Distance Computation and Trajectory Management Using GPS Navigation Positioning Solution

C. C. Chang[1], G. W. Lee[1*] and C. L. Chiang[2]

[1] *Department of Applied Geomatics, Ching Yun University*
[2] *Base Survey Battalion, Armamants Bureau*

ABSTRACT

It has become possible to apply a GPS-based system for a land vehicle to determine the traveled trajectory and distance with spatial information on location and time. The application of such information is also increasingly being requested by road authorities and company managers to monitor driving patterns, reduce traffic costs, or enhance operational performance. In order to provide a better estimation of the distance traveled by a land vehicle using stand-alone GPS-based sequential spatial coordinates, some operational algorithms, such as the data interval approach, vertical offset approach and curve fitting approach, were tested with field trial data sets. Based on the test results, an information system has been designed for vehicular mileage management. The system utilizes the spatial data recorded by the stand-alone GPS to work with some vehicular management functions, e.g. the mileage, toll, over-speed, jammed routes and car parking. This system has been verified to be working properly with the trials carried on for different road types. Moreover, the stand-alone GPS devices were also carried by the golf carts to provide the locations for an in-house designed golf fairway management system to assist the players in avoiding the jammed fairways.

Keywords：distance, trajectory, GPS navigation, vehicle management

運用 GPS 導航定位測算距離與軌跡管理

張嘉強[1]　黎驥文[1*]　江正龍[2]

[1]清雲科技大學應用空間資訊系
[2]軍備局生產製造中心測量隊

摘　要

利用 GPS 衛星導航系統所取得之位置及時間資訊，將可提供車輛決定其所行駛之軌跡及距離。這對道路監理或公司營運而言，可以有效監控駕駛之開車行為、減少運輸成本以及提升運輸效能，因此該類資訊之應用需求已日益殷切。為求提供陸上行車載具利用 GPS 導航定位之連續空間坐標成果，以進行行車距離之最佳估算方式，本文已針對相關之運算方法，如間隔筆數法、垂距法以及曲線密合法等，加以探討並進行資料測試。依據測試所得之最佳化計算模式與參數，本研究亦實際設計並開發出一項行車里程資訊管理系統，該系統可運用 GPS 定位紀錄，從事行車里程、過路收費、行車超速、壅塞路段以及路邊停車等管理功能，該系統亦已透過平面及高速道路完成測試驗證。此外，針對高爾夫球車所載錄之 GPS 定位資料，亦可提供高爾夫球道管理系統所需之空間位置，據以協助球友避開壅塞球道。

關鍵詞：距離，軌跡，GPS 導航，車輛管理

文稿收件日期 100.12.23;文稿修正後接受日期 101.3.28; *通訊作者
Manuscript received December 23, 2011; revised March 28, 2012; * Corresponding author

I. INTRODUCTION

Based on the benefits of high accuracy and real time positioning, the function of GPS is not only limited to the navigation and surveying domains but is also expanded to many applications in transportation, communication, security, and mobile positioning. It has been even following electronic commerce to invent a so-called Location-based Services (LBS) to create the infinite innovation value of using GPS-based geo-spatial information [1,2].

Specified on the telematics, GPS has been applied to a variety of car applications, e.g. navigation, tracking, monitoring, anti-collision and auto-driving etc. [3,4]. Recently, a low-cost GPS-based positioning architecture for vehicle-to-vehicle and vehicle-to-infrastructure systems using a scalable, flexible system with over-the-air messaging and an onboard design to enable a range of in-vehicle safety features has been practically investigated [5]. Furthermore, the development of the so-called Intelligent Transportation System (ITS) is also in great demand [6]. ITS is expected to provide a solution for daily encountered transportation problems, such as traffic accidents, traffic jams, energy consumption, and environmental pollution etc. The architecture of the ITS consists of a logic frame, which is to define the working function and interoperation of each component, and an entity frame, which is to manage the relationship between the driver, vehicle, and control center as well as to serve the data communication between each component. The wide application related to the ITS is summarized and shown in Figure 1.

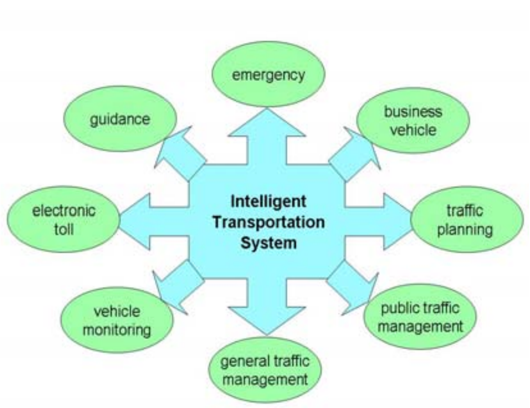

Fig. 1. Application domains of ITS

From a vehicular management point of view, ITS is fundamental and essential to acquire a time series of the locations from cars with any device, such as a GPS receiver, on-board. It is also important to realize the optimal operation of stand-alone GPS positioning solutions, particularly based on a low cost of L1 receiver, to provide the best estimates of the traveled distance and its derivative, the velocity [7]. This paper starts with the investigation of using GPS range-based coordinates and some operation models to determine the best working functions and parameters for the computation of traveled distance. Based on the distance computation algorithm decided, a mileage management system was developed to mainly work for business vehicle management, in particular the realization of the vehicle's trajectory, mileage, speed, toll, and parking. Moreover, a golf fairway management system was also designed to assist the control center monitoring the golf carts on site and dispatching the players to a suitable golf lane.

As the vehicular management information systems described in this paper are prototypes and the communication module has not been practically applied, the functions designed for efficient management have only been tested in an off-line mode so far. However, the spatial information provided by stand-alone GPS has been adequately utilized and verified with the information systems to meet the requirements of vehicular management.

II. DISTANCE COMPUTATION MODELS

To accurately compute the traveled distance from GPS stand-alone position solutions for a vehicle, a set of trial data was applied with two operation algorithms, namely the data interval approach and the vertical offset approach. As a fact that missing data is inevitable during travel periods when the GPS signal was obstructed, a refined type of 2D position solutions worked with a curve fitting approach to refill the data as a whole was also tested and applied to distance computation using the above-mentioned two operation algorithms. The basic definitions to those three approaches are described as follows.

(1) Data interval approach ： The computation of distance traveled by a vehicle can be simply treated as the sum of chord

lengths between fixed numbers of the sequential data points. It can be seen from Figure 2 that the total distance traveled can be obtained by $D=D_1+D_2+D_3$, where a data interval is set to be 2, i.e. using the head and end points and omitting the middle point for every three sequential data points with position solutions to compute the length.

It is easy to understand that the traveled distance error is highly correlated to the positioning errors of the two data points used to calculate the chord length. Therefore, it becomes important for distance accuracy if the data interval in a series of GPS data points can be properly adopted to skillfully balance two sources of error, i.e. the chord length computation error related to the road pattern and the GPS positioning error measured at the data points.

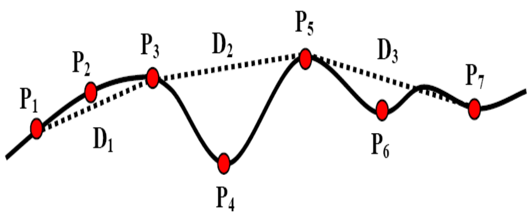

Fig. 2. Chord length computation using fixed data interval (where the data interval is set to be 2)

(2) Vertical offset approach: The operation of so-called vertical offset approach is depicted in Figure 3. In this approach, the first procedure is to compute the vertical offset, e.g. d_1, of a chord composed of first three sequential data points, e.g. P_1, P_2, and P_3. The vertical offset is then compared with a threshold value. If the vertical offset is bigger than the threshold, it means that the road curve formed by these three sequential points is accepted to be not a straight line and its chord length is taken into account as a part of distance summation. Oppositely, as the vertical offset d_2 shown in Figure 3, the third data point (P_5) is abandoned and moved forward to the next data point (P_6) to check the new vertical offset (d_3) with the threshold to compute the accepted chord length [8].

Instead of using fixed interval of data points to compute the chord length, the vertical offset approach has an advantage of neglecting the use of the data points located on a nearly straight line and mitigating the accumulated GPS positioning error from all the data points. However, it is also known that the distance computation accuracy is highly dependent on a proper threshold value adopted, which is not comprehensive to all the road patterns and not easy to be selected.

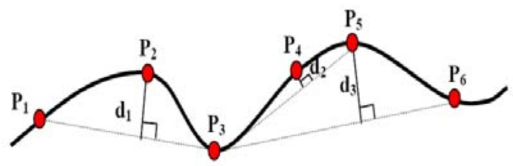

Fig. 3. Chord length computation based on vertical offset

(3) Curve fitting approach: The curve fitting approach is normally applied to express the mathematical relationship between the input and the output variables. In this study, a sequential of data points is inputted with the times and coordinates, in terms of the 2-dimensional coordinates. A mathematical function tested to be the best fitted is given to trace the road pattern with a numerical output (see Figure 4 as an example).

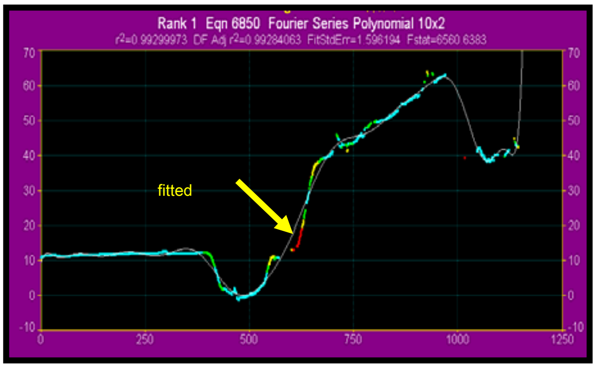

Fig. 4. Curve fitting to GPS data points

The main task of the fitting process is the determination of the type and coefficient belonging to the mathematical function. When the GPS raw data are collected by the vehicles and the coordinate solutions are computed, the curve fitting process can be carried out to provide a best fitting function for the users to establish a smoothing-like coordinate data set without any data missing. This refined type of data set can then be processed with either the data interval or the vertical offset approach to finally obtain the traveled distance for any application.

III. DISTANCE ANALYSIS

3.1 Field trial

A regular road of 9 km in length and 10 m in width, located in Tahsi Township, Taoyuan County, Taiwan, was selected by this field trial for its low traffic flow, easy control of the speed, and a variety of the road patterns, including curves and straight lines (see Figure 5).

Fig. 5. Test road for field trial on distance computation

During the field trial, two Leica SR-9500 GPS receivers were installed on-board and one receiver was operated as a base station to both ensure the data collection and apply for an accuracy assessment, based on a fixed baseline length (see Figure 6). The trial campaign was carried out with a one second data interval and a zero degree elevation cut-off angle used. The vehicle was driven along the same road at different speeds of 40 km/hr, 50 km/hr, 60 km/hr, and up to the maximum limit of 70 km/hr. These vehicle speeds were expected to better understand the distance errors related to the computation models.

In order to ensure the GPS data quality and the positioning accuracy for travelled distance computation, two assessment indicators, namely the success ratio and the baseline agreement, were adopted. The success ratio, i.e. the data epochs of successful positioning ($epoch_{success}$) as a percentage of the data epochs of total collection ($epoch_{obseration}$), is expressed as

$$success\ \ ratio = \frac{epoch_{success}}{epoch_{observation}} \times 100\% \qquad (1)$$

Fig. 6. GPS receivers set up for data collection and accuracy test

Moreover, the baseline agreement can be defined as the root mean square (rms) deviation of each baseline solution (L_i^{nav}) computed using two rovers' navigation coordinates from the known vector (L^{std}) determined using carrier phase-based static GPS positioning and assumed to be theoretically fixed for all the data epochs (n), as follows:

$$L^{std} - L_i^{nav} = \Delta L_i \qquad (2)$$

$$rms = \pm\sqrt{\frac{\sum_i^n \Delta L_i^2}{n}} \qquad (3)$$

The test results of success ratio and baseline agreement for GPS data collected during the field trial are given in Table 1. As can be seen, the success ratios show that the GPS navigation solutions based on L1 pseudo-range observables can be effectively provided to an average level of 95%. The accuracy test results also demonstrate a stable level of positioning performance, in which an average accuracy of 2 m and a slight improvement with the increment of driving speed can be found. The test results confirm that GPS navigation positioning offers a consistent, reliable, and high accuracy solution, which is suitable to the further computation of the travelled distance.

Table 1. GPS data quality and navigation accuracy assessment

Speed (km/hr)	Success ratio (%)	rms (m)
40	94.6	2.70
50	97.4	2.62
60	96.5	1.33
70	97.1	1.32
Average	95.4	1.99

Moreover, in order to evaluate the distance computation error, the precise distance along the test road was also carried out using a Leica TC605L EDM with a spec error of 2 mm+2 ppm. The road was not long and straight so that the distance was practically measured by setting many short straight sections. The distance was precisely estimated to be 9135.05 m±0.022 m.

3.2 Test results

As mentioned, two sets of coordinate solutions, i.e. a raw data set and a fitted data set, were provided for traveled distance computation using data interval approach and vertical offset approach. It was also realized from the field trial that the test road had a complicated pattern so that a commercial software, TableCurve 3D, was adopted to carry on the curve fitting process [9]. In practice, the positioning time was working with each one of the plan coordinate components to constitute the two fitting functions for easting and northing.

The traveled distances computed by two different approaches using two different data sets were found to be not performed consistently. The best operation parameters including the number of data interval and the value of vertical offset adopted to provide the minimum distance error under different driving speeds are listed in Table 2, where an irregular variation can be seen. Another test result for the maximum and average distance errors and ratios, based on an average speed, is listed in Table 3 for a better understanding of the computation errors.

As seen in Table 3, the distance errors computed using fitted data are generally larger than those of using coordinate solutions based on the GPS raw data. It can be inferred that a fitted function is only able to depict the road in a limited pattern. The data made from the fitted function is able to repair the missing data, but somehow introduces more distance computation errors if the road pattern is not simple.

It is also noticed from Table 2 that the best operation parameters for data interval and vertical offset are located between 5 and 9 seconds as well as 2.8 m and 7.3 m, respectively, associated with different vehicle speeds. Therefore, it would be a key point to propose the optimal parameters simply utilized by the two computation models for car speed with 40 to 70 km/hr in general. Figure 7 is the investigation of optimal value applied to the data interval approach, where the computation errors under all test speeds are averaged and plotted with different data intervals for analysis.

Table 2. Best operation parameters for different approaches

Speed (km/hr)	Raw data		Fitted data	
	Data interval (sec)	Vertical offset (m)	Data interval (sec)	Vertical offset (m)
40	8	2.8	1	0.0
50	9	5.2	18	0.9
60	8	7.3	1	0.0
70	5	5.9	26	1.3

Table 3. Distance computation errors with an average speed

Error	Raw data		Fitted data	
	Data interval	Vertical offset	Data interval	Vertical offset
Max. value (m)	-4.76	-6.87	-38.86	40.08
Max. ratio (%)	0.05	0.08	0.43	0.44
Avg. value (m)	3.13	3.49	13.92	32.45
Avg. ratio (%)	0.03	0.04	0.15	0.36

It can be seen in Figure 7 that the correlation coefficient (R) between the numbers of data interval and the distance computation errors is more than 0.9. This high correlation is evident that the data interval is the determinant factor in the distance computation error. As the error trend line crossing the x-axis is also found, it represents a phenomenon that the absolute distance error is increased when the interval number adopted is apart from the optimal data interval. Therefore, the selection of the optimal parameters for the distance computation models is realized to be the node of error trend line passing through the x-axis. The optimal parameters of 7 seconds and 5.2 m are then seen in Figure 7 and Figure 8 for data interval and vertical offset approach, respectively.

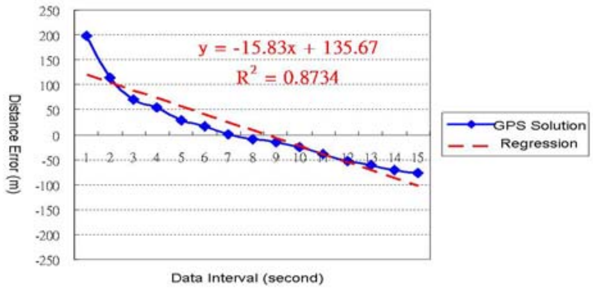

Fig. 7. Distance computation errors with different data intervals applied

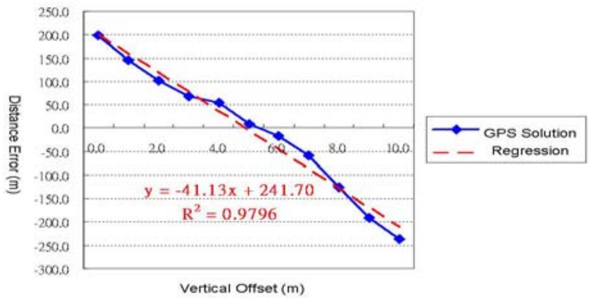

Fig. 8. Distance computation errors with different vertical offsets applied

According to the general cognition of using 1 second data interval to compute the traveled distance, it is of interest to further investigate its error performance, along with those obtained using the optimal parameters proposed (see Table 4). It can be seen in Table 4 that the optimal parameters proposed for the two approaches both give fewer errors than that of using 1 second data interval. The optimal operation of data interval approach using every 7 seconds GPS data provides the lowest error among all approaches tested, in which a ratio of distance computation error relative to the total distance traveled with 40-70 km/hr on the regular roadway is estimated to be 0.11%.

Table 4. Distance computation errors for optimal operation

Error	Data interval (1 sec)	Data interval (7 sec)	Vertical offset (5.2 m)
Max. value (m)	285.69	-18.74	79.26
Max. ratio (%)	3.13	0.21	0.87
Avg. value (m)	197.98	9.54	46.20
Avg. ratio (%)	2.17	0.11	0.51

IV. MILEAGE MANAGEMENT SYSTEM

A prototype of vehicular information system based on GPS positioning record and optimal distance computation approach was designed and developed for users to efficiently manage the business vehicles on duty. The functions provided by this system mainly relied on using two types of GPS-based spatial information, namely distance and velocity. Using distance-related data, the vehicle's traveled distance, trajectory, and toll can be provided and displayed by the system. Using velocity-related data, the system can calculate and show vehicle's real-time speed, over-speed driving, traffic jams, and parking fees.

4.1 System design and operation

The system consists of two main spatial information systems, i.e. GPS to provide coordinate solutions and GIS to contribute maps and graphics, along with the management function and database developed by the study. The data processing flow for this in-house developed management system is shown in Figure 9. The devices, software, data sets, and test procedures applied to the system design and operation are described as follows:

(1) GPS recorder: The Wintec WBT-100 bluetooth GPS receiver was carried by the vehicles to record their traveled data. A data interval of 7 seconds was set up as suggested.

(2) Data transformation: The GPS record was downloaded and transformed to the data format required by the information system.

(3) GIS platform: The Maction PaPaGO! SDK was utilized to work with its electronic maps as a simplified PC-based GIS platform for this system [10].

(4) System programming: The system function was programming with Microsoft Visual Basic 6.0, and embedded in PaPaGO! to

perform an integrated information system.

(5) Database: The vehicle management information, in terms of driving speed, provided by the system can be stored displayed with a detailed list using a simple database of Microsoft Office Access 2003.

(6) System test: A field trial data set was collected and tested by the system to verify function's effectiveness and reliability.

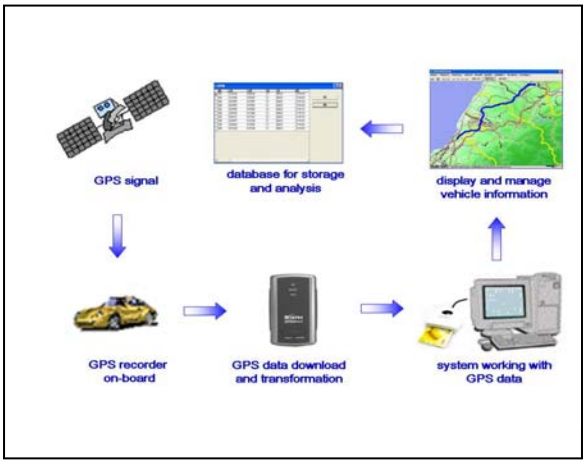

Fig. 9. Operation flow for vehicular management system

Some representative functions, such as trajectory display, mileage display, speed display, and detailed list, provided by the system for the vehicle management are displayed and briefly introduced as following.

(1) Trajectory display: The trajectory traveled by the vehicle with GPS recorder on-board can be plotted by the system with a sequential blue dot (see Figure 10). The system also provides a function to zoom in, zoom out, or shifting the map for a better appearance to the trajectory.

(2) Mileage display: As seen in Figure 11, the total traveled distance of the vehicle is shown on the upper left, and the toll paid for freeway driving is on the upper middle. In addition, when the user picks up any point along the trajectory, the system can show the information on the upper right for the traveled distance, toll, speed, and coordinates (longitude and latitude) at that specified epoch. Also seen in Figure 11, the lower part of the figure, from the left to the right, shows the mileage information for the total parking period, parking fees, over-speed and traffic jam mileage, respectively.

Fig. 10. System display for vehicle's trajectory

Fig. 11. System display for mileage information

(3) Speed display: Along the trajectory shown by the system, the user can also select a function to display the vehicle's over-speed driving with a red dot (see Figure 12) or any jammed section if needed. The accumulated mileage with over-speed driving for the journey can also be found on the lower right corner. These are helpful sources of information for the manager to know driver's habits or escape any customary traffic jams.

(4) Detailed list: The management required information, particularly the driving speed, can be also stored in a database and displayed with a detailed list for the location, speed, date, and time (see Figure 13). This database can be provided for any further management analysis.

Fig. 12. System display for over-speed driving

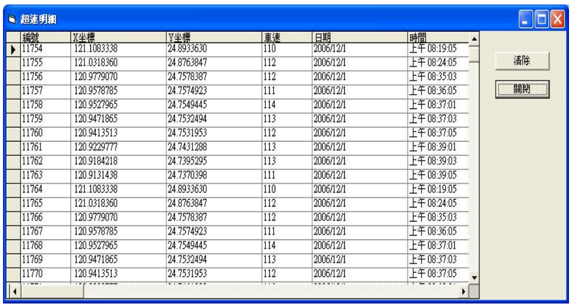

Fig. 13. System display for a detailed list of management information

4.2 Evaluation of distance function

Besides the above-displayed traveled information with the system functions developed, a numerical test, mainly focused on the mileage information of the traveled distance, was also carried out to ensure the effective and reliable operation of the system functions. Two field trial data sets recorded on a section of freeway and regular roadway were collected for a round trip to check up the repeatability of the distance computation values. The trajectories of the field trials are shown in Figure 14 and Figure 15 for two types of road, and test values based on the round trip distances are listed in Table 5.

It can be found in Table 5 that the round trip distance repeatability error ratio, based on the distance computation difference and the road distance, is between 0.3% and 0.85%, which is slightly higher than 0.11% pre-tested for the computation model. This level of error difference is acceptable because the field trial carried on for system operation was in a difficult environment with more traffic interference in the urban area. Also for this reason, driving on the freeway in a relatively stable road condition gives a better distance computation precision. It is believed that the information system designed and developed by this study is effective and available to meet the requirements of vehicle management.

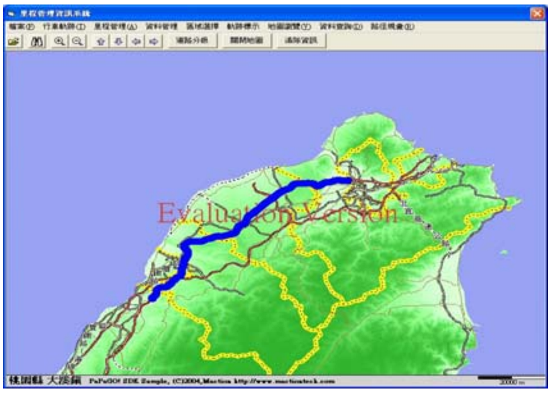

Fig. 14. Field test trajectory for a freeway section

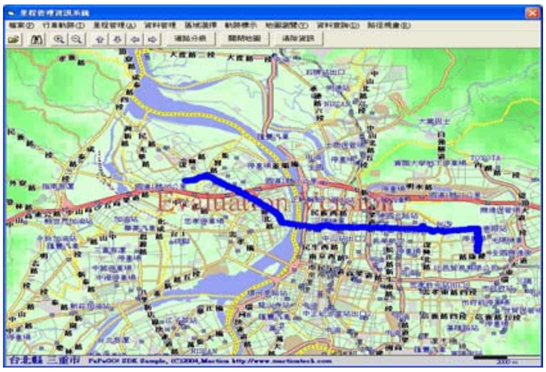

Fig. 15. Field test trajectory for a regular roadway section

Table 5. System test for round-trip distance

Road type	Distance value (km)	Round trip difference (km)	Repeatability error ratio
Freeway	86.878 87.135	0.257	0.30%
Regular	11.093 11.188	0.095	0.85%

V. GOLF FAIRWAY MANAGEMENT SYSTEM

It has always been crowded playing golf during weekends and public holidays in Taiwan. As no real-time information is provided to the players, they play golf only following the hole number along the fairway, and waste so much time waiting at the same golf hole. This is the motivation for this study to implement a golf fairway information system working with golf cart-based GPS receivers to provide their locations to the control center and carry on a better fairway arrangement for the players. Through the use of this information system, the control center is capable of realizing the golf carts' instantaneous locations, watching their spatial distribution, and dispatching them to any available fairway. As all the information can be also stored in a database for any possible management, this system is helpful to improve the fairway's operational efficiency and enhance the customer's playing interest.

5.1 System design

The system is composed of the GPS-based golf carts and an information system working with the simplified GIS, management functions, and database. The operation components of this system are shown in Figure 16. The devices and functions applied to the in-house developed management system include the Wintec WBT-100 bluetooth GPS receivers carried by the golf carts, high resolution satellite imagery played as the base map for the golf course, information system designed as a simplified GIS with the management functions, e.g. showing locations, fairway dispatching, and playing record storage.

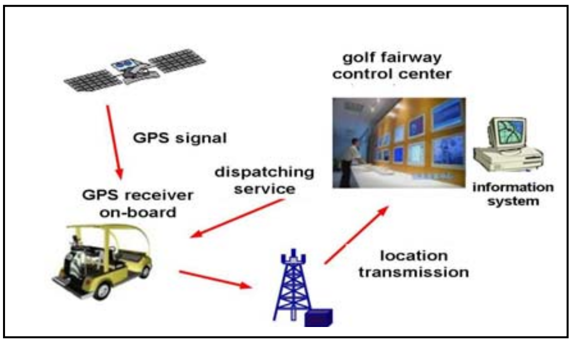

Fig. 16. Operation flow for golf fairway management system

Three main frames including image rectification, system interface, and database content were all designed and developed for the system. The detailed working items in the three main frames cover the image rectification processing for satellite image and GPS locations, the system interfaces operating for graphic display, fairway dispatch as well as player record maintenance, and the database contents designing for players' performance as well as fairway usage.

5.2 System operation

After program coding and function test, the information system was carried out for golf fairway management. The main functions working for this system are displayed and described as follows.

As can be seen in Figure 17, the system platform is exhibited for the main working functions, along with the satellite image-based map, the golf hole number, and an example of golf cart's trajectory on the fairway. On the top of the figure, is the function area for the system operation, where the information for crowded or unused fairways and the data of golf cart playing on a normal duty or dispatching for an alternative fairway can all be found with the text descriptions.

Fig. 17. System platform and golf cart's trajectory

To ensure the system's working functions, a data set collected on site with the designed scenarios were operated by the system to test its effectiveness in an off-line basis. In Figure 18, the system shows a case of four golf carts playing at the hole 1 altogether to start the game. However, the control center understands this situation through the information system, and makes an spatial arrangement to dispatch cart 4 jumping to the hole 2 to play there first (see Figure 19). This management decision can definitely save much waiting time for the players and increase the playing quality for the golf course. Moreover, the system can also show all the dispatching information and playing records with a detailed list and store them in a database (see Figure 20).

Fig. 18. System displaying four carts waiting at the hole 1

Fig. 19. System showing cart 4 dispatched to the hole 2

球道調度資料維護

紀錄日期	球車編號	球道警示訊息
2007/5/30 下午 08:21	4	第一洞壅塞,第4車請前往第二洞開球
2007/5/30 下午 08:21	3	第一洞壅塞,第3車請前往第二洞開球
2007/5/30 下午 08:22	2	第一洞壅塞,第2車請前往第二洞開球
2007/5/30 下午 08:22	4	第五洞壅塞,第4車請前往第六洞開球
2007/5/30 下午 08:22	3	第五洞壅塞,第3車請前往第六洞開球
2007/5/30 下午 08:22	2	第五洞壅塞,第2車請前往第六洞開球
2007/5/30 下午 08:23	4	第4車打球太慢,請加快速度，管控時間
2007/5/30 下午 08:23	2	第一洞壅塞,第2車請前往第二洞開球
2007/5/30 下午 08:23	3	第一洞壅塞,第3車請前往第二洞開球
2007/5/30 下午 08:24	4	第4車打球太慢,請加快速度，管控時間
2007/5/30 下午 08:24	3	第五洞壅塞,第3車請前往第六洞開球
2007/5/30 下午 08:24	4	第五洞壅塞,第4車請前往第六洞開球

Fig. 20. Detailed lists for fairway dispatch record

VI. CONCLUDING REMARKS

Based on the GPS-based point positioning solution, the selected operation algorithms relied on the data interval, vertical offset, and curve fitting for vehicle's traveled distance have been tested to investigate the effectiveness. Two information systems focused on using GPS-based locations and the management functions for vehicular mileage and golf fairways have also been developed. Some concluding remarks are summarized as follows:

(1) The data interval approach using every 7 seconds GPS raw data-based, rather than curve fitting data-based, coordinate solution to compute the chord length and accumulate the stepwise lengths into a traveled distance provided the best distance estimates with an error ratio of 0.11%.

(2) As the tests carried on by this study are only based on a lower speed of the vehicle and a qualitative-oriented, instead of a quantitative-oriented, investigation, it is suggested to widely collect more types of field data to set up the proper algorithm with the best operation parameters, in order to ensure the future application of the GPS-based odometer.

(3) With a repeatability of 0.85% for distance computation, an information system working for many management functions, such as vehicular trajectory, mileage, speed, toll, and parking etc., has been developed and expected to serve the manager to enhance the management efficiency.

(4) Based on the fairway dispatch requirement for the golf course, an information system working with the golf cart-based GPS receiver has also been designed and operated. The function of providing the golf cart locations, fairway dispatching arrangement, and player records are tested to be effective to increase the service quality of the golf course.

REFERENCES

[1] Leick, A., “GPS and L-commerce,” GPS Solutions, Vol. 2, No.4, pp.1-2, 2000.

[2] Dao, D., Rizos, C., and Wang, J., “Location-based services: technical and business issues,” GPS Solutions, Vol.6, No.3, pp.169-178, 2002.

[3] Styles, J., Costa, N., and Jenkins, B., “Location-based services power GPS/Galileo market growth. GPS World,” Vol.14, No.10, pp.1-2, 2003.

[4] Civilis, A., Jensen, C. S., and Pakalnis, S., “Techniques for efficient road-network-based tracking of moving objects,” IEEE Transactions on Knowledge and Data Engineering, Vol.17, No.5, pp.698-712, 2005.

[5] Basnayake, C., “Positioning for driver assistance: communication on the road,” GPS World, Vol.20, No.4, pp.28-36, 2009.

[6] Zhao, Y., Vehicle location and navigation systems: intelligent transportation systems. Artech Hourse, 1997.

[7] Wieser, A., "A GNSS odometer: how far have we come?" GPS World, Vol. 19, No.4, pp.50-55, 2008.
[8] Laurini, R. and Thompson, D., Fundamentals of spatial information systems. Academic Press Limited, 1992.
[9] SYSTAT Software, TableCurve 3D, v4 for Windows user's manual. SYSTAT Software Inc., 2002.
[10] Maction Technologies, PAPAGO! r12 satellite navigation system, PC version design for Windows user's manual. Maction Technologies Inc., 2007.