

Traffic Control System using Wireless Sensor Network

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Abstract— The Real time locating system (RTLS) determines and tracks the location of assets and people. This paper presents a novel application to estimate the position and velocity of vehicle using wireless sensor network. Two Anchor nodes are used as reader along roadside and total distance between them is known. Whenever a moving vehicle with tag comes in between the common part of the operating range of two anchor nodes, exchange of information is done using Symmetric double sided two way ranging algorithm, which gives us position information. Using position information at several interval of time, velocity can be easily obtained. Position and velocity is obtained and displayed on base station. Kalman filtering is used to estimate the position and velocity from noisy measurements. Performance evaluation is done comparing vehicle position speed true values with experimental and estimated values.

Keywords— SDS-TWR, CRLB, Kalman filter, TOA

I. INTRODUCTION

Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power multifunctional sensor nodes that are smaller in size and capable of communicating. These tiny sensor nodes consist of sensing, data processing, and communicating components. Wireless sensor network (WSNs) is a significant technology, attracting considerable research interest. Sensor networks can be used for various application areas like military, health, home and industry. One very important application of sensor network is real time localization. Real time locating system is the system for automatically locating and tracking men and objects. Position information gathered from sensors in sensor network can be used in many positioning and navigation systems. Sensor network localization algorithms estimate the location of sensors with initially unknown location information by using knowledge of absolute position of few sensors and inter-sensor measurements such as distance and bearing measurements. The kind of sensor with known location information are called anchors and deployed at points with known coordinates. Other sensor with unknown location information are called non-anchor and their location information can be found using localization algorithms.

Traffic control system is one such important application of real time locating systems using sensor network.

Traditionally traffic control is done using expensive cameras installed at various check points to monitor the speed of vehicle in order to avoid accidents and maintain a check and balance on over speeding vehicles. In our application, a novel technique for traffic monitoring and control using inexpensive sensor nodes is proposed. There are several techniques which can be followed for real time localization and generally can be divided into range-based and range-free algorithms. Range based algorithm uses point to point distance or angle estimate which include Time of Arrival (TOA), Time difference of Arrival (TDOA), Angle of Arrival (AOA) and Received Signal Strength indicator (RSSI). Range free algorithm does not require absolute distances information. Proposed technique is based on SDS-TWR (symmetrical Double-Sided Two Way Ranging) algorithm which is based on time of Arrival technique patented by Nanotron Technologies [1].

Symmetrical Double-Sided Two-Way Ranging is a ranging methodology that uses two delays that naturally occur in signal transmission to determine the range between two stations [1]. Vehicle speed estimation based on video sequences requires high resolution and high frame rate for high accuracy. Video surveillance requires complex image processing algorithm like segmentation to be used in real time scenario for traffic control system [2], [3]. One approach to estimate vehicle velocity and traffic intensity is by using rectified images [4]. In rectified image approach a “top view” of the observed scenario is considered, this procedure employs by estimating two vanishing points. From vanishing points, rectified images are formed in which a great care has to be done in order to map distance travelled on image plane to distance travelled on ground plane. Consequently requires a scale factor for mapping [4]. In our proposed work which is more simple, scalable and requires less computation and most suitable for such real time scenarios, two stationary anchor nodes are used to measure the speed whenever a moving car with tag comes in between the two anchor nodes.

The rest of the paper is organized as follow; Section II gives the theoretical limit on delay estimation and ranging using Cramer lower bound. Section III discusses the Symmetric double sided two way ranging algorithm. Proposed model and experimental setup is discussed in Section IV. Section V discusses experimental results and application of Kalman filter on noisy measurement obtained. Conclusion and future work are given in last part.

II. THEORETICAL LIMIT ON TIME DELAY ESTIMATION AND RANGING ACCURACY

Symmetric double sided Two Way Ranging (SDS-TWR) uses time of arrival technique which provides the distance between two nodes by estimating the time of arrival of signal that travels from one node to another node. Conventional TOA technique uses matched filtering and correlation operations for ranging. Let the received signal is

$$r(t) = as(t - \tau) + n(t) \quad (1)$$

Where τ is time of arrival, a is the channel coefficient and $n(t)$ is white Gaussian noise with zero mean and a spectral density of $N_0/2$. It has been derived that theoretical limit of delay according to Crammer Rao is [7].

$$\text{var}(\hat{\tau}_0) \geq 1/\text{SNR} \times B_{rms}^2 (\text{sec}^2) \quad (2)$$

Where

$$B_{rms} = \sqrt{\frac{\int_{-\infty}^{\infty} (2\pi f)^2 |S(f)|^2 df}{\int_{-\infty}^{\infty} |S(f)|^2 df}} \quad (3)$$

$$\text{CRLB}_{\hat{R}} = \left(\frac{dR}{dt_0}\right)^2 \text{CRLB}_{t_0} \quad \text{with } R = C\hat{\tau}_0/2$$

$$\text{var}(\hat{R}) \geq \frac{c^2/4}{\text{SNR} \times B_{rms}^2} (m^2) \quad (4)$$

In (3) B_{rms} is the mean square bandwidth, $S(f)$ is the Fourier transform of $s(t)$ and $\text{SNR} = E_b/N_0$ is signal to noise ratio and C is the speed of light. CRLB is inversely proportional to SNR and RMS bandwidth measure which shows that increasing SNR or mean square bandwidth improves the ranging accuracy. Figure.1 shows Crammer lower bound for different signal bandwidth 40 MHz, 60 MHz, 80 MHz, and 100 MHz which are taken around central frequency 2.44GHz. This shows that as bandwidth increases to 100 MHz, variance on delay estimation decreases until reaches to lower bound for different SNR values. Similarly for range, as bandwidth and SNR increases, range accuracy increases. That is why ultra wideband is most efficient for ranging.

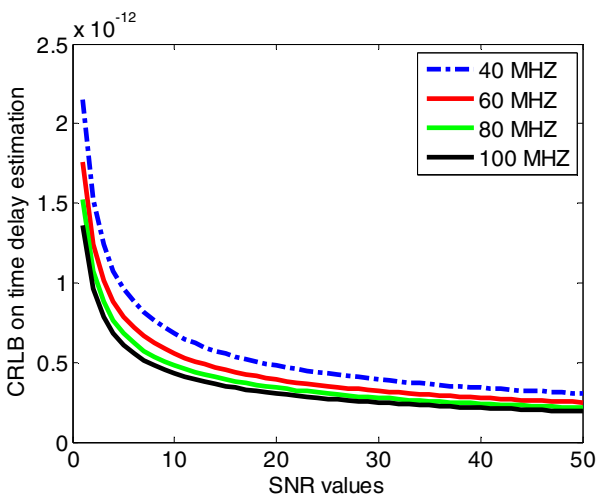


Figure 1. CRLB for delay estimation

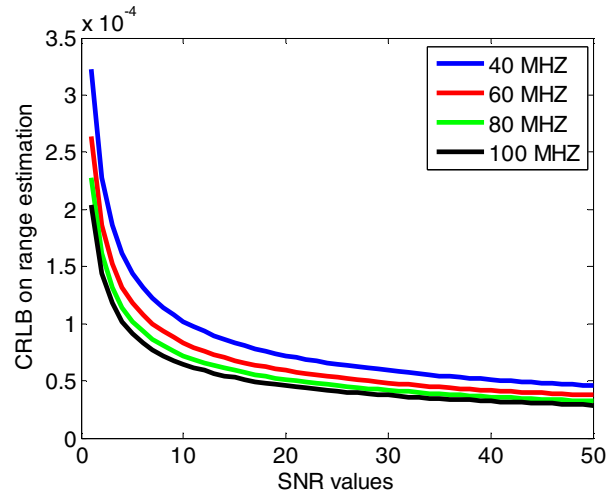


Figure 2. CRLB for ranging accuracy with different signal BW

Since UWB signal has a very large bandwidth, this property allows highly accurate distance estimation using TOA measurement. IEEE 802.15.4a ranging uses Chirp spread spectrum (CSS) patented by Nanotron [1]. CSS operates in the 2.45 GHz ISM band. Chirp signal is given by formula

$$x(t) = a(t) \cos(2\pi f_0 t + \pi \mu t^2) \quad -\frac{T}{2} < t < \frac{T}{2} \quad (5)$$

Where in (5) $a(t)$ is envelope of the chirp signal and f_0 is the instantaneous frequency which if increasing is up chirp signal and if decreasing is down chirp signal as shown in figure.3. CSS is robust against noise and multipath fading due to high Bandwidth Time (BT) product [1]. Figure.4 shows good autocorrelation and cross correlation properties of chirp.

III. LOCALIZATION USING SDS-TWR

In ubiquitous computing application including monitoring and tracking, if the position of node is unknown then data retrieval from nodes is not relatively important. There are several range based techniques which can be used for Real time localization. Bahl *et al*[9] used Received signal strength for localization. Ward *et al*. [10] used Time of arrival technique for ranging and savvides *et al*[11] used time difference of arrival for localization.

SDS-TWR stands for symmetric double sided two way ranging algorithm developed by Nanotron technologies [1]. Symmetrical Double-Sided Two-Way Ranging is a ranging methodology that uses two delays that naturally occur in signal transmission to determine the range between two stations [6]. This algorithm is based on TOA method which requires clock synchronization. While double sided nature of SDS-TWR eliminates the effect of clock drift and offset up to the negligible extent.

Symmetrical means that measurement taken by one communicating station is similar to the measurement taken by another communicating station while double sided means that measurement is taken twice. SDS-TWR uses Chirp Spread Spectrum which provides protection against multipath propagation.

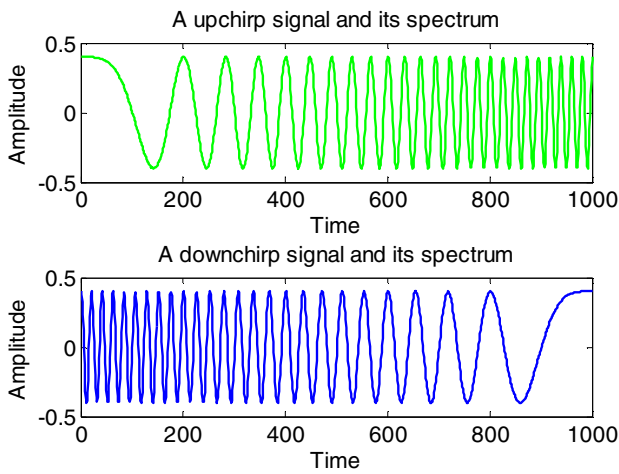


Figure 3. Up chirp and down chirp signal

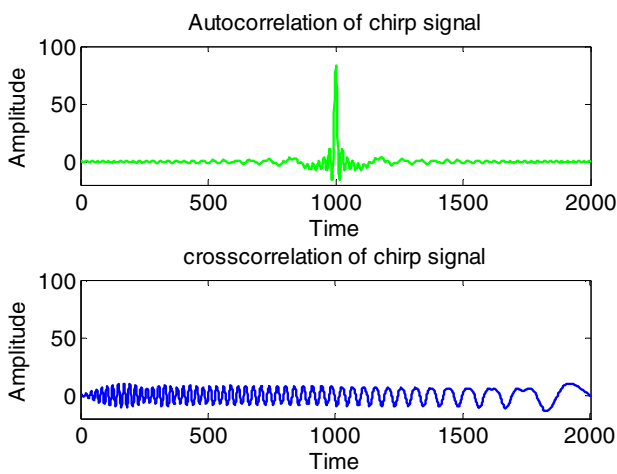


Figure 4. Autocorrelation and Cross correlation

In Ultra Wide band (UWB) communication, ranging method such as SDS-TWR usually use the detection of the leading edge of the cross correlation function to estimate precise moment of signal reception. The wider the signal bandwidth, the narrower the correlation peaks and the more accurate ranging precision. In SDS-TWR a ranging request is initiated by node A as shown in the figure.5 and time measurement is started at node A. Node B starts its time measurement t_{replyB} by receiving the packet from Node A and stop the time measurement when node B reply with packet. When node A receives the acknowledgment packet from node B, it calculates the round trip time t_{roundA} . Propagation time is calculated by difference between time measured by node A and time measured by node B divided by 2 because of two way ranging. There is one problem in TWR scheme, a very fine quality of clock generating oscillator is required for calculation of round trip time up to nanosecond accuracy which is beyond the quality of crystal required for most real time location systems. To zeros out the effect of clock drift (difference in clock speed), first round trip time t_{roundA} is measured and similarly round trip time

t_{roundB} is measured from node B. So the measurements are double sided and symmetric in nature. Propagation time t_p for SDS-TWR algorithm is calculated using the formula as shown in equation (6).

$$t_p = \frac{t_{roundA} - t_{replyA} + t_{roundB} - t_{replyB}}{4} \quad (6)$$

Where t_p is the propagation time which is then multiplied by speed of light to get the distance.

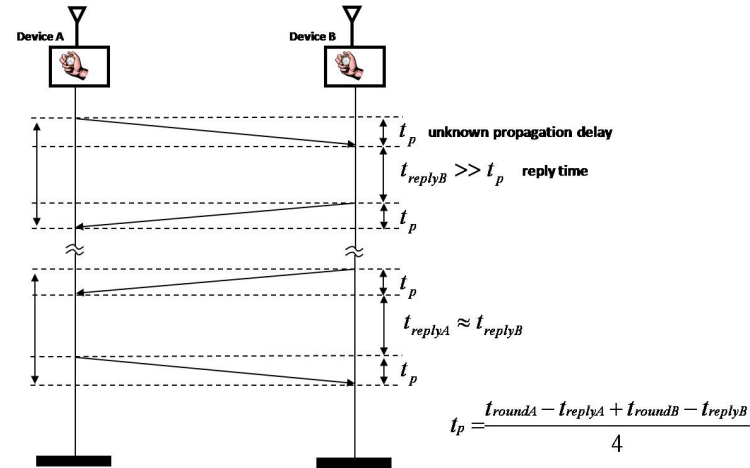


Figure 5. Symmetric double sided two ranging algorithm

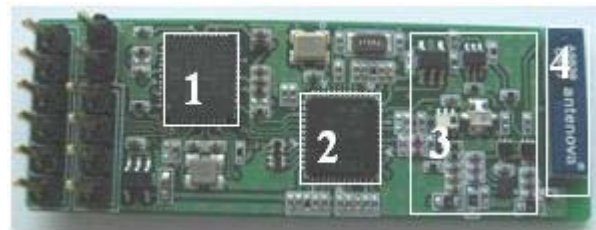


Figure 6. Experimental board

Figure.6 shows the module used for experimentation having size of 17mmx50 mm. The module contains ATMEGA 644(1), NanoLoc(2), Power Amplifier (3), and chip antenna (4).

IV. PROPOSED MODEL FOR TRAFFIC CONTROL AND EXPERIMENTAL SETUP

In our proposed scheme for traffic monitoring, two road side units (Access point) called AP1 and AP2 are used at fixed location as shown in figure 7. Total distance between two AP's is measured manually which is denoted by L. Mobile vehicle is equipped with onboard unit called Tag. When vehicle starts moving from AP1 to AP2 or from AP2 to AP1 covers distance denoted by x, the resultant distance becomes (L-x). At any instant ranging distance between AP1 and mobile vehicle is d1 while ranging distance between AP2 and mobile vehicle is denoted by d2 as shown in figure 7. AP1 and AP2 are installed at such a distance from each other so that there is common area between AP1 and AP2 communication range. Operating

communication range of AP1, AP2, Tag and base station are from (400m-700m). Position and velocity of vehicle is only monitored in common communication range between AP1 and AP2 whenever the distances d1 and d2 are available.

Position and velocity of mobile are calculated on base station. These distances are obtained through SDS-TWR algorithm. Distances d1 and d2 are treated as hypotenuse of two triangles in proposed model. Using Pythagoras theorem resultant position can easily found. Equations for two triangles are;

$$d_1^2 = h^2 + x^2 \quad (7)$$

$$d_2^2 = h^2 + (L - x)^2 \quad (8)$$

Subtracting (8) from (7)

$$d_1^2 - d_2^2 = x^2 + (L - x)^2$$

$$x = \frac{d_1^2 - d_2^2 + L^2}{2L} \quad (9)$$

$$v = \frac{\Delta x}{\Delta t} \quad (10)$$

Where (9) is the position and (10) is the velocity of mobile vehicle. In order to measure the propagation time we have used Nanotron transceivers called nanoLOC for experiments as shown in figure 6. The board makes efficient use of the ISM 2.4 GHz frequency band by employing “chirp spread spectrum” technology. A programmable ATmega 644 microcontroller is used as interface between software and the radio circuitry hardware. nanoLOC supports 7 frequency channels with 3 non overlapping channels with data rates selectable between 31.25kbps and 2 Mbps. The nanoLOC TRX transceiver supports CSMA/CA and also TDMA as MAC protocol with Forward Error Correction (FEC).

Quite a bit of processing is being done by the microcontroller to convert time of flight to distance measured in meters. However the microcontroller itself is limited in the amount of processing it can realistically perform, and does not attempt to do any smoothing or filtering of data.

Therefore we have used Kalman filtering for better estimation. Parameters of the proposed model are summarized in table 1.

Table 1. Parameter table for proposed model

Total Distance L(m)	Position (m)	Height h1(m)	Height h2(m)	d1 (m)	d2 (m)
Total distance between AP1 and Ap2	Position of mobile vehicle	Height of rod at which AP1 is installed	Height of rod at which AP2 is installed	distance of mobile vehicle from AP1	distance of mobile vehicle from AP2

V. EXPERIMENTAL RESULTS AND DISCUSSION

Our proposed model is linear dynamic system. Already some noise is added with measurements we get from experiments. Noisy measurements can be filtered by discrete Kalman filter [8] for good estimation of position and speed of moving vehicle. 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 update from the measurements.

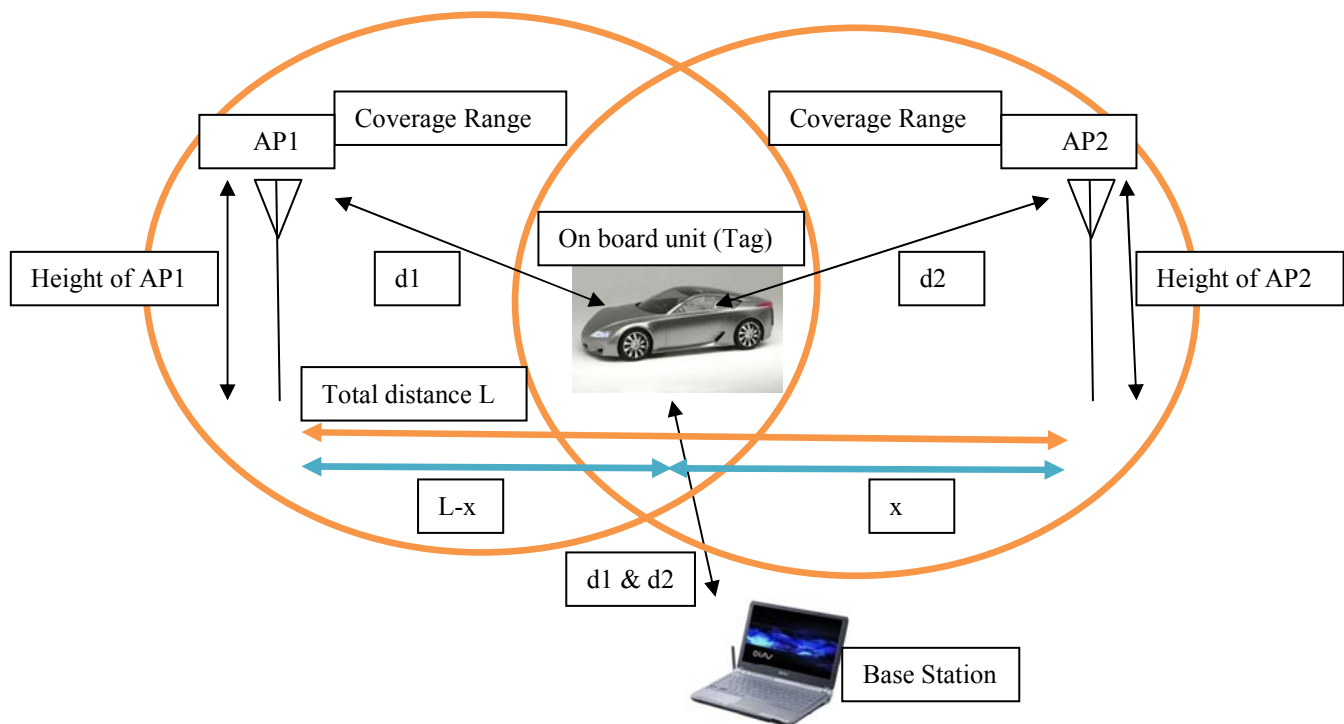


Figure.7 Proposed Model

State equation of system is given below.

$$X_{k+1} = AX_k + Bu_k + w_k \quad (11)$$

$$\begin{pmatrix} x \\ v \end{pmatrix}_{k+1} = \begin{pmatrix} 0 & T \\ 1 & 0 \end{pmatrix} \begin{pmatrix} x \\ v \end{pmatrix}_k + \begin{pmatrix} T^2/2 \\ T \end{pmatrix} w_k \quad (12)$$

Where

$$w_k \sim N(0, Q_k)$$

In (11) A and B are transition matrices and k is the time index. X is the state of the system at particular k_{th} instant of time and u is the known input to the system. The variable w_k represents process noise with zero mean and Q_k covariance. B is the commanded acceleration which is kept constant. The process noise mainly occurs mostly from gusts of wind, potholes and other unfortunate realities. Output measurement equation is given by (13).

$$Y_k = CX_k + Z_k \quad (13)$$

$$Y_k = (1 \ 0) \begin{pmatrix} x \\ v \end{pmatrix}_k + Z_k \quad (14)$$

$$Z_k \sim N(0, R_k)$$

Where in (13) C is the measurement transition matrix and Z_k is noise with zero mean and R_k covariance which mainly occur due to instrumentation errors. The Kalman filter main equation are given below in (15) and (16)

$$K_k = AP_k C(CP_k C^T + S_z)^{-1} \quad (15)$$

$$\begin{aligned} \hat{X}_{k+1} &= (A\hat{X}_k + BU_k) + K_k(Y_{k+1} \\ &\quad - C\hat{X}_k)P_{k+1} = AP_k A^T S_w \\ &\quad - AP_k C^T S_z^{-1} CP_k A^T \end{aligned} \quad (16)$$

Where k is the Kalman gain, P matrix is the estimation error covariance and $\hat{X}$ is estimated state. S_z and S_w are process and measurement noise covariance's respectively with assumption that no correlation exist between these two. Two scenarios have been created to test the proposed model. In scenario 1 instead of using real car, experimentation is done with running person having tag in his hand. Position and speed of running person has been gathered while in scenario 2 a real car having a tag has been used for experimentation.

Scenario 1:

We have applied Kalman filter on noisy measurement data. In the first scenario we obtained results by running person with node in hand. The results are given below
Assumptions for using Kalman filter are;
Measurement noise=3
Acceleration noise=1
Total distance between two AP's L=100
Heights at which AP modules are installed=2.5m

Table 2. Sample Experimental Data

Distance d1(m)	Distance d2(m)	Position x(m)	Net distance (m)	Net time (sec)	Velocity (m/sec)
5.19	99.33	0.80	0.10	0.09	1.06
5.21	99.70	0.44	0.37	0.08	4.59
5.58	99.52	0.63	0.20	0.08	2.49
6.65	99.47	0.75	0.12	0.09	1.44
5.59	99.36	0.79	0.04	0.08	0.56

Position is measured by Nanotron boards and estimated using Kalman filter as shown in figure.8.

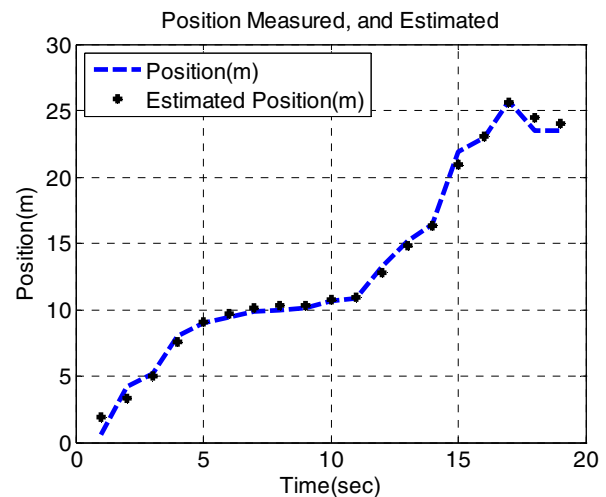


Figure 8. Measured and Estimated Position

And the velocity measured and estimated is shown below in figure .9. Also true speed is taken as the average speed.

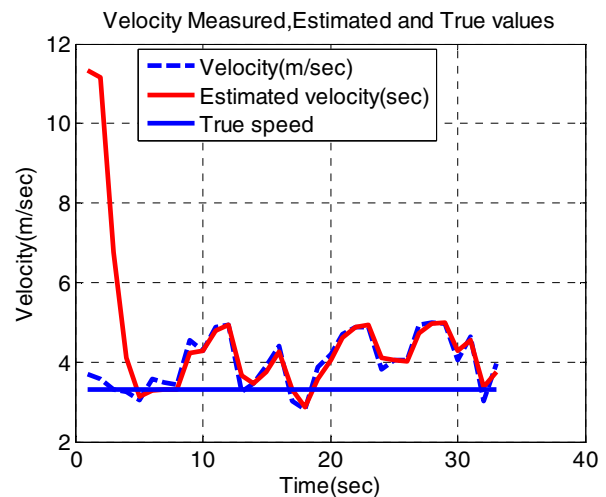


Figure 9. Measured and Estimated Velocity

Scenario 2:

Moving Vehicle with Constant Velocity

We have applied Kalman filter on measurement data obtained by using vehicle which is moving with 20 km/hr

Assumptions for using Kalman filter are;

Measurement noise=3

Acceleration noise=1

Total distance between two AP's L=100

Heights at which AP modules are installed=2.5m

In Estimation of both position and velocity, Kalman filter takes some time to stabilize.

velocity is determined and displayed on base station. The proposed model has several advantages over existing systems; it is more robust and requires less computation than existing systems with expensive cameras. We have evaluated the system performance for single vehicle but it can easily extend for many vehicles.

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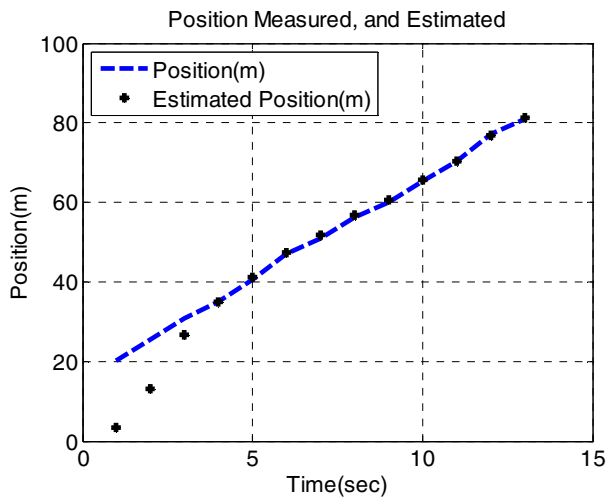


Figure 10. Measured and Estimated Position

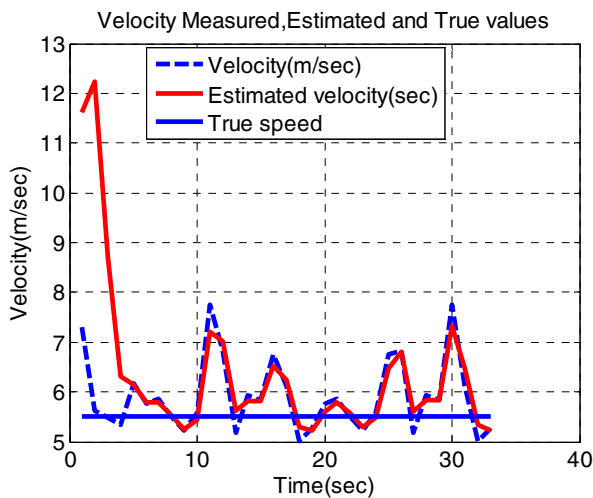


Figure 10. Measured True and Estimated Velocity

CONCLUSIONS AND FUTURE WORK

We have implemented a novel method of traffic monitoring system using wireless sensor networks and practically evaluate the performance of the proposed model. In proposed model whenever the moving car with tag appears in between two anchor nodes its position and