Single-Loop Vehicle Classification and Speed Measurement Using Inductive Loop Signature Technology *

Dr. Lianyu Chu and Dr. Shin-Ting Jeng, CLR Analytics Inc. Steven Jessberger, FHWA

NATMEC 2018
6/12/2018

* Sponsored by USDOT Small Business Innovation Research program
Outline

- Issues
- Solution
- Study sites and data collection
- Performance
- Concluding remarks
National Traffic Monitoring Program

- Quality and trust-worthy data for informed decision making
  - Divide the federal highway funding
  - Carry out legislation and laws faithfully

- Current reporting stations to the FHWA
  - Continuous Counting Station (CCS): 6,000
  - Continuous Vehicle Classification (CVC): 2,500
  - Weigh-In-Motion (WIM): 600

- Data quality, accuracy, consistency
Continuous Counting Station

- Sensor technologies
  - Loop, magnetometer, microwave radar, acoustic, video-image, tube
  - Data from loop sensors are more accurate
- Typical sensor configuration
  - Single loop or double loops
- Data output
  - Count, occupancy, speed (double loops)
- Limitation/Issues
  - Traditionally, aggregated data output only
  - Work under lane-changing, slow, stop-and-go condition
  - Detection error is not traceable
  - May have over-counting or under-counting issues
Vehicle Classification Station

- Axle based and length based
- Typical sensor configuration:
  - Loop-Piezo-Loop, Piezo-Loop-Piezo setup
  - Piezo: used for axle detection
- Data output:
  - Count, speed, class, axle spacing, length
- Limitation/Issues:
  - Data is often aggregated and not reported on a per-vehicle basis
  - Misclassification of some vehicle classes (3, 4, 5, 8) depending vendors
  - Detection error is not traceable
  - Piezo sensor longevity is an issue and replacement (installation, mobilization) is frequent
Smart Sensor with Data Analytics

- **Smart sensors**
  - Per-vehicle data collection and reporting
  - Reliable data collection method & accurate data
  - Traceable sensor health condition
  - Automatic alerts when sensor starts to fail
  - Utilize existing knowledge and learn everyday through AI techniques

- **Big Data Analytics**
  - Multiple data types and sources
  - Data cleaning, mining, association, and analysis
  - Information extraction for decision making
Inductive Loop Signature Technology

- Conventional loop detector card

- Advanced loop detector card
Input Signal

Conventional loop detector

Output Signal

Presence

Inductance (microhenries)

Occupied (Logical)

Time

Time

$O(t)$

$f(t)$
Input Signal

Inductance (microhenries)

Output Signal

Advanced loop detector

Signature

Inductance change

Advanced loop detector  

$O(t)$

$J(t)$

Inductance (microhenries)
Inductive Loop Signatures for Different Types of Vehicles

Vehicle attributes:
• Size
• Metal mass
• Axles
• Distance from road surface
• Energized circuits
• Motors & compressors

Vehicle operation:
• Vehicle speed
• Vehicle offset

Loop / Detector card:
• Loop configuration
• Loop condition
• Loop induction (# of turns)
• Lead-in cables
• Detector circuitry
• Detection sensitivity
• Operation frequency
Smart Vehicle Classification

A smart traffic data collection, processing, analytics, visualization, and reporting solution based on inductive loop signature technology, AI techniques, and big data analytics.
Smart Pre-analysis: Identify Vehicle Lane-Changing

Two signatures from loops on two adjacent lanes =>

Left lane signature

Right lane signature
Smart Pre-analysis: Stop-and-go Traffic Detection

Example of Signature Waveform with Plateau

Plateau Generated by a Stopped Vehicle
Plateau Generated by a Trailer Truck
Health Monitoring

- Real-time/historical signatures
- Communication
- Data missing
- Data Quality
  - Trend Analysis
  - Statistical Analysis
- Sensor health
  - Tuned inductance values
  - Noise signatures / occurrence time / frequency
- Alerts
Convert ITS counting station to classification site

- Converting the existing counting stations to classification stations
  - Plug and play

- Components:
  - I-Loop detector cards
    - Collect vehicle signature data
    - 2 loops per card
  - One CLR master card
    - Vsing Master Gateway with embedded USB Hub and optional cellular modem
  - Data connectivity
    - USB
    - Ethernet

System Deployment at I-15 NB Airport
Signature Detector Card

- Rack mounted
- Conform TEES 2009 (170/2070) and NEMA TS1/2 2003 specification
- 16 programmable frequency levels & 8 sensitivity levels
- 2 Independent loop channels (50 to 1000uH)
- Minimum Inductance change detection: 0.0017%
- Presence and pulse mode
- Bike detection and car/bike differentiation
- Automatic tuning
- Signature data sampling rate up to 5000 Hz
- Four levels of digital filter to remove noises
- Signature output through USB/ Ethernet ports
- Real-time CLR signature data interface
- Can operate as a stand-alone board
- LEDs on the front panel to show operation status
- Integrated inductance measurement
- Built-in lightning and surge suppression
- Hot swapping
- Firmware upgradable
- User programming
- Wide temperature range operation (-40C to +85C)
Field Processing Unit / Gateway

- Signature data collection, processing and transmission to central server
- Small form factor:
  - CLR brand using Multitech part
  - Card format version: SignMaster VC
    - Embedded 7-port USB hub
    - Embedded 3G/4G modems
  - Desktop version: SignMaster VD
    - Embedded 3G modems
- Expandable to more lanes with a USB Hub or Ethernet switch
- Embedded cellular modem
  - FCC approved, 3G or 4G LTE
  - Work with AT&T, Verizon, Sprint
- Linux OS
- 400MHz ARM 9 CPU / 256 MB NAND Flash / 64 MB SDRAM
- SD card slot: support up to 32 GB
  - Store 12 months of raw data for a 8-lane freeway

Card format
Dimension: 6.875“ x 4.5“ x 1.14“
(17.46 cm x 11.43cm x 2.896 cm)

Desktop version
Dimension: 2.8" x 7.0" x 1.2"
(7.1 cm x 17.8 cm x 3.0 cm)
CVC/CCS Solution

PEEK Devices

PEEK Classifier

Serial cable

SignMaster

Wired/Wireless communication

Central Server / Website

SC514-P Contact closure module & harness

I-Loop Duo Cards

Ethernet/USB Hub
CVC/CCS Solution
Phoenix II from Diamond Traffic

Phoenix II classifier
- Custom firmware to support signature output:
  - Motherboard 4.43Z
  - Loop Board: 1.73Z

2-serial to USB adapter

20

I-70 Airpark in Colorado
Ground-truth Datasets

I-405 NB, CA

TH-55, MN

I-25 / I-70 Airpark, CO
Ground-truth Dataset
San Bernardino, LA, Orange, CA

1. WIM_SR-57 NB Orange
2. WIM_SR-57 SB Orange
3. WIM_SR-60 WB Ontario
4. WIM_SR-60 EB Ontario
5. WIM_I-10 EB Colton
6. WIM_I-15 NB Fontana
7. WIM_I-15 SB Fontana
8. CCS_I-15 SB Airport
9. CCS_I-15 NB Airport
10. CCS_I-10 WB San Antonio
11. CCS_I-10 EB San Antonio
12. CCS_SR-60 WB Benson
13. CCS_SR-60 EB Benson
14. CCS_I-15 SB South SR60
15. CCS_I-15 NB South SR60
16. CCS_SR-57 NB Pathfinder
17. CCS_SR-57 SB Pathfinder
Data Collection Setup

- Data collection from 8:00 am to 3:30 pm on 12/13/2016
- Capture the following from videos
  - License plates, number of Axles, body type
- Collect signature data
  - I-Loop Duo detector cards at CCSs
  - Custom loop signature module at WIMs
- Sync time against the same time server
Data Ground-truthing

* Total processed vehicle records: 223,370
* Total trucks: 55,552
* Truck percentage: 25%
Classification Algorithm

Customizable Template Library

FHWA1
FHWA2
FHWA5
FHWA9
FHWA13

Signature data processing, normalization

Distinguishable feature extraction through wavelet transform

Vehicle classification based on KNN and template library
• Analyze 2000 vehicles to build a good classification template library for a class

• Customized library for unique commercial vehicles
Single-loop Vehicle Classification

From a Single Loop

We are improving classification performance by updating template library.
Core Algorithm: Single Loop Speed Estimation

- Regression model with two variables:
  - X: Slew rate
  - Y: Inverse of duration

- Different model parameters for different vehicle class cluster (a group of vehicle classes)

\[ \text{Speed} = a + b \times X + c \times Y \]
Single Loop Speed Measurement

- I-405 NB Sand Canyon Station
Single Loop Speed Measurement (compared against dual-loop speed)

- Establishing model based on 4 hours’ data collected from I-405 NB Laguna Canyon Station (Truck % = 2.3%)
  - No model calibration is required

- Testing on the same freeway at I-405 NB Sand Canyon Station (Truck % = 2.4%)
  - MAPE = 5.1% (1-min interval)

- Testing transferability on different freeway at I-10 EB San Antonio Station (Truck % = 24%)
  - MAPE = 5.7% (1-min interval)
Support 2016 TMG 4-Digit Codes

- TMG 4-Digit code in per-vehicle record
  - Digit 1: Category (Vehicle Type Code)
  - Digit 2: Number of axles/wheels
  - Digit 3: Body type (Body style)
  - Digit 4: Specific body type

- CLR vehicle classification scheme with 5-digit code that can be easily converted to 4-Digit code

CLR 5-digit code: 54520
TMG 4-digit code: 5452

Single-Unit FHWA Class 7 Concrete Mixer
Concluding Remarks

- Quick & easy
  - Use existing loops, **Swap detector cards**
- Cost-effective: a single loop per lane
- A patented technology based on AI and big data analytics
- Accurate count, speed, and classification
- Compatible with existing standards & data collection systems
- Work with extremely **low speed and high volume** conditions
- **Smart features** (sensor health monitoring)
- Rich data for many applications
  - Freight, simulation, safety, operation, planning, emission estimate

- Future work
  - Improve accuracy, detailed classification, customized library
Current Deployments

- **Freeway:**
  - Colorado: 3 CVC sites
  - Minnesota: 2 sites
  - Netherland and China

- **Arterial:**
  - Minnesota: 6 signal sites
  - Alaska: 2 CVC sites

- **Deployed at 120+ sites**
  - Including WIM, CVC, CCS sites
  - Most through UC Irvine researchers
  - More than 300 I-Loop Duo cards are in operation in the field

- **Upcoming:** NM, ID, VA, WA, AZ, etc
Acknowledgement

NATMEC 2018, prime co-chairman

Stephen Ritchie is Director of the Institute of Transportation Studies and Professor of Civil Engineering at the University of California, Irvine. His research interests focus on intelligent and sustainable transportation systems planning and engineering. Particular interests include modeling and assessing the GHG, energy, air quality and health impacts of transportation operations, alternative fueled vehicles, and new shared connected-automated vehicle concepts; new and innovative approaches for statewide freight transportation and commodity flow modeling; collection and integration of high-resolution sensor data for advanced real-time modeling and classification of heavy duty truck characteristics and activity patterns; and real-time traffic performance measurement. Ritchie received his Ph.D. in civil engineering-transportation from Cornell University, Ithaca, NY.
Comments, Questions?

Contact us:
Lianyu Chu
Tel: 949-705-8566
Email: lchu@clr-analytics.com
www.clr-analytics.com
Address: 52 Machly, STE 315, Irvine, CA 92618