z_4)^2}&=c(\tau_1+\tau_{41})\end{aligned} \quad (2)$$

Fig.2 Principle of the Inverse GPS.

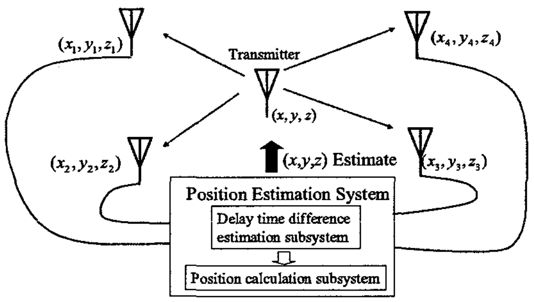


Fig.3 The Inverse GPS based positioning system.

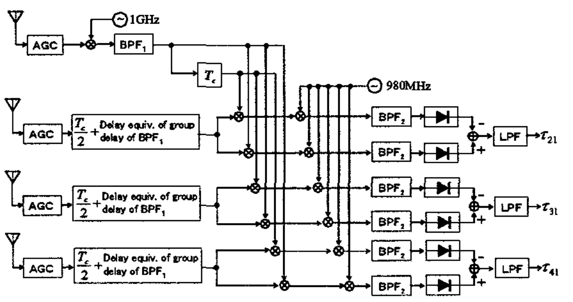


Fig.4 Delay time difference estimation subsystem

III. The Delay Time Difference Estimation Subsystem

A. Specification

The carrier frequency is 2.4GHz. The spreading code is the Barker sequence [15] of length 11 used by IEEE802.11b [16]. The chip rate is 11Mcps.

B. Specification

Fig.4 shows the block diagram of the delay time difference estimation subsystem.

Basic performance of this subsystem is explained. First, receiving signals adjust the power to the same level at AGC (Automatic Gain Controllers). Second, a base antenna is selected in receiving antennas. The received signal multiplied by the signal of 1GHz is passed through a band-pass filter. Thus, the carrier is down-converted to the 1.42GHz intermediate frequency wave. Consideration of group delay is needed, because passing the signal on the band-pass filter results a group delay. The signal is multiplied by the signal of 980MHz. Thus, the carrier is down-converted to the 20MHz intermediate frequency wave. Then, envelope detection is carried out. (Narrow bandwidth band-pass filtering is carried out at intermediate frequency 20MHz in this block diagram). If the timing of the spreading code received by the reference antenna is earlier than the timing of the spreading code received by other antennas, the output of the envelope detector located in *the lower part* in each discriminator in Fig.4 becomes large. On the contrary, if the timing of the spreading code received by the reference antenna is later than the timing of the spreading code received by other antennas, the output of the envelope detector located in *the upper part* becomes large. If the timing of each received spreading code is the same, outputs of both envelope detectors become the same level. The output of the envelope detector located in *the upper part* in each discriminator in Fig.4 is subtracted from the output of the envelope detector located in *the lower part* in each discriminator in Fig.4. Then, according to obtain direct-current component from output on low-pass filters, the output corresponding to the delay time difference is obtained.

This subsystem does not detect the signal on the base-band to avoid influences of carrier phase rotation and band-pass filtering with high Q. Detection is carried out at the intermediate frequency band of 20 MHz using the multiplication signal of 1 GHz and 980 MHz. There is a merit that the subsystem need not know the kind of the spreading code, because of correlation using the same spreading code from each antenna.

C. Parameters

Several parameters used here are shown in Table I. The bandwidth of the band-pass filters in Fig.4 for correlation is discussed in Section IV-B.

TABLE I
PARAMETERS

Parameters	Value
Carrier frequency	2.42GHz
Spreading code	Barker sequence of length 11
Chip rate	11Mcps
Multiplication signal (first)	1GHz
Multiplication signal (second)	980MHz
BPF_1 Center frequency	1.4GHz
BPF_1 Bandwidth	800MHz
BPF_2 Center frequency	20MHz
LPF Cut-off frequency	0.1MHz

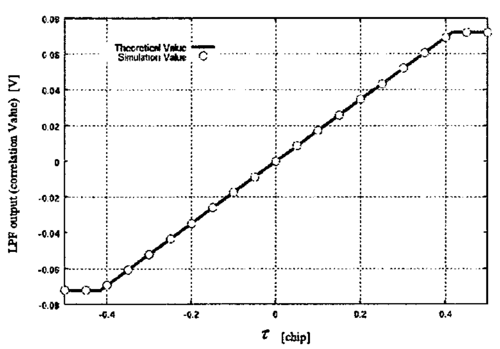


Fig. 5 Delay time estimation characteristic.

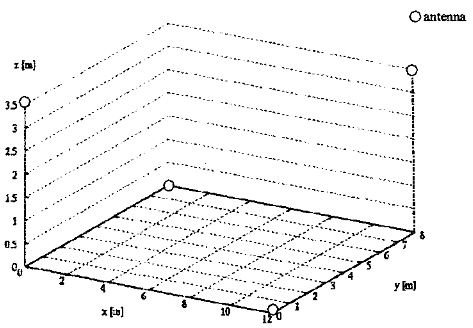


Fig.6 Arrangements of antennas.

D. The delay time difference estimation characteristic

Fig.5 shows a delay time difference estimation characteristic of the subsystem using parameters shown in Table I. It is possible to discriminate a timing difference of each input signal is within ±5/12 chip. Therefore, this paper is based on the premise that a relation between antennas and transmitter's position arrangement fills each condition that a difference of a timing of each spreading code is within ±5/12 chip. Moreover, the difference of the timing of the spreading code within ±5/12 makes positioning possible, even if the position of the transmitter is out of the area that four antennas located.

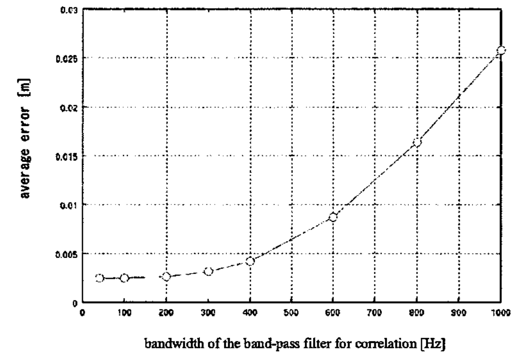


Fig.7 Bandwidth of the band-pass filter for correlation vs. error from the theoretical value.

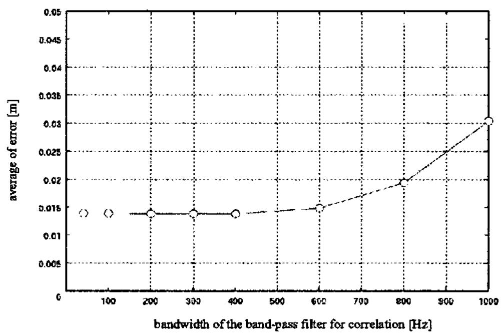


Fig.8 Bandwidth of the band-pass filter for correlation vs. average error of all.

IV. SIMULATION

A. Conditions of simulation

Experimental positioning range is the 12m×8m×3.5m space. Antenna arrangement is illustrated in Fig.6. The coordinate (*x*, *y*, *z*) of the position of the transmitter is (1-11m, 1-7m, 1m) at 1m intervals. It is assumed that there are not multi-path and fading.

B. The bandwidth of band-pass filter for correlation

Fig.7 illustrates the relation between the bandwidth of the band-pass filters for correlation and the error from the theoretical value.

Fig.8 shows the bandwidth of the band-pass filters for correlation vs. the average error of all. Fig.7 and Fig.8 show that less than 300 kHz bandwidth of the band-pass filters for correlation need. Considerations of convergence time and the error are needed for decision of the bandwidth, because the narrow bandwidth makes convergence time long.

C. Convergence time for position estimation

Fig.9 shows the relation between the low-pass filter output and convergence time. For example, the position of the transmitter is (3, 3, 1). As shown in Fig.9, using the

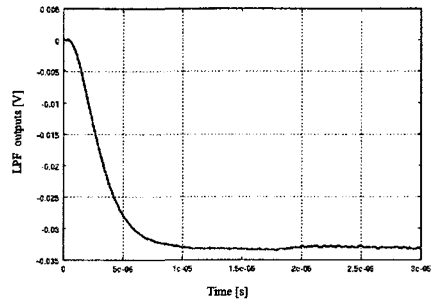


Fig.9 Relation between convergence time and low-pass filter outputs.

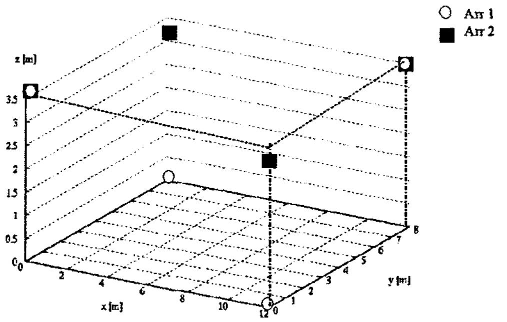


Fig.10 Two kinds of antenna arrangements

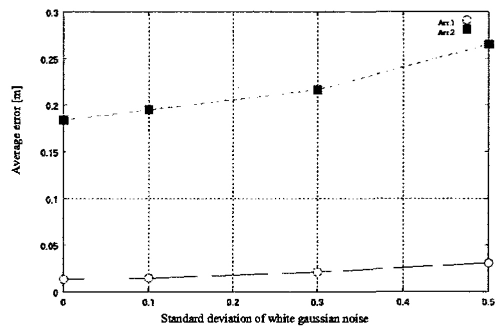


Fig.11 Relation between white gaussian noise and errors

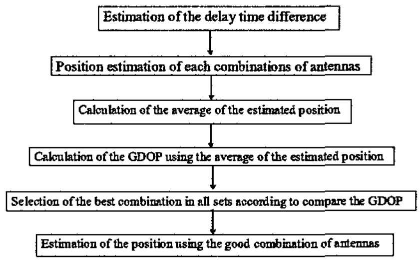


Fig.12 Flow diagram of this scheme.

parameters determined above, transition state almost ended at 10μs. In this simulation, the average value taken for a certain period from the point that we considered transition state almost ended is considered as the output of the low-pass filters.

D. Results of the simulation with white Gaussian noise

As shown in Fig.10, two kinds of antenna arrangements are shown. Arr. 1 has a good GDOP [17]. On the contrary, arr. 2 has a bad GDOP. Results are shown in Fig.11.

V. AN INPROVED SCHEME OF POSITION ESTIMATION USING MORE THAN FIVE ANTENNAS

A. The flow diagram of the improved scheme of position estimation

At least four antennas are needed for positioning. As an improved scheme of position estimation, we propose the scheme that the combination that has a good GDOP for four antennas and the transmitter is selected in all sets of four antennas from over five antennas. Fig.12 shows the flow diagram of the improved scheme of position estimation using more than five antennas. In this scheme, after calculating the estimated positions using all combination of four antennas, and calculates the average. GDOP in each combination of antennas is calculated using a tentative estimated position above mentioned. The final position estimation is performed by using the combination of antennas that brings the best GDOP.

TABLE II
AN EXAMPLE OF THE RESULT

Combination	Tentative GDOP	Error [m]
0	6.65	0.011
1	2.72	0.007
2	5.76	0.009
3	3.34	0.009
4	33.6	0.151

B. An example of the result

An example of the result is shown. Positions of the antenna are set at antenna0 (0.0, 0.0, 3.5), antenna1 (12.0, 0.0, 0.0), antenna2 (0.0, 8.0, 0.0), antenna3 (6.0, 4.0, 1.75), and antenna4 (12.0, 8.0, 3.5), the combination of an antenna is as follows: combination 0:antenna 0-1-2-3, combination 1:antenna 0-1-2-4, combination 2: antenna 0-1-3-4, combination 3: antenna 0-2-3-4, combination 4: antenna 1-2-3-4. An example of a relation between errors of each estimated position and the tentative GDOP is shown in Table II, Table III, and Table IV.

TABLE III

AN EXAMPLE OF THE RESULT

Combination	Tentative GDOP	Error [m]
0	6.91	0.074
1	2.61	0.009
2	4.28	0.040
3	6.17	0.055
4	3.09	0.023

TABLE IV

AN EXAMPLE OF THE RESULT

Combination	Tentative GDOP	Error [m]
0	6.37	0.010
1	2.57	0.005
2	14.9	0.010
3	5.55	0.009
4	2.70	0.007

VI. CONCLUSIONS

A study on parameters of the Inverse GPS scheme (IGPS) based positioning system for hardware experiment using a carrier-level simulator has been done. Less than 300 kHz bandwidth of the band-pass filters for correlation need. Using the determined parameters and 300 kHz bandwidth of the band-pass filters for correlation, transition state has almost ended at 10μs. The improved scheme of position estimation using more than five antennas has been proposed. Future works are hardware experiments using the determined parameters.

ACKNOWLEDGMENT

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