An Experimental Investigation into the Performance of GPS-based Vehicle Positioning in Very Dense Urban Areas

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Abstract

A mobile mapping system essentially consists of two major components, i.e. mapping sensors and positioning sensors. The former is used to acquire images for data acquisition and the latter is for accurate positioning of mapping sensors mounted on a vehicle so that images acquired by mapping sensors can be geo-referenced. However, the usefulness of such a system in very dense urban areas such as Hong Kong could be very limited because the (vehicle) positioning system is normally based on GPS and/or its integration with other sensors and loss of GPS signals is a serious problem in such areas. This paper reports some testing results on vehicle positioning based on GPS and its integration with other sensors in Hong Kong.

Hong Kong's dense skyscrapers and narrow streets create the most challenging environment for satellite based vehicle positioning systems (VPS). In order to evaluate how modern vehicle positioning technologies perform in such an environment, various field tests have been conducted, which include:

a) Satellite based sensors, including GPS and a combination of GPS and GLONASS;
b) Integrated satellite based systems aided with DR.

Various data processing algorithms have also been investigated based on the data obtained from the above tests. Preliminary results from the tests show that only less than 30% of the areas in Hong Kong can have the visibility to sufficient GPS satellites, and about 60% of the areas can be positioned if GPS and GLONASS are combined. It is also shown that when DGPS is aided with the DR system, the real-time vehicle positioning accuracy can reach an order of approximately 20 metres.

1 Introduction

Mobile mapping has been a popular topic in recent years. A number of systems has been developed by researchers from various institutions. Examples are the GPSVan™ by The Ohio State University (Bossler et al., 1991; Novak, 1995) and VISAT™ by the University of Calgary and GEOFIT (Schwartz et al., 1993; Li, 1997). Such a system essentially consists of two major components, i.e. mapping sensors and positioning sensors. The former is used to acquire images for data acquisition and the latter is for the accurate positioning of mapping sensors so that images acquired by mapping sensors can be geo-referenced. Mobile mapping technology has been widely used to acquire data along highways in Canada and USA (Bossler et al., 1991; Schwarz et al., 1993). However, the usefulness of such a system in very dense urban areas could be very limited because the (vehicle) positioning system is normally based on GPS and/or its integration with other sensors and loss of GPS signals is a serious problem in such areas. This paper reports some testing results on vehicle positioning based on GPS and its integration with other sensors.

Research on the integration of various sensors for vehicle positioning systems (VPS) could be found in many academic papers and technique reports (Lapucha, 1990; Vogel and Harrer, 1994;

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Abbott and Powell, 1995; Mar and Leu, 1996; Drane and Rizos, 1998; Krakiswsky et al., 1998). The difference among these systems usually depends on the criteria set up by the nature of the application and financial constraint. Generally the system developer's goal is to maximise the system's performance while minimising its total cost. Basically all the systems augment GPS by a specified dead-reckoning (DR) system to maintain the navigation accuracy during GPS outage. Investigation on the error budget of various sensors and different algorithms for integrated data processing using simulated and field data were presented (Abbott and Powell, 1995; Mar and Leu, 1996; He et al, 1997)

In Hong Kong, the main problem in relying on GPS is that only rarely is more than the minimum required GPS satellites available due to the serious blockage problem. A preliminary test carried out in Hong Kong has showed that this highly urbanised city encounters great problem of poor satellite visibility. The narrow streets in the old and more congested residential areas, among high buildings and in hilly regions are the possible reasons to the reception failure. In those times when this is achieved, the signal is affected by multipath effect and frequently cut off when passing through tunnels, bridges and crossovers, especially in dense commercial area (Chao et al, 1998).

Recently, more comprehensive tests on using GPS and combined GPS/GLONASS for vehicle positioning systems were carried out in different districts of Hong Kong to access the availability and accuracy of these satellite systems under this critical environment. The test results are described and discussed in details.

To investigate the possible solution of a VPS in Hong Kong, a prototype named as ANS2.0 consisting of GPS/DGPS/GPS+GLONASS and a DR system is developed. Test results of the system in Hong Kong are presented.

2 Situation of Vehicle Positioning Systems in Hong Kong

Hong Kong, with a total land area of just 1,100 km^2, among which 15% of the land is considered as built up area, has a population of around 6.3 million. The million passenger trips made daily on a multi-mode transport system, a system with narrow streets surrounded by dense residential and commercial skyscrapers, create the most challenging environment for vehicle positioning in Hong Kong. Though there are already many working VPS employed in Japan, Europe and North America, at this moment commercial system providers have not yet successfully implemented the technology in Hong Kong.

The importance of a localised VPS, as part of the infrastructure of Intelligent Transport Systems (ITS), has been recognised in Hong Kong. Recently, VPS has been proposed in many projects by government agencies as well as private sectors. For example, VPS is one of the two techniques currently under study by Transport Department of HK SAR government, for its plan in Electronic Road Pricing (ERP). The Fire Service Department of HK SAR government also initiates a study on the use of VPS for its "Third Generation Mobilizing System". Some local bus companies are also investigating the use of VPS for bus management and passenger information display system.

2.1 GPS visibility in Hong Kong

In order to have a clear picture of the local environmental restrictions, a feasibility study on the use of sole GPS for positioning has been done in Hong Kong. Test areas include a selection of several different regions such as new town (Sha Tin; Junk Bay), urban area (Central; Wan Chi) and old developed urban area (Mong Kok; Kwun Tong). The classification of the areas is based on the population density provided by the Hong Kong SAR government information center[1].

A test vehicle equipped with GPS receivers was used to conduct the field tests on a specially designed route, covering all the above three regions. Figure 1 shows the test result, which reveals that less than 30% of the test areas are able to receive 3 or more satellites. Among the six districts tested, only Sha Tin and Junk Bay, the new towns with relatively low population density, have

[1] http://www.gov.info.hk.html

better GPS satellite visibility. The rest of the tested areas all experience poor satellite signal reception especially in Wan Chi and Mong Kok, where most of the famous skyscrapers and the old 'downtown' were located respectively.

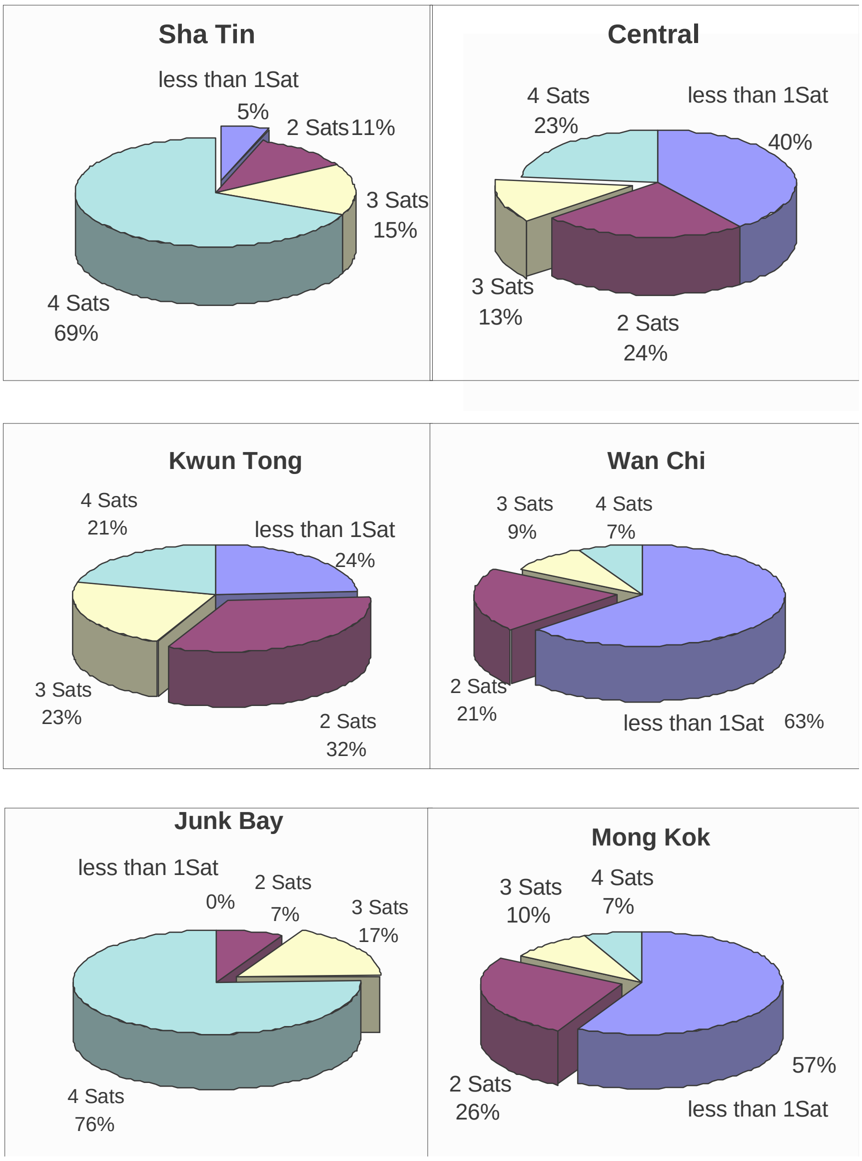

Figure1 Satellite visibility in different districts of HK

2.2 GPS+GLONASS visibility in Hong Kong

The availability of GPS+GLONASS system provides potential improvement in satellite visibility in HK. Similar tests as the GPS visibility test were also conducted in the same regions to evaluate the satellite signal reception of GPS/GLONASS. The result in Table 1 shows the number of satellite observed using combined GPS+GLONASS system. Compared with the averaged number of GPS satellite received, the improvement of the satellite visibility of the combined GPS+GLONASS systems in dense urban area is clear.

3 Vehicle Positioning Systems in Hong Kong: Solely satellite-based

In order to evaluate how modern vehicle positioning technologies perform in such an urbanised environment, various field tests have been conducted, which include:

a) Satellite based sensors, including GPS and a combination of GPS and GLONASS;
b) Satellite based systems integrated with DR.

Test areas in Hong Kong include new town (Sha Tin), urban area (Central; Wan Chi) and old developed urban area (Mong Kok). In , a test route consisting of main roads, narrow streets and small lanes was selected.

Table 1 Satellite Visibility of GPS+GLONASS system

Districts	Average No. of satellites observed
Sha Tin	10
Tsim Sha Tsui	6
Central	3
Wan Chi	3

This section reports the results of tests on solely satellite-based systems, i.e. satellite based sensors including GPS and a combined GPS and GLONASS sensor system. The next section will report the results of test on satellite based systems integrated with DR.

An Ashtech G8 GPS engine and an Ashtech GG24 GPS+GLONASS receiver are used to conduct the tests. Data was collected at one-second interval and real time displayed on the digital map using a PST mobile PC on board of the test vehicle.

3.1 Sha Tin Test

Figure 2 shows part of the vehicle positioning result using satellite based sensors, namely (i) GPS and (ii) GPS+GLONASS in Sha Tin, a new town with a relatively open sky in Hong Kong. Some control points were set up on the roads to compare with the position obtained from the vehicle positioning system. The positional errors obtained using GPS and combined GPS/GLONASS range around 40-80m and 10-60m respectively. Since the test area has an open sky, the difference between GPS and combined GPS/GLONASS in terms of accuracy and availability is not significant.

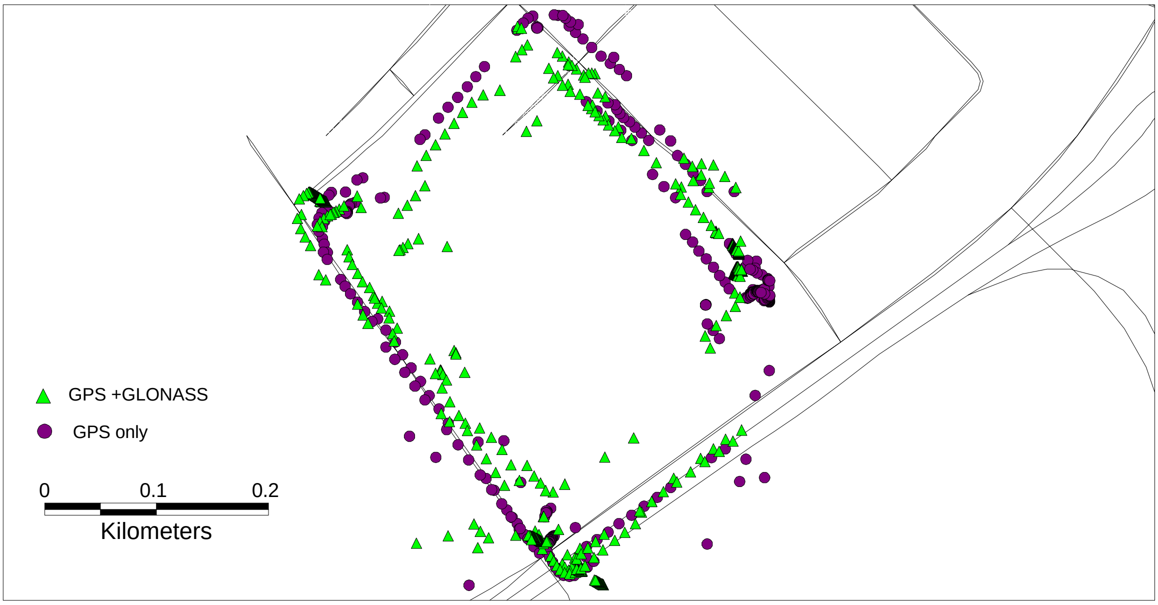

Figure 2. vehicle positioning results using satellite based sensors in Sha Tin (new town)

3.2 Mong Kok Test

A similar test was carried out in Mong Kok, the old developed area in Hong Kong. The result is shown in Figure 3. In Mong Kok, like other old area in Hong Kong, the roads are narrow and surrounded by dense residential and commercial buildings. It can be seen from Figure 3 that the availability and accuracy of combined GPS/GLONASS system is better than GPS only system.

The number of available positions obtained from the combined GPS/GLONASS is about two times more than those obtained from GPS only. It can also be seen from the figure that the positions using GPS scatters wider than those using combined GPS/GLONASS. The overall accuracy achieved in these tests using sole GPS and combined GPS/GLONASS is also around 40-80 m and 10-60 m respectively. The overall performance of combined GPS/GLONASS system is proven to be better than GPS only system.

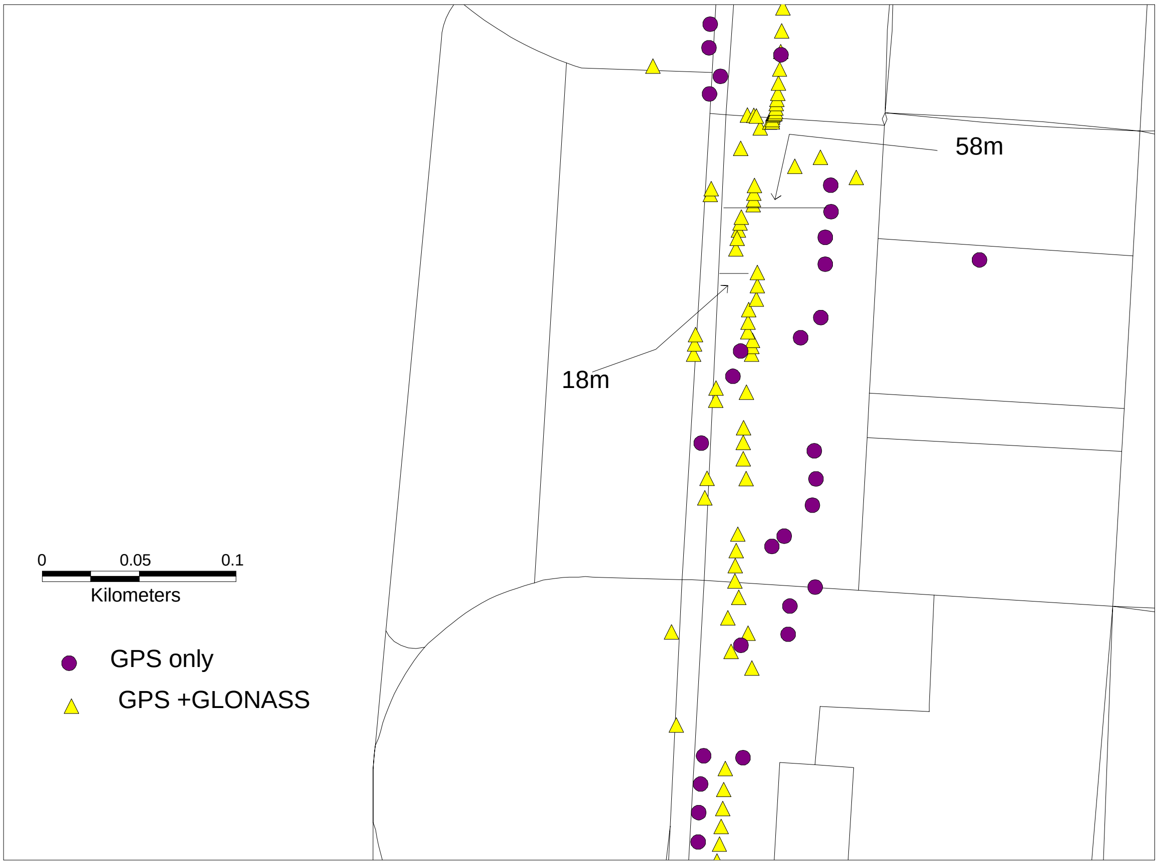

Figure 3. vehicle positioning results using satellite based sensors in Mong Kok (old developed urban area)

3.3 Wan Chi Test

Tests were also carried in Wan Chi, an urban area with extremely narrow roads and dense skyscrapers. Positioning result is shown in Figure 4, which can be seen that the scatter of vehicle positions are spread much wider, both availability and accuracy of GPS are much worse than the other two areas. Obviously, the problem of signal blockage caused by high rise building and narrow road is significant. The positioning accuracy is also affected by the poor satellite geometry due to the same reason. From the test result, it can be found that it is virtually impossible to identify accurate and reliable vehicle position using sole GPS in the region under this type of environment and such a complicated road network.

4 Satellite Based Systems Integrated with DR

The DR system applied in the tests is designed and built in cooperation with Plaska Technology (Taiwan). As DR accuracy level is totally depends on the quality of components to be used, therefore the selection of different DR components or combinations is directly affecting the accuracy. The current model ANS 2.0 aims at a low cost system, which consists of a fluxgate compass and a low-cost vibrating gyroscope. The odometer of the test vehicle is used to feed distance information to the system. The accuracy of different types of these sensors is summarized in table 2 and Table3.

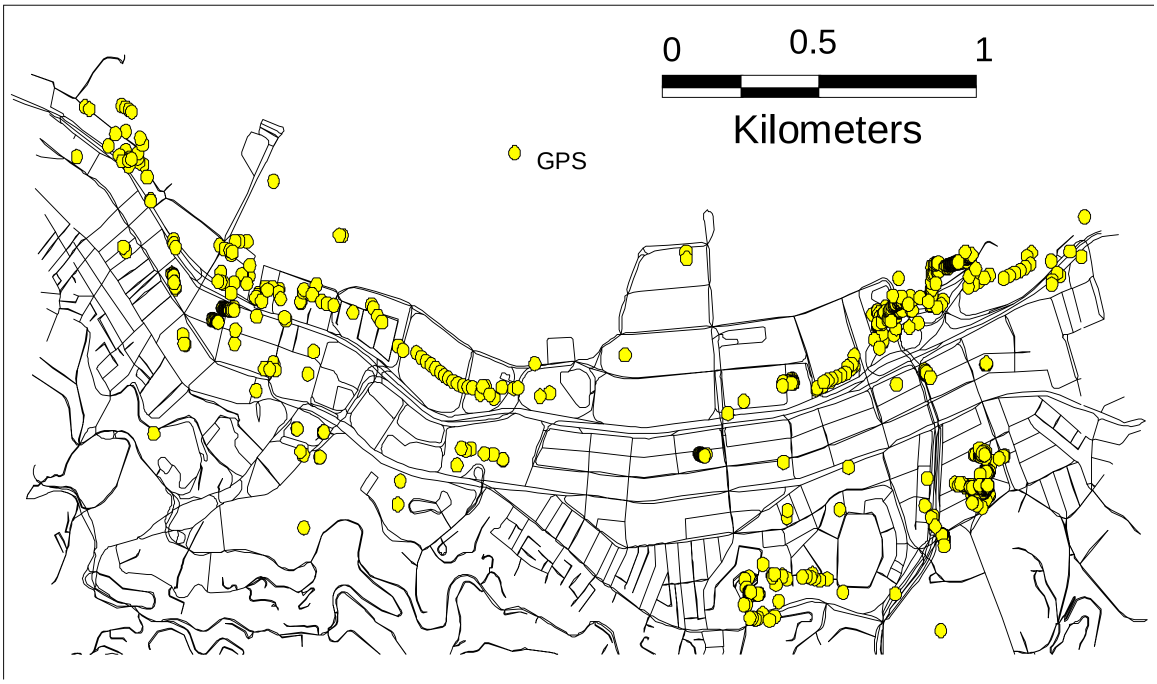

Figure 4. Vehicle positioning results using GPS in Wan Chi (urban area)

Table 2 Accuracy achievable for positional change detection components

Type	Accuracy
Wheel Revolution type (odomete)	0.3-2 % of distance traveled
Speed type	1-3 % of distance traveled
Acceleration type	1-10 mg

Table 3 accuracy achievable for angular change detection components

Type	Accuracy
Vibratory Gyro	0.1-1 deg/sec
Fluxgate compass	0.5 – 5 deg

ANS 2.0 can operate independently or integrates with satellite based sensors such as GPS, DGPS, and combined GPS/GLONASS, as long as the data is fed in a standard NEMA0183 format. When DR integrates with satellite based sensors, vehicle positions are calculated based on a tightly integrated system with at least one satellite visible. The weighting of the sensors are given mainly based on the DoP values of the satellite systems.

Field tests using satellite-based sensors aided with DR were conducted in Hong Kong. Investigation on the combinations of different sensors and processing algorithms were conducted in the aim of finding the optimal design of a localised vehicle positioning system. Tests were conducted in the inner city, which covers all types of districts tested previously using satellite-based sensors.

4.1 Mong Kok Test - GPS aided with DR

Tests using GPS aided with DR (ANS 2.0) was also conducted in Hong Kong. Figure 4 shows the vehicle positions using (i) GPS only and (ii) integrated GPS with DR systems. It shows clearly that the result from the integrated system provides a more accurate, smoother and continuous trajectory of vehicle positions.

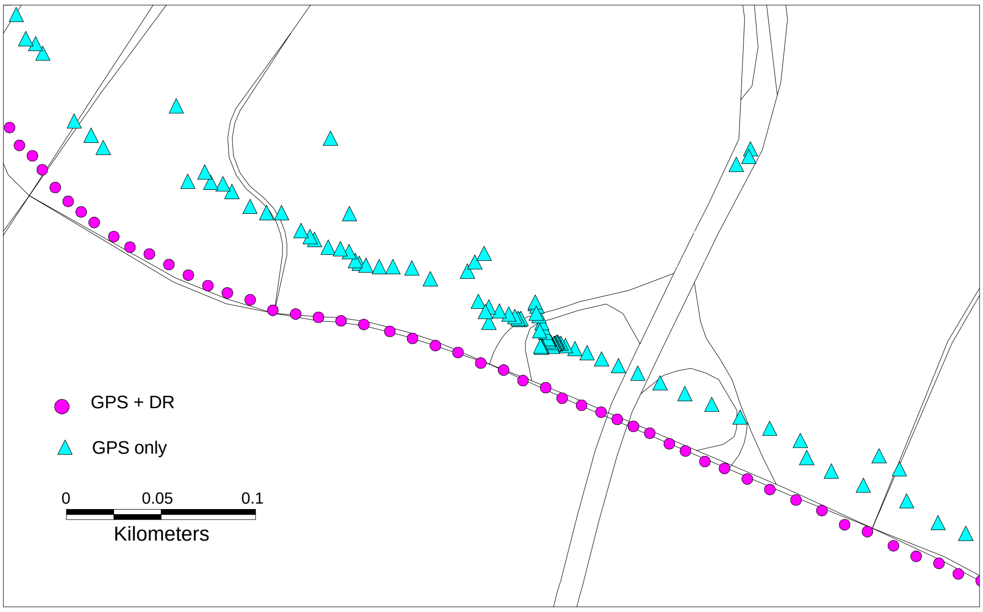

Figure 5 vehicle positioning results using GPS+DR in Mong Kok, HK

4.2 Wan Chi Test - GPS aided with DR

Similar tests were also conducted in Wan Chi, the most challenging area with narrow streets surrounded by dense skyscrapers. Test results shows in Figure 6 clearly demonstrates that the prototype of the vehicle positioning system, integrated GPS aided with DR, is capable to provide continuous and reliable vehicle positions in this area. The accuracy achieved by the integated system is at a level of about 10 to 40 m.

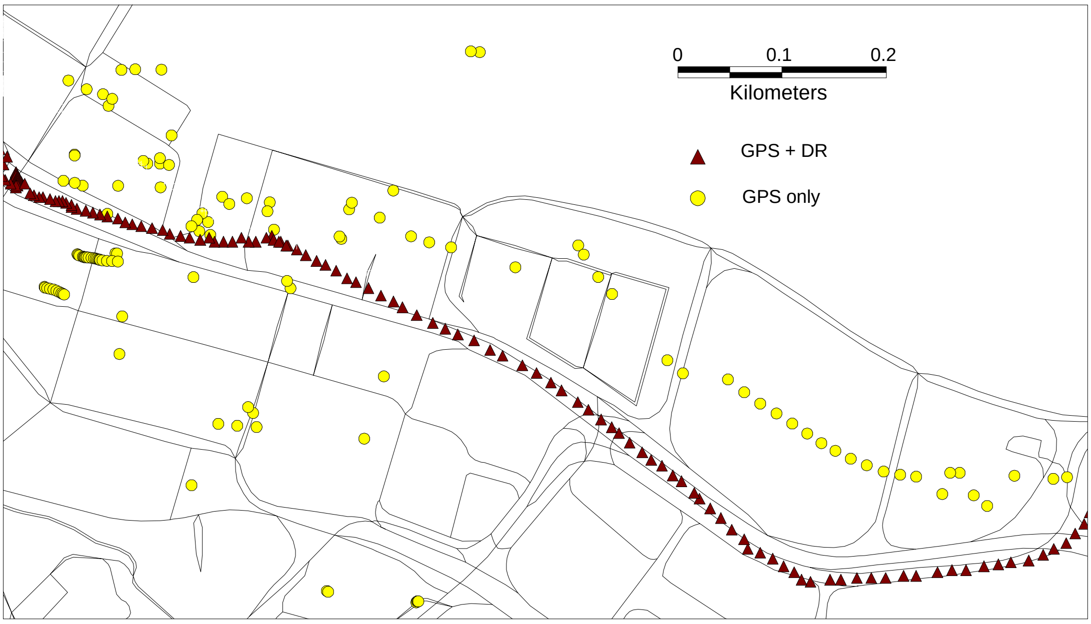

Figure 6 vehicle positioning result using GPS+DR in Wai Chi, HK

5 Conclusions

In this paper, some experimental tests on vehicle positioning based on GPS and its integration with other sensors conducted in various districts of Hong Kong have been reported. It has been found that signal blockage is a severe problem in these areas. Indeed, a vehicle positioning system using sole GPS or even combined GPS/GLONASS will not be capable of providing reliable and continuous vehicle locations in these kind of very dense urban areas.

Then, a low cost DR prototype is developed and integrated with GPS/DGPS to compensate the signal blockage. Results obtained from various tests in Hong Kong reveal that the feasibility and reliability of positioning are much improved in most cases. Further research will be carried out to utilise digital maps for the correction of accumulated errors to further improve the reliability and accuracy of the system.

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