Traffic Sensors

Data Processing (ZDA)

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1. lecture

Contents

- **Why it is necessary to collect traffic data**
- Traffic sensors/detectors
  - Categories
  - Parameters
- Measurement errors
- Intrusive detectors

Why it is necessary to collect traffic data

Useful in following traffic applications:

- control,
- coordination and management,
- enforcement,
- safety systems,
- prediction, planning and statistics,
- …
- Useful in vehicle systems

Why it is necessary to collect traffic data

Traffic control

- Traffic lights
  - Optimization of individual intersections
  - Optimization of area networks (greer wave)
- City traffic control (tunnels)
- Highway traffic control
  - VMS (variable message signs)
    - B20 (speed limit)
    - B22 (no overtaking for heavy vehicles)
      - » …
  - Ramp metering

Why it is necessary to collect traffic data

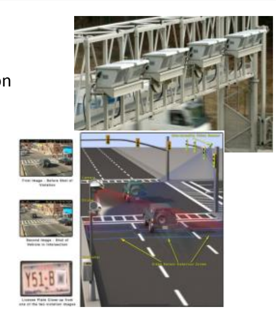
coordination and management

- Management
- Traffic information distribution
- Lane management
- Coordination
- Crisis management
- Fleet management

Why it is necessary to collect traffic data

Enforcement

- Enforcement
- Red light crossing detection
- Size enforcement
- Weight in motion
- Speed measurement
- Close area enforcement

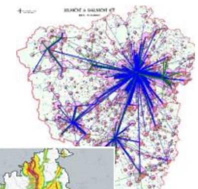


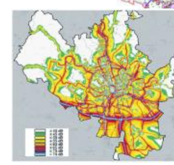
Why it is necessary to collect traffic data
Safety systems

- Telematic Applications
- Informative speed measurement
- Detection of ghost vehicles
- Pedestrian detection
- Road condition measurement

Why it is necessary to collect traffic data
Prediction, planning and statistics

- Prediction and planning for purposes of
- Traffic control
- Road construction
- Traffic simulations
- Statistical evaluation of real impact on
- environment
- road users
- ...





Why it is necessary to collect traffic data
In car applications

- Drivers support systems
- Adaptive cruise control
- Intelligent head lights
- Traffic simulations
- ...
- Active safety systems
- Forward collision warning
- Lateral position monitoring
- Blind spot monitoring
- Safety belts
- ...

Why it is necessary to collect traffic data
Examples

- Pedestrian detection http://www.youtube.com/watch?v=H_wMyUEelzQ
- Blind spot monitoring http://www.youtube.com/watch?v=X-Q8n8wM5PQ
- Enforcement
  http://www.youtube.com/watch?v=5OpEgT7cWFk
  http://www.youtube.com/watch?v=7oRjq_yuLN4
- And many others ...

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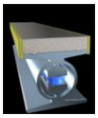
  - Categories
  - Parameters
- Measurement errors
- Detector types
  - Intrusive
  - Nonintrusive
  - Comparison

Discussion

- What is a sensor?

Traffic sensors/detectors




Sensor

A device for translating the magnitude of one quantity to another. The second quantity often has different units of measure and serves to provide a more useful signal. Vibration sensors convert mechanical motion into an electronic typically a voltage proportional) signal.

Contents

Traffic sensors/detectors

categorization

Many different classifications:

- By measured quantity
  - *speed, vehicle count, temperature, pressure, optical, magnetic, electric, mechanic quantities.*
- By physical principle of measuring the quantity
  - *inductance, magnetic, piezoelectric, optic, optoelectric.*
- By contact with measured quantity
  - *Intrusive, non intrusive*
- By function in traffic control
  - *extension, presence (polling), strategic*

Contents

Traffic sensors/detectors - Parameters

Static parameters

- Sensitivity
- Threshold
- Dynamic range
- Reproducibility
- Readability / resolution
- Additive and multiplicative errors
- Linearity
- Output parameters

Dynamic Parameters

- Time response
- Frequency bandwidth
- Quantization parameters
- Noise parameters
- …

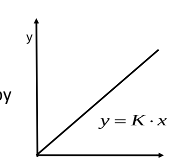
Traffic sensors/detectors - Parameters

Sensitivity

Sensitivity:

- the ability of a detector to react to measured quantity, expressed as the <u>minimum quantity required to produce a specified output</u> signal with a given noise level.
- Ideal function y = Kx,
- Where K is detector sensitivity defined by differences Δx a Δy in following:

$$K = \lim_{\Delta x \to 0} \frac{\Delta y}{\Delta x} = \frac{\partial f(x)}{\partial x}$$



Traffic sensors/detectors - Parameters
Threshold

Threshold:
- The smallest change in the measured variable that will result in a measurable change in an output signal

Dynamic range
- Is given by the interval of admissible values of measured physical quantity
- is bounded by the sensitivity threshold and the maximum value of the quantity

Reproducibility
- is given by the deviation of the measured values while the short sequence constant input quantity is measured

Traffic sensors/detectors - Parameters
Readability / resolution

Readability / resolution
- is the smallest change of measured quantity corresponding to the absolute or relative sensor error
- in analog signal transformation is given by $r_a = \delta_s$, where δ_s is relative sensor error,
- in digital transformation the signal is given by $r_d = \frac{1}{2^n - 1} \doteq \frac{1}{2^n}$ where n is the number of bits

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Measurement errors
Systematic errors

Error
The difference between the indicated and true values of the measured variable. Typically expressed as relative error which is a percentage of the output reading of the *sensor.*

Systematic errors
- are static in nature, distort the output in the same, controlled, manner.
- source of these errors is limited precision of the instruments, measurement method and personal errors.
- to errors caused by limited precision fall e.g. additive and multiplicative errors.

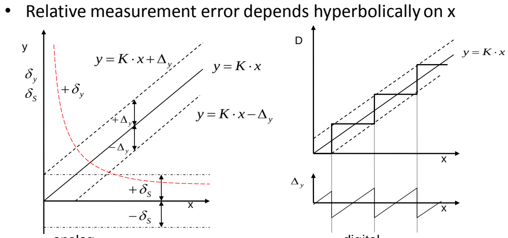
Measurement errors

Absolute and relative errors

- y_N ... measured value
- y_S ... true value
- Absolute measurement error $\Delta_y = y_N - y_S$
- Relative measurement error $\delta_y = \frac{\Delta_y}{y_S}$
- Relative sensor error $\delta_s = \frac{(\Delta_y)_{max}}{y_{max} - y_{min}}$

Measurement errors

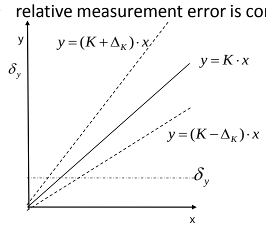
Additive measurement error
- Caused by the offset of nominal linear characteristics
- Absolute measurement error is constant
- Relative measurement error depends hyperbolically on x



Measurement errors

Multiplicative measurement error

- is equivalent to the change of sensitivity of the sensor
- absolute measurement error is dependent on the value of the measured quantity
- relative measurement error is constant



$$\Delta_y = \Delta_K \cdot x$$

$$\delta_y = \frac{\Delta_y}{y} = \delta_K = konst.$$

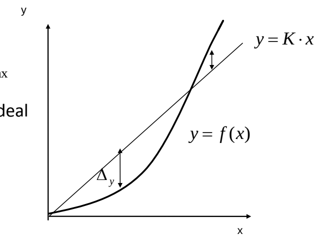
Measurement errors

Linearity error

- given by deviation from an ideal linear characteristics

$$\delta_L = \left(\frac{y_n - y_L}{y_{max} - y_{min}} \right)_{max}$$

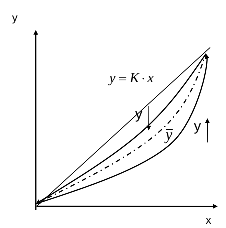
- where y_L is defined by ideal function $y = y_0 + K*x$,
- parameter K can be estimated using linear regression.



Measurement errors

Hysteresis

- Non-uniqueness between two variables as a parameter increases or decreases.
- the maximum difference in output at any given value of the measured variable within the specified range, when the value is first approached with an increasing signal and then a decreasing one..

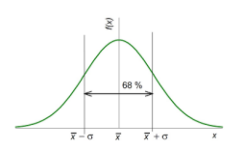


$$\delta_S = \left(\frac{y\downarrow - y\uparrow}{y_{max}} \right)_{max} = \left(\frac{\Delta_{yH}}{y_{max}} \right)_{max}$$

Measurement errors

Random error

- caused by the uncontrolled effects
- error of repeated measurements (and noise) show a statistical patterns
- Gauss distribution, mean value corresponds to the most likely value of repeated measurements



Probability density

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{(x-\bar{x})^2}{2\sigma^2}}$$

DETECTOR TYPES

Vehicle Detection and Surveillance

Intrusive technologies

- Inductive Loop Detectors
- Fiber Optic Sensors
- Magnetic Sensors
- Piezoelectric Sensors
- Pneumatic Road Tube
- Weigh-in-Motion (WIM)

Non-Intrusive technologies

- Infrared Sensors
- Microwave Radar
- Passive Acoustic Array Sensors
- Ultrasonic Sensors
- Video Image Sensors

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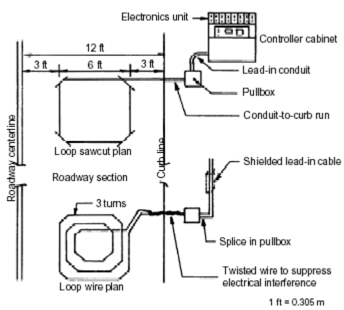
Invasive Detector

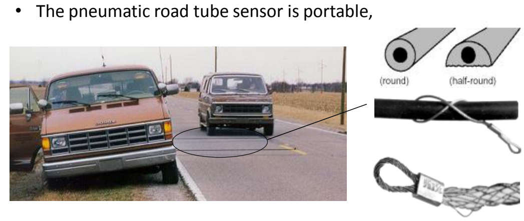
- Small coil of wire embedded in protective housing and installed under the surface of the roadway
  - Electronic amplifiers required
  - Does not work as a presence detector
  - Minimum speed 3 to 5 mph

Principal Components of Inductive Loop Detector



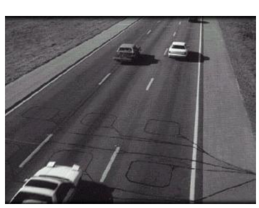
Pneumatic road tube

- Send a burst of air pressure along a rubber tube when a vehicle's tires pass over the tube.
- The pressure pulse closes an air switch, producing an electrical signal that is transmitted to a counter or analysis software.
- The pneumatic road tube sensor is portable,

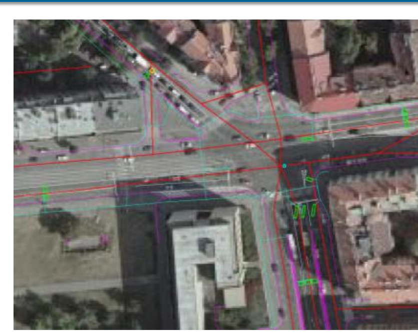


Inductive loops

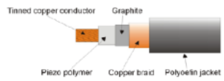
- the most common sensor used in traffic management
- size and shape vary (square, round and rectangular)
- The principal components of an inductive loop detector:
  - One or more turns of insulated wire buried in a shallow sawcut in the roadway,
  - a lead-in cable that runs from a roadside pull box to the controller cabinet, and
  - an electronics unit located in the controller cabinet.



Inductive loops – Prague example



Piezoelectric cable

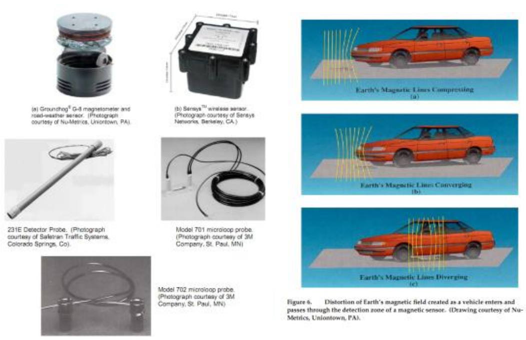


- Piezoelectric materials generate a voltage when subjected to mechanical impact or vibration.
- Electrical charges of opposite polarity appear at the inner and outer faces of the material and induce a voltage.
- The measured voltage is proportional to the force or weight of the vehicle.
- The magnitude of the piezoelectric effect depends upon the direction of the force in relation to the axes of the crystal.
- Since the piezoelectric effect is dynamic, i.e., charge is generated only when the forces are changing, the initial charge will decay if the force remains constant

Magnetic sensor

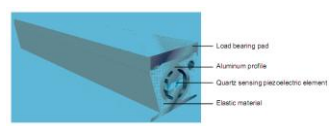
- Magnetic sensors are passive devices that indicate the presence of a metallic object by detecting the perturbation in the Earth's magnetic field created by the object.
- Two types of magnetic sensors are used
  - two- and three-axis fluxgate magnetometers, detects changes in the vertical and horizontal components of the Earth's magnetic field produced by a ferrous metal vehicle. These sensors identify stopped and moving vehicles. http://www.youtube.com/watch?v=_5d0qz_umuE
  - Magnetic detector (induction or search coil magnetometer) It normally detects only moving vehicles by measuring the change in the magnetic lines of flux caused by a moving ferrous metal vehicle. cannot detect stopped or slow moving vehicles.

Magnetic sensor – figures



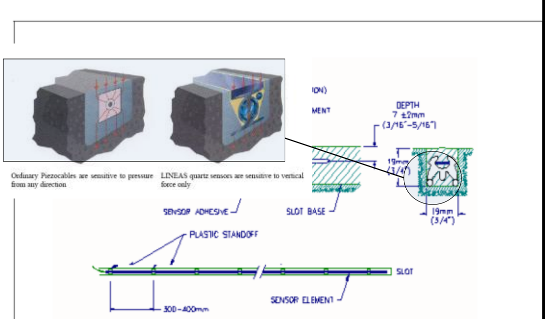
Piezoelectric sensor

- Piezoelectric WIM systems contain one or more piezoelectric sensors that detect a change in voltage caused by pressure exerted on the sensor by an axle and thereby measure the axle's weight.
- As a vehicle passes over the piezoelectric sensor, the system records the sensor output voltage and calculates the dynamic load.



- the dynamic load provides an estimate of the static load when the WIM system is properly calibrated.

Piezoelectric sensor



Bending plate

- Bending plate WIM systems utilize plates with strain gauges bonded to the underside.
- As a vehicle passes over the bending plate, the system records the strain measured by the strain gauges and calculates the dynamic load.
- The static load is estimated using the measured dynamic load and calibration parameters.

- The calibration parameters account for factors such as vehicle speed, pavement condition, and suspension dynamics, which influence estimates of the static weight.

Capacitance Mat

- consists of a sandwich of metal steel sheets and dielectric material
- a stainless steel sheet could be surrounded by polyurethane dielectric material on either side. The outer surfaces of the polyurethane layers are enclosed by other stainless steel sheets.

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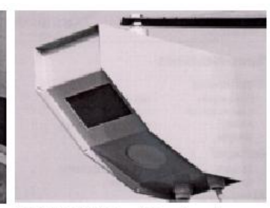
Non-invasive Detection

- You do not have to alter the pavement to use this system
- Types
  - Radar detectors
  - Sonic detectors
  - Video Image Processing (VIPs)
  - Special purpose detectors

Infrared Sensors

ASIM DT 272 Infrared-ultrasonic sensor



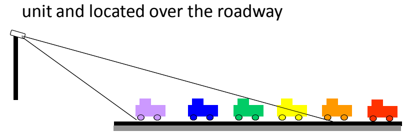
ASIM DT 281 Infrared-Doppler radar sensor

Radar Detection

- Operates on the Doppler effect , as a microwave signal is emitted by the detector and reflected back at the detector by approaching vehicles
- Transmits microwave energy toward the roadway from the detector's antenna
- Senses the frequency of the microwave change in the reflected energy and obtains vehicle speed from the signal

Radar Detection

- Two types of radar units
  - Antenna and detection electronics is fabricated as a single unit and located over the roadway



  - Separate antenna and detection electronics

Radar Detectors

- Detectors require FCC approval
- Newly developed detectors
  - Detect moving vehicles as well as stopped vehicles
  - Covers single or multiple lanes
  - Provides digital and instantaneous speed information

Sonic Detectors

- Transmit pulses of ultrasonic energy through transducers toward the roadway
- Located over the roadway
- Presence of vehicle causes these ultrasonic beams to reflect back to the transducers and it:
  - Senses the reflected wave
  - Converts to electrical energy
  - Relays the energy to a transceiver which provides vehicle presence information

Video Image Processing System (VIPS)

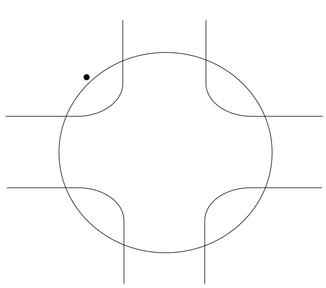
- Research was conducted in the mid 1970's by the University of Minnesota
  - Camera, digitizer, formatter, interface, electronics, microprocessor and power supply was used
  - Theory: one camera to replace numerous detectors
- 1970's and 80's
  - Japan, UK, Germany, Sweden and France used VIPs successfully

Video Image Detection System (VIDS)

- Algorithm for generating both presence and passage detection and speed
- Problems:
  - Shadows
  - Lighting (illumination) change
  - Reflection (camera difficulties)

Video Image Detection System (VIDS)

- Summary of VIDS and VIPS



Entire intersection can be surveyed using one camera

Can have remote or automatic control

Vehicle Presence Detection at an Intersection

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Strengths and Weaknesses of …

Strengths of Inductive loop

- Flexible design to satisfy large variety of applications.
- Mature, well understood technology.
- Large experience base.
- Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, …).
- Insensitive to inclement weather such as rain, fog, and snow.
- Provides best accuracy for count data as compared with other used techniques.
- Common standard for obtaining accurate occupancy measurements.
- High frequency excitation models provide classification data.

Strengths and Weaknesses of …

Weaknesses of Inductive loop

- Installation requires pavement cut.
- Improper installation decreases pavement life.
- Installation and maintenance require lane closure.
- Wire loops subject to stresses of traffic and temperature.
- Multiple loops usually required to monitor a location.
- Detection accuracy may decrease (for design with a large variety of vehicle classes.)

Strengths and Weaknesses of …

Magnetometer

Strengths

- Less susceptible than loops to stresses of traffic.
- Insensitive to inclement weather such as snow, rain, and fog.
- Some models transmit data over wireless (RF) link.

Weaknesses

- Installation requires pavement cut.
- Improper installation decreases pavement life.
- Installation and maintenance require lane closure.
- Models with small detection zones require multiple units for full lane detection.

Strengths and Weaknesses of …

induction or search coil magnetometer

Strengths

- Can be used where loops are not feasible (e.g., bridge decks).
- Some models are installed under roadway without need for pavement cuts. However, boring under roadway is required.
- Insensitive to inclement weather such as snow, rain, and fog.
- Less susceptible than loops to stresses of traffic.

Weaknesses

- Installation requires pavement cut or boring under roadway.
- Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used.

Strengths and Weaknesses of

Microwave radar

Strengths

- Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications.
- Direct measurement of speed.
- Multiple lane operation available.

Weaknesses

- Continuous wave (CW) Doppler sensors cannot detect stopped vehicles

Strengths and Weaknesses of

Active infrared

Strengths

- Transmits multiple beams for accurate measurement of vehicle position, speed, and class.
- Multiple lane operation available.

Weaknesses

- Operation may be affected by fog when visibility is less than 20 feet (ft) (6 m) or blowing snow is present.
- Installation and maintenance, including periodic lens cleaning, require lane closure

Strengths and Weaknesses of

Passive infrared

Strengths

- Multizone passive sensors measure speed.

Weaknesses

- Passive sensor may have reduced vehicle sensitivity in heavy rain, snow and dense fog.
- Some models not recommended for presence detection.

Strengths and Weaknesses of

Ultrasonic

Strengths

- Multiple lane operation available
- Capable of overheight vehicle detection.
- Large Japanese experience base.

Weaknesses

- Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models.
- Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds.

Strengths and Weaknesses of

Acoustic

Strengths

- Passive detection.
- Insensitive to precipitation.
- Multiple lane operation available in some models.

Weaknesses

- Cold temperatures may affect vehicle count accuracy.
- Specific models are not recommended with slow-moving vehicles in stop-and-go traffic.

Strengths and Weaknesses of

Video image processor

Strengths

- Monitors multiple lanes and multiple detection zones/lane.
- Easy to add and modify detection zones.
- Rich array of data available.
- Provides wide-area detection when information gathered at one camera location can be linked to another.

Weaknesses

- Installation and maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway (lane closure may not be required when camera is mounted at side of roadway).

Strengths and Weaknesses of

Video image processor Weaknesses … cont

- Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens.
- Reliable nighttime signal actuation requires street lighting.
- Requires 30- to 50-ft (9- to 15-m) camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement.
- Some models susceptible to camera motion caused by strong winds or vibration of camera mounting structure.
- Generally cost effective when many detection zones within the camera field of view or specialized data are required.

Sources

- http://www.fhwa.dot.gov/publications/research/operations/its/06108/01.cfm
- Traffic Detector Video Training Course - Part 1-4
  - http://www.youtube.com/watch?v=j3CfU-f0JpI
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