Use of Vehicle-Mounted Heat Detection Systems to Reduce Animal-Vehicle Collisions

Requested by
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Executive Summary

Background

Animal-vehicle collisions are a significant problem in many rural areas of California. Researchers have explored various methods of reducing collisions, including roadside animal warning systems, with mixed results. Caltrans is interested in investigating a cost-effective alternative to roadside animal detection and warning systems—a vehicle-mounted system that detects animals on or near the roadway and warns drivers of their presence. The department is particularly interested in aftermarket thermal cameras that capture infrared radiation to detect animals in low-visibility conditions.

To assist with this effort, CTC & Associates conducted a literature search to identify research and other relevant publications that address the effectiveness of vehicle-based thermal imaging systems in detecting animals and generating an appropriate in-vehicle warning. This review sought information about:

- Independent evaluations of animal detection systems that are commercially available as aftermarket additions to passenger vehicles.
- The performance and commercial applicability of systems that are still at the prototype phase.
- Driver behavior in response to in-vehicle alerts or warning systems, especially animal detection systems.

Summary of Findings

Through a literature search, we identified two aftermarket vehicle-mounted heat detection systems: FLIR's PathFindIR II and the Guide N-Driver. Both focus primarily on pedestrian detection but can be used to detect animals as well. However, we did not uncover rigorous, third-party evaluations of these systems. We also did not identify additional prototype systems of this type.

Given the lack of research available on these topics, we broadened our review to include thermal imaging detection systems designed for factory installation. Night Vision, a thermal imaging driving aid produced by Autoliv, has been installed in Audi, BMW and Daimler vehicles. Autoliv touts Night Vision's animal detection system, introduced in 2013, as the first of its type in the world.

We found no research specifically addressing driver behavior in response to alerts from a vehicle-mounted, thermal image-based animal detection system. However, several studies have examined driver behavior in response to in-vehicle alerts from pedestrian detection systems.

Use of Thermal Imaging for Detection

Researchers' examination of thermal imaging to improve night vision has focused on the detection of pedestrians; recent publications have considered the conditions under which this technology is most effective and provided a comparison of sensor performance.

A 2013 University of Minnesota study developed a thermographic roadside deer detection system intended to be used as part of a driver warning system. In comparing roadside detection systems with on-vehicle animal detection technologies, the author said that on-vehicle detection systems “only detect deer or big animals down the road direct to the front of vehicles passively and unfortunately ignore ones on the side of the road.”

Aftermarket Vehicle-Mounted Detection Systems

FLIR Systems and Wuhan Guide Infrared Co. offer vehicle-mounted aftermarket heat detection systems that are used to improve drivers’ night vision. Limited information beyond vendor-produced materials is available for both systems.

The FLIR camera’s thermal sensor, typically mounted behind a vehicle’s front grille, converts the heat detected on the roadway into an image for display on a video monitor inside the vehicle, highlighting pedestrians and animals with yellow boxes. The camera, which is weather-resistant and hermetically sealed, has an operating temperature range of -40º C to +80º C. A 2014 user manual identifies the conditions under which the system is likely to detect an animal. The manual also notes that “[d]epending on conditions and ambient temperatures, the detection algorithms [for the pedestrian and animal detection system] may work poorly or not at all during the daytime,” but does not describe the ideal conditions for effective system operation. A 2015 *CNET* review indicates that the system is easy to install and use, but at $2,500 is “a pricey kit” that may be best for use on larger vehicles given the size of the camera.

The web site describing the Guide N-Driver system indicates that the product’s animal detection function is under development. The N-Driver’s detection system uses a visual display inside the vehicle to highlight images of pedestrians and animals using yellow and red boxes. The visual warning is augmented with an audible alarm.

The features and functionality of Opgal products developed for use on military armored vehicles may inform an examination of systems developed for passenger vehicle use. Opgal’s Tavor is a vehicle-mounted thermal image camera that allows the operator to drive in complete darkness or low-visibility conditions.

Factory-Installed Detection Systems

Factory-installed technologies that provide nighttime driving assistance offer an alternative to aftermarket systems. Night Vision, a thermal imaging driving aid produced by Autoliv, has been installed in Audi, BMW and Daimler vehicles. The vendor touts its animal detection system, introduced in 2013, as the first of its type in the world. Thermal video images that highlight animals and pedestrians are displayed on an in-dash display; an audible alert is generated if the driver does not change the vehicle’s course or apply the brakes. Publications authored by an Indian researcher and an Autoliv employee describe advantages and disadvantages of the system, with the article authored by the Autoliv employee noting that the “[t]he Autoliv night vision animal detection system is complementary to currently used methods for preventing accidents with animals.”

Driver Behavior in Response to Detection System Alerts

We found no research specifically addressing driver behavior in response to alerts associated with a vehicle-mounted, thermal image-based animal detection system. We did identify publications that provide general guidance on user needs and driver behavior in response to in-vehicle alerts. An in-progress NCHRP project is developing guidance for presenting drivers with dynamic information about real-time roadway conditions. In recently completed research, a virtual environment was developed to assess drivers’ performance and distraction related to an infrared thermal imaging system, and researchers examined the effectiveness of different types of auditory and visual warnings.

We reviewed publications that assess driver response to alerts generated by pedestrian detection systems since these systems can also be used to detect animals. A 2012 research study used subjective driver acceptance ratings to inform the design of alerts associated with a night vision pedestrian detection system. Two variables—pedestrian location and motion—were found to influence ratings. Alerts were more accepted when pedestrians were close to or moving toward the vehicle's path. In a 2010 study, researchers examined warning modes and their effect on the behavior of older drivers, concluding that when multiple types of warnings (for example, tactile, auditory and visual warnings) were presented in combination, their effectiveness decreased.

The effect of clutter in visual displays was examined in another 2010 study in which researchers concluded that images with less clutter required shorter search times and fewer glances to detect a pedestrian. In addition, a 2007 conference paper describes the development of a conceptual display for night vision systems. The authors considered user acceptance and annoyance, distraction and expected behavior adaptation in developing what they termed "a simple and potentially effective display for night vision systems."

Gaps in Findings

We found no research-oriented, independent evaluations of the effectiveness of aftermarket vehicle-mounted heat detection systems used to detect animals on the roadway. This could be due to a greater emphasis by vendors on similar technologies used in factory installations, or the recency of development of systems specifically for detecting animals. (Autoliv states that its animal detection system, incorporated into its factory-installed Night Vision system in 2013, is the first of its kind.) We also did not identify prototype vehicle-mounted systems developed by researchers as an alternative to current aftermarket solutions or factory-installed systems. Finally, we found no research that examined driver behavior related to alerts generated by vehicle-mounted heat detection systems that specifically identify animals.

Next Steps

Given the lack of research on the effectiveness of commercially available vehicle-mounted animal detection systems, Caltrans may want to consider conducting a field evaluation of an aftermarket thermographic detection system to assess its performance. Alternatively, Caltrans could conduct a detailed examination of factory-installed heat detection and warning systems to identify similarities with aftermarket systems. If similarities exist between the two types of systems, it may be possible to extrapolate the results of independent evaluations of factory-installed technologies to a similar aftermarket alternative.

Detailed Findings

Consultation with Experts

We contacted two organizations known to have experience with research related to animal-vehicle collisions. Our goal was to identify any independent evaluations of commercially available thermal image-based animal detection systems developed for use as an aftermarket addition to passenger vehicles.

Representatives from the Deer-Vehicle Crash Information Clearinghouse (see http://www.deercrash.org/) and the Western Transportation Institute indicated that their organizations had not conducted such research, nor were they aware of an independent evaluation completed by other researchers.

This response is consistent with the findings of our literature review. While we identified literature that considers the use of thermal imaging to detect both animals and pedestrians, we did not locate published, independent research that addresses the effectiveness of aftermarket on-vehicle heat detection systems designed to detect animals.

Contacts: Keith Knapp, Director, Iowa Local Technical Assistance Program, Deer-Vehicle Crash Information Clearinghouse, Iowa State University Institute for Transportation, 515-294-8817, kknapp@iastate.edu.

Patrick McGowan, Research Engineer, Western Transportation Institute, Montana State University, 406-994-6529, patm@coe.montana.edu.

Use of Thermal Imaging for Detection

While we did not identify research that addresses the use of vehicle-mounted animal detection systems, the sampling of publications below indicates that researchers have examined the use of thermal imaging to improve night vision, particularly in connection with detecting pedestrians.

Detecting Animals

Thermal Image-Based Deer Detection to Reduce Accidents Due to Deer-Vehicle Collisions, Debao Zhou, Intelligent Transportation Systems Institute, Center for Transportation Studies, University of Minnesota, January 2013.
http://www.its.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=2224
This project used roadside thermographic cameras to monitor the surroundings on highways to detect deer. The project developed and tested a deer detection algorithm, but the cameras were not connected to a driver warning system.

The author contrasts this “active roadside detection technology” approach with on-vehicle detection technologies. He identifies limitations of on-vehicle detection technologies (see page 2 of the report; emphasis added):

> Detection roadside technologies developed usually have flashing signs to alert the driver when a deer is detected as a threat in the vicinity. On-vehicle technologies also aim at either deterring or detecting deer to avoid collisions. On-vehicle deterrence technologies include

whistles and TH - High Intensity Discharge lighting systems. However, neither the audible nor visible methods of deterrence proved effective in any studies. *On the other hand, current on-vehicle detection technologies, including forward-collision sensors, ultrasonic sensors, and thermographic cameras that give the driver a thermographic image of the road ahead, only detect deer or big animals down the road direct to the front of vehicles passively and unfortunately ignore ones on the side of the road.*

Detecting Pedestrians

"Thermal-Infrared Pedestrian ROI Extraction Through Thermal and Motion Information Fusion," Antonio Fernández-Caballero, María T. López and Juan Serrano-Cuerda, *Sensors (Basel)*, Vol. 14, No. 4, pages 6666-6676, April 2014.
Citation at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4029647/
From the abstract:

> This paper investigates the robustness of a new thermal-infrared pedestrian detection system under different outdoor environmental conditions. In first place the algorithm for pedestrian ROI [region of interest] extraction in thermal-infrared video based on both thermal and motion information is introduced. Then, the evaluation of the proposal is detailed after describing the complete thermal and motion information fusion. In this sense, the environment chosen for evaluation is described, and the twelve test sequences are specified. For each of the sequences captured from a forward-looking infrared FLIR A-320 camera, the paper explains the weather and light conditions under which it was captured. The results allow us to draw firm conclusions about the conditions under which it can be affirmed that it is efficient to use our thermal-infrared proposal to robustly extract human ROIs.

"Analysis and Assessment of Far Infrared Sensor Performance Parameters and Their Impact on Pedestrian Detection," Stefan Franz**,** Roland Schweiger, Otto Lohlein and Kristian Kroschel, *Proceedings of the13th International IEEE Conference on Intelligent Transportation Systems*, pages 119-124, 2010.
Citation at http://dx.doi.org/10.1109/ITSC.2010.5625274
From the abstract:

> In this contribution four different far infrared sensor setups with different optical configurations are evaluated based on their performance for pedestrian detection. The focus of the measurements is on the impact of resolution and sensitivity on the detection performance. To overcome the expensive and time consuming process of ground truth generation for multiple sensors, an approach for reusing available high sensitivity reference data is presented. Each of the sensors is evaluated at its basic and two simulated resolutions. Classifiers are trained on specially transformed reference data with characteristics of sensors with degraded performance parameters. For the evaluation of the classifiers, data of real world road scenarios is collected with the target sensors mounted in parallel in a test vehicle, following a detailed script for recording a pedestrian scene test catalogue. This allows for a direct analysis and comparison of the different sensors and their impact on the detection performance.

Aftermarket Vehicle-Mounted Detection Systems

The publications below offer a high-level overview of sensors used for vehicle-mounted thermal imaging and an examination of two commercial products—FLIR's PathFindIR II and the Guide N-Driver—that use heat detection in aftermarket applications to provide nighttime driving assistance in passenger and other vehicles. The FLIR product provides a visual warning; the Guide N-Driver provides visual and audible warnings.

A third vendor product—Opgal's Tavor—is also highlighted. This vehicle-mounted thermal image camera, developed for use on military armored vehicles, allows the operator to drive in complete darkness or low-visibility conditions. While not developed for the passenger vehicle aftermarket, the features and functionality of Opgal products may inform an examination of products developed for passenger vehicle use.

"Overview of Benefits, Challenges and Requirements of Wheeled-Vehicle Mounted Infrared Sensors," John Lester Miller, Paul Clayton and Stefan F. Olsson, FLIR Systems, Inc., *Infrared Technology and Applications XXXIX*, Conference Vol. 8704, June 2013.
http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1697129
From the abstract:

> Requirements for vehicle mounted infrared sensors, especially as imagers evolve to high definition (HD) format will be detailed and analyzed. Lessons learned from integrations of infrared sensors on armored vehicles, unarmored military vehicles and commercial automobiles will be discussed. Comparisons between sensors for driving and those for situation awareness, targeting and other functions will be presented. Conclusions will be drawn regarding future applications and installations. New business requirements for more advanced digital image processing algorithms in the sensor system will be discussed. Examples of these are smarter contrast/brightness adjustments algorithms, detail enhancement, intelligent blending (IR-Vis) modes, and augmented reality.

FLIR PathFindIR II

PathFindIR II: Driver Vision Enhancement System, FLIR Systems, Inc., 2016.
http://www.flir.com/cores/content/?id=62945
From the web site:

> PathFindIR II is a powerful thermal night vision camera that lets you see clearly in total darkness, regardless of the vehicle you're driving or the road you're on.
>
> Headlights usually only let you see about 450' straight ahead, but PathFindIR II sees heat not light, so you can see everything in front of you up to four times farther down the road. Now you can see clearly, night and day, in good weather and bad, without being blinded by the glare of oncoming headlights.
>
> Unique in the industry, PathFindIR II is an automotive-qualified system that is hermetically sealed, rated to IP-69, with an integrated, automatic window heater. It uses 12 VDC input power, and standard NTSC video is output for compatibility with most monitors or displays.
>
> Intended as an aftermarket addition, PathFindIR II is based on a 320x240 thermal camera system with a 24° field of view. For applications that require wider or narrower fields of view,

choices of AGC levels, color, digital zoom, higher resolutions, or smaller packing volume, FLIR recommends the Tau 2 or Quark.

As indicated above, the PathFindIR II's 24° field of view can be improved upon with other FLIR products not specifically geared to the passenger car aftermarket:

- Tau 2, a longwave infrared thermal imaging camera, offers narrow and wide fields of view that range from 6.2° to 90°. The vendor indicates that these cameras are "well-suited for demanding applications like Unmanned Airborne Vehicles (UAVs), thermal weapon sights, and handheld imagers." A brochure providing specifications for the three models and nine lens options for the Tau 2 is available at http://cvs.flir.com/tau2-family-brochure?_ga=1.126540168.467744980.1465218944.

- Quark 2, a longwave infrared thermal core camera, is described by the vendor as "the smallest and lightest fully-integrated uncooled camera in existence." The vendor indicates that the Quark 2 is appropriate for applications such as UAVs, handheld imagers, security cameras, maritime cameras and military-grade goggles. Fields of view range from 9.3° to 69°. A brochure describing the product is available at http://cvs.flir.com/quark-brochure?_ga=1.236066308.467744980.1465218944.

The PathFindIR II's camera has an operating temperature range of -40° C to +80º C. A built-in heating element is automatically turned on when the temperature of the window falls below 4º C and is tuned off when the temperature reaches 6º C. The camera's IP rating of IP 69K means that the camera is protected from total dust ingress and from high-pressure, high-temperature wash-down applications.

Related Resources:

User Manual: PathFindIR II, Version 100, FLIR Systems, Inc., February 2014.
http://www.safetyvision.com/sites/safetyvision.com/files/FLIR_PathFindIRII_User_Guide_1.pdf
This user manual describes how the FLIR product works, the installation process and use of the system. As the manual indicates, the PathFindIR's Vision Processor is "primarily designed to detect pedestrians and animals at night time. Depending on conditions and ambient temperatures, the detection algorithms may work poorly or not at all during the daytime." The manual offers no further details as to the conditions and temperatures affecting daytime use.

Page 18 of the manual (page 22 of the PDF) describes the animal detection feature:

4.5.1 Animal Detection
The animal detection is available when the vehicle is in a rural environment. The system is highly likely to detect an animal correctly if:

- The animal is of the deer family (roe deer, fallow deer, red deer, reindeer, caribou, moose, cow, horse etc.)
- The animal is in an upright pose
- The animal is moving
- Most of the animal body is visible
- The system is highly likely to detect correctly even if:
- Not all of the animals' legs are visible

- The animal has attributes such as horns or tail, or is carrying objects such as saddle, saddlebag, collar, leash, necklace and muzzle
- Animals are present in a group or herd. The algorithm most likely detects the most visible animals (which are not obstructed by others) in the group or the ones who somewhat separated from the group. Therefore, the animals that represent the highest risk are detected.

The system is likely to detect correctly, but may give degraded performance if:

- The animal is of the pig family
- The head of the animal is not visible

The system is unlikely to correctly detect an animal if most of the animal body is not visible in the image. The system may incorrectly detect something as an animal if the structure and heat signature in the image is similar to the shape and/or heat signature of an animal. Such structures are sometimes found on various objects, for example warm stones, parts of buildings, parts of vehicles, street lights, and so on.

"FLIR PathFindIR II Review: FLIR Super Powers Cars with Pedestrian-Detecting Night Vision," Wayne Cunningham, *CNET*, February 12, 2015.
http://www.cnet.com/products/flir-pathfindir-ii/
This review of the FLIR PathFindIR II thermal night vision system produced a 6.3 overall rating and these comments:

> **The Good** The Flir PathFindIR II processes its infrared video to pick out pedestrians and large animals, highlighting them on the video monitor. The system installs with plug-and-play ease.
>
> **The Bad** At $2,500, this is a pricey kit, and the chunky camera won't fit well in smaller cars. The pedestrian and animal tracking imagery looks crude.
>
> **The Bottom Line** The PathFindIR II presents very gee-whiz imagery, but its cost and installation put it in a niche market, best for people with larger vehicles who drive dark, rural roads beset with wandering livestock.

The author also notes this:

> With a 24-degree field of view, the image caught traffic and pedestrians immediately in front and in each lane to the right and left.
>
> ....
>
> Many states in the US make it illegal to have a video monitor in view of the driver, although some of these laws specifically ban television signals. A video signal showing the vehicle's surroundings, similar to a back-up camera, may pass legal muster. That said, viewing the PathFindIR II signal involves occasional glances at the screen, especially when the road ahead looks particularly dark.
>
> ….
>
> I called out the crudity of the system graphics and the lack of sophisticated computing. That said, you won't find such sophisticated systems in the aftermarket at present.

Aftermarket Installation of a PathFindIR in a Porsche Cayenne: Application Story, FLIR Systems, Inc., undated.
http://www.flir.com/uploadedFiles/CS_EMEA/Application_Stories/Media/Downloads/KPsports_EN.pdf
This marketing piece describes a user's experience with installation of an aftermarket kit for the FLIR PathFindIR, an earlier version of the PathFindIR II product. Among the user's observations:

- Installing the PathFindIR is fairly easy; the thermal imaging camera is installed behind the radiator grid.
- The PathFindIR is well protected against harsh driving conditions. Rain, salt spray and small rocks hitting the front of the camera have not affected the camera or its operation.

Guide N-Driver

Guide N-Driver: Intelligent ADAS Infrared Night Vision System for Vehicle Navigation, Wuhan Guide Infrared Co., Ltd., undated.
http://guideinfrared.com/Plus/m_default/Cms/docDetail.php?ID=29
From the web site:

> Guide N-Driver, intelligent ADAS infrared night vision system for vehicle navigation, sees through the total darkness, thick smoke, dense fog, heavy rain and snow, reveals unexpected obstacles, highlights sudden events, improves visibility of road signs, navigates on unknown roads and overcomes blindness caused by oncoming headlights, thus dramatically lowers the risks of driving and enhances the safety of lives, properties and profits. Featured razor-sharp live imaging, extremely wide viewing range, incredible durability in diverse harsh environments, instant installation on any vehicles and high affordability for any limited budgets, N-Driver is absolutely the perfect choice of driving assistant vision systems.
>
> ….
>
> **Pedestrian and Animal Recognition function**
> PSA Night Vision driving assist system could automatically identify and highlight the pedestrian and animal whose size exceeds 50cm inside the infrared image (Animal Recognition function is developing), also could make alarming to the possible collision hazards. The detection model is [sic] not only includes the upright walking routine pedestrians in front of vehicle (until 100 m), but also including some cycling, electric cars and motorcycles specially pedestrian.

Related Resources:

User Manual, N-Driver Driving Assistant System, Version 1, Wuhan Guide Infrared Co., Ltd., April 2013.
http://www.holund.no/file/andre/manual-152-680.pdf-1
This user manual, available on a Norwegian electronics vendor's web site, provides information about the technical specifications and use of N-Driver. The manual includes information about the system's pedestrian recognition function but offers no details about animal detection. Excerpts from the manual include:

- The manual indicates that "[u]nder good visual field, far infrared night vision driver assist system effective distance could reach 300m, under bad weather (rain, fog, haze, dust, etc.) conditions, the night visual distance would reduce to a certain extent."
- The system provides automatic speed mode shifting:
    - High-speed mode. When the vehicle speed is higher than 80 kilometers per hour (kph) and the car is moving forward in a straight line, the center area of the image is displayed with 1.5 times magnification, with a detection distance of 90 to120 meters.
    - Middle-speed mode. When the vehicle speed is lower than 30 kph and the car is steering left, the left image area is displayed with 1.5 times magnification; when the car is steering right, the right image area is displayed with 1.5 times magnification.
    - Low-speed mode. When the vehicle speed is lower than 5 kph the pedestrian detection function shuts down.

N-Driver: Thermal Imaging Driving Assistant System, Wuhan Guide Infrared Co., Ltd., undated.
http://guideinfrared.com/Uploadfiles/m_user/Unit_934823954/User_2010041616344060350/m_temp/N-Driver%20Brochure.jpg
This brochure provides specifications for the N-Driver product, among them:

- Field of view: 36° x 27°.
- Operating temperature: -40° C to +70° C (approximate).
- Auto heater: The auto heater is engaged if the front window temperature is lower than 2° C (+/-2° C); the heater shuts off when the front window temperature is higher than 7° C (+/- 2° C).
- Sand and dust: Six working hours under sand and dust density of 10g/m^3 (+/- 3g/m^3).
- Encapsulation: A rating of IP 67, which means the camera is protected from total dust ingress and from immersion between 15 centimeters and 1 meter in depth.

N-Driver Intelligent ADAS Infrared Night Vision System for Vehicle Navigations, Wuhan Guide Infrared Co., Ltd., January 28, 2015.
https://www.youtube.com/embed/cHj-WLLYAGk
This annotated YouTube video provides a real-world look at the N-Driver system in action. With the use of side-by-side images that present the driver's view through the windshield and the image displayed on the in-vehicle monitor, the video shows examples of the yellow and red triangle warnings generated by N-Driver. Also shown is how headlight "dazzling" (when the driver is temporarily "blinded" by oncoming headlights) is counteracted by the system's in-vehicle display.

Opgal

Driver Viewer Enhancer (DVE) / Driver Night Vision System (DNVS), Opgal, undated.
http://opgal.com/DEFENSE/DefenseApplications/DVEDNVSSystems.aspx
From the web site:

> Maintaining clear line-of-sight vision at all times, day or night, is critical to every military vehicle on the battlefield. Drivers must be able to see without being seen. With 30 years of experience in thermal imaging innovation, Opgal manufactures a variety of OEM solutions that help keep military vehicles on the road – and troops safer.
>
> Designed to enhance the operability of armored vehicles, Opgal provides integrators involved in vehicle upgrades with a wide range of driving vision systems that can be incorporated into the vehicles. From external ruggedized cameras to system kits that include suitable cables, Opgal's ir [infrared] cameras provide optimum vision and improved situational awareness for today's 24-hour all-weather battlefield environment.

Two of the external cameras used on military armored vehicles are described below.

Related Resources:

Opgal Tavor SM, Camera Applications, Opgal, undated.
http://opgal.com/Portals/0/pdf/Opgal_Tavor_SM_250613_BRMICROA.pdf
This uncooled miniature camera offers field of vision options of 90° x 68° and 44° x 33° that can be adjusted to meet customer needs. Key benefits of the camera include:

- Enables driving in complete darkness, through smoke, dust and dirt.
- Easy installation in all types of vehicles enabled by low mechanical profile.
- Sealed enclosure, with an IP rating of IP 67.
- Electronic zoom (x2 and x4) or continuous digital zoom x1 to x12.

Opgal Tavor BS, Camera Applications, Opgal, undated.
http://opgal.com/Portals/0/pdf/Opgal_Tavor_BS_261213_BRTVBS00A.pdf
The Opgal Tavor BS is similar to the Tavor SM described above, though larger. Available in a modular kit allowing for selection of components, the system offers a wide variety of viewing angles (up to 64° horizontal) with a digital zoom of x2 and x4.

Factory-Installed Detection Systems

As an alternative to aftermarket heat detection and warning systems, some automakers offer factory-installed technologies that provide nighttime driving assistance. Night Vision, a thermal imaging driving aid produced by Autoliv that provides both visual and audible warnings, has been installed in Audi, BMW and Daimler vehicles. The publications cited below describe the Night Vision product and evaluate its effectiveness.

Night Vision, Autoliv Inc., undated.
http://www.autolivnightvision.com/technology/
Excerpt from the web site:

> **Technology Evolution:**
> Autoliv first introduced Night Vision in 2005 as a driving aid. In 2008, Autoliv enhanced the system by adding Pedestrian Detection and Warning. In 2013, the World's First Animal Detection system was introduced to help solve one of the most complex and dangerous aspects of nighttime driving. In select markets, Night Vision with Spotlight Function is offered to enhance the night time driving experience.
>
> **How it works:**
> Night Vision uses infrared camera technology to highlight animals and pedestrians on the road at night which may not be visible to the naked eye. An infrared camera is mounted in the front grille of the vehicle. It generates thermal video images of the road ahead. An onboard computer (ECU) runs algorithms to detect animals and pedestrians in the path of the vehicle. Night Vision reacts in less than 150 milliseconds to highlight animals and pedestrians on an in-dash display. An alert will occur if the driver doesn't change the course of the vehicle or apply the brakes.
>
> In Europe and Asia, Night Vision with Spotlight Function is offered on select vehicles. Spotlight Function projects a focused high-beam light directly onto animals and pedestrians in the path of the vehicle keeping the drivers eyes on the road.

Related Resources:

> **"Night Vision Animal Detection,"** David Forslund and Jon Bjärkefur, *2014 IEEE Intelligent Vehicles Symposium Proceedings*, pages 737-742, June 2014.
> Citation at http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6856446
> This conference paper authored by an employee of Autoliv and a collaborator from outside the company provides a description of the Autoliv animal detection system. As the authors note, the system is "complementary to currently used methods for preventing accidents with animals." From the abstract:
>
>> In order to reduce traffic accidents involving animals, which is a major concern in worldwide traffic, Autoliv has developed a state-of-the-art vehicle mounted night vision animal detection system. The system is currently used by Audi, BMW and Daimler. The main contributions of this paper include: world's first vehicular animal detection system to reach the customer market, an efficient classification approach based on a cascade boosting concept which is robust to occlusion, pose and scale variations, a large database of thousands of hours of far infrared (FIR) video data recorded worldwide including several hundred thousand example images of animals in traffic situations, a tracking approach to handle animal movement and estimate animal states, a validation

approach to efficiently reduce the number of false detections and human-machine-interface (HMI) and warning concepts to highlight animals at risk of collision. The presented system detects animals up to 200 meters away from the car while generating very few false warnings. For animals that are considered a potential danger, advanced HMIs such as marking lights which actively illuminates the animals are applied, giving the driver the quick and accurate information he or she requires. The Autoliv night vision animal detection system is complementary to currently used methods for preventing accidents with animals. By using it, the driver is given all opportunities to react to dangerous situations and to avoid potential accidents.

"Night Vision System in BMW," Aniket S. Ahire, *International Review of Applied Engineering Research*, Vol. 4, No. 1, pages 1-10, 2014.
http://www.ripublication.com/iraer-spl/iraerv4n1spl_01.pdf
The author of this paper, from India's Pune University, discusses the advantages and disadvantages of the Night Vision system produced by Autoliv and installed in BMW vehicles. The author noted this disadvantage of the system (from page 9 of the PDF):

> Although generic image processing algorithms have been addressing similar goals for many years, there are several problems that are unique to image processing in automotive application[s]. For example, it is difficult to distinguish between objects in the foreground and the background of the image [because] the entire image is continuously changing and because pedestrians vary in scale based on their distance to the viewer.

Driver Behavior in Response to Detection System Alerts

While we found no research specifically addressing driver behavior in response to alerts generated by a vehicle-mounted animal detection system, we did identify publications that address user needs and driver behavior in response to in-vehicle alerts in general. This section includes both general guidance and citations that focus on drivers' response to alerts generated by pedestrian detection systems, since these systems can also be used to detect animals.

General Guidance

Research in Progress: "User Information Needs and Workload Issues Associated with Active Traffic Management Strategies," NCHRP Project 03-124. (This project is classified as pending. The panel was scheduled to meet in February 2016 to select a contractor.)
Project description at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3987
Excerpt from the project description:

> The objective of this research is to develop principles and guidance for presenting drivers with dynamic information that can be frequently updated based on real-time conditions. These principles and guidance should improve the effectiveness of ATM [active traffic management] strategies, which includes systems to manage congestion, incidents, weather, special events, and work zones. The research is expected to explore the following critical questions:
>
> - What information related to ATM strategies does a driver want and need? What characteristics are associated with this information (e.g., reliability, timeliness)?
> - How much information can a driver process via the complementary and contrasting modalities (e.g., visual, auditory), given the context and distractions?

- What existing and potential media could be used to deliver this information? Media that are under the control of transportation agencies (e.g., electronic signs) are of primary interest but alternative and innovative media (e.g., in-vehicle displays, cell phone applications, geographic information systems) and their evolving capabilities and roles must be examined.
- Given a particular message and medium, what are effective ways to prioritize, format, and present the information to achieve a desired and safe response by drivers?

"Auditory Alerts in Vehicles: Effects of Alert Characteristics and Ambient Noise Conditions on Perceived Meaning and Detectability," Jeremiah Singer, Neil Lerner, Carryl Baldwin and Eric Traube, *24th International Technical Conference on the Enhanced Safety of Vehicles: Traffic Safety Through Integrated Technologies: Proceedings*, Paper #15-0455, 2015.
http://www-esv.nhtsa.dot.gov/Proceedings/24/files/24ESV-000455.PDF
This paper describes two studies conducted within the National Highway Traffic Safety Administration's Crash Warning Interface Metrics (CWIM) research program. Researchers gathered information about the criteria required for an acoustic signal to be "unambiguously interpreted as an urgent warning."

- Study 1 (Categorical Perception of Alerts) established criteria regarding the key characteristics of a warning sound that would enable the sound to be quickly and reliably perceived as representing a highly urgent collision warning.
- Study 2 (Warning Perception in Ambient Noise Environments) investigated the effects of different in-vehicle ambient noise conditions on auditory signal detection and perception.

The paper's conclusions, which begin on page 13 of the PDF, include:

- Study 1. Four parameters were found to be most important in influencing categorization as a warning or safety alert: base frequency, number of harmonics, interburst interval (the gap between multiple bursts of sound), and peak-to-total-time ratio.
- Study 2. Results show that many sounds that were easily detected and perceived as urgent in a relatively quiet vehicle interior were much less likely to be detected or perceived as urgent in a louder vehicle interior (e.g., with windows open).

"Field Investigation of Driver Response to In-Vehicle Safety Warning Information," Tai-Jin Song, Seri Park and Cheol Oh, *20th ITS World Congress: Proceedings*, 2013.
Citation at https://trid.trb.org/view.aspx?id=1323718
From the abstract:

> The effectiveness of the advance warning in-vehicle system was evaluated by reviewing drivers' abilities to respond appropriately to unsafe conditions in real-time driving scenarios. A probe vehicle was used to collect individual vehicle speed as well as its speed change rates. The probe vehicle was also equipped with a Global Positioning System (GPS) that generated the individual vehicle trajectory. The driver's response was evaluated under two different types of warning system, emergency warning and general warning, using various combinations of modalities that include text, digital tones, voice messages, and graphics. Study results show that for emergency alert, warning information transmitted by integrating 'voice, graphic and text' or 'repeated computer tone and text' was most effective. In the case of a general warning alert, 'repeated computer tone, voice, graphic, and text' combination was found to be most effective. This study provides an overall guideline for designing an effective in-vehicle warning system.

"Simulation of Infrared Thermal Imaging in a Virtual Environment Driving Simulator," Linzhen Nie, Na Chen and R. Mourant, *First International Conference on Transportation Information and Safety: Proceedings*, pages 1770-1777, 2011.
Citation at http://ascelibrary.org/doi/abs/10.1061/41177%28415%29224
Excerpt from the abstract:

> Night vision enhancement technologies using infrared (IR) thermal sensing can help improve a driver's vision at night. Several advanced IR camera companies are collaborating with world-leading automobile manufacturers with the goal to incorporate thermal IR image devices in real vehicles. However, there is not sufficient evidence to conclude that IR image devices in automobiles will result in less nighttime accidents. Moreover, potential distraction brought by such a device needs to be evaluated as well. This study focuses on creating a nighttime driving environment that simulates thermal infrared imaging in a driving simulator. The nighttime driving environment is built using Unity3d and applied to a driving simulator in the Virtual Environments Laboratory at Northeastern University. Subjects are required to drive in the simulator using the simulated thermal IR imaging system under nighttime conditions. Preliminary results on drivers' performance and distraction are reported.

Pedestrian Detection Systems

"Improving Safety of Vulnerable Road Users: Effectiveness of Environment and In-Vehicle Warning Systems at Intermodal Interchanges," Daniel Carruth and Lesley Strawderman, National Center for Intermodal Transportation for Economic Competitiveness, January 2014.
http://www.ncitec.msstate.edu/wp-content/uploads/2012-02FR.pdf
Excerpt from the abstract (emphasis added):

> The current study investigates the effectiveness of structural and in-vehicle interventions for modifying driver behavior as drivers approach, pass through, and depart from an urban bus terminal. The impact of facility structural elements (pedestrian crossing signs, marked crosswalks, and sidewalks) and an in-vehicle pedestrian warning system was evaluated using the Center for Advanced Vehicular Systems driving simulator. 37 participants completed 186 drives in the driving simulator. Driver speed and lane position were evaluated. *An in-vehicle alarm indicating "high pedestrian areas" led to reduced driver speed but drivers shifted closer to the shoulder (and pedestrians).*

"Assessing Contextual Factors That Influence Acceptance of Pedestrian Alerts By a Night Vision System," Jan-Erik Källhammer and Kip Smith, *Human Factors: The Journal of the Human Factors and Ergonomics Society*, Vol. 54, No. 4, pages 654-662, August 2012.
Citation at http://www.ncbi.nlm.nih.gov/pubmed/22908687
From the abstract:

> **Objective:** We investigated five contextual variables that we hypothesized would influence driver acceptance of alerts to pedestrians issued by a night vision active safety system to inform the specification of the system's alerting strategies.
>
> **Background:** Driver acceptance of automotive active safety systems is a key factor to promote their use and implies a need to assess factors influencing driver acceptance.
>
> **Method:** In a field operational test, 10 drivers drove instrumented vehicles equipped with a preproduction night vision system with pedestrian detection software. In a follow-up experiment, the 10 drivers and 25 additional volunteers without experience with the system

watched 57 clips with pedestrian encounters gathered during the field operational test. They rated the acceptance of an alert to each pedestrian encounter.

Results: Levels of rating concordance were significant between drivers who experienced the encounters and participants who did not. Two contextual variables, pedestrian location and motion, were found to influence ratings. Alerts were more accepted when pedestrians were close to or moving toward the vehicle's path.

Conclusion: The study demonstrates the utility of using subjective driver acceptance ratings to inform the design of active safety systems and to leverage expensive field operational test data within the confines of the laboratory.

Application: The design of alerting strategies for active safety systems needs to heed the driver's contextual sensitivity to issued alerts.

"Investigation of Driver Performance with Night Vision and Pedestrian Detection Systems: Part I: Empirical Study on Visual Clutter and Glance Behavior," Omer Tsimhoni, Yili Liu and Ji Hyoun Lim, *IEEE Transactions on Intelligent Transportation Systems*, Vol. 11, No. 3, pages 670-677, September 2010.
Citation at https://trid.trb.org/view.aspx?id=1094185
From the abstract:

This paper describes two studies in which two night-vision enhancement systems were examined to compare nighttime driver performance in pedestrian detection. In the first study, the levels of clutter in the images displayed by the two types of night-vision enhancement systems were measured objectively and subjectively. The subjective ratings of clutter changed as a power function of the objective measure of clutter intensity. In the second study, the effect of clutter on glance behavior during pedestrian detection was examined in a driving simulator. Night-vision images with less clutter required shorter search times and fewer glances to detect the pedestrian, but the duration of each glance remained relatively constant.

"Investigation of Driver Performance with Night-Vision and Pedestrian-Detection Systems: Part 2: Queuing Network Human Performance Modeling," Omer Tsimhoni, Ji Hyoun Lim and Yili Liu, *IEEE Transactions on Intelligent Transportation Systems*, Vol. 11, No. 4, pages 765-772, 2010.
Citation at https://trid.trb.org/view/2010/C/1091121
From the abstract:

This paper introduces a queueing network-based computational model to explain driver performance in a pedestrian-detection task assisted with night-vision-enhancement systems. The computational cognitive model simulated the pedestrian-detection task using images displayed by two night-vision systems as input stimuli. The system equipped with a far-infrared (FIR) sensor generated less-cluttered images than the system equipped with a near-infrared (NIR) sensor. Using a reinforcement learning process, the model developed eye-movement strategies for each night-vision system. The differences in eye-movement strategies generated different eye-movement behaviors, in accord with the empirical findings.

"**Is More Better? Night Vision Enhancement System's Pedestrian Warning Modes and Older Drivers,"** Timothy Brown, Yefei He, Cheryl Roe and Thomas Schnell, *Annals of Advances in Automotive Medicine*, Vol. 54, pages 343-350, January 2010.
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3242535/
From the abstract:

> Pedestrian fatalities as a result of vehicle collisions are much more likely to happen at night than during day time. Poor visibility due to darkness is believed to be one of the causes for the higher vehicle collision rate at night. Existing studies have shown that night vision enhancement systems (NVES) may improve recognition distance, but may increase drivers' workload. The use of automatic warnings (AW) may help minimize workload, improve performance, and increase safety. In this study, we used a driving simulator to examine performance differences of a NVES with six different configurations of warning cues, including: visual, auditory, tactile, auditory and visual, tactile and visual, and no warning. Older drivers between the ages of 65 and 74 participated in the study. An analysis based on the distance to pedestrian threat at the onset of braking response revealed that tactile and auditory warnings performed the best, while visual warnings performed the worst. When tactile or auditory warnings were presented in combination with visual warning, their effectiveness decreased. This result demonstrated that, contrary to general sense regarding warning systems, multi-modal warnings involving visual cues degraded the effectiveness of NVES for older drivers.

"A Simple and Effective Display for Night Vision Systems," Omer Tsimhoni, Michael J. Flannagan, Mary Lynn Mefford and Naoko Takenobu, *Proceedings of the 4th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, July 2007.
http://drivingassessment.uiowa.edu/DA2007/PDF/047_TsimhoniFlannigan.pdf
From the abstract:

> The next generation of automotive night vision systems will likely continue to display to the driver enhanced images of the forward driving scene. In some displays there may also be highlighting of pedestrians and animals, which has been argued to be the primary safety goal of night vision systems. The authors present here the method that was used to design a conceptual display for night vision systems. Although the primary focus of the method is on safety analysis, consideration is given to driver performance with the system, and exposure to alerts. It also addresses user acceptance and annoyance, distraction, and expected behavior adaptation. The resulting driver interface is a simple and potentially effective display for night vision systems. It consists of a pedestrian icon that indicates when there are pedestrians near the future path of the vehicle. An initial prototype of this night-vision DVI was tested on the road and showed promising results despite its simplicity. It improved pedestrian detection distance from 34 to 44 m and decreased the overall ratio of missed pedestrians from 13% to 5%, correspondingly. The improvement may be attributable to the icon alerting the driver to the presence of a pedestrian. In this experiment, the drivers were probably more alert to the possible presence of pedestrians than drivers in the real world, suggesting that the effect of the icon might be even larger in actual use.

Contacts

CTC contacted the individuals below to gather information for this investigation.

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