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Track Optimization Algorithm for Automotive Telematics System

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ABSTRACT

GPS track accuracy forms the building block of automotivetelematics systems. To enhancetrack accuracy more track points are required constraining bandwidth and data storage. This paper presents a GPS track optimizationalgorithm improving GPS track accuracy while maintaining low track point's count. The algorithm employs a three-step approach;wild-point reckoning, adaptive Kalman filter, and adaptive track-point reduction.Wild-point reckoning method truncates huge deviation in geo-points. Adaptive Kalman filter further reduceserror covariance within GPS data.Track-point reductionoptimize tracking points in GPS data, based on two variables distance and angle, between trackpoints. The algorithm is adaptive to vehicle speed and precision of the GPS receiver to making it universal applicable.The algorithm enhances the efficiency of tracking/telematics system and simultaneouslyreducingDB requirement.The algorithm is a part of the device firmware of Secure Automotive Telematics System (SATS).

Keywords: *GPS,Wild-pointreckoning, Adaptive Kalman filter, Moving average filter, Track point reduction*.

1. INTRODUCTION

Global positioning system (GPS) has now become a household device since its inception in 1973 [1]. GPS is used to obtain geographic location on grid of latitude and longitude around the globe. GPS receivers are readily available and provide accurate location information. GPS receivers in addition also provide GMT time, date and speed information [2]. A majority of GPS receivers update the location data typically at a rate of 1 Hz [3]. Automotive navigation and tracking algorithms make use of this capability of GPS receivers, for the purpose of plotting an accurate track of anautomotive on a GIS grid. The accuracy of track plotted on a GIS grid is of great importance especially in urban tracking [4].

Embedded processors used in automotive tracking devices generally come with limited memory and computing resources. Therefore the tracking algorithms used in these devices is simplified versions of the actual tracking algorithms. Most of the tracking algorithms used in GPS based navigation devices and vehicle tracking devices, are either distance travelled or vehicle speed based [5]. Adaptive Kalman filter is used in track simplification for handheld navigational devices [6].

The optimization algorithm for vehicle GPS tracking needs to be highly robust in order to adapt to the varying GPS receiver accuracy and changing vehicle speed. The optimization algorithm for automotive tracking/telematics systemhas been developed accounting for:

- Optimization of computational intensity of the algorithm for embedded devices,
- Significant data reduction to facilitate fast data transmission and optimize bandwidth usage,
- Capability of real time tracking,
- Optimization of the GPS track plot.

1.1 Secure Automotive Telematics System (SATS)

Secure Automotive Telematics System (SATS) is based on Sierra Wireless M2M Processor AirPrime Q2687 [7]. SATS is a vehicle telematics/tracking system with additional functionalities of on-board diagnostics OBD-II interface and secure communication protocols. Track optimization algorithm presented in this paper, is incorporated in the SATS vehicle device.

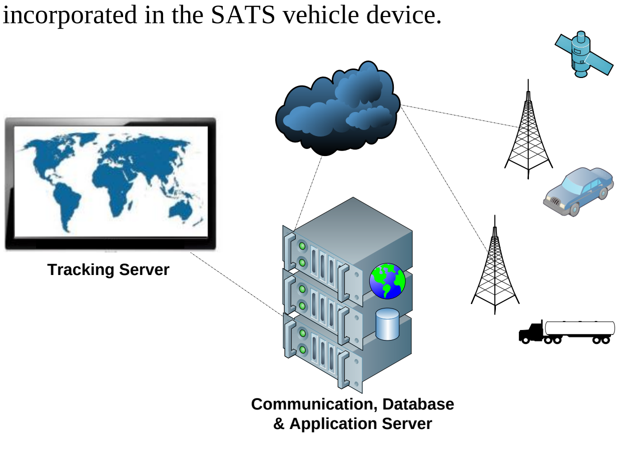

Figure1: Secure Automotive Telematics System – Architecture.

1.2 SATS Device

SATS device is a vehicle telematics unit that provides vehicle position and status data to central server. SATS device acquires position data from GPS and vehicle data from OBD-II interface and transmit this info over GPRS/SMS to the server. The developed SATS device was extensively tested & trialled across Pakistan for GPS track path analysis. The track optimization algorithm running at the heart of SATS device produced optimized track, thus reducing the communication & storage data loads from SATS servers. The SATS device board design is shown in Fig. 2.

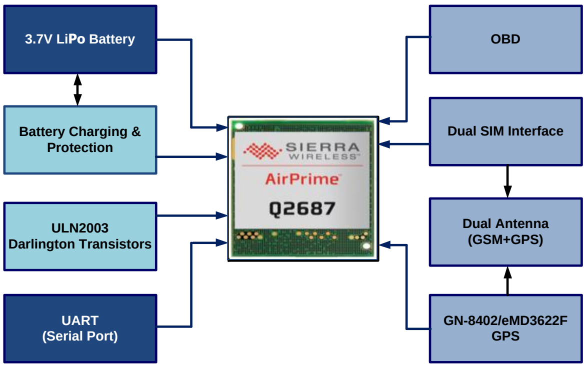

Figure2: SATS Device Board Design & Prototype SATS Device

A plastic casing was developed for SATS prototype. Final SATS product was housed in a ruggedized aluminum case. The SATS prototype device is shown in Fig. 3.

Figure3: SATS Device Board Design & Prototype SATS Device

2. DESCRIPTION OF TRACK OPTIMIZATION ALGORITHM

Track optimization algorithm is based on a three-step approach first wild-point reckoning technique,second adaptive Kalman filtering [8], andthird track-point reduction technique. The developed algorithm optimizes the GPS track, by intelligently filtering erroneous points while preserving the overall track shape integrity. The algorithm is adaptive to GPS accuracy and vehicle speed. The algorithm reduces the number of points that form the vehicle track.

Wild-point reckoning technique is a novel idea, designed & developed for track optimization algorithm. Wild-point reckoning is used to truncate huge deviation in geo-points present in GPS data. Therefore invalid (wild) points are filtered out before localized GPS errors are smoothed using adaptive Kalman filter.Kalman filter minimizes the errors in GPS data and exact position of vehicle is estimated.

Track point reduction works on the basis of distance and angle between two geographic points. The distance and angle thresholds are adaptively updated on the basis of vehicle speed and bearing.The track point reduction ratio can reach up to 50% reduced points as compared to the original track depending upon the shape of the track and speed of the vehicle. Flowchart of the Algorithm is presented below in Fig. 4.

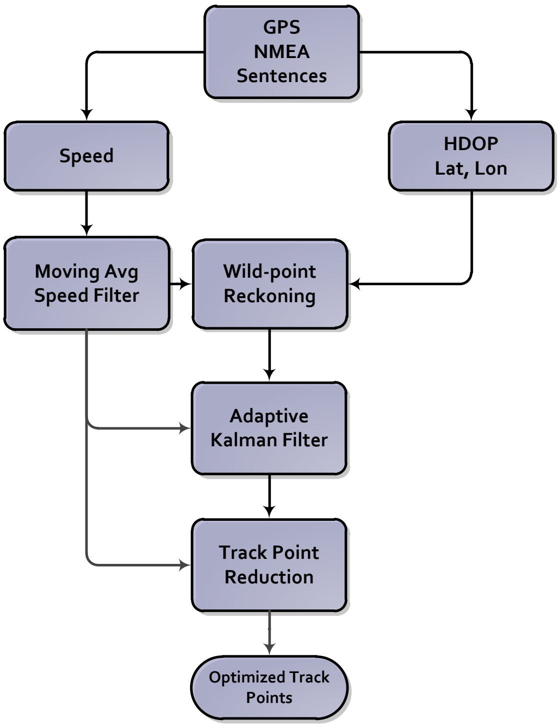

Figure 4: Track Optimization Algorithm.

2.1 Wild-Point Reckoning

The accuracy of a GPS receiver is highly dependent on the number of satellites visible and received signal strength. Horizontal dilution of precision (HDOP) is a measure of the accuracy of the GPS receiver [9]. We have estimated (through experimentation) the value of HDOP for vehicular application to be less than 3.50. The distance travelled by a vehicle at a speed of 200 Km/hr (maximum speed bound set for computation simplicity) in one second is 55.55 meters. To achieve GPS accuracy in a radius of 55.55 meters, error coefficient E_0 value of 10 is used.

$$E_0 = 10, \quad (1)$$

$$E_n = E_0 * HDOP \quad (2)$$

Where E_n, is the acceptable precision radius in meters,of GPS points. Generated GPS points are only accepted if E_n is less than 55.55. The new point in the track is admitted on the basis of vehicle speed. Algorithm is adaptive to the vehicle speed for the admission of a new point into the track. The vehicle speed values are filtered in order to remove spikes from the data. Algorithm implements a three point moving averages filter to obtain a smooth speed value [10].

Moving average filter is a low-pass filter, employed for filtering the speed fluctuations. The transfer function

(H(z)) of the second order moving average filter is given by:

$$H(z)=\frac{1}{3}*\left(\frac{z^2+z+1}{z^2}\right) \qquad (3)$$

The $\hat{V}_n$, moving averages filtered speed is given by:

$$\hat{V_n}=\frac{(X[n]+X[n-1]+X[n-2])}{3} \qquad (4)$$

The most critical error in GPS data is "wild" points. These points occur at very low GPS precision (low HDOP) or when tracking satellites are switching at very high rate. The algorithm ensures complete filtration of such points which degrade the quality of the GPS track.A wild-point reckoning technique is proposed & developed. The wild-point reckoning technique effectively tracks the position of new GPS point included in the track, and reckons a wayward point within a radius $R_w$and angle α_w. The reckoning radius and angle computed on the basis of vehicle speed and angle of the course traversed by that vehicle [11].

The algorithm is designed for vehicle tracking and a GPS point is assumed "wild" which occur outside the radius of 55.55 meters from last valid GPS point assuming maximum speed of 200 km/h. The algorithm instead of filtering a wild-point out of the track, reckons it into a valid track point based on a point-distance-angle calculation. Wild-point dead reckoning calculation is:

$$R_w = 55.55 \text{ Meters} \qquad (5)$$

Where, R_w is the radius of the threshold distance to detect an expected wild-point. If point P_2 is detected as wild-point, than that point will be replaced with the reckoned point. The dead reckoned point distance and angle are computed as

$$d_w = d_2 + (d_2 - d_1) \qquad (6)$$

$$\alpha_w = \alpha_2 + (\alpha_2 - \alpha_1) \qquad (7)$$

Where d_1 is the distance between point P_0 and P_1, d_2 is the distance between point P_1 and P_2, and d_w is the reckoned wild-point distance. And α_1 is the bearing of point P_1, α_2 is the bearing of P_2, and α_w is the reckoned wild-point bearing.
The reckoned point latitude, longitude is computed as:

$$Lon_w = Lon_2 + d_w * COS(\alpha_w) \qquad (8)$$

$$Lat_w = Lat_2 + d_w * SIN(\alpha_w) \qquad (9)$$

Where, (Lon_2, Lat_2) are the coordinates of last valid point, and (Lon_w, Lat_w) are the coordinates of the reckoned wild-point. Thus, the wild point will be replaced by point (Lon_w, Lat_w). The wild-point reckoning technique is represented in Fig.5. The technique ensures that every new GPS point admitted into the track is valid or reckoned close to valid point.

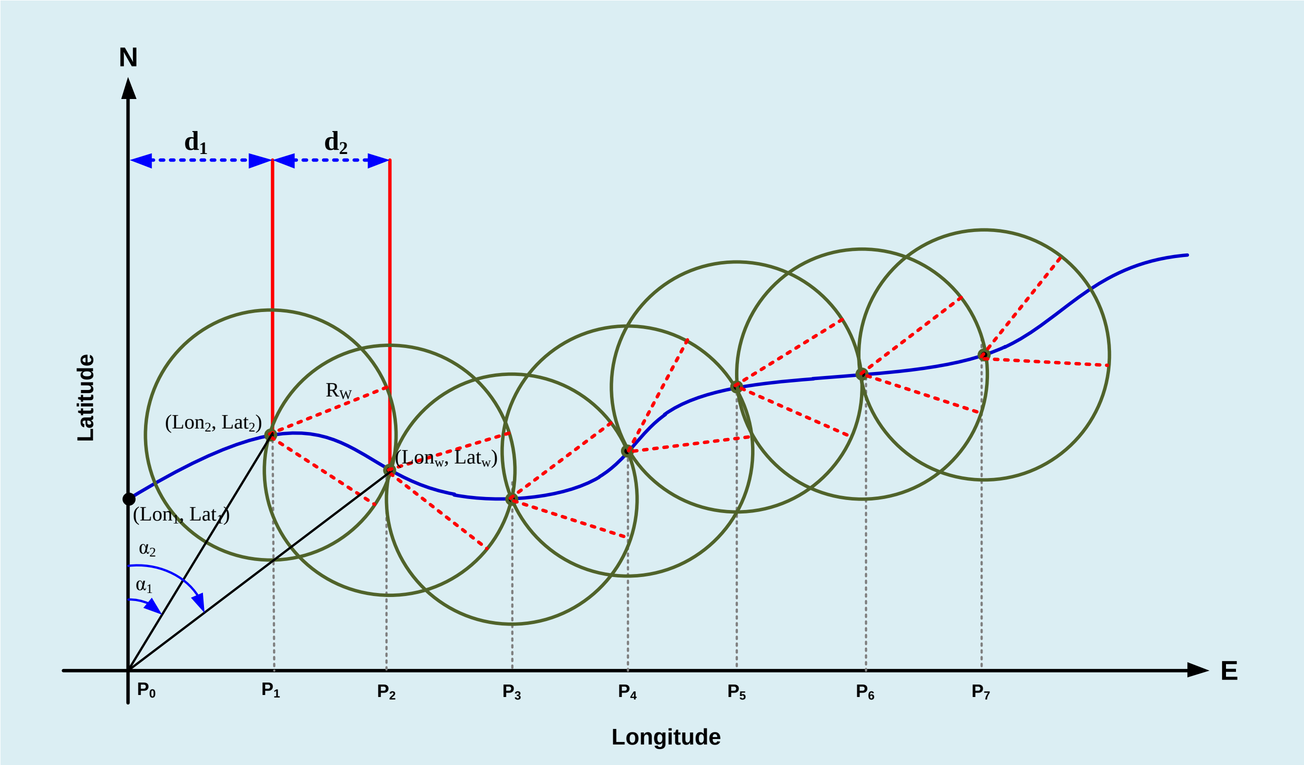

Figure5: Wild-point Reckoning Technique.

2.2 Adaptive Kalman Filter

Kalman filter provides a best estimate of the system state variable from a given discrete linear system and its noisy state variable measurements. Kalman filter assumes that the current state of a system is derivedfrom previous state of system in discrete step intervals. This predictor-estimator is optimal in the sense that it minimizes the estimated error covariance. The adaptive Kalman filter implemented is more accurate vehicle positioning method than the conventional used methods [12].

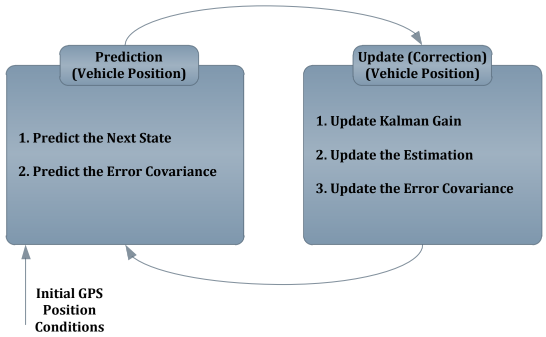

Figure 6: Kalman Filter – Flowchart.

In automotive telematics/tracking systems one of the main sources of error in GPS data is due to transition fromfix-GPS state to unfix-GPS state and vice versa. This type of error in GPS position data (latitude & longitude) can be minimizedby filteringdata through an adaptive Kalman filter. The filter is adaptive to noise variance *r*with limits ($r_{\min}$, $r_{\max}$) in GPS data [13].The value of *r* is computed adaptively depending on the vehicle speed:

$$\Delta V_n = floor(\hat{V}_n/4) \tag{10}$$

$$r_n = r_{\min} if\ \hat{V}_n > 70km/h \tag{11}$$

$$r_n = r_{\max} - ((r_{\max} - r_{\min})/4) otherwise \tag{12}$$

The value of *r* is computed again only if there is variation in speed and:

$$\Delta V_n \neq \Delta V_{n-1} \tag{13}$$

The Kalman filter equations are listed below.
Initialization:

$$P_0 = 0, P_0^- = 1.0, K_0 = 0, \hat{x}_0 = z_0, \tag{14}$$

$$r = r_{\min}, \hat{X}_0^- = z_0, q = 1.0, \tag{15}$$

Prediction (Estimation):

$$\hat{X}_k^- = \hat{X}_{k-1}, P_k^- = P_{k-1} + q \tag{16}$$

Update (Correction):

$$K_k = \left(\frac{P_k^-}{(P_k^- + r)}\right) \tag{17}$$

$$\hat{X} = \hat{X}_k^- + K_k(z_k - \hat{X}_k^-) \tag{18}$$

$$P_k = (1 - K_k) * P_k^- \tag{19}$$

Where priori state estimate of the system is $\hat{X}_0^-$ at time step *k*, and posteriori state estimate of the system is $\hat{X}_k$ at time step*k*. P_k is priori estimate error covariance matrix and posteriori estimate error covariance matrix is P_k^- at time step*k*. Z_k is measured GPS position data, $K_k$is Kalman filter gain, and *q* is noise variance of the system.

The Kalman filter minimizes the error covariance in GPS position data and a fine track path is obtained [14]. The quality enhancement of a GPS track path is a big value addition to the telematics/tracking system.

2.3 Track-Point Reduction

Optimization of the memory in embedded controllers used in automotive telematics/tracking systems is of primary importance thus reduction in track points also plays a critical role to achieve this objective. To realize this goal track point reduction method is implemented in this algorithm that works on the basis of straight path distance traveled and the curve angles traversed [15].

The developed point reduction computation technique is based on the straight line distance travelled and heading angle (from north) between the last three successive GPS points. Point P_1 is the last point entered in the track, than the angle traversed by the vehicle while travelling from point P_0 to P_2 is $\gamma = |\alpha_2 - \alpha_1|$[16]. If $\gamma \geq \gamma_{TH}$than the point belongs to the track. γ_{TH}updated adaptively depending upon the vehicle speed by the equation :

$$\gamma_{TH} = \gamma_{\min} if\ \hat{V}_n > 45km/h \tag{20}$$

If Vehicle speed is greater than 45 km/h the angle threshold is re-computed as:

$$\gamma_{TH} = \gamma_{\max} - ((\gamma_{\max} - \gamma_{\min})/45) * \hat{V}_n \tag{21}$$

On a straight path in a track if the distance travelled is greater than d_{Th} the point is included in the track regardless of the angle traversed, thus reducing the number of points on a straight track. The value of distance thresholdd_{Th} is adaptively updated on the basis of vehicle speed along the path.

$$d_{TH} = d_{\min} if\ \hat{V}_n > 40km/h \tag{22}$$

If Vehicle speed is greater than 45 km/h the distance threshold is re-computed as:

$$d_{TH} = d_{\max} - ((d_{\max} - d_{\min})/40) * \hat{V}_n \tag{23}$$

The track point reduction technique is adaptive to the vehicle speed and a degree of point reduction is achieved on vehicle speeds greater than 40 km/h. The track-point reduction technique is shown in Fig. 7. The track-point reduction technique removes redundant points from the GPS track on the basis of distance & angle threshold.

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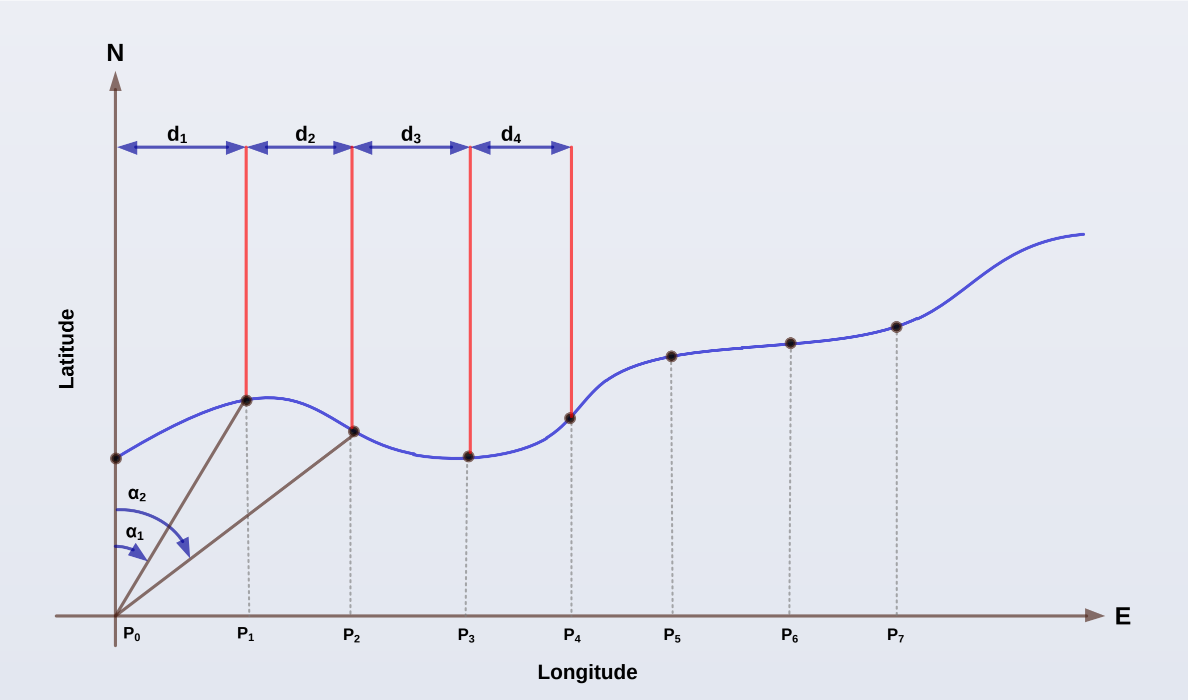

Figure7: Track-point Reduction Technique.

3. TEST & TRIAL RESULTS

The track optimization algorithm (TOA) was modelled in Matlab. A testing track was selected in Islamabad, Pakistan for TOA testing and evaluation. The selected track is along a curved path on the Margalla Hills of Islamabad. GPS data points at a frequency of 1Hz were logged for the testing track. The GPS used for data logging was eMD3622F from eRide. The GPS track data was fed into Matlab and a virtual testing environment was created for the development & testing of track optimization algorithm for telematics system.The speed of the vehicle along the track was extracted. The track selected for the testing is shown Fig. 8.

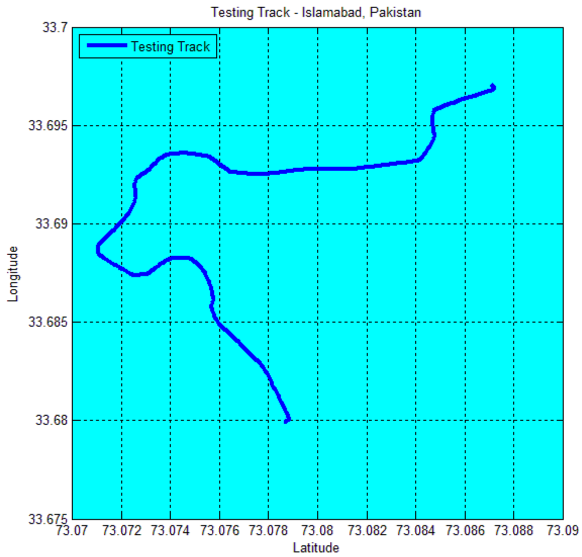

Figure8: Track Optimization Algorithm Testing Track.

The HDOP values for complete track were extracted and number of satellites in view was also analyzed for possible causes of errors in GPS data. The number of GPS satellites in view varied along the testing track but the GPS fix state was maintained by GPS receiver. The variation in the GPS Speed values were smoothed by moving averages filter. Moving averaged speed data along with HDOP filtered position data was fed to Kalman filter.

The spikes in the speed data can lead to invalid calculations. The percentage speed variation is shown in the Fig. 8. There can be spikes of up to 50% of the values of the speed. This type of data should be filtered before using it for some deterministic calculations.

A three point moving averages filter is applied to the speed values to smoothen the speed curve. Moving average filter filters abrupt acceleration &deceleration variations in the speed data, reducing the error covariance and enhancing the performance margin for next stage filter i.e. the Kalman Filter.

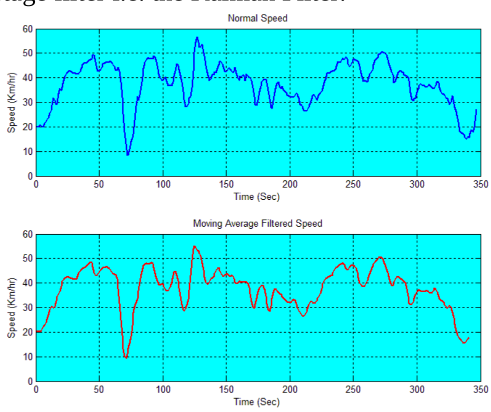

Figure9: Moving Average Filtered Speed.

The moving averages filtered data has reduced variation in the speed values as shown in Fig. 10.

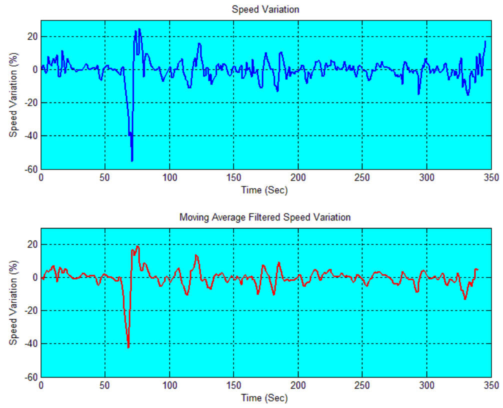

Figure 10: Speed Variation on the Testing Track.

Adaptive Kalman extracts actual position values from measured erroneous values and initiale state conditions. Adaptive Kalman produces a track plot conforming very closly to the actual location of the vehicle on the road. A smooth track plot is achieved as a result of the Adaptive Kalman filter. The Kalman filteredGPS track points are shown in the Fig. 11.

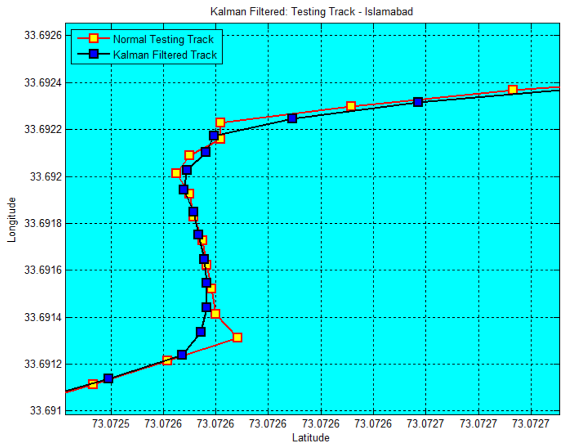

Figure 11: Normal &Kalman Filtered Testing Track

Finally point reduction is applied to reduce the data points while maintaining the original shape of the track.The distance travelled along a straight path produces redundant points without improving the quality of the GPS track. Therefore a distance threshold is computed in Point reduction technique to filter the redundant track points. Similarly Point reduction technique computes an angle threshold to filter track points not required at curves part of the GPS track.

The testing track selected has most of its part along a curved path; therefore angle threshold played a leading role in the application of Point reduction techniqueon this track. The track point reduction technique is based on the distance and angle thresholds and employ's Haversine Formula for this computation [17]. The track point reduction results in reduction of communication bandwidth and DB storage requirements. The track Point reduction technique resulted in GPS track, similar in shaped to the testing track with a benefit of 26% reduction in track points. The track point reduction technique is shown in Fig. 12.

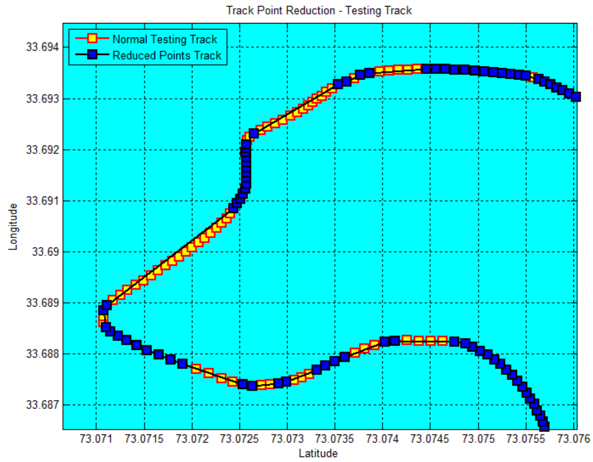

Figure 12: Point Reduction in Test Track.

The track optimization algorithm was incorporated in a Secure Automotive Telematics System (SATS) and a resultant Google Maps based GPS track is shown in Fig. 13.

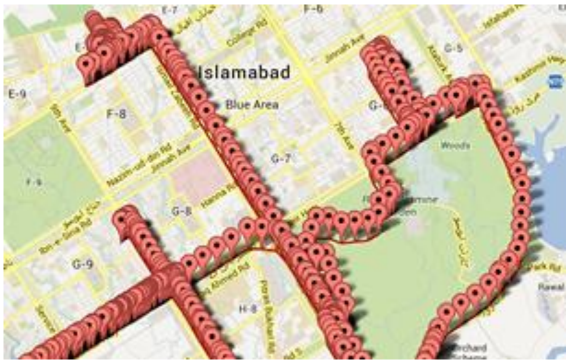

Figure 13: Google Maps plot of SATS with TOA.

4. CONCLUSION

The paper describes a new approach in handling wild points improving the quality of a GPS track. The algorithm not only filters invalid values but also reckons the wild-points to valid points. Leading to an optimized GPS track,concurrently this quality enhancementis achieved with a reduction in GPS data. Track optimized is further augmented with wild-points dead reckoning improving error covariance. This reduced error covariance provides better margin to the adaptive Kalman filter producing better output. The point reduction technique reduced the number of points from the track without affecting the resolution of the GPS track.The presented algorithm is a part of automotive telematics system running on an ARM9 based processor.

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