Vehicle Speed Estimation using Wireless Sensor Network

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***Abstract*—A real time locating system automatically tracks and localizes people and objects. We propose a model for the speed monitoring of vehicles using wireless sensor network-based on real-time localization. Our model is based on symmetric double sided two way ranging algorithm which has the ability to zeros out the effect of clock drifts between transmitter and receiver. In our model two anchor nodes are used as road side units at fixed locations and heights and moving vehicle is equipped with on board unit called a tag. Collected data from tag is used to calculate the speed of the vehicle at the base station. Several experiments are done to evaluate the performance of the proposed model at different sampling intervals of time by moving the vehicle at different speeds. Due to the noisy nature of collected data, discrete Kalman filter is used for better estimation of the speed of the vehicle. We have compared the true values of speed with measured values and estimated values. Experimental results show that the estimated values became close to the true values by applying Kalman filter.**

Keywords-SDS-TWR; Kalman filter; Traffic monitoring.

I. INTRODUCTION

Due to advancements in electronics sensor nodes become smaller and cheaper, while advancements in communication technology made the sensor node to communicate in a better way; for that several efficient protocols and algorithms have been developed [1]. These tiny sensor nodes are working together to make a wireless sensor network. Wireless sensor networks can be used efficiently in several applications like home automation, industrial control, military and health. Real-time localization is one such important application of wireless sensor network to locate objects.

In monitoring and surveillance applications, if the position of the reporting node is not known, the information we obtained is not useful information. Several nodes are deployed with known locations information; such nodes are called anchor nodes. Other nodes, which do not know their position information, are called blind nodes. Anchor nodes are used to locate blind nodes by using different localization algorithms. Ranging is the process to determine the distance between an anchor node and blind node. The distance is fed to localization algorithm to find the resultant location. Traffic surveillance is an important system which monitors the speed and traffic density. This information is useful for law enforcement agencies, to have a check on an over speeding vehicles, and also useful for transportation agencies to make transportation more intelligent by avoiding rush conditions.

In our paper, a system model is proposed for traffic monitoring using wireless sensor network. Traditionally, there are several techniques for traffic monitoring like inductive loops detectors and speed cameras. Inductive loops are installed in pairs in a travel lane for direct speed measurement. However, most of the time single loop detectors are used which cannot measure speed directly; estimation is used for such measurements [2]. Single loop speed estimation can be broadly divided into two types: (1) g-factor approach, and (2) stochastic filtering approach [2]. In g-filtering measured occupancy and volume is used to know the speed of vehicle while in stochastic approach Kalman filter is used for estimation of speed. Video systems used for traffic monitoring generally involves two tasks (1) Estimation of road geometry (2) Vehicle detection. Measurement taken by such system is then matched with the assumed road or vehicle model to determine vehicle speed and position. Such system must have low processing time, cost and high reliability which are difficult to get because of the high computationally expensive process like segmentation. Wu *et al*. [5] present a new algorithm that takes advantage of the digital image processing and camera optics to automatically and accurately detect vehicle speed in real-time. In [6], the algorithm is based on WSNs, which work according to the characteristics of the actual traffic stream, an on-road speed estimation model and algorithm based on wireless magnetic sensor networks was researched. In this model, 3 sensor nodes were working together to estimate the speed of passing vehicle. Totally different approach is followed in [8], which uses acoustic wave pattern to estimate vehicle speed. The acoustic wave pattern is determined using the vehicle's speed, the Doppler shift factor, the sensor's distance to the vehicle's closest-point-of-approach, and three envelope shape (ES) components, which approximate the shape variations of the received signal's power envelope.

In this paper, we propose a different approach from vision based systems. Our proposed system is based on a wireless sensor network, in which a vehicle equipped with on-board unit tag is continuously monitored by fixed access points. Our system is simple and inexpensive system, which can be further enhanced to include many other functionalities.

The rest of the paper is organized as follows; Section II describes the symmetric double sided two way ranging algorithm. Section III gives the proposed system model and discrete kalman filter design. Experimental results and discussion are given in Section IV. Section V discusses conclusion and future work.

II. SYMMETRIC DOUBLE SIDED TWO WAY RANGING (SDS-TWR)

Ranging is the most fundamental technology used in Real Time Locating Systems (RTLS). Nanotron Technologies developed SDS-TWR, which finds the distance between two nodes by measuring RToF symmetrically from both sides [4]. In some ranging systems, fine quality of clock generating crystal is required for measuring distance between two nodes. However, a cheaper way is that transmitter node calculates the round trip time to receiver node. Similarly, the receiver node calculates round trip time to transmitter node, and the resultant is average of two round trip times. The symmetric and double sided nature of transmissions, zero out the effect of clock drifts between transmitter and receiver even using the cheap oscillator on both sides.

In SDS-TWR, measurement of time starts at node A by sending a ranging request to node B, as shown in Fig.1. Node B starts its time measurement by receiving the packet from node A, and stops when it sends a reply to node A. Node A calculates the round trip time from the accumulated time in the received packet from node B. The difference between the measured time by node A minus the measured time by node B, equals to the twice of the time of signal propagation. Similarly, in the second measurement at node B, which sends ranging request to node A and starts its time measurement. Node A starts its time measurement, when it receives the packet, and stops, when it replies with a packet to Node B. Propagation time t_p is given by equation (1).

$$t_p = \frac{t_{roundA} - t_{replyA} + t_{roundB} - t_{replyB}}{4} \quad (1)$$

III. PROPOSED SYSTEM MODEL AND DISCRETE KALMAN FILTER DESIGN

In our proposed system for traffic monitoring, two anchor nodes with known locations and at known heights H, are used. Anchor nodes are called road-side units (Access Points), which are denoted by anchor1 (AP1) and anchor2 (AP2).

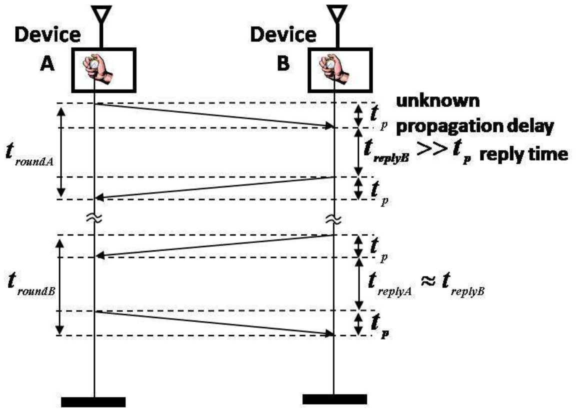

Figure 1. Symmetric Double Sided Two Way Ranging

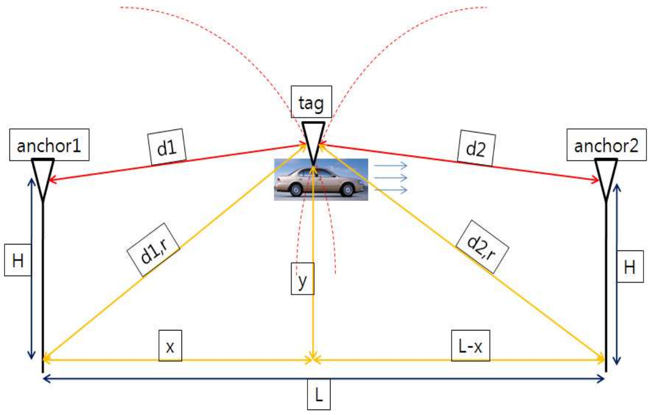

Figure 2. Proposed Model

Moving vehicle is equipped with on-board unit called tag, which is communicating with both anchors, and also with base station. The base station is used to collect data from the tag, and calculates its position and velocity. Total distance between two anchor nodes is measured manually, denoted by L. At any moment, the distance traveled by moving vehicle is denoted by L-x, where x is the traveled distance. Ranging distance between AP1 and tag is denoted by d1 and between AP2 and tag is given by d2, where $d1_r$ and $d2_r$ are real distances and can be calculated as,

$$d1_r = \sqrt{d_1^2 - H^2} \quad (2)$$

$$d2_r = \sqrt{d_2^2 - H^2} \quad (3)$$

$$x = \frac{d1_r^2 - d_{2r}^2 + L^2}{2L} \quad (4)$$

$$y = \sqrt{d1_r^2 - x^2} \quad (5)$$

First time reading: $(x_1,y_1),t_1$

Second time reading: $(x_2,y_2),t_2$

$$v = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \Big/ (t_2 - t_1)$$

where x and y are the coordinates of the moving vehicle and v is the resultant speed of the vehicle. Our proposed system is a linear dynamic system. Kalman filter is used to get a better estimation out of noisy measured data [7].

The Kalman filtering process can be divided into the following steps.

Step 1: State Equation of the linear dynamics system is given below.

$$X_{k+1} = AX_k + \Gamma u_k + W_k \tag{6}$$

$$\begin{pmatrix} x \\ v \end{pmatrix}_{k+1} = \begin{pmatrix} 1 & T \\ 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ v \end{pmatrix}_k + \begin{pmatrix} T^2/2 \\ T \end{pmatrix} u_k + W_k \tag{7}$$

Where Position is given by

$$x_{k+1} = x_k + T.v_k + \frac{T^2}{2} u_k + w_{k.x} \tag{8}$$

Velocity is given by

$$v_{k+1} = v_k + T.u_k + w_{k.v} \tag{9}$$

$w_k \sim N(0, Q_k)$, where w_k is process noise with zero mean and Q_k covariance (in our experiment, it is acceleration uncertainty). A and Γ are transition matrices. T is sampling interval, and U_k is constant input to the system.

Step 2: Measurement equation

$$Y_k = CX_k + Z_k \tag{10}$$

$Z_k \sim N(0, R_k)$, where Z_k is the measurement noise with zero mean and R_k covariance. Measurement noise mainly occurs due to instrumentation errors, while C represents the transition matrix.

Step 3: A priori error covariance and Kalman gain are given in "(11)" and "(12)" respectively. Where $\hat{P}_k$ is the initial estimation covariance.

$$\overline{P_{k+1}} = A\hat{P}_k A^T + \Gamma Q_k \Gamma^T \tag{11}$$

$$K_{k+1} = \overline{P_{k+1}} C^T (C\overline{P_{k+1}} C^T + R_{k+1})^{-1} \tag{12}$$

Step 4: A posteriori state estimate

$$\begin{pmatrix} \hat{x} \\ \hat{v} \end{pmatrix}_{k+1} = \begin{pmatrix} \bar{x} \\ \bar{v} \end{pmatrix}_k + K_k \left[Y_{k+1} - C \begin{pmatrix} \bar{x} \\ \bar{v} \end{pmatrix}_k \right] \tag{13}$$

Velocity and position after estimation are shown in "(13)".

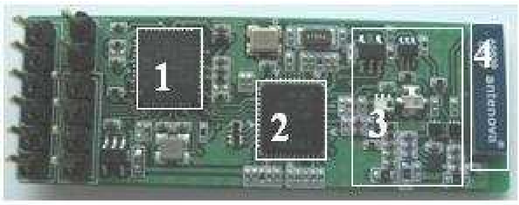

Figure 3. Redesigned module with added Power Amplifier (20mmx50mm)

IV. Experimental Results and Discussion

Performance of the proposed system model is evaluated using nanoLOC TRX Transceiver by Nanotron Technologies [4]. We have redesigned the hardware module by adding a power amplifier to it, as shown in Fig.3. The module contains ATMEGA 644 (1), NanoLOC (2), power amplifier (3), and chip antenna (4). NanoLOC TRX transceiver is used for base station, AP1, AP2, and tag operating in ISM 2.4 GHz frequency band. Proposed system model is evaluated by driving a car equipped with on-board unit (tag) at different speeds, e.g., 20,40,60,80,100,120 km/hr between two APs. During each experiment, the vehicle was moved at a constant velocity. Experimental results are corrupted by noises. There are two noises to cater for.

- Process noise: The velocity is perturbed by noise due to gusts of wind, potholes.
- Measurement noise: Measurement noise is mainly due to instrumentation errors.

Kalman filter exploits the predictable nature of the uncertainty or noise in the signal to optimize the estimation, based on the prediction of the model as well as updates from the measurements. Several parameters of the model are the following.

- Operating range of each device is (400m-700m).
- Height of rod at which AP1 and AP2 are installed is 9.5m.
- Total distance between AP1 and AP2 is denoted by L=356m.
- Several parameters required for kalman filter to work properly are process and measurement noises, which are obtained by carefully observing experimental and actual data.
- Process noise= $4 m/sec^2$, and measurement noise=5m.

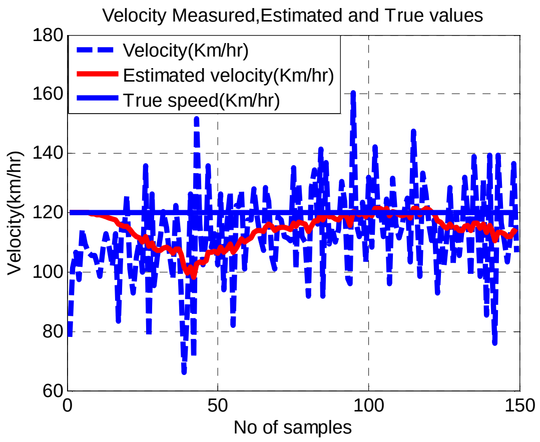

Figure 4. Speed of the vehicle at 120 Km/hr.

In Fig.4, the speed of the vehicle moving with constant speed of 120 km/hr is monitored. A solid blue line indicates the true speed of the vehicle, which is kept constant between two AP's. True speed of the vehicle is given by the vehicle speed meter. The experimental data obtained from the sensors are shown by the blue dotted line in the graphs, which are corrupted by noises. Deviation from the true speed can easily be seen in the graphs. It is difficult to maintain constant speed between two APs, which may also be the source of noise in experimental data. Noises are in the form of acceleration uncertainty. Kalman filter is used on experimental data for estimation, which is shown by the red line in Fig.4. Estimated results are closer to the true speed of the vehicle. Results show that tuning of kalman filter is required to obtain best results out of corrupted data.

Experimental data are taken at different sampling intervals of times, e.g., 90ms, 450ms. Performance is evaluated by comparing the measured data with true data and estimated data from a kalman filter.

In Fig.6, when the vehicle is moving with the lower speeds, e.g., 40 km/hr, then measurement and estimated results are closer to the true results, but at higher speeds, experimental data are more prone to noise and error.

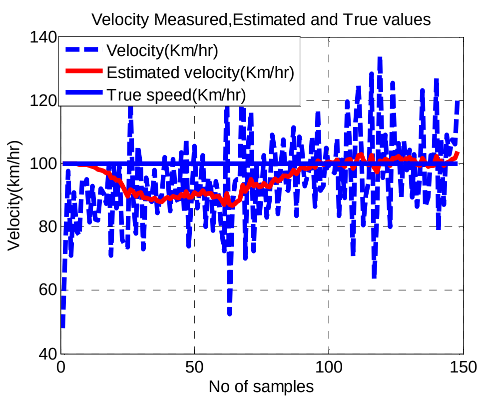

Figure 4. Speed of the Vehicle at 100 Km/hr.

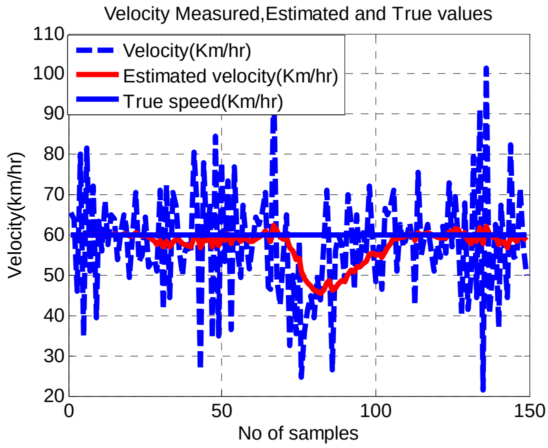

Figure 5. Speed of the Vehicle at 60 Km/hr.

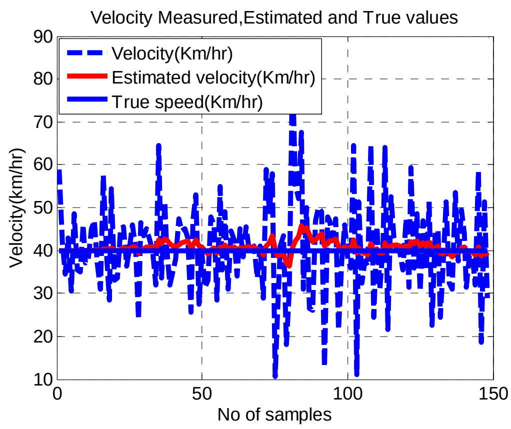

Figure 6. Speed of the Vehicle at 40 Km/hr.

V. CONCLUSION AND FUTURE WORK

In this paper, model for traffic monitoring system using a wireless sensor network has been proposed, and practically evaluated using Nanotron sensor boards. In the proposed model, whenever the moving vehicle with tag appears in between two anchor nodes, its position and velocity are determined and displayed on the base station. Kalman filter is used for better estimation. The proposed model has several advantages over existing systems; it is more robust and requires less computation than existing systems with expensive cameras. Model is evaluated for single vehicle, but it can be easily extended for many vehicles.

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