Processing of GPS Data with Difference HDOP in Guide Robot for the Visually Impaired

Min-Soo Goh Dong-Fan Shen,and Seung-Hong Hong

Dept. of Electronic Eng. Inha University, Korea

Summary
The main object of global localization of the guide robot is reduce the position error. The common solutions of reducing position error is using DGPS or integrate GPS and INS. Whereas, it's hard to use in the guide robot , because the much variety of GPS error in difference environments can not be faded by a single filter. Even if the Extended Kalman Filter, robust in error, have to make a threshold of DOP value and processing the GPS data which DOP is small than the threshold. In fact, the environment of guide robot have few GPS data which satisfy the threshold of DOP, even the data satisfy the threshold of DOP can also have unreasonable error. In this paper, we present a method using the difference of DOP(Dillusion Of Precision) to detection the change of error model and processing the GPS data. The method is improved the efficiency of GPS data in pedestrian navigation.

Key words:
HDOP, GPS, Guide Robot, Localization

1. Introduction

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The self localization in guidance information system for the visually impaired is essential and using GPS is the common way. The interest in self-localization using GPS is accuracy improvement and it's emphasized even more in guidance system because the visually impaired has weak location error correction ability. GPS has default system error and ionspheric, atomispheric, time synchronization, orbital, multipath errors. As the fact, There are many studies on GPS error minimizing in real-time navigation system area.

Most common way to reduce GPS error in pedestrian guidance system is to match GPS data with pavement layer in electronic map and localize the user's position within the pavement. This method was widely adopted in location based system for normal peoples but appling it to the visually impaired there surges matching error problem with additional elements such as crossroad, pavements and braile block. RTA(Robotic Travel Aid) system combines relative localization method of INS(Inertial navigation system) with global localization method of GPS and corrects GPS local error location with INS's relative error location error. Most of studies applies GPS data to EKF only when GPS satellites are enough to secure DOP(Dilution of Precision) value under 2.0. In INS the cumulative error increases rapidly by slip and vibration effect as RTA system requires to be light-weight and small. That means the system requires to correct cumulative error and that hardens to apply it on the guidance system for the visually impaired.

I propose GPS data processing method with HDOP differential value to improve legacy GPS localization problem in metropolitan environment for walking to apply it to the visually impaired. The study defines usable GPS data series as HDOP invariant ones instead of HDOP high and low data. I have applied same position error for constant series of HDOP GPS data and used sub-sensors to update GPS position error when HDOP values changes. I have tested it by walking in HDOP variant zone in many paths and those experiments showed maximum error of 8m only using GPS data. And that means the proposed method can improve GPS accuracy and improve resolution of RTA system using EKF

The structure of this paper will describe GPS error and the definition of DOP and the need of novel evaluation method for metropolitan GPS error in chapter 2. And in chapter 3 there comes GPS data processing method proposal using differential HDOP. In chpater 4 will show experiment and result and for last in chapter 5, the conclusion and future experiment.

2. Definition of GPS error and DOP

Localization of GPS receiver can be calculated using equation (1) in the case of having 4 satellites.

$$P_A^{\varsigma} = ((\mu^{\varsigma} - \mu_A)^2 + (\nu^{\varsigma} - \nu_A)^2 + (\omega^{\varsigma} - \omega_A)^2))^{1/2} + c\delta_A \qquad (1)$$

$(\mu^{\varsigma}, \nu^{\varsigma}, \omega^{\varsigma})$ is GPS satellite position, (μ_A, ν_A, ω_A) is receiver A position, δ_A is receivers timer error and c is velocity of light. Equation (1), can be solved with 4 or more satellite position. I assumed P_A^{ς} to be a function with μ, ν, ω representing a Tailor's series and resulted in equation (2)

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$$p(\mu,\nu,\omega) = p(\mu_0,\nu_0,\omega_0) + (\mu-\mu_0)\frac{\partial p}{\partial u} + (\nu-\nu_0)\frac{\partial p}{\partial \nu} + (\omega-\omega_0)\frac{\partial p}{\partial \omega} \tag{2}$$

The Distance error Δp can be expressed with $\Delta\mu$ and $\Delta\nu$ which comes from the distance from real satellite and receiver $p(\mu,\nu,\omega)$ and calculated distance $p(\mu_0,\nu_0,\omega_0)$

$$\Delta p = \begin{pmatrix} \frac{\partial p}{\partial \mu} & \frac{\partial p}{\partial \nu} & \frac{\partial p}{\partial \omega} \end{pmatrix} \begin{pmatrix} \Delta\mu \\ \Delta\nu \\ \Delta\omega \end{pmatrix} \tag{3}$$

The equation (3) can be expressed in liner form $b = Ax + \nu$ when 4 satellites are received. Here b is row matrix of Δp and x is column matrix of $\Delta\mu, \Delta\nu, \Delta\omega$ and A is square matrix of P's partial differentiation. So the equation to calculate minimum square root for smallest distance error is as next expression.

$$\hat{x} = (A^T A)^{-1} A^T b \tag{4}$$

$(AA^T)^{-1}$ in Equation (4) means covariance matrix and can be expressed as in Equation (5)

$$Q = (A^T A)^{-1} = \begin{pmatrix} \sigma_u^2 & \sigma_{uv} & \sigma_{uw} & \sigma_{ut} \\ \sigma_{uv} & \sigma_v^2 & \sigma_{uw} & \sigma_{vt} \\ \sigma_{uw} & \sigma_{vw} & \sigma_w^2 & \sigma_{wt} \\ \sigma_{ut} & \sigma_{vt} & \sigma_{wt} & \sigma_t^2 \end{pmatrix} \tag{5}$$

The diagonal members of Equation (5) is error in each axis. Letting real measurement error to be 1m then axis μ,ν and ω has σ_u m, σ_v m, σ_w m of error for each. Relative error of receiver and satellite in equation (5) can be expressed as in figure 1. The shadowed part of figure 1. means error range and it is in reverse relation with θ

DOP(Dilution Of Precision) is a scaling parameter of geometric relation between GPS satellite and receiver. The other scaling parameters are HDOP, PDOP, TDOP, GDOP, etc. DOP data is on of packed GPS receiver module output data with localization information and defines GPS error boundaries and effectiveness of GPS localization data. Most commonly used parameter HDOP(Horizontal Dilution of precision) is defiened as Equation (6).

$$HDOP = \sqrt{\sigma_u^2 + \sigma_v^2} \tag{6}$$

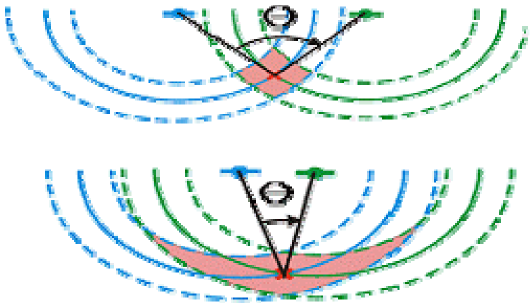

Fig. 1 Range error with different geometry of the receiver's location and the position of GPS satellites.

The Δp in Equation (3) has boundaries, as it is system eigen-error which comes form the difference of real distance and distance between satellite and receiver without consideration of multipath and atmospheric error, and DOP value is decided by the position of satellite and receiver. Generally, DOP value is under 5 and can be 2 when GPS angle of view is good enough to get 5 or more satellites, but the GPS localization cannot be trusted when the conditions are poor and has a big number of DOP value. [1]

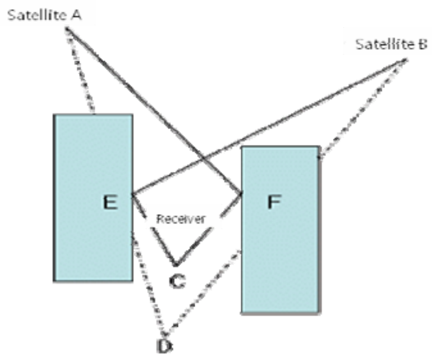

Fig. 2 Position error in multipath environment.

The evaluation of GPS data error by DOP can be applied when the view angle are good as airbone or navigation system but cannot when the view angle is poor. As the result, localization error can not be evaluated to be small even the DOP value is small. The receiver C in figure (2) cannot receive signals from satellite A and B, but it received the distance signal (AF+FC) from satellite A and (BE+EC) from satellite B by multipath and resulted in position D with small DOP value. The guidance robot for the visually impaired is limited to have simple GPS localization because it must act on metropolitan area and has small angle of view. A novel GPS error evaluation is required even using INS or DR sensor as it requires fusion with GPS data.

3. GPS data processing with difference of HDOP

3.1 Configuration of pedestrian guidance system for the visually impaired

The guidance system is configured of administration part based on PC and mobile part based on PDA as in figure 1

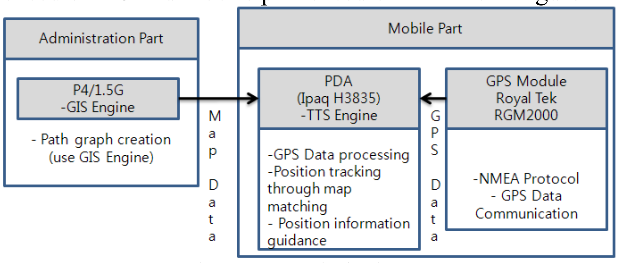

Fig. 3 System Block Diagram

3.1.1 Administration part of path planning system

Administration part has been built with GIS engine GDK (GEOMania Development Kit) 2.5 and 1000:1 map provided by National Geographic Information Institute and mobile part provides search functionality by path graph and matches it with GPS data. The electrical map provided by National Geographic Information Institute is for standard people and has no commodities for the visually impaired.

The roadway layer is enough for the traditional car navigation system but visually impaired need more information than that and must have more on several other layers. The figure 4 is showing pathway on electrical map with buildings and pavements.

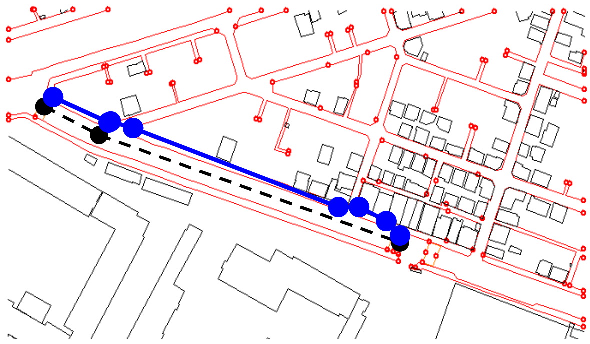

Fig. 4 walk pathway of the visually impaired

The single pathway expressed in figure 4 needs more detailed information for the visually impaired as alley, crossroad, etc. This system configured the path with node and way point with weighted value link.

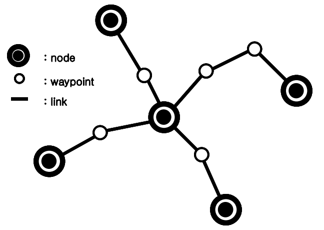

Fig. 5 non-directional weighted graph

Table 1: Weighted value of the link

Links	Weights
Braile block	0.1
footway	0.2
Lane	0.4
Pedestrian crossing	0.8
stair UP	0.9
stair down	1.0

The starting or ending point is defined as node and the path between nodes are defined as way point and between way point the direct line path is assumed. The link is used to classify the kind of path as pavement, crossroad, bridge, etc. Figure 5 shows used non-directional weighted graph and table 1 shows weighted value of the link.

3.1.2 PDA based mobile device

Mobile part is configured with TTS engine and RGM 2000 GPS receiver module in PDA. GPS data is received in NMEA(National Marine Electronics Association) method by RS232C and matched wisth electrical map data. The guidance data is configured with localization data and the result is announced by TTS voice message. The PDA based mobile device is configured as figure 6.

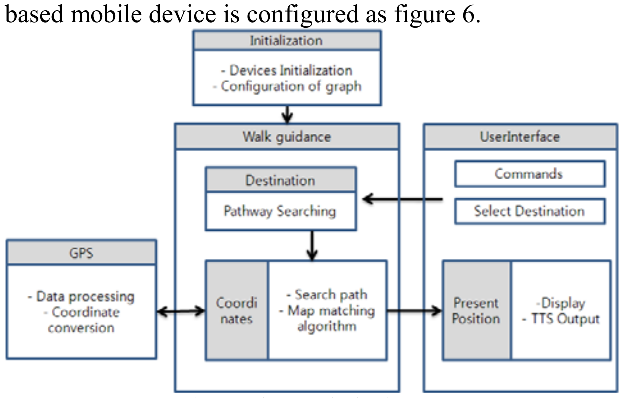

Fig. 6 Software Block Diagram

The RS232C port is initialized 4800bps, 1 stop bit, no parity as defined in NMEA protocol. The software in initialized by loading TTS engine and configures voice output option and loads graph path transmitted from adminstration part.

The goal can be set by using braile keypad in ARS type and also start and end command can be entered to. Map matching result is showed on PDA display and TTS voice guide is provided near way points.

GPS part consists of GPS processing part, with NMEA protocol and HDOP differential value, and coordination changing part for map matching. NMEA is electrical interface and data protocol for maritime communication and has many packets. In this study I have used only GPRMC(Recommended Minimum Specific GNSS Data) packet for GPS localization data and GPGSA(GNSS DOP and Active Satellite) packet for HDOP value with communicated satellite count.

Coordination changing is the process of coordinating paresed GPS received packed data with Republic of Korea's map measurement criteria. GPS latitude, longitude and elevation coordination (λ, ϕ, h) is changed into WGS84 coordination (X, Y, Z) and Molodensky-Badekas method in Equation (2) is applied to change it into Bessel coordination

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} dX \\ dY \\ dZ \end{pmatrix} + (1+\Delta S)\begin{pmatrix} 0 & -x & \phi \\ -x & 0 & \omega \\ \phi & \omega & 0 \end{pmatrix}\begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (2)$$

The variables dX, dY, dZ, ω, φ, κ, ΔS in Equation (2) need to be corrected by geometric positions and near Inha university they are 127.046, -478.916, -665.615, -2.156, -2.341, 1.714, -5.626 for each and can get under 20cm of error

Backtracking algorithm was used as optimal path planning algorithm to generate the path with input data. The weight of link was used to improve safety of the path.

Point-to-curve matching method was used to localization with GPS data and map data. Point-to-curve matching method projects received position to arch of most adjacent road and is easy to use and calculate for pedestrian path. Mininum distance between point c and line A can be aquired by Equation (3) and the result is orthogonal projection position from point c

$$d(c, A) = \sqrt{\frac{\left[(a_2 - b_2)c_1 + (b_1 - a_1)c_2 + (a_1 b_2 - b_1 a_2)\right]^2}{(a_2 - b_2)^2 + (b_1 - a_1)^2}} \quad (3)$$

Equation (4) is satisfied if the projected point is located out of line segment, else Equation (5)

$$\max\{d_1, d_2\} > d_3 \quad (4)$$

$$\max\{d_1, d_2\} < d_3 \quad (5)$$

The walking guide is provided by user interface when the projected localization satisfies equation (5) and the distance between node or way point is less than 10m.

3.2 GPS data processing by HDOP difference

Map matching algorithm from 3.1.2 may cause error when the distance between way point is not far greater than GPS localization error bound. Using GPS data directly can be problematic because of user localization vibration or faster moving beyond walking speed phenomena caused by small way points distance and environmental errors. This paper proposes processing method described in Figure 10 using low walking speed of the visually impaired resulting in relatively constant environmental building position. The proposed method evaluates environmental change by HDOP difference as descriped in chapter 2. This method cannot be applied to evaluate GPS error boundaries on metropolitan area but can be applied to jude the change of error boundaries. HDOP change means the geometrical change of distribution between GPS receiver and satellite and the change in the value of HDOP means change of satellite orbital when receiver is stationary. In General, as receiver's position change is slow as walking speed and GPS satellites change is slow too, as it moves above 20183km with a period of 12 hours ,then HDOP's change is very moderate. In reality, the HDOP's change is speedy and error prone by multipath or limited view angle in metropolitan walking environment.[7]

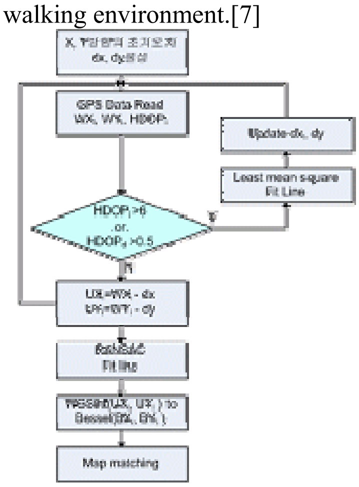

Fig. 7 Processing of GPS data with the difference HDOP.

The GPS error magnitude was evaluated by HDOP and absolute value of HDOP difference(HDOPd) by every second. In the experiment, GPS distribution error was under 5m when HDOPd is smaller than 0.5 and when it grous up to 0.6 then it resulted more than 10m of error. So I have assumed no environmental change when HDOPd is less than 0.5

New position was calculated when HDOPd goes above 0.5 and calculated position is updated to GPS position dx, dy. Previous N positions can be entered into equation (6) and results in equation (7). The moving vector was calculated using SVD with minimal square error C and D. Current position (x_i, y_i) was calculated with $i-1$'s and $i-2$ order GPS received data projected onto line CD localization information x'_{i-1}, x'_{i-2} as in equation (8), and localization error dx, dy is updated with the difference of calculated and GPS received data.

$$y = C + Dx \quad (6)$$

$$\begin{bmatrix} 1 & x_1 \\ 1 & x_2 \\ 1 & \vdots \\ 1 & x_N \end{bmatrix} \begin{bmatrix} C \\ D \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix} \quad (7)$$

$$x_i = x'_{i-1} + (x'_{i-1} - x'_{i-2})$$
$$y_i = C + Dx_i \quad (8)$$

GPS position data was corrected with previous positional error valuse when HDOPd is less than 0.5. The moving path was set to be linear and RANSAC(Random Sample Consensus) was used in HDOP constant path considering small standard deviation in HDOP constant section.

4. Experiments and Results

GPS data was measured in the distance of 6m from a 5 storied building in stationary statues to analyze error relationship between HDOP value end GPS data.

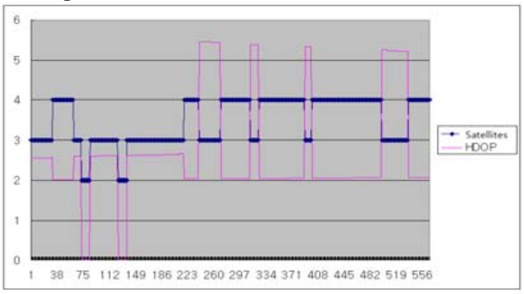

Fig. 8 HDOP and the number of received satellites.

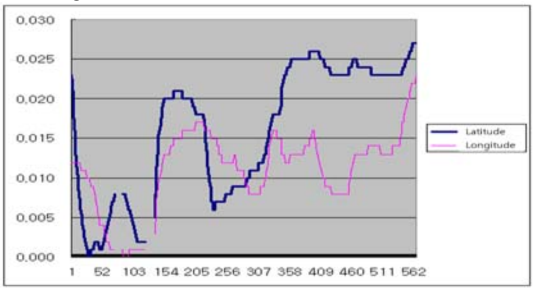

Fig. 9 Latitude and longitude.

The figure 9 is showing related latitude and longitude from figure 8. The latitude varies within 0.028' and longitude within 0.024' gives total approximation of 50m of variant range.

Table 2: The change of HDOP and error of position in immobility state.

No.	time (sec.)	HDOP	Latitude(37° 27')		Longitude(126° 39')	
			Error average	STD dev. (10^{-3})	Error average	STD dev. (10^{-3})
1	31	2.56	0.033'	6.79	0.378'	0.82
2	30	2.01	0.027'	0.94	0.373'	2.45
3	131	2.6	0.038'	7.40	0.376'	6.88
4	21	2.03	0.035'	3.40	0.383'	0.65
5	31	5.46	0.033'	0.80	0.379'	0.96
6	42	2.04	0.035'	1.06	0.377'	1.58
7	12	5.39	0.038'	0.95	0.377'	1.04
8	66	2.03	0.047'	3.30	0.381'	1.27
9	10	5.33	0.051'	0.316	0.382'	0.70
10	99	2.05	0.049'	0.89	0.378'	2.30
11	38	5.24	0.048'	0	0.381'	0.70
12	29	2.06	0.050'	1.42	0.386'	2.62

HDOP change occurred 12 times in table 2 during 9 minutes of GPS data measurement and most of standard variance are less than 4.0x10-3 and the change is within 5m. The first group shows big variance because it was generated during GPS module initialization status and the third had localization inconvenient section with only 2 GPS satellites.

The second and eighth group in table 2 has same HDOP value but differs in latitude 0.02' and longitude 0.01' that makes over 20m of error. This means evaluating GPS data accuracy with only HDOP is enough for standard people as CNS but not for guidance robot for the visually impaired as it requires error within meters.

The 5, 7, 9, 11th group received 3 GPS satellites and has HODP value above 5.0 but they also can have big location error because of no considering elevation data. Most of application discards data above HODP value 5.0, but those data can be utilized if localization error correction is avaliable because their standard variance is very small.

Comparing 6th and 8th groups, 8th has smaller HDOP value but has more localization error and standard variance. This result is from the effect of multipath and shows that evaluating absolute localization error with value of HDOP is not suitable in real metropolitan environment.

The figure 10 and 11 shows HDOP and GPS data measured while doing linear walking movement in grounds. The figure shows that HDOP value change isn't that frequent even real receiver position changes by walking speed and real GPS satellite position by orbit. This result means GPS data error isn't serious without multipath effect.

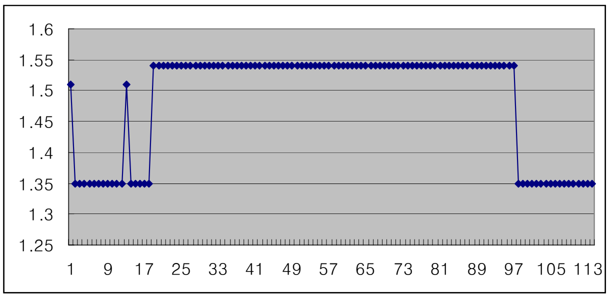

Fig. 10 HDOP of pedestrian straight navigation in schoolyard.

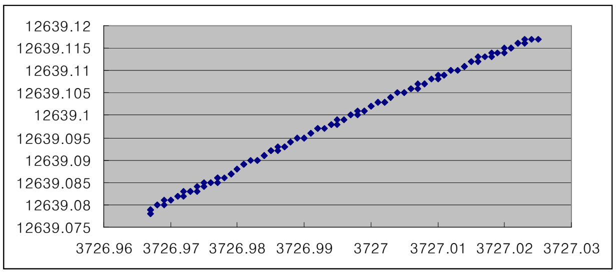

Fig. 11 GPS data of pedestrian straight navigation in schoolyard.

Summarizing experiment result, GPS data error boundaries cannot be evaluated by HDOP value change and constant HDOP means constant error boundaries of GPS data in real multipath environment. And error value has no relationship with HDOP value and that makes to reevaluate GPS locational error when HDOP changes.

GPS data was gathered and processed during walking to evaluate effectiveness of proposed algorithm. The Figure 12 shows used mobile device hardwares(Royaltech GPS receiver and COMPAQ H3800 PDA)

Fig. 12 Device for experiment

GPS data was received following pathway notified in line as in figure 16 and HDOP change is displayed in figure 17. It is notified that GPS data matches real pathway except in area A. In area A there was multipath error because of 15 storied building. HDOP value change for area A is shown in figure 17 and the result of proposed algorithm is shown in figure 18.

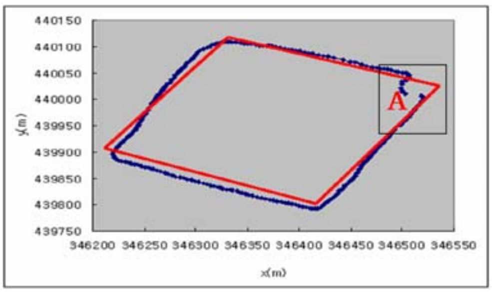

Fig. 13 Real navigation path and GPS data.

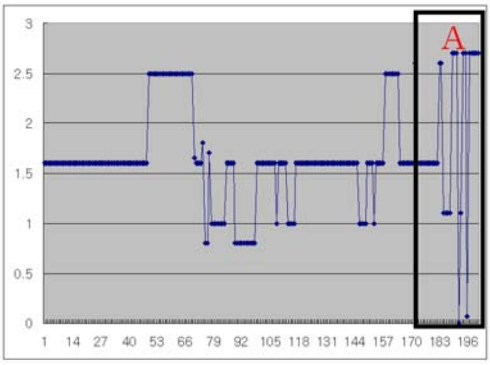

Fig. 14 Change of HDOP.

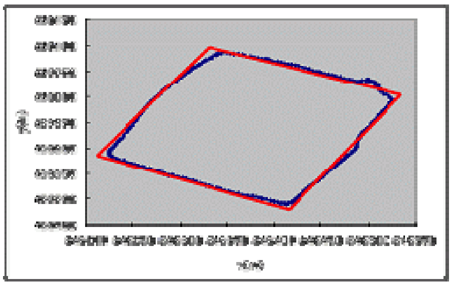

Fig. 15 Result using proposed method.

GPS data was received in pathway A-B-C-D-A in figure 19. AB, BC linear section has 4 storied building at 20m distance each side, CD section had no building within 50m and AD section has 5 storied building at 10m. The received GPS data has similar form with real pathway but also shows various value of error.

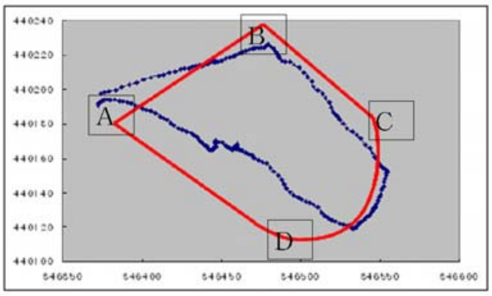

Fig. 16 Real navigation path and GPS data.

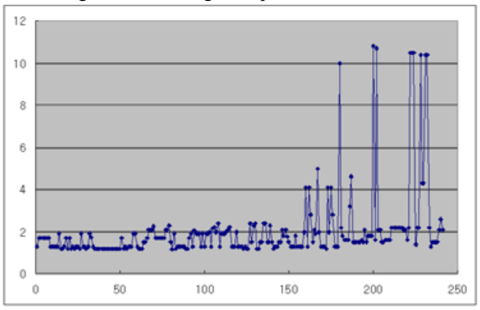

Fig. 17 Change of HDOP.

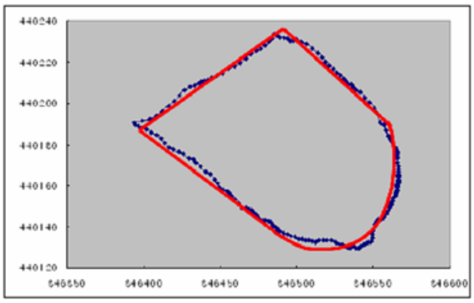

Fig. 18 Result using proposal method.

The proposed algorithm matches more closely to real pathway than legacy one in figure 21, but in CD section showed a big locational error because the path was assumed to be linear with RANSAC algorithm when HDOP changes. This kind of error cannot be corrected only with GPS and needs sub-sensors or robot. In this paper, the movement of the visually impaired was assumed to be linear to improve GPS guidance accuracy.

GPS data received walking around 5 storied building and the real path is showed in figure 13 and its relative HDOP change is in figure 14. HDOP change is relatively small in section 1-2 but big in 2-3 because there is small road of 10m wide. The proposed algorithm resulted maximum locational error because of HDOP changing zone in 2-3 section and its cumulative error. So, It's not suitable to guide the visually impaired only with GPS in small road in long term.

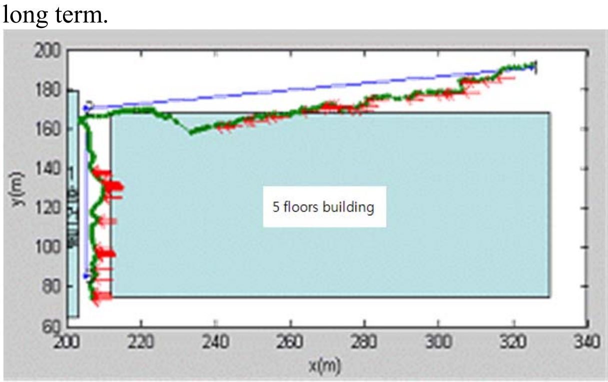

Fig. 19 Real navigation path and GPS data.

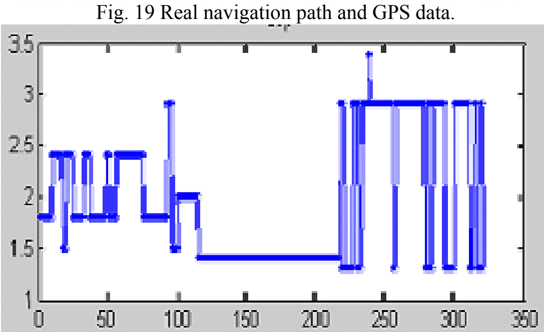

Fig. 20 Change of HDOP.

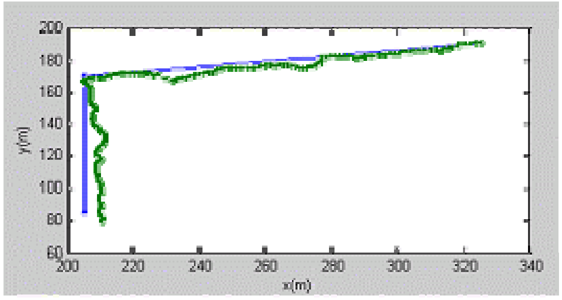

Fig. 21 Result using proposal method.

Table 3:position error in the given point.

Points		Real position	GPS	Measured position	erroro(m)
2	x(m)	205.1	204.0	205.3	0.2
	y(m)	170.1	163.3	168.2	1.9
3	x(m)	205.4	206.8	211.1	5.3
	y(m)	85.0	73.8	80.2	5.2

Figure 15 is result of proposed algorithm and is more accureate than legacy one. HDOP change threshold was set to be 0.5 and apporximation was taken at HDOP changing time by summing previous position and movement. Initial localization error was calculated by seeting specific point on electrical map and comparing it with received GPS data. Table 3 shows locational error at corner point 2 and final point 3. The table also dictates that in relatively constant HDOP zone at section 1-2 the calculated path has very proximity with real path and 2m of error at point 2. At section 2-3 there was frequent change in HDOP value and error was maximized at point 3 but still less than 5m. More accuracy can be expected in real robot by estimating localization using INS or DR sensor at the change of HDOP. GPS data at experiment was classified by HDOP value and GPS data count usable for EKF locational estimation is presented in table 4

Table 4: Usable GPS Data

HDOP	1.0-1.5	1.5-2.0	2.0-2.5	2.5- 3.0	3.0>	total
GPS Data	39	18	74	135	54	320
Proposed algorithm	20	11	45	107	41	224
Normal EKF	39	18	0	0	0	57

Normal EKF algorithm uses 57 GPS data over 320 total data and novel algorithm uses 224 data with error boundaries within 8m.

5. Conclusion and Research

Small HDOP value zone is very limited in real metropolitan environment and multipath effect cannot be ignored even with small value of HDOP. Also experiment showed standard distribution even with large HDOP value. This paper proposed using HDOP differential value making group processing of same HDOP section and updating the localization error when HDOP varies. The result showed 8m of accuracy can be secured only with GPS data and greatly improved the usability of GPS.

Proposed method is based on **normal** walking speed and can be appled in HDOP constant section. In the case of fast moving speed such as CNS the HDOP value varies by receivers position and could not be applied. Long term localization with INS and DR in frequently changing HDOP value zone can cause big cumulative error. This kind of cumulative error cannot be corrected by using only GPS data but more precise map matching. This paper didn't consider real atmospheric and ionspheric delay. This can lead to big localization error but can be corrected by using DGPS.

References

[1] M. S. Grewal. L.R. Weill and A.P. Andrews, "Global Positioning Systems, Inertial Navigation,and integration,", John Wiley & Sons,Inc. Publication, pp. 103-130, 2001

[2] H. Degawa, "A new navigation system with multiple information souces," in Proceedings of the Vehicle Navigation and Information Systems Conference, pp. 359-363,1992.

[3] P. G. Matoos, "Integrated GPS and dead reckoning for low-cost vehicle Navigation and tracking," in Proceedings of the vehicle Navigation Systems Conference, pp. 569-574, 1994.

[4] R. Jirawimut, P. Ptasinski, V. Garaj and F. Cecelia, "A Method for Dead Reckning Parameter Correction in Pedestrian Navigation System", IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 52, NO. 1, pp. 209-215, February 2003.

[5] S. Panzieri, F. Pascucci and G. Ulivi, "An Outdoor Navigation System Using GPS and Inertial Platform," IEEE/ASME Transactions, Vol. 7, No.2, pp. 134-142, June 2002.

[6] R. Klukas, G. Lachapelle, C. Ma and G.I. Jee, "GPS Signal Fading Model for urban centers," IEE Proc-Microw, Antennas Propag., Vol. 150, No. 4, Auguest 2003

[7] Lieutenant Daniel K. Pickles, "The Effect of Global Positioning System (GPS) Satellite Geometry on the Coast Guard's," CGSIC Winter/Spring 2001.

Min-Soo Goh received the B.S. degree in Electronic Engineering from Inha University, Incheon, Korea, in 1999. And the M.S. degree in Electronic Engineering from School of Electronic Engineering from Inha University, Incheon, Korea in 2001. He has been received the Ph.D. course in Electronic Engineering at the School of Electronic Engineering from Inha University, Incheon, Korea from 2001 His main research interests are in the areas of robot vision, robot localization system.

Dong-Fan Shen received the B.S. degree in Computer Engineering fromYanBian University, JiLin, China, in 1998. and the M.S. degree in Electronic Engineering from School of Electronic Engineering from Inha University, Incheon, Korea in 2001. He has been received the Ph.D. course in Electronic Engineering at the School of Electronic Engineering from Inha University, Incheon, Korea. His main research interests are in the areas of robot vision, embedded system.

Seung-Hong Hong received the B.S. degree in Electrical Engineering from Inha University in 1963. He received the M.S.degree in Electrical Engineering from Inha University in 1966, and the Ph.D. degree at the School of Biomedical Engineering from Tokyo University, Japan in 1975, respectively. He was a director and chairman at the Institute of Electronic Engineer of Korea from 1981 to 1994. He was a director, vice chairman, and chairman at the IEEE Korea Section from 1983 to 1997. He has been with the Department of Electronics Engineering at Inha University. His main research interests are in the areas of bio-signal processing, rehabilitation engineering, medical image processing.