ROADWAY MONITORING AND DRIVER WARNING SYSTEMS FOR WILDLIFE-VEHICLE COLLISION AVOIDANCE

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ABSTRACT

Wildlife-vehicle collisions are one of the leading causes of insurance claims and motorist injuries in North America. Key requirements for wildlife-vehicle collision mitigation systems are reliability, fast response, low cost per unit road length and low environmental impact. This paper reviews recently developed roadside animal detection systems, including virtual tripwire and radar-based systems. It also provides an in-depth examination of the physical design, processing, deployment and recent performance results of LADS (Large Animal Detection System), a radar-based system currently deployed in Ontario, Canada. Implemented correctly, roadside animal detection systems can lead to increased adoption of such intelligent transportation systems and play an important role in effectively reducing wildlife collisions and improving road safety.

Keywords: wildlife-vehicle collision (WVC), wildlife management, road safety, animal detection system, accident reduction, Intelligent Transportation Systems (ITS), vehicle speed, reliability, wildlife, animal-vehicle collision.

INTRODUCTION

Wildlife-vehicle collisions (WVCs) are one of the key causes for insurance claims and motorist injuries in North America. In the United States alone, national crash databases estimate the total number of reported WVCs at 300,000 per year, but this number is severely under reported due to a variety of reasons, including the typical exclusion of accidents with less than $1,000 in property damage, a lack of resources to collect the necessary detailed information about these collisions, and animals which often leave the roadway after an accident to die elsewhere [1]. In the United States, the best estimate of the total annual cost associated with WVCs is calculated to be around $8.4 billion [1]. In Canada, this number is close to at least $200 million [2]. With continued human expansion into wildlife habitats, WVCs on roadways will only continue to increase in frequency, putting human and animal lives at risk.

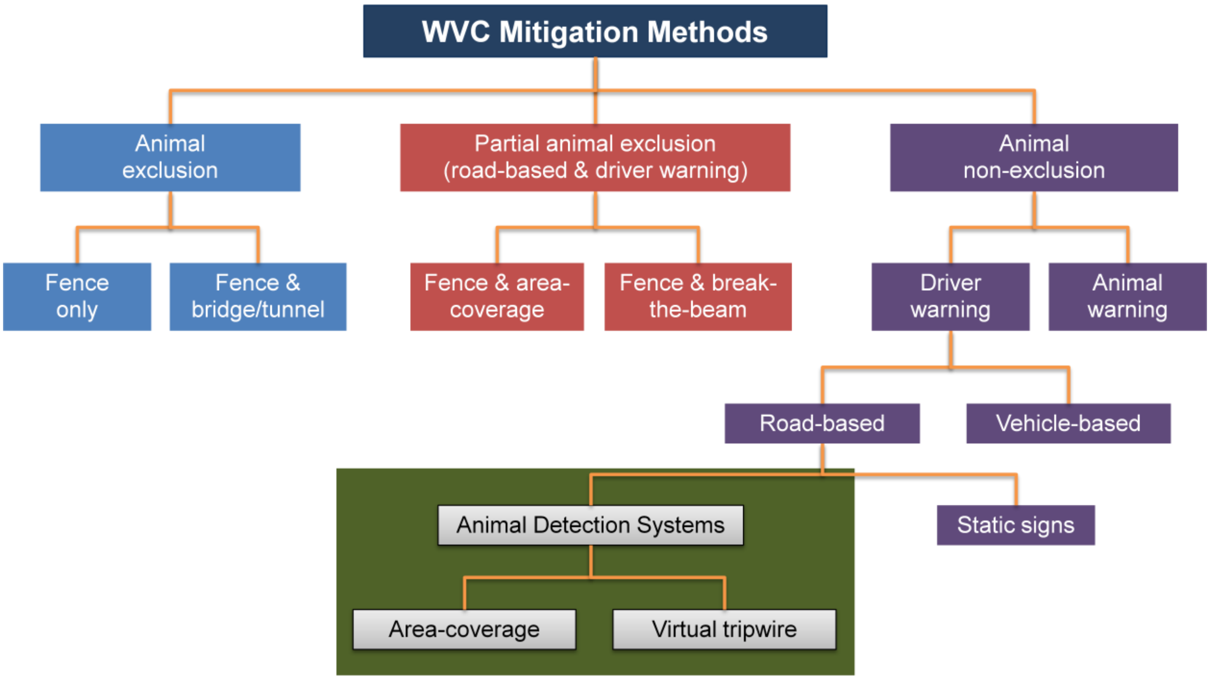


Figure 1: A categorization of WVC mitigation systems

Many solutions have been attempted to mitigate this problem with WVCs. Figure 1 provides a categorization of such solutions. Most exclusion-based systems involve high capital investment to remove wildlife from the road entirely, which creates a positive benefit for drivers and wildlife. These systems may include fencing and crossing structures (such as underpasses and overpasses), or a combination of the two. While these exclusion systems and techniques are often effective at reducing collisions, they remain expensive to maintain and often present a potentially negative environmental impact during the construction stage [3]. This impact and the associated costs often reduce the viability of this option. Other basic, historical deterrents (categorized as animal warning system in Figure 1) such as reflectors, deer whistles and chemical repellents have been proven to be generally ineffective by past studies [4].

Partial-exclusion solutions have also been developed with mixed results. Using a combination of fencing and driver-warning tools, such as virtual tripwire or area-coverage detection and warning systems, these solutions may create false positives for drivers due to interference from weather, debris or even other drivers. Partial fencing may also lead to animals getting stuck in the right of way (ROW) or following the fence until it opens up to the roadway at a key point or intersection [5]. The detection systems used in these solutions also struggle with maintenance issues and alarm fatigue due to increased false positives [6]. While initially effective in some cases, their success is highly dependent on a strict maintenance schedule, weather and other environmental factors.

Beyond roadside solutions, vehicle-based warning systems for WVCs have also recently been developed by car manufacturers such as Volvo, Audi, BMW, Cadillac and Mercedes-Benz [7]. These systems indicate when large animals such as deer and moose are in the roadway and provide a warning to the driver if the animal enters the vehicle's path. None of these systems have been independently tested and many still remain under development [8]. While vehicle-based warning systems may protect drivers who can afford to invest in them, they offer little to no benefit to average drivers on the road. Wide-spread adoption remains unlikely unless legislated and remains cost-prohibitive.

Based on the preceding discussion, road-based wildlife detection and driver warning systems can offer viable solutions to improve road safety when exclusion of animals from the road is not feasible. In the following sections, road-based wildlife detection and driver warning technologies (called animal detection systems for brevity) are discussed in detail. A wildlife detection system (LADS[1]) is described in detail, including its design, deployment and recent performance results.

BACKGROUND

In this section, different animal detection systems, deployed to mitigate WVCs, are discussed with emphasis on their capabilities. These systems are either used in tandem with partial fencing that preserves crossing area for animals (partial animal exclusion) or used standalone (animal non-exclusion). Following [9], the animal detection systems are categorized into two main types:

1. Area-coverage systems detect animals anywhere inside its coverage area (Figure 2).
2. Virtual tripwire systems detect animals while entering/leaving a roadway (Figure 3).

When an animal is detected these systems activate warning apparatus, such as flashing beacons, to warn motorists. Different deployments and the capabilities of corresponding systems are provided in the following sections.

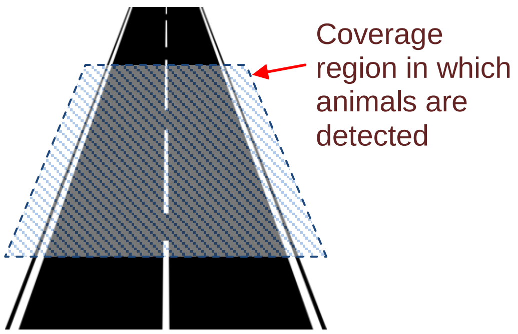


Figure 2: Area-coverage system.

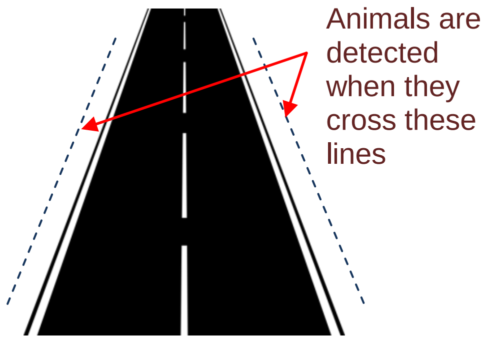


Figure 3: Virtual tripwire system.

A detailed review of road-based driver warning systems prior to Feb. 2006 is provided in [9]. Such systems were deployed as early as 1993 in Switzerland. Other early adopters include the European countries Germany, Finland, the Netherlands and Sweden. The systems were used to detect moose, different species of deer and wild boar on roadways. The first road-based driver warning systems in Europe were area-coverage systems and later a number of break-the-beam virtual tripwire systems were installed. All these systems used fences or existing barriers to funnel animals to crossings on road where their presence was detected and

[1] AUG and MTO received the 2013 ITS Canada Award of Excellence – Projects in Smaller Jurisdictions for LADS (Large Animal Detection System) in recognition of its significant and notable advancement of ITS services

motorists were alerted. Area-coverage systems included passive infrared and short range (50 m) directional (60° horizontal angle) radar. Break-the-beam systems used infrared beams.

Most infrared systems (both area-coverage and break-the-beam) were operational only at night. There are different rationales for this including higher false alarm rate during the day (area-coverage) and less animal activity during the day (break-the-beam). Nevertheless, both area-coverage and break-the-beam systems were prone to false detections. While rain was the major reason for false detections in area-coverage systems, proximity to ground was the main reason for break-the-beam systems. Other limitations of these early systems include the possibility of an animal being stuck inside the fenced section of roadways.

Known North American systems were installed after 2000. The systems installed in North America up to February 2006 were mostly beak-the-beam systems using narrow beams of microwave and infrared as virtual trip-wires [9]. Animals were detected when they blocked the beam between aligned transmitter and receivers pairs. Of the four types of area-coverage systems deployed during 2000-2006, one used 2 passive infrared (thermal) sensors covering 1 km stretch of road [10] in Kootenay National Park, British Columbia, and another system used 34 radars to cover 804 m of road [9] near Thompsontown, Pennsylvania. The third type of area-coverage system, which was deployed in two locations in Wyoming, used passive infrared scopes and geophones and alerted drivers when both sensors indicated animal presence. The fourth type of area-coverage system used receivers picking up signals from elk radio collars to warn motorists. Collaring a high percentage of large animals is not a feasible solution in most locations. The above discussed North American systems were used mainly to detect moose, different species of deer, elk and pronghorn on the ROW.

More recently a partial animal exclusion structure was developed in Preacher Canyon Section of State Route 260, Arizona, to prevent WVCs on a 4 km stretch of road [11]. This system includes fencing to funnel large animals, such as elk and white-tailed deer, to a crosswalk monitored by an infrared (thermal) area-coverage system. This system was installed in Feb. 2007. Other than the break-the-beam systems that rely on obstruction of narrow electro-magnetic beams between aligned pairs of transmitters and receivers, disturbance of electro-magnetic field, generated by buried cable, can also be used to detect animals crossing a line [13]. In 2008, a buried cable based animal detection system was deployed on about 1.6 km stretch of U.S. Highway 160 east of Durango, Colorado. The cables are buried around 30cm deep, 9 m from either side of the highway.

In 2007, a camera-based (visible and night-vision) system to detect crossing animals and warn motorists was deployed on Interstate 40 in Tijeras Canyon, New Mexico. The system operates in tandem with electrified mats that funnels animals to a crossing point. When an animal is detected in the vicinity of the mats warning beacons are triggered [16]. The characteristic of this system is similar to the area-coverage systems. Another system, also deployed in New Mexico (on Route 333), uses camera-based (visible and night-vision) motion detectors to detect animals on either side of the right of way. This system has the characteristics of a break-the-beam system.

There are a number of recent deployments of road-based driver warning systems in Canada. In Nov. 2009, an infrared-based virtual tripwire system was installed along a 1.5 km stretch of Highway 17, north of Sault Ste. Marie, Ontario. In 2012, a similar system was deployed on a 3.5 kilometre section of Highway 6, north of Little Current, Ontario. Past 2011, two area-coverage animal detection systems based on 360° scanning radars were deployed in southern

Ontario. The target of all these systems in Ontario is reduction of WVCs involving white-tailed deer. In Nov. 2011, two infrared-based virtual tripwire systems were deployed on Trans-Canada Highway in Newfoundland and Labrador: one located west of St John's (1.5 km corridor) and the other one located near Grand Falls Windsor (2 km corridor). The target of these systems was moose-vehicle collision reduction.

In Jan. 2012, a virtual tripwire system was deployed on a 2 km stretch of US 41 near Big Cypress National Park, Florida. This deployment particularly targeted reducing WVCs involving Florida panther, an endangered subspecies of cougar. For a limited time in early 2014 a Doppler-radar based area-coverage system was deployed on U.S. 95, south of Bonners Ferry, Idaho.

In addition to the operational deployments, microwave based virtual tripwire systems were tested on a 1070 m stretch along State Route 3 near the city of Fort Jones, northern California for 10 month period starting from Oct. 2011 [12]. Results from this test and the other North American systems discussed above are used to judge the capabilities of different road-side driver warning systems.

Break-the-beam type virtual tripwire systems have the advantage of detecting animals at the instant they cross into the ROW. The trip-wire nature of break-the-beam systems make them very quick in providing information to the motorists. This cannot be achieved by area-coverage systems as all such systems suffer from detection delays. However, break-the-beam systems have several disadvantages:

- Break-the-beam systems can only detect the animals when they block the transmission as they move into or off the road. Such systems are incapable of tracking the animals at other times even if they are in the ROW. For example, the animals may continue to move on the road; they may just linger around the area. For this reason beacons are typically kept activated for 3 minutes after each detection event. Nonetheless, it is possible that the beacons are deactivated in a break-the-beam system while the animals are still on the road, failing to warn the travelers of the presence of animals in the ROW.
- Break-the-beam systems cannot distinguish whether animals are entering or leaving the monitored area when they break the beam; therefore such systems unnecessarily keep the beacons activated for a long time after the departure of an animal from the monitored area.
- Break-the-beam systems require line of sight between sensors and for animal detection this line is required to be very close to the ground. Hence, regular vegetation and snow clearance (if applicable) is required in order to keep these systems operational.
- Break-the-beam systems require precise alignment between transmitter and receiver, which can even be disturbed by wind [6, 12].
- Break-the-beam systems can generate high false alarms due to flying birds, weather conditions, such as fog, rain and snow.
- Break-the-beam systems can be unsuitable for terrain with abundance of ridges, gullies and rocky outcrops [14].

While some of the above discussed drawbacks, such as high false alarm rates and requirements of precise alignment and vegetation clearing, can be addressed by improved system set-up, regular maintenance, improved sensors and processing, other drawbacks, such as inability to detect animals anywhere on ROW, are fundamental and cannot be eliminated from any break-the-beam system.

Buried cable electro-magnetic field systems have the advantage of not generating false alarms due to fog, rain, snow and birds and also does not require regular vegetation and snow clearance. However, such systems require substantial digging. Based on the data from the system deployed on U.S. Highway 160 east of Durango, Colorado, [17] found that the system is prone to generate high false negatives.

Area-coverage systems address the fundamental drawback of break-the-beam systems, which is their inability to monitor animals beyond the virtual tripwire. These systems are capable of tracking animals anywhere inside the ROW. In cases when an animal walks along the road, instead of crossing it laterally, an area-based surveillance system can continue monitoring the animal and warning motorists. Other advantages of area-coverage systems are that they do not need precise alignment of separately installed transmitter-receiver pairs and they can be set-up in places where the terrain includes abundance of ridges, gullies and rocky outcrops.

As discussed before, a fundamental drawback of area-coverage systems is detection delay. There can be up to several seconds of delay in warning motorists. Consider a scenario in which an animal runs and crosses the road. In such a situation, area-coverage systems may not be able to immediately provide warnings. It can be argued that these warnings, which can be available from virtual tripwire systems, may not be useful as they may be too late for a driver to react. From a collision avoidance perspective, scenarios of higher interest are ones in which an animal moves slowly while crossing a road or when it lingers on the road. Even with the detection delay area-coverage system can be useful in these scenarios. Nonetheless, it is possible to construct scenarios in which the detection delay can limit the usefulness of the system.

Some drawbacks of area-coverage systems are sensor-specific. Geophones have limited use as a standalone area-coverage sensor, particularly in the presence of vibration due to heavy trucks and trains [9]. The other area-coverage sensors, infrared (thermal) camera, visible and night vision camera and radar, already have been used in standalone scenarios. Active infrared systems for night-time detection have also been tested in a controlled environment [6]. The drawbacks of infrared-based systems include:

- Poor detection performance in inclement weather conditions, such as fog, rain and snow
- Challenge of detecting animal heat signatures in a broad range of background temperatures
- Challenge of filtering out vehicles
- Sensors have to be placed sufficiently high (7 m [10]) to obtain a top view of the road. This requires constructing tall towers near the ROW, with added concerns related to cost, public safety and aesthetics.

In particular, the infrared system deployed in Kootenay National Park, British Columbia, in 2002, could not be used during daytime, possibly due to a high false alarm rate. A high false alarm rate was observed at night time as well [10]. On the other hand, [11] found that the infrared area-coverage system deployed in Arizona (2007) was very reliable and achieves low false negatives and false positives. In particular, about 98% of time the system detected at least one of each group of elk and white-tailed deer while they were present in the detection zone [11]. The possible reasons for discrepancies in evaluated performance of the two studies are the advancement of infrared detectors and processing technology, the difference in set-up (partial animal exclusion vs. no animal exclusion) and climate, and the different performance criteria examined.

The camera-based (visible and night vision) animal detection system, deployed in Tijeras Canyon, New Mexico, found to have problems due to swaying of poles (9 m tall) [16]. The system also had unacceptably high rate of false positives, at least in the initial stages [18].

One advantage of a radar-based area-coverage system over an infrared one is that the former can be placed at a considerably lower height (around 3m) from the ground which is not too low to require brush clearing. Another advantage is that, in general, radars can provide longer range monitoring capability compared to infrared cameras, which means fewer sensors and poles are needed to cover the same stretch of road. Challenges specific to radar-based area-coverage systems are related to filtering out moving vehicles, swaying branches and water spray. A short-range radar system deployed near Thompsontown, Pennsylvania in 2004 was found to have difficulty in distinguishing vehicles and animals [9]. Radars, particularly the ones that use millimetre wavelength, are also affected by rain and snow, although weather related performance degradation is more severe in the case of infrared sensors. Among different types of radar, Doppler radars cannot detect slow and stopped animals or animals that move cross-range. On the other hand, non-Doppler radars need to subtract complex background clutter of ROW to detect animals. Statistical information on the performance of radar-based area coverage systems, particularly the longer range systems deployed in Ontario, is unavailable at this time due to insufficient data.

In addition to the above-mentioned drawbacks, a number of animal detection deployments suffered from power related issues causing significant downtime.

It is clear improvements are required in animal detection systems. Best performance of such systems is observed in tandem with partial fencing [11]. An area coverage system appears to be the best solution for detecting animals on cross walks as these systems monitor the complete ROW. A collaborative virtual tripwire system can be considered to enhance the performance further. One advantage of this setup, even when the animal detection system is not perfect, is that the drivers need to pay attention only for a short distance (often less than 100 meters) compared to tens of kilometres without partial fencing. The disadvantages are the environmental fallout and the possibility that animals get caught within fenced sections of road. The latter disadvantage can be mitigated by using deterrents, such as electrified mats, that discourages animals leaving the crosswalk [11]. If fencing is not a possibility, such as in critical environmental zones, an area-coverage system that has long range (less digging) is the best solution. WVC mitigation performance of such a system can be improved by improving system robustness and animal detection performance.

LADS: SYSTEM DESCRIPTION AND FIELD PERFORMANCE RESULTS

The previous section explored the merits of different road-based systems for reduction of WVCs. Among the various technologies, area-coverage systems provide persistent monitoring of animals within a region, leading to reliable driver warning. One such area-coverage system, LADS, was developed by A.U.G. Signals Ltd. (AUG) through a project sponsored by the Ministry of Transportation Ontario (MTO), Canada. LADS is described in detail in this section.

How It Works

As a road-based WVC avoidance system, LADS consists of two parts: one part tracks large animals as they approach the road and travel through the monitored region, while the other part warns the drivers by activating flashing beacons. The tracking part of LADS includes a radar and associated processor, while driver warning is achieved using flashing beacons with wireless links.

When an animal enters the monitored area, it is picked up by LADS' radar. The processor examines the radar's signal and determines it to be a large animal. The driver warning system then activates flashing beacons connected over wireless links. LADS not only detects animals but also detects and distinguishes between animals and vehicles.

LADS delivers high reliability by reducing false alarms in detecting animals. This is achieved by combining a radar with advanced tracking algorithms that can accurately track large animals – as well as people and vehicles – moving anywhere within its monitoring range. To the best of our knowledge, LADS is the first system of its kind to use a 360° scanning radar for animal detection and monitoring. LADS consists of a number of independent components – both hardware and software – integrated to achieve reliable and accurate tracking in a low-power, cost-effective and environmentally friendly manner. The system is designed to be modular, which allows upgrading or replacing one or more components without expending too much effort.

LADS: Breakdown of Components/Modules

The system architecture, shown in Figure 4, clearly illustrates the modular composition of LADS.

The figure shows the process flow and the interaction among the different components. The major components (or modules) are: supervisor, radar data acquisition, processor and output handler.

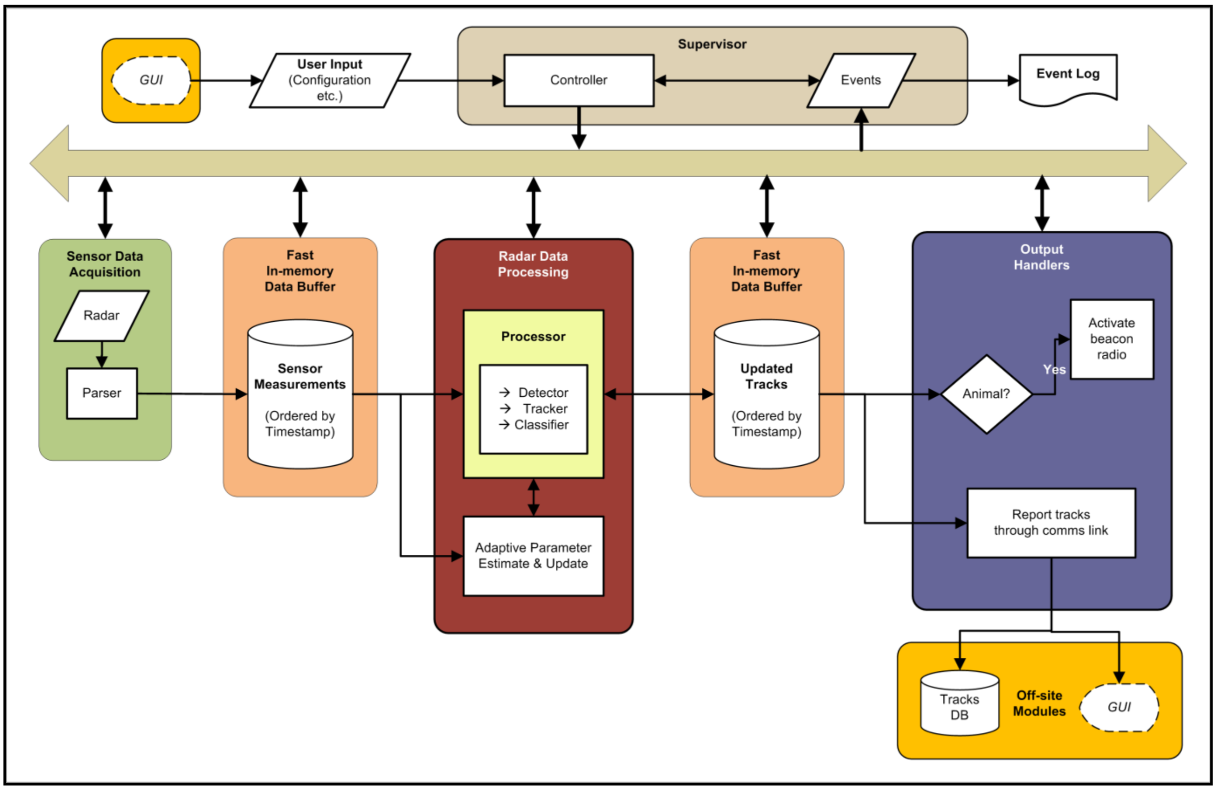


Figure 4: A modular system architecture for LADS

<u>Supervisor</u>

The *supervisor* (beige module at the top) acts as the interface between the operator and the other modules. It is also the interface between any two modules, and handles the input, processing and outputs. This design allows users to replace any module with another as long as both present the same interface to the supervisor. The supervisor reads configuration information from files and passes them to relevant modules, accepts operator (user) inputs (e.g. configuration parameters, enable/disable driver warning or status requests) and executes user requests. It effectively controls the operation and behaviour of all the modules and logs events and, if requested, data during operation.

<u>Radar Data Acquisition</u>

The *radar data acquisition* (green module on the left) consists of the radar and a software parser. Unlike prevalent automotive radars, which typically use Doppler radars, LADS employs a 360° scanning radar with a range of 700 metres. The radar can effectively pick up incursions anywhere within a circular perimeter of radius 700 m. The parser collects all radar measurements and converts them into a digital form suitable for radar data processing.

<u>Radar Data Processor</u>

The *radar data processor* of LADS utilizes advanced non-Doppler radar signal processing that accurately detects each target (vehicle or animal), tracks them through the monitored zone and classifies them. LADS uses spatiotemporal Constant False Alarm Rate (CFAR) detection procedure to detect targets from the complex background of ROW and to adapt to the changes in the background due to weather conditions, such as rain and snow. In order to minimize the time delay in detection, which is inherent to all area-coverage systems, targets are detected and tracked long before they enter the ROW. A novel signature-aided tracking procedure is developed to accurately track targets. Target signature and motion information is used to determine their class – animal or vehicle. Flashing beacons (to warn travellers) are activated only if a tracked target, classified as an animal, enters the ROW. Figure 5 shows a LADS radar image of a divided highway and Figure 6 shows vehicle tracks based on half an hour of accumulated data. Figure 7 shows tracks and animal (human in this case), cars and trucks classification results based on half an hour of accumulated data on a local road.

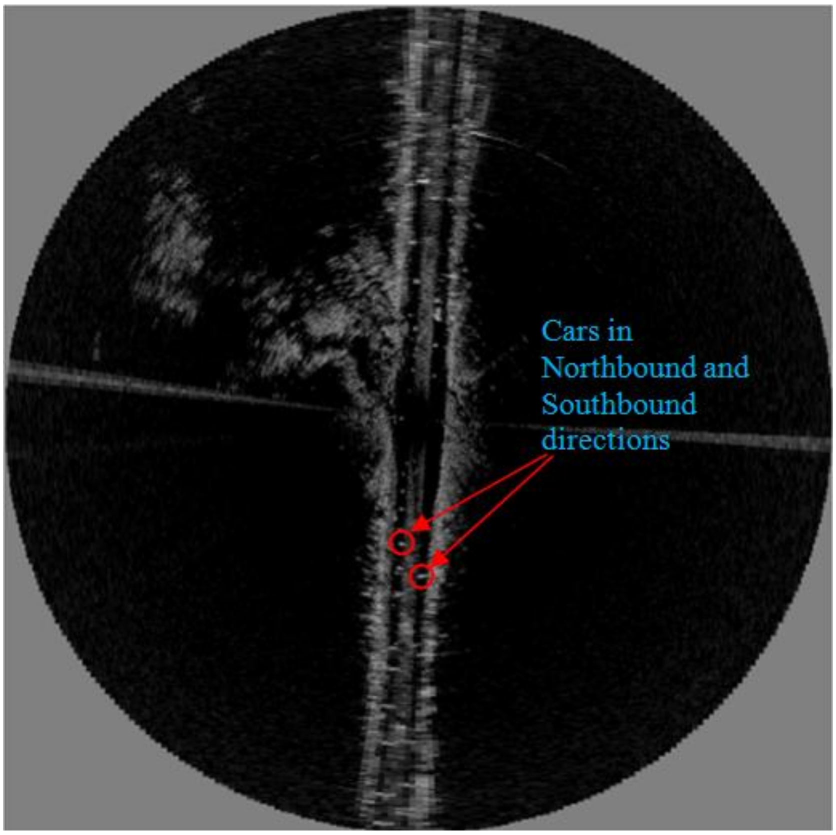


Figure 5: Radar image of Highway 416, near Kemptville, Ontario.

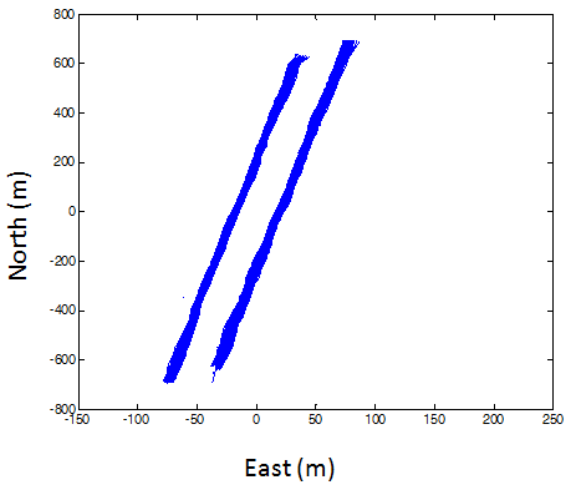


Figure 6: Vehicle tracks accumulated over 30 mins on Highway 416, near Kemptville, Ontario.

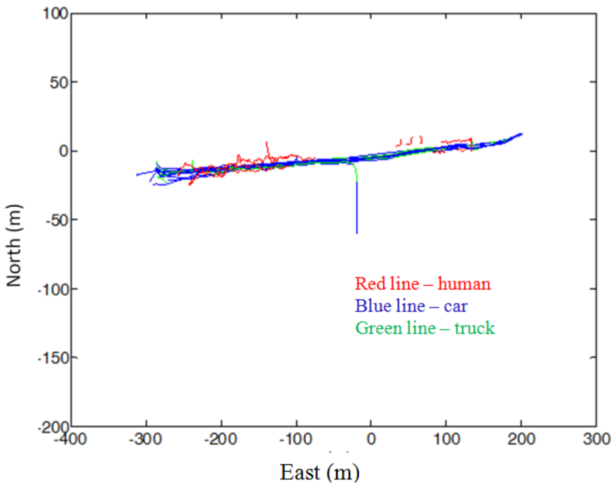


Figure 7: Classified tracks accumulated over 30 mins on a local road.

Output Handler

LADS can support multiple *output handlers* depending upon the intended application. The processor produces tracks of moving entities within the monitored area, categorized as animals or vehicles. At the time of writing, three output handlers are available: the first is the driver warning system, which activates flashing beacons wirelessly when animals are detected; the second is a track save module that archives or logs tracks locally; and the third is a track reporter that communicates tracks over the internet.

The *driver warning system* integrates solar LED flashing beacons with 900 MHz (unlicensed ISM band) wireless radios. A software output handler transmits the activation signal to the flashing beacons through a wireless radio unit whenever it finds an animal track within the monitored region. Note that the size of the monitored region may be smaller than the coverage area of the radar. The total monitored region can consist of one or more enclosed blocks or zones that the operator specifies during configuration.

The *track save module* archives all tracks to files on the local computer. The tracks are stored using the open Google Protocol Buffers® format. The files can be retrieved by operators later and used for analysis. The *track reporter* sends all tracks to an off-site location through a cellular internet modem. The tracks are then stored in a PostgreSQL® database for future use, and can be replayed as well as analysed using the LADS Analysis Software Toolkit (LAST).

Remote Access

Through wired/wireless network, LADS provides remote access capability which allows remote users (using office computers in the office or in a vehicle) to view live road traffic and animal data, to playback historical data, to download animal and vehicular traffic detections, and optionally to control the system's operation. Figure 8 below illustrates the information flow and capabilities of LADS with wireless links and remote access enabled.

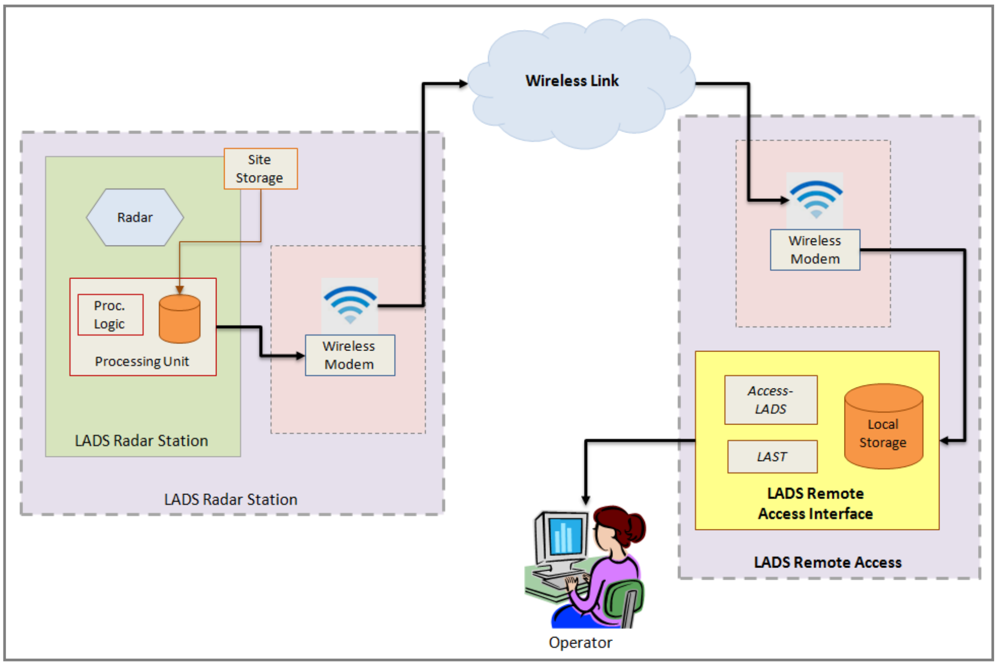


Figure 8: Illustration of Information Flow with Wireless Remote Access of LADS

Access-LADS

LADS provides a software program, *Access-LADS*, run on office computers and laptops, enabling users to retrieve recorded data as well as monitor and control LADS. Using *Access-LADS*, authorized users are able to:

- Start and stop LADS remotely;
- Enable and disable warning beacons remotely; and
- Retrieve recorded animal and vehicle detection data remotely.

The retrieved data contains (1) Timestamps, (2) Locations, (3) Speed, and (4) Heading of every animal and vehicle detected in the monitored ROW. This is stored locally in a PostgreSQL® database on an office computer or database server. *Access-LADS* also provides a user interface to this database, and allows users to generate reports in a Microsoft Office Excel®-compatible format.

Remote access to LADS stations is protected through multi-level authentication so that only authenticated users can gain access from authorized computers. Operators can use *Access-LADS* to determine the operational status of LADS radar stations remotely. Authorized users can also start/stop the system and enable/disable beacon activation in case of scheduled work or in an emergency. In order to prevent unauthorized access, *Access-LADS* includes two levels of access, namely *Administrator* and *Operator*. Both the Administrator and Operator accounts are password-protected. Users must be authenticated before they can gain Administrator access to control the beacons and system operation. Operator access allows users only to monitor LADS and retrieve data, but not control its operation.

LADS Analysis Software Toolkit (LAST)

LAST complements Access-LADS by enabling display of live data as well as visual playback (see Figure 9) and analysis of recorded animal and vehicle data from LADS. It allows operators to:

- Display live road traffic (including vehicle and animal) tracks overlaid on a map.
- Analyze recorded road traffic data, e.g. report traffic volumes at different times of the day, calculate average speed of traffic, and facilitate other analyses of interest to the users.
- Analyze driver behaviour to beacons and signs, e.g. determine whether drivers reduce speed when the system beacons are active.
- Monitor and display recorded traffic data overlaid on a map, e.g. vehicle and animal tracks within the monitored ROW with their speed and heading updated every 5 seconds; vehicle tracks color coded by speeds.

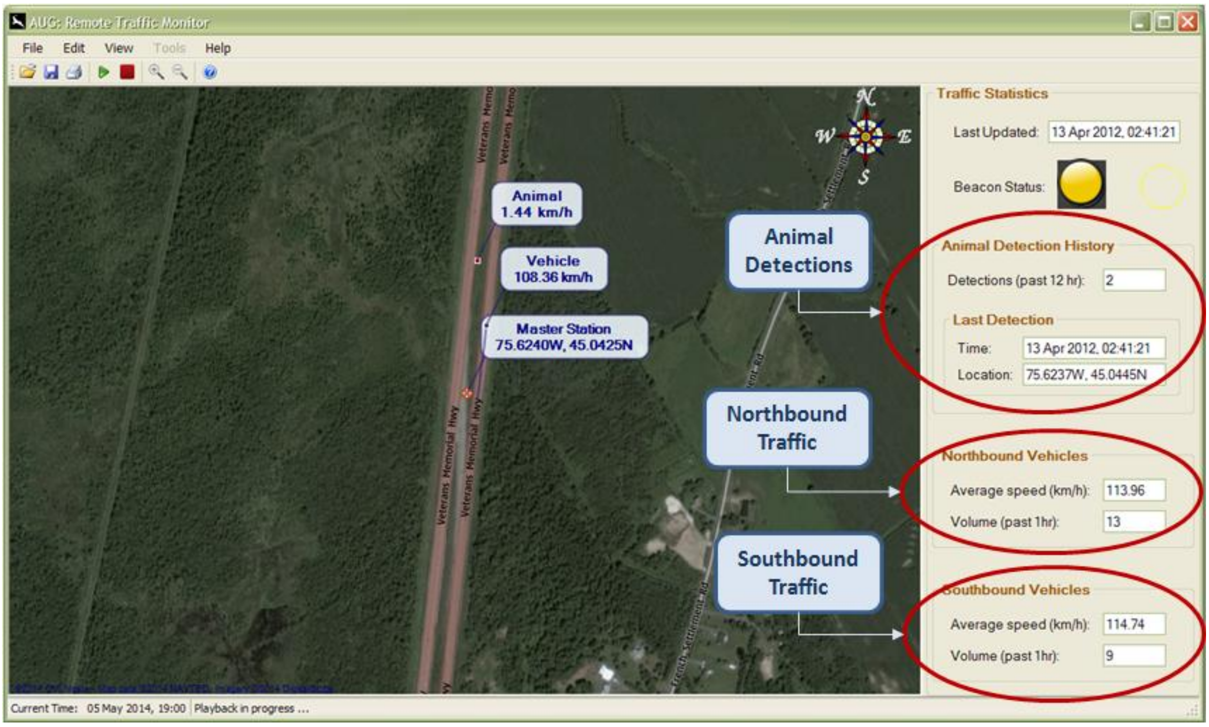


Figure 9: Visual playback of LADS data from 13 April, 2012 on Highway 416, near Kemptville, Ontario.

Installation Site Description

LADS has been installed and in pilot operation since April 2012 for the area along Highway 416 depicted in Figure 10. Highway 416 in this area is a rural freeway divided into four lanes with a posted speed limit of 100 km/h and oriented in a north-south direction. Within the planned installation site, the highway ROW is generally covered with low-lying vegetation, hardwood trees and wet areas (such as marshes and swamps). Highway fences, utility poles and overhead wires typically occupy both sides of the highway at the ROW limits.

The stretch of Highway 416 within the monitored area is fairly straight, without any curves, and level (the elevation difference is less than 1 metre and changes gradually). The width of the highway median is ca. 30 metres; the elevation of the median section is generally lower than the main road, where the lowest part is ca. 1 metre lower. Bushes with the height of ca. 1 metre were growing in the median at the time of the site survey (November 2011).

Installation Site Assessment

There are two municipal drain watercourses that cross the highway within the limits of the monitored site. In order to protect the environment and avoid disturbing the natural habitat of resident and migratory species, no vegetation was cleared within a 30-metre "buffer zone" of the watercourses. Sensor post placement was avoided in the ditch line because sections of cattail mineral marsh within the ditch line may also represent seasonal fish habitat.

It is recommended, where possible, that the bed of water bodies should not be disturbed so as not to alter the existing rock material. Construction equipment was not operated within the defined channel of the watercourses.

To avoid adverse impacts on coyote and fox populations, construction activity avoided dens as much as possible as the timing of installation of the LADS coincided with the denning period for these two species.

The stretch of Highway 416 depicted in Figure 10 is a hot spot of animal-vehicle collisions (mainly deer) due to the existence of the two watercourses. From 2003 to 2009 inclusive and part of 2010, 29 wild animal and vehicle collisions were recorded within the monitored region, based on data provided by Ministry of Transportation Ontario Canada (MTO). 24 out of the 29 collisions occurred around the two watercourses. In light of this evidence, along with the fact that the monitored site is fairly straight and level and has a 30-metre wide median, LADS site layout was designed to provide a compact and safe system, which can be installed with minimal environmental disruption and require minimal maintenance. The detailed system layout is provided in the following section.

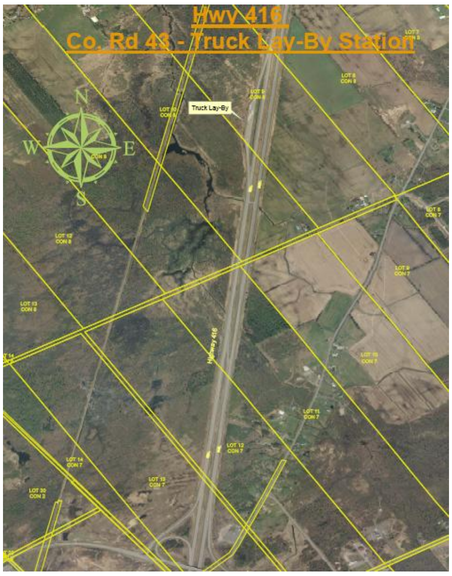


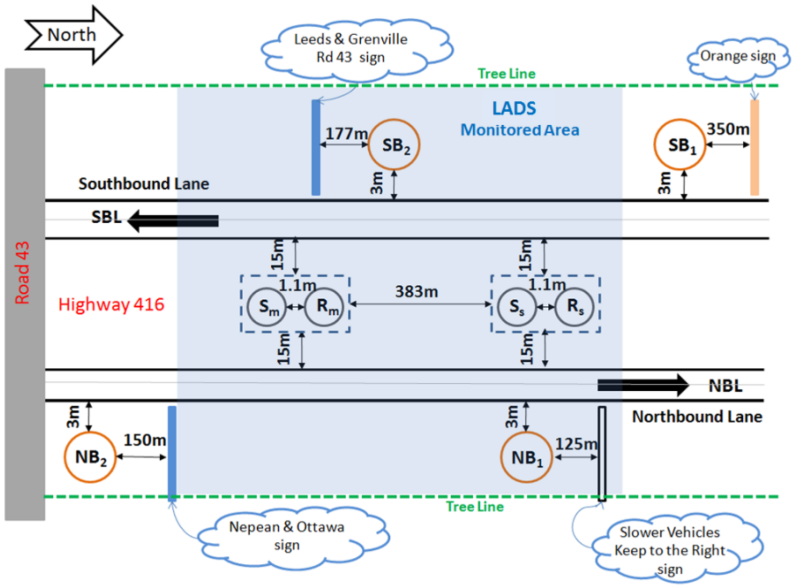
Figure 10: The area along Highway 416 which LADS monitors, ca. 500 m north of the Highway 416/Leeds and Grenville Road 43 Interchange, northerly for 1.5 km. [Image provided by MTO]

LADS System Layout at the Installation Site

The LADS on Highway 416 provides accurate and high-resolution detection of large animals on the ground to a range (radius) of 700 metres over a circular area 360° around the radar. The radar scans a full 360° per second, effectively monitoring ca. 1.5 km^2, provided that the radar has a clear line of sight for the area. Given the condition of the monitored site (as described above under Installation Site Description), only two radars are needed, since they are sufficient to cover the entire monitored stretch of the 1.5 km long highway segment, including the areas on both sides of the road (in front of the tree line), the areas on the road, as well as the areas in the median. Figure 11 illustrates the LADS system layout on Highway 416. Please note that the distances in Figure 11 are not to scale and are provided for illustration purposes only.

LADS on Highway 416 includes two radar stations **RS (R_s, S_s)** and **RM (R_m, S_m)** and four beacon poles (two on the northbound **NB_1** and **NB_2**, two on the southbound **SB_1** and **SB_2**).

The two radars stations are installed in the highway median and each station is located 15 metres away from the inner driving lane. The radar station on the south side is the Radar Master Station **RM**; the radar station on the north side is the Radar Slave Station **RS**. For each radar station, the solar pole is installed on the south side of the radar pole with solar panels facing south to supply power for the radar and the processing and communication unit; the distance between the solar pole and radar pole is 1.1 metres.



Symbol	Denotes
NB_1, NB_2, SB_1, SB_2	Beacon poles with beacons and antennas
R_m, S_m	Radar Master Station with radar pole R_m and solar pole S_m
R_s, S_s	Radar Slave Station with radar pole R_s and solar pole S_s

Figure 11: LADS system layout illustration (not to scale)

LADS' monitored area, indicated in Figure 11 as the blue shaded area, covers the areas on both sides of the road (in front of the tree line), the areas on the road as well as the highway median, and matches the tree lines as they meander and change during different times of the year. The LADS is configured to trigger flashing beacons whenever large animals appear at any time inside LADS' monitored area. The locations of the two radar stations have large enough overlapping coverage so that they fall within each other's radar scan range; by doing this, the radar blind spots, which are the areas within a 10 metre range from the radar (i.e. a circle with a 10 metre radius from the radar), are covered and closely monitored by LADS.

Upon detection of large animals, the Radar Slave Station **RS** immediately informs the Radar Master Station **RM** through the wireless data transmission from the slave radio installed in **RS** to the master radio installed in **RM**. The Radar Master Station **RM**, upon receiving the "animal detected" signal from **RS** and/or upon the detection of large animals by the radar of **RM**, triggers the four flashing beacons through wireless transmission from the master radio of **RM** to the slave radios installed on the beacon poles. The beacons will keep flashing as long as large animals are being detected within the LADS monitored area. If no more large animals are detected, the beacons will stop flashing after 15 seconds (compared to 3 minutes required by break-the-beam type virtual tripwire systems).

The four beacon poles are installed at the shoulder of the highway and each of them is 3 metres away from the outside edge of the outer traffic lane. Figure 12 is a screenshot from the street view on Google Maps®, which shows one of the two radar stations installed in the median of Highway 416 and one of the four remotely controlled beacon signs installed on the shoulder.

Figure 12: Google Street Maps view of LADS installed on Highway 416, near Kemptville, Ontario. Site geo-coordinates: (45.04248, -75.62396)

RESULTS

For any wildlife detection system to achieve the goal of reducing the number of wildlife-vehicle collisions, it needs to 1) have reliable detection of large animals; 2) influence driver behaviour so that drivers can avoid a collision.

Ultimately driver response determines the effectiveness of the system in avoiding or reducing animal-vehicle collisions. Proper driver response, including a higher state of alertness, lower vehicle speed, or both, results in reduced risk of a collision with the animal and less severe collisions. In [12] the authors studied about 10 months of data (from August 2011 to May 2012) to analyze the effect of the dynamic animal warning signs on the traffic speeds when illumined. The result shows that mean traffic speeds were reduced from 56.2 mph (90.4 km/h) when the warning signs were covered to 53.1 mph (85.5 km/h) when the warning signs were illuminated.

The dynamic animal warning signs appeared to be more effective in the evening and overnight hours with an average mean speed reduction of 4.9 mph (7.9 km/h), or 8.7% speed reduction. The speed reduction remained relatively constant, ranging from 4.5 to 5.8 mph (7.2 to 9.3 km/h) throughout the study period. The result from [15] also demonstrated the reduction of vehicle speed in response to activated warning signs, though to a smaller degree. The speed of passenger cars, pick-ups, and vans was 1.52 mph (2.45 km/h) lower with warning signs activated; for trucks, vehicle speed was 0.91 mph (1.46 km/h) lower with warning signs activated.

Analysis of the road traffic data and system operation data collected by LADS shows drivers slow down when the warnings are active, see Table 1. It is clear from Table 1 that when the beacons are on, warning drivers about the presence of large animal on the ROW, there is about 16.46 km/h or 15% reduction in vehicle speed in the monitored area. At LADS deployment site, vehicles travelled at higher speed than those studied in [12] and [15], even more so at night time, since LADS was installed along a highway with a speed limit of 100 km/h. This may be one reason the speed reduction when warning signs are activated is more significant in LADS. Unlike the findings presented in [12], the result from LADS does not show significant difference between the day time speed reduction and night time speed reduction.

Table 1: Driver Response from LADS Highway 416 near Kemptville, Ontario, June 15-July 30, 2012

Average Speed	Beacons OFF (km/h)	Beacons ON (km/h)	Absolute Reduction in Speed (km/h)	Reduction in Speed (%)
Overall	105.79	89.33	16.46	15.6
Day Time	105.58	89.30	16.28	15.4
Night Time	110.11	93.58	16.53	15.0

Reliable detection of animals is another key factor which affects the effectiveness of the system. Too many false positives (the system gives warning to the presence of an animal when there is no animal present) result in drivers ignoring the warnings from the system. On the other hand, false negatives (the system fails to detect when an animal approaches) should be avoided as drivers expect an animal detection system to detect all or almost all large animals when they are present. LADS employs advanced detection and tracking technology to warn drivers when animals enter ROW and continues monitoring them throughout their presence in ROW. The verification process of LADS' detection reliability is underway, which involves utilizing cameras for detection validation.

CONCLUSIONS

Wildlife vehicle collisions remain an important, increasingly frequent problem for road safety in North America. While a number of potential solutions currently exist, no single system or technique can adequately address all aspects of these collisions. Animal detection systems focused on monitoring animal movement and alerting drivers to their presence can play a role in increasing road safety, alongside more traditional solutions such as fencing and underpass construction. In its current installation without fencing, LADS presents a unique example as an environmentally-conscious system designed to protect drivers and wildlife. As a specific example, its recent performance results point to effective warnings and signage contributing to slower speeds and fewer accidents. More tests are necessary to verify the different animal detection systems available, including LADS, based on unique terrain, climate and road conditions. Animal detection systems present viable and feasible solutions with the correct application and support from larger intelligent transportation systems, including infrastructure. Unified solutions drawing from a number of safety resources can potentially eliminate the majority of WVCs in North America.

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