Estimation of Turning Ratios at Intersections Based on Detector Data using Kalman Filter

Master's Thesis of Huimin Zhang

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1. Introduction

Adaptive signal control system shows strong flexibility and high performance in traffic signal control compared with other control systems. Even though there are still difficulties in estimation of turning ratio on so called mixed lanes, on which traffic streams turn to different directions. Therefore, an improved turning ratio estimation is the subject of this thesis.

2. Method

The main idea of this thesis is to use the dynamic behavior of traffic as it depends on signal: the vehicle detected by downstream detectors at a certain time point at a signalized intersection is released by a certain signal.

A well-known method for parameter estimation in automatic control theory is the **„Extended Kalman Filter (EKF)“** as shown in Fig 1:

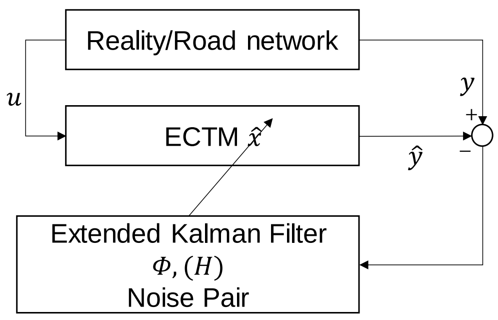

Fig 1: Extended Kalman Filter

In this thesis an **Extended Cell Transmission Model (ECTM)** is used to predict the traffic detected downstream ($\hat{y}$) based on the upstream traffic (u). The difference between the predicted traffic downstream and the actual detected traffic downstream (y) is used by EKF to correct the traffic state $\hat{x}$ of the ECTM. A small X-shaped intersection modeled by 14 cells as shown in Fig. 2 is used to demonstrate the working principle.

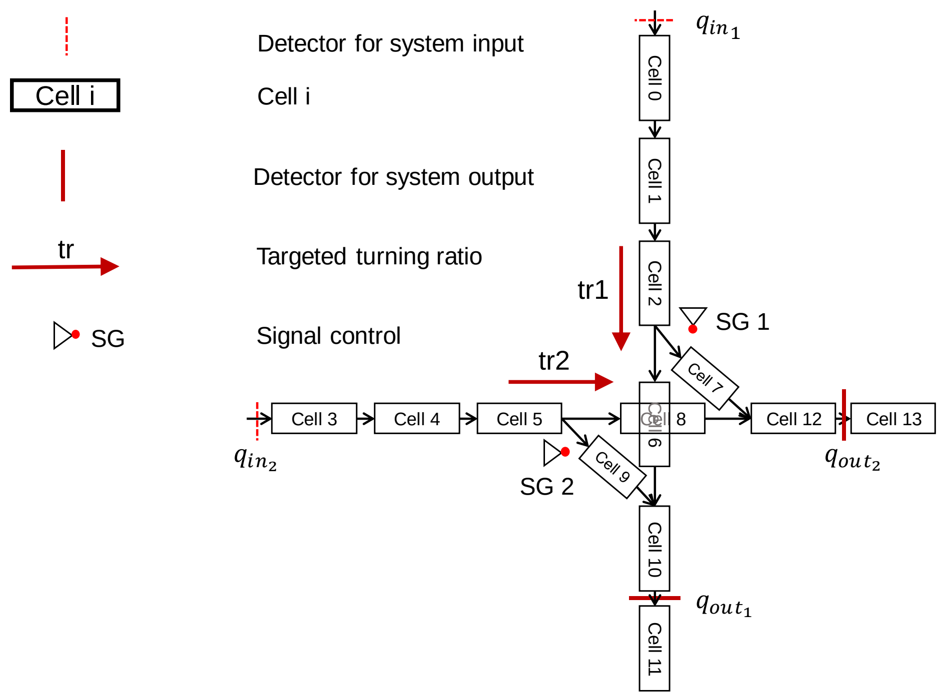

Fig 2: ECTM representation of small X-shaped intersection

System state $x(k)$ contains the densities of cells $n_i(k)$ and both turning ratios $tr_1(k)$ and $tr_2(k)$:

$$x(k) = \left(n_0(k), n_1(k) \cdots n_{13}(k), tr_1(k), tr_2(k)\right)^T$$

System input $u(k)$ contains the detected upstream traffic flows:

$$u(k) = \left(q_{in_1}(k), q_{in_2}(k)\right)^T$$

System output $y(k)$ contains the downstream traffic flows:

$$y(k) = \left(q_{out_1}(k), q_{out_2}(k)\right)^T$$

The EKF is based on a linearized system represented by the system matrix Φ, the output matrix H and noise pair (process noise and output noise) in Fig 1. Therefore the ECTM has to be linearized.

The system equations describe how the system state changes from time step k to $k+1$:

$$n_i(k+1) = n_i(k) + q_{i-1}(k) - q_i(k)$$

$$tr_m(k+1) = tr_m(k).$$

The density of cell i based on the density of itself at previous time step together with the inflow and the outflow, while the turning ratios are simply assumed same as last time step. The linearization of system equations is separately done for the linear part denoted in blue and the nonlinear part denoted in red:

$$\boldsymbol{\Phi} = \boldsymbol{\Phi_1} + \boldsymbol{\Phi_2}$$

Linearization of the linear parts yields a unit matrix Φ_1. For deriving the linearization $\boldsymbol{\Phi_2}$ of the nonlinear parts the calculation of traffic flow $q_i(k)$ is logically changed. Usually $q_i(k)$ is calculated as the minimum of sending ability of cell i and receiving ability of cell $i+1$. Instead, $q_i(k)$ is assumed to consist of two parts: the sending traffic flow $S_i(k)$ of cell i and the rejected traffic flow $J_{i+1}(k)$ from cell $i+1$ back to cell i (Fig. 3).

$$q_i(k) = S_i(k) - J_{i+1}(k)$$

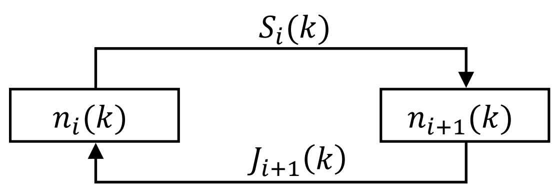

Fig 3: Sending and rejected traffic flow

While the sending traffic flow is calculated as usually, the rejected traffic flow is the maximal value of zero and difference between the sending traffic of cell i and the available space in cell $i+1$.

$$S_i(k) = min\{n_i(k), Q_i(k)\}$$

$$J_{i+1}(k) = max\{\left[S_i(k) - \partial\left(N_{i+1}(k) - n_{i+1}(k)\right)\right], 0\}$$

Φ_2 splits into two subparts Φ_{2S} and Φ_{2J}, indicating the impact of the sending traffic flow and the rejected traffic flow in relation to cell densities:

$$\Phi_{2S}(i,i) = -\frac{S_i(k)}{n_i(k)} \qquad \Phi_{2J}(i,i+1) = \frac{J_{i+1}(k)}{n_{i+1}(k)}$$

$$\Phi_{2S}(i+1,i) = \frac{S_i(k)}{n_i(k)} \qquad \Phi_{2J}(i+1,i+1) = -\frac{J_{i+1}(k)}{n_{i+1}(k)}$$

3. Result

Fig. 4 shows the result of turning ratios estimated for a normal size X-shaped intersection with 300m distance to downstream detectors, which is simulated in Vissim. It is proven that the estimated turning ratios follow the configured turning ratios in Vissim.

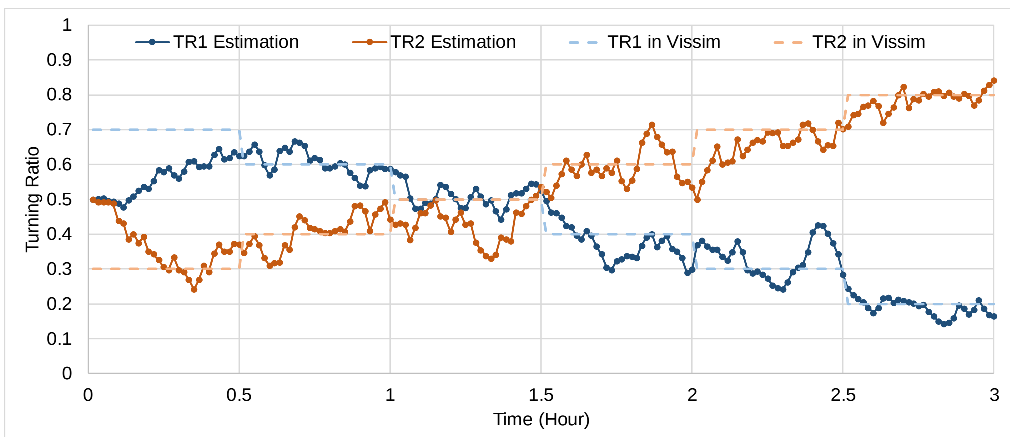

Fig 4: Turning ratio estimation with ECTM based EKF for X-shaped intersection