

The Minnesota Mobile Intersection Surveillance System

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Abstract – Detailed crash analyses indicate that poor gap selection, rather than stop sign violation, is the primary causal factor in crashes at rural, unsignalized intersections. To determine under what conditions the gap selection process fails, a transportable rural intersection surveillance system has been designed and implemented. The system can be installed at any rural intersection, and can be used to collect data regarding the gap acceptance behavior of drivers at the rural intersection.

Described herein is the design and performance of the transportable rural intersection surveillance system. This system will be deployed at eight rural intersections in eight US states, from April 2006 through December 2008. Data collected by the system will be used to determine whether regional differences in gap acceptance behavior exist. If differences exist, they will be quantified and used in the design of an Intersection Decision Support system, a device under development designed to assist a driver at a rural intersection with the gap selection process.

I. INTRODUCTION

MORE than 30% of all vehicle crashes in the US occur at intersections; these crashes result in nearly 9000 annual fatalities, or approximately 25% of all traffic fatalities. Moreover, these crashes lead to approximately 1.5 million injuries/year, accounting for approximately 50% of all traffic injuries. In rural Minnesota, approximately one-third of all crashes occur at intersections [1].

Under State Pooled Fund Project TPF-5(086), crash analyses, including field visits and crash database reviews, for Michigan [2], North Carolina [3], and Wisconsin [4] have shown that in these states, poor gap acceptance on the part of the driver is the primary causal factor in approximately 60% of rural thru-Stop, right-angle intersection crashes.

To determine under what conditions the gap selection process fails, a rural intersection surveillance system (the Minnesota Rural Test Intersection, or MRTI) has been designed and deployed at the intersection of US Highway 52 and County State Aid Highway 9 (CSAH9) near Goodhue, MN. The MRTI is a test bed for a rural Intersection Decision Support (IDS) system [5], which is designed to assist a driver at a rural intersection with the gap selection process using an infrastructure-based dynamic sign.

To provide a richer set of gap driver acceptance behavior

data, the Minnesota mobile intersection surveillance system (MMISS) has been designed and tested. MMISS is based on the MRTI system at US 52 and CSAH 9. MRTI uses sensors, processors, and a communication system to determine the intersection “state.” Mainline state information includes the position, speed, (derived) acceleration, and lane of travel of each vehicle within the surveillance zone. This state information, combined with known intersection geometry, facilitates the real time tracking of traffic gaps on the mainline. State information for the minor road includes the position and speed of the vehicle on the minor road, and an estimate of the classification of the vehicle. Present classification separates vehicles into four categories: Motorcycle/passenger cars, SUV/light truck, medium duty truck/school bus, and heavy-duty truck/semi/motor coach/farm equipment. A central processor computes the “state” of the intersection at 10 Hz.

The primary differences between the MMISS and the MRTI system are that the MMISS uses wireless communication to provide sensor data to the main system processor and a distributed system to provide power to the remote system sensors.

II. SYSTEM OVERVIEW

Figure 1 below provides a plan view of the MMISS as it would be installed on a rural expressway intersection. Mainline sensing is provided by an array of radar sensor spaced 122m (400 ft) apart, and connected to the central processor through an IEEE 802.11b wireless local area network. A station adapter is associated with each radar sensor, and transmits radar sensor data to the central processor. Sensing on the minor road is provided by a fusion of radar and scanning lidar sensors, also connected to the central processor through the local 802.11b local area network. These sensors are designed to detect the presence, location, and speed of a vehicle approaching the major road on the intersection’s minor leg, and to classify the vehicle into one of four categories. Median crossroads surveillance is accomplished using an array of scanning lidar sensors, also connected to the central processor via the local 802.11b wireless network. The purpose of the median sensor is to determine the presence and location of vehicles located in the median crossroads. The mainline sensor system, the minor road sensor system, the crossroad sensor system, central processor, and power distribution systems are discussed in detail below.

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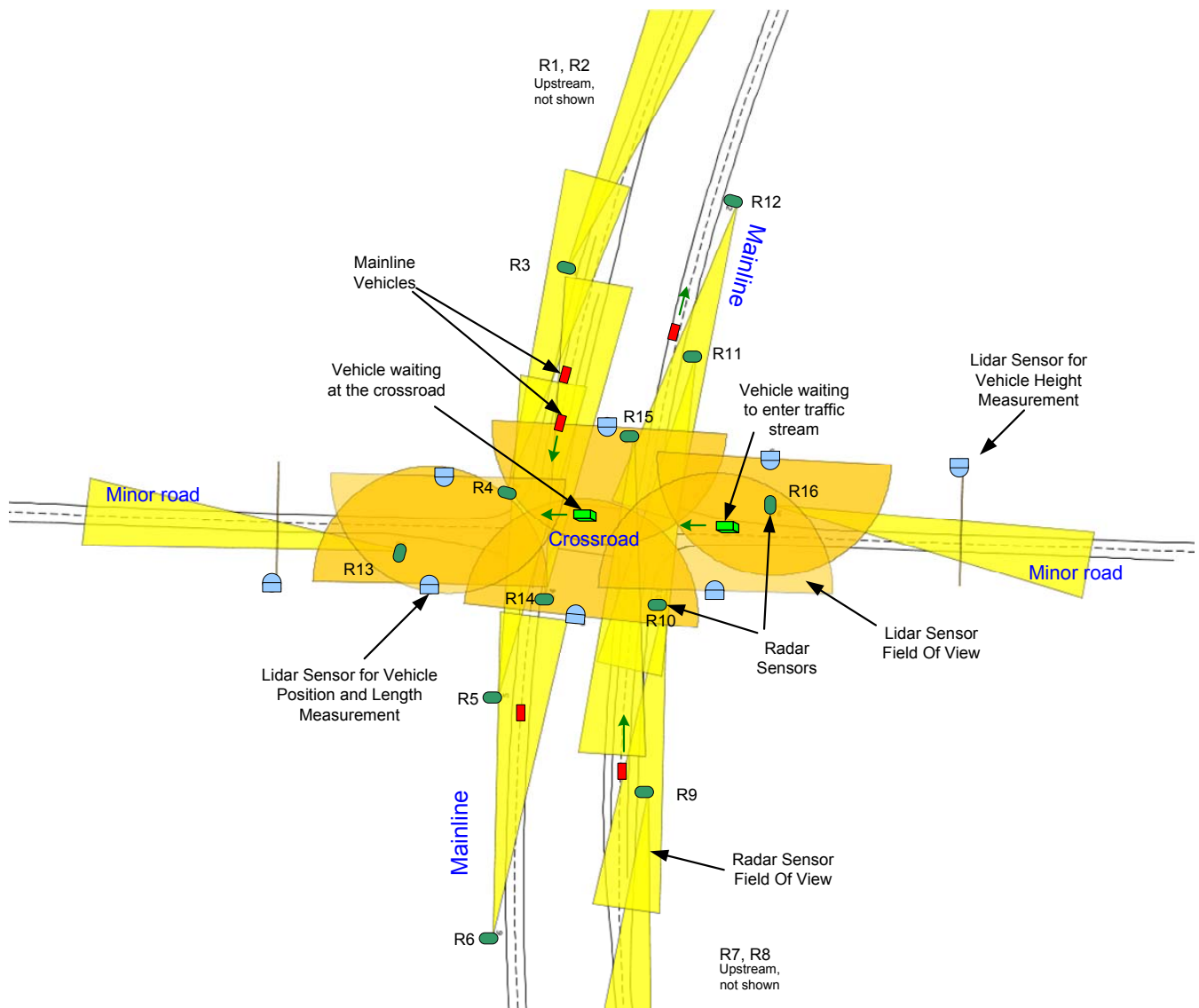


Fig. 1. Plan view of a typical instrumented rural expressway intersection. Sensors are radar and scanning lidar; all data is broadcast wirelessly from sensor processors to the main data acquisition computer via 802.11b wireless devices. Of particular interest for driver behavior research is the crossroad surveillance area. Approximately eighty percent of crashes at rural expressway intersections having higher than expected crash rates, occur on the “far” side of the intersection. Understanding of behavior in the median will facilitate the development of an effective rural IDS system.

III. SURVEILLANCE SUBSYSTEM: SENSOR ZONES

A. Mainline

1) Sensors

Radar has been used in many traffic engineering applications. MMISS functional requirements specify that the surveillance system provide lane-of-travel information for the vehicles detected by the surveillance system. Radar designed for traffic monitoring use very narrow horizontal fields of view (width of transmitting cone is less than one lane width at maximum range), and are typically mounted on overhead gantries, with one sensor per lane. Because of the lack of available overhead structures on which conventional traffic radar can be mounted at rural intersections, their applicability was discounted.

However, new generation automotive radar can provide

range, range rate, and azimuth angle to multiple targets (up to 8 targets) with a single sensor. *A priori* knowledge of the road geometry combined with the sensing capability of new automotive radar allows the sensor to provide the information needed to determine vehicle lane-of-travel.

The Eaton Vorad EVT-300 is used in this system. The EVT-300 was subject to an extensive performance evaluation in the context of a roadside sensor [6], where the performance claims of the EVT-300 were found to be conservative, especially its maximum range, which was found to be approximately 134m (440ft). Moreover, the EVT-300 utilizes a carrier frequency of 24.5GHz, which is less sensitive to signal attenuation due to atmospheric moisture than European or Japanese radar which use a carrier frequency of 76 GHz [7].

2) Intersection Sensor Layout

Figure 1 shows that radar sensors R1-R5 and R7-R11

provide coverage on the mainline leading to the crossroads. In a rural IDS system, these sensors provide gap data needed to control the dynamic warning sign. Sensors R6 and R12 are used for driver behavior research purposes to acquire acceleration data for drivers entering the traffic stream as well as to determine the response of mainline traffic should a driver accept too small a gap and create a conflict.

3) Local Radar Electronics

Figure 2 shows the layout of the electronic system used to acquire data from the radar sensor and broadcast it to the central processor. Upon power-up, a PIC processor initializes communication with the EVT-300 through the J1708/RS-232 converter. Once the EVT-300 is initialized, it sends target range, range rate, and azimuth angle information to the PIC, which relays the target information to the central processor wirelessly via the IEEE 802.11b local area network.

The electronic package is compact, and is mounted on the same roadside post as the radar sensor.

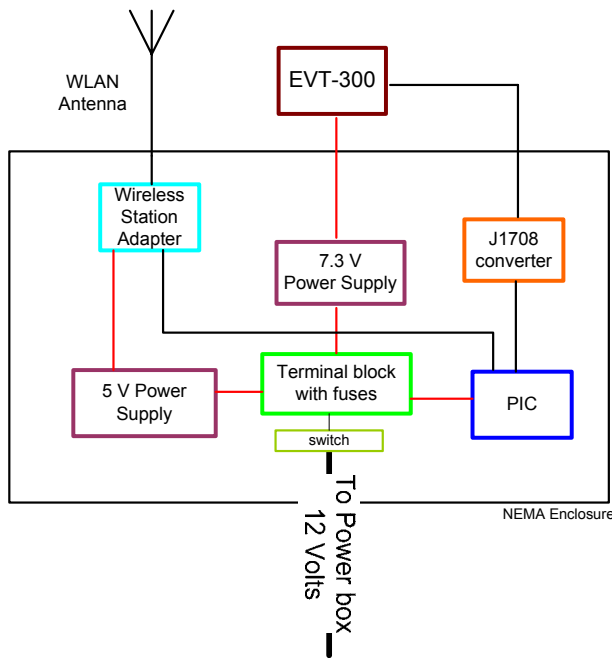


Fig.2. Layout of radar electronic subsystem.

B. Minor Road Surveillance Subsystem.

1) Sensors

A three-sensor suite is used for vehicle detection and classification: an EVT-300 radar sensor, and two scanning lidar sensors. The EVT-300 is used to sense the location and speed of vehicles approaching the intersection on the minor road. A horizontally-oriented lidar detects both slow moving and vehicles stopped at the stop bar. The horizontal sensor tracks the vehicle as it passes along the vertically mounted lidar sensor. The vertically-oriented lidar captures the height profile of the vehicle as it passes by. Figures 3 and 4 show how the vertical and horizontal lidar data are used to compute a “snapshot” of the side profile of a vehicle.

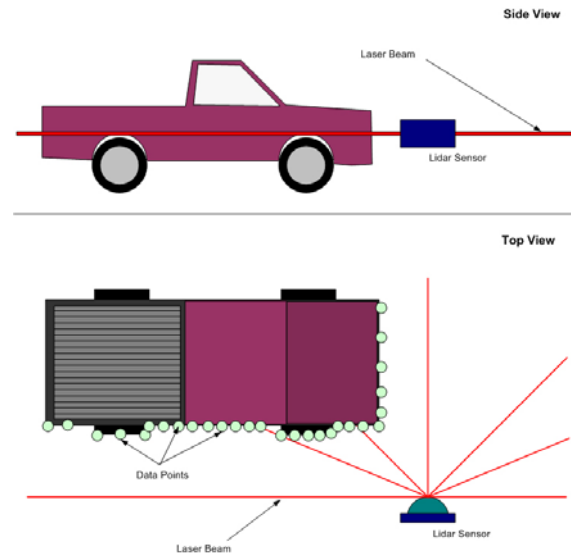


Fig. 3. Horizontally oriented lidar detecting front corner and right side of vehicle.

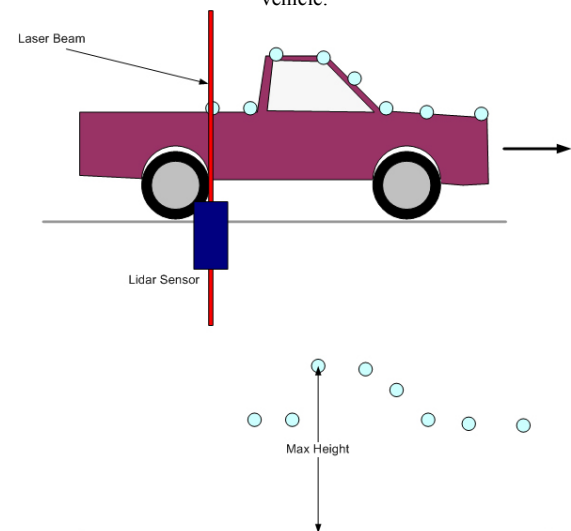


Fig. 4. Vertical profile of vehicle as determined by the horizontal and vertical laser scanner. Vehicle location is determined by the horizontally oriented sensor. Vehicle height profile is determined by the highest reflected ray from the lidar scanner; vehicle length is determined by the point at which lidar energy is no longer reflected back to the lidar sensor.

2) Components and signal flow

The electronic component layout for the minor road sensor suite is shown in Figure 5.

Radar data is directly relayed to the central processor via the lidar computer. Because the lidar sensor scans a 180 degree field of view with 0.5 degree resolution at 30 Hz, the lidar sensor generates a significant volume of data. Because the MMISS system uses eight lidar scanners (six on the minor road, two in the median), broadcasting “raw” lidar data would consume most of the wireless communication system bandwidth. To reduce the consumption of bandwidth, a local computer executes clustering and pattern matching algorithms on the raw lidar data. Once the vehicle height, length, and profile data are available, the lidar computer broadcasts this pre-processed data in a relatively compact message to the central processor.

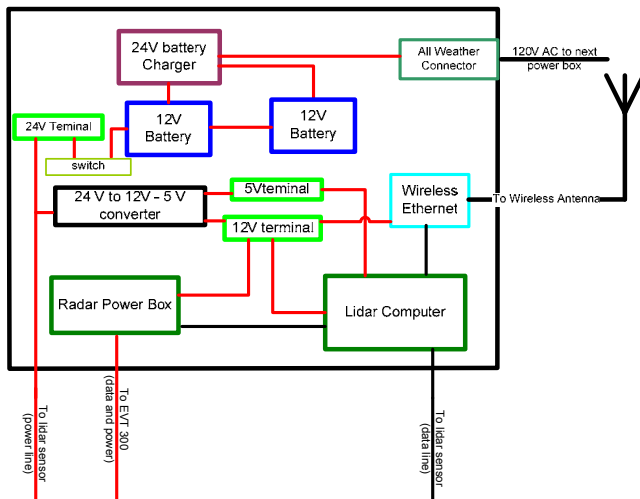


Fig. 5. Layout of lidar-radar subsystem for minor road surveillance sensors. The radar power box contains the J1708 to RS-232 converter and power supply for the EVT-300 radar sensor. This equipment is located in an industrial tool box adjacent to the sensor mount.

C. Median Crossroad Surveillance

Median crossroads sensing is accomplished with a pair of scanning lidar sensors, similar to those used for minor road sensing. The use of lidar in this area represents a departure from the system found at the Minnesota Rural Test Intersection [8], which used an array of visible light cameras and thermal imagers to track vehicles in the median. Sensors in the median were discouraged by the Minnesota Department of Transportation due to their vulnerability to damage (i.e., snowplows, sliding cars, snowmobiles) during the winter months. Vehicle presence and location is determined by identifying the vehicle “corners” and sides in the data returned by the lidar sensors. Presence and location allow the system to determine the length of time a vehicle was in the median, and how time spent in the median affects the gap acceptance decision.

Crash analyses in Minnesota and other partner states have shown that for intersections with higher than expected crash rates, approximately 80% of crashes which occur happen on the “far” side of the intersection; in other words, 80% of the drivers involved in a crash make it safely to the median, but are hit after leaving the median. Driver behavior data measured from the median crossroad will provide insight into the causes of these crashes.

IV. CENTRAL PROCESSOR AND WIRELESS NETWORK

Figure 6 below shows the hardware layout for the MMISS. Primary components include:

- Main processor. The main processor receives both raw and pre-processed sensor data, determines the intersection state, and provides the intersection data acquisition computer information required to capture driver behavior.
- Intersection data acquisition computer, or iDaq. The iDaq records all engineering and video data

assimilated by the main processor and records it on a 400 GByte hard drive, capable of storing two months’ worth of data.

- Camera. A single camera, 7.6 meters (25 ft) above the roadway, is aimed at the crossroads to provide a visual record of near-misses or crashes. This video data is compressed in real time, and recorded by the iDaq in the H.264 format.

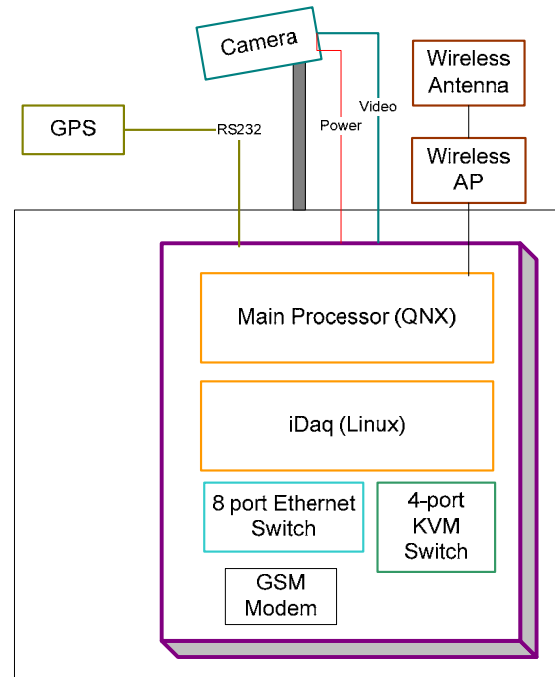


Fig. 5. Layout of the system central processor. The equipment shown above resides in a 6 meter (24 foot) long trailer adjacent to the intersection.

Supporting equipment includes a GSM modem, which is used to provide system status information from the remote site back to the University of Minnesota, and a GPS receiver to support Network Time Protocol (NTP) synchronization. Sensor data is transmitted to the central processor wirelessly using one of two wireless subnets (one access point (AP) per subnet).

A. Main processor

The main system processor receives data from the mainline, minor road, and crossroads median sensors, and estimates the dynamic state of the intersection at 10 Hz. State information includes vehicle position, speed, lane of travel, and classification (where appropriate). Raw radar sensor data is delivered wirelessly to the mainline processor at 16 Hz. This raw data is transformed from the sensor coordinate system to the local state plane coordinate system. Once the data is transformed, the transformed target data is filtered using a local, high accuracy map of the intersection roads [9]. Only those targets found to be on the driveable surface are considered legitimate, and are used to update the present state of the intersection.

Raw minor road and media crossroads lidar data is pre-processed locally by a computer located adjacent to the

sensors. Local pre-processing consists of clustering, pattern matching, coordinate transformation, and filtering against the known roadway digital map. Once legitimate targets are identified locally, their presence, location, and classification (where appropriate) is transmitted wirelessly to the main processor to update the present state of the intersection.

Figure 6 illustrates the intersection state estimation process. Four primary processes occur in a single estimation cycle; the state estimator runs at 10 Hz.

Assimilation of sensor data is the first of the four processes. Validated radar target data is available at a rate of 16 Hz; validated lidar target data is available at a rate of 30 Hz. At the beginning of an estimator clock cycle ($t + \Delta t$), the latest radar and lidar data (prior to $(t + \Delta t)$), including the time at which it was made available, is collected.

The second process is to temporally align the radar and lidar data. All sensors run asynchronously; therefore, all available radar and lidar data is temporally aligned by projecting forward from the time the data was published to the beginning of the clock cycle, $(t + \Delta t)$. The measurement projected to time $(t + \Delta t)$ is represented by the ‘Measurement ($t + \Delta t$)’ block in Figure 6.

The third process rectifies the results of the measurement process with the most recent state estimate to determine how the state has changed (Figure 6, light green box entitled ‘Measurement + Estimated State Matching’). Four outcomes are possible when comparing the ‘Measurement ($t + \Delta t$)’ with the ‘Projected State ($t + \Delta t$)’:

1. An existing target is verified.
2. A new target is identified.
3. A target has been determined to be missing.
4. A target has been determined to have exited the intersection.

Targets may be missed on occasion due to shadowing of the radar beam. Radar sensors are mounted on the right side of the road, and vehicles in the right lane can block vehicles in the left lane from the radar unit. If a previously tracked target is missing for more than eight seconds, it is assumed to have left the intersection.

With existing, new, missing, and exiting targets identified, the fourth process produces an updated ‘Current Estimated State ($t + \Delta t$)’. This new state is represented by the rightmost box in Figure 6.

Once the ‘Current Estimated State ($t + \Delta t$)’ is known, the process repeats with the next estimator clock cycle. The intersection state estimator runs at 10 Hz.

More detail on the intersection state estimator and its performance can be found in [8].

B. iDaq

Both engineering and video data is collected and stored by the iDaq computer. The iDaq is synchronized with the central processing computer using NTP. Intersection state

data is provided to the iDaq from the central processor via a local, hardwired 100Mbit/s LAN.

Video data is collected continuously, and stored as MPEG 4 at a data rate of 1024 Kbit/s in the H.264 format.

To minimize the chance that data will be lost or corrupted due to disk drive failure, both engineering and video data is written to a pair of hard drives. Hard drive one is a 400 GByte, removable drive; hard drive two is a 400 GByte, internal drive. Because of the high video data rate, external drives are too slow to provide tertiary backup.

C. Wireless network.

Surveillance of a highway intersection requires instrumentation on both sides of a road to allow gaps from both the right and left to be analyzed. Because the system is designed to collect data for a period of two months, pushing a data conduit under roads or suspending data cables overhead become expensive and time-consuming tasks. To simplify system installation and keep costs down, a wireless 802.11b wireless network was used to transit sensor data to the central processor.

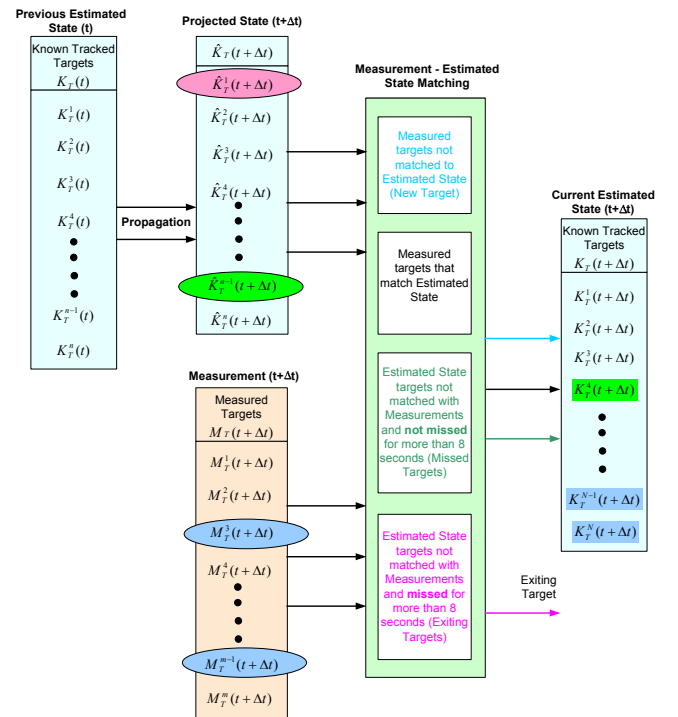


Fig. 6. Signal flow diagram. Bright blue indicates new targets, dark green represents missing (or shadowed) targets, and red represent targets which have exited the intersection.

A number of architectures were examined, with the primary concern being the ability of the wireless communication system to provide continuous sensor data packets to the central processor. However, the architecture chosen and tested consisted of two subnets, each with an access point located at the central processor, and an omnidirectional, 15dB gain antenna mounted at a height of 7.6 meters (24 feet). Each subnet communicates with one ‘side’ of the intersection sensors; moreover, each subnet

uses a unique SSID and non-interfering radio channel.

Each sensor station is assigned a subnet, and is equipped with a station adapter, and its own omni-directional, 15dB gain antenna. To reduce conspicuity, the antenna was mounted on a standard traffic post at a height of one meter (3.3 ft).

Data transfer reliability has been proven to be quite high, primarily attributed to the deployment of the system in rural areas where use of the unlicensed 2.4 GHz spectrum is low.

V. POWER DISTRIBUTION SYSTEM

Similar to the use of a hardwired LAN for data communication, the distribution of electrical power to the four quadrants of an intersection from a single source is both expensive and time consuming. Likewise, the provision of a power drop from the local electrical utility for each quadrant of the intersection is also expensive and time consuming.

To expedite system setup and takedown, and to keep expenses minimized, a power distribution system was designed and implemented. The power distribution system takes a hybrid approach, using battery arrays and a Programmable Logic Controller (PLC) controlled, electric start generator to maintain battery charge.

One leg of the power distribution system is shown in Figure 7 below.

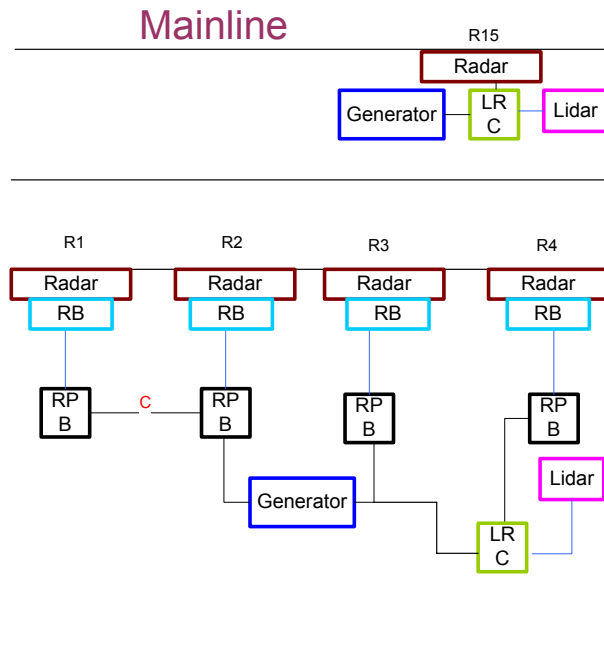


Fig. 7. One leg of an intersection instrumented. ‘RB’ represents the processor local to the radar sensors, ‘RPB’ represents the power supply box for a radar, and LRC represents the power supply box for a lidar and radar station.

Each power supply box is supplied with an Advanced Glass Mat (AGM) battery sized so that the battery, when loaded, discharges to 25% of its capacity in a three-hour time period. Moreover, each power supply box is equipped with an automatic AGM battery charger capable of

providing 33% of the capacity of the battery in one hour. With this arrangement, the PLC runs the generator for one hour, then turns it off for three hours. This duty cycle ensures that batteries never fall below 25% of their capacity; this leads to an estimated battery life of approximately 1000 cycles. A 60 Liter fuel tank mounted to the generator allows the system to run without fuelling for a minimum of five days. With this fuel consumption rate, the system can run over weekends and holidays without the need to refuel.

VI. CONCLUSIONS

The design of the Minnesota mobile intersection surveillance system (MMISS) has been described. This system has been tested for more than two months at the Minnesota Rural Test Intersection. The wireless network performance has proven robust in the rural environment. The power distribution system has performed well, only suffering from occasional generator carburetor icing in extreme cold.

Under State Pooled Fund Project TPF-5(086)), the system will be deployed for two month data collection periods in partner states, starting in April, 2006. “Between state” analysis will indicate gap acceptance variability found throughout the US; this information will be used to design a final system which can be widely and effectively deployed.

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