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THERMAL RANGING™

for ADAS and ROBOTIC MOBILITY APPLICATIONS

INTRODUCTION

Since most road accidents occur due to human error[1], automotive companies consistently invest and develop an array of technologies that can be deployed to prevent road accidents. These technologies, which proactively alert drivers to hazards, prevent on-road collisions, implement safeguards, and even take control of the vehicle, if necessary, are referred to as Advanced Driver Assistance Systems (ADAS). ADAS features include adaptive cruise control, in lane departure warning, lane centering and collision avoidance enabled by Automated Emergency Braking (AEB) systems. The newest challenge for AEB is adapting these systems to support pedestrian, cyclist, and large animal safety response (PAEB). ADAS's automated systems are proven to reduce road fatalities by minimizing human error[2], and the American Automotive Association (AAA) believes that ADAS could potentially prevent 2.7 million crashes, 1.1 million injuries, and 9,500 deaths each year in the United States[3].

The current de-facto ADAS sensor suite typically comprises mutually dependent visible-light cameras and radar, but when one of these sensors becomes ineffective or impaired, so too does the sensor suite. This scenario happens all too often, especially when it comes to pedestrians, cyclists, and animals, which are smaller than surrounding objects, such as vehicles. Cameras struggle to

> "...of the 1.3 million people who die each year as a result of road traffic crashes more than half are among vulnerable road users: pedestrians, cyclists and motorcyclists."
>
> -2021 World Health Organization Report

see in darkness and other Degraded Visual Environments (DVE) such as fog, dust, rain, or solar glare. In addition, radar is a very coarse detector that can miss overlapping or adjacent objects. The Insurance Institute for Highway Safety (IIHS) study, published in February 2022, found vehicles equipped with PAEB systems reduce pedestrian injury crashes by 30 percent versus vehicles not equipped with these systems. However, the study also found that there was no difference in crash risk for vehicles with or without PAEB when operating at night. Three-quarters of fatal pedestrian accidents occur at night[4]. Couple these findings with the 2021 World Health Organization report that estimates that "of the 1.3 million people who die each year as a result of road traffic crashes more than half are among vulnerable road users: pedestrians, cyclists and motorcyclists."[5] Clearly, there is significant room for safety enhancement.

While SAE International Level 4 and 5 self-driving Autonomous Vehicles (AV) are working hard to continuously improve autonomous safe operation, the preponderance of the technology in use today is in support of ADAS level 2 to 3 and robotic mobility (RM) applications where RM sensors are likewise hindered by DVE and nighttime operation. Owl AI believes that safety starts with perception and that advancement in sensor technology will continue to play a critical role in ADAS, AV, and RM safety enhancements. Through primary research gathered from dozens of interviews, demonstrations and customers, Owl distilled OEM manufacturer and Tier 1 sensor concerns into four areas related to sensor performance consistency. To summarize, today's ADAS systems must sustain safe operation (1) day or night (2) in both persistent DVE conditions that can obscure sensing like fog and dust as well as (3) in momentary DVE conditions like solar glare that can blind sensors.

Finally, (4) ADAS systems may no longer rely on the vehicle operator alone to make critical course corrections. The vehicle's perception computer system must now be able to react to a critical safety situation independent of the vehicle operator.

Computer based decision making relies on advanced computer vision techniques which rely on sensor fusion to consistently distill instantaneous perception of a vehicle's surroundings. This requirement introduces numerous sensor challenges including "always-available" high-quality, high-resolution imaging for object detection and identification. For object location, it is an imperative to eliminate sensor fusion ambiguity for the accurate mapping of disparate sensor modalities such as 2D RGB camera images at night to ultra-low resolution 3D Radar. The technical challenges identified here constitute many of the key short comings of today's PAEB systems as discussed earlier. Before addressing how to overcome current PAEB safety concerns, a deeper understanding of current safety system implementation is warranted.

1 Brookhuis, Karel A. de Waard, et al., (2001-06-01). Behavioral impacts of Advanced Driver Assistance Systems–an overview.

2 Abdul Hamid, et al., (2017-12-01). "Autonomous emergency braking system with potential field risk assessment for frontal collision mitigation". 2017 IEEE Conference on Systems, Process and Control (ICSPC). pp. 71–7

3 McDonals, Ashley, et al., "Vehicle Owners' Experiences with Reactions to ADAS" 2018, University of Iowa and AAA

4 IIHS HLDI, "Pedestrian crash avoidance systems cut crashes -but not in the dark" 2022

5 World Health Organization, "Road Traffic Injures" 2021

CONTENTS

ADAS and AV PERCEPTION TODAY

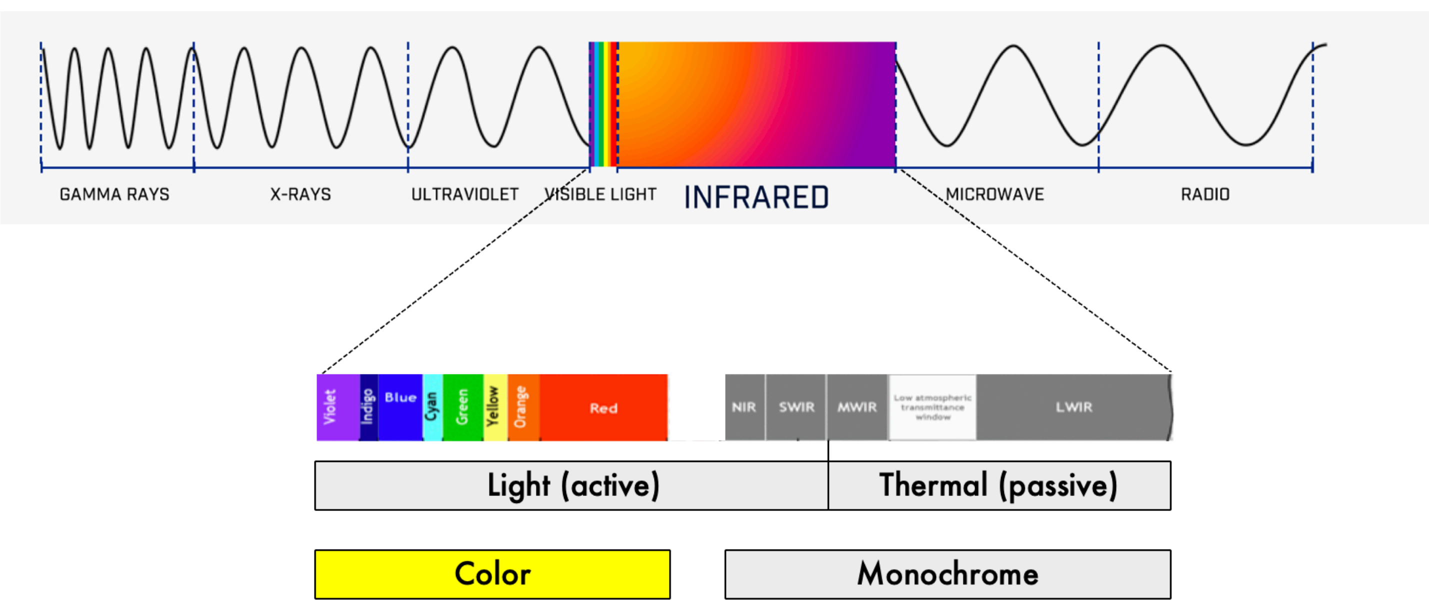
ADAS, AV and RM sensing fall into three categories[6]: (1) self-sensing using proprioceptive sensors to measure the current state of the vehicle's internal dynamics, (2) localization to determine the vehicle's local and global position (e.g., GPU, IMU & camera), and (3) surrounding sensing using exteroceptive sensors to perceive and understand the world outside the vehicle. For localization and surrounding-sensing functions, both detection and classification are needed. Detection defines the location of objects and classification identifies what the objects are. To achieve this, manufacturers have generally coalesced on the choice of two main ADAS sensor types – cameras and radar.

TWO MAIN **ADAS** SENSOR TYPES

CAMERAS

RADAR

Cameras are indispensable in capturing the detail necessary to understand the surrounding environment, but a camera alone is not enough. Without a sense of depth and scale, the 2D camera's perception is insufficient to determine a course of action, such as slowing down, steering, or braking. Radar plays a key role in providing range data to all objects. The fusion of 2D camera data with radar range data allows perception stacks to do a much better job of seeing and understanding the environment, obstacles, and other vehicles. When these sensors are coupled with a powerful on-board processor, the vehicle can then attempt to understand, map, and safely navigate the environment around it. Though we traditionally associate cameras with human visual wavelengths, cameras may be tuned to a much broader range of wavelengths beyond just visual. The figure below shows wavelengths within the Infrared (IR) spectrum which includes visual bands that may be imaged with today's camera sensors. Beyond visible we have Near IR (NIR), Short Wave IR (SWIR), Mid-Wave IR (MWIR) and Long Wave IR (LWIR) also sometimes referred to as Far IR (FIR).



6 Maurer et al., 2016

A few properties associated with these different wavelengths are highlighted in the figure. Specifically, colored visual (400nm to 700n), NIR (750nm-1000nm) and SWIR (1000nm to 2500nm) are light based IR sensors. Sensors operating at these wavelengths are sensitive to reflected light in the form of light-based photons. These sensors are considered active sensors as there must be an independent light source to illuminate the scene. The light source may be generated by the sun, streetlights, or headlights. Whatever the case, in the absence of an active light source transmitted into the scene at the appropriate wavelength, no image can be sensed.

Interestingly, infrared imagers can be built that sense non-light-based photons.

Interestingly, infrared imagers can be built that sense non-light-based photons. These sensors, generally known as thermal sensors produce images in the MWIR (3,000nm to 5,000nm) and LWIR (8,000nm to 14,000nm) part of the infrared spectrum. Thermal sensors still sense photons; however, the photons are not light based but rather generated via a phenomenon known as emissivity. Emissivity is the measure of the effectiveness of a material surface in emitting energy as thermal radiation. All objects in the universe warmer than zero degrees Kelvin have some level of emissivity. It should be noted, for the purpose of this paper, we are discussing imaging which requires relative emissivity values, not absolute ones. This is opposed to the measurement of object temperature itself whereby absolute temperature values are desired. To affect this measurement, generally a known temperature must be placed into the scene (may be a black body). Thermal sensors operate within certain energy bands (temperature ranges) and emissivity producing elements in the scene that fall within the range are imaged. For LWIR this range is 8,000nm to 14,000nm. Thermal sensors are passive sensors, as no independent photon (energy) source is needed. Rather, the scene, along with the objects in the scene are the energy sources. Moreover, thermal sensors do not sense reflected energy, as again the scene itself is the source of the photons.

CAMERAS

Cameras are the only sensors that perceive the world in any sort of detail that resembles human sight. They can detect traffic signs and objects and can inexpensively build a 2D map of the area surrounding a vehicle. Visible-band (400 – 700 nm) cameras see color as well and are by far the most popular choice within ADAS and RM sensor suites because they are relatively inexpensive but have high-quality and high-volume sensor data. Cameras that operate in other bands are also available, although adoption is not as pervasive. Seeing slightly longer wavelengths than visible cameras, Near Infrared (NIR) cameras image in the 750 nm – 1000 nm and can be very inexpensive, using commodity silicon imagers. And when coupled within visual cameras, they can offer a little broader response. Longer still in wavelength are somewhat exotic and much more expensive Short-wave InfraRed (SWIR) cameras that see in the 0.1 – 1.9 µm band, and up to 2.5 µm in the Extended SWIR (eSWIR) band.

Some automotive OEMs deploy stereo cameras. A stereo camera is a structure made up of two or more identical cameras separated by a known never-changing rigid distance known as the baseline. Both cameras are focused on the same point in the distance forming a triangular overlap within the field of view. Via this technique, range may be calculated to all objects within the overlapping field of view. The longer the baseline the further the range. All stereo (multi-camera) ranging systems must overcome a series of shortcomings to be of use. Physical stability is critical to accurate ranging. Rigidity must be maintained while compensation for vibration effects of roll, pitch, heave, yaw, surge, and sway are critical. The longer the baseline the more complex the compensation. Finally, though the system is constructed with multiple cameras the 3D field of view is smaller than the field of view of a single camera as only the field of view within the overlap produces the desired result. For automotive applications, which generally prefer wide fields of view to image curb to curb (especially for inner city applications), this is a difficult trade-off. A new technique for camera ranging, known as monocular (single camera) ranging, is significantly less sensitive to vibration and will be introduced later in this paper.

RADAR

Radar is a mature technology that has been in use for nearly 100 years to accurately calculate the position, speed and direction of distant objects (e.g., aircraft and ships). Advantages of radar for automotive applications include robust performance through nearly all DVE conditions due to its long wavelength. Radar is also unaffected by lighting conditions. Today many modern cars use radar sensors for hazard detection and range-finding in features like advanced cruise control (ACC) and automatic emergency braking (AEB). Most systems operate at a frequency of 24 GHz, but emerging systems will operate at 76-77 GHz and 77-81 GHz for long-range and short-range applications respectively. These newer units are much smaller than earlier units and are therefore easier for vehicle makers to discreetly integrate into the vehicle.

However, ADAS cannot rely purely on radar for perception due to radar's inability to perform robust object classification and road marking detection. Radar's long wavelength also presents some inherent limitations, specifically that radar has much lower spatial resolution than cameras and is not effective at discerning object detail or particularly helpful in classifying objects. Radar's angular and range resolution is also coarse. For example, with a typical radar angular resolution of 1.2° and range accuracy of about 10cm[7], there is little room for error, where the consequences can be a near miss or a tragic collision.

LiDAR

LiDAR (Light Detection And Ranging), with a resolution that somewhat straddles that of cameras and radar, may someday help Level 4 and 5 fully autonomous vehicles see and navigate the world, but to date remains a technology possessing more potential than practical adoption. One of the key factors holding back LiDAR is its high cost per unit. Another perhaps larger hurdle facing LiDAR is its operating wavelength in the NIR or SWIR bands, which make it highly vulnerable to DVE and solar glare, much like visible-band cameras. LiDAR has gained much attention with extensive institutional investment and several recent SPACs, but thus far LiDAR systems have largely underperformed expectations within the automotive industry.

7 ERM RTTT Radio Equipment in the 77 GHz to 81 GHz band for Automotive Collision Warning Short Range Radar, 2004, ETSI, France

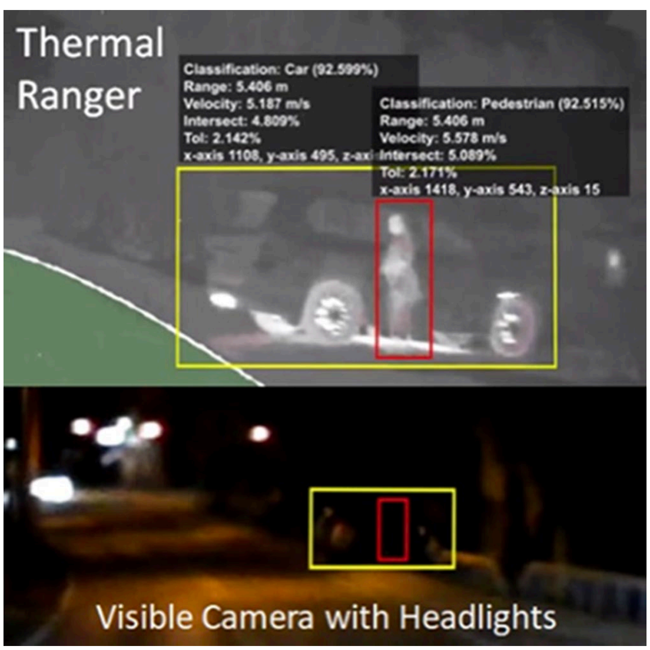
MOVING BEYOND ACTIVE VISUAL SENSORS IN SUPPORT OF ADAS

ADAS applications such as PAEB need to become operationally robust across varied conditions. As such, ADAS, AV and RM sensors must be designed to encounter and gracefully cope with all forms of visual challenges, including low light, no light, high humidity, fog, dust, and smoke. Unfortunately, consistent perception in poor environmental conditions, vital to reliable ADAS, AV and RM, has proven to be as problematic for sensors as it has been for human drivers.

Next, we examine specific conditions that challenge visual cameras and present options for mitigation.

LOW LIGHT, NO LIGHT, DEGRADED VISUAL ENVIRONMENTS (DVE)

Today most ADAS and RM cameras operate on visible band reflected light. However, with a dependence on an external light source, these cameras do not work well in low-light or no-light conditions. For example, at night these cameras cannot see beyond the reach of the headlights and are therefore essentially blind beyond 50m[8]. As a rule, longer wavelengths more easily propagate through obscurants, but all reflected light cameras operate at relatively short wavelengths, which makes them highly vulnerable to DVE. This presents a significant downside to using these camera sensors as the sole imaging device in safety critical ADAS applications. For example, in snowy conditions, it has been found that cameras have extreme difficulty[9] sustaining performance.



Fortunately, there are cameras that operate in wavebands that require no illumination source whatsoever, detect energy emitted directly from objects in the environment, and are capable of detecting objects 300m to 400m away, even in the dark. The LWIR (8 – 12 microns) "thermal band" a.k.a Far IR (FIR) cameras are completely passive and detect thermal energy radiated from every object, making them ideally suited to ADAS, AV and RM applications. Thermal imaging solutions are especially effective in detecting warm blooded creatures, such as humans or animals, since these objects have a unique thermal signature as compared to the surrounding environment. The adjacent figure illustrates the stark difference between a visible camera operating in low-light DVE and a thermal image captured simultaneously with a FIR camera. In the former, detection is not possible, while the thermal camera has no difficulty resolving fine detail for detection and classification. The FIR thermal band delivers fundamentally different information than the reflected light wavebands, which can be exploited for sensor diversity, which extends the potential use of AI/ML.

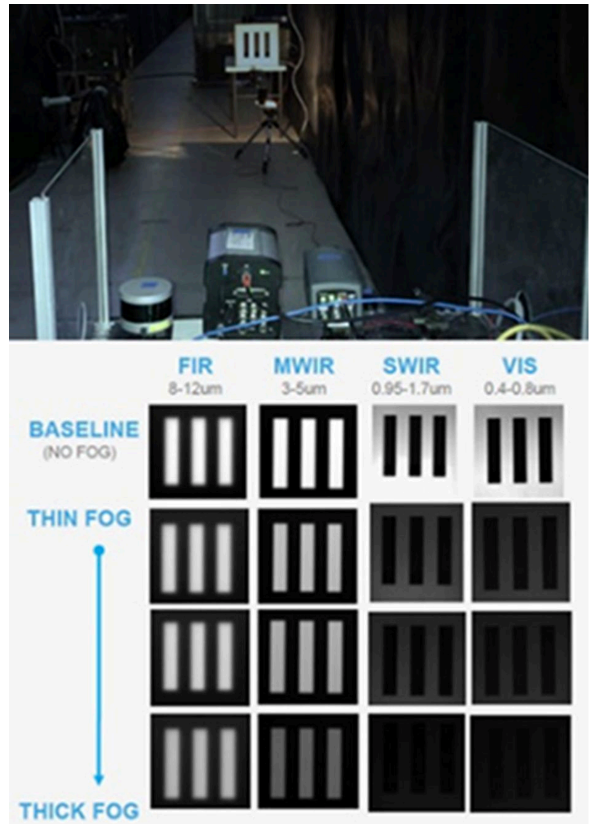
8 National Highway Traffic Safety Administration

9 Rasshofer, R.H., Gresser, K., 2005. Automotive radar and lidar systems for next generation driver assistance functions. Adv. Radio Sci. 3 (B.4), 205–209

OBSCURANT INDUCED DVE

Most obscurants are made up of particles much smaller than the wavelengths used by thermal and therefore, due to Rayleigh scattering, the thermal device sees through most of these obscurants. Smoke and haze, typically composed of particles sized at about 0.5 microns (note this is within visible band), are generally handled with ease by LWIR, with wavelengths being 10-20X larger, respectively. Particles of sizes closer to LWIR wavelength, such as certain types of fog and clouds, induce moderate scattering (Mie scattering) which is manageable and still offers much more detail than radar.

The energy that can be coupled back to the camera depends on the type, particle size and density of the obscurant. Controlled experimental results as shown in the adjacent figure[10] from Teledyne FLIR illustrate the effects of fog on reflected light sensors (visible, SWIR and MWIR) and LWIR (a.k.a. FIR) bands. The results illustrate that in the presence of fog, both thick and thin, the performance of FIR is categorically superior. Therefore, thermal offers excellent sensor extension and redundancy with visible-light cameras and eliminates a key point of failure.



PERCEPTION IN SOLAR GLARE ENVIRONMENTS

Lens flare is a phenomenon wherein light is scattered or flared in a lens system, often in response to a bright light such as the sun or oncoming headlamps, producing undesirable image artifacts or overwhelming sensor dynamic range. Lens flares and specular solar reflections present difficulties for visible-light cameras. The sun is a powerful source of light, and the moment when a sharp reflection strikes both driver and sensor alike can be as capricious as it is debilitating. And hiding alongside every over-illuminated area is a deep shadow that poses its own set of challenges. For example, vision systems may confuse large shadows to be parts of other objects[11].

Many solutions have been tried, with mixed results, including polarizing filters and high dynamic ranges. Even software has been brought to bear. For example, Stanford University addressed light condition problems on their robot by relying on a priori information about the environment to detect objects in differing lighting conditions using an a priori list of object locations[12]. Nevertheless, relying on a priori information can cause detection problems when applied to ever-changing environments. Fortunately, thermal is invulnerable to solar glare and thus offers excellent sensor redundancy in ADAS applications.

10 Image and test results from FLIR Systems Inc.

11 Balan, A.O. 2007. Shining a light on human pose: on shadows, shading and the estimation of pose and shape. 2007 IEEE 11th Int. Conf. Computer Vision

12 Levinson, J. et al., Jun 2011. Towards fully autonomous driving: Systems and algorithms. In: 2011 IEEE Intelligent Vehicles Symp. (IV).

CROSSTALK IN HIGH-DENSITY ENVIRONMENTS

As the development of active sensors within ADAS and AV technology becomes increasingly pervasive, these signals may begin to interfere with each other[13], thereby confusing sensors and rendering them ineffective. In sensing and communication, this phenomenon is referred to as crosstalk, where a signal transmitted by one sensor creates an undesired effect for another sensor. For example, in high-density traffic conditions, radar and LiDAR systems may pick up other vehicles' radar signals, causing false detections, interference and resulting uncertainty[14]. Passive systems do not face this limitation, which is a key factor leading many researchers to focus on vision as a primary perception mode for future AV systems[15]. Thermal imaging is completely passive and therefore impervious to signals from other sensors and immune to crosstalk.

FUSION AMBIGUITY BETWEEN MODALITIES

PAEB systems rely on the fusion of 2D camera data with radar range data to enable 3D perception stacks. Cameras deliver high resolution imaging critical to detection and classification while radar places these objects in 3D space providing position, trajectory, and velocity. This mapping of high-resolution objects to their corresponding radar range values is achievable in most cases, though challenges exist. Clearly, DVE conditions degrade image quality, impacting detection and classification resulting in unreliable fusion. As discussed, this can be addressed with the addition of thermal imaging. However, even with reasonable detection and classification, reliable fusion may still be challenged. Though radar generally provides a high-quality response inmost condition, mapping of the correct set of 3D data points to a particular object in a flat 2D image space can be complicated, thus resulting in object mapping ambiguity. This problem is amplified in chaotic scenes with numerous objects of interest, where radar is returning numerous reflections but little to no detail. Object motion may be helpful to mitigate some fusion ambiguity, though object motion alone is not sufficient as objects of interest may be at rest. Improvements in radar spatial resolution provides limited benefit.

The ideal solution for accurately fusing image and range information is for high resolution cameras (visual and thermal) to self-generate high density 3D point clouds that are optically registered with their native 2D image data sets. Objects even in chaotic scenes or at rest are much more easily identified and are directly associated with their corresponding range. This solution dramatically reduces camera and radar fusion mapping ambiguity. The result is high accuracy object detection, classification, range, velocity, and trajectory, the must-have components of safe vehicle pedestrian automatic braking systems.

13 Bertozzi, M., Broggi, A., Fascioli, A., 2000. Vision-based intelligent vehicles: State of the art and perspectives.

14 Hischke, M., Sep 1995. Collision warning radar interference. In: Proc. Intelligent Vehicles '95

15 Bertozzi et al., 2000; Ranft and Stiller, 2016; Sivaraman and Trivedi, 2013

WHAT'S NEXT?

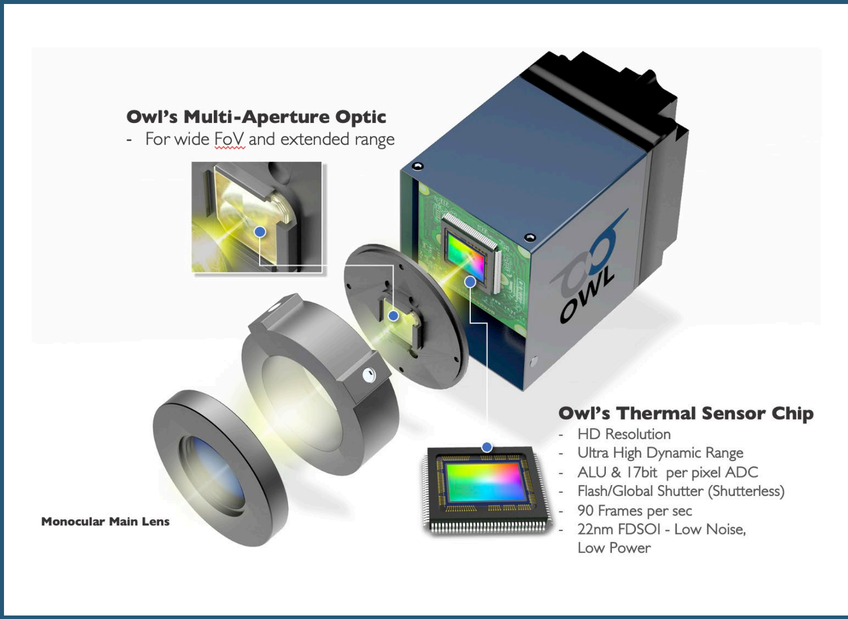
The inescapable limitations of today's safety sensors cannot be fully mitigated through additional processing or adding more sensors of the same type. The leading AV robo-taxi companies have repeatedly utilized a multi-modality approach to enhance safety, but the approach is too costly for commercial ADAS applications, as the sensor/compute suites for some of these AV systems now exceeds $100,000 USD while still falling short of needed safety thresholds. Only through the addition of a broader base of sensor modalities that specifically addresses the current limitations, can safe and robust ADAS, AV and RM be realized.

That new sensor modality is Owl's 3D Thermal Ranging, which delivers reliable and vivid computer vision quality video in DVE conditions while simultaneously generating ultra-dense 3D range maps. Thermal Ranging helps to overcome the daunting safety challenges associated with DVE, solar glare and fusion ambiguity by addressing the limitations of RGB cameras and radar through complementary sensor diversity and redundancy, thereby making ADAS, AV and commercial RM safer.

THERMAL RANGER: NEW MODALITY

Owl's new monocular ranging sensor system, called the Thermal Ranger, outputs a megapixel (MP) of thermal (night vision) video in conjunction with optically fused, 3D range-maps that are similar in appearance to LiDAR and radar range map formats, but delivering orders of magnitude more data points per second. Owl's solution is analogous to recent announcements of 3D single camera computer vision systems operating in the visual domain; however, Owl's Thermal Ranger is unique as it delivers rich detail and 3D response day or night, including operation in extreme visually impaired environments known as DVE.

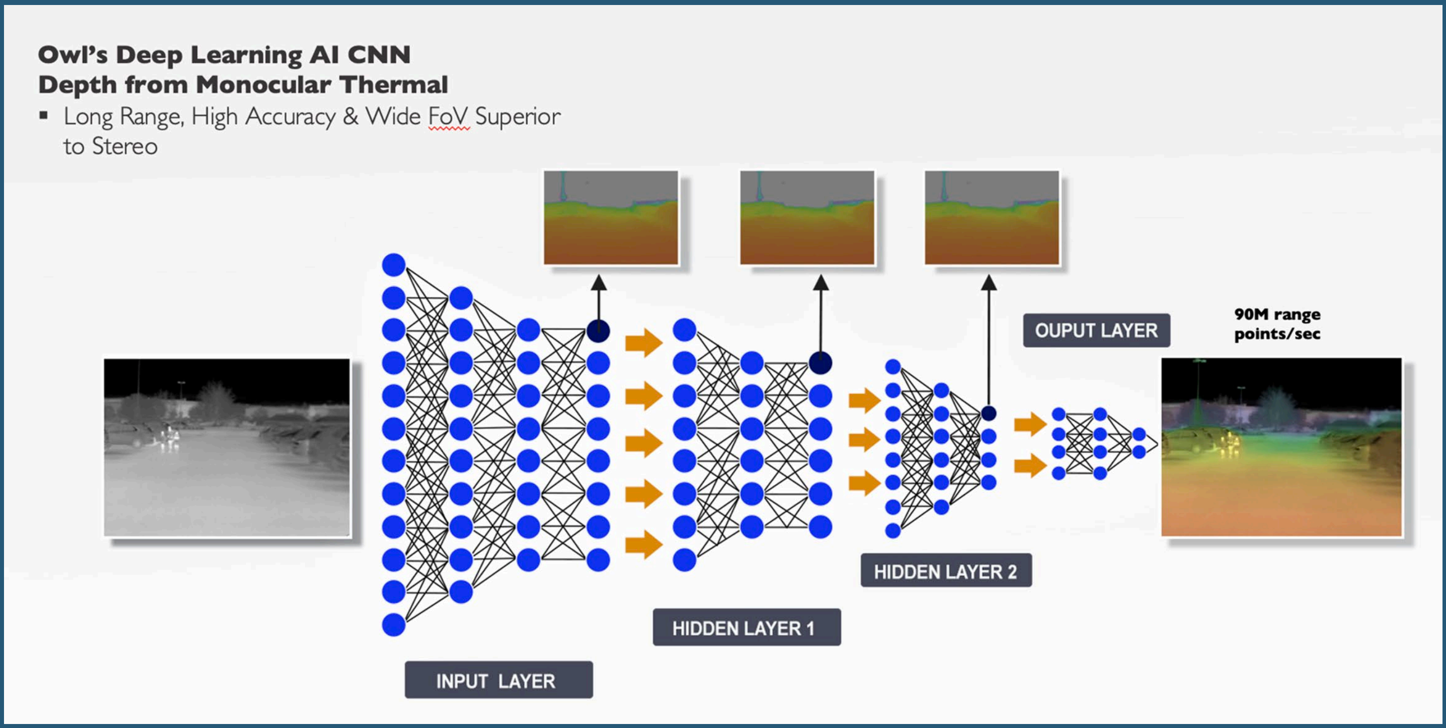
THE THERMAL RANGER



The Thermal Ranger is composed of a first of its kind Megapixel Digital Focal Plane Array (MP-DFPA) producing nearly four times the resolution of today's analog-based VGA thermal cameras. The Thermal Ranger also includes a multi-aperture optical component (MLA), and a suite of Convolutional Neural Network (CNN) ranging software for true thermal computer vision. The sensor operates in the thermal spectrum (long-wave Infrared) allowing it to see the world clearly, in high-resolution, through adverse DVE and any lighting condition for instant classification and 3D location of pedestrians, cyclists, animals, vehicles, and other objects of interest. This is a true no light system, not to be misconstrued with a low light camera (NIR or SWIR).

This low cost, compact, single lens (monocular) system outputs megapixel HD thermal video producing vivid clarity, while simultaneously generating 3D range maps of up to 90 million points per second, delivering orders of magnitude more angular and spatial resolution than LiDAR or radar sensors. For PAEB systems, the novel MLA enables simultaneous capture of both wide angle and telephoto fields of view (FOV) through a single main lens providing wide angle curb to curb response for inner city driving (100 degrees) while enhancing 2D long-range response to well beyond 300 meters and delivering high accuracy 3D range response at distances of over 185 meters. Or for long haul highway applications the system can be configured with a telephoto lens with a narrower FOV that enables object detection response up to 400m, well beyond any other sensor available today, including LiDAR.

A key innovation to monocular ranging lies in Owl's proprietary Artificial Intelligence (AI) Convolutional Neural Network (CNN) thermal ranging software, which exploits angular, spatial, temporal and intensity characteristics to produce range and depth data at frame rate. Therefore, unlike stereo-camera systems, LiDARs, and radars, this range map is ultra-dense, covers the entire field of view, and unlocks instant and accurate AI 3D perception and classification. Owl is at the forefront of monocular thermal ranging and now has entered field trials for automotive test cases. Owl also has recently been awarded a multimillion-dollar contract from the US Army for dual use application of our thermal computer vision capabilities.



Example videos of our **THERMAL RANGER** in action can be found on our **YouTube Channel** at this link.

YouTube

"OWL'S THERMAL RANGER is unique as it delivers rich detail and 3D response day or night."

CASE STUDY: PEDESTRIAN AUTOMATIC EMERGENCY BRAKING

As discussed previously, the 2021 World Health Organization report estimates that "of the 1.3 million people who die each year as a result of road traffic crashes more than half are among vulnerable road users: pedestrians, cyclists and motorcyclists". This equates to a ~2.5 pedestrians being killed every minute of every day around the world. Of these total traffic related fatalities 76% of them occurred in dark or low-light DVE conditions.

Among the many emerging vehicle safety features becoming standard in some new cars, pedestrian automatic emergency braking (PAEB) systems have been hailed for their potential to prevent or reduce the severity of collisions that result in personal injury and death. PAEB systems are specifically designed to detect pedestrians who enter the roadway in the direct path of a car using information from forward-looking sensors to automatically apply the brakes when a pedestrian is in danger of being hit by a vehicle.

Test results from Cornell University[16] have shown that in cloudy, sun-glare, snowy, rainy, and dark conditions PAEB systems using de facto visible-light cameras will face partial or total failure in these DVE conditions. Radar also struggles with pedestrian detection due to its inherent low resolution; it simply can't discern proximate or overlapping objects from one another, especially in busy urban environments.

But by adding the Thermal Ranger to the sensor suite, high resolution video is preserved in DVE conditions, exemplifying true sensor redundancy and diversity with traditional cameras. Likewise, the Thermal Ranger also delivers 3D megapixel range maps in busy and complex conditions that are severely challenging for radar-based sensors. Therefore, the Thermal Ranger is ideally suited to complement cameras and radar to sustain and fortify PAEB perception and make ADAS systems safer.

16 Radecki, P. et al., 2016. All weather perception: Joint data association, tracking, and classification for autonomous ground vehicles.

CONCLUSION

Thermal Ranging delivers vital range and video sensor redundancy. Radar reliably delivers all-weather location but cannot be confidently used for object detection and identification due to low resolution data. In nominal operating conditions, that deficiency is addressed with high-resolution visible cameras, but visual RGB cameras suffer at night and in the presence of almost any obscurant, resulting in the potential for gross failure or high fusion ambiguity. The Thermal Ranger's longer operating wavelength sustains performance in DVE conditions, thereby vastly improving ADAS/AV safety. The Thermal Ranger delivers redundant 2D video to pair with radar even in the most challenging conditions, thereby sustaining safe operation. Likewise, the Thermal Ranger delivers range data in conditions where the radar is confounded by dynamic complexity, or the cameras lack detail. The Thermal Ranger's redundant range maps perfectly complement the visible-band camera's 2D video.

Owl's Thermal Ranger also delivers sensor diversity through 2D video that is fundamentally different than reflected-light cameras and eliminates reliance on an illumination source. Thermal images are complementary to visible images, and the dissimilar modality can be exploited for improved automated AI classification with much fewer false alarms (e.g., PAEB). Likewise, the Thermal Ranger's diverse range data is derived from a completely orthogonal source (passive thermal) to those used in active radar. This passive range data diversity can be reconciled and fused for higher aggregate range and velocity estimates.

Finally, the introduction of a high dynamic range HD megapixel thermal imager enhances all aspects of the solution within this problem space. Higher resolution refers to the number of pixels per unit viewing area, while dynamic range refers to the breath or number of colors (in the case of thermal the number of shades of gray from white to black) available per pixel. Taken together these enhancements result in crisper images, sharper edges, greater contrast, and more detail, both near and far, especially with the ability for simultaneous capture of both wide angle and zoomed images, sustaining image quality across wider fields of view. Specific to ADAS this results in higher quality imaging for superior computer vision perception, wider field of view, and longer range in both 2D and 3D.

In conclusion, this paper illustrates how the Thermal Ranger offers much needed sensor redundancy and diversity to today's ADAS and RM sensor suite to overcome the challenges most affecting safety, namely reliable operation in DVE, solar glare and generation of high-quality computer vision-based perception. Today's ADAS sensors routinely fail in these commonly encountered conditions, rendering the vehicle blind and making for dangerous driving. Through steady advancements in technology, today's drivers have been behaviorally conditioned to rely on automotive systems to augment their own driving capabilities and perform consistently, without regard to encountered conditions. Owl's Thermal Ranging solution represents the next generation technology that augments and extends todays visible cameras and radar ranging systems to a previously unachievable level of performance, taking automotive safety to new heights, and saving lives.

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