# Collision-Avoidance Algorithm with High Precision on Location, Velocity and Acceleration

Po-Jen Tu, Jean-Fu Kiang, and Chia-Cheng Ho Department of Electrical Engineering and Graduate Institute of Communication Engineering, National Taiwan University E-mail: jfkiang@cc.ee.ntu.edu.tw.

### Introduction

Adaptive cruise control (ACC), parking aid, collision avoidance, and pre-crash detection require reliable calculation pending on the accurate estimation of target location, velocity and acceleration. Several methods have been proposed to trilaterate a specific target based on detecting these kinetic parameters from multiple signals. In [1], Klotz presents a method to trilaterate a target using multiple FMCW echoes in a least-square sense. Given the relative range measured at the sensor, a one-stage linear Kalman filter is used to estimate the relative range and relative velocity [2]. However, the acceleration can not be estimated accurately when the target is making a turn in a short period. Furthermore, a two-stage linear Kalman filter has been built upon the one-stage linear Kalman filter, with a new bias vector to estimate the relative acceleration [3]. Nevertheless, the convergence time will be too long if the target is making a turn in a short period. Hence, the extended Kalman filter is used to estimate all the kinetic parameters of the target using only one sensor [4]. However, the error in some parameters can be very large when the target is making a turn.

In this work, we propose a minimum-delay Kalman filter to reckon the kinetic paramaters by taking the measured FMCW (frequency-modulated continuous wave) echoes. A second Kalman filter is also used after trilateration to significantly reduce the convergence time for estimating the acceleration. Demonstration is given with a vehicle making a turn across the adjacent lane in front of the host vehicle. The trajectory of moving target with respect to the host can be calculated to predict the time for collision.

# **Detection Methodology**

Fig.1(a) shows the scenario that the target vehicle makes a left turn across the lane of the host vehicle. Assuming the length and width of both vehicles are 4 m and 1.8 m, respectively, the reference point of the host vehicle is chosen at its front center. Fig.1(b) shows the frequency variation of two LFM signals with positive slopes  $s_A$ and  $s_B$ , respectively. Typical parameters are  $f_A(0) = 77$  GHz,  $B_{\text{sweep}} = 150$  MHz,  $f_B(t) - f_A(t) = 300$  kHz,  $T_{\text{LFM}} = 51.2$  ms, and N = 256 [5]. The difference of frequency of the second signal measured at  $t = 2n\tau$  and that of the first signal at  $t = (2n-1)\tau$  is  $f_{\text{shift}} = f_B(0) - f_A(0) + s\tau$ .

Fig.2 shows our new approach, called the minimum-delay one-stage Kalman filter. It consists of four steps. First, the range  $r_i$ , radial velocity  $v_i$ , and radial acceleration

 $a_i$  are extracted from the hybrid FSK and LFM signal echoed from the target vehicle to the *i*th sensor. Secondly, a one-stage linear Kalman filter will be used to estimate  $\hat{r}_i(t), \hat{v}_i(t)$  and  $\hat{a}_i(t)$ . Thirdly, trilateration will be applied to determine  $\hat{x}(t), \hat{y}(t),$  $\hat{v}_x(t), \hat{v}_y(t), \hat{a}_x(t)$  and  $\hat{a}_y(t)$ . At last, another one-stage Kalman filter will be used to fine-tune  $\tilde{x}(t), \tilde{y}(t), \tilde{v}_x(t), \tilde{v}_y(t), \tilde{a}_x(t)$  and  $\tilde{a}_y(t)$ .

#### **Results and Conclusion**

Fig.3 shows the prediction error of kinetic estimation using minimum-delay onestage Kalman filter, extended Kalman filter and two-stage linear Kalman filter, respectively. With the two-stage linear Kalman filter, the results during 800  $T_p \leq t \leq 1,000 T_p$  show that the errors of x and y are within 4 cm, the errors of  $v_x$  and  $v_y$  are within 1.1 and 0.65 m/s, respectively, and the errors of  $a_x$  and  $a_y$  are within 15 and 6 m/s<sup>2</sup>, respectively. With the extended Kalman filter, the results during 800  $T_p \leq t \leq 1,000 T_p$  show that the errors of x and y are within 11 and 6 cm, respectively, the errors of  $v_x$  and  $v_y$  are within 0.42 and 0.27 m/s, respectively, and the errors of  $a_x$  and  $a_y$  are within 1.7 and 3.3 m/s<sup>2</sup>, respectively. The extended Kalman filter. Similar to the two-stage Kalman filter, the convergence time for location, velocity and acceleration is longer than those of minimum-delay one-stage Kalman filter.

#### References

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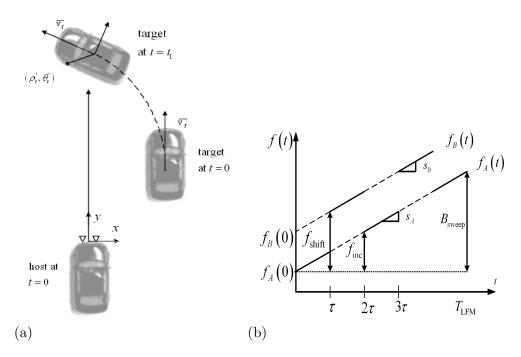


Figure 1: (a) Scenario of the target vehicle making a left turn in front of the host vehicle, —: host trajectory, - -: target trajectory. (b) Hybrid FSK and LFM.

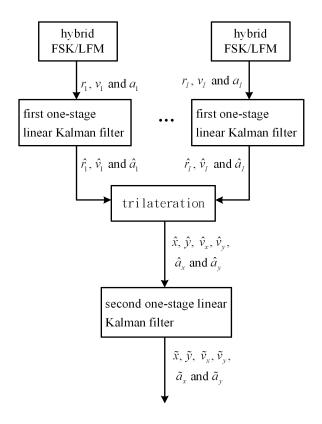


Figure 2: Procedure of minimum-delay one-stage Kalman filter to estimate target kinetic parameters.

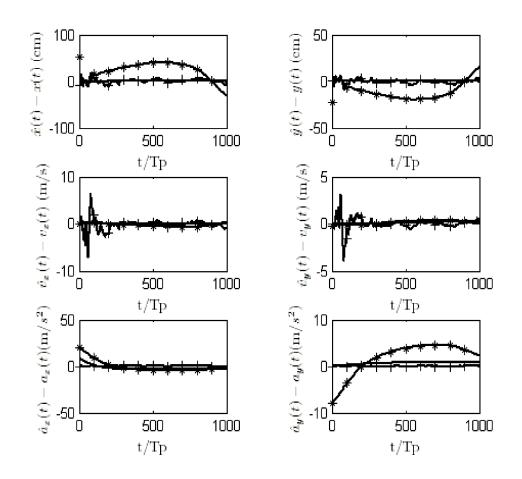


Figure 3: The lines with no mark show the prediction errors of minimum-delay Kalman filter,  $T_p=200 \ \mu s$ ,  $\sigma_x = \sigma_y = 0.015 \ m$ ,  $\sigma_{v_x} = \sigma_{v_y} = 0.09 \ m/s$  and  $\sigma_{a_x} = \sigma_{a_y} = 7.5 \ m/s^2$ . The lines with + mark show the prediction errors using two-stage linear Kalman filter,  $T_p=200 \ \mu s$ ,  $\sigma_r = 0.05 \ m$ ,  $\sigma_v = 0.02 \ m/s$  and  $E\{a^2\} = 400 \ m^2/s^4$ . The lines with \* mark show the prediction errors using extended Kalman filter,  $T_p=200 \ \mu s$ ,  $\sigma_r = 0.02 \ m/s$  and  $\sigma_a = 1 \ m/s^2$ .