MRERA (MINIMUM RANGE ERROR ALGORITHM): RFID - GNSS INTEGRATION FOR VEHICLE NAVIGATION IN URBAN CANYONS

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ABSTRACT:

A new GPS positioning algorithm for vehicle tracking namely the "Minimum Range Error Algorithm" (MRERA) was proposed by E. Mok and L. Lam, to track vehicles in dense high-rise environments without the use of dead reckoning, and it can also be used for general geolocation positioning applications. With this algorithm, it is possible to identify which section of road network the mobile user is located, even when insufficient number of satellites are available for position fixing. This algorithm combines psuedorange measurements and coordinate information available in digital maps, used to identify which road section the GPS receiver falls into. Radio beacons should be available at regular intervals along the road network to transmit coodinate information for the MRERA processing engine to be able to compute the true range between the road point position and the available satellites.

This paper discusses the integration of the emerging Radio Frequency Identification Technology (RFID) into the MRERA. Different RFID tags are now availabe on the market and a selection of RFID's have been tested for the suitabilty of integrating into the MRERA. Particularly the type of RFID tags able to carry out long range commuincations under high dynamic conditions is suitable for this task. Such long range active RFID tags can be located along the road network and readers will be installed in the vehicles. Tests reported in the literature have shown that the tags information (e.g. the coordinates of its loctaion) can be read with vehicle speeds up to 150 km/h. If an insuffcent number of satellites in GNSS positioning is detected the integrated RFID - MRERA will be activated to estimate the vehicle's position. The RFID approach compared to other radio transmission devices will be discussed.

1.INTRODUCTION

Vehicle navigation systems have become popular in the last decade and are nowadays employed by many users. As most available systems rely manly on satellite positioning (GNSS) in combination with dead reckoning sensors for the measurement of the heading of the vehicle and the distance travelled, their ability for continuous position determination and reliabilty is affected by high-rise buildings causing obstructions of the satellite signals in urban environment. However, the dead reckoning method may not be convenient to drivers as installation and calibration procedures are needed. Moreover, the cost for setting up a dead reckoning GPS system is relatively higher than a stand-alone system which may not be acceptable by some vehicle owners. Mok and Lam (2001) proposed the "Minimum Range Error Algorithm" (MRERA) which is able to estimate vehicle positions even with three or less satellites. Mok et.al (2002) proposed the use of localization capability of GSM phones and the integration of determined positions in the vehicle navigation system by taking the advantage of the rapid developments in the electronics and wireless positioning technologies. It was then proposed by Mok and Xia (2005) a processing algorithm to enable integration of GPS with different wireless positioning data sources such as from WiFi and Ultra-Wide band systems. The algorithm was then further extended to the hybrid GPS and Wireless System for geolocation positioning in urban canyons (Mok and Xia, 2006) which incorporates the MRERA as an alternative positioning estimation method in case of bad satellite geometry and under adverse site conditions in urban canyons.

In this paper, application of the emerging Radio Frequency Identification (RFID) technology to enhance accuracy and reliability of the hybrid GPS and Wireless System is discussed.

2.THE MINIMUM RANGE ERROR ALGORITM (MRERA)

MRERA is a GPS positioning algorithm for vehicle tracking to locate vehicles in dense high-rise environments without the use of dead reckoning sensors. This algorithm can also be employed for general geolocation positioning applications. With this algorithm, it is possible to identify which section of road network the mobile user is located, even when insufficient number of satellites are available for position fixing.

The basic principle of MRERA is illustrated in Figure 1 below. Consider that a series of "road points" with known coordinates in WGS84 are stored in a road network database. A GPS user

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when travelling along a section of road and continuously receiving GPS signals from at least one satellite, the pseudorange measurement data and the geometric range computed from the satellite and road point coordinates can be obtained. By applying proper error corrections to the pseudorange data, the difference between geometric range and GPS range will vary with respect to the closeness of the GPS user and the road point. In other words, if the GPS user is travelling towards a particular road point, the range difference will be decreasing. The difference will reach its minimum value when the user is nearest the road point, then increasing when the user is moving away from the road point. This phenomenon is illustrated in Figure 2.

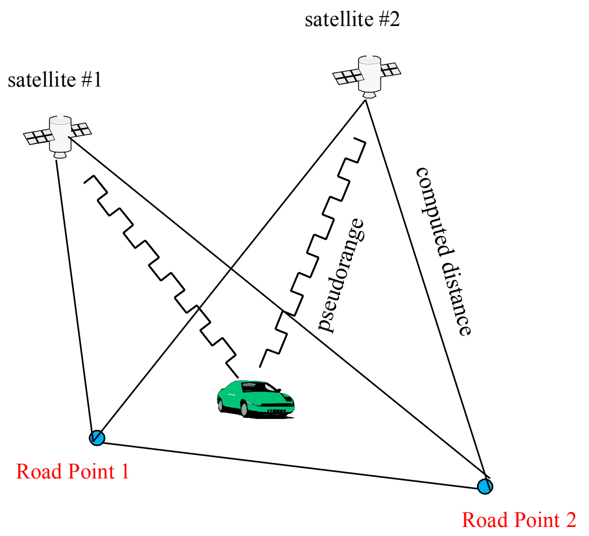

Figure 1. Vehicle's position between road points 1 and 2.

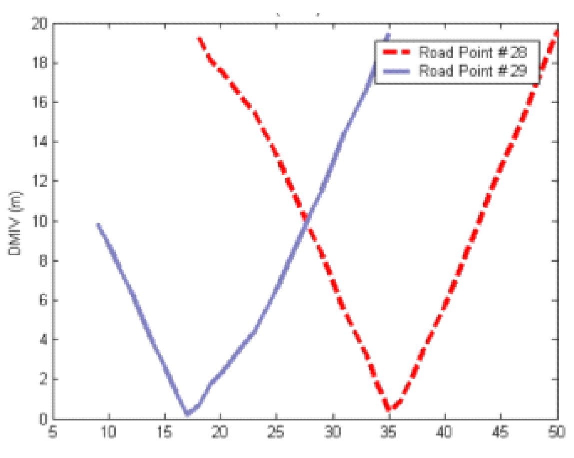

Figure 2. The minimum of the two curves represents the road points nearest the GPS receiver position

As mentioned above, proper corrections need to be applied to the pseudorange data for the range difference to be reliable for position estimation. The major corrections include ionospheric, tropospheric, multipath and receiver clock errors. The MRERA algorithm can also be modified to the differencing model, in order to eliminate the receiver clock errors which is very difficult to model for some low-cost GPS receivers. For details on the MRERA please refer to Mok and Lau (2001), and Mok and Xia (2006).

Improvement of the MRERA is under investigation for it to be practically used to supplement the GPS alone method when less than 4 satellites are visible, or when the receiver-satellite geometry is poor (large DOP value). However, it should be noted that the differencing model of MRERA may amplify other sources of errors, and the number of observations is reduced by one. It is therefore suggested that the un-differencing mode to be applied if receiver clock errors can be accurately modeled and predicted.

3. A HYBRID SYSTEM INTEGRATING MRERA AND WIRELESS POSITIONING

MRERA is a way to solve insufficient visible satellite, or bad geometry problem in dense high rise environments. However, when no satellite data is available, other satellite dependent positioning techniques such as WiFi and cellular network positioning could be applied to fill the gap.

Wireless communication with the IEEE802.11 networks, generally called Wireless Fidelity (WiFi) has become increasingly popular due to its low installation cost and high connectivity. Recent research has shown that indoor positioning with WiFi systems can generally achieve a positioning accuracy of 1 to 4 m indoor and 10 to 40 m in the outdoor environments (Retscher and Mok, 2006). WiFi is nowadays avaiable at many universities, in office buildings and public spaces. Therefore we suggest to use the radio signals to access points together with pseudorange observations to GPS satellites for position determination of a mobile user.

In WiFi positioning usually the signal strength to the surrounding access points is determined and used to obtain the position fix using the so-called fingerprinting method (Retscher et al, 2007 a). For that purpose an estimate of the location of the mobile device is obtained on the basis of these signal strength measurements and a signal propagation model inside the building. The propagation model can be obtained using simulations or with prior calibration measurements at certain locations. In the second case, the measured signal strengths values at a certain location in the building are compared with the signal strengths values of calibrated points stored in a database. Then the calculation of the location of a user takes place in two phases: an offline and an online phase. During the offline phase, which has to be executed only once for each building, a so-called radiomap will be composed. This radiomap can be considered to be a collection of calibration points at different locations in the building, each with a list of radio signal strength indicator (RSSI) values for visible access points at that particular location. This process is also known as fingerprinting. During the online phase, the calibration points are being used to calculate the most probable location of the user, whose actual location is unknown. The main disadvantage of the WiFi fingerprinting, however, is the time consuming and costly calibration of the system in the beginning. Therefore an approach has been developed where the measured signal strenght values can be converted directly into the ranges to all visible access points. This approach has been presented in Mok et al. (2006). It could be shown that the signal strenght can be converted in ranges even in unfavourable site conditions with high signal propagation errors. The success rate of the conversion was 90 % in a 20 m radius area surrounding the access point with the accuracy threshold set to 5 m.

Although WiFi positioning can fulfill the general geolocation positioning requirements in the indoor and some outdoor environments, positioning accuracy for location-based services (LBS) can be further improved with the emerging Ultra Wideband (UWB) technology, to enable more reliable, accurate and efficient emergency decisions. The increasing demand for high speed wireless transmission of multimedia information and precise geolocation positioning in indoor environments have led to specific interests on UWB; a radio-communication technology originally developed for military applications in 1960 (see e.g. Barrett, 2000). Using UWB it is claimed by product vendors that a positioning accuracy of 0.3 to 0.6 m can be achieved for indoor location determination (Alabacak, 2002; Eshima, 2002). It is not difficult to predict that, the fusion of UWB, GNSS and wireless networks will be the trend for providing sub-metre level (or less) ubiquitous 3-D positioning services. To enable successful development of such a system, it requires investigations into an optimized location model for UWB in indoor and outdoor environments, and ground network (like UWB, WiFi) and GNSS integration algorithms. The principle of the integration algorithm for location determination using different data sources was presented in Mok and Xia (2005).

4.PRINCIPLE OF RFID POSITIONING

Apart from WiFi and UWB another emerging radio frequency technique may be employed in indoor and urban environments for location determination of a mobile user. Radio Frequency Identification (RFID) is an automatic identification method based on trilateration measurements of a user in relation to “base stations”. It relies on storing and remotely retrieving data using devices called RFID tags or transponders. Typical RFID systems consist of transponders (called tags) with antennas and readers. Long range RFID tags can be placed at known locations and a user who carries a reader can retrieve the tag information (e.g. the 3-D coordinates of the tag) within the read range. The postion of the user can be then located using the network of the tags. The read range depends on the type of tag (active or passive). Long range tags are usually active tags with their own power supply and have a possible read range of up to 100 m. To achieve a higher positioning accuracy for location determination, the read range can be limited by reducing the sensitivity in the reader (Retscher et al., 2006).

A RFID tag is a small object that can be attached to or incorporated into a product and an object (e.g. an animal or a person). RFID tags contain silicon chips and antennas to enable them to receive and respond to radio-frequency queries from a RFID transceiver or reader. RFID tags can be either active, semi-active or passive. Passive tags require no internal power supply, whereas active tags require a power source. Lack of an onboard power supply means that the device can be quite small. For example, there exist commercially available products that can be embedded under the skin. As of 2006, the smallest such devices are measured 0.15 mm by 0.15 mm and are thinner than a sheet of paper (7.5 micrometres); such devices are practically invisible. The minute electrical current induced in the antenna by the incoming radio frequency signal provides just enough power for the complementary metal oxide semiconductor (CMOS) integrated circuit in the tag to power up and transmit a response. The passive tags do have, however, a smaller read range than active tags. Passive tags have practical read distances ranging from about 2 mm up to several metres depending on the chosen radio frequency. On the other hand, long range active tags with their own power supply could have a read range of up to 100 m. Another advantage is that active tags have larger memories than passive tags and the ability to store additional information (apart from the tag ID) sent by the transceiver. To economize power consumption, many active tags (or beacon) concepts operate at fixed intervals. At present, the smallest active tags are about the size of a coin.

In a typical RFID system, individual objects are equipped with a small, inexpensive tag. There are two ways to communicate between readers and tags, i.e., inductive coupling and electromagnetic waves (Finkenzeller, 2002). The tag contains a transponder with a digital memory chip that is given a unique electronic product code. The interrogator, an antenna packaged with a transceiver and decoder, emits a signal activating the RFID tag so it can read and write data to it. When an RFID tag passes through the electromagnetic zone, it detects the reader's activation signal. Using inductive coupling the antenna coil of the reader induces a magnetic field in the antenna coil of the tag. The tag then uses the induced field energy to communicate data back to the reader. The reader decodes the data encoded in the tag's integrated circuit (silicon chip) and the data is passed to the host computer. Inductively coupled RFID tags have been used for years to track everything from cows and railroad cars to airline baggage and highway tolls. Inductive coupling only applies to short distances and is used for passive tags only. Using active tags the reader radiates the energy in the form of electromagnetic waves. After the tag wake up, some of the energy is reflected back to the reader. The reflected energy can be modulated to transfer the data contained in the tag. Figure 3 shows a typical interactive flowchart of a RFID reader and an active tag and Figure 4 an example for an active tag and a PC card reader.

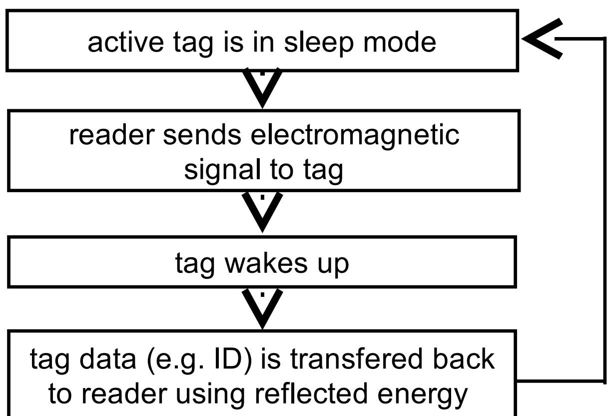

Figure 3. A typical interactive flowchart of a RFID reader and an active tag (after Retscher et al., 2006)

(a)

(b)

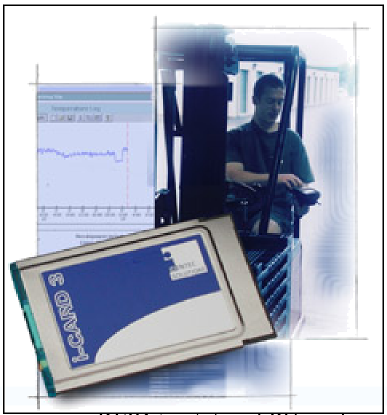

Figure 4. Long range RFID tag (a) and PC card reader (b) (Identec Solutions, 2006)

Three frequency bands are generally used for RFID systems. Low-frequencies (125-134.2 kHz and 140-148.5 kHz) and high-frequency (13.56 MHz) RFID tags can be used globally without a license. Ultra-high-frequency (868-928 MHz) tags cannot be used globally as there is no single global standard. In North America, UHF can be used unlicensed for 908-928 MHz, but restrictions exist for transmission power. In Europe, UHF is under consideration for 865.6-867.6 MHz. Its usage is currently unlicensed for 869.40-869.65 MHz only, but restrictions exist for transmission power. The North American UHF standard is not accepted in France as it interferes with its military bands. For China and Japan, currently there is no regulation for the use of UHF. Each application for UHF in these countries needs a site license, which needs to be applied for at the local authorities, and can be revoked. For Australia and New Zealand, 918-926 MHz is unlicensed, but restrictions exist for transmission power (Wikipedia, 2006).

The concept of RFID systems has been around since World War Two when the British Royal Air Force used the technology to identify friend and foe aircrafts. Since then, new technology combined with today's demanding competitive environment has made RFID more attractive and thus increasingly tested for real world applications. The use of RFID in tracking and access applications first appeared in early 1980s. RFID quickly gained attention because of its ability to track moving objects. As the technology is refined, more pervasive and possibly invasive uses for RFID tags will emerge.

The most common use of RFID in transportation and telematics is for electronic toll collection. Another proposed application is for intelligent traffic signs called "Road Beacons (RBS)" (Road Beacon, 2006). Such solutions are based on the use of RFID transponders buried under the pavement that are read by an onboard unit (OBU) in the vehicle which filters the different traffic signs and translates them into voice messages or gives a virtual projection using a heads-up display. Its main advantage compared with satellite-based (e.g. GPS) systems is that road beacons do not need digital maps associated with them, as long as they provide traffic sign symbol and actual position information by themselves. RFID road beacons are also useful for complementing GNSS systems in places like tunnels or indoors.

The significant advantages of RFID are the miniaturised unit, non-contact, non-line-of-sight nature of the technology. Some tags can be read through a variety of substances such as concrete, snow, fog, ice, paint, and other environmentally challenging conditions which cannot be achieved with barcodes or other optically read technologies. RFID tags can also be read in these circumstances at an amazing speed (< 10 milliseconds) (Identec Solutions, 2006).

Chon et al. (2004) have introduced a concept of a RFID positioning system for vehicle navigation. In their approach RFID beacons are installed along roads. On the tags accurate location information along with other necessary information is stored. The vehicles are equipped with RFID reader modules and they retrieve the information of passing-by tags. The RFID reader module is part of the vehicle navigation system and is used along with GNSS and a gyroscope for location determination. Using this approach the reliability and accuracy of position determination in urban areas and in tunnels is significantly improved. Tests have been performed concerning the vehicle speed to read the tag's ID and it was reported that the vehicle can travel with a speed of up to 150 km/h to read the tag's information. Figure 5 shows a concept for location of active RFID tags along a major road (e.g. a highway). The active RFID beacons will first be installed alternately along the road boundary lines and the centerline where the initial minimum distance between the tags is chosen at a distance of 25 m. This value has to be varyfied in field tests to obtain the required minimum distance between the tags. It is expected that the distance will depend on the maximum speed of the vehicles along the selected road segment.

For traffic flow monitoring it could be also considered to equip vehicles with RFID tags and have readers installed at certain waypoints along the roads. Then it is possible to determine the number of vehicles passing by a certain location and monitor their way along certain road sections.

3.SIMULATION STUDY FOR THE INTEGRATION OF WIRELESS TECHNOLOGIES WITH GPS

Simulations have been performed to validate the feasibility of integrating wireless technology with GPS (see Mok and Xia, 2005; Retscher et al., 2007 b). For that purpose a test network was selected and the scheme is designed for simulation of hybrid location scenarios based on a static GPS network. The lengths of the baselines in the network range from 15 m to about 35 m, which can simulate effectively the possible ranges for WiFi, UWB and RFID. Using the RFID as a distance source we can also deduct the range from the reader installed in the vehicle to the RFID tags in the surrounding environment. If it is possible to establish a communication between the reader and the tag then it is known that the user is located nearby the tag in a circular shape cell with an radius equal to the possible read range. In reducing the sensitivity in the reader it is then possible to estimate the range to the tag with an accuracy of a few metres. So the deducted range to the RFID tag can be used similar to a GPS pseudorange. Figure 7 shows the positioning result if ranges to two satellites and three ground transmitter stations are used. As can be seen from Figure 7, the 3-D coordinates can be determined with a standard deviation of a few metres and the maximum deviations are within 30 m. Figure 6 gives results from two GPS satellites and two simulated ground stations, in the initial stage, satellite PRN 30 has lower elevation and deviation is somewhat larger. DOP values and their changes are shown in Figure 8 if one more ground station was added.

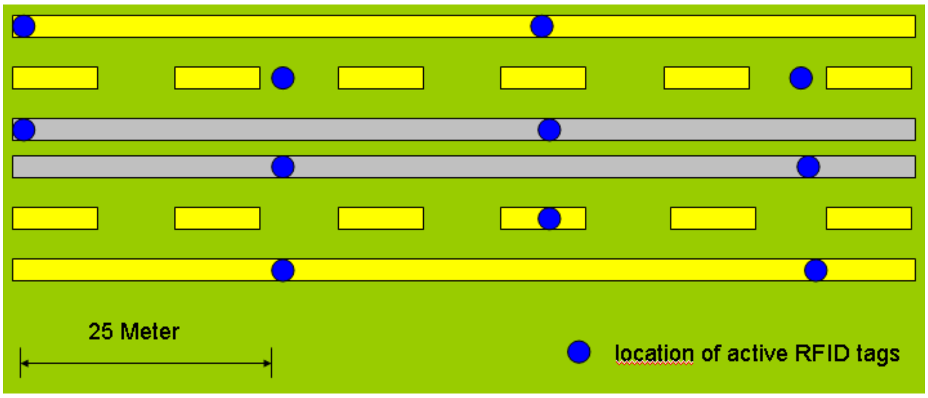

Figure 5. Concept for the location of active RFID tags along a highway

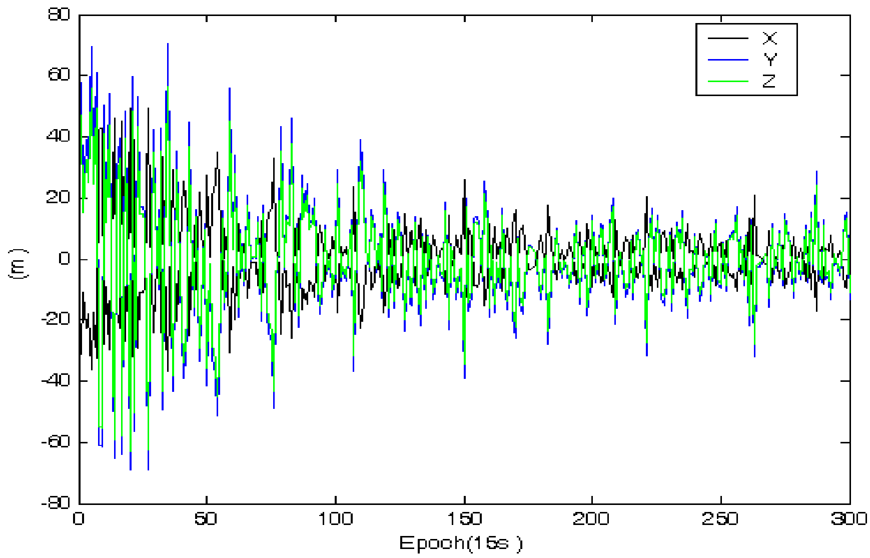

Figure 6. Positioning results of X, Y, Z coordinates if ranges to two satellites (PRN22 and PRN30) and two ground transmitter stations are used

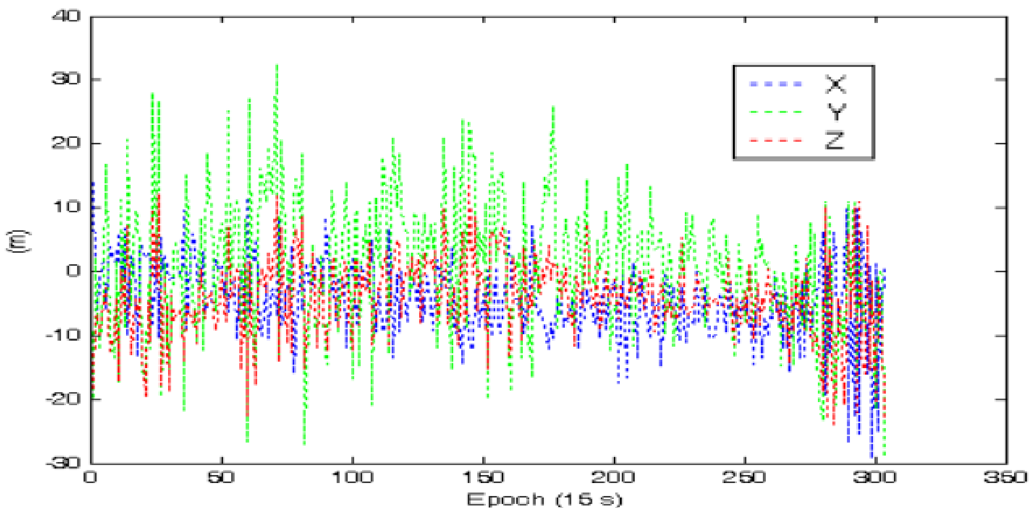

Figure 7. Positioning results of X, Y, Z coordinates if ranges to two satellites (PRN18 and PRN22) and three ground transmitter stations are used

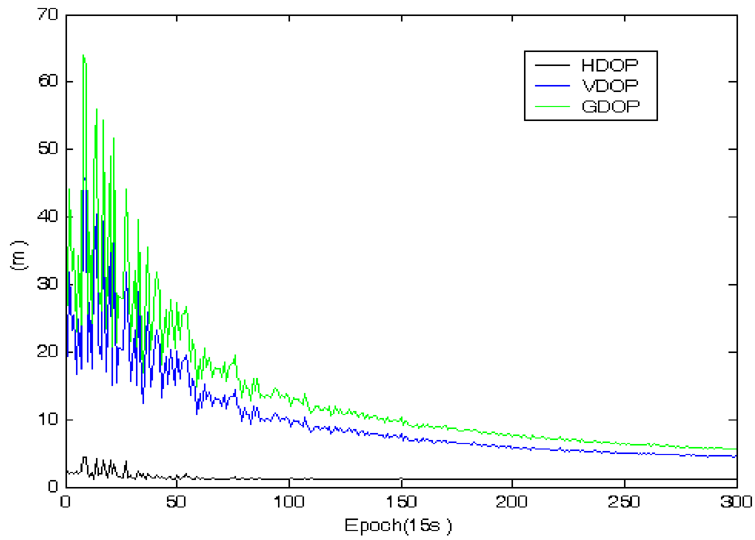

Figure 8. DOP factors and their changes using two satellites (PRN22 and PRN30) and three ground transmitter stations for positioning

In the tests it was found that when only two satellites were visible as under the case of an urban canyon situation and two simulated ground station were employed, the positioning outputs are sensitive to the satellite distribution in the sky. The result will be obviously improved when the number of satellites is increased to 3. On the other hand, if one more ground station was added, performance of horizontal solutions can be remarkably enhanced as reflected in Figure 7. Tests also show that the geometrical location of the ground transmitters in respective to the satellites has to be considered.

4.CONCLUSIONS

In the future research the integration of RFID positioning with GNSS and other wireless positioning techniques such as WiFi and UWB will be performed. The presented hybrid GPS and wireless positioning system designed based on authors' past research efforts has been proposed for the integration of all available data. This system makes full use of all available positioning information and state-of-the-art geolocation positioning techniques possible to provide ubiquitous positioning in both indoor and outdoor environments. The following investigations are however necessary in the development stage:

1. Successful identification of road points based on the MRERA Indicator Value (MIV) is very much dependent on accurate modeling of receiver clock errors, further investigation is needed on a clock error prediction model. The authors have started investigating combining height constraints when height information can be extracted from GIS, and Autoregression (AR) models to tackle the complicated clock error cases (see Mok and Xia, 2006).
2. Accuracy and reliability of the MIV and DMIV (Differential MRERA Indicator Value) values could be further improved if multipath effects could be reduced and more accurate ionospheric models are applied.
3. It is possible to use MRERA and combined data processing model for position determination. However, a decision making algorithm to select the optimum solution under different site conditions, data availability and data quality is necessary.
4. The accuracy achievement of RFID positioning under different indoor and outdoor urban environments and the range deduction to the surrounding RFID tags needs further investigation.
5. In addition, if Assisted GPS service is available, integration of AGPS into the proposed system could improve the accuracy and reliability. Again, an intelligent algorithm for deciding adoption of MRERA, AGPS and combined processing methods for optimum solutions is necessary.

5.ACKNOWLEDGEMENTS

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7.BIOGRAPHICAL NOTES

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