GPS Datum Conversion and Improvement in GPS Accuracy

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Abstract— GPS Positioning has numerous applications in the field of navigation and Geodesy.GPS positioning is mainly based on the different Geodetic Datum. This paper mainly discusses the improved datum conversion equations for the conversion of World Geodetic System (WGS-84) to Universal Transverse Mercator (UTM), vice versa and the reduction of errors introduced while datum conversion. By applying the different filters like Least Squares Algorithm (LSA), Kalman Filter (KF) and Modified Kalman Filter (MKF) a considerable improvement in consistency has been observed. Comparatively Modified Kalman Filter gives better accuracy in positioning.GPS coordinates data samples are collected in different environments like heavy traffic area, tall buildings area are taken to validate the results.

***Keywords**:* Global Positioning System, World Geodetic System, Universal Transverse Mercator, Least Squares Algorithm, Kalman Filter, Modified Kalman Filter

I. Introduction

The enormous demand for the storage, analysis and display of complex and voluminous data has led, in recent years, to the use of Geographic Information System (GIS) for effective data handling, analyzing and transferring the information around the world. The heart of GIS is the Global Positioning System (GPS).

GPS is a burgeoning technology, which provides unequalled accuracy and flexibility of positioning for navigation, surveying and GIS data capture. GPS is a Global Navigation Satellite System (GNSS) developed by the United States Department of Defense. It uses a constellation of between 24 and 32 Medium Earth Orbit satellites that transmit precise microwave signals, which enable GPS receivers to determine their current location in longitude, latitude, and altitude, time, and velocity.

Using the Global Positioning System (GPS, a process used to establish a position at any point on the globe) the following two values can be determined anywhere on Earth

(1) One's exact location (longitude , latitude and height co-ordinates) accurate to within a range of 20m to approx 1mm.
(2) The precise time (Universal Time Coordinated, UTC) accurate to within a range of 60ns to approx 5ns Speed and direction of travel (course) can be derived from these co-ordinates as well as the time. The coordinates and time values are determined by 28 satellites orbiting the Earth.

The NAVSTAR Global Positioning System (GPS) is a satellite-based radio-positioning and time transfer system designed, financed, deployed, and operated by the U.S. Department of Defense. GPS has also demonstrated a significant benefit to the civilian community who are applying GPS to a rapidly expanding number of applications. What attracts us to GPS is:

– The relatively high positioning accuracies, from tens of meters down to the millimeter level.
– The capability of determining velocity and time, to an accuracy commensurate with position.
– The signals are available to users anywhere on the globe: in the air, on the ground, or at sea.
– It is a positioning system with no user charges, which simply requires the use of relatively low cost hardware.
– It is an all-weather system, available 24 hours a day.
– The position information is in three dimensions, that is, vertical as well as horizontal information is provided.

GPS receivers are used for positioning, locating, navigating, surveying and determining the time and are employed both by private individuals (e.g.for leisure activities, such as trekking, balloon flights and cross-country skiing etc.) and companies (surveying, determining the time, navigation, vehicle monitoring etc.). GPS (the full description is: NAVigation System with Timing And Ranging Global Positioning System, NAVSTARGPS) was developed by the U.S. Department of Defense (DoD) and can be used both by civilians and military personnel.

The civil signal SPS (Standard Positioning Service) can be used freely by the general public, whilst the military signal PPS (Precise Positioning Service) can be used by authorized government agencies. There are currently 28 operational satellites orbiting the Earth at a height of 20,180 km on 6 different orbital planes. Their orbits are inclined at 55° to the equator, ensuring that at least 4 satellites are in radio communication with any point on the planet. Each satellite orbits the Earth in approximately 12 hours and has four atomic clocks on board.

The GPS is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The system provides critical capabilities to military, civil and commercial users around the world. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver.

GPS is based on the World Geodetic System 1984 (WGS-84).The coordinates received from the Global Positioning System (GPS) are prone to various errors like ionospheric delays, satellite and receiver clock errors, multipath errors, satellite geometry, signal propagation errors, receiver errors, etc. The current standard reference coordinate system used by the GPS is the WGS84 system in which any point on the earth is identified by its latitude and longitude.

On a conformal map, meridians and parallels intersect at right angles, and the scale at any point on the map is the same in any direction, although it will vary from point to point. Conformal maps therefore allow the analysis, control or recording of motion and angular relationships. Hence they are essential for the generation of navigational charts, meteorological charts and topographic maps. An example of a conformal projection is the Transverse Mercator projection, which is used extensively around the world as a basis for grid coordinates and is therefore treated in more detail here. This projection mathematically derived and utilizes a cylinder that is tangent to a chosen meridian, called the central meridian (CM) as shown in Figure 1.1 The scale is therefore true (i.e. unity) along the central meridian but increases with increasing distance from it, thereby causing a growing distortion in scale.

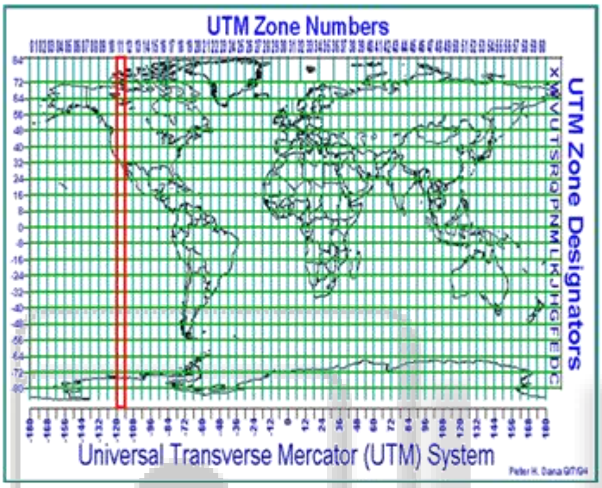


Fig. 1.1: Universal Transvese Mercator (UTM) System

The Transverse Mercator projection is most appropriate for regions exhibiting a large north-south extent but small east-west extent. However, by splitting up the area to be mapped into longitudinal zones of limited extent and merging the resulting plane maps, the entire world can be mapped with minimal distortion.

The Universal Transverse Mercator (UTM) projection utilises a zone width of 6° and ensures that the scale is very close to unity across the entire zone by defining a central scale factor of 0.9996 for the CM which results in a scale of 1.0010 at the zone boundary located 3° away from the CM. The UTM projection divides the world into 60 zones, zone 1 having a CM at longitude 177°W, while the latitudinal extent of each zone is 80°S to 84°N, indicated by 20 bands labeled C to X with the exclusion of I and O for obvious reasons. All latitude bands are 8° wide, except the most northerly (X) which is 12° wide to allow Greenland to be mapped in its entirety.

The increasing distortion in scale evident at high latitudes is caused by the north-south gridlines not converging at the poles, i.e. the poles would be projected as lines rather than points. The island of Tasmania, e.g., is located in zone 55G. Note that while the latitude extent is generally part of the coordinate display in most GPS receivers, in a GIS environment it is often replaced by N or S to indicate the hemisphere when a global UTM system is used.

WGS84 [7] is a 3-dimensional angular coordinate system, but when a point has to be mapped i.e. 2-dimensional projection on a paper, then the preferred coordinate system is the UTM. Hence, the necessity to convert the WGS84 coordinates to their corresponding UTM values. The coordinate conversion causes some error to be produced in the resulting UTM values [12].

First the conversion of the coordinates from WGS84 to UTM has been done using asset of conversion equations proposed by Steven Dutch which showed a large error of about 100m in Eastings and 300m in Northings coordinates.

Having to present parts of the Earth, which is originally an ellipsoid, on the paper, which is plane (bi-dimensional), it is necessary to project the geographic coordinates onto the flat surface of a map, using one of the existing methods. The cartography uses different methods of projecting the geographic coordinates. Even nowadays, different countries apply different, local geodetic systems (datum). This is due to historic reasons and the need of the countries to maximally adopt the geodetic system to their local circumstances. This is why a large number of geodetic systems were developed. Then the conversion of the coordinates from WGS84 to UTM has been done using a set of equations proposed by Milenko.T.Ostojic [7] to reduce the error in the Eastings to 25m and Northings to 100m which shows the large improvement in accuracy of the position [5].

WGS84 was adopted as standard world geodetic system, but its application will be gradual, in view of a rather rich geodetic material which exists in the world. The proposed technique by Milenko.T.Ostojic defined more closely a mathematical device which provides conversion of geodetic coordinates into coordinate system in the plane and vice versa. The existing techniques discuss the reduction of the above said coordinate conversion error using a Least squares Algorithm and Kalman filter. MATLAB software has been used for the coordinate conversion and the design of the filter. The estimation of the error and its reduction using a Least square Algorithm [3] and Kalman filter and has been done in the existing method. After applying Least squares Algorithm and Kalman filter to the UTM values, there was a visible improvement in the consistency of the coordinates.

The Least squares Algorithm called LOWESS algorithm is used for smoothening the GPS coordinates for accurate position estimation. The name "LOWESS" is derived from the term "locally weighted scatter plot smooth," as this method uses locally weighted linear regression to smooth data. The smoothing process is considered local because each smoothed value is determined by neighbouring data points. The process is weighted because a regression weight function is defined for the data points. In addition to the regression weight function, the regression model lowess uses a linear polynomial. Better smoothening of GPS data can be done using Kalman filter compared to LOWESS algorithm

The Kalman filter is extensively used for state estimation for linear systems under Gaussian noise. When non-Gaussian Levy noise is present, the conventional Kalman filter may fail to be effective due to the fact that the non-Gaussian Levy noise may have infinite variance. So a Modified Kalman filter [6] for linear systems with non-

Gaussian Levy noise is devised. It works effectively with reasonable computational cost.

This paper mainly discusses the Modified Kalman Filter which can be applied to linear systems which reduces the error in conversion from WGS84 to UTM by 1 to 3 meters in Eastings and Northings when compared to Kalman Filter, which is about 50% reduction of the conversion error when compared to the Steven Dutch's WGS84 to UTM conversion error.

Then the reverse conversion of UTM to WGS84 is done using the conversion equations given by Milenko.T.Ostojic. The reverse conversion coordinates is compared with the WGS84 coordinates from the receiver to know the accuracy of the data.

II. Improved GPS Datum Conversion Methodology

This section introduces the improved technique of datum conversion i.e WGS-84 to UTM and vice versa.

A. WGS-84 to UTM Conversion

These equations define more closely a mathematical device which provides conversion of geodetic coordinates into a coordinate system in the plane and vice versa. In this, the point on the ellipsoid is defined by its latitude (φ), longitude (λ) and it is projected onto the plane **(*x*, *y*)**.This requires projection conformity.

In the Transverse Mercator projection, the projection of a point from ellipsoid **(**φ, λ**)** is carried out onto a plane **(y, *x*)**, which leans on the ellipsoid. The convention is to give ***y*** first, because of the correspondence **(y, *x*)** with **(**φ, λ**)**. Since the middle meridian is projected without distortion, the longitude is given as value ***(l)*,** which is the longitude counted from the middle meridian. The projection is performed according to the following formulas.

$$y = B(\phi) + \frac{t}{2}N\cos^2(\phi)l^2 + \frac{t}{24}N\cos^4(\phi)(5 - t^2 + 9\eta^2 + \eta^4)l^4 + \frac{t}{720}N\cos^6(\phi)(61 - 58t^2 + t^4 + 270\eta^2 - 330\eta^2)l^6 + \frac{t}{40320}N\cos^8(\phi)(1385 - 3111t^2 + 543t^4 - t^6)l^8 \quad (2.1)$$

$$x = N\cos(\phi) + \frac{1}{6}N\cos^3(\phi)(1 - t^2 + \eta^2)l^3 + \frac{1}{120}N\cos^5(\phi)(5 - 18t^2 + t^4 + 14\eta^2 - 58t^2\eta^2)l^5 + \frac{1}{5040}N\cos^7(\phi)(61 - 479t^2 + 179t^4 - t^6)l^7 \quad (2.2)$$

where $B(\phi)$ is ellipsoid length of the meridian arc from equator to the observed point is calculated according to the following formula:

$$B(\phi)=\alpha(\phi + \beta\sin(2\phi)) + \gamma\sin(4\phi) + \delta\sin(6\phi) + \varepsilon\sin(8\phi)$$

N is the curvature radius per vertical and equals to

$$N = \frac{a^2}{b\sqrt{1+\eta^2}}$$

$\eta^2=e^2\cos^2(\phi)$, $e^2$is the eccentricity equal to $(a^2 - b^2)/b^2$
$t = \tan(\phi)$, auxilary value
$l = \lambda - \lambda_0$, longitude in respect to the central meridian
λ_0=longitude of the central meridian
The coefficients are as given as follows

$$\alpha = \frac{a+b}{2}(1 + \frac{1}{4}n^2 + \frac{1}{64}n^4 \ldots.)$$

$$\beta = -\frac{3}{2}n + \frac{9}{16}n^3 - \frac{3}{32}n^5 \ldots\ldots$$

$$\gamma = \frac{15}{16}n^2 - \frac{15}{32}n^4 \ldots\ldots$$

$$\delta = -\frac{35}{48}n^3 + \frac{105}{256}n^5 \ldots\ldots.$$

$$\varepsilon = \frac{315}{512}n^4 \ldots\ldots.$$

n= (a-b) / (a+b)

Thus the WGS84 coordinates can be converted to UTM coordinates by the equations mentioned above.

B. UTM to WGS-84 Conversion

Inverse projection of the point in the plane **(*y*, *x*)** , onto the ellipsoid **(**φ **,**λ**)**, is carried out as follows:

$$\phi = \phi_f + \frac{t_f}{2N_f^2}(-1 - \eta_f^2)x^2 + \frac{t_f}{24N_f^4}(5 + 3t_f^2 + 6\eta_f^2 - 6\eta_f^2t_f^2 - 3\eta_f^4 - 9t_f^2\eta_f^4)x^4 + \frac{t_f}{720N_f^6}(-61 - 90t_f^2 - 45t_f^4 - 107\eta_f^2 + 162\eta_f^2t_f^2 + 45\eta_f^2t_f^4)x^6 + \frac{t_f}{40320N_f^8}(1385 + 3633t_f^2 + 4095t_f^4 + 1575t_f^6)x^8$$

(2.3)

$$\lambda = \lambda_0 + \frac{1}{N_f\cos(\phi_f)}.x + \frac{1}{6N_f^3\cos(\phi_f)}(-1 - 2t_f^2 - \eta_f^2).x^3 + \frac{1}{120N_f^5\cos(\phi_f)}(5 + 28t_f^2 + 24t_f^4 + 6\eta_f^2 + 8t_f^2\eta_f^2).x^5 + \frac{1}{5040N_f^7\cos(\phi_f)}(-61 - 662t_f^2 - 1320t_f^4 - 720t_f^6).x^7$$

(2.4)

Where

$$\phi_f = y1 + \beta1\sin(2y1) + \gamma1\sin(4y1) + \delta1\sin(6y1) + \varepsilon1\sin(8y1) + \cdots$$

The coefficients are calculated as follows

$$\alpha1 = \frac{a+b}{2}(1 + \frac{1}{4}n^2 + \frac{1}{64}n^4 + \cdots)$$

$$\beta1 = \frac{3}{2}n - \frac{27}{32}n^3 + \frac{269}{512}n^5 + \cdots$$

$$\gamma1 = \frac{21}{16}n^2 - \frac{55}{32}n^4 + \cdots$$

$$\delta1 = \frac{151}{96}n^3 - \frac{417}{128}n^5 - \cdots$$

$$\varepsilon1 = \frac{1097}{512}n^4 + \cdots$$

$$y1 = x/\alpha1$$

Where a and b in equation are the major and minor axes of the reference ellipsoid given by a=6377397.155, b=6356149.9884347 respectively.

Thus the reverse conversion that is UTM to WGS-84 can be done using the formulae given above where x & y represent Eastings and Northings respectively and λ & ϕ represents Longitude and Latitude respectively.

III. Error Reduction In GPS Datum Conversion

A. Least Squares Algorithm

Least squares Algorithm is also known as Local regression smoothing algorithm. The name "LOWESS" is derived from the term "locally weighted scatter plot smooth," as it uses locally weighted linear regression to smooth data. The smoothing process is considered local because each smoothed value is determined by neighbouring data points. The process is weighted because a regression weight function is defined for the data points. In addition to the regression weight function, a robust weight function, can be used which makes the process resistant to outliers. Finally, the model used in the regression LOWESS uses a linear polynomial.

The regression smoothing and robust smoothing procedures are described in detail below.

B. Local Regression Smoothing Procedure

The local regression smoothing process follows these steps for each data point:

(1) Compute the regression weights for each data point in the span. The weights are given by the tricube function shown below.

$$w_i = \left(1 - \left|\frac{x - x_i}{d(x)}\right|^3\right)^3 \quad (3.1)$$

x is the predictor value associated with the response value to be smoothed, *xi* are the nearest neighbours of *x* as defined by the span, and *d*(*x*) is the distance along the abscissa from *x* to the most distant predictor value within the span. The weights have these characteristics:

– The data point to be smoothed has the largest weight and the most influence on the fit.

– Data points outside the span have zero weight and no influence on the fit.

(2) A weighted linear least squares regression is performed. For LOWESS, the regression uses a first degree polynomial.

(3) The smoothed value is given by the weighted regression at the predictor value of interest.

C. Kalman Filter

Kalman filter is a linear recursive filtering technique that estimates the user position from the initial state of the system, statistics of system noise and sensor noise measurements (Malleswari B.L et al, 2009). The Kalman filter estimates a process state at some time and also obtains noisy measurement of the state as feedback

The Kalman filter, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, containing noise (random variations) and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone. More formally, the Kalman filter operates recursively on streams of noisy input data to produce a statistically optimal estimate of the underlying system state. The filter is named for Rudolf (Rudy) E. Kalman, one of the primary developers of its theory.

At each cycle, the state estimate is updated by combining new measurements with the predicted state estimate from previous measurements.

The $\hat{x}_k^- \in R^n$ is defined as the a priori state estimate at time step k when the process prior to step k is known, and the a posteriori state estimate at step k when the measurement is known. The priori and a posteriori estimates errors can be defined as:

$$e_k^- = x_k - \hat{x}_k^-$$

$$e_k = x_k - \hat{x}_k$$

Where e_k^-=priori estimate error.

e_k=posterior error estimate error.

x_k = present state estimate at time k.

$\hat{x}_k$ = posteriori state estimate at step k.

$\hat{x}_k^-$ = priori state estimate at step k.

The P_k^- priori estimate error co-variance is,

$$P_k^- = E[e_k^- e_k^{-T}]$$

Where E [ ] = expectation (mean)

The a P_k posteriori estimate error covariance is,

$$P_k = E[e_k e_k^T]$$

The next step involves finding an equation that computes an a posteriori state estimate as a linear combination of an a priori estimate and a weighted difference between an actual measurement and a measurement prediction

$$\hat{x}_k = \hat{x}_k^- + K(z_k - H\hat{x}_k^-) \quad (3.2)$$

Where K=optimal Kalman gain

H= is the observation matrix which maps the true state space into the observed space

z_k=the observation or measurement at time k and is given by

$$Z_k = H_k x_k + v_k \quad (3.3)$$

v_k= is the observation noise which is assumed to be zero mean Gaussian white noise with covariance R_k

The Kalman gain calculated from the equation:

$$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1} \quad (3.4)$$

Where P_k^-= priori estimate error covariance

R_k=measurement error covariance

The Kalman Filter estimates a process by using a feedback control like form. The operation can be described as the process is estimated by the filter at some point of time and the feedback is obtained in the form of noisy measurements. The Kalman filter equations can be divided into two categories: time update equations and measurement update equations. To obtain the a priori estimates for the next time step the time update equations project forward (in time) the current state and error covariance estimates. The measurement update equations get the feedback to obtain an improved a posteriori estimate incorporating a new measurement into the a priori estimate.

The notation $\hat{X}_{n|m}$ shows the estimate of X at time n, when observations till time m are obtained.

The two variables that can represent the filter:

$\hat{X}_{k|k}$, the a posteriori state estimate at time k

$X_{k|k}$, the a posteriori error covariance matrix (a measure of the estimated accuracy of the state estimate).

The prediction equations of Kalman filter are as given below:

Predicted (a priori) state is calculated as given in equation

$$\hat{x}_{k|k-1} = A_k \hat{x}_{k-1|k-1} + B_k u_k$$

Predicted (a priori) estimate covariance is estimated as given in equation

$$P_{k|k-1} = A_k P_{k-1|k-1} A_k^T + Q_k$$

The Updating equations of Kalman Filter are as given below

Innovation or measurement residual which is used to calculate Updated estimate is as given in equation

$$\tilde{y}_k = z_k - H_k \hat{x}_{k|k-1}$$

Innovation (or residual) covariance which is used to calculate Kalman Gain are as given as in equation

$$S_k = H_k P_{k|k-1} H_k^T + R_k$$

The Optimal Kalman gain is calculated as given in equation

$K_k=P_{k|k-1}H^TS_k^{-1}$

The Updated (a posteriori) state estimate is given by equation

$\hat{x}_{k|k}=\hat{x}_{k|k-1}+K_k\tilde{y}_k$

The Updated (a posteriori) estimate covariance is given by equation

$P_{k|k}=(I-K_kH_k)P_{k|k-1}$

(3.5)

Where $\hat{X}_{k|k}$= represents the estimate of $\mathbf{X}$ at time k given observations up to, and including at time k.

$\hat{X}_{k|k-1}$= represents the estimate of $\mathbf{X}$ at time k given observations up to, and including at time k-1.

$X_{k|k}$= represents error covariance of $\mathbf{X}$ at time k given observations up to, and including at time k.

$P_{k|k-1}$= represents error covariance of $\mathbf{X}$ at time k given observations up to, and including at time k-1.

$P_{k-1|k-1}$= represents error covariance of $\mathbf{X}$ at time k given observations up to, and including at time k-1.

B_k = is the control-input model which is applied to the control vector $\mathbf{u}_k$

Q_k = is covariance matrix.

Thus the Kalman Filter is applied converted data which smoothened data and improved the accuracy in GPS positioning.

D. Modified Kalman Filter

The quality of the GPS data strongly depends on the GPS signal condition, usually represented by the number of satellites and PDOP values. When the condition of the GPS signal does not reach the sufficient level of minimum requirement, such as at least four satellites in view and PDOP values less than or equal to eight, the measurement errors are much greater than the above estimates. In addition, the most important component of the Kalman filter is the measurement error since the measurement error determines how much random GPS random error should be reduced. Thus modified the conventional discrete Kalman filter by using two measurement errors based on the GPS quality criteria, the number of satellites and PDOP values. Researchers estimated the first measurement error in the conditions of at least four satellites in view and PDOP values less than or equal to eight and the second measurement error from the other GPS signal conditions.

The Kalman filter is extensively used for state estimation for linear systems under Gaussian noise. When non-Gaussian L´evy noise is present, the conventional Kalman filter may fail to be effective due to the fact that the non-Gaussian L´evy noise may have infinite variance. A modified Kalman filter for linear systems with non-Gaussian L´evy noise is devised. It works effectively with reasonable computational cost. Simulation results are presented to illustrate this non-Gaussian filtering method.

The Time update and the Measurement Update equations of Modified Kalman Filter are as given below:

Let $\tilde{v}_k$ represent the clipped version of the L´evy measurement disturbance v_k, and let $\tilde{z}_k$ represent the corresponding clipped observation. Thus

$$\tilde{z}_k = H_k x_k + \tilde{v}_k$$

In practice, since the measurement noise, v_k is unknown, we propose to clip the observation z_k instead v_k of in a component-wise way by the following operation:

$$\tilde{z}_k^i = \left\{\sum_j \mathbf{H}_k^{i,j} + C.\mathrm{sign}(\mathbf{z}_k^i - \sum_j H_k^{i,j}\bar{x}_k^j)\right\} \quad \text{if} \left(\mathbf{z}_k^i - \sum_j H_k^{i,j}\bar{x}_k^j\right) \geq C$$

$$= z_k^i \quad \text{if} \left(\mathbf{z}_k^i - \sum_j H_k^{i,j}\bar{x}_k^j\right) < C$$

Where C is some positive threshold value, z_k^i and $\bar{x}_k^i$ represent the i-th components of the vectors z and x respectively. Note that C is determined by the statistical properties of the measurement noise v_k. Replacing the observation value z with its clipped value, we get

$$\hat{X}_k = \bar{x}_k + K_k(\tilde{z}_k - \bar{H}_k\bar{x}_k)$$

On substituting and calculating the above values we get

$$K_k = P_k^- H^T(2.HP_k^- H^T + R)^{-1} \qquad (3.6)$$

Combining KF equations and the modifications done we obtain the Modified Kalman Filter.

The results of GPS datum after conversion are applied to the three filters discussed above for the reduction of error introduced while conversion.

IV. RESULTS AND DISCUSSIONS

Table 1 shows the reduction of error in GPS datum conversion. Table 2 &3 shows the comparision of Error after applying Least Squares Algorithm, Kalman Filter, Modified Kalman Filter respectively.

S.No	Error b/w UTM receiver and Steven Dutch equations (meters)		Error b/w UTM receiver and Milenko.T.Ostojic equations (meters)	
	Eastings	**Northings**	**Eastings**	**Northings**
1.	133.58	312.92	28.98342	162.9848
2.	136.65	318.39	32.02523	159.9094
3.	135.38	320.24	32.9776	159.9496
4.	134.54	321.16	33.92997	159.9897
5.	135.61	321.72	31.9776	159.9496
6.	135.65	322.1	31.9776	159.9496
7.	136.14	327.36	34.92997	154.9897
8.	138.1	320.57	33.9776	161.9496

9.	136.83	319.73	30.02523	162.9094
10.	137.83	322.86	33.9776	159.9496
11.	135.84	320.96	31.9776	161.9496
12.	136.84	323.05	32.9776	159.9496
13.	137.66	323.13	31.02523	159.9094
14.	137.51	322.2	31.02523	160.9094
15.	137.54	322.25	33.9776	160.9496

. Table 1: Error between UTM receiver and Equations of previous method and the improved method

S.No	**Error b/w UTM receiver and equations after applying Least squares Algorithm**		**Error between Receiver and Equations UTM after Kalman Filtering**	
	Easting (meters)	**Northings (meters)**	**Easting (meters)**	**Northing (meters)**
1.	28.34628	162.3028	28.98342	162.9848
2.	33.08795	161.047	32.0041	161.4631
3.	32.9776	159.9496	30.99036	160.9611
4.	32.23938	159.9667	30.22479	160.7183
5.	32.82289	159.961	31.37602	160.5639
6.	32.82289	159.961	31.47727	160.4605
7.	33.23938	154.9667	31.9784	155.3922
8.	33.9776	161.9496	33.9783	162.3356
9.	31.71582	162.9324	32.64006	163.2867
10.	33.1323	159.9381	33.67515	160.2517
11.	31.9776	161.9496	31.704	162.2229
12.	32.1323	159.9381	32.72816	160.1987
13.	31.87052	159.9209	33.50547	160.1749
14.	31.87052	160.9209	33.31355	161.1544
15.	33.1323	160.9381	33.36208	161.1394

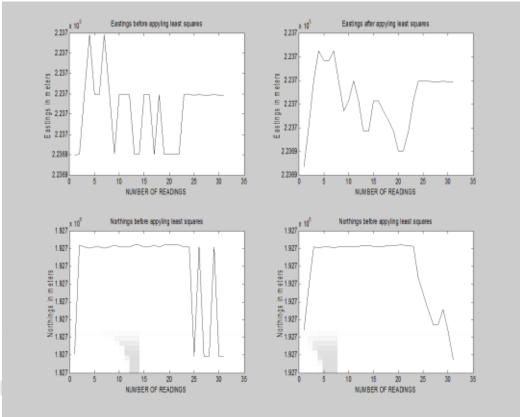
Table 2: Comparision of error after applying Least Squares Algorithm and Kalman Filter

S.No	**Error b/w UTM receiver and equations after applying Kalman Filter**		**Error between Receiver and Equations UTM after Modified Kalman Filtering**	
	Easting (meters)	**Northings (meters)**	**Easting (meters)**	**Northing (meters)**
1.	28.98342	162.9848	28.98342	162.9848
2.	32.0041	161.4631	32.0043	161.4486
3.	30.99036	160.9611	31.48766	160.7007
4.	30.22479	160.7183	31.69102	160.3481
5.	31.37602	160.5639	32.3345	160.1489
6.	31.47727	160.4605	32.1561	160.0493
7.	31.9784	155.3922	33.51015	155.0202
8.	33.9783	162.3356	34.75479	161.9854
9.	32.64006	163.2867	32.15699	162.9528
10.	33.67515	160.2517	33.56165	159.9512
11.	31.704	162.2229	31.7682	161.9504
12.	32.72816	160.1987	32.87256	159.95
13.	33.50547	160.1749	33.19582	159.9403
14.	33.31355	161.1544	32.57635	160.9315
15.	33.36208	161.1394	33.08341	160.938

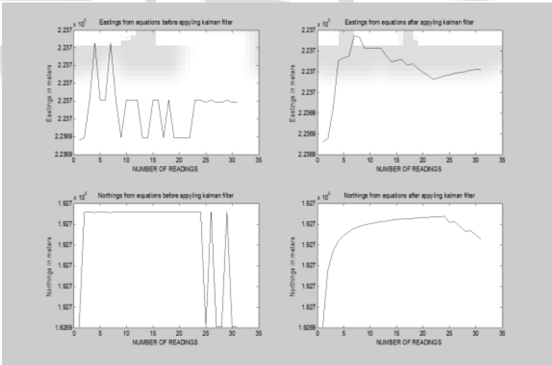
Table 3: Comparision of error after applying Kalman Filter and Modified Kalman Filter

A. Simulation Results

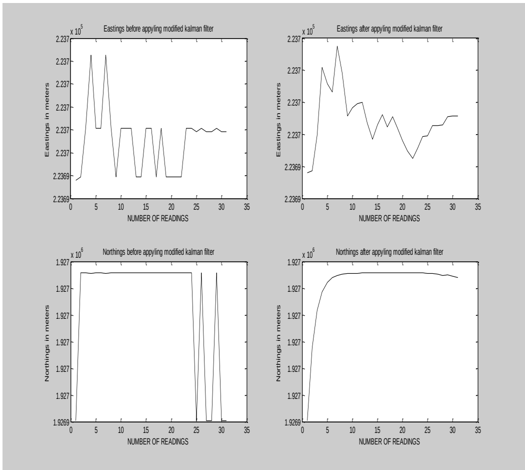
The figures 2, 3, 4 show the simulation results before and after applying the Least Squares algorithm, Kalman Filter and Modified Kalman Filter respectively.



(a)

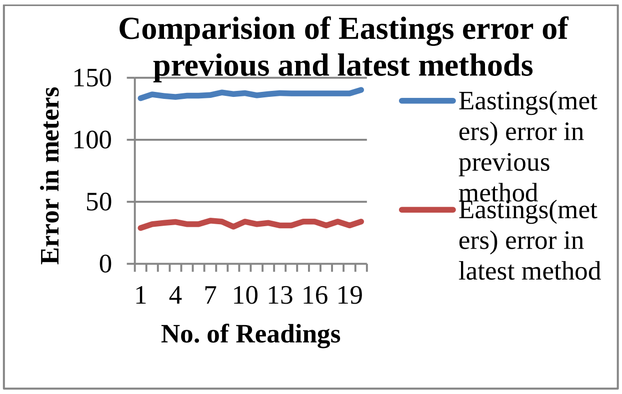


(b)

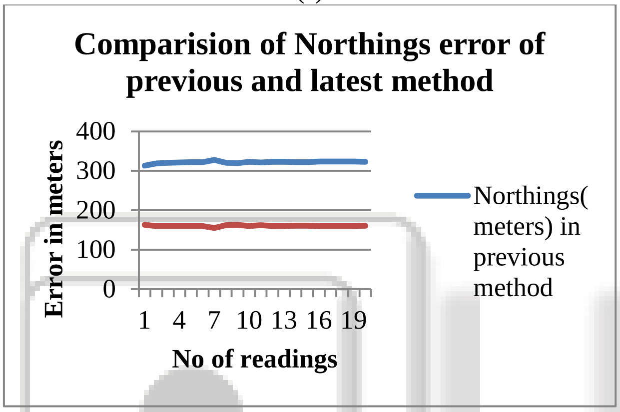


(c)

Fig. 4.1(a): UTM from equations before and after applying least Squares Algorithm (b) UTM from equations Before and after applying Kalman Filter (c) UTM From equation before and after applying Modified Kalman Filter.

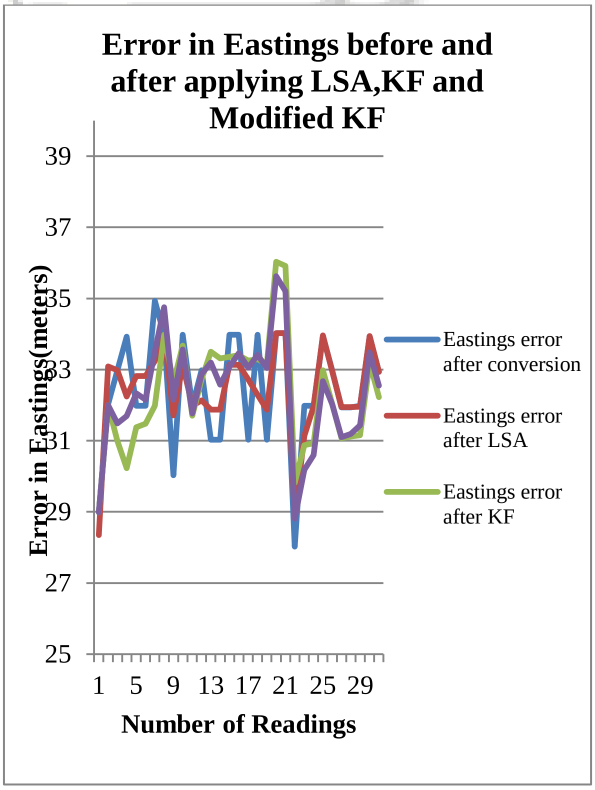


(a)



(b)

Fig. 4.2: shows the comparision of previous and latest method.



(c)

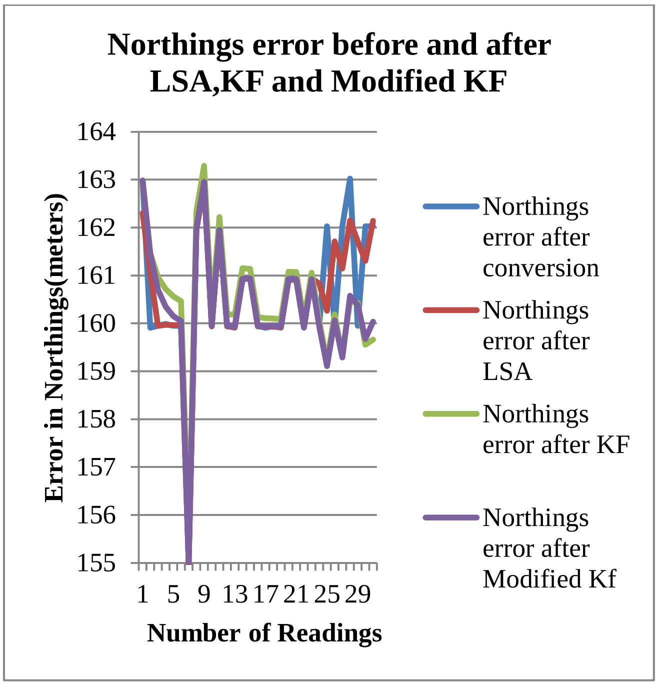


Fig. 4.2: (a) & (b) comparision of Eastings and Northings error of previous and latest method (c) & (d) Eastings and Northings Error before and after LSA,KF & Modified KF

S.No	WGS-84 from Receiver		WGS-84 obtained from Modified Kalman filtered UTM using Milenko UTM to WGS-84 conversion formulae	
	Latitude (North)	Longitude (East)	Latitude (North)	Longitude (East)
1.	17.4129	78.39886	17.40585	78.4000
2.	17.413	78.39886	17.40587	78.4000
3.	17.413	78.39888	17.40587	78.4000
4.	17.413	78.39891	17.40588	78.4000
5.	17.413	78.39888	17.40588	78.4000
6.	17.413	78.39888	17.40588	78.4000
7.	17.413	78.39891	17.40588	78.4000
8.	17.413	78.39888	17.40588	78.4000
9.	17.413	78.39886	17.40588	78.4000
10.	17.413	78.39888	17.40588	78.4000
11.	17.413	78.39888	17.40588	78.4000
12.	17.413	78.39888	17.40588	78.4000
13.	17.413	78.39886	17.40588	78.4000
14.	17.413	78.39886	17.40588	78.4000
15.	17.413	78.39888	17.40588	78.4000

Table 4: WGS-84 from receiver and Modified Kalman Filtered UTM

V. CONCLUSIONS

In the latest method "GPS datum conversion and Improvement in GPS accuracy" some of the errors involved in transforming the geographical coordinates from one system to other (i.e., WGS-84 to UTM and vice-versa), are Ionospheric delays, Atmospheric delays, Satellite and Receiver clock errors, Multipath, Dilution of Precision, Selective Availability(S/A) and Anti-Spoofing (A-S) that degrade the GPS position form a few meters to tens of meters. By using the latest conversion equations about 50% of the error is reduced compared to the previous method. By using Modified Kalman Filter instead of Kalman Filter the error can be reduced by approximately 1 to 2 meters. The Table 4 shows the reverse conversion coordinates which are very close to the WGS-84 coordinates taken from GPS receiver.

REFERENCES

[1] "An Introduction to mapping Coordinate systems & use of GPS datasets with Ordnance Survey of India", Ordnance Survey.

[2] "Coordinate Conversion and Transformations including Formulae",OGP Publication 373-7-2 – Geomatics Guidance Note number 7, part 2 – June 2013

[3] Greg Welch and Gary Bishop "An Introduction to the Kalman Filter", , TR 95- 041,Department of Computer Science, University of North Carolina at Chapel Hill, Chapel Hill-,NC-27599-3175, 24th July, 2006

[4] Janssen, V. (2009). Understanding Coordinate Systems, Datum and Transformations in Australia. In: Ostendorf, B., Baldock, P., Bruce, D., Burdett, M. and P. Corcoran (eds.), Proceedings of the Surveying & Spatial Sciences Institute Biennial International Conference, Adelaide 2009, Surveying & Spatial Sciences Institute, pp. 697-715. ISBN: 978-0-9581366-8-6.

[5] Malleswari.B.L, Seetaa.M, MuraliKrishna.I.V ,Lal Kishore.K, Nagaratna.P.Hegde "Performance of Kalman Filters for GPS Datum Conversion" http://www.itc.nl/issdq2007/proceedings/postersession/barooru%20malleswari.pdf

[6] Maria Isabel Ribeiro "Kalman, Extended Kalman Filters, concept, Derivation and Properties", Institute for Systems and Robotics Instituto Superior T´ecnico Av. Rovisco Pais, 11049-001 Lisboa PORTUGAL, 2004Liu, R and Tan, T. "An SVD-Based Watermarking Scheme for Protecting Rightful Ownership." IEEE Transactions on Multimedia: 4, 121-8.

[7] Milenko T. Ostojić "Conversion of Geodetic Coordinates of Standard Ellipsoids" International conference on Telecommunications, IEEE,pp 539-543,2007.

[8] Rudolf Kalman "A New Approach to linear filtering and prediction problems" Transactions of the ASME– Journal of Basic Engineering, 82 (Series D): 35-45. Copyright © 1960 by ASME

[9] Swapna Raghunath, Malleswari B.L,Karnam Sridhar, "Error Reduction in GPS Datum Conversion Using Kalman Filter in diverse scenarios," International Journal of Geomatics and Geosciences, Vol.3, No.3, pp.593-604, September 2013

[10] Swapna Raghunath, Malleswari B.L, Karnam Sridhar, "Analysis of GPS Errors in different times in a Day", International Journal of Research in Computer Science eISSN 2249-8265 Volume 2 Issue 1 (2011) pp. 45-48.

[11] Xu Sun, Jinqiao Duan ,Xiaofan Li and Xiangjun Wang "State Estimation under Non-Gaussian Levy Noise: A Modified Kalman Filter Method" March 2013.

[12] William.S. Cleveland, "Robust Locally Weighted Regression& Smoothing scatter plots", Journal of American Statistics association, Vol.74, No.368.pp 829-836, 2005.

