Vehicle Infrastructure Integration System Using Vision Sensors to Prevent Accidents in Traffic Flow

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Motivation

• Background
  – Fatalities from traffic accidents: gradually decreasing
    • Legal measures such as making the use of seat belts compulsory
    • Development of emergency medical care
  – The number of accidents: has increased
    • Improvement of road safety is required
    • Considered with special attention

• Incident detection systems worldwide
  – Vehicle Infrastructure Integration (VII), USA
  – SARETEA, Europe
  – Advanced cruise assist Highway System (AHS), Japan
    • California, field tests of collision warning systems in intersections
    • Japan, field tests of collision warning systems for obstacle forward in Tokyo metropolitan expressway
Overview of the VII system by vision

• Factor analysis of traffic accidents in the Akasaka tunnel
  – Data: both ultrasonic wave sensors, video cameras
  – Result: two categories of traffic accident

• Boundary of shock waves
  – Saturated traffic: vehicles do not move at constant speed
    • Traffic density low: 40 km/h
    • Traffic density high: almost stalled
  – Almost rear-end accident: rapid speed difference

• Traffic jam
  – Low speed about 10 km/h
  – Driver’s carelessness
Proposal of the VII system to prevent accident

- Shinjuku route of Tokyo Metropolitan Expressway
  - Ultrasonic wave sensors
  - Surveillance video cameras, every 70-80 m
Overview of the VII system

• Three parts of system
  – Vehicle tracking
  – Detection
  – Information providing

• Tracking
  – Average velocity of traffic flow
  – Result of the vehicle tracking part in vision sensor

• Detection
  – Incoming shock wave
  – Algorism based on the calculated average velocity

• Shock wave detection
  – Warning information: dedicated short-range communications (DSRC)
  – Position where the shock wave existes at the time
Vehicle tracking algorithm

- **S-T MRF model**
  - Segmentation of the object region in the spatio-temporal image
  - Tracking the object against occlusions

- **Segmentation of spatial MRF**
  - Image pixel by pixel, usually
  - Usual video cameras do not have such high frame rates: objects typically move ten or 20 pixels among consecutive image frames.

- **Neighbouring pixels within a cubic clique**
  - Never correlate in terms of intensities or labelling
  - Image into blocks as a group of pixels
  - Optimized the labelling of such blocks by referring to the texture
  - Combination with their motion vectors.
  - Image: 640*480 pixels, block: 8*8 pixels
Detection of shock waves by the vision

- Detection algorithm
  - Average speed of vehicles that pass the vision sensor
  - Speed of vehicles: calculation by tracking the results of the S-T MRF model

- Score
  - $n$: frame number per 0.1s

\[
\text{score}_n = \begin{cases} 
1 & \text{average velocity} \geq V_{\text{flow}} \text{ (km/h)} \\
2 & V_{\text{cong}} < \text{average velocity} < V_{\text{flow}} \\
3 & \text{average velocity} \leq V_{\text{cong}}
\end{cases}
\]

\[
\text{average score} = \left( \frac{\sum_{i=n-128}^{n} \text{score}_i}{128} \right)
\]

- Condition

\[
\text{condition}_n = \begin{cases} 
\text{flow} & \text{average score} \leq \text{Score}_{\text{flow}} \\
\text{critical} & \text{Score}_{\text{flow}} < \text{average score} < \text{Score}_{\text{cong}} \\
\text{congestion} & \text{average score} \geq \text{Score}_{\text{cong}}
\end{cases}
\]

\[
\text{shockwave detection}_n = \begin{cases} 
on & \text{condition}_n = \text{congestion} \\
on & \text{condition}_n = \text{critical and condition}_{n-1} \\
o & \text{condition}_n = \text{flow}
\end{cases}
\]
Detection of shock waves by the vision

Proposed method
Steps of detection

• Step 1
  – Score in each frame is decided by the average speed calculated by tracking results of S-T MRF model. The score is a value from 1 to 3.

• Step 2
  – The average score is calculated from scores of past 128 frames (12.8 s).

• Step 3
  – Traffic conditions in the present frame are estimated \{flow, critical, congestion\} by the average score.

• Step 4
  – The propagation of shock waves is detected if the current traffic condition is ‘congestion’ or ‘critical’, when the last traffic condition is ‘congestion’. In this algorism, the ‘critical’ condition has a role of preventing unstable changing of traffic conditions.
Parameters settings of shock wave detection

- Parameter: $V_{\text{flow}}$, $V_{\text{cong}}$, $\text{Score}_{\text{flow}}$, $\text{Score}_{\text{cong}}$
  - Analysis of incidents at Akasaka tunnel: high-accident prone location
  - 150 incidents’ data in the past years
  - Shock wave with wave sensor data

- Result of analysis
  - Traffic flow changes from critical to the congestion
  - Velocity of traffic flow: $30\sim40\text{km/h} \rightarrow 20\sim10\text{km/h}$
  - $V_{\text{flow}}$: 40, $V_{\text{cong}}$: 20
  - $\text{Score}_{\text{flow}}$: 1.6, $\text{Score}_{\text{cong}}$: 2.4
Experiments

- Vehicle tracking
  - Akasaka tunnel
  - 40 min. images at each location by applying the S-T MRF model

- Result
  - 1266 vehicles
  - S-T MRF: 1181
  - About 93% successful
Experiments

Detection of shock wave

• Evaluation indexes
  – The number of shock waves: count of shock waves by visual observation.
  – Correct: count of shock waves observed both in visual and the system.
  – Lack: count of shock waves not observed in the system, whereas it was observed in visual.
  – False: count of shock waves observed wrong in the system, whereas it was not observed in visual.

<table>
<thead>
<tr>
<th>Number of shock wave</th>
<th>Result of detection</th>
<th>Vision condition</th>
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</table>

• Result
  – No recall reports in any condition
Optimization of the proposed VII system

- Environment
  - 7662 vehicles passed
  - 22:00~7:00
  - 2 days
  - November 2007

- Analysis
Experiments

Prediction success rate

\[
prediction\ success\ rate = \frac{N_{\text{success}}}{N_{\text{total}}}
\]
Conclusion

- Vehicle tracking and detecting shock waves in saturated traffic algorithms
  - Point of view that the propagation is caused by downstream bottleneck in traffic flow
  - One of main factors for traffic accident in the critical flow
- VII system that informs arrival of such shock waves to drivers
  - Investigated by the vision sensor network.
  - To increase the reliability of the VII system, a technique to correct an error about a prediction of the shock wave arrival time has been proposed.
- By the detailed analysis of the propagation of shock waves by the vision sensor network in our system,
  - This technique achieves around 5% prediction success rate improvement at the maximum compared to the case without error correction
- We are going to evaluate the tolerance from the view of human-factors engineering in the future