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

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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 parameters 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, $B_{\rm sweep} = 150$ MHz, $f_B(t) - f_A(t) = 300$ kHz, $T_{\rm LFM} = 51.2$ 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 $f_{\rm shift} = f_B(0) - f_A(0) + s\tau$.

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 ith 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 one-stage 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^2, 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^2, respectively. The extended Kalman filter generates larger errors than those of the minimum-delay one-stage 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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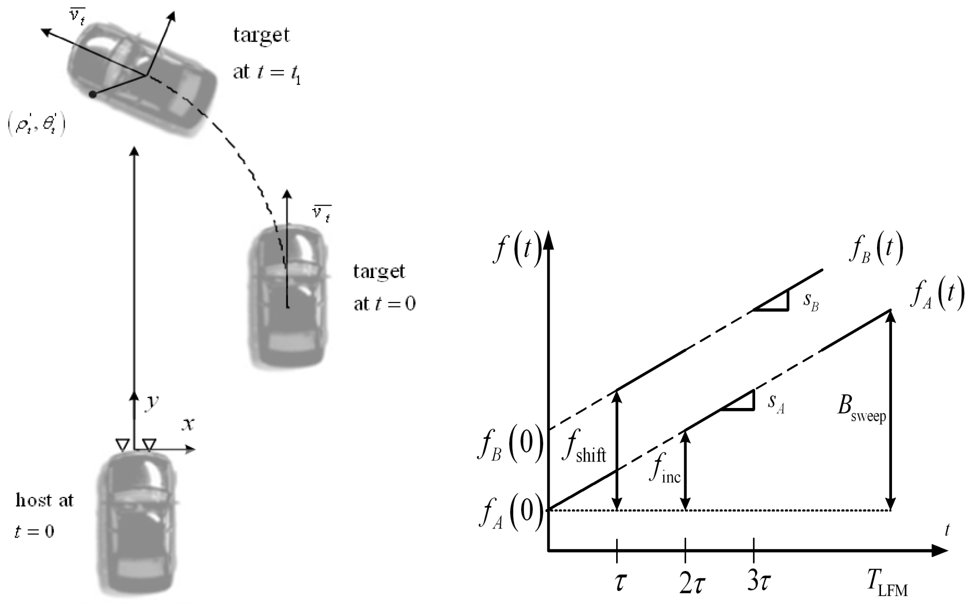

(a) (b)

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.

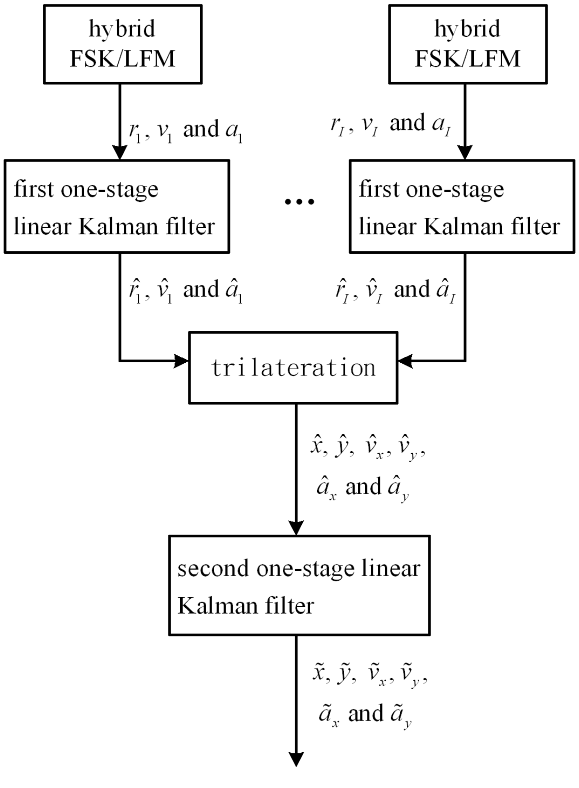

Figure 2: Procedure of minimum-delay one-stage Kalman filter to estimate target kinetic parameters.

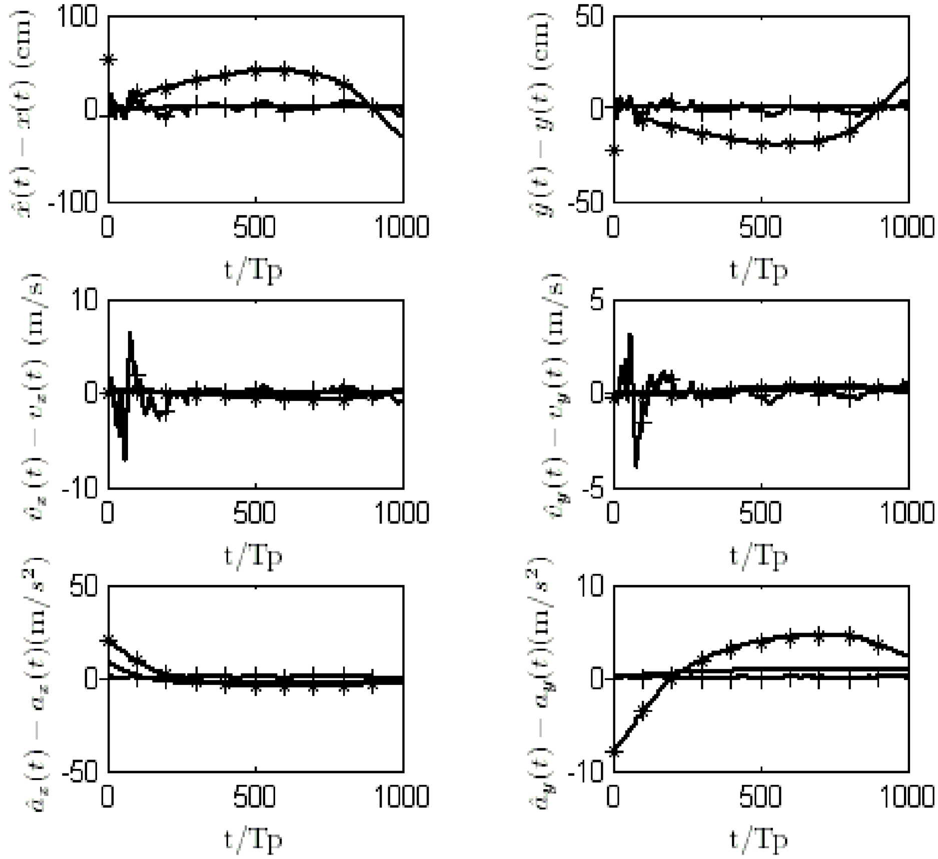

Figure 3: The lines with no mark show the prediction errors of minimum-delay Kalman filter, T_p=200 μs, $\sigma_x = \sigma_y = 0.015$ m, $\sigma_{v_x} = \sigma_{v_y} = 0.09$ m/s and $\sigma_{a_x} = \sigma_{a_y} = 7.5$ m/s^2. The lines with + mark show the prediction errors using two-stage linear Kalman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