Chapter 1

Traffic Sensing Technologies

Safe and efficient operations of transportation systems rely heavily on applications of advanced technologies. As a result, recent decades have witnessed wide applications of communication, sensing, and computing technologies in traffic surveillance, incident detection, emergency response, fleet management, and travel assistances. Figure 1.1 illustrates a snapshot of a transportation system with various applications of these technologies.

Figure 1.1: An Illustration of ITS (photo credit: www.etsi.org)
1.1 Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) refer to efforts that apply information, communication, and sensor technologies to vehicles and transportation infrastructure in order to provide real-time information for road users and transportation system operators to make better decisions. ITS aim to improve traffic safety, relieve traffic congestion, reduce air pollution, increase energy efficiency, and improve homeland security. ITS encompass a suite of applications that address the above objectives: Advanced Traffic Management System (ATMS), Advanced Traveler Information System (ATIS), Advanced Public Transportation System (APTS), Intelligent Vehicle Initiative (IVI), Commercial Vehicle Operation (CVO), etc. Recent development of ITS emphasizes the application of Dedicated Short Range Communications (DSRC) in vehicle-to-vehicle and vehicle-to-roadside wireless communications, i.e., the Connected Vehicle Technology according to the United States Department of Transportation.

The following subsections highlight two sources of data that will be used throughout this book: NaviGAtor and NGSIM.

1.1.1 NaviGAtor - Georgia’s ITS

The NaviGAtor is the Georgia Department of Transportation’s Intelligent Transportation System. NaviGAtor’s Video Detection System (VDS) is the primary source of real-time information about current travel conditions. Approximately 1,645 VDS stations are installed approximately every 1/3 mile along most major Interstates in Atlanta Metropolitan area. These VDS cameras provide continuous speed and volume data to the Traffic Management Center (TMC) and allow the system to generate travel times for the Changeable Message Signs (CMS). NaviGAtor also uses about 500 full-color Closed-Circuit Television (CCTV) cameras, positioned about every 1 mile on most major Interstates in Atlanta. The CCTVs have tilt, pan and zoom capabilities and serve as traffic cameras sending real-time footage to the operators at the TMC for enhanced situational awareness. The information collected from these cameras allows them to confirm incident details, dispatch HERO units, and request appropriate emergency resources.

Figure 1.2 shows a real-time traffic map of NaviGAtor in Atlanta Metropolitan area. On this map, roadway links are color-coded to highlight the level of congestion. In addition, locations of some of the video cameras and change-
able message signs are labeled on the map. A sample image from a video camera on Georgia State Route 400 (GA400) is illustrated in the top left corner of the figure.

The data collected by the automated surveillance systems on GA400 were archived every day in the form of a single compressed file. This archived file contains observations at each station during the day. Each entry of data represents 20 seconds aggregation of classified vehicle counts, time mean speed, occupancy, etc. Figure 1.3 illustrates three-dimensional traffic density (converted from field data collected on Friday, Oct. 11, 2002) over time and space.

### 1.1.2 Next Generation Simulation

The Next Generation Simulation (NGSIM) program was initiated by the United States Department of Transportation (US DOT) Federal Highway Administration (FHWA) in the early 2000’s. The program developed a core of open behavioral algorithms in support of traffic simulation with a primary focus on microscopic modeling, and collected high-quality primary traffic and trajectory data intended to support the research and testing of the new
algorithms. The NGSIM program has actively engaged traffic simulation vendors to accelerate the inclusion of advanced or improved algorithms in the commercial models used across the world.

One of the NGSIM’s efforts was to collect detailed vehicle trajectory data on a set of sites including freeways, arterial, and urban streets. Figure 1.4 illustrates one of the sites on I-80 in California. The left pane shows an aerial photo of the site where seven video cameras were set up on top of a 30-story building with each camera covering part of the study area. The right pane visualizes a camera and its perspective. These cameras shot the site at different angles such that a vehicle entering from the upstream is monitored continuously and consecutively by these cameras till it exits the study area.

Videos captured by these cameras were then processed by a customized software application which was able to identify, track, and record while a vehicle traversed the study areas. The resultant vehicle trajectory data provided the precise location of each vehicle within the study areas every one-tenth of a second, resulting in detailed lane positions and locations relative to other vehicles. Figure 1.5 illustrates a sample result of such vehicle trajectory data. The y-axis (not shown) is the highway running from south to north and the
Vehicle trajectories are so fine and dense that disturbances of traffic flow and its propagation are clearly visible as ripples in water.

1.2 Traffic Sensors

This section lists a few types of traffic sensors that are often employed in traffic surveillance and data collection. The discussion of each type of sensor focuses on how it works, what traffic data it is capable of collecting, its advantages, and its disadvantages.

1.2.1 Inductive-Loop Detectors

Inductive-loop detectors are widely used at intersections with traffic-actuated signals, freeway entrance with automatic ramp metering, highway segments monitored by traffic counting programs, and entrances of gated parking facilities.
How it works

As illustrated in Figure 1.6, an inductive-loop detection system consists of an inductive loop, which is simply a coil of wire embedded in the road’s surface, and a detector, which typically sits in a signal cabinet and links the signal controller to the inductive loop. When a vehicle enters or crosses the loop, the body and frame provide a conductive path for the magnetic field. This produces a loading effect, which in turn causes the loop inductance to decrease. The decreased inductance causes the resonant frequency to increase from its nominal value. If the frequency change exceeds the threshold set by the sensitivity setting, the detector module will output a detect signal (i.e., an “ON” status). Otherwise, the detector does not output a signal (i.e., an “OFF” status).

Figure 1.6: An inductive-loop detection system (photo credit: www.ustraffic.net)

The output of the detector can be used for many applications. For example, an actuated signal controller relies on the detector output to decide whether a green indication is granted to the approach that is monitored by the detector. For another example, when a vehicle exits a gated parking garage, an inductive loop is able to detect the vehicle in advance so that the gate automatically opens for the vehicle. Yet another innovative application is red-light-running camera. 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 red light, the camera will be triggered and a picture of vehicle will be taken as the evidence of red light violation.
Data collected

An inductive-loop detector monitors a point of roadway and is able to collect (classified) traffic counts, vehicle instantaneous speed, headway (temporal separation between two consecutive vehicles), ON time (time during which the detector outputs an “ON” status), etc.

Advantages

An inductive-loop detector is able to monitor traffic on a regular basis (i.e., day-round and year-round) under all weather and lighting conditions.

Disadvantages

Installation of inductive-loop detectors is intrusive to traffic (i.e., the traffic must be interrupted in order to put the loop in pavement). In addition, setup and maintenance costs of inductive-loop detectors is high. Inductive-loop detectors can fail under weather conditions, especially snow and ice.

1.2.2 Video Image Processing System

Video image processing system (VIPS) is widely used for traffic surveillance and hence an essential component of ITS.

How it works

A video image processing system comprises: (1) an image processing system, e.g., a video camera mounted overhead above the roadway that captures real-time images/video streams of the traffic under surveillance, (2) a telecommunication system, e.g., modem and a telephone line that transmit images/video streams to the image processing system, and (3) an image processing system, e.g., a computer that processes frames of a video clip to extract traffic data.

The left pane of Figure 1.7 illustrates a video camera which is monitoring traffic. The right pane shows an image of roadway traffic (not necessarily a match to the view of the video camera in the left pane) with detection zones set up on the screen. When a vehicle enters a detection zone, the VIPS outputs an “ON” signal which remains till the vehicle exits the detection zone, at which time the VIPS switches to an “OFF” signal. Multiple detection
zones can be set up, e.g. one for each lane. Hence, these detection zones constitute a detection station.

Data collected

Similar to inductive-loop detectors, the VIPS monitors a point of roadway and is able to collect (classified) traffic counts, vehicle instantaneous speed, headway, ON time.

Advantages

The VIPS is an automatic system and is able to collect traffic data on a regular basis. Its overhead installation makes this technology non-intrusive to traffic flow. Flexible in setting up detection zones and aggregation intervals. It provides video footage in addition to traffic monitoring.

Disadvantages

The VIPS is expensive - setup cost is high. It is vulnerable to visual obstruction e.g. inclement weather; shadows, poor-lighting conditions, and strong winds.
1.2.3 Pneumatic Tubes

Pneumatic tubes are portable traffic data collection devices and are ideal for short-term traffic engineering studies.

How it works

A rubber tube with a diameter of about 1 cm is placed on the surface of the 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. The other end of the tube has a small opening, to prevent reflection of the air wave. The box counts axles that travel over the tubes and stores the data for later analysis.

![Installation of pneumatic tubes](photo credit: www.arlingtonva.us)

Figure 1.8: Installation of pneumatic tubes (photo credit: www.arlingtonva.us)

Figure 1.8 illustrates how pneumatic tubes are installed. From left to right: a technician is nailing tubes on the road; the technician is programming the data recorder with a laptop computer to collect the desired information; the technician is connecting the pneumatic tubes to the data collector; The installation is complete and the system is collecting traffic data.

Data collected

Pneumatic tubes are able to collect traffic data such as instantaneous speed, direction of flow, volume, vehicle classification, and the time of day associated with each data sample.

Advantages

Pneumatic tubes are portable devices for automatic traffic data collection. The cost is moderate and the system can be reused at other locations. The system requires installation which does not require much efforts (manageable by one or two persons)
Disadvantages

The system has a limited lane coverage and is not intended for use on a regular basis (year-round). The system can be damaged by vehicles or roadway maintenance causing inaccurate data collection. The system may be intrusive to traffic and nearby properties.

1.2.4 Global Positioning System (GPS)

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 functionalities, and hence they are considered in the same category of GPS.

How it works

The GPS is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense. GPS satellites circle the earth twice a day in a very precise orbit and transmit signal information to the earth. GPS receivers take this information and use triangulation to calculate the user’s exact location, see Figure 1.9 for an illustration. Essentially, the GPS receiver compares the time a signal was transmitted by a satellite with the time it was received. The time difference tells the GPS receiver how far away the satellite is. Now, with distance measurements from a few more satellites, the receiver can determine the user’s position and display it on the unit’s electronic map.

Figure 1.9: The Global Positioning System (photo credit: wikipedia.org)

Suppose 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. Therefore, the vehicle would leave a trace of spatial-temporal points in the time-space diagram and a curve that connects these points depicts the vehicle’s spatial-temporal trajectory. From this trajectory, the motion of this vehicle can be understood.

**Data collected**

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

**Advantages**

GPS now becomes an affordable technology since one only need a GPS receiver to receive positioning signals. It is simple to install and operate. It works under all weather and lighting conditions.

**Disadvantages**

GPS receivers only provide vehicle-specific data. Traffic information has to be obtained from all vehicles in the traffic stream. In addition, GPS signals can be obstructed by tall buildings and trees.

1.2.5 Acoustic/Ultrasonic Sensors

Acoustic/ultrasonic sensors can be used for vehicle detection, automotive radar, and assisting vehicle parking.

**How it works**

The sensors 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. In traffic applications, these sensors can be used to count pedestrians and vehicles by knowing the relative distances between a pedestrian/vehicle and the sensor. In mechanical applications, these sensors can be used to measure fluid levels. The picture here has them installed in the rear of a vehicle as a parking sensor. The sensors measure the distance between the
vehicle and an object behind, and then display a color corresponding to the distance on the dashboard panel. When the display turns red, the driver can stop and be perfectly parked.

![Acoustic/Ultrasonic Sensors](https://www.liveozshop.com)

Figure 1.10: Acoustic/Ultrasonic Sensors (photo credit: www.liveozshop.com)

**Data collected**

The sensor collects the time of sound wave travel, and then converts it to distance.

**Advantages**

The sensor is inexpensive in general and involve relatively simple hardware.

**Disadvantages**

The sensor covers only a short range and has slow response times. Accuracy is limited by the surface of the objects. Sound waves may bounce off of varying surfaces differently, which may throw off readings on the sensor.

### 1.2.6 Aerial/Satellite imaging

**How it works**

This technology 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. Illustrated in Figure 1.11, the helicopter can be used to capture images of the ground and the images are stored or transmitted to a work station for analysis. The outcome includes vehicle counts, vehicle speeds, and traffic density.

![Unmanned helicopter as traffic sensor](photo credit: www.draganfly.com)

**Data collected**

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 further mean traffic speed.

**Advantages**

Traffic surveillance can be taken at high accuracy. There is no need for hardware installation or near roadways, i.e., it is a non-intrusive and non-interruptive technology. It can provide bird’s eye view of system-wide traffic conditions.
Disadvantages

Helicopters are expensive and require pilots to operate. It is time- and resource-consuming to collect traffic data. Analysis of aerial photos is complicated, e.g. aligning aerial photos captured from different angles.

1.2.7 RFID Technology

Radio-frequency identification (RFID) is the core technology of many traffic sensors know as transponders (e.g., E-ZPass tags), Automatic Vehicle Identification (AVI), etc.

How it works

Radio-frequency identification (RFID) is a technology that uses radio waves to exchange data between a reader and an electronic tag attached to an object for the purpose of identification and tracking. Figure 1.12 illustrates an electronic toll collection (ETC) system which consists of: (1) a transponder on the vehicle, (2) a tag reader antenna at each plaza toll lane, (3) lane controllers that control the lane equipment and track vehicles passing through, and (4) a host computer system. All of the toll plaza controllers are connected to a central database. When a vehicle comes to the toll booth at a speed, the tag reader detects the transponder and records the its unique ID, the time instant, and other account-related information such as balance and toll paid.

Figure 1.12: Electronic toll collection system (photo credit: HowStuffWorks)
Data collected
RFID is able to record and the IDs of equipped vehicles and time-stamp the arrival of such vehicles.

Advantages
RFID is inexpensive. It does not interrupt traffic.

Disadvantages
RFID only detects equipped vehicles at a point of roadway.

1.3 Traffic Sensor Classification
Traffic sensors can be classified in many ways. For example, according to its working principle, a traffic sensor can be a

- **mobile sensor** if it resides in a vehicle and collect data only specific to this vehicle. Examples of mobile sensors are GPS receivers, acoustic/ultrasonic sensors, and cell phones.

- **point sensor** if it is mounted at a fixed location along the roadway and only observes traffic at this particular location. Examples of point sensors are inductive-loop detectors, video image processing systems, pneumatic tubes, and RFID technology (e.g., transponder-reader system).

- **space sensor** if it is up in the air and is able to take a snapshot of traffic on a stretch of road. Examples of space sensors are helicopters and satellites.

According to the extend to which a sensor intrudes into roadway and traffic, the sensor can be

- **intrusive** if installation of the sensing system requires pavement work and interrupting traffic. Examples of intrusive sensors are inductive-loop detectors and pneumatic tubes.
• *non-intrusive* if installation of the sensing system does not require pavement work and interrupting traffic. Examples of intrusive sensors are video image processing systems and RFID technology.

• *off-roadway* if the sensor is not fixed to a location of the roadway, i.e. the sensor can move with vehicles or float in the sky. Examples of space sensors are GPS receivers, acoustic/ultrasonic sensors, cell phones, helicopters, satellites.