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A THREE DIMENSIONAL LOCATION SYSTEM FOR HIKER WALKING SPEEDS BASED ON CONTOUR LINES

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ABSTRACT. GPS is especially suitable for location systems in flat areas, but the availability of GPS is limited in highly urbanized and mountain areas, due to the nature of satellite communications. Dead reckoning is generally used to solve a location problem when a pedestrian is out of range of GPS coverage. To extend the apparent coverage of the GPS system for a hiker in mountain areas, we propose an integrated 3D location system that interpolates a 3D dead reckoning system based on information about contour lines. The speeds of hikers vary according to the inclination of the ground in sloped areas such as mountains. To reduce location measurement errors, we determine the angle of inclination based on the contour lines of the mountain, and use the speeds based on the inclination in the location system. The simulation results show that the proposed system is more accurate than the existing location system.

AMS Mathematics Subject Classification : 00A06, 03B70, 03F50
Key words and phrases : Location system, 3D, dead Reckoning, walking speed, contour lines, mountains, sloped area.

1. Introduction

Recently, extensive studies have been performed on personal navigation systems.[1 - 3] It is apparent that a GPS receiver is ideal for this purpose. GPS is well-known for its efficiency in flat areas, due to the nature of satellite communications. Unfortunately, the availability of GPS is limited in highly urbanized and mountain areas.[4, 5] Other techniques are used to interpolate when users are out of range of a GPS system. Such interpolation is performed by systems known as DR(Dead Reckoning) systems, which involve estimating the current location by tracking movements from the last known GPS position.[6 - 12]

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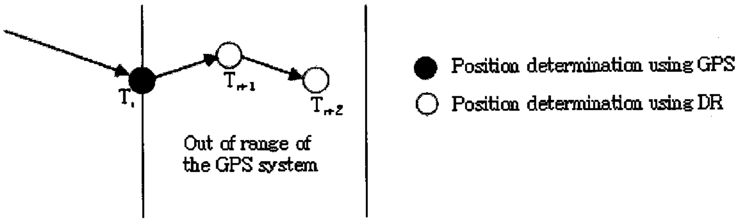

FIGURE 1. A conventional DR interpolation system

While hikers traverse a non-GPS mountain area, a DR system is used to extend the apparent coverage of the GPS system, as shown in Fig.1. The locations of pedestrians are generally calculated using a 2D DR. However, there is a difference between 2D and 3D position estimation, when hikers are in sloped areas such as mountains. Therefore, we propose an integrated 3D location system for hikers based on contour lines in mountain areas. A 3D DR system is used while hikers traverse a non-GPS mountain area. The speeds of hikers change according to the inclination of the ground in the mountain area.

To provide seamless location services and to reduce location errors in mountains, we initially obtain the angles of the inclination using the contour lines of the mountains. Then, we calculate the speeds of the hikers based on the inclination of the ground. Finally, we use the speeds in the 3D DR system. The remainder of this paper is organized as follows. Related work is provided in Section 2. The architecture of our integrated location system and integrated 3D location system using the speeds of the hikers based on the inclination of the ground is discussed in Section 3. Experimental results are provided in Section 4. Finally, the conclusion is provided in Section 5.

2. Related work

PDR(Pedestrian DR) systems are highly suited to indoor use, and in urban areas where GPS signals are weak or unavailable because the geometry is unsuitable. Jussi Collin analyzes major factors in PDR system position errors, viz. step-length error and heading error, and proposes a theoretical method of performance analysis of the accuracy in 2D PDR navigation systems. They use a pedestrian's average step-length, which can be calibrated with a specific RF foot-to-foot range measuring technique in an analytic model. The heading can be computed using gyroscopes or a levelled compass.

When a magnetic compass is coupled with a gyro, magnetic disturbances can potentially be detected. Therefore, if accurate navigation is required, the system requires other means of determining the heading, such as gyros.[1] Cliff Randell compares a number of sensors that can be used to achieve a robust and accurate PDR system, and performs case studies based on real-world applications.[2] Peter Sladen et al. present a positioning system that integrates both a GPS and a 2D

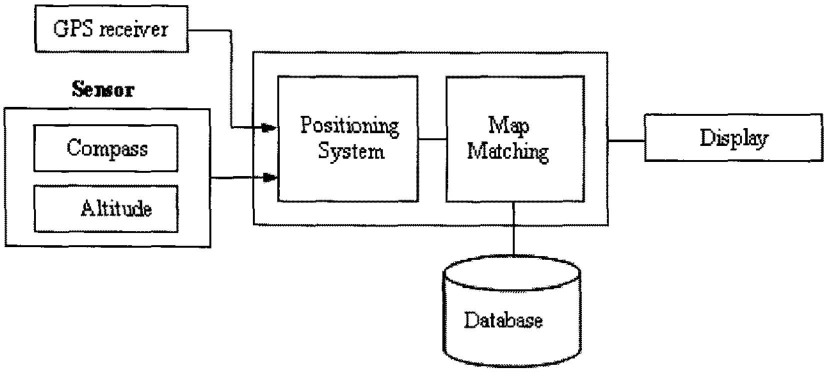

FIGURE 2. Contour lines and points at intervals of contour lines

dead reckoning method using sensors such as gyros, accelerometers, compasses, etc.[6]

3. An integrated 3D location system

In this section, we introduce an integrated 3D location system system for hikers, to provide seamless location services and reduce location errors in sloped areas such as mountains. A 3D DR system is used while a hiker traverses a non-GPS area. It uses the speeds of hikers based on the inclination of the ground. The architecture of the integrated 3D location system system is shown in Fig.2. The system, which consists of a GPS receiver, a direction sensor, and an altitude sensor, aims to provide pedestrians with data.

When the proposed location system is switched on, the system searches for a GPS signal. If GPS signals are of sufficient strength, then the system processes the signal and displays the location of the hiker. If GPS signals are not of sufficient strength, then the system records the hiker's current position as the starting position for tracking and initiates tracking. Once tracking has been initiated, any movements of the hiker away from the recorded starting position are tracked by the proposed DR system.

3.1. GPS positions

The GPS elevation has an error between 50m and 200m, due to SA(Selective Availability). The accuracy of the GPS elevation varies between 15m and 20m, due to random errors other than SA factors. To provide accurate location coordinates, elevation readings from an altimeter sensor are integrated with readings from the GPS-determined elevation coordinates for the locations of the pedestrian.[13] Map matching is necessary to reduce GPS random errors and cumulative errors resulting from DR. Roads can be described as a fixed series of points (R_0, R_1, R_2, ..., R_N) in our proposed system. The series of points are located

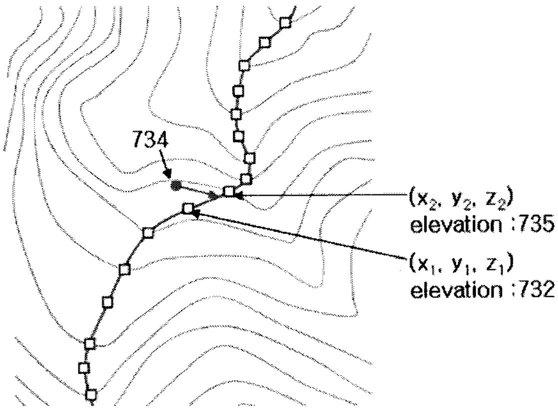

FIGURE 3. Architecture of the location system

along the road at intervals of contour lines, as shown in Fig. 3. In the case in which the distance between contour lines is large, due to a gentle slope, an additional point is set between the two points on the neighbor contour lines. The attributes of the points are coordinates (x, y, z) that identify the 3D location. Map matching is accomplished by comparing the point on the nearest road with the determined position.

In Fig. 3, the integrated elevation coordinate is associated with an elevation of 734m. When the distance between the measured location coordinate and the location associated with an elevation of 734m on the road is within a certain range, the location of the hiker is determined as the point on the road. The location associated with an elevation of 734m on the road is determined by Eq. (1).

$$\begin{aligned} x &= (x_2 - x_1)(z - z_1)/(z_2 - z_1) + x_1, \\ y &= (y_2 - y_1)(z - z_1)/(z_2 - z_1) + y_1. \end{aligned} \tag{1}$$

3.2. 3D DR system using the speeds of hikers based on inclination

The location system estimates the positions of a hiker based on his/her initial position and subsequent movements, using measurements from direction and altitude sensors while the hiker traverses the non-GPS area. The 3D DR system uses a direction sensor, and an altitude sensor to provide hikers with data. The position of the hiker is determined by Eq. (2).

$$\begin{aligned} z_{i+1} &= z_i + (-)h, \\ x_{i+1} &= x_i + d\cos\phi_i \sin\theta_i, \\ x_{i+1} &= x_i + d\sin\phi_i \cos\theta_i, \end{aligned} \tag{2}$$

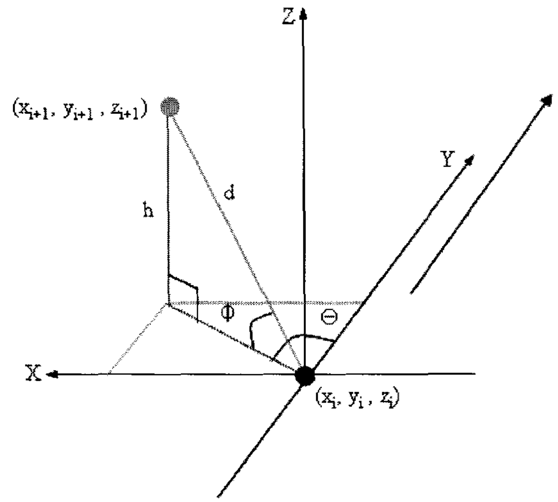

FIGURE 4. Angles of direction and inclination

Where is the angle obtained from the direction sensor, is the angle of the inclination, which is calculated as $=\sin^{-1}$(h/d), h is the difference between the (i+1)th and ith measurement of the altitude, and d is the distance the hiker has moved.

The positions of the hiker are calculated at n-second intervals, to reduce the computational overhead and ensure efficient battery use. Eq. (3) determines the positions of the hiker along a curved path, at n-second intervals, as shown in Fig. 5.

$$\begin{aligned} z_{i+1} &= z_i + \sum_{k=1}^{n} h_k, \\ x_{i+1} &= x_i + d\sum_{k=1}^{n} \cos\phi_{i,k} \sin\theta_{i,k}, \\ x_{i+1} &= x_i + d\sum_{k=1}^{n} \sin\phi_{i,k} \cos\theta_{i,k}. \end{aligned} \tag{3}$$

To reduce location errors in the mountains, we initially obtain the angles of the inclination using the contour lines of the mountains. Then, we calculate the speeds of hikers based on the inclination of the ground. Finally we apply these speeds to the 3D DR system. Contour lines can be used to obtain the inclination of the ground. In Fig. 6, D_i is the distance between two points on contour lines, which changes according to the angle of the inclination. The angle

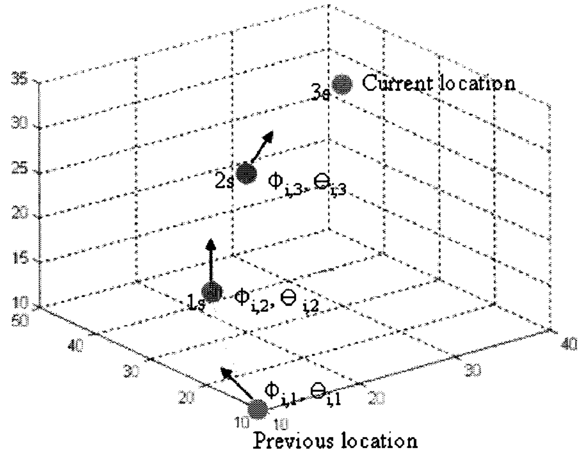

FIGURE 5. Angles of direction and altitude based on movements

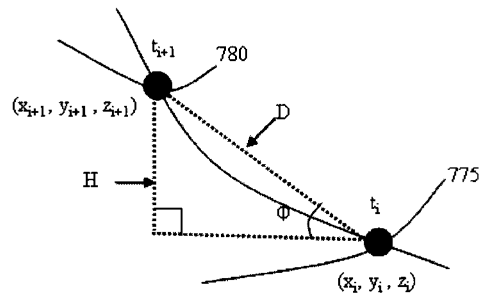

FIGURE 6. Distances based on angles of inclination

of the inclination is calculated as $=\sin^{-1}(H/D_i)$, where H is a constant of an interval of a contour line.

T_i is the elapsed time required for a hiker to traverse the distance(D_i) between two points on contour lines, and is calculated as the difference between t_{i+1} and t_i in Eq. (4). And, the hiker speed is expressed by dividing D_i by T_i in Eq. (5).

$$T_i = t_{i+1} - t_i. \tag{4}$$

$$d_i = D_i/T_i. \tag{5}$$

Table 1 shows the speeds based on the angle of inclination. The interval of contour lines in the digital map is 5m, and the angle of the inclination is calculated as $=\sin^{-1}(5/D_i)$. The hiker speed is set to 1.6m/s according to fast

TABLE 1. Hiker speeds based on the angle of inclination

Angle of Inclination	Elapsed Time(T_i)	Hiker Speed(d_i)
0	1.6	1.6
5	1.5	1.1958
10	1.2	0.9603
15	1.0	0.8054
20	0.9	0.7315
25	0.8	0.6964
30	0.7	0.6666
35	0.7	0.6228
40	0.6	0.5984
45	0.6	0.5891

walking speeds in flat areas. The elapsed time(T_i) is measured at a 5 degree interval of the inclination, and the hiker speeds(d_i) are determined by Eq. (5).

The location based on the inclination of the ground is determined by,

$$\begin{aligned} z_{i+1} &= z_i + \sum_{k=1}^{n} h_k, \\ x_{i+1} &= x_i + d(h) \sum_{k=1}^{n} \cos\phi_{i,k} \sin\theta_{i,k}, \\ x_{i+1} &= x_i + d(h) \sum_{k=1}^{n} \sin\phi_{i,k} \cos\theta_{i,k}, \end{aligned} \tag{6}$$

where d(h) is the speed of the hiker based on the inclination of the ground.

4. Experiments and the results

We collected angles of inclination and calculated speeds based on the inclination of the ground at intervals of contour lines in a single digital map of a mountain, as shown in Fig. 7.

We calculated the positions in order to verify the accuracy of our proposed system. The results show that positions determined by speeds based on inclination are similar to those comprising the route of a hiker, and the method is more accurate than a method using the average speed. The position error of the 2D route calculated using the average speed is larger than that of the 3D route calculated using the average speed, as shown in Table 3. We calculated the positions in another digital map of a mountain, as shown in Fig. 9.

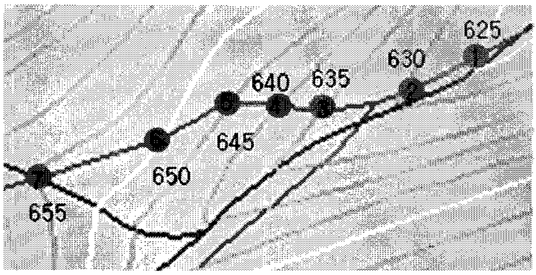

FIGURE 7. Map of a mountain

TABLE 2. Angle of inclination and hiker speeds based on inclination

Points at intervals of contour lines	Angle of inclination	Hiker speeds based on inclination
1-2	14.94	0.9603
2-3	8.35	1.1958
3-4	27.77	0.6964
4-5	10.55	0.9603
5-6	24.15	0.7315
6-7	7.75	1.1958

The results also show that the positions determined by speeds based on inclination are similar to those comprising the route of the hiker, as shown in Fig. 10 and Table 5.

5. Conclusions

We proposed an integrated 3D location system for hikers in sloped areas such as mountain areas. A 3D DR system was used while a hiker was traversing a non-GPS mountain area. To reduce errors, we used the speeds of the hikers based on the inclination of the ground in a 3D DR system. The results showed that positions determined by the speeds based on inclination were similar to those comprising the route of the hiker. The experimental results demonstrate the effectiveness of the proposed system.

REFERENCES

1. Jussi Collin, *Pedestrian DR-A Solution to Navigation in GPS Signal Degraded Areas*, Geometica Vol. 59, No. 2, pp. 175-182, 2005.

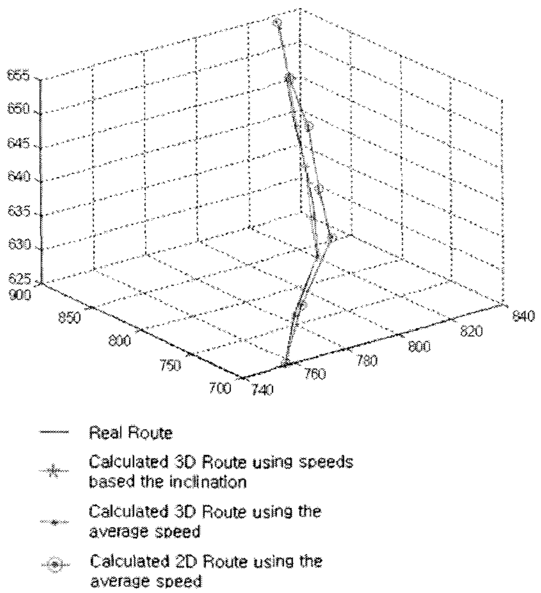

FIGURE 8. Calculated positions

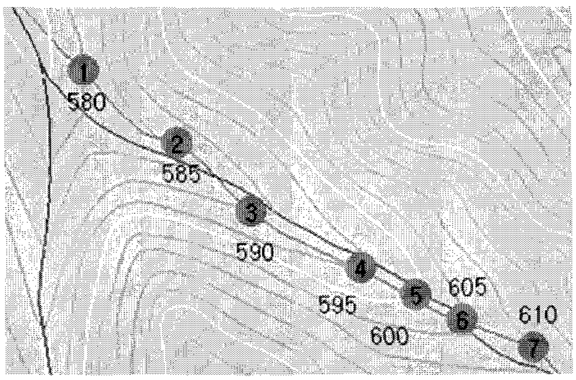

FIGURE 9. Map of a mountain

2. Cliff Randell, Chris Djiallis, Henk Muller, *Personal Position Measurement Using DR*, Proceedings of the Seventh IEEE International Symposium on Wearable Computer, pp. 166-173, 2003.
3. Szymon Ceranka, *Sensor Fusion Algorithm for Pedestrian Location, Methods and models in automation and robotics*, Vol 2, pp. 1343-1348, 2002.
4. Choi Hyea-ok, *LBS, Location-Based Service, Journal of TTA*, v.86, p.60, 2003.
5. Han S. C., Kwon J. H., Jekeli C, *Accurate absolute GPS positioning through satellite clock error estimation*, Journal of geodesy, v.75 no.1, pp.33-43, 2001.

TABLE 3. Calculated positions

	1	2	3	4	5	6	7
Real-world route							
x	757.48	767.26	786.68	789.38	794.69	795.94	801.81
y	702.22	718.54	745.45	755.52	777.84	791.93	815.86
z	625.00	630.00	635.00	640.00	645.00	650.00	655.00
Calculated 3D route using speeds based on inclination							
x	757.48	766.95	785.32	786.93	794.25	795.41	801.46
y	702.22	717.10	743.18	752.01	776.90	788.09	811.89
z	625.00	630.00	635.00	640.00	645.00	650.00	655.00
Calculated 3D route using average speed							
x	757.48	773.25	797.84	801.53	813.73	816.27	824.36
y	702.22	727.01	761.91	782.20	823.66	848.14	879.98
z	625.00	630.00	635.00	640.00	645.00	650.00	655.00
Calculated 2D route using average speed							
x	757.48	774.12	798.98	802.98	815.94	818.71	827.00
y	702.22	728.47	763.87	787.02	830.08	856.67	889.22
z	625.00	630.00	635.00	640.00	645.00	650.00	655.00

TABLE 4. Angle of inclination and hiker speeds based on inclination

Points at intervals of contour lines	Angle of inclination	Hiker speeds based on inclination
1-2	5.85	1.1958
2-3	7.06	1.1958
3-4	5.14	1.1958
4-5	12.34	0.9603
5-6	12.95	0.9603
6-7	10.67	0.9603

6. Peter Sladen, Winchester, Position Determination, *Position Determination*, United States Patent Application Publication, Pub. No. : US 2002/0105460 A1, Aug. 8, 2002.
7. Wei-Wen Kao, *Integration of GPS and Dead-Reckoning Navigation Systems*, Vehicle Navigation and Information Systems Conference, v.2, Paginations pp.635-643, 1991.
8. Washington Yotto Ochieng, J.W. Polak, R.B. Noland, J.-Y. Park, L. Zhao, D. Briggs, J. Gulliver, A. Crookell, R. Evans, M. Walker, W. Randolph, *Integration of GPS and DR for real-time vehicle performance and emissions monitoring*, GPS Solution 6:229-241, (2003).

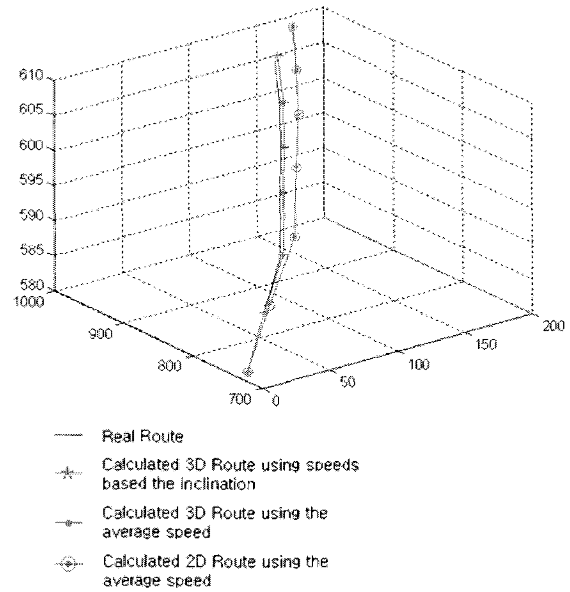

FIGURE 10. Calculated positions

TABLE 5. Calculated positions

	1	2	3	4	5	6	7
Real-world route							
x	9.65	40.96	67.69	93.90	105.01	113.92	123.08
y	739.62	777.13	807.39	856.48	876.47	896.31	921.23
z	625.00	630.00	635.00	640.00	645.00	650.00	655.00
Calculated 3D route using speeds based on inclination							
x	9.65	40.96	74.26	100.47	111.58	120.49	129.65
y	739.62	777.13	814.83	863.92	883.91	903.75	928.67
z	625.00	630.00	635.00	640.00	645.00	650.00	655.00
Calculated 3D route using average speed							
x	9.65	51.55	96.10	131.17	149.68	158.29	164.32
y	739.62	789.81	840.25	905.93	939.23	958.42	974.81
z	625.00	630.00	635.00	640.00	645.00	650.00	655.00
Calculated 2D route using average speed							
x	9.65	51.77	96.66	131.87	150.81	159.65	165.79
y	739.62	790.08	840.90	906.84	940.93	960.62	977.30
z	625.00	630.00	635.00	640.00	645.00	650.00	655.00

9. Yi Yang, Zhengqi Gu, and Lin Hu, *Research on the information fusion method of the Global Positioning System-DR vehicle integrated navigation system*, Proceeding of IMechE Vol.221, 2007.
10. Jin-ichi Meguro, Jun-ichi Takiguchi, Yoshiharu Amano, Takumi Hashizume, *3D Reconstruction Using Multibaseline Omniderectional Motion Stereo Based on GPS/Dead-reckoning Compound Navigation System*, The international Journal of Robotics Research, Vol 26, NoUnited States Patent, Patent number 5646857, Date of Patent Jul. 8, 1997. 6, pp. 625-636, June 2007.
11. Bevly D. M., Gebre-Egziabher D., Parkinson, B., *PARAMETRIC ERROR EQUATIONS FOR DEAD RECKONING NAVIGATORS USED IN GROUND VEHICLE GUIDANCE AND CONTROL*, journal of the Institute of Navigation, v.53 no.3, pp.135-148, 2006.
12. Carlson C. R., Gerdes J. C., Powell J. D., *ERROR SOURCES WHEN LAND VEHICLE DEAD RECKONING WITH DIFFERENTIAL WHEELSPEEDS*, journal of the Institute of Navigation, v.51 no.1, pp.13-28, 2004.
13. Paul McBurney, Paul Braisted, *Use of an altitude sensor to augment availability of GPS location fixes*, United States Patent, Patent number 5646857, Date of Patent Jul. 8, 1997.

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