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Metropolitan Area Geographic Positioning System using Kytoons

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Abstract

Kytoon based navigation and radio positioning using concepts underlying Global Positioning System (GPS) are advocated for a low cost Metropolitan Area Geographic Positioning System (MAGPS). Technological implications of achieving the positioning acccuracies offered by the Precise Positioning Service (PPS) in this context are examined. Analogous to the concept of differential GPS(DGPS) system the design implications for improving accuracy are outlined. Stabilized Kytoons (four for 3-dimensional position) are required to be hoisted in appropriate locations in the Metropolitan Area so that the entire city comes within the line of sight of all the Kytoons. These Kytoons provide on independent active reference for position determination. Describing the principles of aero-dynamic design of kytoons, the spatial stability as it affects the position measurements are examined and approaches to their correction are suggested.

Borrowing design principles from the DGPS as employed in the erstwhile differential Omega and Transit System, the design of the kytoon based differential geographic positioning system can be optimized. While ionospheric and tropospheric errors found in DGPS are avoided here, the ephemeris(position) errors, clock errors, multi-path and receiver errors are relevant, though in a controlled manner, and do not pose much problem due to the much lower distance between the kytoons and the user receiver. From these considerations, it is shown that the performance using differential operation gets substantially improved in the kytoon based DGPS.

Among the applications, the measurement of several types of pollutions over the city, ground truth, utility mapping, vehicle location, tracking etc. are recommended. The cost effectiveness of kytoons makes such a system a low cost proposition.

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1. INTRODUCTION

The recent strides in GPS and DGPS technologies have brought about new designs of subsystems for the space segment, control segment and user segment for navigation and positioning applications.[1] These new developments have opened new possibilities for the revival of the kytoon technology which had been developed more than two decades ago to high levels of sophistication. According to the scheme presented here, the satellites in the space segment of GPS can be substituted by a near distance triad or quad of kytoons typically tethered at heights of 1 to 2 kilometers. The kytoons can transmit a continuous string of data on L-band frequencies which is the frequency employed for GPS . These frequencies are biphase modulated by pseudo-random codes utilizing the same code structure as in the case of GPS to maintain compatibiliity with GPS usage, and carry data message from each kytoons. The receiver used can thus be of a similar design as GPS and is addressed as KGPS receiver in the scheme presented here.

In a city, the control segment can be situated in a single suitable location to monitor and evaluate the kytoon transmitted data from each kytoon . It will also monitor the clock and ensure synchronisation between the kytoons. The computed correction data in the form of integrity data can be broadbase to an appropriate kytoon via the uplink. This, in turn, will broadcast the data to all suitably equipped KGPS users. For a 3-dimensional positioning, four kytoons would be required, while three are adequate if only 2-dimensional (latitude and longitude) positioning is needed In order to ensure that four kytoons are always available over the given area, an additional active spare (fifth) kytoon can be hoisted to take over the function of any malfunctioning or unavailable kytoon From each of the four kytoons signals are acquired by the user receiver KGPS for obtaining psuedo ranges so that the 3-dimensional positioning and time giving speed of a moving user receiver can be calculated. As with the GPS principle, the KGPS receiver determines the transit time for the signal to travel from the kytoon to the receiver by cross correlation of the pseudo random code transmitted by kytoons with that of a copy of the code generated locally. When these transit times are multiplied by the wave velocity, it converts the values from time to distance units, called the pseudorange, which in turn, leads to the position determination.

The transmission conditions between the kytoon and the user receiver are such as not to pose any communication problems due to the fact that the pseudorandom coded transmissions are used, which, with even low power of transmitter can achieve large ranges. Further, as four kytoons are used to cover a metropolitan area, no gaps or shielding affects are likely to be observed. Besides the control station working as an integrity monitoring station, ensures that user receivers are provided with integrity/ reliability information on kytoon signals.

The differential GPS concept works on measuring the errors in the radio position solution obtained using the GPS receiver at some known location, which in turn, is transmitted through VHF, UHF, HF or MF radios etc. to the GPS users in the form of corrections to the measurements. The same principle applies in the case of Kytoon based system also. The appropriate communication link for transmitting these corrections depends on the covered area, acceptable signal delay, the geographic distribution of users and the reliability.

The kytoon based system, however, avoids a number of electronic equipment which are basically motivated by the need to contend with moving constellation of satellites. In the case of the kytoons which are relatively stationary, a number of equipment such as Control and Monitoring Stations and Satellite electronics can be avoided. However, the kytoons will not retain the positional integrity with time to the extent required for accurate(PPS) level of position resolution. For this the control station is required to have equipment which will measure the extent of position perturbation over the kytoons over their mean location, both statistically as well as deterministically. The statistical measurements which are slowly changing, will use the mean value, standard deviation and skew factors for the positional perturbation over the mean fixed location. The statistical indices are sufficient for lesss precise applications like pollution measurements, whereas deterministic estimation of the positional perturbation would be required for more precise position applications like vehicle positioning, rapid transit transportation management system and precision utility mapping. Certain special equipment are required for such estimations.One mechanism can be to use DGPS receivers in the kytoons to determine real time position through GPS measurement and then developing differential corrections from ground(at monitoring station) and transmitting them to the kytoons.

Kytoons or tethered balloons resemble a balloon filled with light gas to generate buoyancy while it resembles a kyte for generating aerodynamic lift forces under wind conditions. The kytoons while afloat take up a stationary position in equilibrium with the aerodynamic, aerostatic and gravitational forces. The positional perturbations basically arise from the time varying dynamic pressure due to the wind forces. The balloon nose would dimple or cup if it does not have a greater internal pressure to overcome this.dynamic presssure The cupping creates a large increase in the drag. An internal pressure of 5 to 220 cm. of water column is maintained in the hull, depending upon the size of the kytoon and an internal pressure of 7.5 to 9 cm. of water column is maintained in the fins used for stabilization. The aerodynamic drag results from the disturbances created in the air flow as a result of the resistance offered by the body of the kytoon. The drag is minimised by giving a suitable aerofoil shape to the body. The aerodynamic drag coefficient depends on the fineness ratio which is defined as the ratio of the length to the maximum diameter of the body. Therefore, the body is given a lift force to counteract the drag force by inclining the longitudinal axis of the body to the direction of the air flow. These two indices, namely, the fineness ratio and the angle of attack, determine the aerodynamic lift and acts as a reaction through a body point on the longitudinal axis, called, the centre of pressure.

Kytoon moves about its three axes - longitudinal axis, rotational axis of rolling and rotational axis of yawing. The lateral axis is a straight line through the centre of gravity at right angles to both the longitudinal and the normal axis. There is also a rotary motion about the lateral axis, called, pitching. Contemporary kytoons have four fins for stability, two vertical and two horizontal. The vertical fins stabilise the kytoon in yaw, while the horizontal fins stabilise it in pitch. In order to minimise the positional perturbation described above and hence increase the accuracy of positioning, the stability in pitching is achieved by designing the aerofoil and the fin structure so that the distance between the center of gravity, G and the centre of pressure, P, called static margin, is not less than 0.15 times the characteristic length of the kytoon. Also it has to be ensured that the distance between the centre of buoyancy, B and G, called the metacentric margin, is atleast 0.03 times the characteristic length of the body.

Experimental studies have shown that the body of revolution with a fineness ratio of about 3.3 has the minimum drag. The geometry of the kytoon is given in Fig. 1. Fig. 2 gives the centre of pressure of the body versus fineness ratio of the nose.

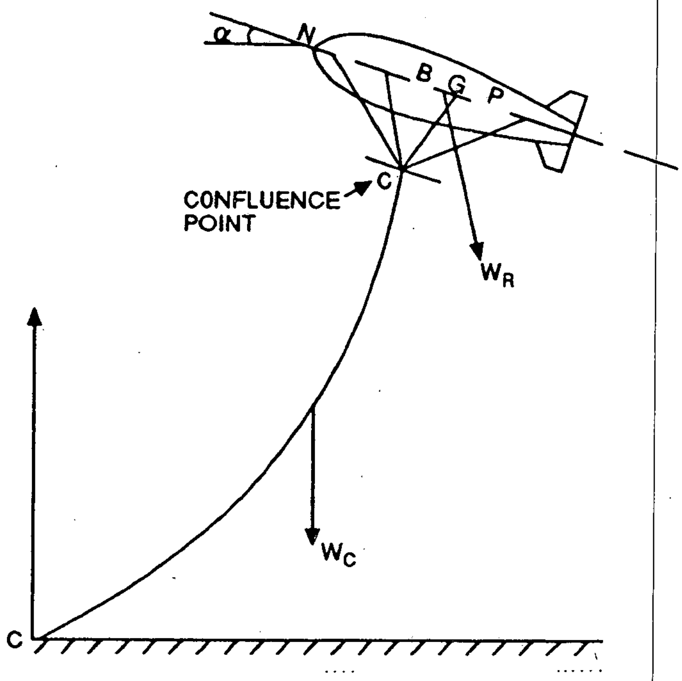

Fig. 1. Geometry of kytoon

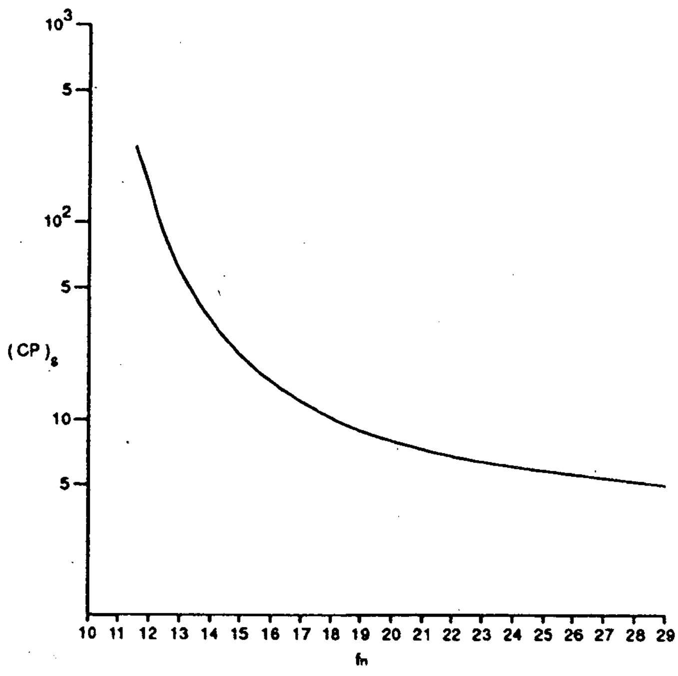

Fig. 2. Centre of pressure off the body $(CP)_B$ versus fineness ratio of the nose (f_n)

Fig. 3 calculates the centre of buoyancy and centre of gravity of the body versus fineness ratio of nose along with calculated centre of gravity of the bodies. These experiments were conducted by the SAC-TIFR on the Kytoon of 275 cubic meter volume (2). The SAC-TIFR Kytoon experiments have given valuable insight into the design parameters required for minimising the drag and hence the positional perturbation. A carefully designed Kytoon on these lines can given adequate resolution for most applications with only statistical corrections applied. This is because, except in very rare cases, the atmospheric turbulence over the metropolitan area and the relative motion between the four kytoons on account of changes in wind velocity, will be extremely small, because the wind velocity is not expected to be substantially different in the four different kytoon locations. Using the relatively higher precision of location of the four kytoons, simple ground based measurements and corrections can be applied.

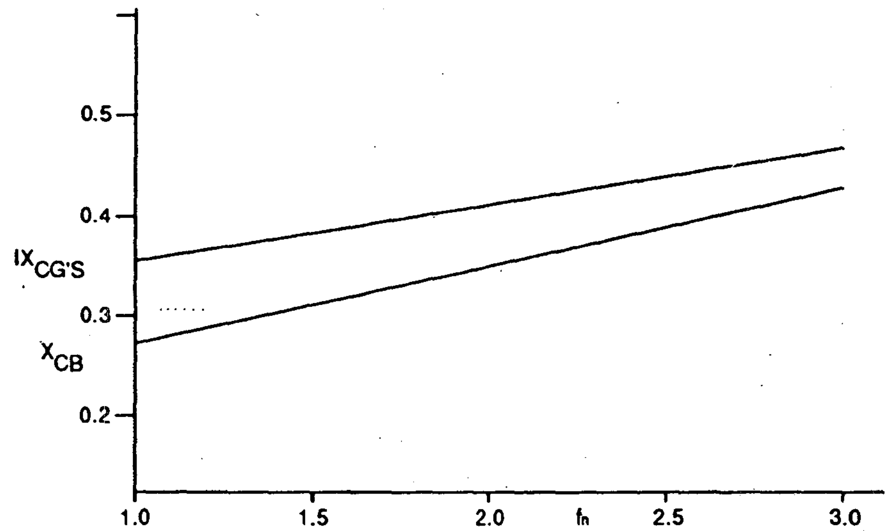

Fig. 3. Centre of buoyancy (X_{CB}) and centre of gravity of body (X_{CG}) $_B$ versus fineness ratio of the nose (f_n)

2. DIFFERENTIAL KYTOON-BASED GEOGRAPHIC POSITIONING SYSTEM (DKGPS)

The basic concept of DKGPS is similar to the one employed in differential Omega or differential GPS. This is shown in Fig. 4. In this application, the reference station consisting of a kytoon based user receiver and a correction receiver is set up. The corrections so determined at a given known location are broadcast to all user receivers. The radio link used for such broadcast can be any of the conventional links such as UHF, VHF, or HF/MF radio depending on the area to be covered, and data rates needed. No ionospheric or tropospheric errors due to signal propagation caused as a result of traversal of satellite signals through the atmosphere are encountered here due to the nearness of the kytoons to the user receivers. The ephemeris errors, clock errors and multi-path errors which contribute a small error to the total error budget, can be controlled through a suitable design of the user receiver.

CONCEPT OF DIFFERENTIAL GGPS

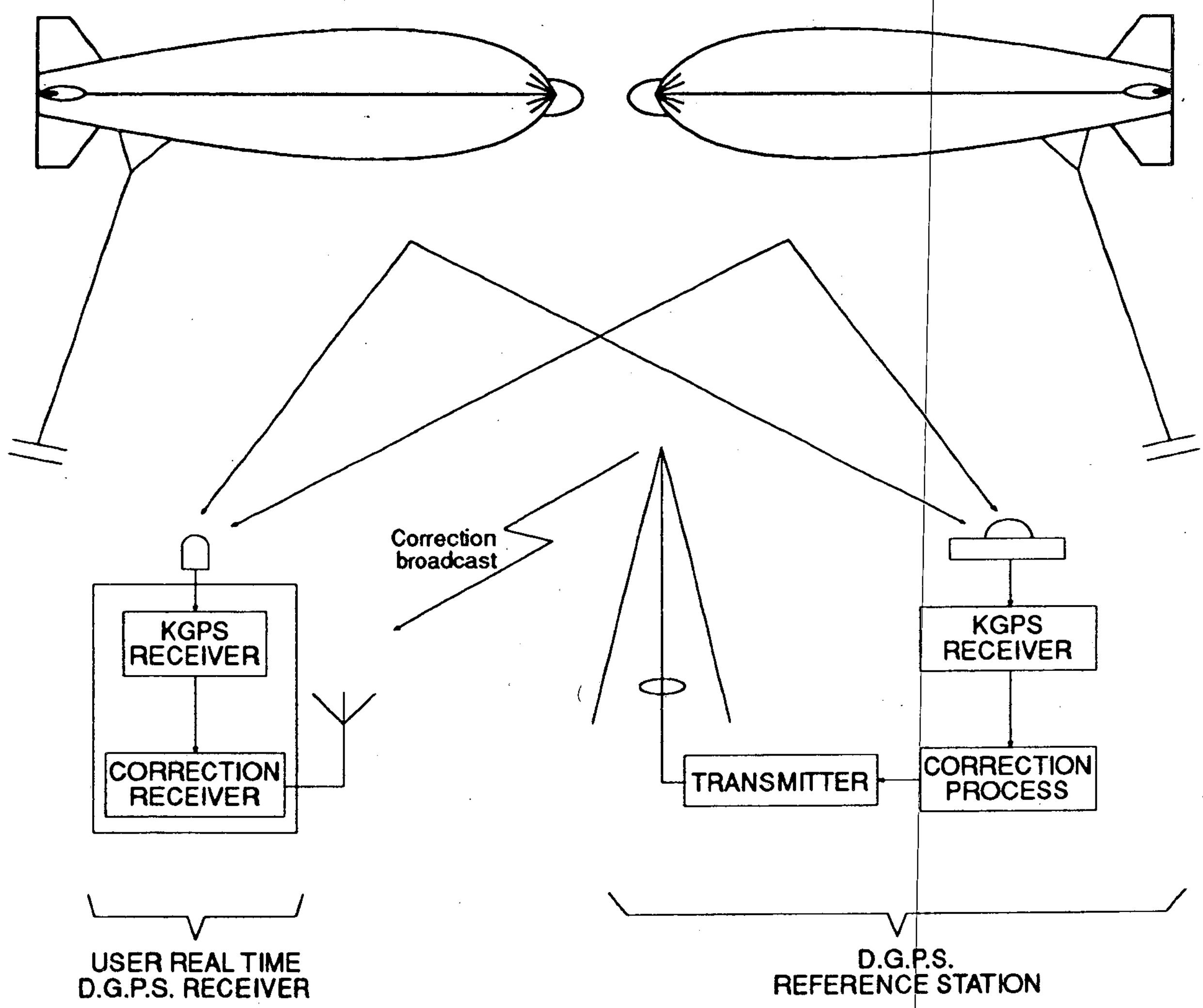

Fig. 4. Concept of Differential KGPS

Such a differential operation can help in determining the user position to within 10 meters of accuracy in real time, as is the case with differential GPS operation. Further, as in the case of conventional DGPS operation, all the three approaches of communicating error from the reference station to the user receiver are possible. These are: transmission of differential corrections in navigation coordinates as ΔX, ΔY and ΔZ; differential corrections of the above type to be superimposed on the kytoon type navigation data generated from reference station; and differential corrections to be transmitted in the form of errors in the pseudo range to all the kytoons. Out of these three approaches, one in which the pseudorange errors to each kytoon are computed, is the most appropriate. The data formats for transmission of differential corrections are maintained the same as what have been already suggested by various international committees such as RTCM, RTCA, etc. in order to maintain the standard in design of user receivers.

The design of reference station is simple, in that it only uses a user receiver of KGPS type from which the corrections are computed knowing the exact location of the station. The corrections in positioning are then transmitted through simple radio communication link. For computation of corrections the reference station receiver is organised as shown in Fig.5. A typical configuration of reference station using MF/HF radio is shown in Fig.6.

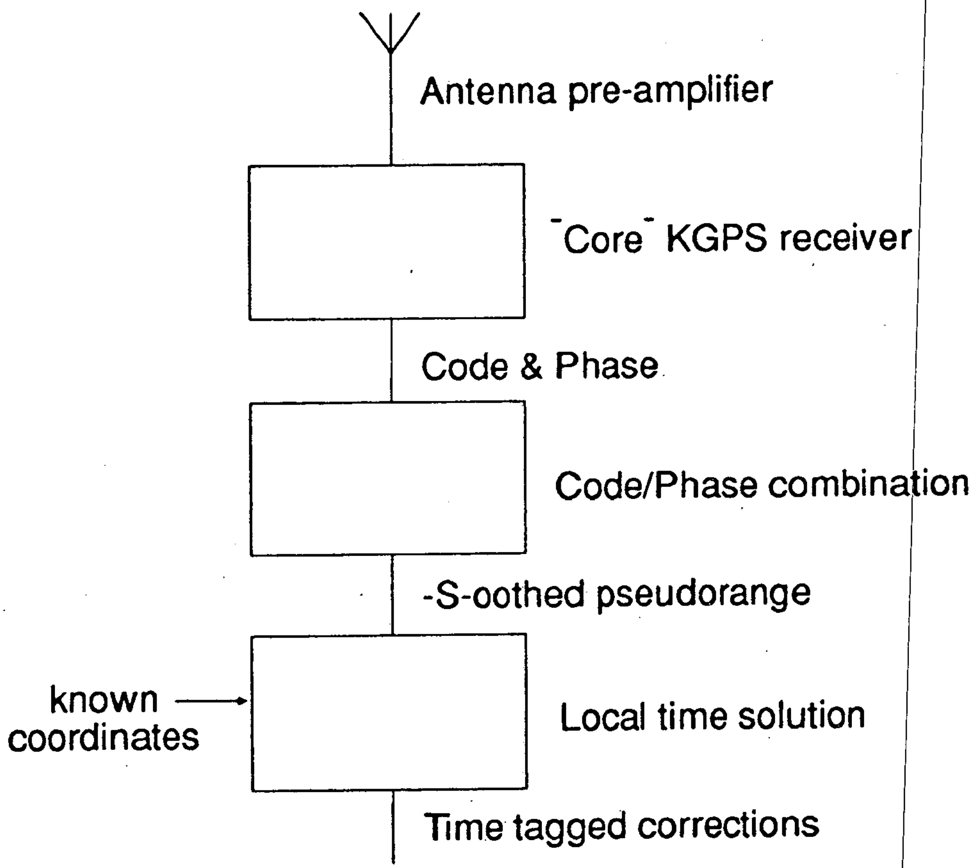

Fig. 5. Organization of DKGPS Reference Station Receiver

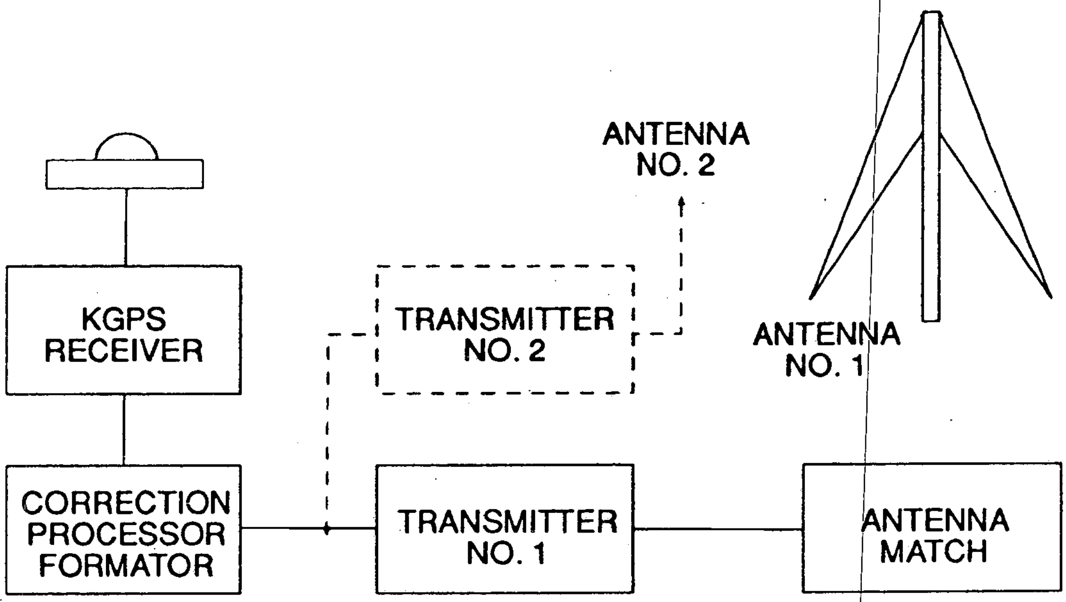

Fig. 6. DKGPS Reference Station Configuration

In order to extend the area of coverage in a metropolitan city and avoid any obstructions of Kytoon signals and the line of sight limitation, the differential operation can be achieved by transmitting the error signals from the reference station to a kytoon which in turn, broadcasts these error signals to all the users located in the area of coverage of the kytoon. Frequency of such broadcast corrections can be kept same as that of the kytoon signals, namely L-band, so that the user receiver can receive the normal navigation signals from the kytoon as also the correction signals. This, therefore, works on the same principle as a wide area differential GPS being experimented upon for a wider area coverage.

3. KGPS/DKGPS APPLICATIONS

DKGPS system as described above has the potential to meet the accurate positioning requirements of various users dealing with vehicle location and traffic management, utility mapping, precise ground surveys, oil exploration, etc. KGPS system, however, serves other applications not requiring high position accuracy.

Metropolitan Area Pollution Monitoring

Using an appropriate instrumentation package consisting of pollution sensor and a KGPS/DKGPS receiver, it is possible to dynamically monitor the profile of pollution spread over a metropolitan city. It will also help to provide a plot of pollution migration as a function of time and space. Knowing this information, corrective steps could be taken to control the pollution or identify areas where pollution can be prevented. Such measurements could also be extended to coastal areas.

Ground Truth Measurement

Using a suitably equipped DKGPS receiver, various ground truth data can be collected on various survey sites for an off-line mapping and survey. The receiver can store a variety of information fed manually into it together with the position information as the user moves over the survey area. This data stored in the receiver could be off loaded to a computer for analysis.

This concept can be extended to a detailed and accurate ground utility mapping application. In this the work connected with laying of water or gas pipelines, drainage pipes and construction sites can be accurately carried out.

Ground Survey

As in the case of conventional differential GPS application, the DKGPS scheme helps in accurate ground survey as also offshore survey. Since much of the analysis for survey is done in a post-processing mode, considerable amount of data can be collected over different locations for such off-line accurate survey including oil explorations, and plotting charts.

Vehicle location and Traffic Management

The GPS is increasingly being used in vehicle location and guidance applications. Its usage in a dense city traffic area has special signficance. Such an advantage is equally derived in the use of DKGPS system at a much lower cost at the same time. A low cost DKGPS receiver in a vehicle would enable its accurate position to be determined in real time. Such positions can be monitored centrally by a traffic centre for a metropolitan city and guidance information can be provided.

This concept can be extended in online control of the fast transit transport system in a metropolitan area. In this case a central monitoring and control station would receive the real time accurate position data from the fast moving transport to enable efficient control and monitoring.

Fishing Vessels Monitoring

Fishing requires repeating the exercise of fishermen going and collecting the fish from fish shoal concentration areas regularly. This exercise can be improved if accurate position of the fishing boat can be traced and retraced in every journey. This can be achieved through the use of conventional DGPS technique. The KGPS/DKGPS receiver lends itself for a convenient use on a fishing boat in offshore areas under the foot-print coverage of kytoons.

Remote Area Monitoring

A number of applications in disaster management, remote construction sites, flood forecast and management and monitoring over remotely laid pipelines require accurately known position of the sites where work is carried out. Such applications can be adequately served through KGPS/DKGPS systems.

4. COST EFFECTIVENESS

The kytoon based MAGPS with the extensive line-of-sight achievable, the free space electromagnetic environment, correspondingly simple and low powered equipment carried aloft and the myriads of usagess, is a highly cost-effective system. To quantify the cost-effectiveeness of the kytoon based MAGPS, one needs to compare cost of satellites and control segment of the GPS with that of kytoons and the monitoring station for the given area of coverage, reliability and life. This requires extensive costing of the operational system. However, suffice to state that while a US $ 10 B GPS of USA is to cover the globe, a kytoon based MAGPS would not cost more than even a US $ 1 M to cover a big metropolitan area. The DKGPS is also consequently a cost-effective approach to serve accurate positioning applications in a given metropolitan area.

5. CONCLUSION

A scheme of the Metropolitan Area Geeographic Positioning System (MAGPS) using Kytoons has been presented. It is derived from the concepts used in the Global Positioning System (GPS). The cost-effectiveness of Kytoons makes this scheme a low cost proposition.

Four kytoons with a fifth spare one are proposed which transmit at L-band frequencies by phase modulated pseudorandom codes of the same type as used in GPS, carrying data messages. A control/ monitoring station evaluates the signals transmitted by the kytoons and sends integrity data to all users. The user receiver, KGPS, simple low-cost of GPS type, can give position accuracies of around 100 m. For applications requiring 10 m. accuracy, a differential kytoon based GPS, DKGPS, a system analogous to the scheme of DGPS, is proposed.

A number of applications relevant to a metropolitan city area operations are suggested. These include pollution monitoring, ground truth measurement, ground survey, vehicle location and tracking etc.

REFERENCES

[1] Arora, R.K. and Meharde, R.C.,Global Positioning Technology and Applications, Proc. Intl. Conf. on Globalization of Computer & Communication : Perspectives for Developing Economies, Tata Mcgraw-Hill, Conf; Bombay, Nov. 25-27,. 1993.

[2] Report of the Panel on Utilisation of Tethered Balloon Technology, Electronics-Information & Planning, Vol., 5, No. 3, December 1977