Travel Time Estimation for Pedestrian with GPS Cell Phones as Probes

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***Abstract*—This paper estimates the travel time for pedestrian in Kist Medical Hospital- Balkumari route using cell phones' GPS as probes. Using Google Map's individual timeline, GPS data was traced for this route. Then, Kalman Filter Algorithm is used to estimate the travel time for pedestrian for that week day. Using algorithm result, statistical tool is used to measure the accuracy of travel time in particular origin-destination pair. Kalman filter algorithm is better approach for travel time estimation since the parameters get updated quickly if there is traffic fluctuation. Based on mean travel time, Kalman filter has better travel time estimation of 16.6 min with the help of historical data in compared to Google Map estimation of 18 min irrespective time of day in above origin-destination pair. Real observation is close to estimated travel time which signifies estimated travel time. Here author manages to compare the mean travel time between Kalman filter estimation and Google map data estimation.**

I. Introduction

TRAVEL time is one of the most used factors to measure performance of urban traffic system. This travel time estimation and prediction is important for Advanced Traffic Management System and Advanced Traveler Information System as integral of Advanced Intelligent Transportation system. Pedestrian Mode greatly affects the crosswalk and sidewalks of urban traffic operations by interacting with other modes (bicycle, automobile, transit) [1].

Providing travel time estimation helps to take decisions regarding path (route) selection and it helps to manage and monitor the traffic congestion. Travel time data is collected from different sources as Automatic Number Plate Recognition (APNR Cameras), Loop Detectors, Bluetooth Devices, cellphone, GPS probe vehicles. It is costly to use APNR cameras and to install those devices for estimating travel time however they produce less error. In North America, loop detectors are highly used at different stations of arterial and freeway road network but it probes error due to equipment malfunctions. But in context of Nepal, no any devices like APNR, Loop Detector are used in highway and/or city roads.

With decrease in telecommunication price, increase in GPS accuracy data has led to using GPS probes for estimating and predicting travel time. Proper techniques should be implemented which gives better travel time estimation based on historical GPS probe data. Due to lack of sensors in roads in Nepal, only GPS data from cell phone can be used as source of data collection. This paper is organized as follows:

II. Problem Statements

The problem of estimating travel time for given O-D (origin-destination)pair takes consideration of estimating travel time for pedestrian based on historical data for that specific day. The objective of this research is to develop methodology to estimate travel time from GPS data collected from cell phone via Google cloud using Kalman filter algorithm. First,the collected data over given O-D pair was preprocessed and remove the outlier data. It is challenging task to determine the pedestrian travel time on routes where there is unsignalized intersections, road constructions ongoing. Road traffic conditions is not same all time the day. These traffic conditions are complex and depends on time of day, weather, traffic congestion, arterial road network or pedestrian pavement. Even, human beings don't have uniform walking speed on arterial road network or pedestrian pavement but close and walking speed depends on physical body structure, construction works, roadway characteristics.

III. Research Objectives

To estimate travel time, various research has been carried out using GPS collected data. At first, Kalman filter[2], considers linear dynamics of road networks. But in actual, nonlinearity of road network must be considered. So, extended Kalman filter and Unscented Kalman Filter can be used to consider non-linearity of the problem. The proposed methodology will be applied to data collected from GPS cell phones and travel time for pedestrian will be estimated from proposed methods. This research article will show how proposed method will estimate travel time on heavy traffic volume and unsignalized intersection in road network of Kist Medical College to Balkumari route.

IV. Literature Review

Travel time estimation models can be classified into two groups- parametric models and non-parametric models. Parametric models consists of historic average model, time-series models, state-space models [3]. Non-parametric model consists of Neural Network, K Nearest Neighbor Methods. Time series model consists of autoregressive model(AR), moving average model(MA), Seasonal Autoregressive Integrated Moving Average Time Series Model.

[1] Time Series Models:

The author applied ARIMA models to estimate travel time data. This model can be applied to stationarity data[4]. The non-stationarity data can be made stationarity through differencing. The fist differencing of series may not produce stationarity series either. So, autocorrelation function is used to indicate seasonal differencing and stationarity series. This model compromise of Autoregressive Model (AR) and Moving Average Model (MA).

1. Autoregressive Model:

$X_t = \delta + \phi_1 X_{t-1} + \phi_2 X_{t-2} + \cdots + \phi_p X_{t-p} + A_t$; X_t-Time Series, A_t-White noise $\delta = (1 - \sum_{i=1}^{p} \phi_i)$ μ; μ- Process mean, p-order of model

2. Moving Average Model (MA):

$$X_t = \mu + A_t - \theta_1 A_{t-1} - \theta_2 A_{t-2} - \cdots - \theta_q A_{t-q}$$

where $\theta_1, \ldots \ldots, \theta_q$ parameters of model, q-order of MA model.

Then Box-Jenkins ARMA model is combination of AR and MA model. While differencing stationarity series to produce stationarity, multiplicative seasonal autoregressive integrated moving average model is defined. This model in [4] provides effective travel time forecasts irrespective of probe vehicles, loop detector data.

[2] Kalman Filtering Models

Kalman first published paper on new approach to linear filtering and prediction problems[5]. Kalman filter is mathematical model that is accurate and recursive computation approach to estimate the previous states and predict future states. Kalman filter is recursive filter where new value is predicted and corrected with help of previous states. This also minimizes the mean square error of estimated parameters. Kalman filter is best linear estimator. It consists of transition equations and measurement equations. Kalman Filter algorithm is listed as:

$x_{k+1} = \phi_k x_k + w_k$

where, x_k is travel time to be predicted, ϕ_k state transition parameter relating x_k to x_{k+1}, w_k- Zero mean Gaussian noise with covariance Q_k.

Observation equation is

$Z_k = x_k + v_k$

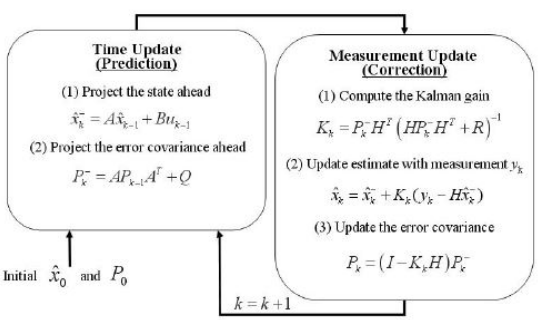

Fig.1. Flowchart of Kalman Filter Operation

Kalman filter is a dynamic system that consists of two parts: measurement equation and update equation. New state is predicted through process equation. After that measurement is predicted through measurement equation. This system uses prior knowledge (historical database) for estimating and predicting travel time. In second stage, the predicted state is corrected on the difference of true and predicted measurements.

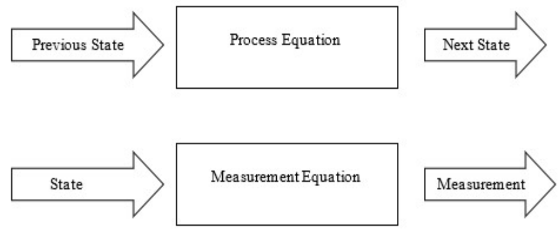

Fig.2. Block Diagram of Kalman Filter Operation

Here Q and R represents the process noise covariance and the measurement noise covariance resp. These process noise and measurement noise are assumed as zero mean and Gaussian. The authors in [6] fused floating car data and fixed detector data to improve accuracy of travel time prediction for Kalman. The result found in this research shows error value of Kalman prediction model based on multi-source data is relatively small and prediction's accuracy increases by 13.4 % and 7.2 % in compared to fixed detector data and floating car data.

V. Methodology

In this section,the detail process of algorithms used in this research is described. It consists of three major steps- data collection form GPS data, removing of outlier data, estimating travel time.

A. Data Collection

In this research, data is collected from Google map's individual timeline send from location enabled cell phone" SamsungGalaxy Core LTE". This GPS based cell phone collected latitude and longitude of every destination with time. I have used almost 10 days data from end of March 2017 to mid of April which consists of both departure and arrival from/to Balkumari. The sample of data collected from cellphone traced on Google map is:

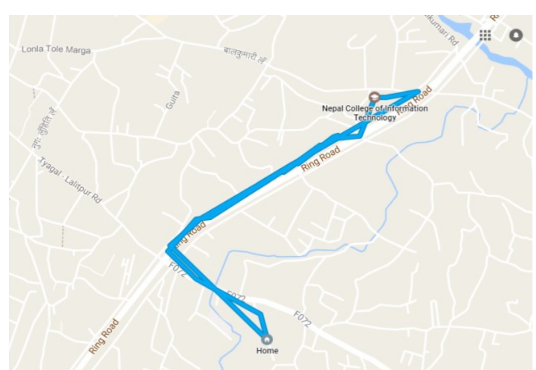

Fig.3. Snapshot of GPS collected data traced in route

B. KF based tracking

Kalman filter is a series of mathematical equation which minimizes the mean of squared error which gives efficient way to determine state of a process. It can estimate on past, present and future time even when the nature of model is unknown[7].Kalman filter is more flexible in case of any kind of motion other than pure translational motion.Kalman filter is based on motion while some other filter like correlation filter is based on appearance. Kalman filter performs better than Means Shift algorithm under noisy atmospheric conditions[8]. Autoregressive model is fixed and can't update to the process and measurement noise intensities, resulting in performance reduction to some extent[9]. For the above OD pair Kalman filter is used to track the movement of mobile probes with individual pedestrian. The Kalman filter estimates the process state at some time and feedback is obtained with noisy measurements. To track the moving cell phone carried by pedestrian, state vector is expressed as

$$X(t) = [x(t) \quad 0\ ]^T \qquad (1)$$

Where x(t) is the travel time in minutes taken for specific route. The dynamics matrix A is calculated from the dynamics of Egomotion.

$$A = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad (2)$$

The observation Y(t) is determined by measurement equation.

$$Y(t)= H\ X(k) \qquad (3)$$

With the measurement matrix

$$H = [1 \quad 0] \qquad (4)$$

It is assumed that speed and direction of pedestrian doesn't change significantly sothat motion is assumed to be uniform in a straight line[10]. At beginning,initial covariance matrix P_0 for initial state $X_0$is assumed. P_k is updated iteratively. Initial error covariance matrix P_0 is as:

$$Po = \begin{bmatrix} 25 & 0 \\ 0 & 25 \end{bmatrix} \qquad (5)$$

The process noise can be modeled with process noise covariance matrix Q.

$$Q = \begin{bmatrix} 5 & 0 \\ 0 & 5 \end{bmatrix} \qquad (6)$$

$$R=[2] \qquad (7)$$

Using prediction and update equations, state vector and covariance matrix are estimated for each data set. The time update equations are responsible for projecting forward (in time) the current state and error covariance estimates to obtain the a priori estimates for the next step[5].The measurement update equation is responsible for feedback to obtain improved a posteriori estimate. These two equations can be taken as predictor and corrector equations. At first Kalman gain is computed and posteriori state estimated by taking consideration of measurement. The final step is to obtain posteriori error covariance. At each time and new measurement, process is repeated with historical posteriori estimates or new priori estimates. This algorithm is based on previous estimates[5].

VI. RESULTS AND DISCUSSION

Since author is using cell phone GPS data as data source, some data is removed from calculation. These outlier data may be due to inaccuracy of GPS devices. While mapping the GPS latitude and longitude data on the route , GPS points lies outside of road link . In this case, such GPS data is removed as outlier.

The actual time taken for given origin destination pair from GPS data is compared with Kalman Filter estimation. The estimated values from Kalman filter for specific day is shown in chart below.

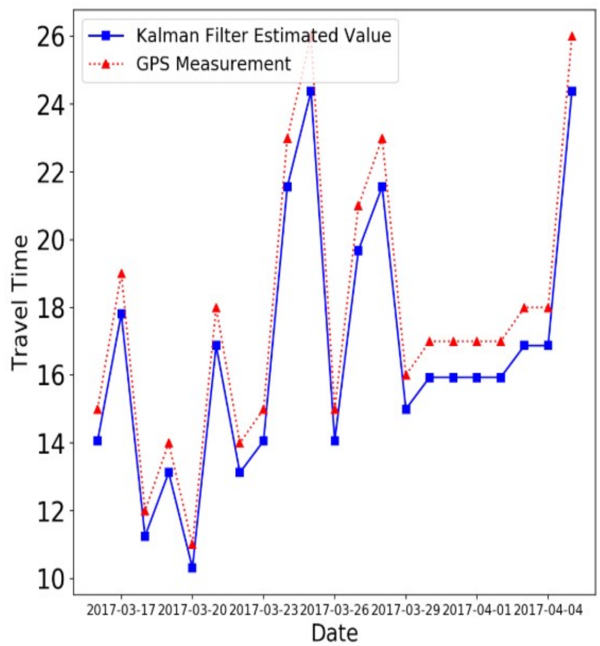

Fig.4. Comparison between GPS Measurement Travel Time and Kalman Filter Estimated Travel Time

Descriptive Statistics for travel time is shown in Table I.

Table I

Descriptive Statistics for travel time

Travel Time Estimator	Mean(m)	Standard Deviation(σ)
Raw Data	17.714286	4.112698
Kalman Filter	16.6071	3.85564

In comparison to Kalman Filter, raw data has more mean and standard deviation. For the same origin-destination pair, if we use Google Map for travel time estimation, it shows 18 min for any day (either weekday or weekend). It doesn't take consideration of specific days. But in real environment, walking time for pedestrian depends on time of day (morning, daytime, evening). In the morning time, traffic is low took 14 minutes to reach destination. But it can't be considered in general because for same time, it took up to 23 minutes due to construction works in road, unsignalized intersections. During 9-10 am of weekday, there is heavy traffic as schools and government offices about to open and takes longer time about 23-26 minutes to walk same OD pair. For estimating travel time on specific day for next week, I use previous week specific day' data as historical data.

With the consideration of this historical data, new travel time is estimated on that route.

VII. Conclusions

The methodology based on Kalman Filter is used to estimate the travel time for fixed origin-destination pair. Historical data collected from GPS assisted cellphones is feed to Kalman filter and it estimates the travel time and updates every time if there is traffic fluctuation. Results show thatestimated travel time is closed to real observations. The algorithm used works for linear dynamics of road network.

VIII. Recommendations

In this research, linear dynamics of road network is considered but arterial road network and freeway road network, non-linearity is considered. Due to linear characteristics of Kalman filter, improved or extended form of Kalman filter needs to be implemented. Sometimes in trail road, GPS signal reception may be blocked due to tall buildings and trees. To solve this problem, Doppler shift measurement can be used and Kalman filter & its extension can be used to estimate. Other limitation of using cell phone is that GPS signal reception doesn't work if phone is locked. To continue the signal reception, phone needs to be active all time. For pedestrian travel time, there are many other factors to be considered during estimation. Signalized and unsignalized intersections also need to be taken in account. Slow and fast walking pedestrians also need to be included to increase accuracy of estimation.

IX. References

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X. Biographies

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