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New Developments in GPS and GIS

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Abstract:

Since the advent of the Global Positioning System (GPS) in the late 1980's the number of applications for which it has found a use have begun to proliferate. With this there has been an exponential increase in personal computing power allowing software applications to migrate from large work stations to desktop PC's. Geographical Information Systems (GIS) are a product which has followed this migration pattern. These factors combined have opened up GPS and GIS integration into a number of new and innovative applications. The paper will discuss some of these new applications that GPS/GIS is being used for at the Transport Systems Centre. These will include showing how new real time centimetre accuracy GPS techniques are revolutionising the surveying and mapping industries. Together with new GIS technologies that allow satellite, aerial and even street directory images to be displayed and manipulated in real time. Examples varying from applications within the South Australian Police Force to new forms of public transport systems will highlight the use of these new techniques. Examples of how the Radio Data System (RDS) is already being used by the Triple J radio station and how proposed traffic monitoring can be implemented on RDS will be elaborated on in the paper. Technology is a progressive and dynamic entity: it is up to the individual to seize the opportunity and make the best possible use of it.

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Introduction

The Global Positioning System (GPS) and Geographical Information Systems (GIS) have been developing independently of each other at rapid rates. GPS is now at the stage where it can provide centimetre level accuracies in real time. GIS's packages have now migrated from work stations to the new ever more powerful desktop and laptop personal computers. This paper will go on to show how the Transport Systems Centre of the University of South Australia has integrated these new developments and applied them in a number of wide ranging applications.

The application for which these new technologies have found a use include real time congestion monitoring, real time kinematic surveying, new public transport systems, the use of GPS and GIS in police helicopter applications and the use of GPS and GIS in environmental analysis. These applications will be elaborated on in the paper with specific examples describing how these new technology tools have provided the solution.

New developments in GPS and GIS technology

Since GPS has become fully operational the increase in the accuracy and reliability of the system has grown tremendously. GPS receivers have migrated from computer boards that took up the rear section of a four wheel drive land cruiser to the new PCMCIA card GPS receivers that are slightly bigger than a credit card. This decrease in size has also been matched by an increase in performance and reliability.

GPS developments

Some of the more recent developments include the advent of Differential GPS (DGPS) infrastructure. DGPS has the potential to increase the real time accuracies of GPS from within 50m to well within 5m and better. Private and government bodies have set up systems that broadcast the differential correction over wide areas. The broadcasting mediums includes satellite communications that although has a wide coverage are expensive to subscribe to. The omnistar system developed by Furgo and operating in Australia is an example of this. HF broadcasts for maritime navigation are also another example. The US Government has set up a number of DGPS stations along its coast to aid vessels in the navigation of its coastal waters. In Australia the AUSNAV DGPS system developed by the Australian Land Information Group (AUSLIG) in alliance with Differential Corrections Incorporated and ABC radio are providing a DGPS service. It is a DGPS system that integrates the differential correction data onto a the ABC radio frequency which is government owned radio station. Therefore where ever the radio station is heard the differential correction can also be accessed if the user is subscribed to the system and a differential GPS base has been set up in that region. The most popular use of the AUSNAV system has been in regional centres where crop dusters can use higher accuracy GPS to navigate their planes more accurately instead of using ad hoc methods or flagmen on the ground as was the case in the past. In a DGPS system the communications link between the DGPS base station and the other mobile units had always been regarded as the weakest link in the chain. Hence the number of DGPS systems that are available that a users can subscribe to instead of having to go through the expense of setting up their own base and communications system.

The amount of data a GPS receiver can process has also now significantly changed as well as the algorithms used to process the data. This has allowed the real time differential accuracy to again increase form the standard 5m accuracy to 1m accuracy. These real time accuracy gains have been limited to the more expensive high end surveying grade GPS receivers that are usually more expensive than the simple Original Equipment Manufacture (OEM) receivers. Tests have shown that using the AUSNAV system one metre accuracies are achievable, with the right GPS receivers. However the differential correction data that is used by the AUSNAV system has been optimised to give these increased accuracies (ref Tan et al 1996).

One of the most interesting developments to GPS in recent times is the advent of Real Time Kinematic GPS (RTK). It has the ability to deliver accuracies of a few centimetres in real time, this has opened up many application not only in transportation but also asset management, topographical surveying, machine control etc. While the accuracies obtainable from this method are high there are other issues which limit the applicability of this method. Some of these include the base receiver and the roving receiver can be no more than approximately 50 km apart. The number of satellites in view must greater than or equal to 5 and in a good configuration, while this is not an issue under good GPS conditions. If the rover is in amongst trees or tall buildings then the number of satellites in view could become an issue. As with DGPS the weakest link in this system is obtaining a reliable communications link between the base and the roving GPS receiver. This problem is compounded by the fact that the amount of data needed to be transferred across the communications link for RTK to be successful is far greater than that of the differential correction, and the sensitivity of the system to data latency is also greater than that of DGPS. Hence a more sophisticated communications systems is required adding to the expense and decreasing the reliability of RTK systems. However most systems now have quality indicators that allow the user to determine the reliability and accuracy of the system. Applications of this high accuracy technique and the use of the AUSNAV system will be introduced later in the paper.

GIS developments

In parallel with the GPS developments the exponential growth in desktop computing power has seen GIS packages migrate from large, powerful and expensive work stations to smaller portable less expensive and almost equally as powerful desktop computers. GIS's running on desktop computers now have the ability to display and manipulate all sorts of raster images including satellite imagery, aerial photography and even street directory images. Until recently this sort of functionality was only possible on large powerful work stations.

With the migration of GIS packages to the desktop there has also been a change in operating system, now with the windows based operating systems a more user friendly and workable environment exists. GIS packages are now more standardised on a GUI which has allowed many custom written applications to be developed that are based on large complex GIS packages. Therefore making the learning of GIS a much simpler task for a novice since the amount of exposure can be regulated. With the move to these new operating system other programming languages are now able to be seamlessly incorporated into the GIS either in real time or as part of a function library. This has opened up GIS to complete custimisation and flexibility, developers are no longer confined to the limits of the GIS. This development has seen many new GIS based applications emerge especially in the field of real time GIS such as Automatic Vehicle Location (AVL). Some examples of these developed at the TSC will be expanded on later in the paper.

Radio Data System (RDS) DGPS and Triple J

AUSNAV uses RDS to modulate the differential correction data onto the Triple J radio station in this way not interfering with the normal voice transmission of the radio station. RDS has other features that enable encoding of data in this way a special decoders must be used to decode the differential correction data and apply it to the GPS receiver. In this way AUSNAV is able to charge a yearly subscription fee to use the service, as well as the differing levels of service available through RDS. The user has a choice of three different levels of service which decrease in accuracy as the subscription fee also decreases, this functionality has been incorporated as apart of the RDS protocols. Another advantage of using RDS is that a large amount of data can be transmitted through a radio station, the system as it stands at the moment has the ability not only to send the differential correction data but also other data. The TSC with AUSNAV have proposed that traffic congestion data could also be incorporated into the AUSNAV system as well as the differential correction data.

Real time congestion information

The provision of real time traffic data has become the focus of many American and European research projects. In the US the use of new technologies to obtain maximum efficiency of existing infrastructure has been put into the category of Intelligent Transportation Systems (ITS) and in Europe has been labelled Advanced Transport Telematics (ATT). The budgets that have been allocated to these initiatives can be measured in the hundreds of millions of dollars. The projects can be grouped into the broad categories of congestion monitoring, advanced traveller information systems (ATIS), incident detection on freeways and so on. Some of the projects are now so mature that their results showing real time congestion are displayed on the Internet (see ref).

In Australia ITS (Intelligent Transport Systems) has not yet shared the same large commitment by government however there are several projects underway that have an ITS flavour to them. While there are no Australian projects that have reached the maturity of having their real time results displayed on the Internet, there are initiatives such as the ANTTS in Sydney (Longfoot, J E and Quail,DJ (1990)) that monitors and records vehicle travel times. This system as well as the American and European projects take advantage of inductor loops that have been fitted at major road intersections and in some cases along freeways that can detect particular cars ("probe vehicles") as they cross over the loops. Therefore travel times and average speeds can be determined for each car and a picture of congestion can be built up of the particular road network. Advanced driver information systems (ADIS) may then be used to display or relay route choice information to drivers in real time. However these systems only measure traffic conditions at several isolated locations in the road network, due to the fixed nature of the inductor loops systems these projects are using. Some of the American cities using inductor loops to determine congestion include Los Angeles, Houston, Orange County and San Diego. France also has its airport monitored for real time traffic information, these projects are so mature that their real time results can be viewed on the Internet (see ref for Internet addresses).

Real time traffic information is already available for parts of Europe and the United States using transponder based systems to gather traffic information. Most of the overseas research into real time traffic congestion has been implemented on freeways where there are high volumes of high speed traffic. Even a small incident could cause catastrophic effects, hence the massive investment in inductor loops and transponders to try and detect and prevent these incidents. The use of GPS to gather traffic data is a concept that has been worked on at the TSC for several years. Since GPS does not suffer the limitations of transponder based systems of only being able to collect data over certain fixed routes. It has the ability to build up a representative picture of traffic conditions no matter where in the traffic network the "probe vehicle" is. For GPS will provide position, time and speed data as long as their is a view to the sky. This flexibility is more suited to Australian traffic systems and especially Adelaide, since the amount of freeway systems is significantly lower than those of America and Europe. Together with the fact that GPS is more effective in the central business district of most Australian cities due to there lower high rise skyline.

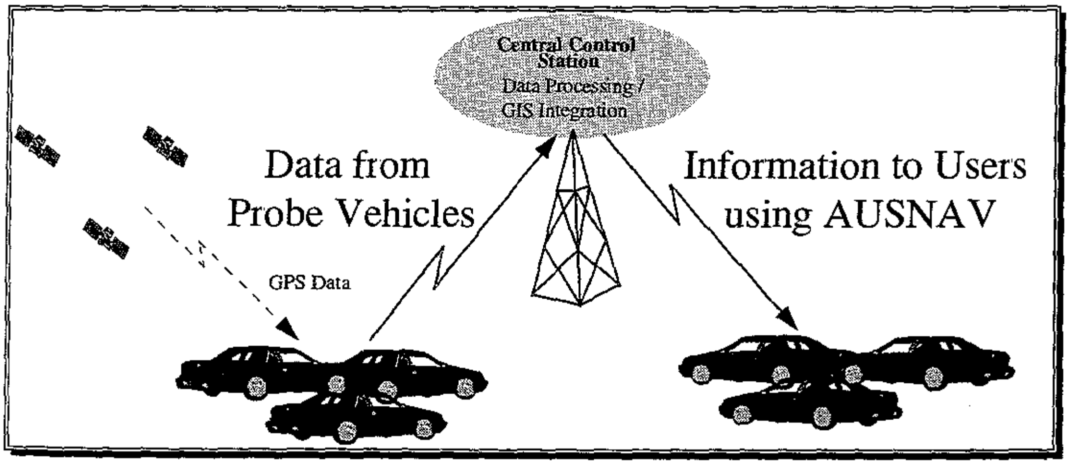

Figure 1 Schematic of Real Time Monitoring System

Figure 1 shows a schematic diagram of how the proposed system will work, the final stage shows information being broadcast by AUSNAV to the users as part of an ADIS. The data will initially be collected by a number of probe vehicles anywhere in the street network. Raw data such as time, position and speed data will be collected and sent to a central base via a real time communication system. This raw data will then be processed in a GIS environment so a real time representative picture of congestion can be built up, ie turning raw data into useful information. This information will then be broadcast through the AUSNAV system to subscribers of the system who will then have access to real time traffic information. This type of system already exists in some European cities however the traffic data is only incident based. Warning are given of traffic accidents etc by people who phone up the radio station to advise them of the occurrence of delays.

Real time kinematic GPS

Topographical surveying

As was mentioned RTK GPS is capable of centimetre accuracies in real time, this make it an excellent tool for topographical surveying. Figure 2 shows an area that has been surveyed once using traditional surveying equipment and then again using RTK GPS. The figure shows that the shape of the contour plots are very similar, the absolute values cannot be compared since GPS uses a global datum and the surveyed data uses a local datum. However since the contours are of very similar shape indicating the same topology and level of accuracy. It is interesting to note that to perform the survey using traditional means it took a small team of surveyors two days to complete the survey then download and process the data to get the contour plot. Using RTK it was simply a matter of driving a vehicle with the GPS receiver in it over the area in question then which took approximately 2hrs then going back to the office and creating the contour map from the raw data collected. The saving in man hours is quite significant when comparing the two methods, to achieve the same result.

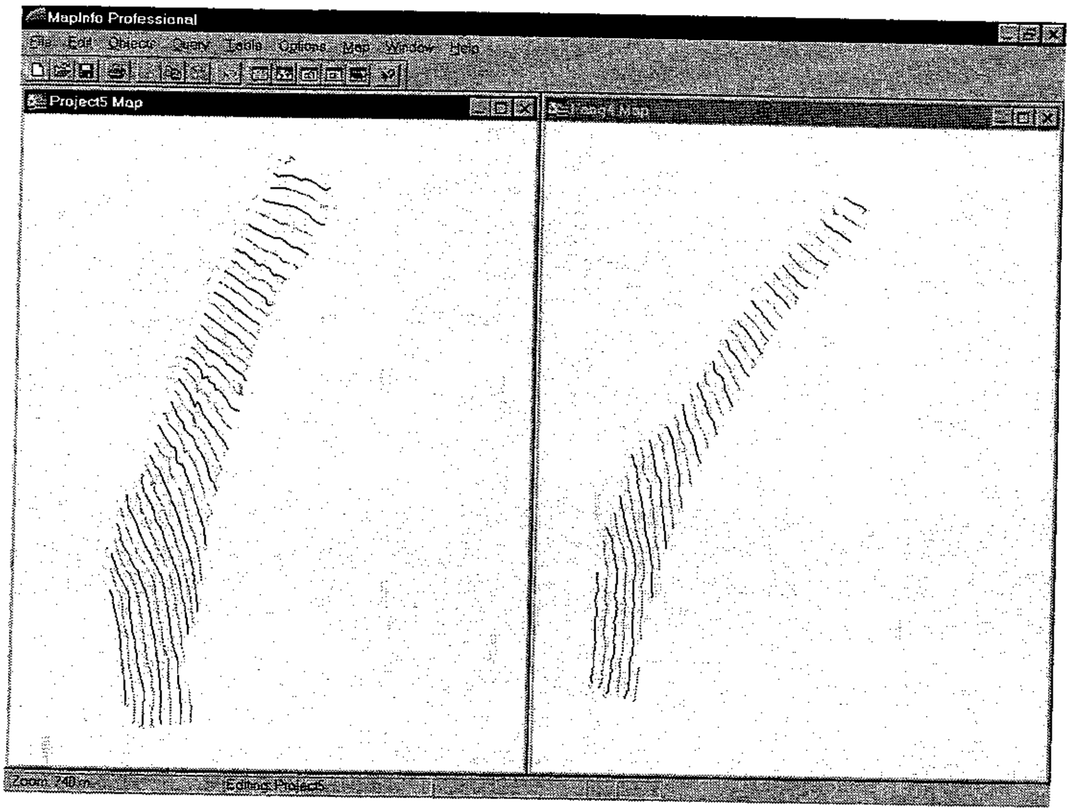

Figure 2 Topographic Surveying

RTK in Mining

Due to the accuracy of the coordinates RTK can also be applied in a mining situation, the TSC together with Macmahon Mining Contractors are working on ways of implementing RTK to their mine sites. Some of the potential applications include the determination of cut and fill volumes. Since most mines work on the volume of ore and soil moved it is a very simple matter of just driving or walking a GPS receiver over the area in question to determine the volume of earth moved. Using the same sort of principles that have been applied in topographical surveying example. The ease of this method means that more ground can be covered using fewer resources in a smaller amount of time implying large saving to the mining company if these sorts of methods are implemented properly.

Another application of RTK on the mine site is for drill rig placement, for the preparation of blast holes. The correct placement of these holes is critical if the blast is to be effective. With a RTK system the GPS antenna can be placed on the head of the drill rig and guided into the exact position using the real time output. This has been identified as a tremendous time and resource saving since traditional methods are very labour intensive. Requiring a surveyor to firstly coordinate a point in the mine pit then lay out the appropriate grid. However there are limitations to the methods since inaccurate results could occur if the required number of satellites are not in view due to the shear face of the mine causing blockages. Therefore there are the accuracy and reliability issues that must be considered as well as the potential savings when implementing such a system.

Haul path determination is also another aspect of where higher accuracy GPS techniques need to be implemented The haul paths are the paths vehicles follow from various sources to destinations on site. An example is the dynamic nature of haul roads at mine sites were the haul paths are continually changing. Therefore with RTK these gradual changes can be monitored and any large deviation by a truck from the haul path an appropriate warning could be given. These large deviations would be detected by simpler OEM GPS receivers on board the trucks. The high accuracy data obtained by the RTK system could be used as a standard to compare the GPS data obtained from OEM GPS receivers.

Demand responsive public transport

Demand responsive public transport is a new type of public transport system that does not run on a fixed route or adhere to a fixed timetable but is responsive to the demands users place on the system (D'Este et al. 1994) and (Radbone et al 1994). It is an application that has been worked on at the Transport Systems Centre and are in the process of a negotiating a demonstration project with one of the northern area councils in Adelaide to implement this type of system. The system involves tracking the vehicles with GPS then feeding the positional data back to a central control centre where the data is processed in a Geographical Information System (GIS). Information derived from GPS based monitoring can be incorporated into an Advanced Traveller Information System (ATIS) involving 'smart' bus stops and information kiosks. Commuters can be informed of the arrival time of the next bus and also notified of any delays that may have occurred, in real time.

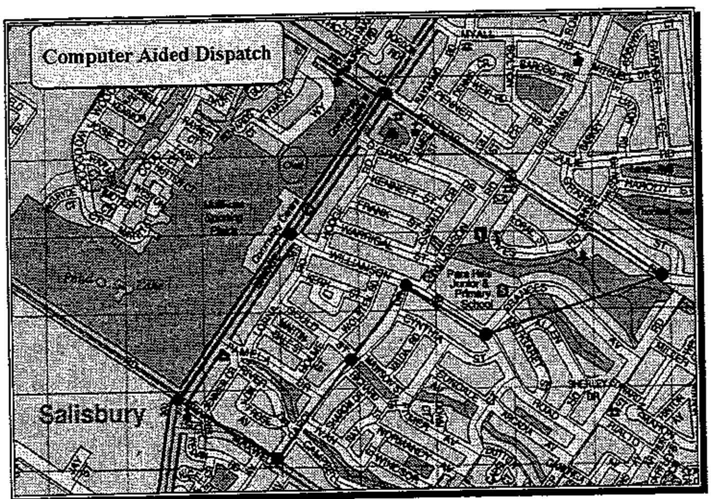

Figure 3 Computer Aided Dispatch in Demand Responsive Public Transport

The next step after obtaining the position of the vehicle and customers is to incorporate the data into a computer aided dispatch system. A typical scenario could be that a new request has just been made and entered into the system, all the vehicles in the fleet would then be polled to ascertain their location and work load. Then a dispatch algorithm would assign the new request to the appropriate vehicle in the fleet, and the driver would be notified of the new job to be added to his current work schedule. This type of system has the potential to increase efficiency and productivity, and quickly pay for itself. The initial cost is probably one of the drawbacks of new technology products. This type of system could probably best be utilised by the taxi industry, couriers, emergency services and public transport. There are examples of this type of technology already being used by some US taxi companies. GPS and computer aided dispatch also opens the way for efficient demand responsive public transport. This application is a focus of research at the Transport Systems Centre.

One algorithm investigated at the Transport Systems Centre is the use of space filling curves (Bartholdi and Platzman 1992) and (Stampoultzis and Chambers 1989) to determine an efficient schedule for a number of points scatter over an area. The algorithm determines a value theta for a point that is derived from its coordinates. These values are then sorted to provide the order in which these points should be visited in order to achieve a near optimal solution. The algorithm has been implemented into the GIS and allows for real time scheduling and re-scheduling. The advantages of the algorithm are that it is easy to implement and so can process a result in real time, which is ideal for real time computer aided dispatch. It has the advantage that it works with coordinates which is the direct output from GPS as well as GIS also being coordinate based. Figure 3 shows a sample route calculated by this algorithm for a simulated pattern of trip demands in a small suburban area. The route is shown as a series of straight line segments. These are displayed on top of the actual street network, and the driver can choose the exact path visually. Some of the disadvantages of the present algorithm are that as yet it does not cater for time windows, but this aspect is under further research at the Transport Systems Centre. It does not provide an exact path through the network for the vehicle to follow. For this to be achieved the exact position of the vehicle must be known. For example the minimum amount of information required would be which link the vehicle is on but ideally the exact position on the link should be known. From this a shortest path through the network can be calculated to service all customers. However if the GPS accuracy is only within 50m in tight street networks the vehicle could be identified as travelling on the wrong link, hence making the shortest path algorithm invalid. With 5m GPS accuracy the exact link the vehicle is on can be identified since a standard lane width is approximately 3.5m making the total carriageway at least 7m usually. Hence this higher accuracy GPS methods are more suited to these types of sophisticated CAD applications. However this aspect of computer aided dispatch is questionable. Should a computer tell a driver exactly what to do ? Or should a driver with extensive local knowledge and experience be allowed to make his owned decisions about which route is the best to take to reach the desired destination ?

Police helicopter applications

The South Australian Police Department and the Transport Systems Centre of the University of South Australia are taking the initiative of applying new technologies to law enforcement. Some 12 months ago the South Australian Police Department approached the Transport Systems Centre to discuss the possibility of using the Global Positioning System (GPS) together with Geographical Information Systems (GIS) to improve the performance of police operations. There were numerous areas in the police force that were identified as potential benefactors of these new technology products.

The factor that links all the identified areas is that they have a spatial dimension related to their operations. This is where the integration of GPS and GIS in real time such as in high speed chases, as well as stored post-processed geographical data that can be used as evidence can provide the biggest advantages.

Collaboration between the S.T.A.R. Division Helicopter Operations and the Transport Systems Centre has already begun in the developing of a prototype real time GPS/GIS system for helicopter operations. The helicopter prototype requires more research and development work to bring it to a fully operational level.

The prototype system built by the TSC was based on the extensive work that the TSC has undertaken in land vehicle tracking and real time GPS/GIS integration. There are many published references to this work (see Zito, R, Taylor, MAP and D'Este, GM (1995) and Zito, R and Taylor, MAP(1995)) as well as commercial products developed for the contract mining area which use real time GPS/GIS integration for incident detection and overall quality assurance applications. The use of real time GPS/GIS techniques in a helicopter is a novel application and increases the unknowns due to the different physical characteristics of a helicopter when compared to a land vehicle. The prototype system consists of a laptop computer connected to a GPS receiver in the helicopter. Software was written to integrate the GPS information into a GIS in real time. The layering capabilities of GIS allowed several different geographical databases to be overlaid. For the prototype a vector and raster representation of the Adelaide street network is being used. The raster map comprises digital aerial photographs of the Adelaide metropolitan area available from the Department of Environment and Natural Resources. This did not allow all streets to be identified easily, a raster image of the UBD street directory is required for this purpose and is also available commercially. The S.T.A.R. Division has identified the UBD raster image as crucial layer to the GIS system for the easy identification of street names so that this information can then be relayed to ground crew to cordon off offenders.

Vehicle engine performance and analysis system

The Energy and Engines Research Group are affiliated with the Transport Systems Centre at the University of South Australia. They have developed a system that predicts vehicle performance and emission parameters in realtime, called VEPMAS. This engine performance data is then combined with the spatial information given by an onboard GPS receiver, thereby giving a spatial dimension to the engine data. It is this combination that allows the data to be displayed and analysed in a GIS, in this way producing useful information.

The engine data captured by the VEPMAS system includes, the manifold pressure, engine speed (rpm), the total distance travelled so far, the percentage of oxygen in the exhaust, the gear the vehicle is travelling in, the temperature of the exhaust, the speed the vehicle is travelling at in km/h, the amount of fuel being used in g and the fuel rate in g/sec.. These are combined with GPS data such as the latitude, longitude and height of the point, the GPS fix type and the age of the GPS data. All of these GPS and VEPMAS variables give a comprehensive picture of where the vehicle has travelled and how its engine is performing in realtime. The info tool dialog box in figure shows some typical values that have been associated with each point in the journey.

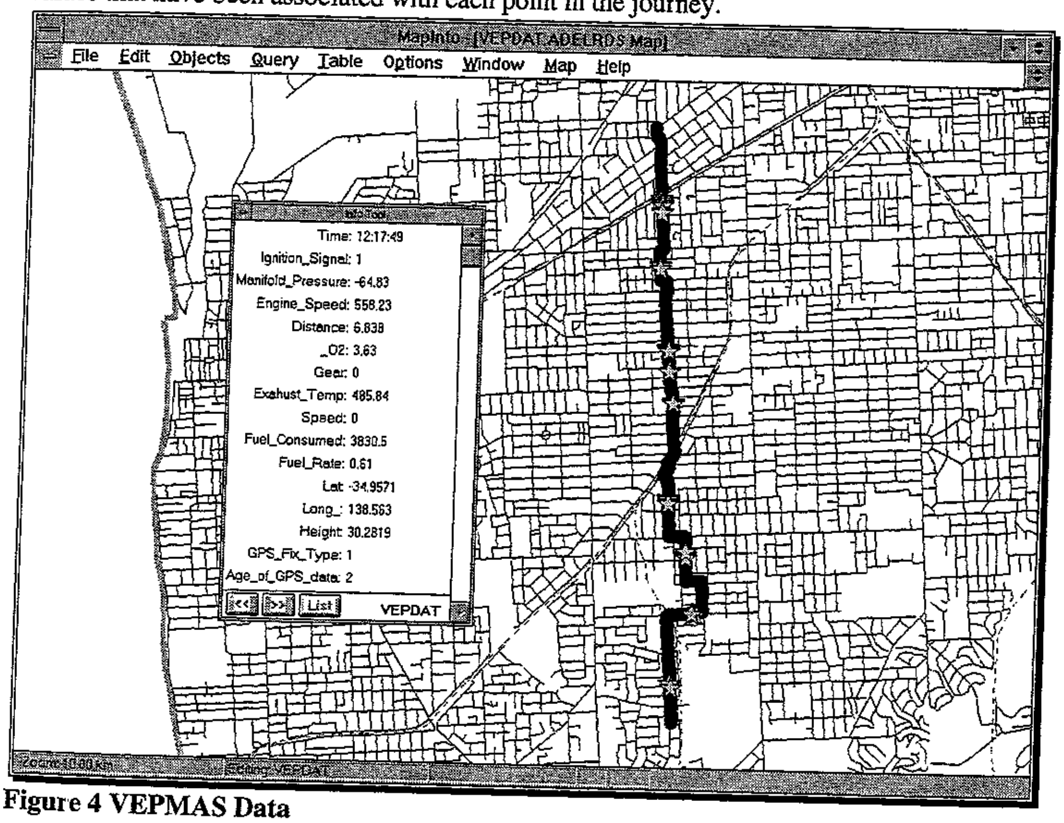

Figure 4 VEPMAS Data

The VEPMAS system has been developed to such a level that other emission parameters that are not logged in real time can be later derived with the use of engine maps. Some of the derived parameters include nitrous oxide, carbon dioxide and carbon monoxide emissions. These are all green house gases that must be controlled and monitored if benefits to the environment are to be achieved. All this data as well as the GPS data is being collected at rates of once per second. Therefore even over short periods of time huge amounts of data can be collected, the voluminous amount of data must be managed so that it can be turned into useful information, hence the need for a data management system such as GIS.

Figure 4 can be used to show where the higher concentrations of green house gases are found, and thus remedial actions can be selected to suit the specific locations. For example if another layer was to be added to figure 4 showing land use boundaries, then policies could be formed that would put strict environmental controls around residential areas, schools and public gathering places. These controls could then be lifted or relaxed in areas that were not as environmentally sensitive. This type of process is a good example of the advantages available with the spatial analysis capabilities of a GIS.

Another example of the spatial analysis capabilities of a GIS is also shown in figure 4, where the stars represent all points in the journey where the speed is greater than 50 km/h and the gear the vehicle is in is equal to 4 ie top gear. This is a simple example showing how queries can be displayed graphically. The map displaying this query shows the points along the route where the vehicle is travelling at the greatest speeds.

If this type of spatial analysis is repeated before and after an environmental control measure is adopted, then the benefits and or dis-benefits of the measure can then be quantified and an assessment made as to their effectiveness. This allows the policy maker to make more informed decisions as to which environmental control methods are likely to be successful in different situations.

The type of data being collected by VEPMAS and GPS can also help in assessing individual driver techniques. Since different driving strategies will produce different engine performance, and hence different emission characteristics. Drivers could be educated and trained to drive in a more 'green' fashion. Since 'green' driving usually leads to a reduction in fuel consumption, and hence a reduction in greenhouse gas emissions, these could be quantified using GIS analysis.

Conclusions

The increase in the accuracy and reliability of GPS has opened it up to many new and varied applications. By itself however the GPS system can only provide data, further processing is needed to turn this raw data into useful information for a user. The development of GIS and its integration with GPS both in real time and post processed has opened up many new applications that can now benefit from these new technology tools. The integration f the two systems has provided a total solution and examples of this solution have been described in this paper. The technology has arrived it is up to the users to make the best use of it !

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Real time traffic congestion sites on the internet

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http://www.club-internet.fr/sytadin/orly.htm