Appendix

Chapter A1

Testbed for Technology Development

Introduction

Testbeds are composite abstractions of systems that are used to study system components and interactions in order to learn more about the underlying system's importance. They're made up of prototypes and real-world system parts, and they're used to show how a system's elements work. The testbed provides a realistic hardware-software environment in which components can be tested without having access to the final system. The testbed allows for a better knowledge of the system's functional needs and operational behaviour.

Traffic congestion is a huge issue all throughout the world, resulting in slower speeds, longer travel times, and longer lines of vehicles. It not only increases the fuel consumption but consequently leads to increase in carbon dioxide emissions, outdoor air pollution as well as increase in the exposure time of the passengers. Intelligent Transportation System (ITS) technologies acts as a solution to reduce travel time, congestion, emissions and crashes and improves safety, driving experience and road capacity. To reduce CO_2 emissions by using ITS technologies such as Advance traffic management system a testbed was constructed in IIT Hyderabad to assess the efficiency of technologies in reducing CO_2 emissions. The primary objective of the testbed has been focused on improving safety and also increasing traffic mobility. In addition, it may helpful to reduce the transportation related environmental impacts that include pollutant emissions which leads to poor air quality as well as energy consumption and greenhouse gas emissions.

Figure A-1 represents the IITH testbed. The components of IITH testbed are

1. Advance Driver Assistance System for Safe Merging deployed near IITH main gate
2. Speed Enforcement Warning System deployed near faculty towers
3. Intersection Conflict warning System deployed near Academic block A
4. Bluetooth and Wi-Fi sensors and Gas sensors are deployed on NH-65.

Testbed help in developing advance traffic management system, advance traveller information system and reduce CO_2 emissions.

Technologies deployed in the Testbed

1: Intersection Conflict Warning System (ICWS)

In India, rural highways have numerous minor roads intersecting them and carry mixed traffic. According to MORTH, 449,002 road crashes were recorded in 2019, out of which 20.6% of the crashes occurred at uncontrolled intersections. Crashes at intersections are more likely to be angle crashes which have a higher risk of serious or fatal injury. Intersection Conflict Warning System is one such ITS technology that helped to reduce crashes at intersections. The objectives of ICWS is to evaluate the safety, effectiveness and efficiency of ICWS in order to promote safe gap acceptance of vehicle at an uncontrolled intersection and to reduce the frequency of crashes at uncontrolled intersection by warning drivers on the major and minor approach for cross traffic presence. The working principle of ICWS is discussed below.

2: Working principle of ICWS

ICWS gives a warning to drivers as they provide real-time information about intersection conditions to driver to reduce intersections crashes. Static signing, detection and dynamic elements are used to provide substantial warnings to drivers at intersections where poor sight distance or gap acceptance have contributed to high crash rates.

The intersection conflict warning system combines warning lights with roadside detectors. This system collects real-time vehicle data and transmits the results to drivers in a timely manner via the warning lights. Conflict warning lights are set on the major road and the minor road, respectively and has two states: continuously flashing or off. When no conflict is detected, the warning light remains off, meaning that vehicles may pass safely. When the system detects a conflicting vehicle on the major road it warns the drivers on the minor road about the presence of vehicle on the major road by activating warning lights. Similarly, when the system detects a vehicle entering from minor road it informs the major road drivers about the presence of vehicle on the minor road by activating warning lights. This situation results in reduced conflicts as drivers get alert about the possible approaching vehicle, resulting in lower approach speeds and improved driver gap acceptance. The type of sensors deployed at Intersection Conflict Warning System was described in the next section. Figure A-2 and Figure A-3 represents

Figure A-1 IITH testbed

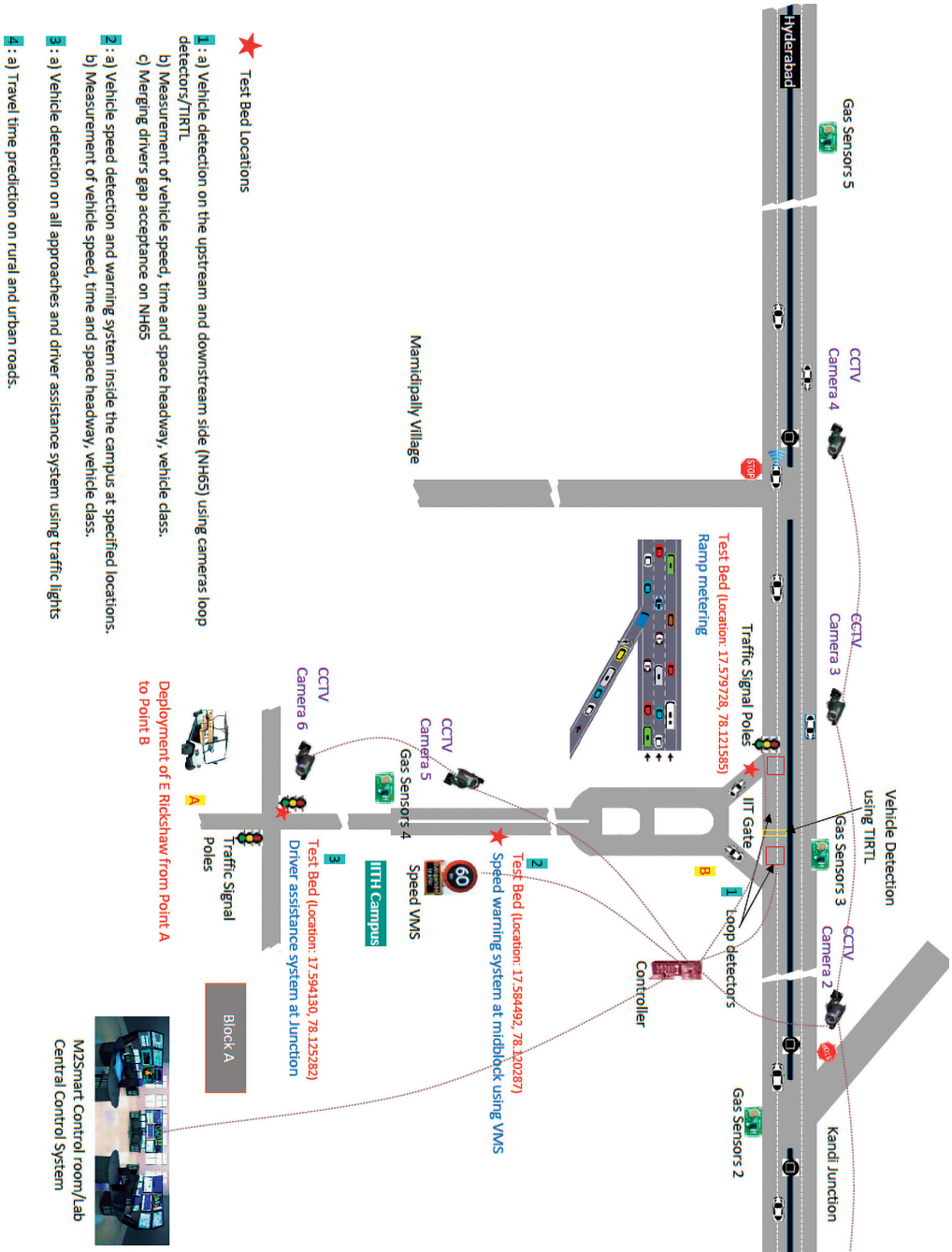


Figure A-2 Intersection Conflict Warning System (ICWS) Near A-block, IITH

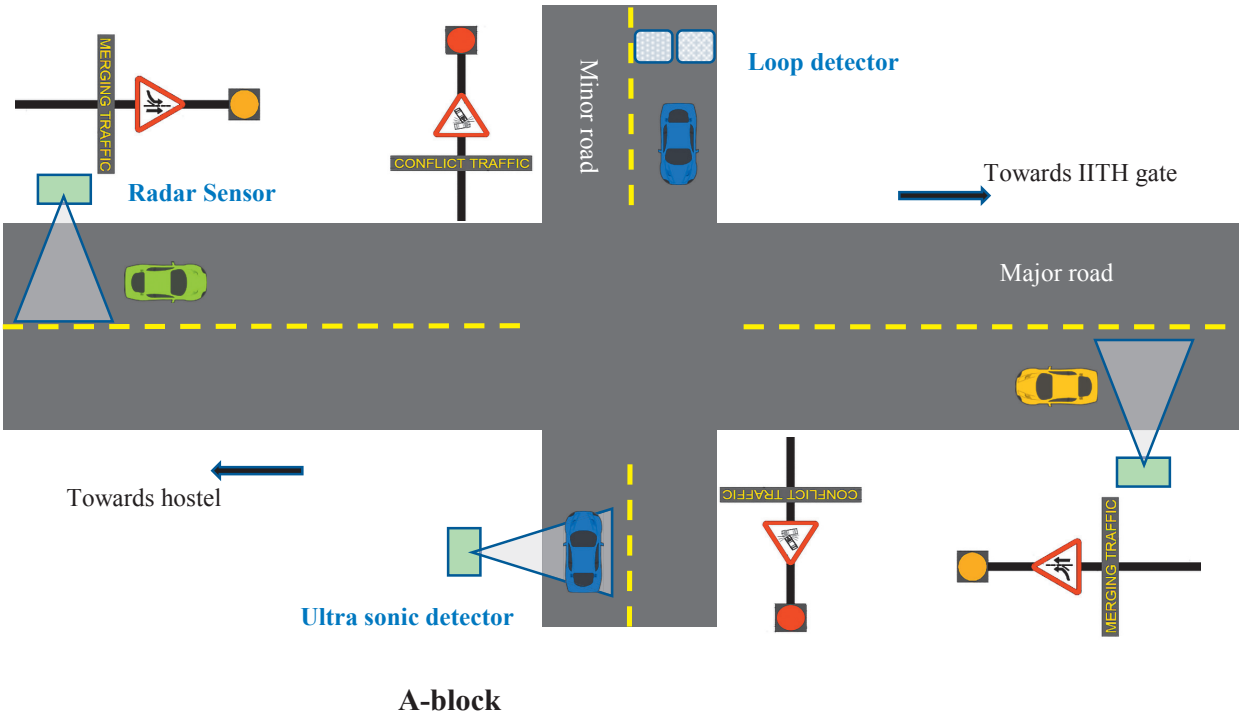


Figure A-3 Traffic merging signs with warning lights

the intersection conflict warning system installed near A block, IITH and warning signs on major and minor road.

3: Speed Enforcement Warning System

Speeding has been implicated as a major contributing factor in all fatal vehicle crashes. Law enforcement in the recent years has increased with technologies like Global Positioning System (GPS) based vehicle tracking system, Speed gun, Speed Camera System to catch speeding motorist and to improve road safety as well as fleet management application. The Speed Enforcement Warning System (SEWS) is the latest technology used to monitor driver's compliance with the speed limit. The objectives of speed enforcement warning system are to design speed warning system that will monitor the vehicle speed by warning the drivers. When driver exceed the pre-set speed limit board (30 kmph) and to automatically record the number plate from ANPR (Automatic number plate recognition) and camera for further action that will be stored as a data base in controller room.

4: Working principle of Speed Enforcement Warning System

Speed enforcement is a system that monitors local speed of the driver by warning, so that driver can maintain optimum speed. Automatic number plate Recognition (ANPR) is a mass surveillance method that performs optical character recognition on images to read the license plate of the vehicle. It is also used for detection of average speed of the vehicles. Sign boards are placed alongside road to inform speed limit to the drivers. Loop detectors are installed prior to sign boards to classify vehicle types. Lidar speed board detects the speed of vehicle that is shown with speed limit sign board. ANPR is installed to detect the number plates of vehicle that are going above speed limit and it'll send that data to server. Figure A-4, A-5 and A-6 represents the speed enforcement warning system near faculty and staff housing at IITH.

Figure A-4 Speed Enforcement Warning System Near Faculty and Staff Housing, IITH

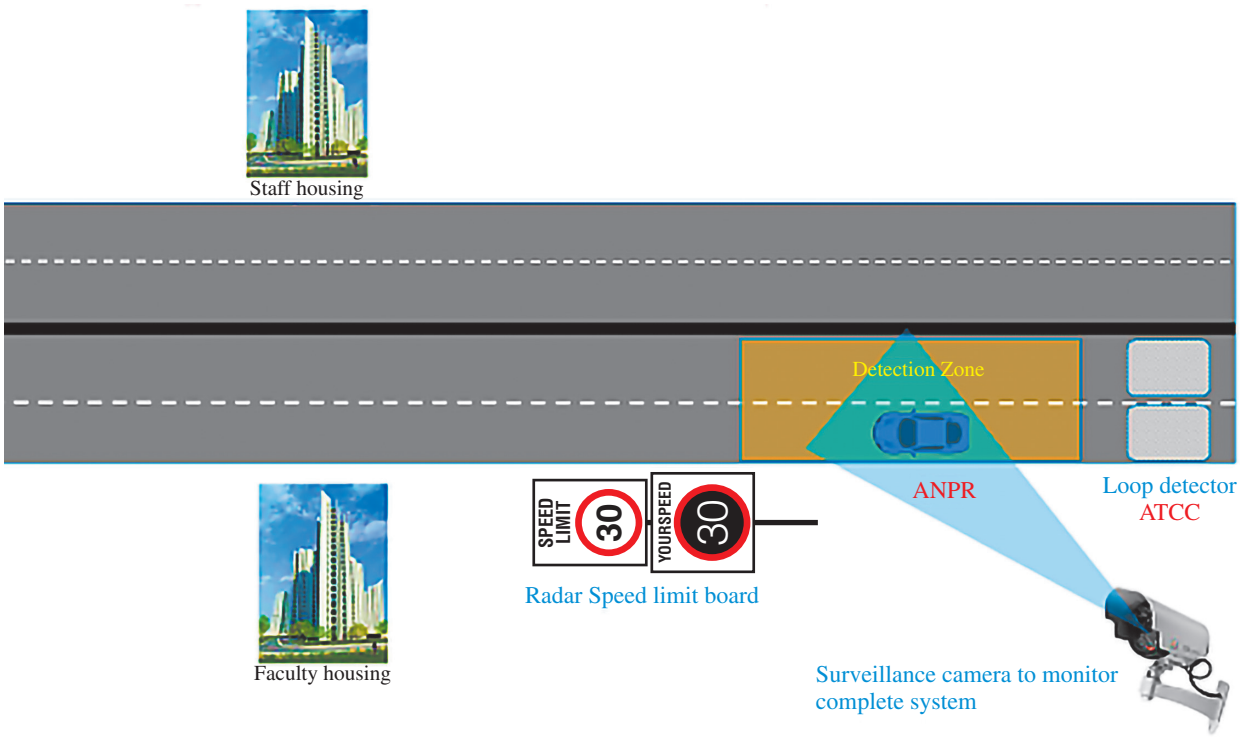


Figure A-5 Automatic Number Plate Recognition (ANPR)

Figure A-6 Speed warning signal system

5: Driver Assistance system for safe merging

Driver assistant system is the primary elements for addressing repeatedly occurring freeway congestion on main line. The system consists of traffic signal on minor and major approach. The system controls the rate of vehicle entering into mainline, thereby allowing the freeway to carry the maximum volume at a uniform speed, such that freeway throughput is maximized. The objectives of driver assistance system for safe merging were to control the number of vehicles that are allowed to enter the freeway and to reduce the risk of accidents arising out of sudden driver decisions.

6: Working principle of Driver Assistance system for safe merging

It is a method by which traffic seeking to gain access to a busy highway is

Figure A-7 Advance driver assistance system for safe merging near IITH main gate

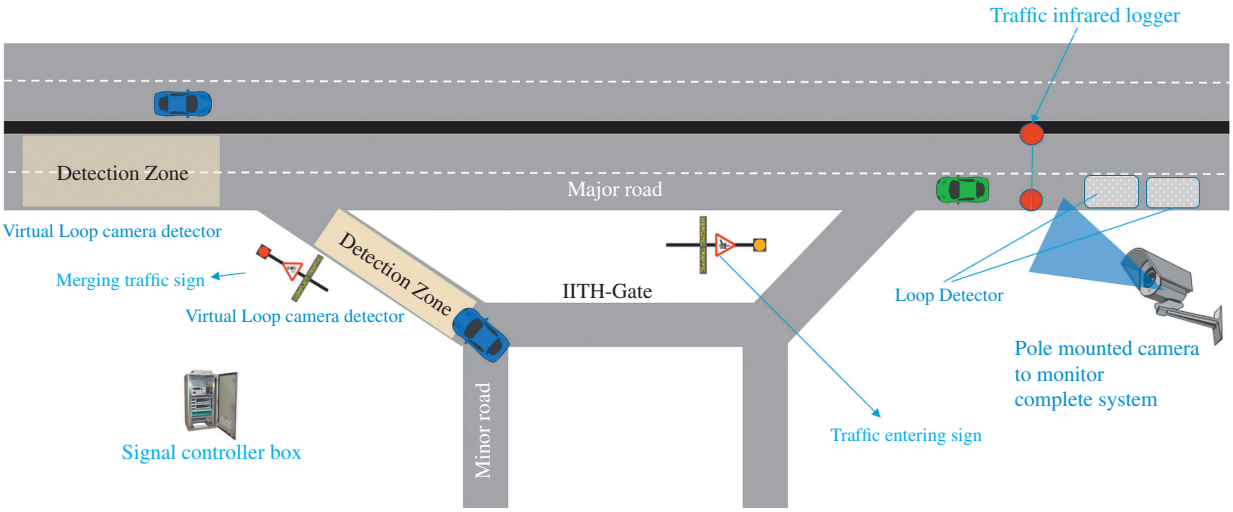


Figure A-8 Traffic Entering sign

Figure A-9 Traffic conflict sign

controlled at the access point via traffic warning signs. It reduces overall freeway congestion by managing the amount of traffic entering the freeway and by breaking up platoons that make it difficult to merge onto the freeway. The system warns the driver on the minor road (IITH exit) based on the traffic approaching on a major road in real-time condition and vice-versa. Virtual loop camera sensor detects the real-time vehicle position of the minor road approaching traffic and sends the signal to the traffic entering sign present on NH-65 (major road) by flashing amber light.

For minor approach vehicles to safe merging into NH-65, TIRTL (The Infrared Traffic Logger) and loop detector sensor embedded on major approach detects the vehicles and sends the signal to conflicting traffic by flashing red light to minor road. Figure A-7, A-8 and A-9 represents the driver assistance system for safe merging installed near IITH main gate

Sensors deployed in IITH testbed

The type of sensors deployed for different technologies in the IITH testbed are described below.

1: Radar Sensor

AGD traffic radar sensor was deployed on one leg of intersection conflict warning system where traffic goes towards IITH main gate. It is a frequency modulated continuous wave radar with detection range up to 150 meters. Radar sensor detects traffic volume, speed, occupancy, presence, vehicle type and direction of motion of vehicle. Radar sensor detection rate and their images are shown in Table A-1 and Figure A-10.

Table A-1 AGD traffic radar sensor detection rate

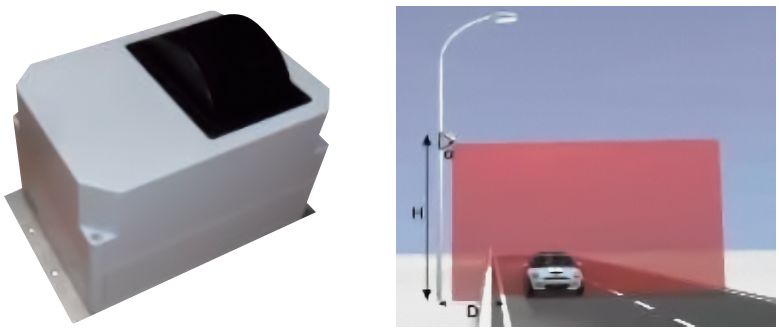
	Car	Bike	Truck	Auto	Total	Percentage
Detected	350	1663	6	35	2054	68.31
Not detected	1	952	0	0	953	31.69
Total	351	2615	6	35	3007	
Detection percentage	99.72	63.59	100	100		

Figure A-10 AGD Traffic Radar

Table A-2 Laser sensor detection rate

	Car	Bike	Bus	Truck	Auto	Ambulance	Total	Percentage
Detected	88	161	33	1	5	1	289	26.81
Not detected	150	604	29		5	1	789	73.19
Total	238	765	62	1	10	2	1078	
Detection Percentage	36.97	21.05	53.23	100	50	50		

Figure A-11 ExLSR Ⅲ laser sensor



2: Laser Sensor

ExLSR Ⅲ laser sensor was deployed on one leg of intersection conflict warning system where traffic goes towards academic block. It has a laser class of 1-905 nm and a scanning angle of 96 degrees. Laser sensor can be used for vehicle count and classification of vehicle. Laser sensor detection rate and their images are shown in Table A-2 and Figure A-11.

3: Inductive Loop Detector

Inductive loop detectors were installed in IITH at an intersection minor road approach where conflict warning system was deployed and on NH64 road for an assistant driver warning system. Inductive loop detector can measure speed, volume, occupancy and length of the vehicle. Inductive loop detector detection rate and their images are shown in Table A-3 and Figure A-12.

Table A-3 Inductive loop detector detection rate

	Car	Bike	Bus	Truck	Auto	JCB	Tractor	Total	Percentage
Detected	46	70	4	178	6	8	8	320	86.02
Not detected	0	46	0	1	5	0	0	52	13.98
Total	46	116	4	179	11	8	8	372	
Detection Percentage	100	60.34	100	99.44	54.55	100	100		

Figure A-12 Inductive Loop Detector

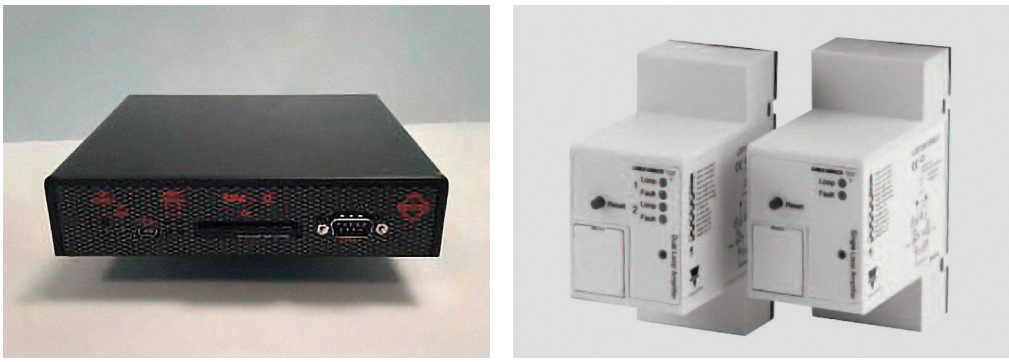
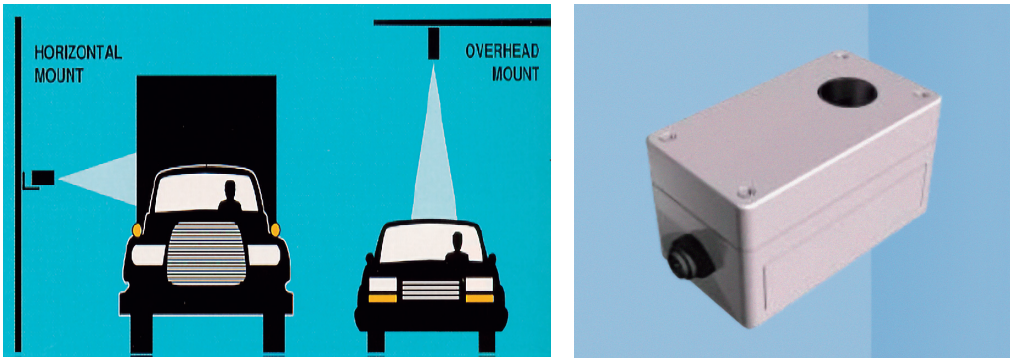


Figure A-13 AUS 6003 Ultrasonic sensor



4: Ultrasonic Sensor

AUS 6003 Ultrasonic sensor was installed in IITH at an intersection minor road approach where conflict warning system was deployed and it uses ultrasonic technology for the detection of the presence of vehicles and their height / profile. Ultrasonic sensor was installed at a height of 5–7 meters from ground surface with sensor facing downward direction. Ultrasonic sensor can classify vehicles based on their height, measure speed and traffic volume. The image of ultrasonic sensor was shown in Figure A-13.

5: The Infrared Traffic Logger (TIRTL)

TIRTL had been installed on NH 64 for Assistant Driver Warning System. It gives the vehicle-by-vehicle data consisting of timestamp, vehicle speed and vehicle type in real time through an ethernet interface. TIRTL detection rate and its image is shown in Table A-4 and Figure A-14.

6: Virtual Loop Detector

FLIR traffic camera was installed at IITH exit gate for an assistant driver warning system. It consists of both CMOS camera and video detector which acts as a vehicle presence detector. When a vehicle passes through this camera it detects the vehicle presence and information is send to controller unit. TrafiCam allows you to exactly position and verify the vehicle presence detection zones. TrafiCam detection rate and its image is shown in Table A-5 and Figure A-15.

Conclusion

Testbed is mainly used for testing the developed technologies and to provide insights that would be helpful

Table A-4 TIRTL detection rate

	Car	Bike	Auto	LCV	HCV	Total	Percentage
Detected	409	418	85	38	124	1074	93.07
Not detected	17	36	9	2	16	80	6.93
Total	426	454	94	40	140	1154	
Detection percentage	96.01	92.07	90.43	95	88.57		

Figure A-14 TIRTL

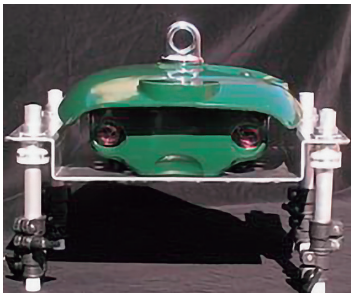


Table A-5 Virtual loop detector detection rate

	Car	Bike	Truck	Auto	Total	Percentage
Detected	350	1663	6	35	2054	68.31
Not detected	1	952			953	31.69
Total	351	2615	6	35	3007	
Detection Percentage	99.72	63.59	100	100		

Figure A-15 FLIR TrafiCam

before deploying it in the real-world traffic. This chapter presents about Intelligent Transportation System (ITS) testbed deployed in IITH. The main objective of ITS testbed is to reduce accidents, congestion and CO_2 emissions by deploying various ITS technologies such as Advanced traffic management, Advanced traveller information and Bluetooth/Wi-Fi sensors and improve safe, secure and efficient travel to road users. The technologies that are deployed in testbed and their objectives and working principles was discussed in detail. ICWS technology helps to reduce collisions at uncontrolled intersections, Speed enforcement warning system helps drivers to travel in a safe speed, Driver assistance system for safe merging helps the drivers intend to merge the highway by avoiding sudden braking behaviours and can reduce accidents and Wi-Fi/ Bluetooth sensors and Gas sensors installed on NH-65 provides about the information of vehicles travelling on Highway. The testbed deployed in IITH may influence the driving behaviour and would aid in the development and implementation of efficient eco driving solutions to minimize vehicular emissions. Furthermore, IITH testbed may help the designers, traffic management system and policy makers to have an idea about the countermeasures needed to be taken to reduce congestion, accidents and greenhouse gases.