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Evaluating the Positional Accuracy of GPS enabled Smart Phones using RTK-GPS.

[1] D. Ravi Kanth, [2] K. BalaGopi Krishna, [3]B. Ravali, [4] M. Narendra

[1,2, 3]Assistant Professor, Department of Civil Engineering, Vignan's Foundation for Science, Technology and Research, Vadlamudi, Guntur, India-522212.
[4]Assistant Professor, Department of Civil Engineering, Chalapathi Institute of Technology, A.R. Nagar, Mothadaka, Amaravathi-522016

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Abstract:
Global Positioning System (GPS) has become a potential tool for capturing positional information. This study investigates the factors that affect the accuracy of GPS receivers and how accurate the positional information obtained by smart phones. This test starts with collecting data by considering two different scenarios, open area to represent ideal conditions and build up area in AIT campus with characteristics of urban type. In the analysis it became evident that positional accuracies obtained from individual Smart phones and Hand held receiver were different in different timings of the day and in different environments. The HTC and LG Nexus5 has given accuracies around 4-7m whereas Garmin has given accuracies around 3-5m during night time and in the morning time the positional accuracies of HTC and LG Nexus5 are around 4-8m but the Garmin receiver has given highest amount of positional error i.e. around 9m. In the second analysis the accuracies of smartphones were device dependent and type of environment. The smartphones (HTC Desire, LG Nexus 5) gives better accuracies in urban type of environment than Hand held receiver (Garmin Oregon 550t). From these results the functionality of GPS in smart phones tells us we no longer need to own a standard GPS unit for navigation and in other applications which doesn't require higher accuracies like detection of earthquakes of magnitude larger than 7, in agriculture for estimation of crop water, agriculture land management and coastal monitoring by geo-tagging the images.
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***Keywords:**GPS, HTC Desire, Garmin Oregon 550t, Geo-tagging.*

I. INTRODUCTION

Global Positioning System (GPS) has become an integral part oflife. It has become more and more important for land surveying, geodesy, cadastral surveying and marine surveying etc. but unfortunately, GPS do not guarantee centimeter level accuracy[1]. Though GPSreceivers are reliable still there exists an uncertainty, positioning measurements of GPS is influenced by multipath, durations of a day, arrangement of satellites in the sky, clocks of receiver and geographic regions.Though RTK-GPS is the most accurate one, it is also affected by surrounding buildings and trees whichwill affect the positioning measurements. Several GPS accuracy tests were conducted to determine how positional accuracies vary with open sky environments and tree canopies.[2]stated that GPS accuracy also affected by tree canopy when the antennas of GPS is at a lower than the tree height, as the height of antennae decreases, the surrounding vegetation blocks the view of antenna and it is similar to elevation mask of setting[3]. So understanding the factors which affecting the positioning accuracies could help us to achieve better accuracies. More than a decade GPS (Global Positioning System) has become an aid in navigation, since it implementation by US Department of Defense the no of users has been increasing, providing its service to unlimited users. The satellites utilizes the one way time ranging concept broadcasting theirEphemeris, pseudo range and carrier phases on two frequencies i.e. L1 (1575.42 MHz) and L2 (1227.6 MHz)[4].Even though they transmit on two frequencies, 90 % of users are using L1 frequency this is due to fact that most of the single frequency users are people who embedded GPS receivers in the mobile phones and low consumer grade or standard GPS users and rest of them were using double frequency receivers for scientific and geodetic applications [6].

Mobile phones with GPS receivers have been available since 1990s, in 2014 there were 960 million mobile phones sold that incorporated GPS and it is also giving positional accuracies on par and more accurate than standard GPS receiver [7]. It is providing more conveniences to people for e.g. GPS in cell-phone can provide information of restaurants within a certain distance, traffic information and weather information of a region (Location based services). [8]When a person visiting unknown place or new city, knowing one's own location in the outdoors and as well as indoors is generally a basic necessity for people .

So using a smart phone we can compute our positions calculate routes and to geo-localize images. We can also get locational information by different technologies like AGPS (Assisted GPS)[9], positioning using Wi-Fi positioning and cellular networks. Most of the smart phones are single (L1) frequency receivers and they use GPS and GLONASS constellation to identify position. But we don't know the accuracy of positioning measurements obtained by these smart phones, there are number of factors which affects the accuracy of GPS receiver. The GPS signals undergo different transformations while travelling through atmospherecausing signals time delay, urban canyons which cause multipath and also geometry of satellite being used. For achieving better accuracies it is essentialto know about different sources of positioning errors in these sensors. So our objective is to find the positional accuracy of smart phones containing inbuilt GPS receivers and hand held GPS receiver considering outdoor and urban canyon scenarios and comparing them.

II. Review of Literature

A. Study Area

The study area is AIT (Asian Institute of Technology) which is in Pathumthani province, 25 miles north of Bangkok, Thailand. It is located at 14˚04ʹ44.82ʹN 100˚36ʹ40.88ʹE. Pathumthani is one of the central provinces of Thailand.

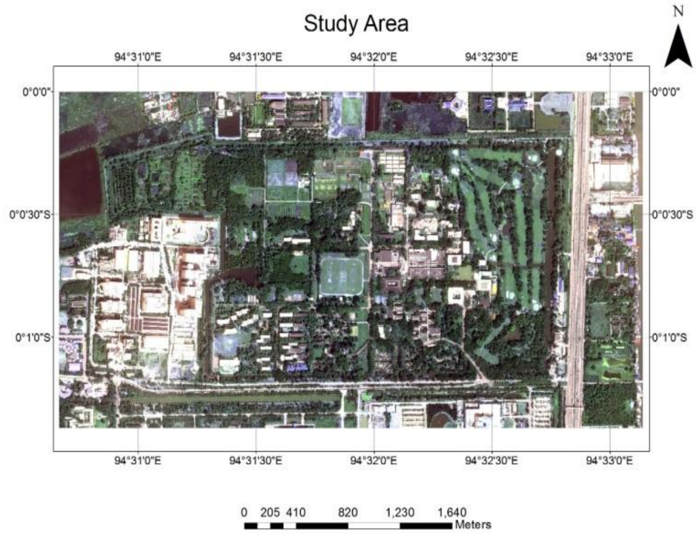

Figure.No. 1. Study Area

The accuracy of positioning measurements collected using three positioning modes (A-GPS, WIFI and Cellular positioning) from IPhone is evaluated using different methods. A-GPS positioning measurements are evaluated using benchmarks available in the region and compared to consumer grade receiver. The Cellular and WIFI positioning measurements are evaluated using high resolution imagery and the results indicate that A-GPS modefrom IPhoneis much less accurate than those from regular GPS showing (median error of 8m)and it is sufficient for most location based services (LBS).WiFipositioning measurements shows (median error of 74 m) and error is due to calibration in WIFI positioning system. WIFI positioning measurements fail to meet published accuracy specifications. Positional errors. Cellular positioning is the least accurate positioning method (median error of 600m)out of three positioning mode from IPhone.

In any Mapping projects, data collection is an inexorable part and success of any GIS mapping project depends on collection of accurate spatial data. [9]Alsotested the accuracy of two regular GPS devices and GPS-enabled IPhone-devices within an urban landscape. Availability of GPS enabled smart phones (IPhone) at low cost, making these devices very attractive to community-based mapping projects. [10] Also compared the four receivers at 15 different locations, overall results indicated that the Garmin GPS receiver provided the greatest relative accuracy within an urban landscape and relative accuracy ranging from 3.65 m to 6.50 m. Enabling these devices reliable for community-based mapping approaches, such as urban storm water management. In this study smart phones when compared with benchmarks and RTK-GPS [11]. The accuracy of these smart phones is obstructed by geographic area of region.

For Coastal Monitoring a smart phone based technique has been used and evaluated the accuracy of data such as images, three-dimensional coordinates, and attitude obtained from smartphone. First, calibration is performed on smartphone camera by determining intrinsic orientation of camera. The results of calibrated and non-calibrated are similar or slightly better.3-D coordinates obtained from assisted GPS (A-GPS) which is embedded in the smartphone showed lower accuracy[11]. Accelerometers and Magnetometers were used to calculate the attitude showed a standard deviation of 0.33–2.04° when compared with ω, φ, and κ of extrinsic orientation (EO) parameters. From the acquired images and Digital elevation model from terrestrial laser scanners, an orthophoto is generated. Using these ortho rectified images shore line maps are generated and its profile of a representative cross-shore also composed. The results described the actual intertidal zone well. From the results of Horizontal, vertical positional accuracies of extracted shore line, a smart phone based technique is considered for coastal monitoring application.

[12] Conducted a study on measuring the performances of two smart phones i.e. IPhone 4 and Samsung S5 stating that smart phones are having a difficulty to record the raw measurement data or having a direct access to internal sensors. The accuracy of the GPS enabled smart phones positioning measurements depends mainly on the environment(in terms of Land use/ Land cover) satellite visibility which is also affected by the constellations that a receiver can track and multipath. However, precision and accuracy improvements could be realized by computing a differential positioning solution.

B. Measurement of Performance

To evaluate positioning errors there is basically a benchmark which will evaluate positioning measurements with respective to the existing ones. In this study we have detailed each criteria for evaluating and comparing of these positioning methods and its measurements. Accuracy is defined as how close will be a measured locationto its true position (unknown location) while precision refers to how close an estimate is to mean estimate If the measured measurement is closer to actual measurement then the measurement is more accurate. Sometimes there is a possibility of high accuracy but low precision. In the below figure, the center of circle represents known position and Dot represents the estimated measurements.

Any positioning accuracy is limited by three types of Errors. Gross, Systematic and Random Errors, Gross errors are result of equipment malfunction or

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man-made errors like not setting up correct height of antenna these can be corrected, Systematic errors are those which biases the observations like Atmospheric errors these can be removed from observations by modeling [13].

Gross errors are result of equipment malfunction or man-made errors like not setting up correct height of antenna these can be corrected, Systematic errors are those which bias the observations like Atmospheric errors these can be removed from observations by modeling. When we remove gross and systematic errors only random errors are remained.

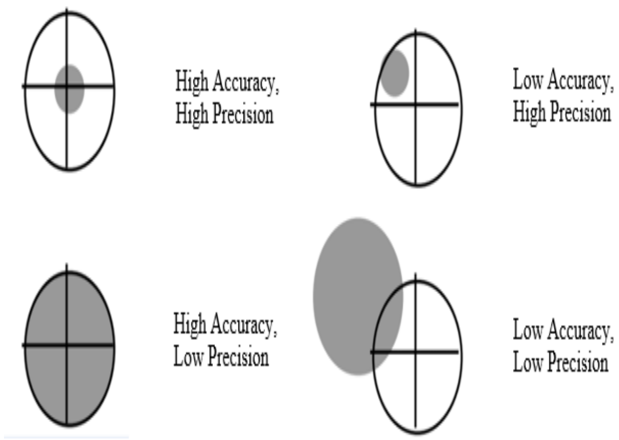

Figure.No 2. Accuracy and Precision

In statistical theory,Random errors are dispersed around the mean following a normal distribution and they also have a property that if sufficient observations are made there is equal chance of obtaining positive and negative errors, yielding a mean value of zero. The area under the curve represents all potential random error outcomes according to the theory of normal distribution[13].

The standard deviation is represented by the symbol σ (Sigma) which is used to quantify the dispersion of observations around the mean and is shown on the Gaussian distribution (Figure 3). The Normal distribution function describes the relationship between theobservation around the mean. For example, deviation of 1σrepresents that 68.3% of observation dispersed around the mean (the percent of the area under the curve in Figure 3 bounded by ±1) and a 95% probability is associated with 1.96σ

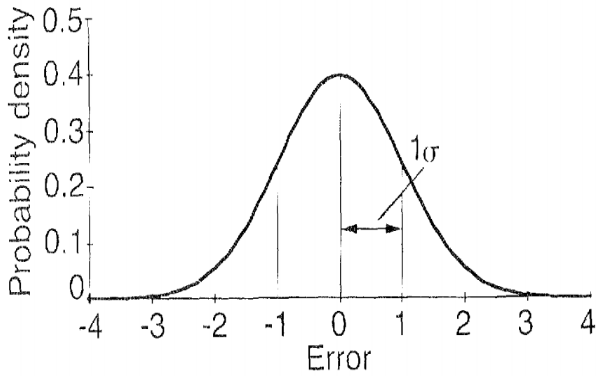

Figure.No 3.The Gaussian Probability distribution function.

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For evaluating the accuracy of positioning measurement, widely used function is the square root of the mean of squared errors (RMSE). Where RMSE is given by:

$$\text{RMSError} = \sqrt{\frac{1}{N}}\sum_{i=1}^{N}[\text{Xmeasured}(k) - X(T)](\frac{2}{1})$$

Where T is True Position or Known Position, N the number of measurements and k is the index of the measurement. The two dimensional accuracy is mainly used in mobile positioning also calledas horizontal accuracy stated as 2D RMSE if RMSE score is used. 1 D accuracy is nothing butanelevation accuracy, we use different evaluation measureslike Circular Error Probability (CERP) for 2-dimensional accuracy measure and Spherical Error Probability (SERP) for 3-dimensional accuracy cases. 2D-CERP is the most widely used unit. Example, 95% CERP within 50 meters means that 95% of the location measurements are within 50m from the true location. Error probability can also be used to set limits for maximum inaccuracy allowed.

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III. METHODOLOGY

A. Reconnaissance Survey

To obtain positioning data from Smart phone, RTK and Hand held receiver.First reconnaissance survey is done to check whether there exists any actual or original coordinates exist in the study area. The Base Station of GPS is setup on known location (i.e. on School of Engineering and Technology (SET) in AIT Pathumthani Bangkok, Thailand.In the study area, there is no complete type of urban environment. Most of the study area is of semi urban and open type environment. So classification of zones is based on interferences and elevation angle.

Figure.No 4.a) Base station set up b) RTK-GPS Rover set up

Figure.No 5 Devices

B. Setting up devices and Data acquisition

A typical GPS survey system set up is made of a Base and Rover. Base station is setting up over a known point and it collects data at known location, measure the errors and send these data to Rover. Rover receives these data and makes corrections for the data collected at unknown location.To set up the Base receiver, we already have the base station receiver on the top of SET building. To set up a Rover receiver, RTK GPS TRIUMPH-1 by Javad were utilized to collect the field data. One was set as a reference station which located at a known point. Others were used as the rover that can move and survey any points of interest. Both receivers make observations of the GPS signals at the same time. Then, data from reference will be sent to rovers; thereafter the calculation of coordinates is done by the assistant of the radio data link. VHF and UHF frequency communications systems are well suited for this communication. Two smart phones (HTC Desire and LG Nexus) and Hand held receiver (Garmin Oregon 550t).

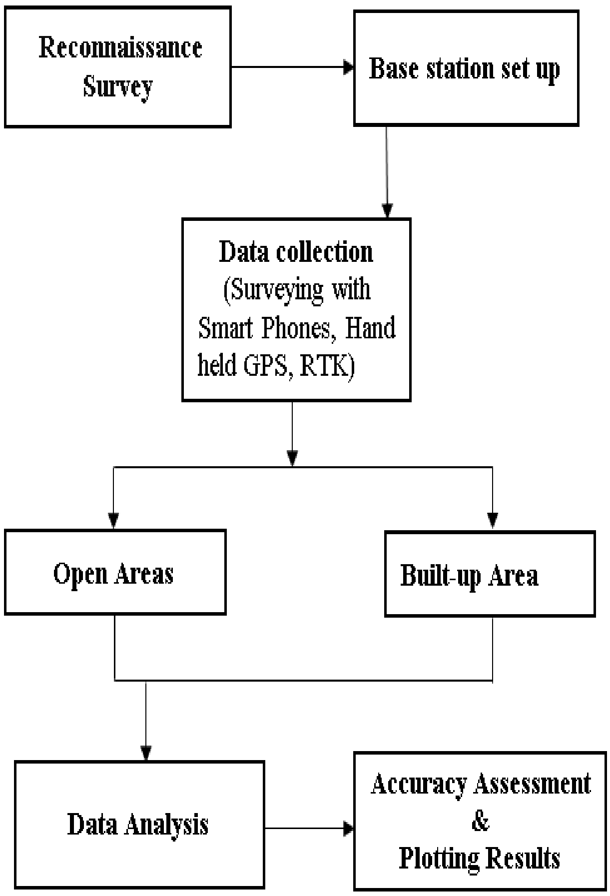

Figure.No6 Conceptual Framework

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Data is collected around semi- urban and open type of environments by four devices (Garmin Oregon 550t, HTC Desire, LG Nexus 5 and RTK). Total 40 observations were taken in the afternoon. To know how accuracies vary with time of the day, we collected 3 observations at 5 minutes interval by each device at open and urban scenarios in the night and in the morning total 60 observations were made.For these devices no post processing is required. Finally data analysis and plotting the results of positional accuracies of these devices is done.For this study we don't have any actual coordinates exist in the study area, so we considered measurements taken from Static GPS data as actual coordinates.For measuring error we subtracted measurements taken from static GPS data and four devices. We calculated the positioning errors only for North-East direction, because we cannot take measurements in Z direction using mobile phone.After that we calculated Mean (Accuracy), Standard deviation (Precision) and 2D CERP

V. RESULTS AND DISCUSSION

The horizontal positioning errors of the three different devices displayed different error behavior and produced different accuracies under different environmental conditions.

Table.No. 1.Error Statistics in Open Environment

Devices	RMSE (m)		Mean (m)		Standard Deviation (m)	
	N	E	N	E	N	E
Garmin Oregon 550t	2.05	3.11	-0.94	2.25	2.32	2.58
HTC Desire	2.49	4.72	-1.19	2.30	3.18	1.62
LG Nexus 5	3.84	3.00	-1.94	2.00	3.86	2.73

Table.No.2. Error Statistics in Urban type of Environment

Devices	RMSE (m)		Mean (m)		Standard Deviation (m)	
	N	E	N	E	N	E
Garmin Oregon 550t	2.86	4.09	-2.37	3.30	1.86	2.68
HTC Desire	8.33	3.51	1.95	2.97	9.05	2.28
LG Nexus 5	3.50	4.22	-2.71	3.30	2.45	2.94

From the table error statistics in urban type of environment, these results indicate that the LG Nexus 5 was affected by multipath more than HTC Desire and Handheld receiver. Accuracy (mean) is less for LG Nexus 5 than the other two devices but Precision is high for LG Nexus 5 than the HTC Desire.From the results we can clearly say that Accuracy is more for Smart phones and Precision is more for Hand held receiver.When we observe the accuracy of these devices in open environment Garmin's hand held receiver accuracy and precision is more than the Smart phones. When we observe the accuracy of smart phones LG Nexus gives less accuracy and Precision than the HTC Desire.

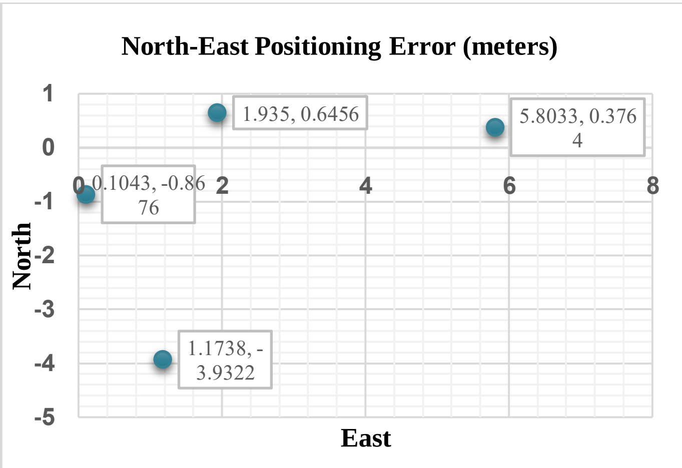

Figure.No 7 North-East positioning error in an open areas for Garmin Oregon 550t

we observe in open areas the maximum positioning error for Garmin receiver in north direction is -3.93m and minimum error is 0.37m. In the East direction maximum error is 5.8m and minimum error is 0.1m.

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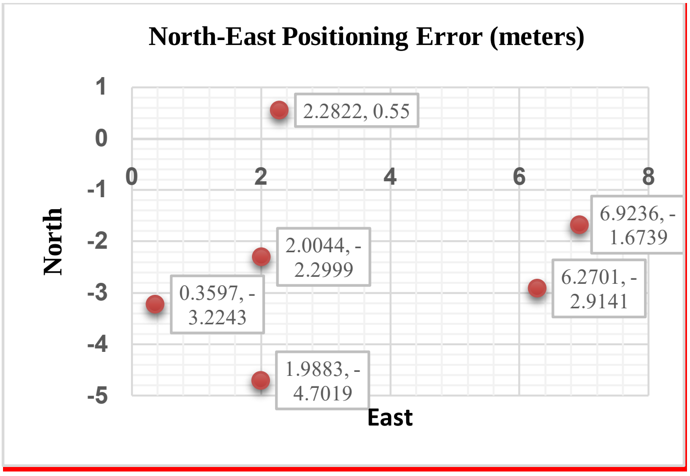

Figure.No 8. Horizontal positioning error in an Urban Canyon for Garmin Oregon 550t

we observe in Urban type the maximum error for Garmin receiver in north direction is -4.7m and minimum error is 0.55m.In the East direction maximum error is 6.92m and minimum error is 0.36m.

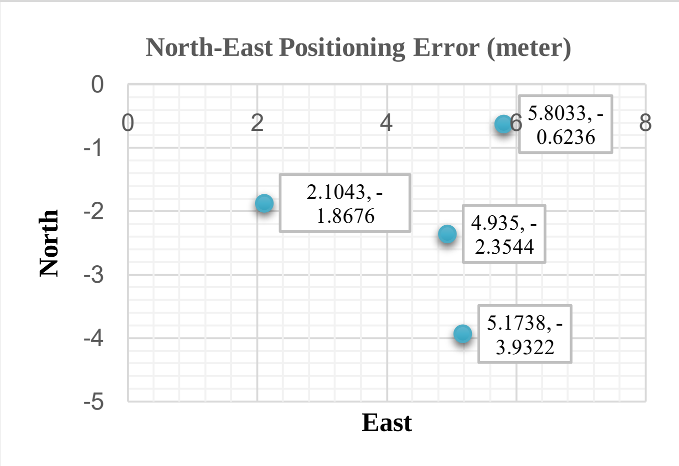

Figure.No9 North-East positioning error in an open areas for HTC Desire

In open areas the maximum positioning error for HTC Desire in north direction is -3.93m and minimum error is -0.62m.In the East direction maximum error is 5.8m and minimum error is 2.1m.

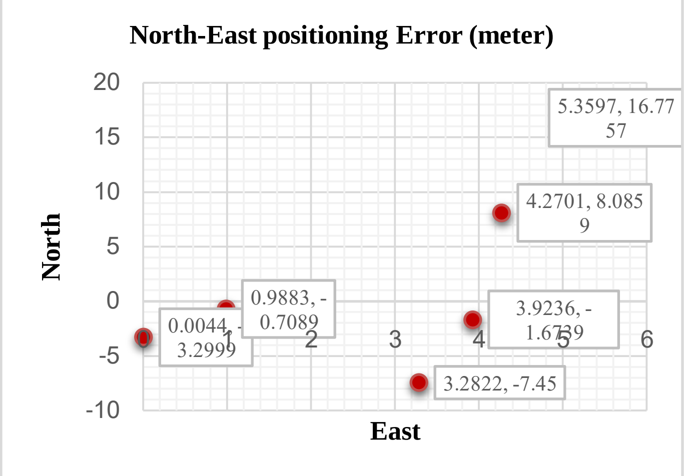

Figure.No10.North-East positioning error in an Urban Canyon for HTC Desire

we observe in urban type the maximum error for HTC Desire in north direction is 16.77m and minimum error is -0.7m.In the East direction maximum error is 5.3m and minimum error is 0.1m.

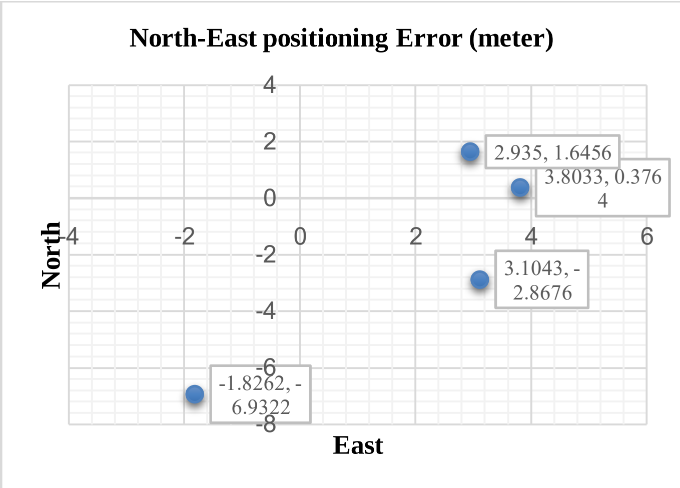

Figure.No 11.North-East positioning error in an open areas for LG Nexus 5

we observe in open areas the maximum error for LG Nexus in north direction is -6.93m and minimum error is 0.37m.In the East direction maximum error is 3.8m and minimum error is -1.9m.

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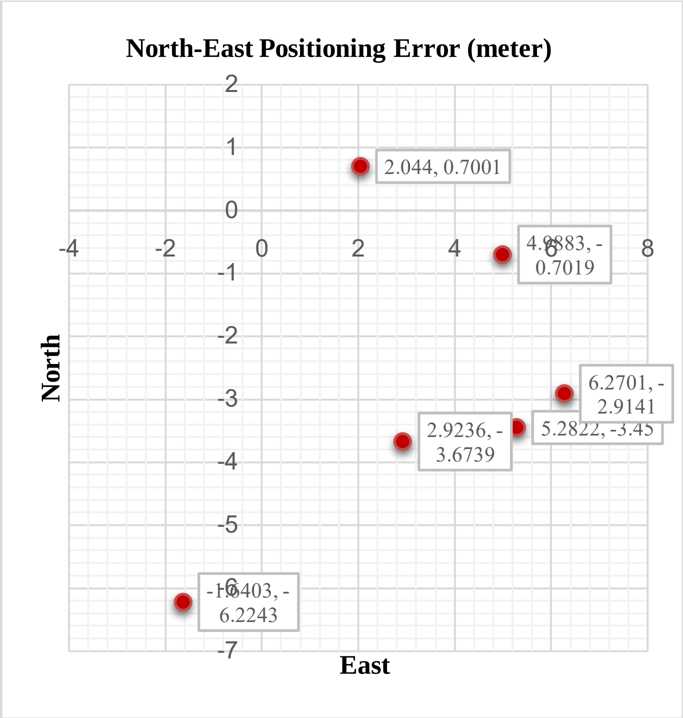

Figure.No12.North-East positioning error in an Urban Canyon for LG Nexus 5

we observe in urban type the maximum positioning error for LG Nexus in north direction is -6.22m and minimum positioning error is 0.7m.In the East direction maximum positioning error is 6.27m and minimum positioning error is -1.6m.

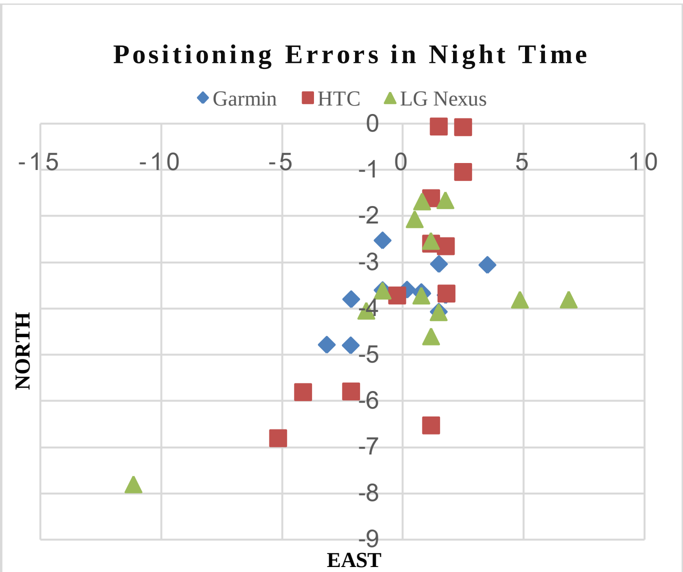

Figure.No 13.Positioning Errors in Night Time

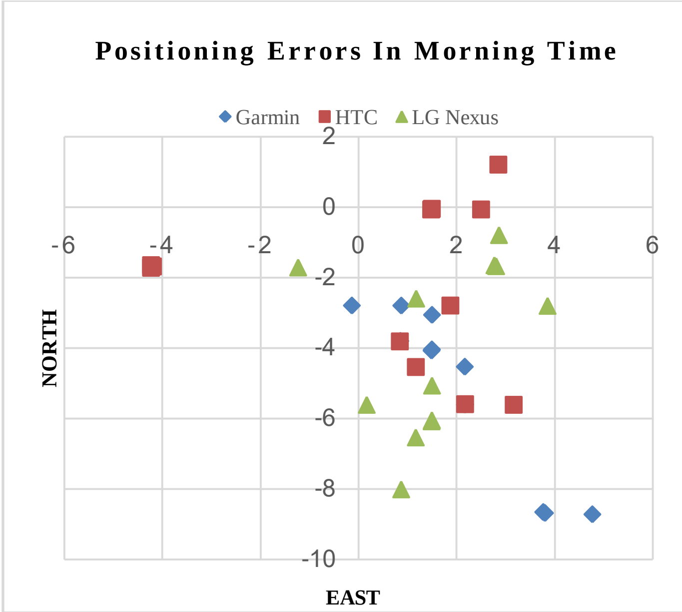

Figure.No14.Positioning Errors in Morning Time

The positioning errors are south east direction, compared to night time the position accuracies weremore affected, this is due to ionosphere errors. Out of these three devices Garmin has given highest amount of error i.e. in urban environments.

Error statistics in the morning and night time, we clearly see there is difference in positional accuracies of same device taken at same location. The difference in positional accuracies may be due to ionospheric errors, in the morning time due to solar radiation the ions in the atmosphere gets activated concentration of ions also increases results in delay of GPS signals.

With these accuracies we can generally map on to large scales, generally there is no standard scale of map. A map is classified as based on different scales i.e. (small scale, medium scale and large scale). Large scale shows smaller areas in more detail.For large scale map generally the range is 1:0 to 1:600000 and the accuracy of GPS in smart phones ranges from 2-5m during night times and in the morning times 3-6m. So if we want to map a town with smart phones the scale range is 1:5000 for a town. 2:5000 m represents 2m object on a map is 5000m on real world. i.e 0.0004m that is very small on the map. With these we can map a place with high level of detail.

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Table.No. 3. Error Statistics of Open Environment in the Morning and Night time

Devices		RMSE (m)		Mean (m)		Standard Deviation (m)		HDOP (m)	2DCEP (m)
		N	E	N	E	N	E		
Garmin Oregon 550t	Morning	5.270	2.164	-5.246	2.164	6.454	2.651	3.017	5.258
	Night	3.893	2.109	-3.847	0.261	4.129	2.237	2.5233	3.699
HTC Desire	Morning	5.270	2.313	-5.246	2.164	6.454	2.833	2.744	5.371
	Night	4.163	1.164	-3.579	0.998	5.099	1.426	2.554	3.332
LG Nexus 5	Morning	5.192	0.956	-4.912	0.831	6.358	1.171	3.047	4.287
	Night	3.677	1.067	-3.579	1.164	4.504	1.307	2.410	3.740

Table.No. 4. Error Statistics of Urban Environment in the Morning and Night time

Devices		RMSE (m)		Mean (m)		Standard Deviation (m)		HDOP (m)	2DCEP (m)
		N	E	N	E	N	E		
Garmin Oregon 550t	Morning	5.759	2.569	-5.180	2.039	6.109	2.725	2.972	5.110
	Night	3.893	2.109	-3.847	0.261	4.129	2.237	2.5233	3.699
HTC Desire	Morning	1.892	2.915	-1.180	-0.182	2.007	3.092	2.258	3.041
	Night	4.068	2.773	-3.291	-0.182	4.315	2.942	2.694	4.240
LG Nexus 5	Morning	3.600	2.292	-2.958	1.817	3.819	2.431	2.500	3.646
	Night	4.031	4.068	-3.625	0.484	4.275	5.047	3.053	5.524

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VII. CONCLUSION

From these tests modern smartphones and hand held receivers had provided an overview of positioning accuracies and its precision. We analyzed the positioning information obtained from these devices to understand how accurate the data obtained from these devices. In the analysis first it can be clearly seen that accuracy of HTC Desire, LG nexus 5 and Garmin receiver slightly differ in different environments and in different timings of the day.Modern Smart phones can help users in many known ways like knowing accurate positions of them, though the technology is not developed to such a extent to take advantage of inbuilt sensors. For example with the smartphones we cannot actually record the raw measurement data and we didn't had any direct access to internal sensors.Even though there is substantial difference between benchmarks (RTK positioning) and the estimated (smartphones and Garmin receiver) in urban and open environments it is still useful in number of application like Navigation. The positional accuracies of smartphonesdepend mainly on the geographical area, surrounding environment and no of constellations it can track, visibility of satellite, multipath.With these accuracies we can use this in agricultural land management, coastal management, tracking farm work activities, crop water estimation and we can also analyses the social behavior of humans like most visited shopping centers, tourist places. During disasters by analyzing the GPS data obtained from people we can find shortest route for evacuation.

With these accuracies we can generally map on to large scales, generally there is no standard scale of map. Large scale shows smaller areas in more detail. We can track species which are at extinction with low cost, we can also track movement of animals from which travels from one place to another.

For large scale map generally the range is 1:0 to 1:600000 and the accuracy of GPS in smart phones ranges from 2-5m during night times and in the morning times 3-6m. So if we want to map a town with smart phones the scale range is 1:5000 for a town. 2:5000 m represents 2m object on a map is 5000m on real world. I.e. 0.0004m that is very small on the map. With these we can map a place with high level of detail; it is useful during disasters to map a place.

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Author Biographies:

D. Ravi Kanth,is working as Assistant Professor in Department of Civil Engineering at

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Vignan'sFoundation for Science, Technology and Research (Deemed to be University), Vadlamudi, Guntur District, Andhra Pradesh, India. He is a member of ISRS (Indian Society of Remote Sensing) and ICI (Indian Concrete Institute).

K. BalaGopiKrishna,is working as Assistant Professor in Civil Engineering Department at Vignan's Foundation for Science, Technology and Research (Deemed to be University), Vadlamudi, Guntur District, Andhra Pradesh, India. He is a lifetime permanent member of IFERP.

B. Ravali,is working as Assistant Professor in Department of Civil Engineering at Vignan's Foundation for Science, Technology and Research (Deemed to be University), Vadlamudi, Guntur District, Andhra Pradesh, India. She is a life member of ICI (Indian Concrete Institute).

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M. Narendra,is working as Assistant Professor in Department of Civil Engineering at Chalapathi Institute of Technology, Mothadaka, Guntur District, Andhra Pradesh, India. He published 5 research papers in various UGC approved journals.