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Collision Avoidance and Automated Traffic Management Sensors

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Assessment of driver vision enhancement technologies

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ABSTRACT

Driver vision enhancement systems provide augmented information to improve the driver's perceptual ability when visibility is reduced. Vision enhancement is a technologically-challenging mission. We surveyed two classes of technologies: imaging systems (visible and infrared) and radars (millimeter-wave and laser radars). Night (IR) vision and radar-based systems promise meaningful vision enhancement functionality to the driver. Available field test data give thermal imagers operating in the range of 8 to 12 μm an edge. This spectral regime has a long (miles) clear night range, adequate object discrimination and handles inclement weather conditions better than other shorter wavelength imagers. Uncooled thermal imagers, because of their potentially low-cost, are emerging as a front runner technology. All weather penetration of a radar based system is attractive for certain driving scenarios. They are not particularly adept in high resolution imaging. This combination makes them more of interest as automated warning devices. Icons replace the actual objects imaged to indicate the hazard ahead. True all-weather high-resolution vision enhancement systems are beyond near-term capabilities. Overall, vision enhancement systems under development today will have good utility with the challenge that they become 'affordable'.

1 INTRODUCTION

Environmental and physiological factors limit driver vision. Driving a car under conditions of reduced vision often creates considerable discomfort that contributes to traffic accidents. Statistics show that approximately 42 percent of crashes and 58 percent of fatal crashes occur at night or during some degraded-visibility conditions caused by inclement weather. Illumination characteristic of the automobile's headlights limits driver vision at night. Adverse weather conditions such as fog, rainfall, heavy mist, sleet, snowfall or dust, further reduce acuity and range of vision. Imaging technologies offer a way to extend night vision both in range and field of view (FOV), improve visibility in inclement weather and provide better identification of objects within the FOV (better acuity). These features are particularly relevant to drivers over the age of 50 who generally have diminished night vision acuity.

Vision is the primary source of information for the driver at all levels of driving functions such as vehicle control and navigation. During driving, the driver performs a number of visual activities including perception of vehicles ahead, awareness of pedestrians, recognition of traffic signs and lights, road limits and markings, and perception of optical signals such as brake lights, rear lights, turn indicators and hazard warning signals. During nighttime, the driver's eyes are operating at a 'mesopic' level where contrast sensitivity is reduced compared to the daylight conditions (photopic vision). Confusion can result from fluctuations in the brightness distribution within the driver's field of vision. Such fluctuations can come from changes in road lighting, illumination from oncoming vehicles or even great changes in the brightness of the scenery. Glare resulting from these sources has a stronger detrimental effect on older drivers.

Atmospheric effects also impact driver visual performance. Rain or spray from passing vehicles reduces contrast between objects and background. Likewise, snowfall creates similar effects to night driving in that the vehicle's illumination is reflected by the snow. Dense fog gives the most negative effect on visual perception. All of these detrimental effects impact the performance of the visual task, limiting the ability to judge distances to objects, or to estimate one's speed or the speed of other vehicles. High incidence of accidents from dusk to dawn is attributable to reduced visibility.

This study assesses imaging systems in the visible and infrared regions of the electromagnetic spectrum, radars operating in various bands from 30 to 300 GHz and laser radars. Many technologies have potential for developing automotive vision enhancement systems. The U.S., Japan and various European countries are actively working on the development of systems for the intelligent vehicles. The technology base existing in the U.S., as well as other countries, finds its roots in the military establishment. Although defense and civilian applications' scenarios are quite different, the automobile industry benefits from this wealth of technologies. The challenge is adapting these military technologies to an automotive industry that requires high performance at low cost. This transition is now underway. Examples include: uncooled thermal imaging devices, millimeter wave radars based on monolithic integrated circuits and head up displays that project virtual images of the night scenery captured by IR cameras. These fledgling technologies are moving into production with limited runs and finding their way into demonstration programs.

2 IMAGERS (CAMERAS)

Imagers or cameras define the scene by detecting radiation reflected from or emitted by the various objects within the field of view. Imager sensor materials span the entire electromagnetic spectrum from the UV through the IR. Yet, the "ideal" sensor still needs to be discovered. Our goal is to seek out those that can provide high performance at a low cost. Terrestrial environments are dominated by visible radiation and thermal radiation. Figure 1 shows the terrestrial spectral radiance attributable to solar reflectance, thermal earth shine, along with emission from blackbodies at temperatures of 200K, 300K and 700K. Solar reflectance is contained mostly in the visible diminishing to a small value beyond several micrometers. Thermal earthshine has effectively no visible content, but peaks in the 8 to 14 μm region. Its spectral shape is quite close to the thermal emission from a 300K blackbody. Of particular note, is the rapid falloff in spectral emittance below 5 μm. As a consequence, optical detection below 5 μm generally requires some form of external lighting source such as from sunlight or headlights.

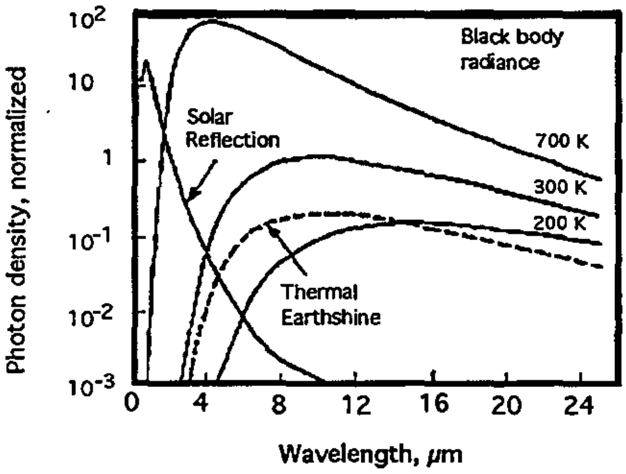

Fig. 1 Spectral characteristics of terrestrial radiance.

The atmosphere is mostly transparent in this spectral regime of interest. Figure 2 shows the spectral atmospheric transmission over a long 0.3 km path over the Chesapeake Bay area. Because of the strong absorption bands, imager systems are generally optimized for one of four transmission bands:

1.) 0.4 to 1.0 μm (VIS-NIR),
2.) 1.0 to 2.5 μm (SWIR),
3.) 3 to 5 μm (MWIR)
4.) 8 to 14 μm (LWIR).

Imagers of many types and characteristics have been developed for operation in each of these four regimes. Besides spectral response, imagers are categorized by their temporal response, by their cooling needs, and by their array size. System performance parameters include: resolution, noise equivalent differential temperature (NEDT), modulation transfer function (MTF), minimum resolvable temperature (MRT), and minimum detectable temperature (MDT). These parameters are interrelated and need to be measured for complete characterization of the imaging system.

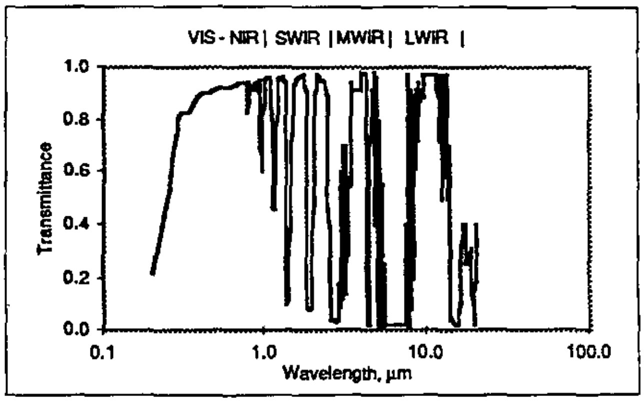

Fig. 2 Atmospheric transmittance over a 300 meter path in the Chesapeake Bay area.

3 TECHNICAL ASSESSMENT CRITERIA

Patterson[1] in his paper on "Multiple Function Sensors for Enhanced Vision Application" defines the need for sensor selection criteria to support functional integration. Along these lines, the following criteria are used for assessing the characteristics of the various imager technologies:

1. Clear night performance.
2. Inclement weather performance.
3. Maturity / projected availability.
4. Product maintainability / survivability.
5. Cost / projected cost.

Under criteria 1 and 2, visual factors[2] include: acuity, field of view, spectral sensitivity, and depth perception. Sensor factors include: sensitivity, signal-to-noise ratio, component time constants, spectral response, dynamic range, image resolution, scene contrast, cooling requirements, allowable field of view and array size constraints. These parameters are interrelated, so it may not be possible to correlate individual control operation and effects among the various technological approaches. Criteria 3 through 5 are educated projections of where the various technologies will evolve in 3 to 5 years.

4 IMAGER TECHNOLOGY ASSESSMENT

4.1 Imaging Optics

Visible/near-IR optics are commercial and affordable. Such optics can fulfill any foreseeable application related to the vision enhancement scenario. MWIR and LWIR optics are limited and expensive. The optical elements involve expensive materials (e.g., germanium, zinc selenide, etc.)

And because of the longer wavelength in the IR, the optical elements are larger in order to achieve sharp (i.e., diffraction-limited) images. A major problem in the IR is caused by the detector array "seeing" radiation other than the desired scene radiation from object space. These effects are analogous to stray-light problems often encountered in the visible. They can be obviated by good optical design, but at significant cost.

4.2 Pickup Element (Sensor Array)

Table 1 presents an overview of the various detector technologies that are available today for optical imaging. Mechanical scanner imagers are excluded for the vision enhancement scenario because of their inherent complexity and high cost.[3] The table includes: detector type, material spectral response and overall system spectral response. Holst et al[4] gives expanded details of photon sensor arrays.

4.3. Vidicons

Vidicons comprise a broad class of camera tubes. Each operate in a specific spectral range that spans the visible, NIR, MWIR and LWIR portions of the spectrum. Vidicons are the mainstay of commercial broadcast and industrial TV. They are highly developed to achieve high spatial resolution. Operationally, they are complex, fragile, and costly. Their dominance in the field will diminish as solid-state CCD imagers come to the forefront. The main variant in vidicon types is the material used as a "target". The silicon vidicon utilizes a silicon photodiode array as a target and has the characteristics of high sensitivity, low dark current, very low lag and non-burn-in. This vidicon can be exposed to direct sunlight without damage and has a spectral response that extends out in the IR to about 1.1 µm. The Harpicon[5] is another recently developed tube. This vidicon tube uses a HARP (High-gain Avalanche Rushing amorphous Photo-conductor) target. This technology promises a 100-fold increase in sensitivity with no loss in picture quality. Low sensitivity pyroelectric vidicons used in the MWIR and LWIR have been commercially available for over 20 years. Pyroelectric vidicons produce images only in response to changes in target temperature. Therefore, some provision must be made to provide a time varying temperature profile over the scene. For fixed installations, the incoming thermal radiation is normally chopped or shuttered at a controlled interval. One of the key obstacles in all vidicons is "registration". Low performance vidicons may run a few hundred dollars, but a high performance vidicon with excellent resolution will run in excess of $5000.

4.4 Image Intensifiers

The image intensifier technology was originally developed as an amplifying element in military night vision systems. All pickup elements have the characteristic of a lower electronic noise floor and consequently a higher sensitivity when cooled, relative to the ambient environment. The tradeoff is more complexity (cooling hardware and control) and a slower response. This slower response precludes standard video in general. The image intensifier technology[6] has emerged to provide both sensitivity and adequate speed of response. Today's third-generation image intensifiers are still expensive (> $10,000).

Table 1 Imaging technologies.

Detector type	Detector Temperature	Typical Spectral Range
Vidicons	Amb.	
Visible		0.4 - 0.7 µm
Silicon		0.4 - 1 µm
Harpicon		0.4 - 0.7+ µm
Pyroelectric		8 - 12 µm
Image intensifier (I^2)	Amb.	0.5 - 0.9 µm
ARRAYS (Near ambient)		
Silicon CCD	Amb.	0.4 - 0.7 µm
InGaAs	Amb. (TE)	0.9 - 1.7 µm
PbS	Amb. (TE)	1 - 3 µm
PbSe	Amb. (TE)	1 - 5.5 µm
HgCdTe	200K	3 - 7 µm
Ferroelectric (pyroelectric)	Amb. (TE)	8 - 14 µm
Bolometric	Amb. (TE)	8 - 14 µm
Tunneling Golay	Amb.	8 - 14 µm
ARRAYS (Cryo- cooled)		
Pt Si	80K	3 - 5.5 µm
InSb	80K	3 - 5.5 µm
HgCdTe	80K	8 - 11 µm

4.5 Ambient Arrays

Silicon CCD

Remarkable improvements in CCD imaging technologies has occurred in recent times. CCD imaging cameras are now available with resolutions exceeding 4 million pixels per frame, image dynamic range exceeding 12 bits, and data transfer rates of more than 100 MB/s. In the consumer-video market, CCDs are smaller and inexpensive. Useful CCD cameras are advertised for less than a hundred dollars.

InGaAs

InGaAs arrays[7] is an emerging technology. InGaAs detectors have high quantum efficiencies $(\eta > 0.7)$ in the (1 to 1.7 µm) spectral range. Mean detectivities of the FPAs, $D^*_{\lambda pk}$ have

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