Making Transportation Infrastructure Smarter with IoT and AI Technologies

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November 17, 2020
Transportation Infrastructure Challenges
The U.S. has been underfunding its highway system for years, resulting in a $836 billion backlog of highway and bridge capital needs.
Outlays from Federal Grants for Transportation Infrastructure, as a Share of U.S. GDP
Current Transportation Infrastructure System
Future Smart Transportation Infrastructure System

- Connected
- Interactive
- Responsive
- Proactive
- Flexible
- Efficient
- Safe
Dangerous Roads and Dangerous Conditions

Connected Vehicles (CV) technologies can help! Potentially reduce up to 80% of the crashes.

- USDOT Website: https://www.its.dot.gov/cvBasics/cvBasics_what.htm

- Eight people killed in 2013 on California Highway 62

- 3.3 fatal crashes for every 100 million miles driven

- The average for all California roads was 1.1

Conceived Connected Vehicle (CV) Applications
CV Devices Are Increasingly Deployed

Roadside Units Deployed by CV Pilot Site by Date

- NYC (actual)
- NYC (projected)
- Tampa (actual)
- Tampa (projected)
- Wyoming (actual)
- Wyoming (projected)

U.S. Department of Transportation

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Conceived C-ITS Are Powerful But Too Complicated
Consolidating Sensor Data Is Already Complicated

Data collection

Dataset

Data analysis

Decision making and visualization
Our Cost-Effective Solution:
Mobile Unit for Sensing Traffic (MUST)
MUST: Application of IOT and Artificial Intelligence

An Innovative IoT Technology for Comprehensive Traffic Sensing and V2X Communications
Innovative IoT Technology for Comprehensive Traffic Sensing and V2X Applications

- Vehicle Counting & Classification
- Road Condition Monitoring
- Temperature & Humidity
- Travel Time
- V2X Communications
- Visibility
- Vehicle Counting & Classification
Innovative IoT Technology for Comprehensive Traffic Sensing and V2X Applications

Data collection & Data fusion

Data analysis

Decision making and visualization

ATIS
Application to Highway Monitoring

- System To Be Installation
  - E8 corridor in Norway
  - Significant weather challenge
  - Nine MUST sensors with Ethernet
  - Test period: starting soon
Application to Highway Monitoring

- Objectives (Safety and Efficiency)
  - Detect incidents and send warning message to traffic operation centers
  - Section travel time and reliability
  - Road surface condition
  - Vehicle detection and classification
  - Temperature and humidity

Image source: https://www.vegvesen.no/_attachment/2172674/binary/1237125?fast_title=Heavy+vehicles+in+demanding+winter+conditions.jpg
Application to Highway Monitoring

- AI trigger method
- Road detection
- Road classification
- Traffic volume detection
- Traffic classification
Road detection and road mask generation
Application to Highway Monitoring

- Data collection
  - WSDOT cameras
  - WSDOT weather stations
  - Random forest for classification
Application to Highway Monitoring

- Dry, snowy, partial-snowy, rainy
- Features: Temperature, humidity, image intensity, image dark channel value
- Random Forest classifier outperforms K-NN, NB, SVM, ANN, etc.

<table>
<thead>
<tr>
<th></th>
<th>Dry</th>
<th>Snowy</th>
<th>Partial-snowy</th>
<th>Rainy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>97.5%</td>
<td>0.4%</td>
<td>0.7%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Snowy</td>
<td>0.2%</td>
<td>97.9%</td>
<td>1.8%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Partial-snowy</td>
<td>1.6%</td>
<td>4.6%</td>
<td>90.6%</td>
<td>3.2%</td>
</tr>
<tr>
<td>Rainy</td>
<td>7.6%</td>
<td>1.7%</td>
<td>5.4%</td>
<td>85.3%</td>
</tr>
</tbody>
</table>
Application to Highway Monitoring

- Traffic volume detection and vehicle classification
- Background subtraction + blob detection
- Deep neural network classifier
Application to Highway Monitoring

- Traffic volume detection and vehicle classification
  - Transfer learning
  - Mobilenet pretrained on ImageNet and finetuned on MIO-TCD

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Truck</th>
<th>Bus</th>
<th>Cyclist</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>91%</td>
<td>5%</td>
<td>2%</td>
<td>2%</td>
<td>0</td>
</tr>
<tr>
<td>Truck</td>
<td>6%</td>
<td>87%</td>
<td>4%</td>
<td>3%</td>
<td>0</td>
</tr>
<tr>
<td>Bus</td>
<td>1%</td>
<td>2%</td>
<td>96%</td>
<td>1%</td>
<td>0</td>
</tr>
<tr>
<td>Cyclist</td>
<td>2%</td>
<td>2%</td>
<td>1%</td>
<td>95%</td>
<td>0</td>
</tr>
<tr>
<td>Background</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100%</td>
</tr>
</tbody>
</table>
Application to Smart Parking Surveillance

• System Installation
  • Angle Lake parking garage
  • 3rd floor (six parking spots)
  • 6th floor (top) (ten spots)
  • Two MUST sensors with cell data
  • Test period: 09/2018 – 12/2018
Application to Smart Parking Surveillance

IOT devices with edge artificial intelligence

BG-based Detection → Detected Blobs

IoT devices with edge artificial intelligence

SSD Mobilenet

finetune → SSD-based Occupancy

MIO-TCD

Object Types

Detection Probabilities

Cellular network

Modified SORT → Vehicle Tracks

BG-based Occupancy

Data server with occupancy judgement algorithms

Extreme Lighting?

Matching

SSD-based Occupancy

Occlusion?

Occupancy Detection Results

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Application to Smart Parking Surveillance

• Vehicle detection at the edge
  • Single Shot Multibox Detector (SSD) with Mobilenet as the backbone
  • Transferred learning with MIO-TCD dataset and implemented with TensorFlow Lite
• Background subtraction modeling

Application to Smart Parking Surveillance

- SSD-Mobilenet transfer learning with MIO-TCD dataset
Application to Smart Parking Surveillance

• Vehicle detection at the edge (MUST sensor)
Application to Smart Parking Surveillance

- Vehicle tracking on the cloud/server (modified SORT)
### Application to Smart Parking Surveillance

- Detection Accuracy

<table>
<thead>
<tr>
<th></th>
<th>Sunny</th>
<th>Rainy</th>
<th>Cloudy</th>
<th>Foggy</th>
<th>Day</th>
<th>Night</th>
<th>Average</th>
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<tbody>
<tr>
<td><strong>Average</strong></td>
<td>91.4%</td>
<td>93.5%</td>
<td>95.5%</td>
<td>89.9%</td>
<td>92.7%</td>
<td>98.4%</td>
<td>95.6%</td>
</tr>
<tr>
<td><strong>On third Floor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Weekday)</td>
<td>92.3%</td>
<td>91.8%</td>
<td>92.6%</td>
<td>92.0%</td>
<td>92.2%</td>
<td>99.1%</td>
<td>95.7%</td>
</tr>
<tr>
<td><strong>On third Floor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Weekend)</td>
<td>94.3%</td>
<td>94.5%</td>
<td>93.9%</td>
<td>93.1%</td>
<td>94.0%</td>
<td>99.0%</td>
<td>96.5%</td>
</tr>
<tr>
<td><strong>On sixth Floor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Weekday)</td>
<td>88.5%</td>
<td>93.7%</td>
<td>97.5%</td>
<td>85.7%</td>
<td>91.7%</td>
<td>97.3%</td>
<td>94.5%</td>
</tr>
<tr>
<td><strong>On sixth Floor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Weekend)</td>
<td>93.8%</td>
<td>96.2%</td>
<td>99.2%</td>
<td>91.6%</td>
<td>95.4%</td>
<td>98.9%</td>
<td>97.2%</td>
</tr>
</tbody>
</table>
Application to Smart Parking Surveillance

- Detection Accuracy

(a) Cloudy, 6th floor
(b) Rainy, 6th floor
(c) Sunny, 6th floor
(d) Foggy, 6th floor

(c) Night, 6th floor
(f) Night, 3rd floor
(g) Weekend, 3rd floor
(h) Occlusion, 3rd floor
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System input</strong></td>
<td>Video</td>
<td>Video</td>
<td>Image</td>
<td>Image</td>
<td>Multiple videos</td>
<td>Video</td>
</tr>
<tr>
<td><strong>Comp platform</strong></td>
<td>Desktop</td>
<td>IoT devices</td>
<td>IoT devices</td>
<td>NA</td>
<td>Desktop</td>
<td>IoT devices and server</td>
</tr>
<tr>
<td><strong>Process mode</strong></td>
<td>Post analysis</td>
<td>Onboard processing</td>
<td>Onboard processing</td>
<td>Post analysis</td>
<td>Post analysis</td>
<td>Onboard processing</td>
</tr>
<tr>
<td><strong>Pipeline logic</strong></td>
<td>Detection</td>
<td>Classification</td>
<td>Classification</td>
<td>Classification</td>
<td>Detection</td>
<td>Detection</td>
</tr>
<tr>
<td><strong>Primary algorithms</strong></td>
<td>SVM, HOG, BG</td>
<td>Haar, F-test</td>
<td>CNN</td>
<td>Random forest</td>
<td>Faster R-CNN, fusion</td>
<td>SSD, BG, SORT, fusion</td>
</tr>
<tr>
<td><strong># of training frames</strong></td>
<td>1,800</td>
<td>469</td>
<td>4,323</td>
<td>390,000 (patches)</td>
<td>23,741</td>
<td>127,125</td>
</tr>
<tr>
<td><strong>Validation data</strong></td>
<td>Several days real-world validation</td>
<td>90 detections</td>
<td>CNR Park + EXT image dataset</td>
<td>24,000 image patches</td>
<td>1,000 frames</td>
<td>Three months real-world validation</td>
</tr>
<tr>
<td><strong>Testing scenarios</strong></td>
<td>Outdoor, sunny, cloudy, rainy, daytime, occlusion</td>
<td>Outdoor, daytime</td>
<td>Outdoor, sunny, cloudy, rainy, daytime</td>
<td>Indoor</td>
<td>Outdoor, clear, rainy, daytime, nighttime</td>
<td>Outdoor, indoor, occlusion, sunny, cloudy, rainy, foggy, daytime, nighttime</td>
</tr>
<tr>
<td><strong>System efficiency</strong></td>
<td>5 frames per second</td>
<td>NA</td>
<td>3 spaces per second</td>
<td>NA</td>
<td>NA</td>
<td>1 frame per second</td>
</tr>
<tr>
<td><strong>System accuracy</strong></td>
<td>93.9%</td>
<td>91%</td>
<td>&gt; 90%</td>
<td>98.6%</td>
<td>&gt; 90%</td>
<td>95.6%</td>
</tr>
</tbody>
</table>
A Technology for Smarter and Safer Infrastructure

- Roadside and above the road installation
- Does not need broad bandwidth communication
- Works for -40°F to 158°F
- Broadcast information to road users through various channels
- Benefit transportation agencies at all levels and road users of all modes
Thank you!