Traffic Sensing Technologies

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Introduction

- Safe and efficient operations of transportation systems rely heavily on applications of advanced technologies.
- Over the last decade, sensor technology has become ubiquitous and has attracted a lot of attention.
- Sensors have been deployed in many areas such as healthcare, agriculture, forest management, and vehicle fleet monitoring.
- Wide applications of communication, sensing, and computing technologies in traffic surveillance, incident detection, emergency response, fleet management, and driving assistance.
- This section describes a few types of traffic sensors that are often employed in ITS and other traffic surveillance and data collection systems.

Introduction

- The development of intelligent transportation systems has had a great influence on many aspects of road transportation systems.

- Traffic measurement technology conducted using various types of detection devices, has influenced the analysis of traffic flow.

- The collection of vehicle information, including the traffic flow rate and the presence, speed, and location of vehicles, is the most basic requirement for an intelligent transportation systems (ITS).

Maximizing the efficiency and capacity of existing transportation networks is vital because of the continued increase in traffic volume and the limited construction of new highway facilities in urban, intercity, and rural areas.

Introduction

- The increase in demand, relative to the limited construction of new roads, has caused recurring congestion throughout the industrialized world, as well as in developing nations.
- An alternative to expensive new highway construction is the implementation of strategies that promote more efficient utilization of current road, rail, air, and water transportation facilities.
- These strategies are found in Intelligent Transportation Systems (ITS) roadway and transit programs that have among their goals reducing travel time, easing delay and congestion, improving safety, and reducing pollutant emissions.
- ITS contains electronic surveillance, communications, and traffic analysis and control technologies.
- ITS brings benefits to transportation system users and managers.
  - Users gain from the information and guidance provided by ITS.
  - Transportation managers and agencies profit from improved ability to monitor, route, and control traffic flows and disseminate information.

Introduction

- Millions of research and operations dollars are budgeted for managing traffic and alleviating congestion and delay on the Nation's existing streets and freeways.
- ITS applications :
  - Advanced Traffic Management Systems,
  - Advanced Traveler Information Systems,
  - Commercial Vehicle Operations,
  - Advanced Vehicle Control Systems,
  - Advanced Public Transit Systems, etc.
- ITS rely on traffic flow sensors to provide vehicle detection, incident detection, automatic traveler surveillance, real-time traffic adaptive signal control, archival data, and data for traveler, commercial, and emergency information services.

The success of these intelligent transportation systems depends to a large extent on the proper design, installation, and maintenance of the sensor component of the overall system.

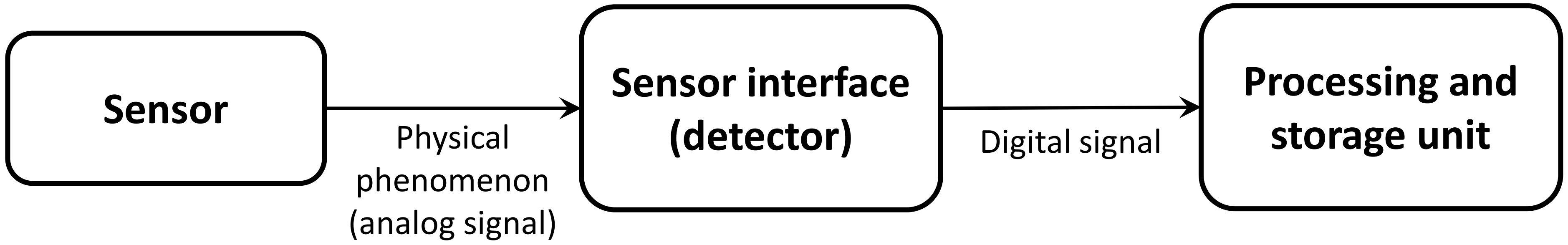
What to measure?

- Collecting high quantity of different types of good quality data improves our understanding of complex traffic and transportation phenomena and provides a good base for making decisions in case of uncertainty.

- Nowadays, technological advances such as
  - increase in computing power,
  - lower energy needs of electronic devices, especially computers,
  - computer networks and distributed computing and storage (the "cloud"),
  - ubiquity of computers, tablets, phones smart, etc. for collecting and disseminating information,
  - proliferation of inexpensive sensors connected to the Internet (“Internet of things”).

  have simplified data collection processes and made traffic and transportation data more accessible.

General data collection system



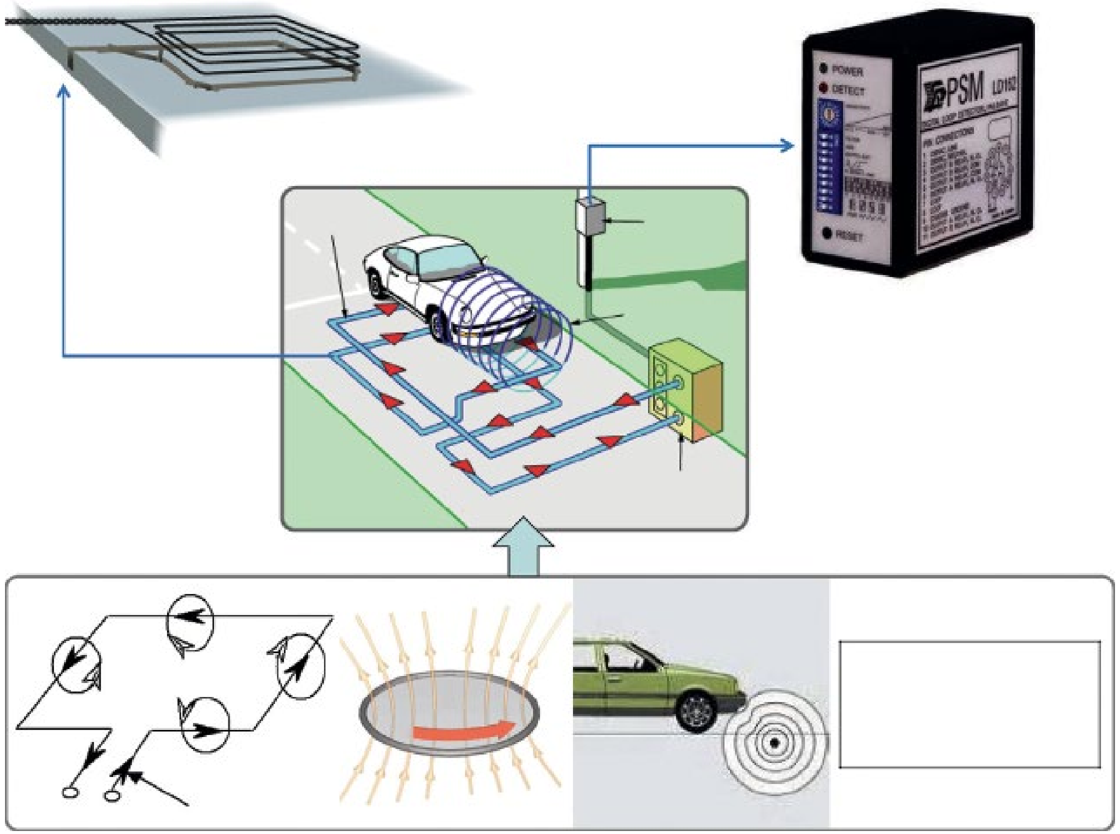
- Sensor: transforms a physical phenomenon into a usable quantity (analog signal), such as an electric voltage or a height of mercury.
- Sensor interface (detector) : transforms the signal analog to digital signal (0/1)
- Processing and storage unit (database) or display

Objectives of data collection

- Understanding transport demand, its evolution;
- Improving transport efficiency;
- Before-after studies;
- Provide information to users;
- Assess potential impacts: pollution (emission, noise), accidents, etc.;
- Detect the presence of users to take actions, e.g. for adaptive traffic light control strategies, access management, access to parking lots, etc.;
- Detect incidents.

Inductive-Loop Detector

- Since its introduction in the early 1960s, the inductive-loop detector has become the most utilized sensor in a traffic management system.
- It mainly consists simply of a coil of wire embedded in the road's pavement
- The detector drives an alternating flow of current through the loop, which produces a magnetic field.
- The detector senses the presence of a conductive metal object by inducing currents in the object, which reduce the loop inductance and changes the frequency.



An inductive-loop detection system

Inductive-Loop Detector

Applications

<u>Traffic actuated signal controllers:</u> These adaptive signals rely on the detector output to decide whether a green indication is granted to the approach that is monitored by the detector.

<u>Red-light-running camera</u>: An intersection with such a system has the detector connected to the signal controller and an overhead camera. As a result, when a vehicle is running a red light, the camera will be triggered, and a picture of the vehicle will be taken as evidence of red-light violation.

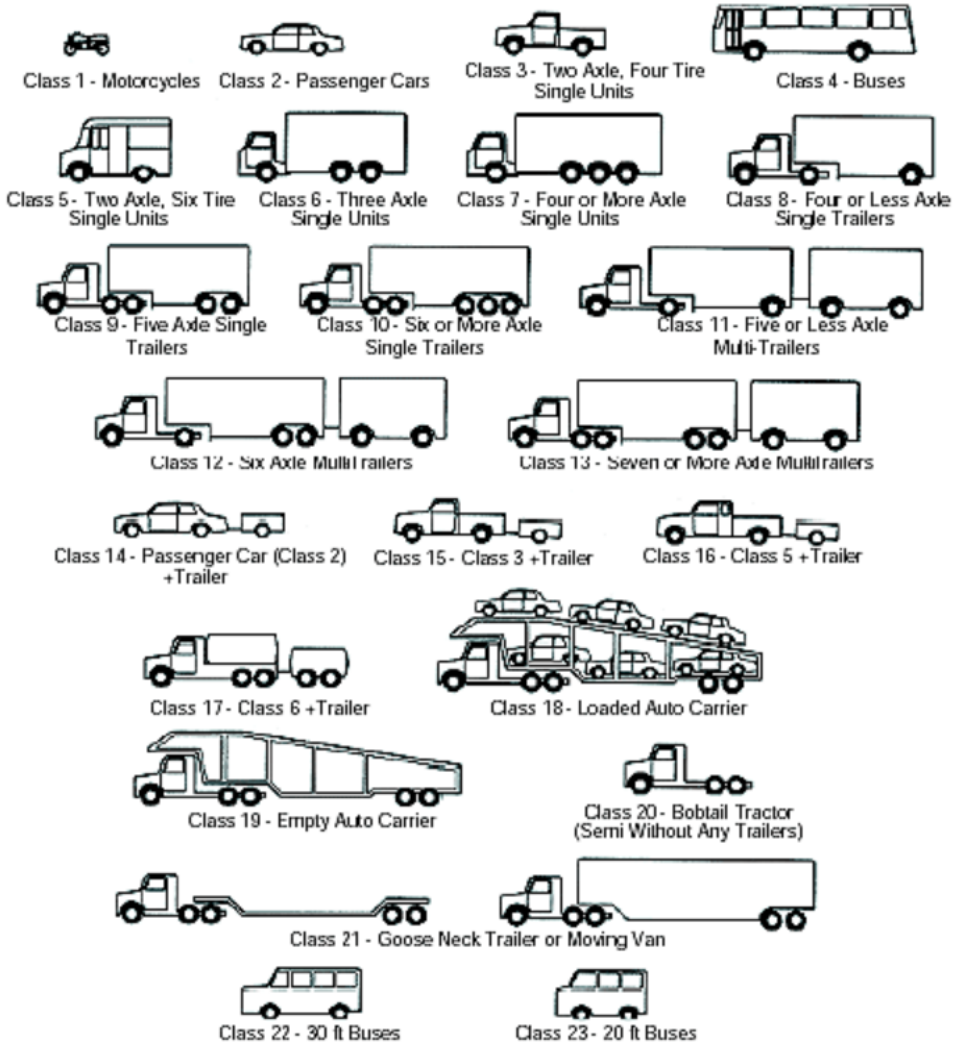
<u>Parking gates and ramp metering measures:</u> When a vehicle exits a gated parking garage, an inductive loop can detect the vehicle in advance so that the gate automatically opens for the vehicle. They are also used at freeway entrances with automatic ramp metering.

<u>Traffic counting programs:</u> Inductive loop detectors are often used for highway segments monitored by traffic counting programs.

Inductive-Loop Detector

Data Collected

- Time-stamped traffic counts
- Vehicle classification: Use of artificial neural network software to classify the traffic stream into the 23 categories
- Instantaneous speed of the vehicle
- Headway: Temporal separation between two consecutive vehicles
- On time: Time during which the detector outputs an "on" state



Classes available from inductive-loop classifying sensor

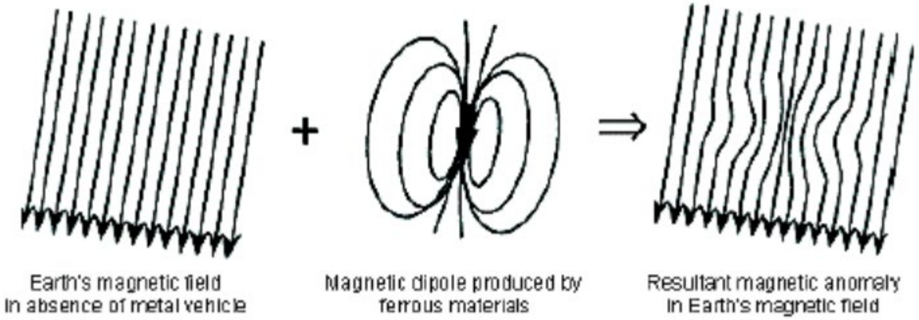
Inductive-Loop Detector

Advantages	Disadvantages
➢ Can monitor traffic on a regular basis (i.e., day-round and year-round) . ➢ 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, headway, and gap). ➢ Insensitive to inclement weather such as rain, fog, and snow and lighting conditions. ➢ Provides best accuracy for count data as compared with other commonly used techniques. ➢ Common standard for obtaining accurate occupancy measurements. ➢ Can provide classification data.	➢ Installation and maintenance is intrusive to traffic and require lane closure. ➢ Installation requires pavement cut. ➢ Improper installation decreases pavement life. ➢ Wire loops are subject to stresses of traffic and temperature and often break as a result of damage from vehicles that pass over them. ➢ Setup and maintenance costs are high. ➢ Multiple loops usually required to monitor a location. ➢ Detection accuracy may decrease when the detection of a large variety of vehicle classes is required.

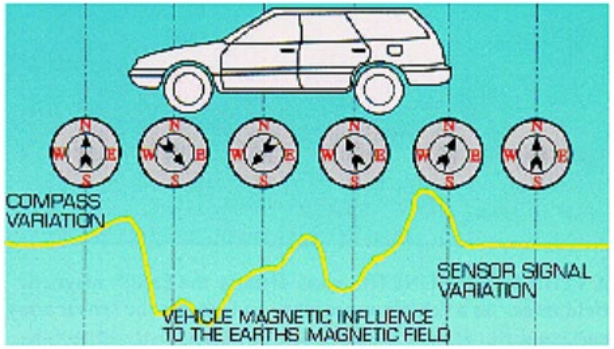
Magnetometer

- Magnetic sensors are devices that detect the presence of a ferrous metal object through the perturbation they cause in the Earth's magnetic field

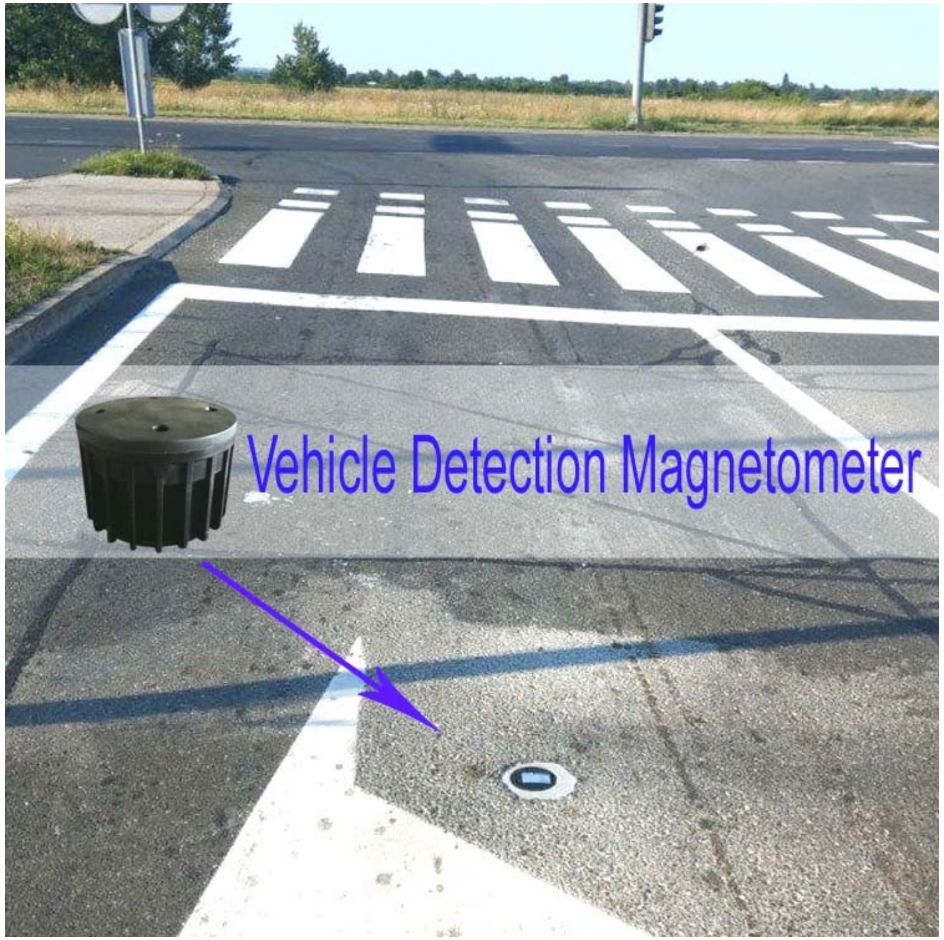
Magnetic anomaly in the Earth's magnetic field induced a ferrous metal vehicle



(a) Magnetic anomaly induced in the Earth's magnetic field by a magnetic dipole.



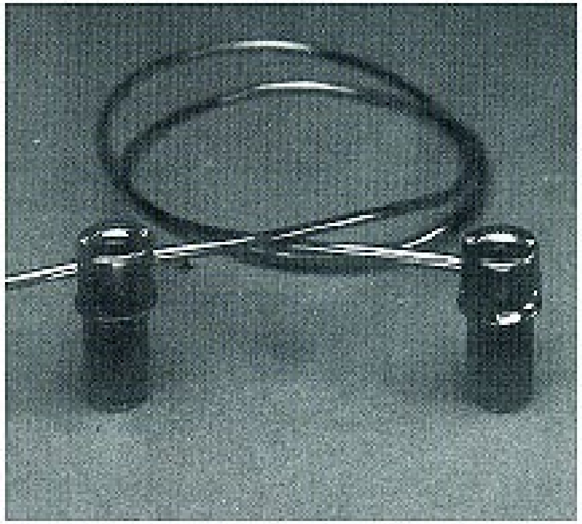
(b) Perturbation of Earth's magnetic field by a ferrous metal vehicle
(Source: Nu-Metrics, Vanderbilt, PA).

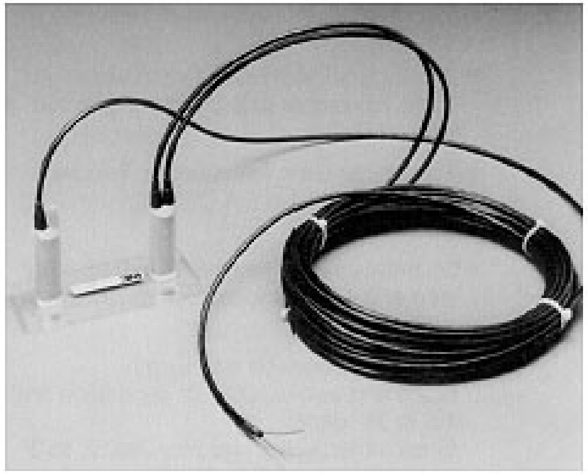


Vehicle detection magnetometer

Magnetometer

- Another form of magnetic detectors is called microloop probes.
- It has been primarily designed to be used for the vehicle detection where existing conditions prevent the installation of Inductive-Loop Detector
- The microloop probe detects a change of inductance in the vertical component of the earth's magnetic field caused by the presence or passage of a large metallic body such as a vehicle.
- Often two or more microloop probes are connected in series to detect a range of vehicle sizes and obtain required lane coverage.





Microloop probes

Magnetometer

Data Collected

- Time-stamped traffic counts.
- Presence of vehicle.
- They can provide occupancy, and speed data based on the detection zone size and an assumed vehicle length.

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

Pneumatic Tubes

- Pneumatic tubes are portable traffic data collection devices and are ideal for short-term traffic engineering studies.
- A rubber tube with a diameter of about 1 cm is placed on the surface of a road. When a vehicle passes, the wheel presses the tube and the air inside the tube is pushed away. One end of the tube is connected to a box that contains a membrane and an electrical switch. The air pressure moves the membrane and engages the switch.
- This air pulse is sensed by the unit and is recorded or processed to create volume, speed, or axle classification data.
- While one road tube is used to collect volume, two road tubes can be used to collect speed and class data.

Pneumatic tubes

Pneumatic Tubes

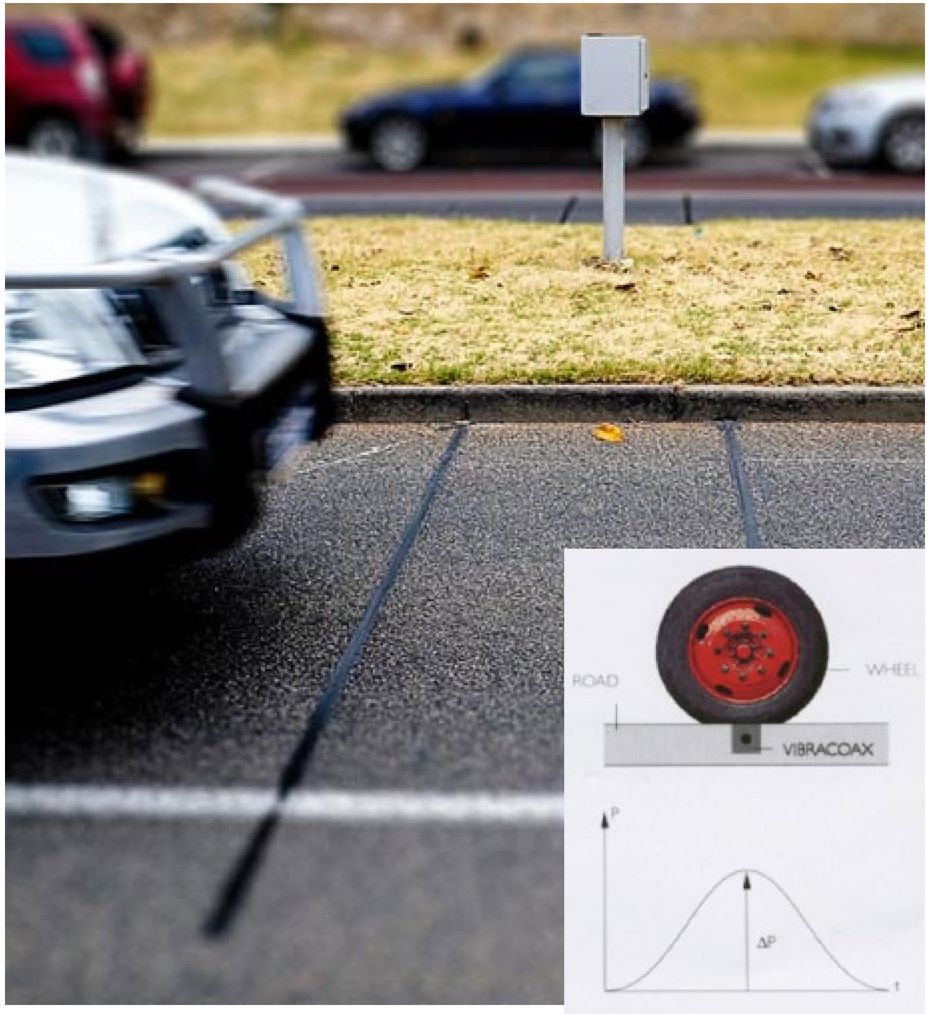
Data Collected

- time-stamped axle counts, from which vehicle classification, direction of flow, traffic counts, flow, vehicle instantaneous speed, headway, and occupancy time can be inferred.

Advantages	Disadvantages
➢ Suitable for temporary data collection ➢ Easy installation ➢ Suitable for low to medium traffic volume ➢ Widely used and inexpensive ➢ Very well-known technique	➢ Limited lane coverage ➢ Not suitable for use on a regular basis ➢ They are subject to stresses of traffic and temperature and often break as a result of damage from vehicles that pass over them. ➢ The system can be damaged by roadway maintenance, street sweepers and snowplows. ➢ It may be intrusive to traffic and nearby properties.

Piezoelectric Sensor

- Piezoelectric sensors collect data by converting mechanical energy into electrical energy.
- When used to count vehicles, the sensor is mounted in a groove cut into road's surface.
- When a car drives over the piezoelectric sensor, it squeezes it and causes an electric potential - a voltage signal. The size of the signal is proportional to the degree of deformation. When the car moves off, the voltage reverses.
- This change in voltage can be used to detect and count vehicles



Piezoelectric Sensor

Piezoelectric Sensor

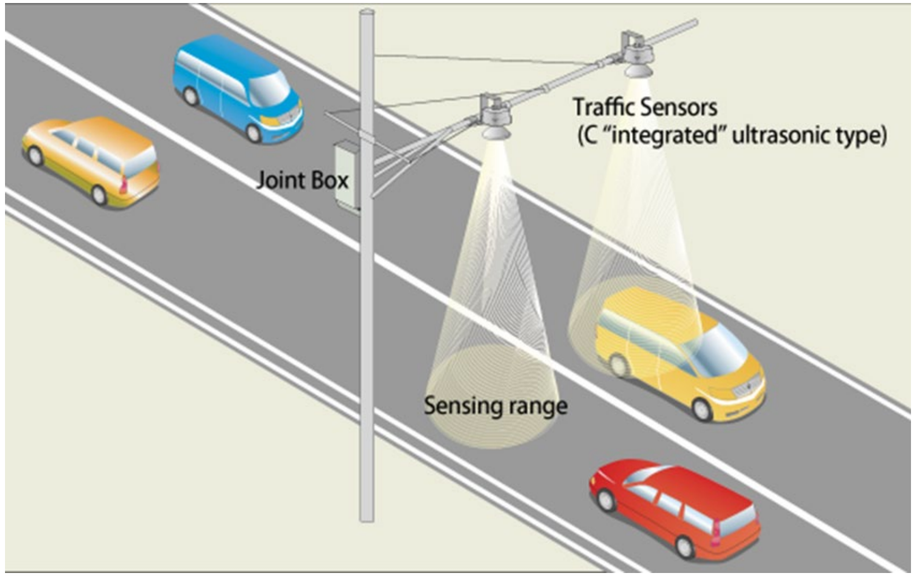
Data Collected

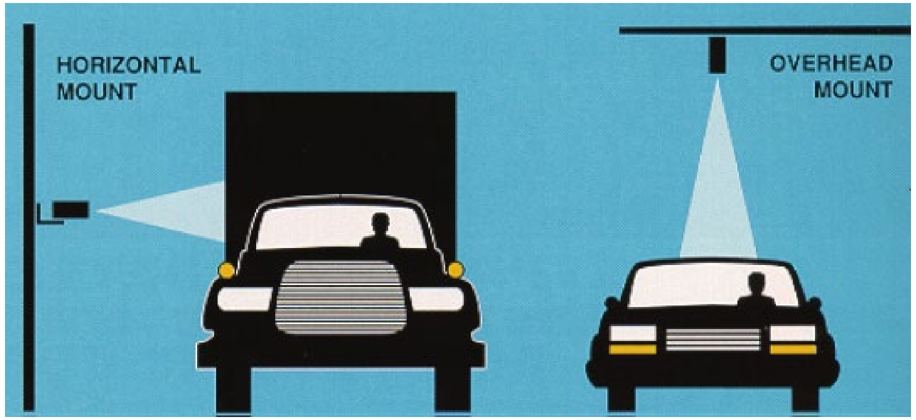
- Very accurate at measuring axles strikes.
- They are used in application for counting, classification (speed and axle), weigh-in-motion, tolling and even law enforcement installations such as speed and red light running.

Advantages	Disadvantages
➢ Can be used for weigh-in-motion applications. ➢ Very accurate at measuring axles strikes.	➢ Installation and maintenance is intrusive to traffic and require lane closure. ➢ Installation requires pavement cut. ➢ Improper installation decreases pavement life. ➢ They are subject to stresses of traffic and temperature and may break as a result of damage. ➢ Needs calibration for better performance. ➢ Influence of the temperature on the sensitivity of the piezoelectric load sensors

Ultrasonic Sensor

- "Ultrasonic" refers to high-frequency sound waves that are beyond a human's audible range.
- Waves with frequencies between 25 and 50 kHz are commonly used.
- The sensor shoot a beam of sound, like radar, which travels until it hits an object.
- The sound wave then bounces back and returns to the sensor.
- The sensor then measures the time it takes the sound wave to travel.
- Knowing the speed of sound, the sensor outputs the distance between the sensor and the object.
- Typically, an ultrasonic sensor transmits a sound pulse from above the road and measures the reflected pulses from the vehicle or ground.
- The performance of ultrasonic sensors is much better than that of other types of pulse devices.

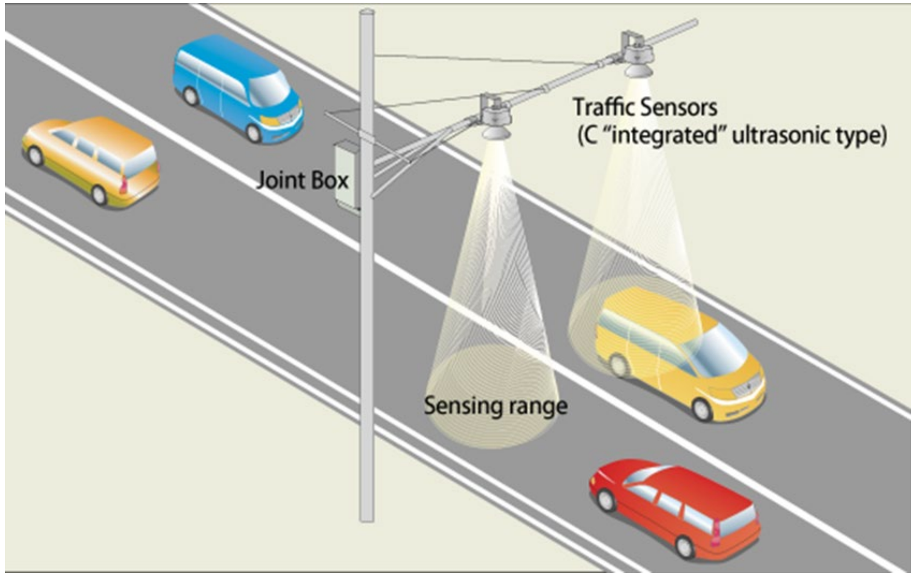


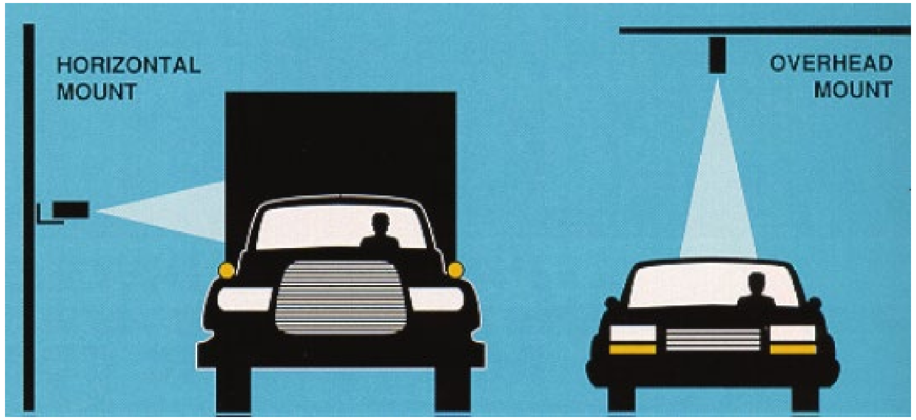


Ultrasonic sensors

Ultrasonic Sensor

- Once the default distance from the detector to the ground is set, if a vehicle passes through the detection range of the ultrasonic sensor, the distance value changes depending on the vehicle's size, and the detection system detects the presence of the vehicle based on the distance data received.
- Most ultrasonic sensors detect vehicles by measuring from top to bottom or from side to side.
- However, these approaches require that a detector be installed for each lane because each detector measures only one lane on a road.
- Furthermore, ultrasonic sensors require considerable infrastructure on a road.
- The vehicle detection accuracy achieved using this method is approximately 99.5% for each ultrasonic sensor installed on each lane.





Ultrasonic sensors

Ultrasonic Sensor

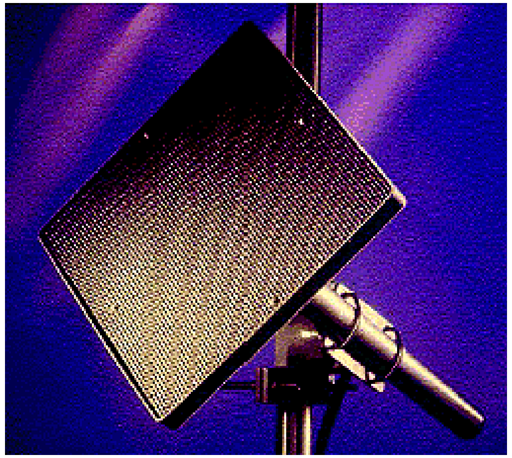
Data Collected

- ➢ The sensor collects the time of sound wave travel, and then converts it to distance.
- ➢ Time-stamped vehicle counts, presence of vehicle, occupation

Advantages	Disadvantages
➢ Affordable and inexpensive. ➢ Involves relatively simple hardware. ➢ Multiple lane operation available ➢ Capable of over height vehicle detection. ➢ Large Japanese experience base.	➢ Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation function is built into some models. ➢ the pulse frequency may affect the quality of occupancy measurement on freeways with vehicles traveling at moderate to high speeds. ➢ Accuracy depends on the surface of the objects. Sound waves may bounce off various surfaces differently, which affects readings on the sensor.

Passive Acoustic Sensor

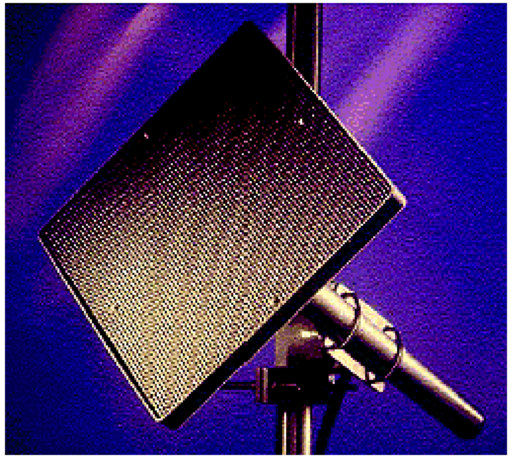
- Acoustic sensors measure vehicle passage, presence, and speed by detecting acoustic energy or audible sounds produced by vehicular traffic from a variety of sources within each vehicle and from the interaction of vehicle's tires with the road.
- When a vehicle passes through the detection zone, an increase in sound energy is recognized by the signal processing algorithm and a vehicle presence signal is generated.
- When the vehicle leaves the detection zone, the sound energy level drops below the detection threshold, and the vehicle presence signal is terminated.
- Sounds from locations outside the detection zone are attenuated.
- Single lane and multiple lane models of acoustic sensors exist.



Passive acoustic sensor

Passive Acoustic Sensor

- The system is built out of an array of sound sensors.
- The difference in the arrival time of the sound between different sensors is translated into vehicle speed.
- It is recommended for data collection applications on bridges and other roads where nonintrusive sensors are required.
- Preferable to use in fluid traffic because congestion produces too much noise pollution and prevents a precise detection of vehicles.
- The sensor is not recommended where a mix of stop-and-go and free-flow traffic occurs, such as on a freeway with the potential for congestion, because the vehicle detection algorithm cannot switch between these two flow conditions fast enough to detect the onset of the change in flow.



Passive acoustic sensor

Passive Acoustic Sensor

Data Collected

- Volume, lane occupancy, vehicle speed, and average speed for each monitored lane
- Time-stamped vehicle counts, Presence of vehicle, Occupation

Advantages	Disadvantages
➢ Passive detection. ➢ Insensitive to precipitation. ➢ Multiple lane operation available in some models.	➢ Cold temperatures may affect vehicle count accuracy. ➢ Mix of free-flow and slow-moving stop-and-go pattern affect the precision

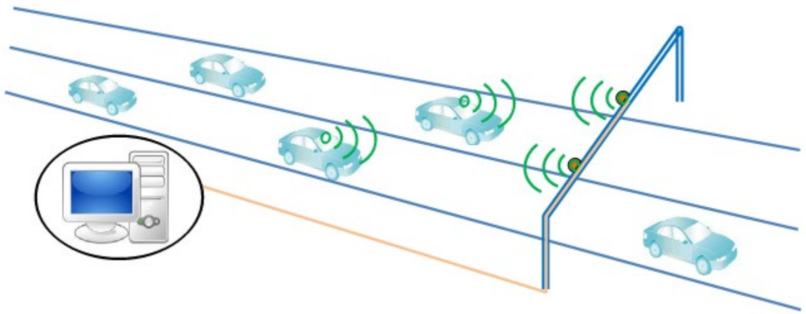
Radio-Frequency IDentification Technology

- Radio-Frequency IDentification (RFID) is the core technology of many traffic sensors known as transponders (e.g., E-ZPass tags), and is used for automatic vehicle identification.

- It uses radio waves to exchange data between a reader and an electronic tag attached to an object for the purpose of identification and tracking.

- When a vehicle comes to the toll booth, the tag reader detects the transponder and records its unique ID, the time instant, and other account trelated information such as balance and toll paid.

- System which consists of (1) a transponder on the vehicle, (2) a tag reader antenna at each plaza toll lane, (3) antenna, and (4) a central host computer system

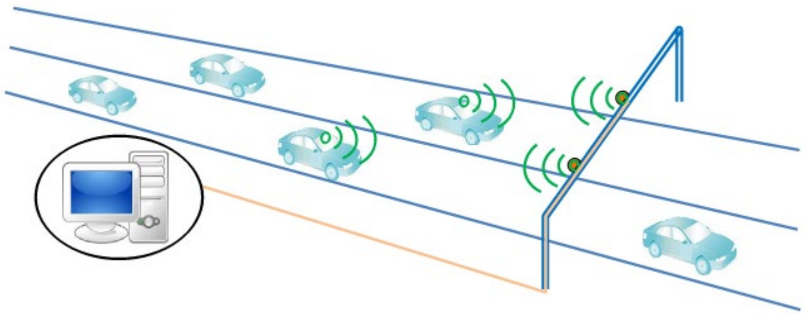


Electronic toll collection system

Radio-Frequency IDentification Technology

- In most applications, the chip is used to store information about the object, product or shipment that the company needs to follow.

- RFID is similar to bar-coding, as they both use labels and scanners to read the labels and a back-end software to store the data, but the RFID system does not require a clear line of sight and multiple parallel reads are possible.



Electronic toll collection system

Radio-Frequency IDentification Technology

Data Collected

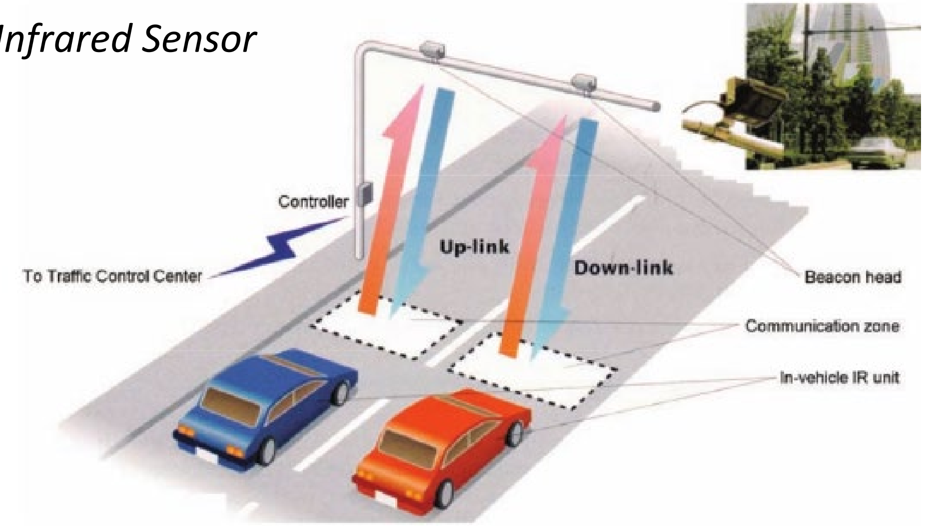
- RFID technology is able to record the IDs of equipped vehicles and timestamp the arrival of these vehicles.
- Further applications become available if the reader reads the data stored in the tags. Various kinds of vehicle-relevant information, such as vehicle type, engine size, fuel type, curb weight, total emission, special/dangerous cargo etc. can be written in the tags.
- Using these data more accurate traffic statistics can be derived, e.g. recording the vehicle categories the traffic flow classification can be solved.
- Based on similar method the emergency vehicles can be detected on a road segment and alert can be generated to the vehicles in the neighborhood.

Advantages	Disadvantages
➢ RFID technology is inexpensive. ➢ It does not interrupt traffic.	➢ RFID only detects equipped vehicles. ➢ Metals and liquids effectively block the radio waves.

Infrared Sensor

- ➢ Passive: detects the heat emitted
- ➢ Active: consists of a transmitter (LED) and a receiver

Infrared Sensor



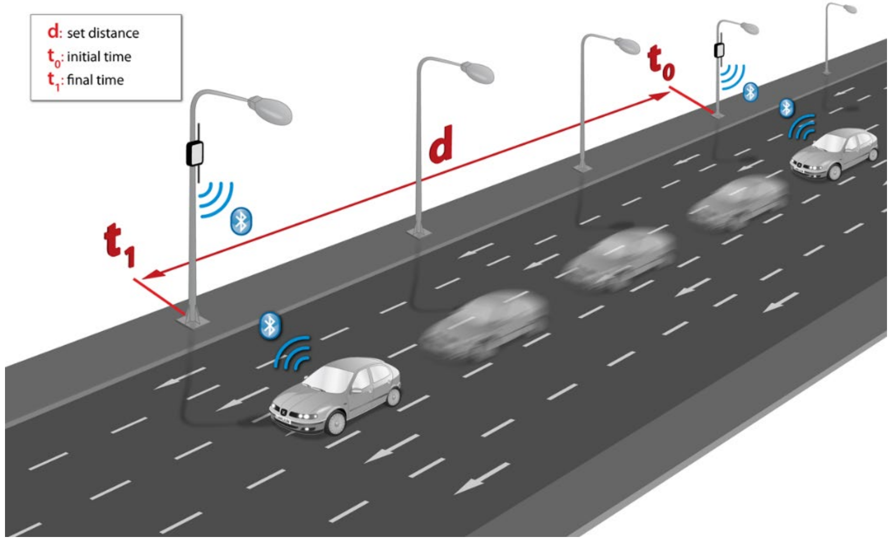
Advantages	Disadvantages
➢ Emits multiple beams for a precise measurement of vehicle position, speed and class. ➢ Possibility of multiple lane operation. ➢ Specific applications for presence detection in parking lots and for counting pedestrians.	➢ Performance may be affected by fog when visibility is less than 6 m or there is blowing snow. ➢ Installation and maintenance, including regular lens cleaning, requires lane closure and traffic interruption. ➢ The sensitivity of passive sensors may be reduced by rain, snow or heavy fog.

Bluetooth Sensor

- Bluetooth is a wireless technology standard that allows electronic devices to communicate directly with one another over relatively short distances using radio frequency communication.

- The potential of Bluetooth in traffic monitoring began to appear in the academic literature near 2010.

- Very rapid evolution in the past 10 years and will undoubtedly continue to evolve rapidly.



Bluetooth Sensor

Bluetooth Sensor

- Bluetooth detection systems work by actively searching for in-range Bluetooth devices and capturing the unique media access control (MAC) address of each device.
- For a Bluetooth detection system to read the MAC address of a device, the device must be turned on and be in "discoverable" mode.
- Because each device has a unique and permanent MAC address, Bluetooth detection systems can determine vehicle travel times and speeds by calculating the time it takes for vehicles containing Bluetooth devices to travel between two or more Bluetooth sensors that are a known distance apart.
- Bluetooth can be used to measure travel times of those vehicles that have Bluetooth devices. This may only be a small fraction of all vehicles plying any particular route. Hence, it is important to understand the percentage of vehicles from which data can be collected using this method, namely penetration rate analysis.

Bluetooth Sensor

Bluetooth Sensor

Data Collected

- ➢ Volume
- ➢ Means of forecasting travel times
- ➢ Origin-destination data for route choice studies

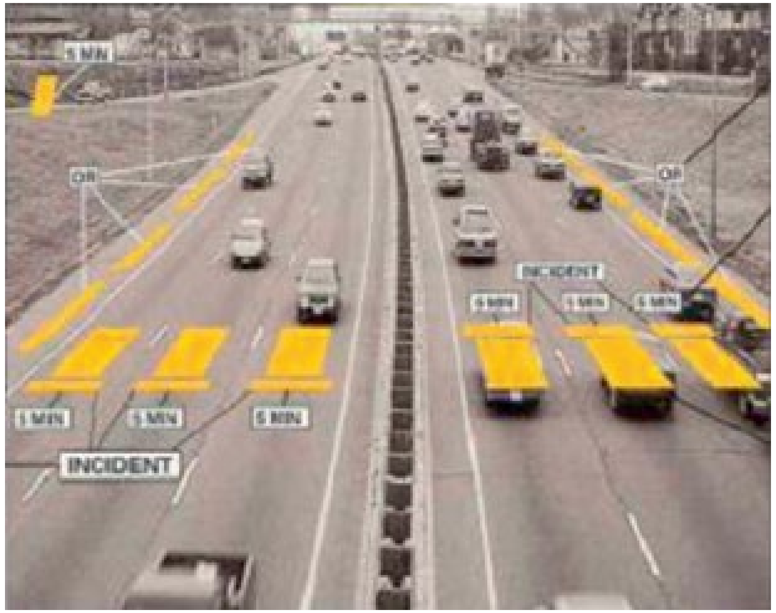
Advantages	Disadvantages
➢ Less expensive than many other options ➢ Bluetooth data collection does allow for the flexibility of one-time use or continuous data collection at established sites at a lower cost than videotaping plates	➢ Some potential privacy concerns ➢ Detection technology relies on drivers' use of Bluetooth-enabled devices

Video Image Processing System

- Video cameras were introduced to traffic management for roadway surveillance based on their ability to transmit closed-circuit television imagery to a human operator for interpretation and traffic surveillance.

- Present-day traffic mangers utilize video image processing to automatically analyze the scene of interest and extract information for traffic surveillance and management.

- Video image processing system comprises:
  - An image capturing system
    e.g., a video camera mounted above the roadway that captures real-time images/video streams of the traffic under surveillance,
  - A telecommunication system
    e.g., a modem and a telephone line that transmit images/video streams to the image processing system
  - An image processing system
    A computer that processes frames of a video clip to extract traffic data.



Video image processing system

Video Image Processing System

- Development since the 1970s of computer vision methods:
  - Difficulty operating in real time
  - Treatment of small areas

- Recent Progress: The computing power of computers are improved, and new methods have been developed.

- Gap between the state of the art in computer vision and practical applications in transport

Video image processing system

Video Image Processing System

Data Collected

- Can replace several in-ground inductive loops, provide detection of vehicles across several lanes, and perhaps lower maintenance costs.
    - Time-stamped traffic counts
    - License plate recognition
    - Headway
    - Vehicle classification
    - Vehicle presence
    - Lane occupancy
    - Speed
    - Trajectory and turning movements
    - Accidents
    - Lane changes
    - Vehicle density
    - Link travel time, etc.

Video Image Processing System

Advantages	Disadvantages
➢ Monitors multiple lanes detection zones. ➢ 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. ➢ Can collect traffic data on a regular basis. ➢ Its overhead installation makes this technology nonintrusive to traffic flow. ➢ Expensive but generally cost effective when many detection zones within the camera field of view or specialized data are required. ➢ Capacity of subsequent data verification	➢ Installation and maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway. ➢ Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; day-to-night transition; vehicle/road contrast. ➢ Reliable nighttime signal actuation requires street lighting. ➢ Requires a sufficient installation height for optimum presence detection and speed measurement. ➢ Susceptible to camera motion caused by strong winds or vibrations.

Video Image Processing System

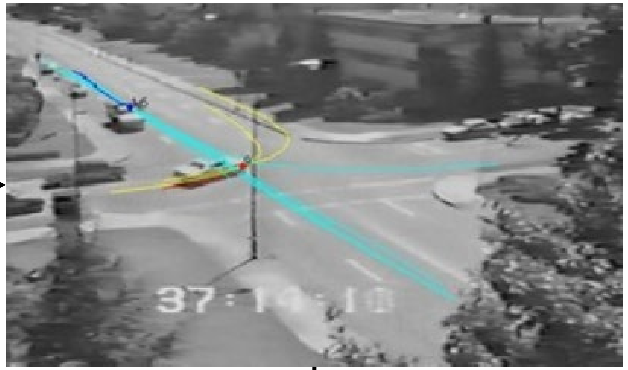
Image sequence

+

Camera calibration

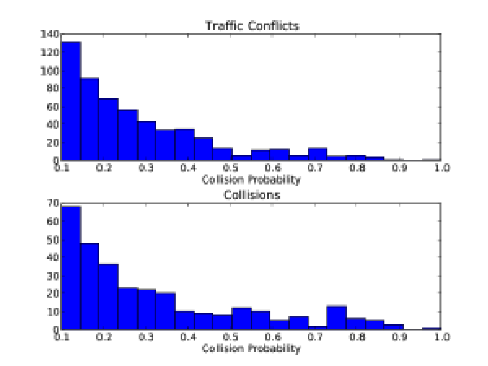
+

Images labeled by user type



Applications

Distribution of movements, volumes, identification of origins-destinations, user behavior, etc.



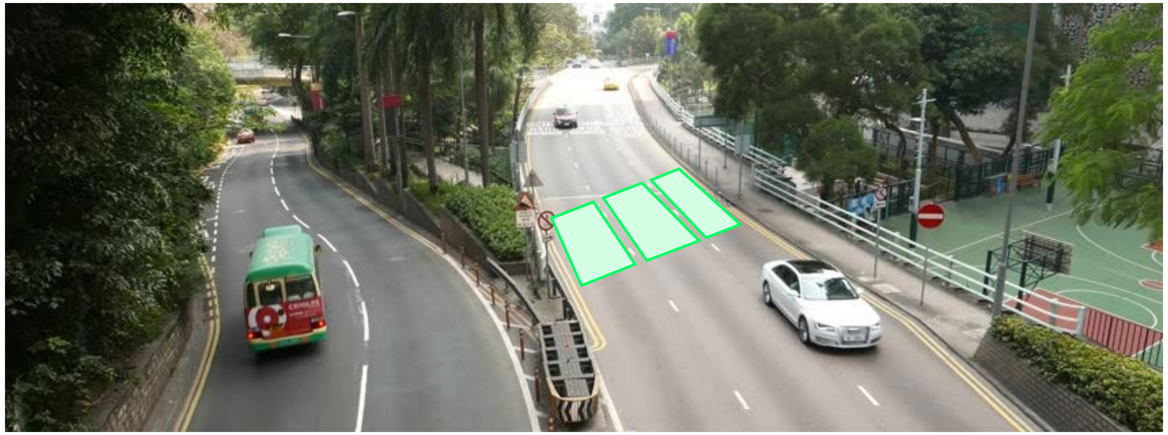
Traffic conflicts, severity and exposure measures, interacting behavior, etc.

Video Image Processing System

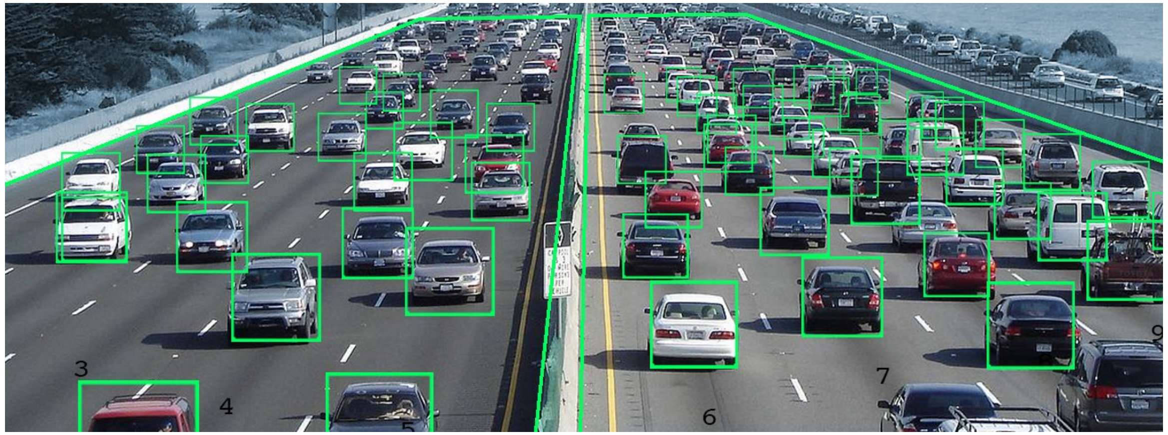
Principles of video analysis

- Images are pixel arrays
- 2 methods
    1. Processing of limited areas of the image (detection zones): definition of lines and regions of interest on the pavement image, which emulate "virtual sensors", such as inductive loop detectors.

    2. Processing of the entire image: detection of all objects of interest and their trajectories (needs additional information to interpret movements)



Processing of the detection zones

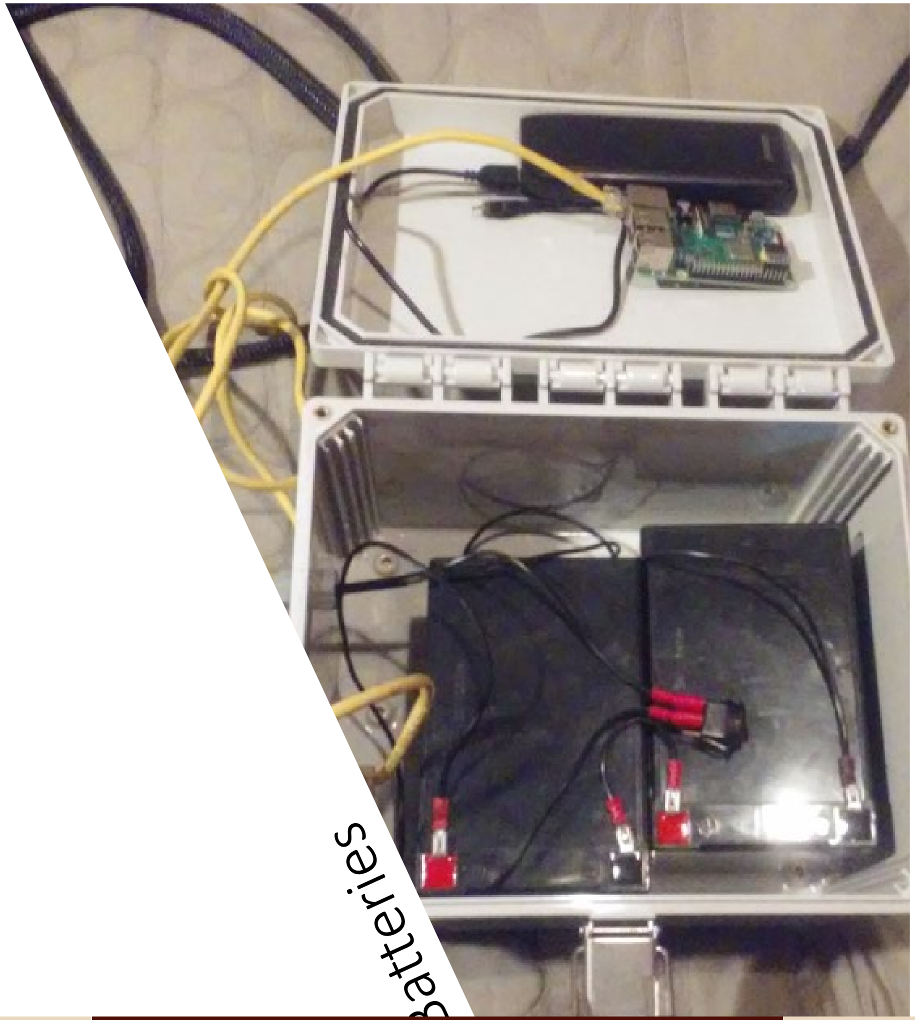


Processing of the entire image

Video Image Processing System

- Application example

Installations of two cameras

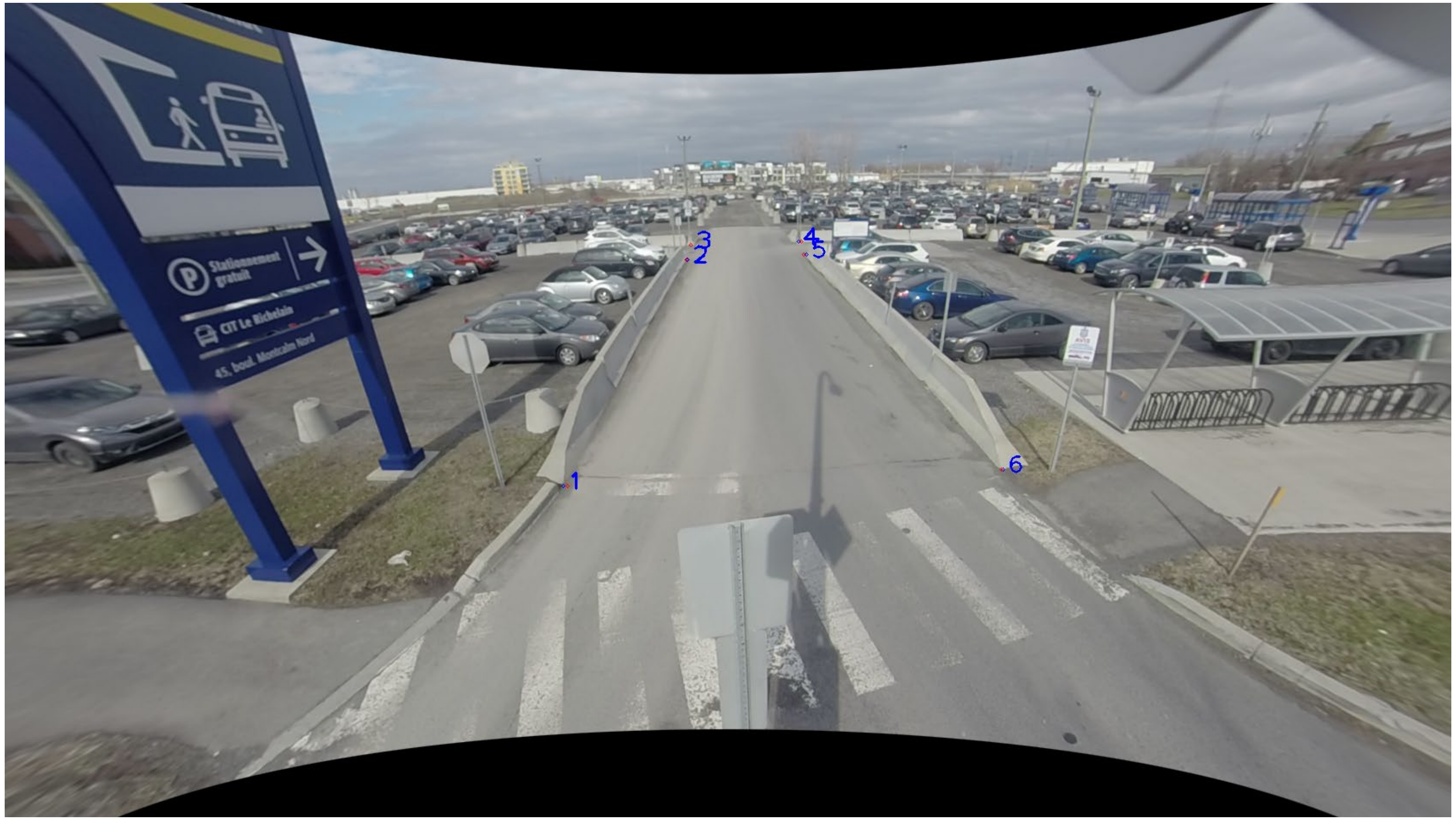


Batteries

Video Image Processing System

Video Analysis

1. Image distortion is corrected



Video Image Processing System

Video Analysis

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2. The relationship between the positions in the image and the positions of vehicles at ground level in the real world is determined using reference points.

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Video Analysis

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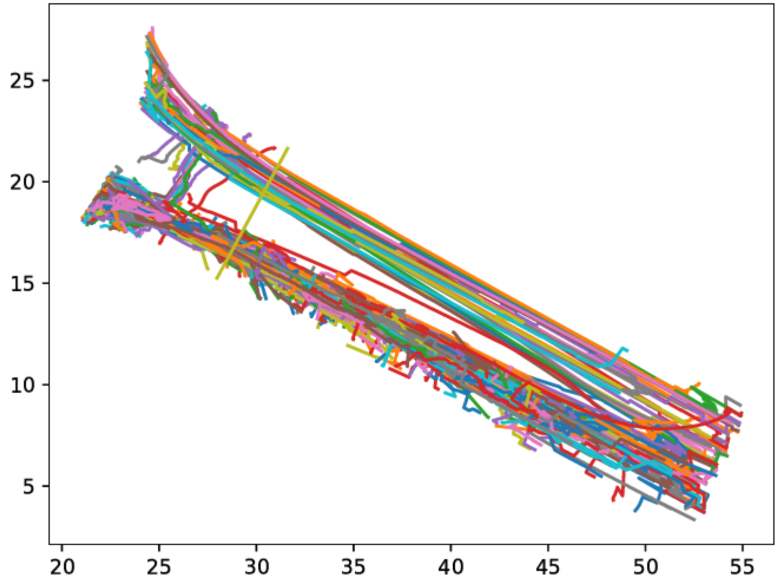
3. Vehicle detection and tracking: "Traffic Intelligence“.
4. Calculation of the moments of entry or exit of vehicles.

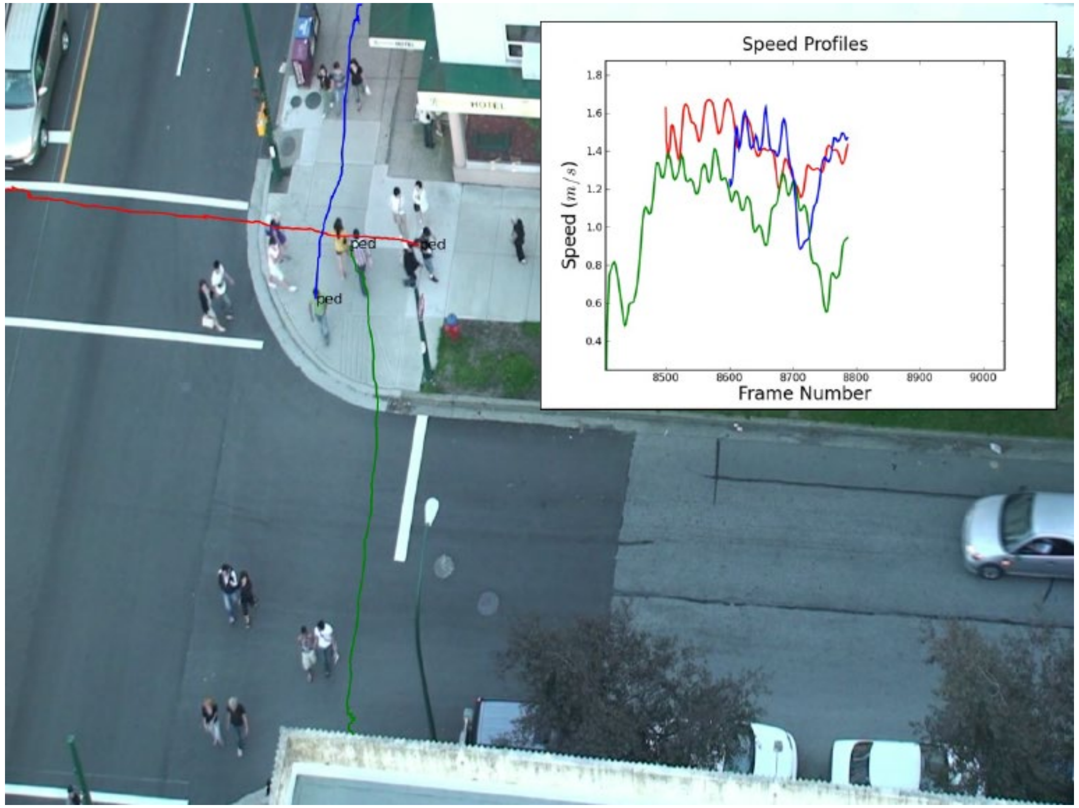


Video Image Processing System

Tracking examples

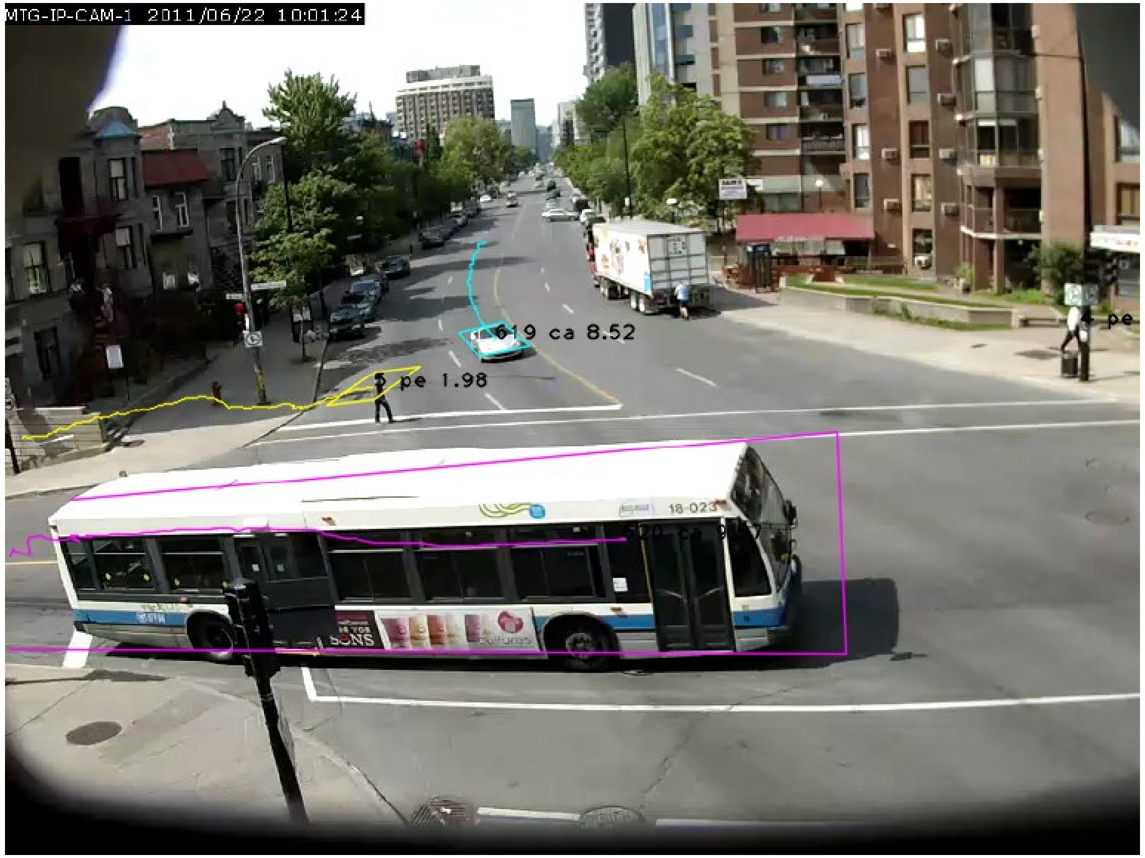
Video Image Processing System

Tracking examples



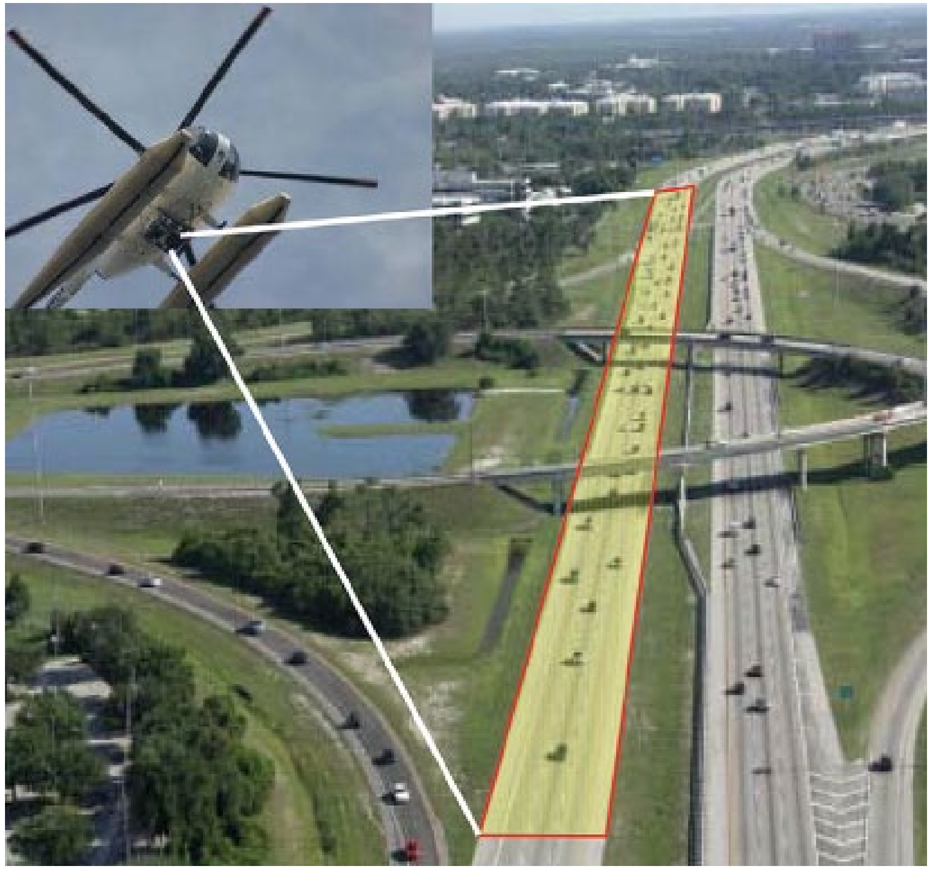
Video Image Processing System

Tracking examples



Aerial/Satellite Imaging

- Transportation projects have benefitted from aerial photography in many ways:
  - Route location, topographic surveys, digital terrain modeling and contour generation.
- Aerial imaging usually requires the use of either manned or unmanned helicopters in the sky to monitor and observe traffic on the ground for data collection purposes.
- The captured aerial photos contain snapshots of traffic on roadways, from which spatial traffic data such as spacing (i.e., spatial separation between two consecutive vehicles), vehicle counts over a segment of roadway, and traffic density can be obtained.
- In addition, analysis of consecutive aerial photos may yield information about vehicle speeds and mean traffic speed.



Unmanned helicopter as a traffic sensor

Aerial/Satellite Imaging

Data Collected

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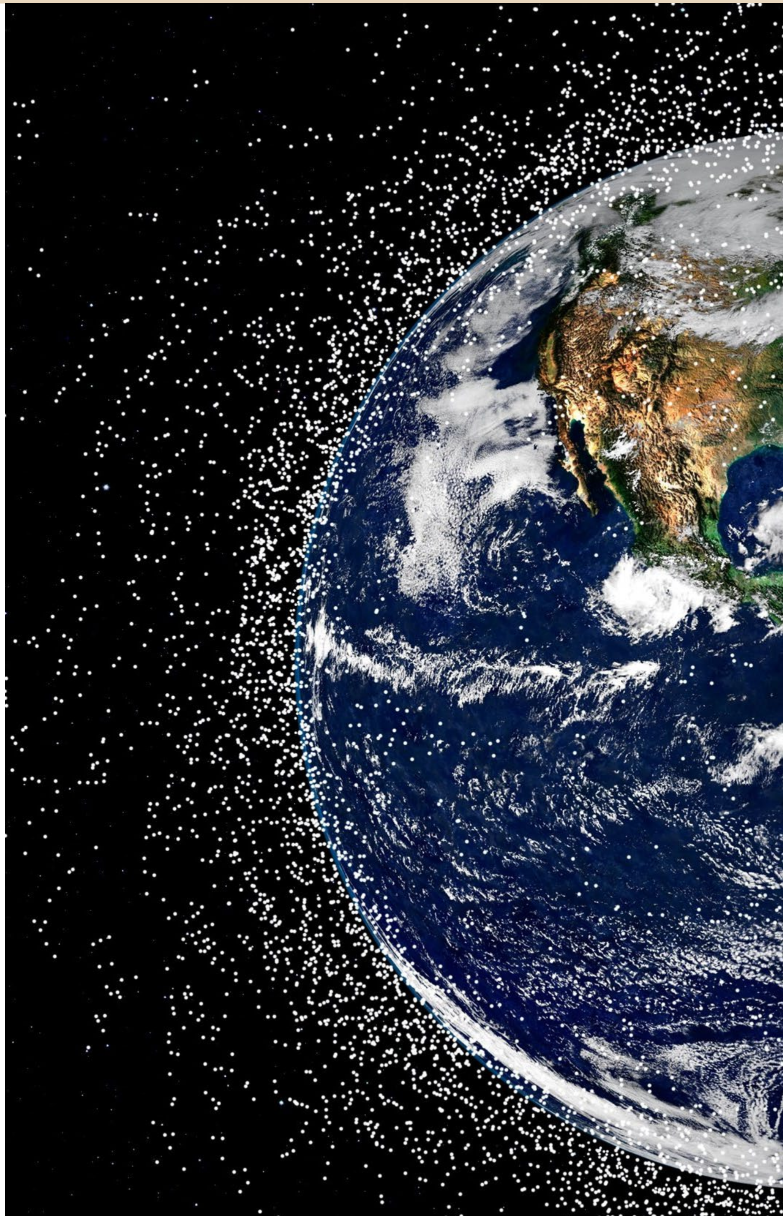
Advantages	Disadvantages
➢ Traffic surveillance can be done at high accuracy. ➢ There is no need for hardware installation on or near roadways—that is, it is a nonintrusive and non-interruptive technology. ➢ More area can be covered, and it can provide a bird’s eye view of system-wide traffic conditions.	➢ Helicopters are expensive and may require pilots to operate them. ➢ It is time consuming and resource-consuming to collect traffic data. ➢ Limited period of data collection. ➢ Analysis of aerial photos is complicated. ➢ Weather conditions reducing the visibility affect the results.

Global Positioning System Receiver

- The global positioning system (GPS) is widely used in automotive navigation and traffic engineering studies such as traffic time studies.
- Many cell phones are equipped with positioning functions, and hence they are considered in the same category as the GPS.
- If a vehicle carries a GPS receiver on board and it is set up to log GPS signals, it is possible to record the positions of the vehicle and the time when a location is passed as the vehicle moves along the road.
- The vehicle would leave a trace of spatial-temporal points in the time-space diagram
- A curve that connects these points depicts the vehicle's spatial-temporal trajectory.
- From this trajectory, the motion of this vehicle can be understood.

Time-space diagram of vehicle trajectories



English: https://youtu.be/FU_pY2sTwTA
French: https://youtu.be/V51dGqHw_24

Global Positioning System Receiver

Data Collected

- Vehicle-specific motion data such as instantaneous speed, average running speed, distance traveled, and travel time are collected.

Advantages	Disadvantages
➢ Affordable ➢ Easy installation ➢ Not sensitive to weather and lighting conditions ➢ Widely used ➢ More efficient routing	➢ GPS receivers provide only vehicle-specific data. To have reliable traffic information, data needs to be collected from a fleet of vehicle. ➢ GPS signals can be obstructed by tall buildings and trees.

Global Positioning System Receiver

Data Collected

- The German radar satellite TerraSAR-X launched in 2007 allows vehicle tracking

- Advantage: Insensitive to weather conditions

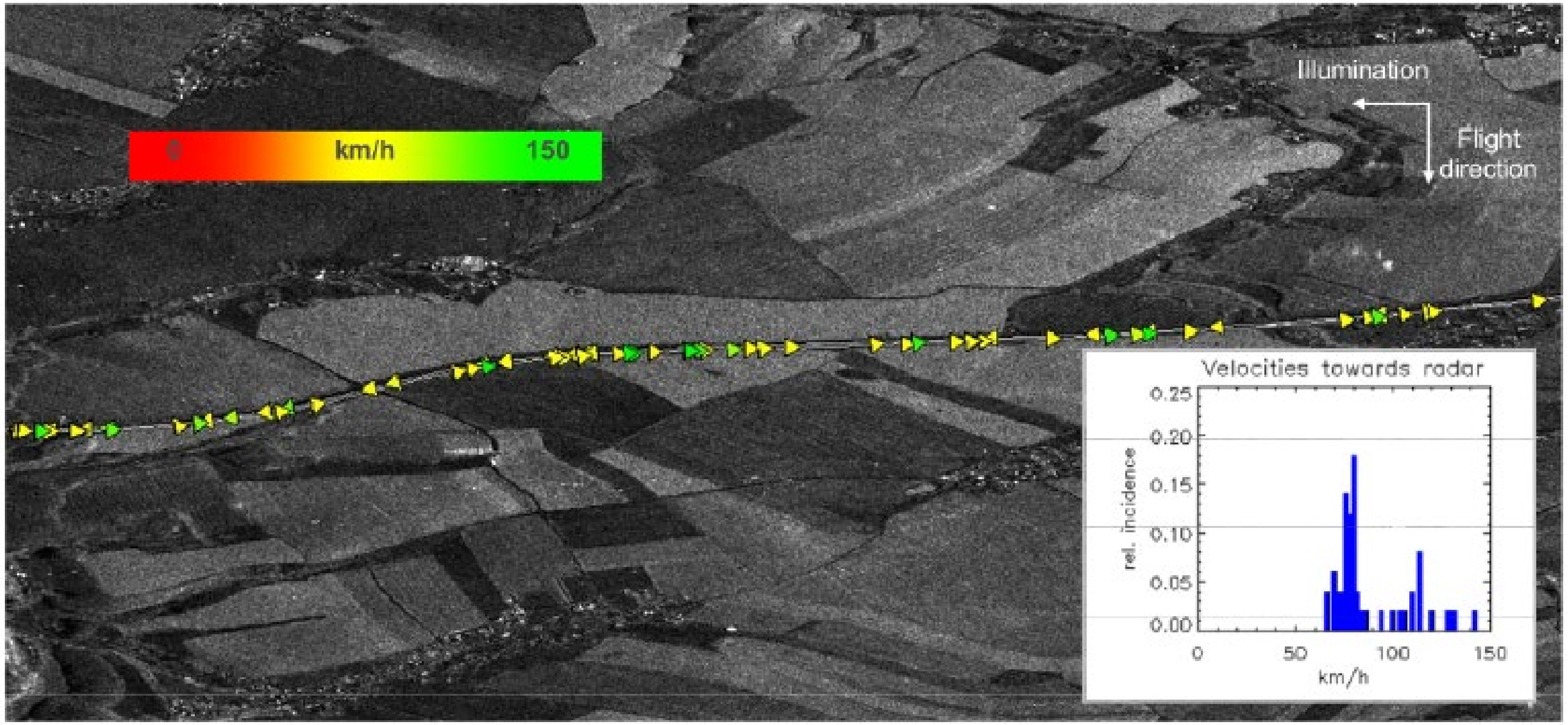


Figure 2 TerraSAR-X Traffic Measurement on the A4 Motorway West of Dresden, Germany

Traffic Sensor Classification

According to its location and placement, the sensor can be:

- ***Mobile sensor*** if it resides in a vehicle and collects data only specific to that vehicle. GPS receivers and cell phones are examples of mobile sensors.

- ***Point sensor*** if it is mounted at a fixed location along the roadway and observes traffic only at this particular location. Inductive-loop detectors, pneumatic tubes, and RFID technology are examples of point sensors.

- ***Space sensor*** if it can take a snapshot of the traffic on a stretch of the road. Helicopters and satellites are examples of space sensors.

Traffic Sensor Classification

According to the extent to which a sensor intrudes into the roadway, the sensor can be:

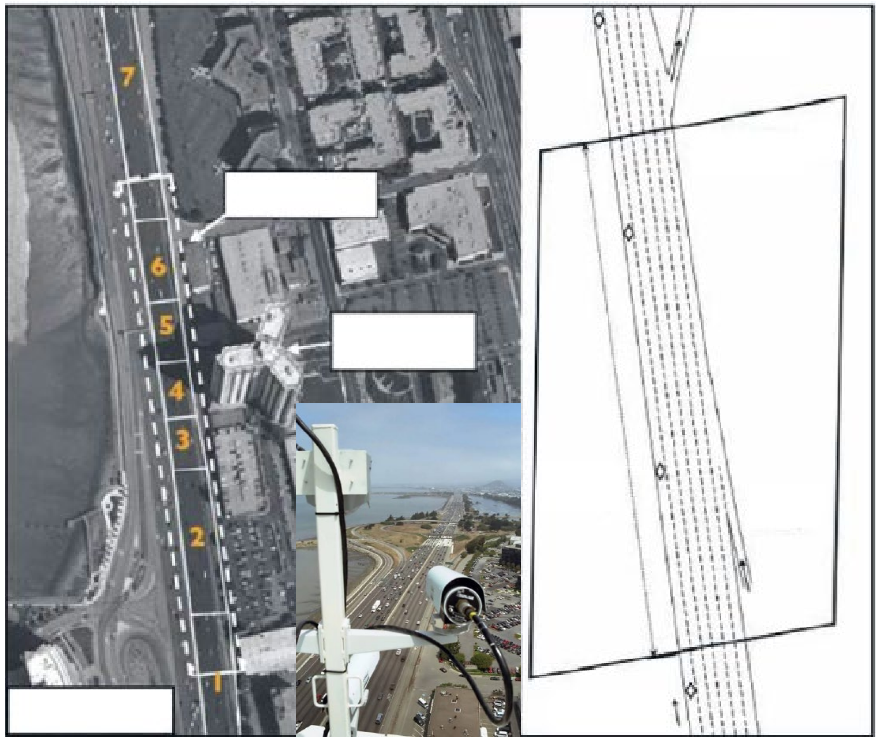
- ***Intrusive*** if installation of the sensing system requires pavement work and interruption of traffic. Inductive-loop detectors and pneumatic tubes are examples of intrusive sensors.

- ***Nonintrusive*** if installation of the sensing system does not require pavement work and interruption of traffic. Video and RFID technology are examples of nonintrusive sensors.

- ***Off-roadway*** if the sensor is not fixed to a location on the roadway—that is, the sensor can move with vehicles or float in the sky. GPS receivers, cell phones, helicopters, and satellites are examples of space sensors.

Example of data sources

- One of the biggest challenges facing traffic studies is the lack of sufficiently accurate microscopic data for the detailed analysis of vehicle interactions to understand the nuances of traffic flow leading to empirically based model development, calibration, and validation.
- Collecting such data is very challenging.
- Therefore, advances of microscopic traffic flow theory are very slow.
- By the early 2000's the traffic flow theory community recognized the need for accurate empirical microscopic data, which lead to the collection of the Next Generation Simulation (NGSIM) data sets
- There are two NGSIM freeway data sets:
  - I-80 with 5,678 vehicles collected over 45 min during the congested evening commute across 0.33 mi of freeway containing a single on-ramp,
  - US-101 with 6,101 vehicles collected over 45 min during the congested morning commute across 0.42 mi of freeway containing one on-ramp and one off-ramp.



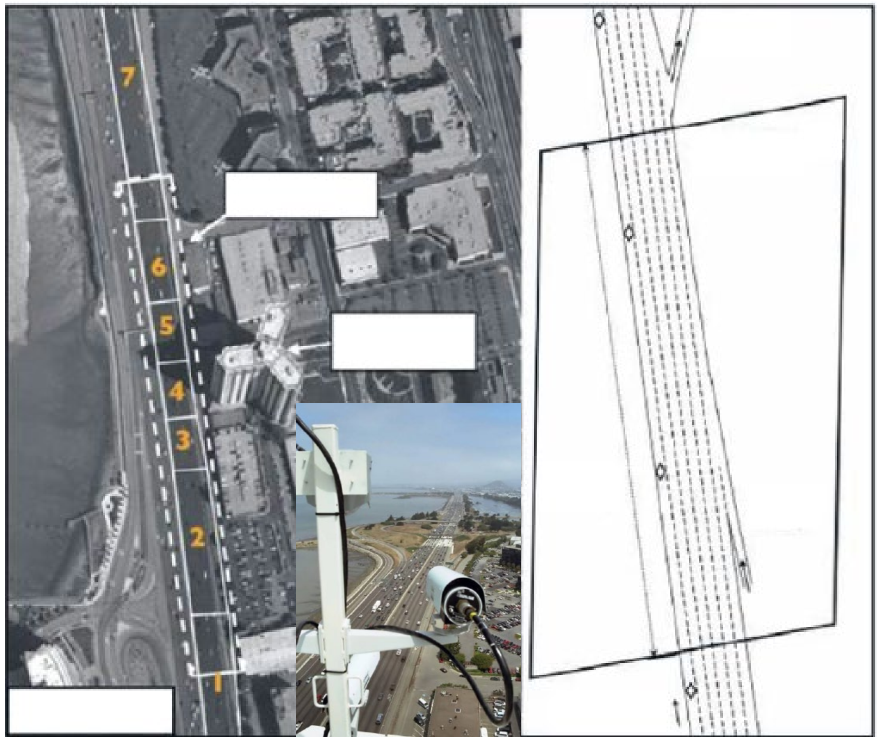
I-80 in California

Example of data sources

- Seven video cameras were set up on top of a 30-story building with each camera covering part of the study area.

- These cameras shot the site at different angles such that a vehicle entering from upstream is monitored continuously and consecutively by these cameras until it exits the study area.

- Since the NGSIM data were released ten years ago the number of empirical microscopic traffic studies has exploded and the NGSIM data now form the basis for many recent advances in empirical microscopic traffic flow theory.

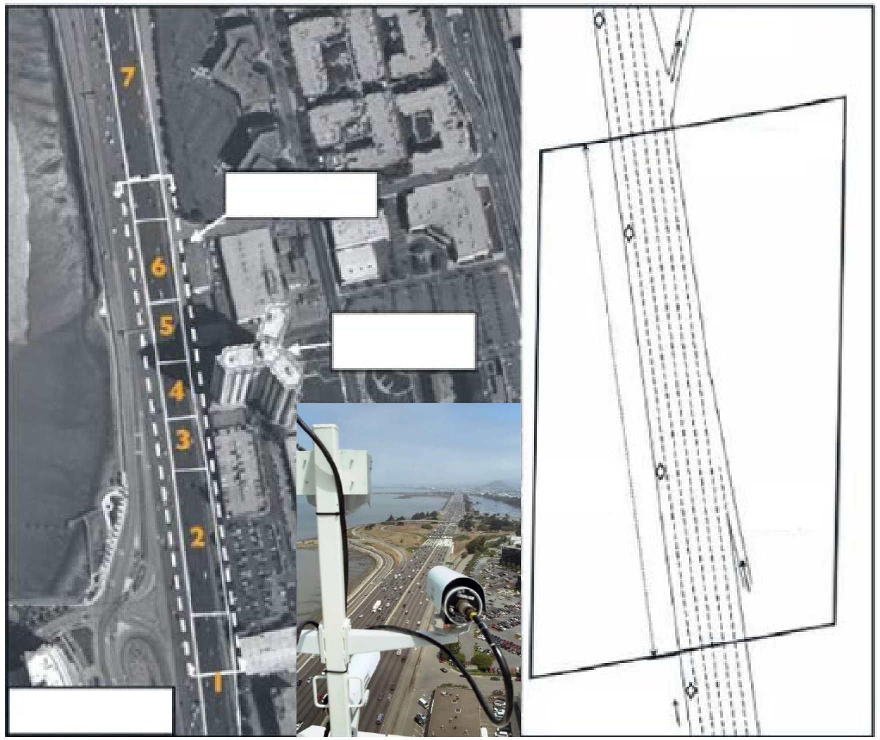


I-80 in California

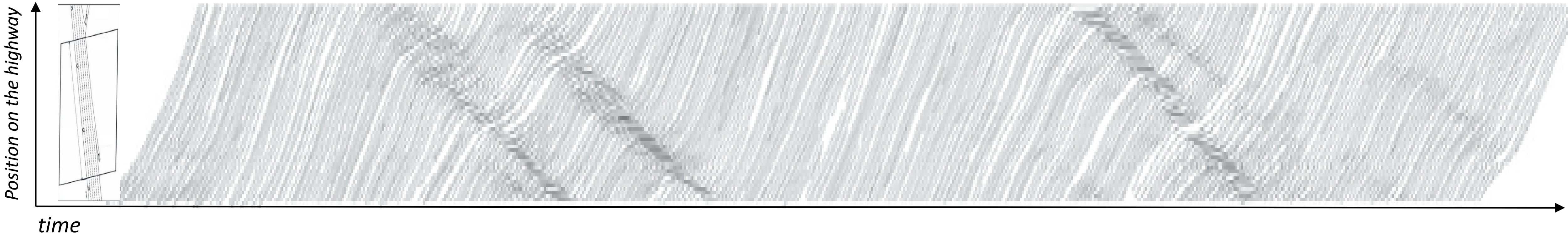
Example of data sources

- Videos captured by these cameras were then processed by a customized software application which identifies, tracks, and records every vehicle's temporal-spatial positions as the vehicle traverses the study areas.

- The resultant vehicle trajectory data provided the precise location of each vehicle within the study areas every 0.1 s.



I-80 in California



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Thank you
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