COMPUTER VISION AND INTELLIGENT SYSTEMS IN ROAD TRAFFIC CONTROL

Edouard Ivanjko, Martin Gregurić, Kristian Kovačić, Sadko Mandžuka, Hrvoje Gold

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University of Zagreb, Croatia
- Established in 1669.
- 29 faculties and 3 academies
- 4,850 research staff members and 50,000 students

Faculty of Transport and Traffic Sciences
- Established in 1984.
- 15 departments
  - Cover all transport modes, logistics, ITS, aeronautics
- 100 research staff members / 2200 students
- Publisher of the journal
  PROMET – Traffic&Transportation
  - Cited in SCIE, TRIS, Geobase, FLUIDEX, and Scopus
Outline

- Introduction
- Computer vision in road traffic
- Experimental results
- Ramp metering
- Intelligent cooperative ramp metering
- Experimental results
- Conclusion & Future work
• Today’s local urban roads, urban highways and they interconnections cannot fulfil desired level of service (LoS) due congestions caused by
  – Large demand for mobility at peak hours
  – Lack of space for infrastructural build-up
  – Urban network serves local and transit traffic

• Solution in intelligent transport systems (ITS) based traffic control systems
  – Ramp metering
  – Variable Speed Limit Control (VSLC)
  – Optimization of traffic lights signal planes
  – Various driver information systems, etc.
• ITS state-of-the-art solution for urban traffic control
  – Application of hybrid intelligent system in control
  – Cooperation between several traffic control systems
• Reliable real-time measurements of traffic parameters is required for ITS control systems
• State-of-the-art solution is in real-time video surveillance and computer vision application
  – Several traffic parameters can be estimated from road traffic video footage
    • Origin-Destination (OD) matrices
    • Vehicle class, trajectories and velocity
    • Estimation of vehicle country of origin using license plate recognition, etc.
• Problem with video cameras used for real time traffic parameters measurement
  – Weather conditions
  – One camera per road lane
• Tracking vehicles on multiple lanes simultaneously with only one camera
• Preprocessing algorithm
  – Noise reduction
  – Gaussian filter with 5x5 matrix
• **Background subtraction method**
  (a) Creation of background image model
  (b) Detection of foreground objects

• **Object clustering method**
  – Check if adjacent pixels exist and combine them into cluster
  – If cluster area $A \leq threshold$, remove cluster
• **Object tracking method**
  - Compare all objects in the new frame with objects in the previous frame and combine only those with maximal weight $w$

• **Postprocessing object location**
  - Extended Kalman Filter (EKF)
  - Histogram for computing average values of position ($x, y$), velocity ($v$), acceleration ($a$), direction ($\phi$), angular velocity ($\omega$) based on EKF output
  - Setting initial values of state vector $x$ by histogram

$$w_{\text{dist}} = 1 - \frac{d - d_{\text{min}}}{d_{\text{max}} - d_{\text{min}}}$$

$$w_{\text{area}} = 1 - \frac{a - a_{\text{min}}}{a_{\text{max}} - a_{\text{min}}}$$

$$w_{\text{cover}} = \frac{a_{\text{is}}}{\max(a_{\text{obj}}, a_{\text{cl}})}$$

$$w = \frac{w_{\text{dist}} + w_{\text{area}} + w_{\text{cover}}}{3}$$
• Optimization for real-time execution
  • Executing algorithms on GPU as much as possible
  • Adding support for CPU SIMD instructions to algorithms which are incapable to run on GPU
  • Performing computations using multiple threads
    • Parallelization of image processing algorithms
Experimental results Vehicle detection accuracy

- **Vehicle counting approaches**
  - Check if vehicle bounding box / trajectory is overlapping with one of virtual markers

<table>
<thead>
<tr>
<th>Approach</th>
<th>Vehicle count per lane</th>
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<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Left</td>
</tr>
<tr>
<td>Overlap check</td>
<td>Hits</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>FP / FN</td>
<td>0 / 6</td>
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<tr>
<td></td>
<td>Accuracy</td>
<td>95,6%</td>
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<tr>
<td>Trajectory check</td>
<td>Hits</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>FP / FN</td>
<td>1 / 4</td>
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<tr>
<td></td>
<td>Accuracy</td>
<td>96,2%</td>
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<td>True vehicle count</td>
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<td>132</td>
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</table>

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Experimental results

Vehicle trajectory estimation accuracy

- Simulation of 3D road traffic scene with known parameters
  - Synthetic environment designed in Autodesk 3ds Max
  - Noise added to measured trajectory
- Uncontrolled platooned vehicle entry from on-ramps (urban arterial roads) into mainstream (urban highway) induce
  - Slowdowns in mainstream
    - Downstream bottleneck
    - Traffic „shock wave“ upstream back-propagation
  - Queues at on-ramps
    - Traffic can spill over onto urban arterial roads
  - Higher risk of incidents
• Urban highway control approach **ramp metering**
  – Special road signals (traffic lights) at on-ramps
  – Ramp metering algorithm determines the "access rate reduction," according to traffic data from sensors
  – Ramp metering control algorithm
    • Local (only one on-ramp)
      – ALINEA
      – Demand-Capacity
    • Cooperative
      – Competitive
        » SWARM
        » Bottleneck
      – Comparative
        » HELPER
        » LINKED
      – Integrated
        » *Fuzzy* logic based, MATALINE, etc.
• Matlab based macroscopic highway traffic simulator for ramp metering evaluation
  – Based on the Asymmetric Cell Transmission Model
• Original version contains local ramp metering only
• Augmentation for cooperative ramp metering and VSLC
- Fluctuations in traffic demand is a significant traffic problem on urban highways
  - One metering strategy cannot respond on every traffic situation

- Learning framework for intelligent cooperative ramp metering
  - Summarized knowledge from several different ramp metering strategies into one control structure
  - Cooperation between different ramp metering strategies

Intelligent cooperative ramp metering
• Application of hybrid intelligent system in ramp metering control
  
  – Adaptive neural-fuzzy inference system (ANFIS)
    • Neural Network (ANN) – learning component
    • Fuzzy Inference System (FIS) – uncertainty component
  
  – ANFIS algorithm learned using several standard ramp metering algorithms
    • HELPER - cooperative knowledge
    • ALINEA – local control
    • SWARM – predictive component
• Zagreb bypass urban highway, section between nodes Lučko and Jankomir as use case
• Congestion created near node Lučko
• Quality measures
  – Travel time (TT)
  – Delay
  – LoS categorization according to HCM 2010
  – Average on-ramp queue length

<table>
<thead>
<tr>
<th>No Control</th>
<th>No Control</th>
<th>ALINEA</th>
<th>SWARM</th>
<th>HELPER</th>
<th>VSRC</th>
<th>HELPER + VSRC</th>
<th>ANFIS</th>
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<tr>
<td>LoS</td>
<td>E</td>
<td>D</td>
<td>A</td>
<td>C</td>
<td>E</td>
<td>C</td>
<td>B</td>
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<tr>
<td>Average TT [min]</td>
<td>14.32</td>
<td>5.61</td>
<td>3.99</td>
<td>4.41</td>
<td>11.01</td>
<td>4.63</td>
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<td>Average Delay [vh]</td>
<td>5.42</td>
<td>20.53</td>
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<td>10.94</td>
<td>4.51</td>
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<td>Average Queue [v]</td>
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<td>79</td>
<td>89</td>
<td>58</td>
<td>13</td>
<td>57</td>
<td>38</td>
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</table>
System based on computer vision methods is capable to
- Detect and track vehicles
- Provide traffic flow measure
- Easily be integrated in existing road traffic measurement systems
- Obtain traffic data from multiple lanes using only one camera

System is tested on video footage from Croatian highways
- Obtained accuracy of the system is over 95%

Intelligent cooperative ramp metering algorithm realized through an ANFIS control structure
- Produce balanced ratio between TT and Delay, second best LoS

Cooperation between ramp metering and VSLC
- Improved results compared to the standalone VSLC and HELPER application

Future work
- Vehicle type classification from road traffic video footage
- Augmentation of ANFIS learning with on-line learning
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Experimental results

Overall execution time

Execution time distribution per image processing component

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• Standalone urban highway control strategies not efficient enough to resolve congestions

• Cooperation between ramp metering and
  – VSLC, Selectively prohibiting lane changes, Vehicle On-Board-Unit (OBU) and Driver information systems
Experimental results

24 hour simulation run

- Cooperation between HELPER and VSLC produces smaller Delay compared to standalone HELPER algorithm
- ANFIS produces lowest Delay values compared to other ramp metering algorithms