A REAL-TIME DATA FUSION FRAMEWORK FOR CORRIDOR TRAVEL TIME ESTIMATION WITH MULTIPLE DATA SOURCES

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ABSTRACT

Due to technological improvements in recent years, the available independent data sources for reporting travel time on highway and arterial corridors has increased. Combining and fusing data from different sources and turning data into useful information is an important part of any integrated transportation system. A suitable data fusion framework improves real-time data coverage and accuracy, and is capable of improving reliability by quantifying underlying uncertainties. This paper presents a multi-source real-time travel time fusion framework, based on Dempster-Shafer evidential theory (D-S theory). Data source credibility and real-time data variation extracted for each heterogeneous data sources are considered as time-dependent variables in the proposed model. The model is independent of underlying technology behind each sources and the number of input sources is not limited. An application of the fusion framework by using mean world data collected from three sources on a Maryland freeway corridor is presented and discussed. The results from case study show that the fusion scheme is successful in merging data along with reliability indicator, and its resolution can be adjusted with respect to the intended application.

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ACQUISITION

Travel Time Measurements
• Identification and Re-identification Method
  - Use identification and re-identification timestamps of the vehicles to estimate travel time between consecutive detection stations installed along the route.
  - Applications: Bluetooth and Wi-Fi detections.
• Stationary Detector Based Estimation Method
  - Use weighted speed data collected at each single point to estimate travel time of the adjacent segment.
  - Applications: Loop Detector, and Microwave Radar.
• Continuous Vehicle Tracking Method
  - Use average travel time and information awareness and internet connected mobile devices to estimate travel time of a particular path.
  - Applications: Probe travel time archived by INRIX.

Estimation Uncertainty
While most applications use a single value as average travel time, the variation associated with the travel time samples within the corresponding interval is very useful to understand and analyze travel time uncertainty.
• Uncertainty for the Re-identification and Tracking Methods
  \[ \sigma_k = \sqrt{\sum_{i=2}^{N} (\hat{u}_i - \hat{u}_k)^2} \]
  where, \( \hat{u}_i \) = weighted speed data collected at each single point, \( \sigma_k \) = sampling variance, \( \hat{u}_k \) = average travel time.
• Uncertainty for Stationary Detector Method
  \[ \sigma_k = \sqrt{\sum_{i=2}^{N} (\hat{u}_i - \hat{u}_k)^2} \]
  where, \( \hat{u}_i \) = speed data collected at each single point, \( \sigma_k \) = sampling variance, \( \hat{u}_k \) = average travel time.

Real-time Information Credibility
Recognize real-time data reliability before further fusion (i.e. Naïve vs. real-time).
• Re-identification and Tracking Methods
  \[ a_i = 1 - (1 - \gamma)^n \]
  \[ \gamma = \frac{1}{1 + e^{-\Delta t \cdot t - \alpha}} \]
• Stationary Detector Method
  \[ a_i = 1 - \frac{t - \alpha}{\Delta t} \]
• Dempster-Shafer evidential theory: is a probability based data fusion scheme, also called D-S theory.
• D-S Theory based Fusion Model
  \[ K = \frac{1}{N} \sum_{i=1}^{N} \frac{\sigma_i}{\sigma_k} \]
  \[ \sigma_i = \sqrt{\sum_{j=2}^{M} (\hat{u}_j - \hat{u}_i)^2} \]
  \[ \sigma_k = \sqrt{\sum_{j=2}^{M} (\hat{u}_j - \hat{u}_k)^2} \]
  where, \( \hat{u}_i \) = weighted speed data collected at each single point, \( \sigma_k \) = sampling variance, \( \hat{u}_k \) = average travel time.

Multi-source Travel Time Fusion Framework
For each time window (e.g. 5min or 15-min):
Step 1: At each time window, estimate the travel time distribution and the information credibility function for each data source based on their detection samples.
Step 2: For each data source, generate a set of travel time judgement propositions according to the estimated distributions in Step 1. The propositions consist of k high likelihood propositions \( \{P_1, P_2, \ldots, P_k\} \) belonging to the low confidence bands representing other possibilities.
Step 3: Calculate the probability masses for the propositions of each data source, by considering both the real-time information and the historical reference and with respect to the information credibility functions.
Step 4: Apply the combination rules of D-S evidential theory to calculate the fused probability mass of each option proposition contributed by all data sources.
Step 5: Output the travel time proposition with the largest fusion mass as the final result, representing the travel time value of the current time window.

CONCLUSIONS
• Proposed a multi-source travel time fusion framework based on Dempster-Shafer (D-S) evidence theory.
• Confidence score evaluating the fused travel time reliability can be stochastically generated by the fusion model.
• Real-time information credibility and sampling variation for each type of travel time collection methods are formulated and considered.
• More datasets with ground truth value will be used to comprehensively test the proposed data fusion framework.

SELECTED REFERENCES