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Modified Kalman Filter for Vehicle Kinematic Parameter Estimation and Inter-vehicle Communication

Dnyaneshwar V. Avatirak, Dr. S.L. Nalbalwar, Assit. Prof N.S.Jadhav
EXTC Dr.BATU Lonere,
India

Abstract*— *This paper proposes a filter in collision avoidance system that can estimate kinematic parameters of the target vehicle to avoid possible vehicle collision. In this system radars are placed at different location on vehicle along with inter-vehicle communication system. Kinematic parameters are extracted from radar signal with appropriate waveform modulation. Hybrid linear frequency modulation (LFM) and frequency- shift keying (FSK) is used in radar so that more than one target is detected with high range resolution and high time update. Extracted kinematic parameters are than processed using Modified Kalman Filter (MKF) along with trilateration process. Other filter like Linear Kalman Filter (LKF) is also used to compare response of the two systems. Sensor network is useful for 360 degree protection of individual car. Sensors used in sensor network are 77GHz wide range radar and 24GHz ultra-wide band (UWB) short range radar (SRR).

Keywords*— *Automotive Safety, Collision Avoidance (CA), Inter-vehicle communication, Kalman filter, Radar.

I. INTRODUCTION

A study shows that 60% of rear-end collisions can prevented if driver get 0.5s of early warning [1]. In car accidents million people die and more than 30 million are injured every year in the world [2]. In many of the cases, the driver did not hit the brake before an accident, because they either not aware of the danger or had less time to react. Radar based an autonomous cruise-control (ACC) scheme can be help in avoiding rear-end collisions, and a lane-departure warning, and that will significantly reduce the number of car accidents. For total 360 degree protection it is needed to use sensor network because single radar sensor has limited range and limited azimuthal angle. Today in the market different type of radars are available such as 77GHz wide range radar with maximum range of 200m and it has azimuthal range of $\pm 10°$ and 24GHz ultra-wide band short range radar with maximum range of 30m and it has azimuthal range of $\pm 70°$[7]-[8]. The important requirement for collision avoidance system is the simultaneous target vehicle kinematic parameter measurement with high resolution. For this purpose there is need to use appropriate waveform modulation technique to get accuracy even in multi-target situations. Hybrid linear frequency modulation (LFM) and frequency- shift keying (FSK) is used in radar so that more than one target is detected with high range resolution and high time update [3].

For proper working of Collision avoidance system the signal receives from radar network must be noiseless but due to noisy environment there is no guaranty of getting noiseless signal. To remove noise, receive signal must process using filter. MKF is used along with trilateration process to estimate kinematic parameter of target vehicle. Along with this collision avoidance system there is need of inter-vehicle communication because of limited line of sight at certain places on road. The kinematic parameter of one vehicle on road must be known by its neighboring vehicles so that potential collision can avoid. In this paper, propose system contain MKF which improve accuracy of estimated kinematic parameters. In section II inter-vehicle communication concept is discus. The propose approach explain in section IV. LKF is explained in section V. The two filters are compared under different scenarios in section VI.

II. INTER-VEHICLE COMMUNICATION

Inter-vehicle communication is necessary for certain conditions like at turn and road intersection point drivers are unable to see vehicles approaching the same intersection from another direction due to obstacles, especially a large number of buildings in an urban area. Moreover, an intersection point and turn is a place where drivers often violate traffic regulations. So reduce risk at such places there is need of inter-vehicle communication in which each vehicle broadcasts its current information (location, heading direction, velocity, vehicle id, etc.) and other vehicles must receive such information in time. Today, the Global Positioning System (GPS) is widely used for large applications because the GPS receiver provides vehicle position and velocity data in global coordinates. However, a standalone GPS receiver can’t fulfil the positioning requirements due to the occasional temporary loss of satellite connection and signal errors. On the other hand to fulfil positioning requirements along with GPS, the concept of dead reckoning used that uses vehicle motion sensors such as wheel speed sensors, a yaw rate sensor, an accelerometer, and a steering sensor. To increase the accuracy differential GPS can be used. Figure 1. shows the general Block diagram of inter-vehicle communication. In this system CIVIC (communication inter vehicule intelligente et cooperative) protocol can be used. The CIVIC protocol is a cooperative MANET protocol integrated the supports of roadside infrastructure. It has mechanisms to adapt to multiple wireless standards [8]. Due to vehicular communication every other vehicle knows its neighbouring vehicle state and kinematic parameters.

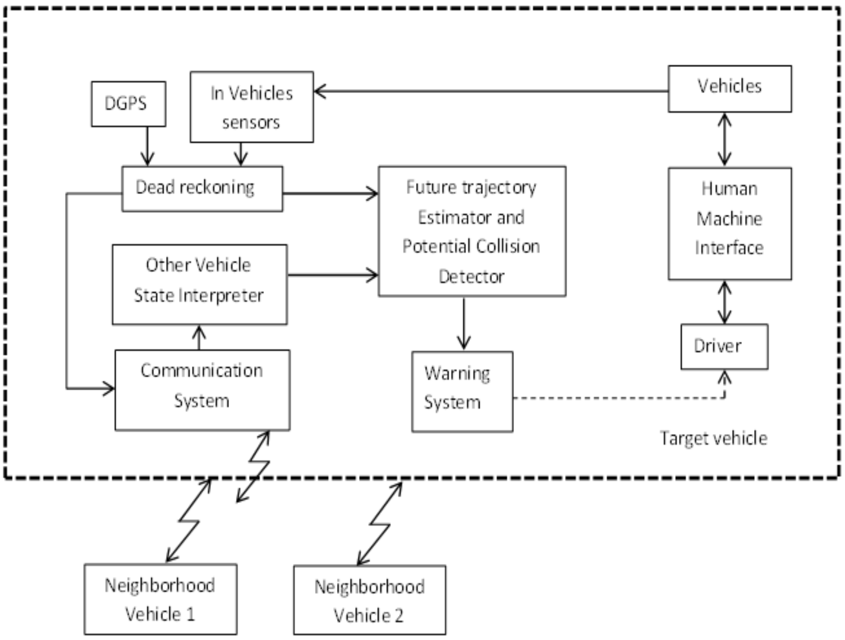

Figure1. Block Diagram for inter-vehicle communication.

III. RADAR IN COLLISIONS AVOIDANCE SYSTEM

In collision avoidance system many type of sensor are used like radar**,** lidars and image sensor [5]. Propose system uses radar sensor because it has advantages. These are:

- A relative distance and velocities can be measure with good accuracy.
- Multiple targets can be detected.
- Measurements time is very short.
- Robots against changing light conditions.

Different types of Radars are available in a market. For 360 degree protection of individual vehicle, multiple numbers of radars are useful. 24GHz radar is useful for Collision warning, Collision mitigation, Blind spot monitoring, parking aid (forward and reverse),Lane change assistant, Rear crash collision warning. It has detection range of 0.2 to 30 m, a range resolution of 15 cm, a range accuracy of 7.5 cm and opening angle of±70°. During overtaking there is need of long range object detection, for this purpose 77GHz radar can be useful. It has range from less than 1m to up to 200 m, up to ±14° opening angle in long range and a relative velocity range of up to ±260 km/h [7].

For proper protection of vehicle like car, 10 radars of short range and 2 radars of long range can be used. Figure 1 shows placement of radar on car. These Radars are grouped into four different subsystems like front subsystem, right subsystem, left subsystem, rear subsystem. Front subsystem consists of two 24GHz radars and two 77GHz radar. These radars are useful for collision warning, Precrash and stop and Go. Right and left subsystems consist of three radars each of 24GHz type. These are useful for Blind Spot Detection and Cut-in collision warning. Rear subsystem consists of two 24GHz radars for Parking Aid and Rear-end collision warning. Figure 2 show that Maximum area around vehicle is covered by two or more radars for trilateration process.

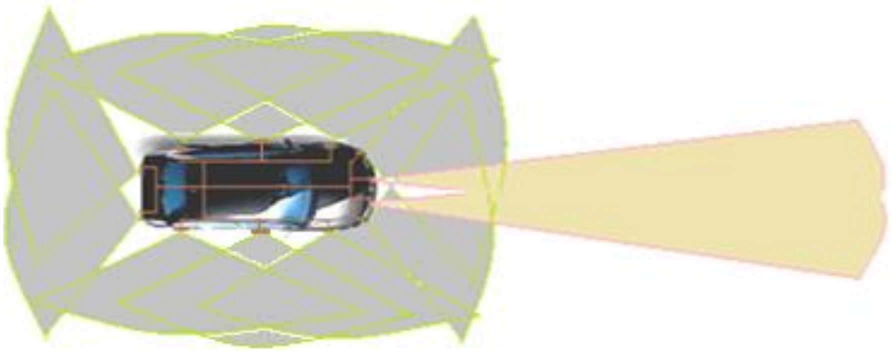

Figure 2. Sensors network on vehicle and their covered area.

IV. MODIFIED KALMAN FILTER

A. Filter equation.

Equation for Kalman filter in [4] and its modification are given below as.

$$\hat{x}[n+1|n]=F[n+1|n].\,\hat{x}[n|n] \tag{1}$$

$$K[n+1|n]=F[n+1|n].K[n|n].F^{T}[n+1|n]+Q_1 \tag{2}$$

$$R[n]=c[n].\,K[n|n-1].C^{T}[n]+Q_2 \tag{3}$$

$$G[n]=K[n|n-1].C^{T}[n]/R[n] \tag{4}$$

$$\hat{x}[n|n]=\hat{x}[n|n-1]+G[n].\alpha[n] \tag{5}$$

$$\alpha[n]=y[n]-C[n].\,\hat{x}[n|n-1] \tag{6}$$

$$K[n|n]=K[n|n-1]-G[n].C[n].K[n|n-1]-N[K[n|n-1]] \tag{7}$$

Where

$\alpha[n]$= Innovation vector at time n.

$y[n]$= Observation at time n.

$\hat{x}[n|n]$= filtered estimate of the state vector at time n.

$\hat{x}[n+1|n]$= Predicted estimate of the state vector at time n.

$G[n]$= Kalman gain at time n.

$K[n|n]$= Correlation matrix of error in $\hat{x}[n|n]$

$K[n+1|n]$= Correlation matrix of error in $\hat{x}[n+1|n]$

$C[n]$= Measurement matrix at time n.

Q_1= Correlation matrix of process noise.

Q_2= Correlation matrix of measurement noise.

The measurement vector and dynamic state vector for *i*th sensor is define as

$$y_i[n]=\begin{bmatrix} r_{i[n]} \\ v_{i[n]} \\ a_{i[n]} \end{bmatrix} \qquad \hat{x}_i[n]=\begin{bmatrix} \hat{r}_{i[n]} \\ \hat{v}_{i[n]} \\ \hat{a}_{i[n]} \end{bmatrix}$$

For j=2. The state transition matrix can be derived as

$$F[n+1|n]=\begin{bmatrix} 1 & T & T^2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}$$

where T is the time interval for state update.

Initial condition for matrices is as follow.

$$Q_2=\begin{bmatrix} \sigma_r^2 & 0 & 0 \\ 0 & \sigma_v^2 & 0 \\ 0 & 0 & \sigma_a^2 \end{bmatrix} \qquad Q_1=0 \qquad C[n]=I_{3x3}$$

$K[1|0]=I_{3x3}$

There is change in measurement update equation of state error covariance matrix.

N[K[n|n-1]]=Modification function of K[n|n-1]

$$N[K[n|n-1]]=\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & e^{K_{(3,3)}[n|n-1]} \end{bmatrix}$$

Where $e^{K_{(3,3)}[n|n-1]}$ means last element (i.e 3,3) of 3x3 $K[n|n-1]$ matrix varies exponential.

B. Trilateration

Now let's consider two sensors are located at$(x_1,0)$ and $(x_2,0)$ location on vehicle. These sensor tracking the target located at $(\hat{X},\hat{Y})$, moving at velocity $(\hat{v}_x, \hat{v}_y)$, acceleration $(\hat{a}_x, \hat{a}_y)$. Estimated parameter from sensors given to MKF for filtering process and then filtered signal is used in trilateration process to calculate target relative distance, velocity and acceleration in x-y direction [6].

The range from two sensors can express as

$$\hat{r}_1^2=(\hat{X}-x_1)^2+\hat{Y}^2 \qquad \hat{r}_2^2=(\hat{X}-x_2)^2+\hat{Y}^2 \tag{8}$$

After eliminating $\hat{y}$, we get

$$\hat{X}=\frac{x_1^2-x_2^2-\hat{r}_1^2+\hat{r}_2^2}{2(x_1-x_2)} \tag{9}$$

Then, $\hat{y}$ can be determined as

$$\hat{Y}=\sqrt{\frac{\hat{r}_2^2+\hat{r}_1^2-(\hat{X}-x_1)^2-(\hat{X}-x_2)^2}{2}} \tag{10}$$

Target velocity and acceleration can be derived as

$$\begin{bmatrix} \hat{v}_x \\ \hat{v}_y \end{bmatrix}=\begin{bmatrix} \frac{\hat{X}-x_1}{\hat{r}_1} & \frac{\hat{Y}}{\hat{r}_1} \\ \frac{\hat{X}-x_2}{\hat{r}_2} & \frac{\hat{Y}}{\hat{r}_2} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \hat{v}_1 \\ \hat{v}_2 \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} \hat{a}_x \\ \hat{a}_y \end{bmatrix} = \begin{bmatrix} \frac{\hat{X} - x_1}{\hat{r}_1} & \frac{\hat{Y}}{\hat{r}_1} \\ \frac{\hat{X} - x_2}{\hat{r}_2} & \frac{\hat{Y}}{\hat{r}_2} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \hat{a}_1 \\ \hat{a}_2 \end{bmatrix} \quad (12)$$

V. LINEAR KALMAN FILTER

Equation of Kalman filter in [4] equations are given as.

$\hat{x}$[n+1|n]=F[n+1|n]. $\hat{x}$[n|n] (13)
K[n+1|n]= F[n+1|n].K[n|n].F^T[n+1|n]+Q_1 (14)
R[n]=c[n]. K[n|n-1].C^T[n]+ Q_2 (15)
G[n]= K[n|n-1].C^T[n]/ R[n] (16)
$\hat{x}$[n|n]= $\hat{x}$[n|n-1]+G[n].α[n] (17)
α[n]=y[n]-C[n]. $\hat{x}$[n|n-1] (18)
K[n|n]=K[n|n-1]-G[n].C[n]. K[n|n-1] (19)

Above equations along with initial condition as mention for MKL are used for simulation purpose. LKF also use trilateration process mention in section IV-B.

VI. COMPARISON OF FILTERS

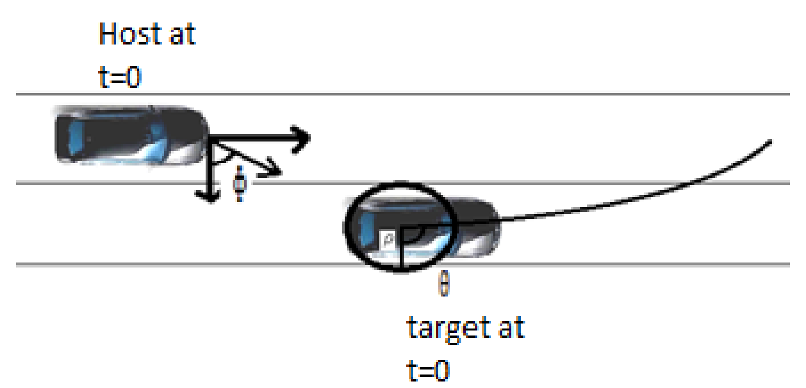

Figure 3.Target vehicle makes a left turn in front of the host vehicle

For different scenarios both MKF and LKF are compared in this paper. Let consider two vehicles are moving on XY-plane. Host vehicle is moving with constant velocity in Y-direction and target vehicle tries to take left turn in front of host vehicle with different speed and acceleration.

The center of mass of target vehicle is at ($x_{tc}(t), y_{tc}(t)$) and center of front bumper of host vehicle is origin of reference coordinate. ρ is the radius from center of mass of target vehicle to its longest edge. θ is the polar angle of vehicle motion. ϕ is the initial azimuthal angle of the polar coordinate with respect to reference coordinate. Trajectory of target vehicle can be given by following equation.

$x_t(t)=x_{tc}(t)+ \rho$ cos θ (t) (20)
$y_t(t) = y_{tc}(t)+ \rho$ sin θ (t) (21)
θ (t)= $tan^{-1}[\frac{v_{ty}(t)}{v_{tx}(t)}]+ \phi$- 90^0 (22)

Where $v_{tx}(t) and\, v_{ty}(t)$ are target vehicle velocity in x and y direction respectively.

The radial parameter between given target point and ith sensor thus be express as [6]

r_1^2 (t)=$(X'(t) - x_1)^2 + (Y'(t) - y_1)^2$ (23)
$r_2^2(t)=(X'(t) - x_2)^2 + (Y'(t) - y_2)^2$ (24)

$$\begin{bmatrix} v_1(t) \\ v_2(t) \end{bmatrix} = \begin{bmatrix} \frac{X'(t) - x_1}{r_1} & \frac{Y'(t) - y_1}{r_1} \\ \frac{X'(t) - x_2}{r_2} & \frac{\hat{Y}'(t) - y_2}{r_2} \end{bmatrix} \cdot \begin{bmatrix} v'_x(t) \\ v'_y(t) \end{bmatrix} \quad (25)$$

$$\begin{bmatrix} a_1(t) \\ a_2(t) \end{bmatrix} = \begin{bmatrix} \frac{X'(t) - x_1}{r_1} & \frac{Y'(t) - y_1}{r_1} \\ \frac{X'(t) - x_2}{r_2} & \frac{Y'(t) - y_2}{r_2} \end{bmatrix} \cdot \begin{bmatrix} a'_x(t) \\ a'_y(t) \end{bmatrix} \quad (26)$$

$X'(t) = x_t(t)$-$x_h(t)$ $Y'(t) = y_t(t)$ -$y_h(t)$ (27)
$v'_x(t) = v'_{tx}(t)$- $v'_{hx}(t)$ $v'_y(t) = v'_{ty}(t)$- $v'_{hy}(t)$ (28)
$a'_x(t) = a'_{tx}(t)$- $a'_{hx}(t)$ $a'_y(t) = a'_{ty}(t)$- $a'_{hy}(t)$ (29)

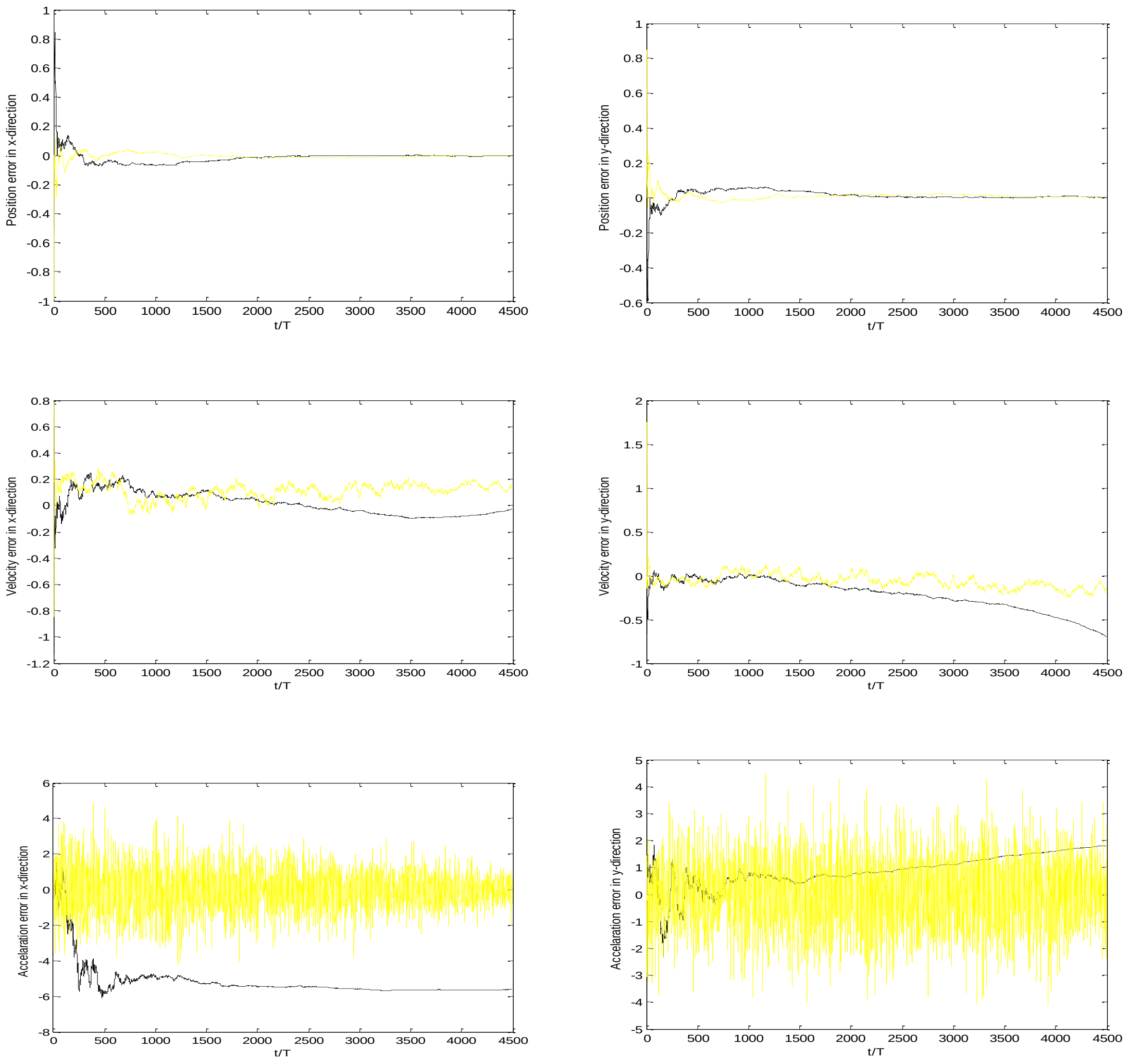

Figure 4. Estimation errors. (Solid line) MLKF and (dash-dot line) LKF

Where $x_t(t)$,$y_t(t)$, $v'_{tx}(t)$, $v'_{ty}(t)$, $a'_{tx}(t)$, $a'_{ty}(t)$ are position, velocity, and acceleration of closest point of target vehicle from host vehicle.

Similarly$x_h(t)$, $y_h(t)$, $v_{hx}(t)$, $v_{hy}(t)$, $a'_{hx}(t)$, $a'_{hy}(t)$ are position, velocity, and acceleration of reference point on host vehicle.

For demonstration point of view, let's consider length and width of both vehicles are 4m and 1.8m respectively. The centre of front bumper of host vehicle is chosen as origin of reference coordinate. The two sensors are placed at 0.8m (i.e. (0.8,0) and (-0.8,0))away from centre of front bumper towards right and left side.

Scenario 1: Initial Kinematic parameters for both vehicles are chosen as follow.

$x_t(t) = 5m$, $y_t(t)$ =10m, $v'_{tx}(t)$ =0m/s, $v'_{ty}(t)$ =11m/s, $x_h(t) = 0m$, $y_h(t)$ =0m, $v'_{hx}(t)$ =0m/s, $v'_{hy}(t)$ =21m/s, $a'_{hx}(t)$=0 m/s^2, $a'_{hy}(t)$=0 m/s^2. Suffix h stand for host vehicle and t stand for target vehicle. At t=0 target vehicle begins to take a left turn with a velocity $v'_{ty}(t) = 11m/s$ and turn radius R=10m. Due to circular motion, acceleration of magnitude $a'_{tx}(t)$= -8.06 m/s^2 (a=v^2/R) will act on vehicle. The RMS errors of estimated kinematic parameters for system containing MLKF and EKF at *t* = 0.8 s are listed in the column s1 in Table I.

Figure 4 shows evolution of kinematic parameter for scenarios '1' using both filter approaches. The RMS error for estimated kinematic parameter are given by

$$\varepsilon_\gamma=\sqrt{\frac{1}{M}\sum_{n=1}^{M}[\hat{\gamma}(n) - \gamma]^2} \qquad (30)$$

Here $\gamma = x, y, v_x, v_y, a_x, a_y$ and superscript (n) denote nth trial of Monte Carlo simulation with M=100.

Scenario 2: Initial Kinematic parameter for target vehicle is chosen as, $v'_{ty}(t)$ =30m/s. At t=0 target vehicle begins to take a left turn with a velocity $v'_{ty}(t) = 30m/s$ and turn of radius R=10m,$a'_{tx}(t)$ =-90m/s^2. The RMS errors of estimated kinematic parameters for system containing MLKF and EKF at *t* = 0.4 s are listed in the column s2 in Table I

Scenario 3: Initial Kinematic parameter for target vehicle is chosen as, $v'_{ty}(t)$ =20m/s. At t=0 target vehicle begins to take a left turn with a velocity $v'_{ty}(t) = 20m/s$ and turn of radius R=15m, $a'_{tx}(t)$ =-26.$06m/s^2$. The RMS errors of estimated kinematic parameters for system containing MLKF and EKF at *t* = 0.6 s are listed in the column s3 in Table I.

TABLE I

RMS ERROR OF ESTIMATED KINEMATIC PARAMETERS

	LKF (s1)	**MKF (s1)**	**LKF (s2)**	**MKF (s2)**	**LKF (s3)**	**MKF (s3)**
ε_x	0.0088	0.0057	0.0173	0.0188	0.0174	0.0150
ε_y	0.0147	0.0123	0.0092	0.0096	0.0062	0.0059
ε_{vx}	0.0142	0.1439	0.5028	0.1280	1.4575	0.2525
ε_{vy}	0.7455	0.1632	2.2774	0.9321	2.0355	0.4554
ε_{ax}	5.6241	0.3686	11.243	0.9947	2.4222	0.8184
ε_{ay}	1.6840	0.6984	0.6580	0.5759	1.8736	0.3467

s1: Scenario 1 s2: Scenario 2 s3: Scenario 3

From table I.it is clear that LKF acceleration RMS error is more with respect to MKF. There is also other kinematic parameter RMS error reduce. It is very difficult to just an accelerating vehicle position using LKF. In s2, acceleration error increases drastically for LKF. In scenarios 3 except position error other error are increasing for LKF with respect to MKF.

VII. CONCLUSIONS

Proposed system contains MKF to estimate kinematic parameters of target vehicle. MKF has high accuracy than LKF. In different scenarios estimate parameter variation in LKF is more than MKF. The overall performance of MKF is better than LKF. Comparatively graphical error for acceleration is more for MKF than LKF but RMS error is less for MKF. Three scenarios are used to demonstrate the effectiveness of proposed system.

REFERENCES

[1] Motor Vehicle Accidents--Number and Deaths. [Online]. Available: http://www.census.gov/compendia/statab/cats/ transportation/ motor _vehicle_accidents_and_fatalities.html.

[2] The Commissions Intelligent Car Flagship Under the i2010 Initiative, Brussels, Feb. 21, 2006. [Online]. Available: http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/06/86.

[3] H. Rohling and M. M. Meinecke, "*Waveform design principles for automotive radar systems*," in Proc. IEEE Radar, Oct. 2001, pp. 1–4.

[4] S. Haykin, Adaptive Filter Theory., 4th ed. Englewood Cliffs, NJ: Prentice-Hall, 2002.

[5] S. G. Wu, S. Decker, P. Chang, T. Camus, and J. Eledath, "*Collision sensing by stereo vision and radar sensor fusion*," IEEE Trans. Intell. Transp. Syst., vol. 10, no. 4, pp. 606–614, Dec. 2009.

[6] J. V. Kleff, J. Bergmans, and L. Kester, Multiple-hypothesis trilateration and tracking with distributed radars. [Online]. Available:http://staff.science.uva.nl/~jvanklee/Publications/data/174.pdf.

[7] J. Wenger, "*Automotive radar—Status and perspectives*," in Proc. IEEE Compound Semicond. Integr. Circuit Symp., Oct. 2005, pp. 21–24.

[8] M. Klotz, "An automotive short range high resolution pulse radar network," Ph.D. dissertation, Technische Univ. Hamburg-Harburg, Hamburg, Germany, 2002.

[9] Xunxing Diao, " Cooperative Inter-vehicle Communication Protocol with Low Cost Differential GPS" JOURNAL OF NETWORKS, VOL. 4, NO. 6, AUGUST 2009.