Urban Fleet Monitoring with GPS and GLONASS

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The increasing volume of traffic in urban areas has resulted in steady growth of the mean driving time on fixed routes. Longer driving times lead to significantly higher transportation costs, particularly for vehicle fleets, where efficiency in the distribution of their transport tasks is important in staying competitive in the market. For bus fleets, the optimal control and command of the vehicles is, as well as the economic requirements, a basic function of their general mission. The Global Positioning System (GPS) allows reliable and accurate positioning of public transport vehicles except within the physical limitations imposed by built-up city 'urban canyons'. With a view to the next generation of satellite positioning systems for public transport fleet management, this paper highlights the limitations imposed on current GPS systems operating in the urban canyon. The capabilities of a future positioning system operating in this type of environment are discussed. It is suggested that such a system could comprise receivers capable of integrating the Global Positioning System (GPS) and the Russian equivalent, the Global Navigation Satellite System (GLONASS), and relatively cheap dead-reckoning sensors.

1. INTRODUCTION. In common with many metropolitan areas, the city centre of Perth, Western Australia suffers from traffic congestion, mainly during rush hours. Congestion, characterised by unpredictable disturbances, makes bus arrival times difficult to predict. The use of Intelligent Transportation Systems (ITS) technology provides the opportunity for real-time tracking of buses and thereby predictions of bus times to be generated at individual bus stops. Such a sophisticated system is the Central Area Transit (CAT) bus system service, which operates around the central Perth area, and has a bus fleet amongst the most technologically advanced in the world. Operation commenced in August 1996 with state-of-the-art satellite positioning and tracking capabilities in order to ensure increased efficiency of their services.

The CAT system has an on-bus electronic display and audio announcement upon arrival at each transit stop, giving passengers the location of the current stop and the destination of the next stop. Electronic displays and audio announcements at transit stops inform waiting passengers of future bus arrival times. The whole system is controlled by a central computer which displays the location of each CAT city-bus in service.[1] The location of each bus is given by differential GPS pseudo-range observations whereby the control centre generates differential

https://doi.org/10.1017/S0373463398007929 Published online by Cambridge University Press

Fig. 1. Bus of the CAT system in the Perth urban canyon

corrections and transmits them to all CAT buses at 10-second intervals providing a 90% confidence of bus location to within 1–5 metres.[1]

However, the main issue for any fleet management operation is that of information continuity and position accuracy due to restricted satellite visibility in the urban canyon. Even with the availability of a fully operational constellation of GPS satellites, signals cannot propagate through solid objects, so tall buildings and, to varying degrees, trees and foliage, high-sided vehicles and subways, inhibit GPS operation in the urban canyon environment. This results in discontinuities for the bus tracking operation which, in turn, affect the prediction times and thus increase the uncertainty regarding bus arrival times. The most obvious way to alleviate such problems is to increase the number of visible satellites and enhance the geometry of the satellite coverage.

With a view to the next generation of fleet management monitoring, trials have been conducted on the CAT system using Ashtech GG24 GPS/GLONASS receivers to illustrate the potential improvement offered to current GPS-only based positioning systems by integrating observations from the Russian equivalent of GPS, GLONASS (GLObal Navigation Satellite System), with GPS observations.

2. THE CAT FLEET MANAGEMENT SYSTEM. The design of the CAT fleet management system adopts a two-level location approach, whereby the primary level involves a direct and automatic bus-and-transit stop identification whilst the secondary level uses a geographical information system (GIS)-based spatial

proximity method utilising coordinates and linear distances.[1] There are three main components of the CAT fleet management system: command and control centre, in-vehicle hardware, and transit stops.

The main task of the control centre is to maintain communication with the individual CAT buses and transit stops, establish current status of the vehicles' positions by viewing these in a geographical information system of the Perth city area, and calculate the relative positions of buses and transit stops. In addition, the centre is interfaced with the GPS reference receiver, which is a Navstar XR5-M 12 channel, and is responsible for making available to the individual buses the differential corrections for each bus location. The GPS reference station is located approximately 6 km from the city centre of Perth. The correction differential GPS (DGPS) data are accessed at 10-second intervals and are broadcast to all vehicles via a UHF radio network. With this rate, a 90% confidence level of accuracy of 5 metres is maintained.[1]

The on-board bus system includes a Motorola Oncore VP 8 channel GPS receiver with carrier assisted code tracking, a UHF radio transceiver and other devices for the information display of the transit stop names. The main communication system employed is a two-way UHF radio network made up of two transceiver base stations, located in Perth Central Business District (CBD) approximately 2 kilometres apart, which provide seamless radio cover to city streets.

The transit stops are equipped with a radio-receiver to read updated bus movements every 45 seconds, thus keeping its bus arrival time information accurate to within one minute. When no update has been received, the transit stop system is unable to advise on the bus schedule.

The information on the bus arrival at each stop is based on the pseudo-range GPS position of the vehicle and the distance between each stop measured by the signal interface board which operates off the bus odometer. In addition, the signal interface board senses when the door is open in order to display the current and the next stops on the information display of the vehicle. Predicted time is based on the above information whereby the central computer works out the exact position of the bus on the route, and also the transit time of the previous bus travelling from this to the next stop, and sends this information to the transit stops.

The precise relationship between buses and transit stops is based on the reliable positioning of each vehicle using differential GPS. It is evident that long outages in the urban canyon (Fig. 1.) will affect the accuracy of the information broadcast to the transit stops.

Continuity is unaffected, however, as the odometer of each vehicle still provides linear distance information.

The improvement in the quantity of reliable positioning information which can result from augmenting differential GPS with differential GLONASS is discussed in the following sections with results from tests performed on the CAT system in Perth CBD.

3. THE GLOBAL NAVIGATION SATELLITE SYSTEM. The Russian Global Navigation Satellite System (GLONASS) was developed by the Soviet Union as a

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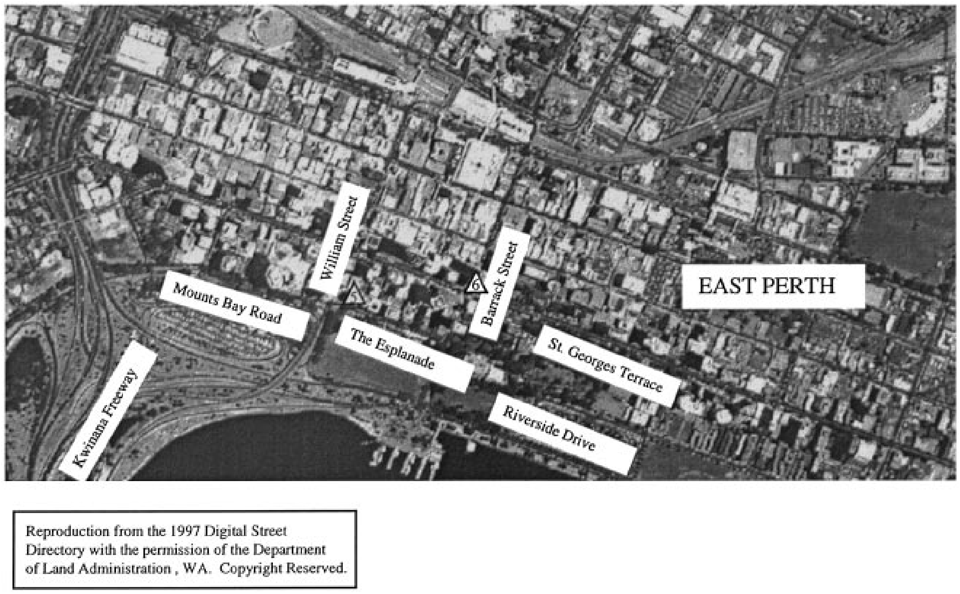

Fig. 2. Orthophoto of Perth central business district

military system in early 1970s.[2] It is now being promoted as a purely civilian system. After full deployment, the system will be composed of 24 satellites (21 active plus 3 spares). GLONASS structure and operation is very similar to GPS and, in principle, observations from GPS and GLONASS satellites can be combined to give solutions for receiver positions. Combination of GPS and GLONASS offers a distinct advantage in positioning for mapping applications in that the increased number of visible satellites will allow positioning in environments previously hostile to GPS-only positioning systems. For further details regarding the composition of the GLONASS system and the practical integration of GLONASS with GPS, the reader is referred to References 2–6.

To date, few receivers capable of receiving GLONASS signals have been available to general users. However, the potential for combined use of GPS/GLONASS has caused considerable interest in the surveying and mapping industry and combined GLONASS/GPS receivers are slowly entering the market, for example the Ashtech GG24.[7] The current status of the GLONASS system and its acceptance in the surveying and navigation community can be compared with that of GPS in the late 1980s, and, as with GPS over the past decade, GLONASS receiver availability and costs promise to improve radically as we approach the millennium.

4. GPS AND GLONASS TESTS ON THE CAT SYSTEM. Field tests using combined GPS and GLONASS observations were run through Perth Central Business District (CBD) on 5 August 1997. Data were logged simultaneously from two GG24 Ashtech receivers, one of which was situated over the top floor of the Library building at the Curtin Campus and the second was mounted on the CAT bus which at that time (9:30 a.m.) started servicing the north-south loop of the Perth city centre, where the CBD area was typically congested. The baseline

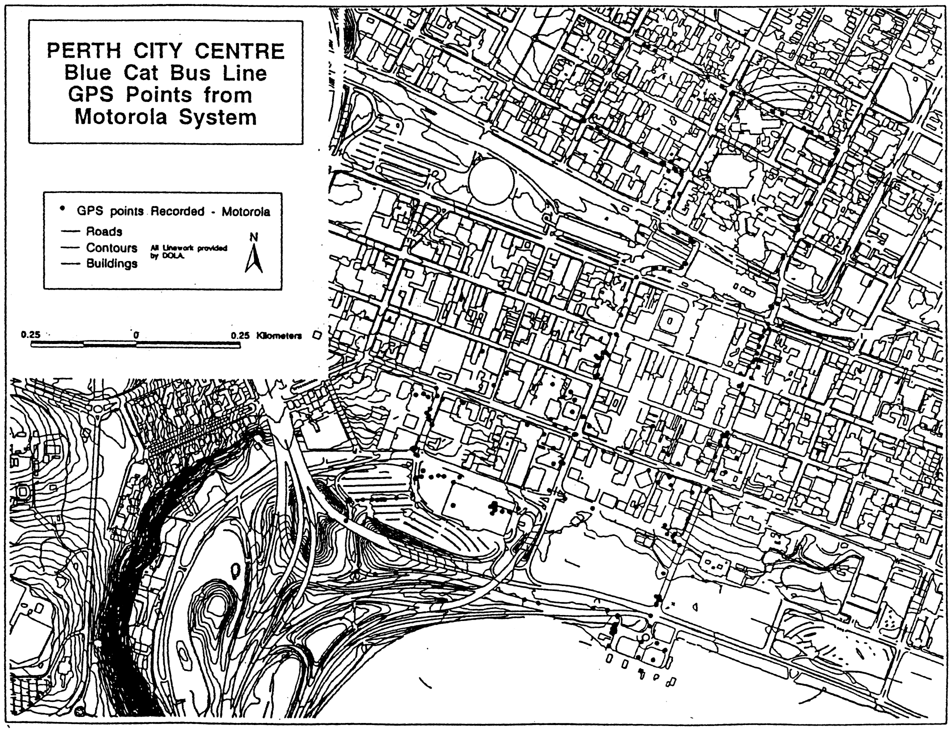

Fig. 3. CAT DGPS real-time positioning system (Motorola receiver)

length between the reference and roving receivers was approximately eight kilometres.

The capabilities of positioning system configurations, in the context of the urban canyon as represented by the Perth central business district (Fig. 2.) will be discussed in the context of: (a) GPS only; (b) GPS+GLONASS.

4.1 *GPS only*. Figure 3 shows two-dimensional position fixes in the Australian Map Grid (AMG) from the real-time differential GPS Motorola system configuration that is used on the CAT buses. The position fixes are available from the system every 45 seconds and the trajectory represents fixes from two loops around the specified route. The total test run was conducted along tree-lined boulevards, streets flanked by buildings of height less than five stories and in the Perth CBD which contains predominantly high-rise tower blocks. It is evident from the figure that the position fixes follow well on the route on the map but there are gaps of the DGPS solution not only due to the poor satellite visibility of the city centre but also to breaks in the real-time communication link for the DGPS system in the urban canyon environment. The Perth urban CBD, comprising high-rise office buildings and relatively dense low-rise commercial areas with offices, cafes and restaurants mainly in the northern and western parts, is harsh on signal propagation and may cause occasional radio frequency disturbance. Although the software implemented at the CAT system disregards most of the spurious or illogical coordinate data and inserts a linear projection of the buses coordinates

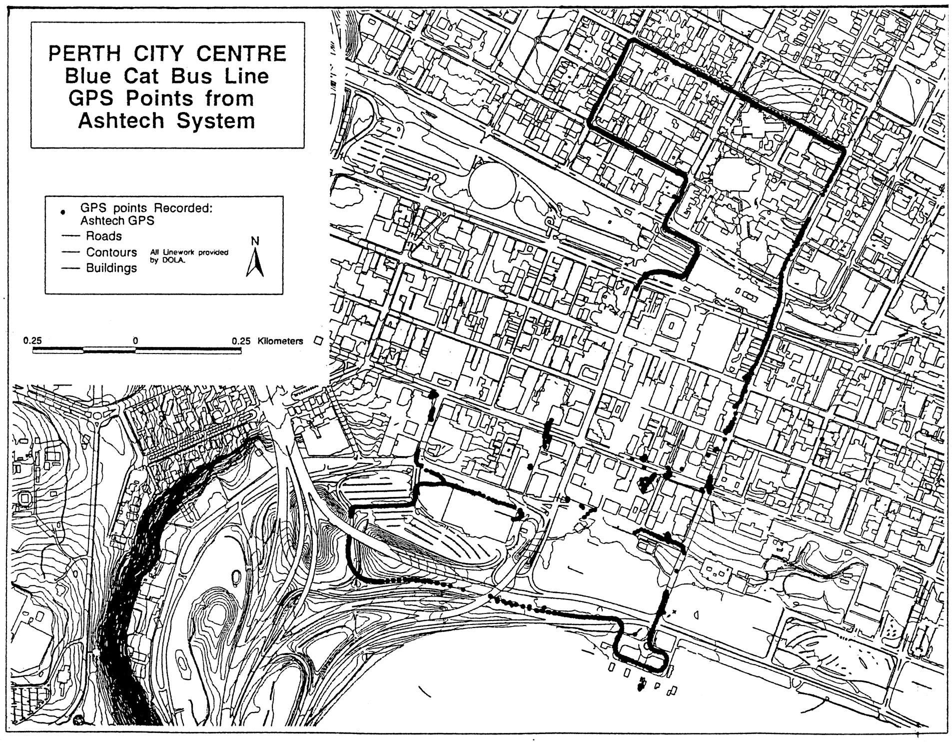

Fig. 4. DGPS post-processed position fixes (Ashtech receiver)

there is still a large number of position fixes that are outside the roads delineated on the map.

Figure 4 represents post-processed DGPS solutions using date from the Ashtech GG24 receivers. The fixes are phase smoothed pseudo-range solutions obtained from in-house GPS/GLONASS software written at Curtin University. The post-processed solution is not subject to communication difficulties so outages represent situations in which an insufficient number of satellites can be viewed to compute a solution. Again, the fixes represent solutions from two loops of the bus route. It is evident from Fig. 4 that the DGPS system behaved well on the tree-lined boulevard of Riverside Drive and amongst the relatively low buildings of east Perth, such as Aberdeen Street and James Street.

The slowing motion of the bus at Riverside Drive is depicted by the reduced spacing between the estimated points. However, on St. Georges Terrace there is a degradation of position fixes caused by poor satellite geometry, the well-known dilution of precision (DOP) effect.[8] A sufficient number of satellites can be observed to compute a two-dimensional position but the distribution of the satellites in the sky, such as when the satellites are clustered closely together, greatly reduces the attainable precision. The DOP values varied from 5 to 10 for most of the duration of the test with events where the values were even higher.

In the urban canyon of the Perth CBD, however, particularly along William Street, Barrack Street, and St. Georges Terrace, insufficient GPS satellites can be viewed to adequately compute regular fixes. This is not unexpected, since satellite visibility in these areas is highly restricted, as illustrated by Figs. 5 and 6 which graphically represent the approximate restriction to satellite visibility

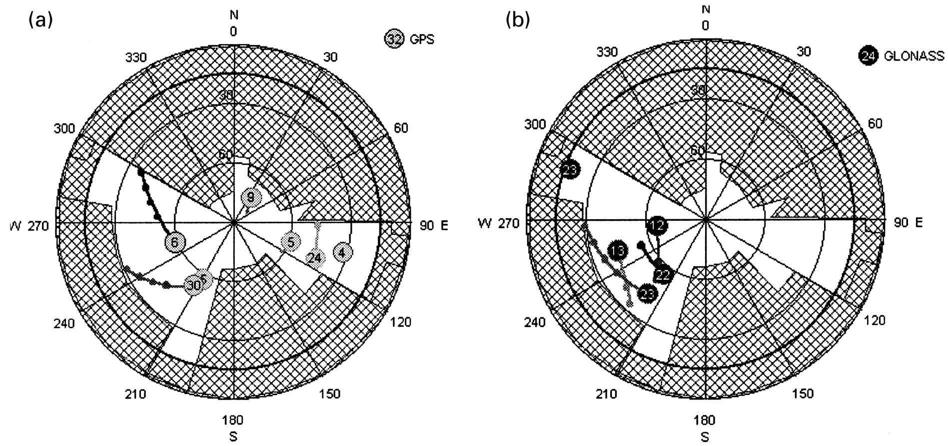

Fig. 5a. GPS-only visibility plot showing sky obstruction on William Street
Fig. 5b. GLONASS-only visibility plot showing sky obstruction on William Street

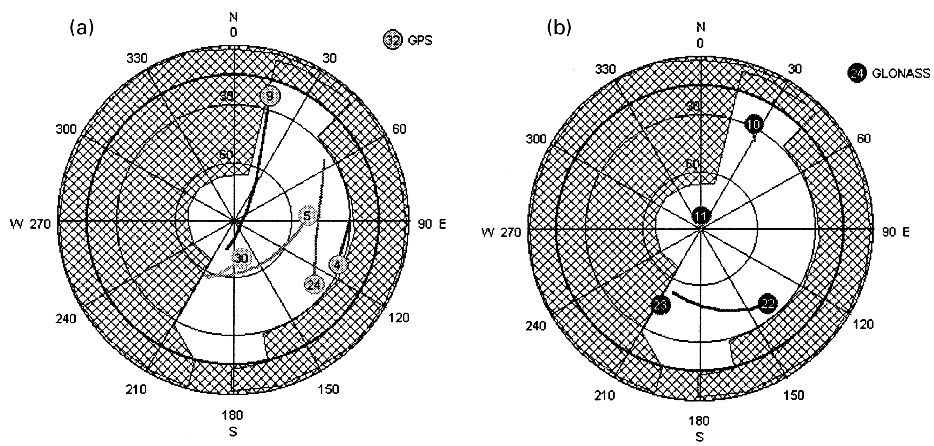

Fig. 6a. GPS-only visibility plot showing sky obstruction on Barrack Street
Fig. 6b. GLONASS-only visibility plot showing sky obstruction on Barrack Street

for the duration of the test at selected points on William Street and Barrack Street respectively. These two points are two of the bus stops in the CAT route. These points are labelled 5 and 6 on Fig. 2.

Figure 7 presents two-dimensional DGPS solutions with fixed height. Due to the fact that GPS cannot provide a position fix unless there are at least 4 satellites available, this requirement can be lowered if the user can reasonably constrain the solution by fixing the height component to an assumed known value. An important observation from Fig. 7 is that the fixed height constraint gives more

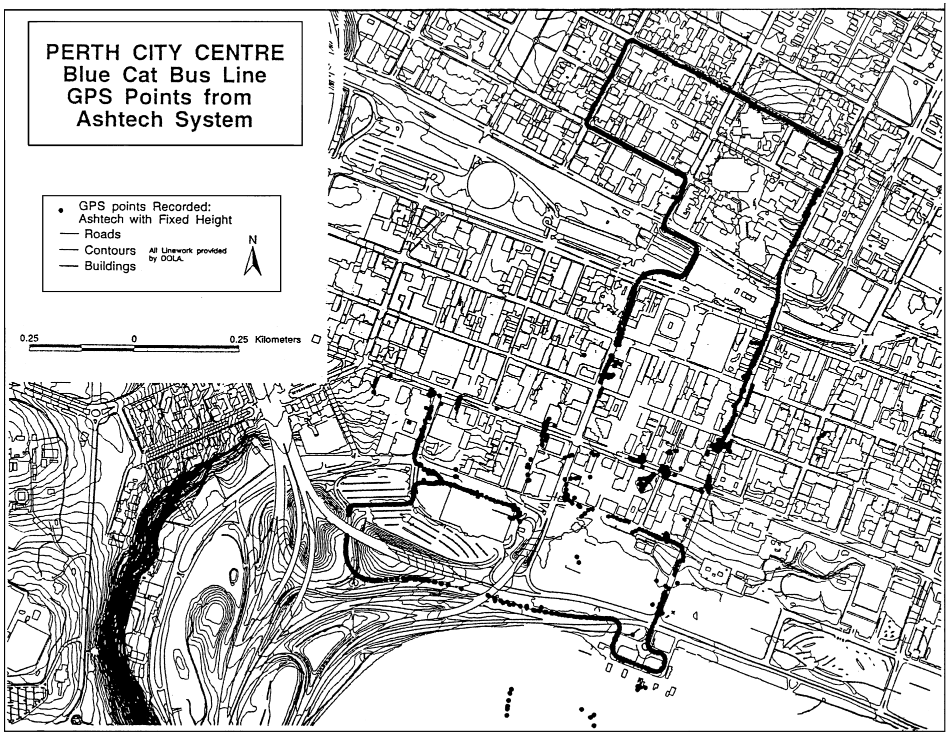

Fig. 7. DGPS post-processed position fixes with fixed height (Ashtech receiver)

position fixes. This is particularly evident on William Street and The Esplanade (cf. Fig. 2). In addition, the constraint of height results in improvement in geometrical strength because the enhanced redundancy can give improved accuracy for the solution of the remaining unconstrained parameters.

Furthermore, in both Figs. 3 and 7 some position solutions can be seen to drift off the road, particularly at the top of Barrack Street and St. Georges Terrace. Poor solutions such as this are caused by poor DOPS. Overall, though, there is an improvement in the total number of position fixes which increased from 2529 without height fixing to 3112 with height fixing, an addition of 583 fixes, with obvious advantages to the continuous monitoring of the bus fleet.

4.2 *GPS + GLONASS*. Figure 8 illustrates the combined GPS/GLONASS position fixes for the same CAT test run. The fixes represent phase-smoothed pseudo-ranges with height constrained solutions. A greater number of position fixes versus GPS-only solutions (cf Figs. 3 and 7) is noticeable in Fig. 8 and especially in areas where previously there were not many (e.g. one section of William Street) or any at all (e.g. the majority of St. Georges Terrace). Although there is a significant increase in the number of points, it must be noticed that these are more scattered and noisier. This may be explained by residual clock errors, caused by the multiple frequencies broadcast by the GLONASS satellites,[9,10] which have been left unmodelled in the current version of the processing software implemented at Curtin University.

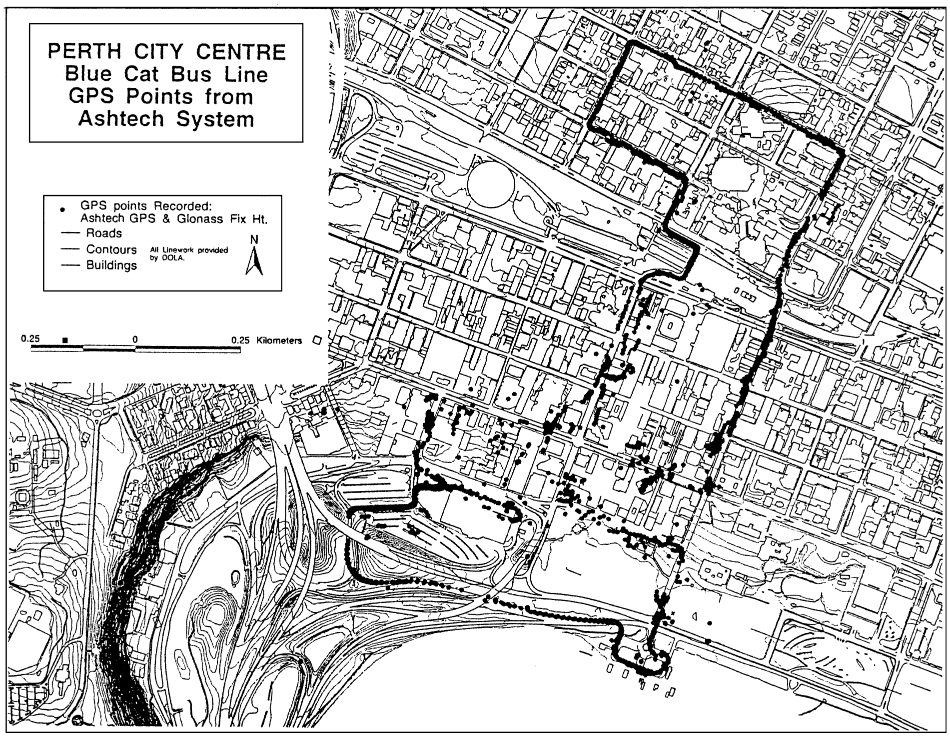

Fig. 8. Differential GPS/GLONASS post-processed position fixes with fixed height (Ashtech receiver)

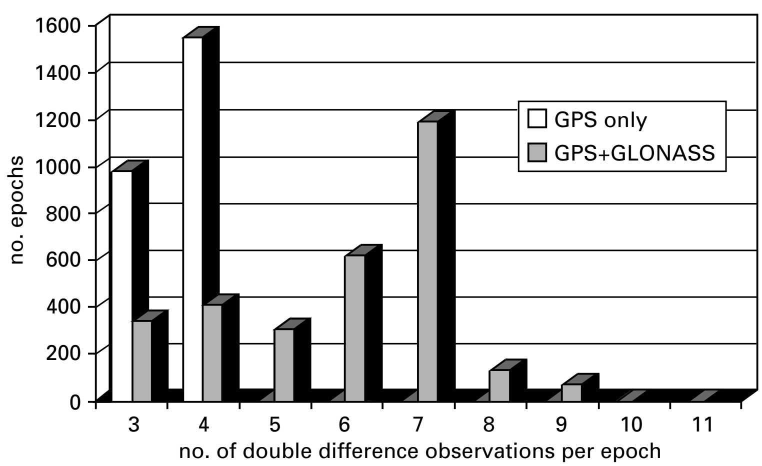

Fig. 9. Number of double difference observations per epoch in GPS-only and GPS/GLONASS solutions

As a comparison, the number of double difference observations from the combined GPS/GLONASS signals per epoch versus GPS-only double difference observations formed during data processing for the test period is shown in Fig. 9.

From Fig. 9, it can be seen that during the duration of the test in the urban canyon, a GPS-only positioning system can only give three-dimensional position fixes (i.e. able to form at least three double difference observations) for 29% of the total duration of the test which was about 1·5 hours (i.e. 5400 one-second epochs). As illustrated by Fig. 9, the number of GPS double-difference observations are only 3 or 4 and there are none that exceed 5 or more per epoch. This means for the remaining time, the GPS-only positioning system cannot provide positioning information for continuous monitoring of the vehicle. On the other hand, when GLONASS is available the combined number of double difference observations increase resulting to three-dimensional positioning for 70% of the duration of the test. It is therefore clear that, whereas a GPS-only positioning system is practically inoperable in the urban canyon of St. Georges Terrace or Mounts Bay Road, the combined GPS/GLONASS system has a potential to at least deliver position fixes for the majority of the time. Double difference observations using combined GPS/GLONASS are plentiful per epoch and range from 3 up to 9.

The improvement of the integrated GPS/GLONASS solutions is not only in the increase of the number of observations but more importantly in the improvement of the geometrical strength of the solution. It is evident from Fig. 10 that the

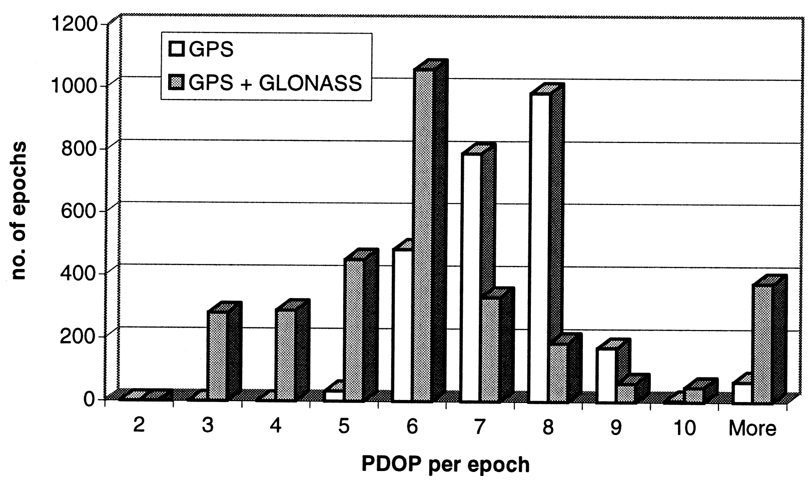

Fig. 10. PDOP values per epoch in GPS-only and GPS/GLONASS solutions

combined GPS/GLONASS constellation outperforms the GPS-only constellation in terms of improved geometry during the test period. Indeed, for an average DOP value of 6 there are around 1060 GPS/GLONASS fixes, whereas for the GPS-only system only 483 fixes have the same DOP value. For lower values of the geometrical strength of the constellation, such as 3 or 4, there are no GPS-only fixes, whereas GPS/GLONASS provides 570 fixes.

Whilst Fig. 9 shows the potential improvement possible by combining observations from the two satellite positioning systems rather than utilising GPS-only positioning systems, the feasibility of successfully operating the combined system for continuous monitoring of bus vehicles in the urban canyon is still doubtful. Some 30% of the time no position fix at all is available as even the combined GPS/GLONASS satellite constellation is unable to guarantee regular, reliable position fixes in the urban canyon. It therefore follows that in stretches of urban canyon where 3 or less satellites are visible, some other form of positioning system is required to supplement the limited satellite information available. The nature of the urban canyon offers a simple solution to this problem, combining the strengths of satellite positioning and dead reckoning (DR).

The DR systems, usually comprising an odometer, a compass or gyro and tilt meters, are subject to instrumental drift which accumulates with time and distance travelled and require continuous calibration by the satellite-based sensor. Combined GPS/GLONASS as shown gives more position fixes which can calibrate the DR system in an urban canyon environment for longer periods than with a GPS-only based system. Therefore, continuous vehicle positioning in the urban canyon can rely on the combined satellite system to fix position and calibrate the DR system during the route. When no satellites position fixes are available in a heavily masked street, such as St. Georges Terrace, there are still the junction intersections where satellites can be viewed. Street intersections generally are not more than a few hundred metres apart in the urban canyon environment thus allowing the DR system to be recalibrated sufficiently regularly to avoid accumulation of significant errors. Obviously, in situations where sky visibility is less extreme, the combined GPS/GLONASS positioning system would remain as the primary system. It is also possible that in situations where only three satellites are available, GPS/GLONASS and DR observation could be integrated to provide a more robust solution than either system can provide in a stand-alone sense.

5. CONCLUSIONS. Fields tests using the combined GPS and GLONASS satellite positioning systems for the continuous monitoring of bus fleets have been performed. This paper has demonstrated that the fundamental problem for satellite-based vehicle navigation systems for continuous positioning in the urban canyon is the low number of visible satellites. Any positioning system based primarily on GPS will be unreliable at best, and unusable at worst, in the urban canyon. The addition of the Russian GLONASS system to the GPS constellation effectively doubles the number of satellites available and improves the geometry of the visible satellites.

It is unlikely, due to the extreme hostility of the urban canyon environment to satellite based positioning systems, that even a combined satellite constellation of 48 satellites can enable reliable, 24-hour positioning. For this reason the positioning system of an urban fleet management service should comprise DR sensors which will be able to provide regular fixes and would operate as the primary positioning system in the most extreme urban canyon situations where 3 or fewer satellites are visible.

Although, in comparison to GPS, GLONASS receiver technology is still in its infancy, the next generation of monitoring systems promises to revolutionise precise positioning for fleet management applications entering the next century, much as GPS is revolutionising navigation today.

ACKNOWLEDGMENTS

This study is funded by a research grant from Curtin University of Technology, Western Australia. The authors would like to acknowledge the help of TransPerth during the data collection.

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KEY WORDS

1. GPS/GLONASS. 2. Vehicle navigation. 3. Fleet management.