Automotive Cameras
for Safety and Convenience Applications

White Paper by SMaL Camera Technologies, Inc.

2004 Version 1

SMaL Camera Technologies

Contents

1. What's New in Automotive Safety?

Automobile safety technology advanced by great strides throughout the 20th century, from the first appearance of speedometers and electric headlamps, to the development of seat belts and safety glass, to the emergence of anti-lock brakes and airbags. As consumers demand safety, more and more automobile manufacturers are providing sophisticated technology, first as special options on luxury models, then as standard equipment across entire product lines.

No so long ago, auto safety was limited to measures whose purpose was to protect occupants during a collision. These are *passive* safety systems, intended to protect the car's occupants against injury or reduce the severity of injuries in the event of an accident. Seat belts and air bags are examples of passive safety systems.

As we move into the 21st century, passive systems are being complimented by *active* safety systems, which help to avoid collisions altogether. An active approach to safety aims at avoiding personal injury by preventing an accident from happening. Anti-lock brakes and blind spot monitoring are examples of active safety systems.

Figure 1 analyzes the major causes of the worst accidents in 2002, showing that failure of drivers to stay within a lane caused more vehicular fatalities than any other single cause in the United States. While passive safety technology continues to be important, active safety systems, such as those that can detect an unintended lane change and alert the driver *before a collision happens*, will be required if consumers are to expect dramatic additional improvements in automobile safety.

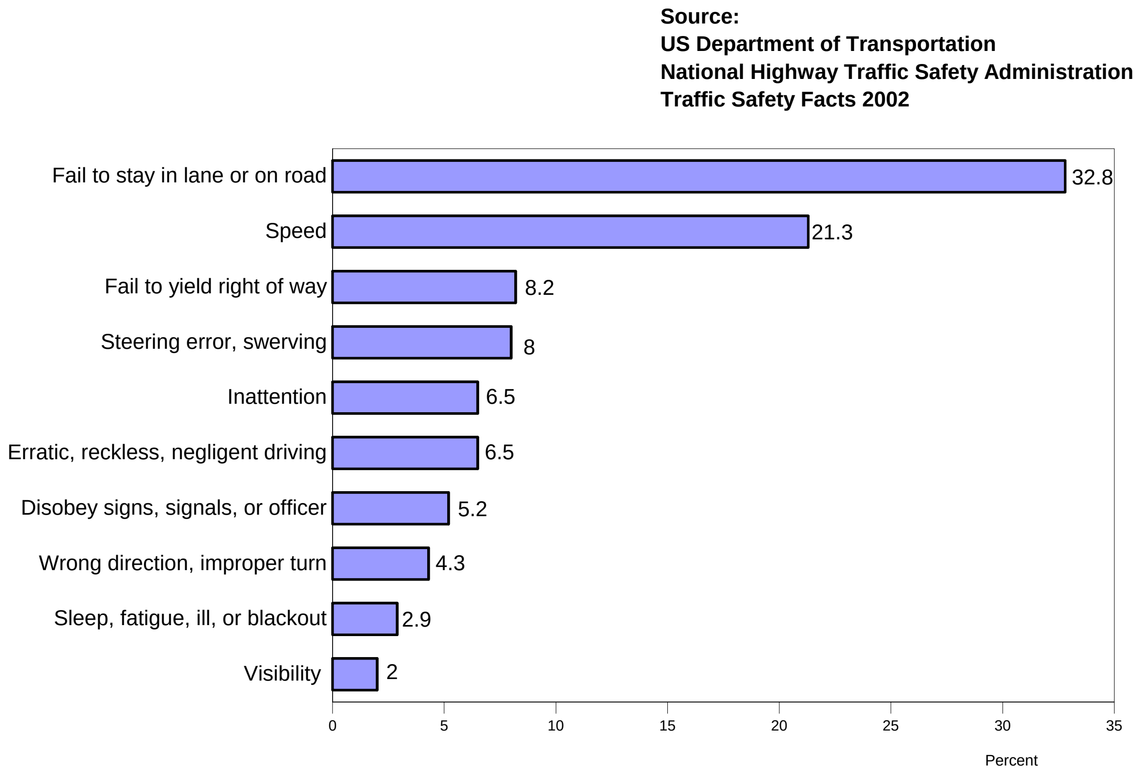

Figure 1 Major factors for drivers involved in fatal crashes

The eventual—and optimal—outcome of automotive safety system development will be a fusion of active and passive safety systems, working together as an integrated web to prevent accidents, reduce severity of inevitable accidents, and protect effectively in the case of an accident. Furthermore, systems will be *intelligent*, using advanced technologies including smart sensing. An example of an intelligent safety system is an airbag system that uses remote sensors to characterize the vehicle occupants and adjusts the rapid deployment to prevent injury to smaller passengers.

This paper looks at intelligent sensing in active and passive automotive safety, specifically vision-based technologies—systems that use cameras for remote sensing. With the advantage of higher resolution for better object recognition, cameras are already being deployed in applications such as rear view enhancement, night vision, and lane departure warning.

The first generation of vision-based systems used general-purpose cameras that were not designed specifically for automotive applications. Such cameras do not stand up to the automotive environment and do not provide the necessary high level of performance. The future of automotive vision depends on the development of *automotive-specific* cameras, devices that are designed and manufactured specifically for use in vehicles. Such cameras will provide a higher level of performance than general-purpose cameras, while meeting automotive quality standards and providing low unit costs at high volume. The development and manufacture of such cameras is not a trivial undertaking and presents many unique challenges.

SMaL Camera Technologies, Inc. has taken the lead in developing fully-integrated imaging solutions designed specifically for automotive vision systems. SMaL strives to be the world's leading supplier of advanced automotive imaging solutions.

2. Remote Sensors in Intelligent Safety Systems

What is needed for this integrated web of active and passive safety systems to become reality? The key technological advancement that will facilitate its realization is the development of *intelligent* safety systems. Intelligent safety systems differ from their predecessors in that they actually *sense* real-world conditions and adjust their performance accordingly. For example, in a conventional braking system, brake pressure is determined solely by how hard the driver presses the pedal. In an intelligent braking system, the system would actually *sense* whether an object was in the vehicle's path and would apply or assist with braking appropriately.

Any intelligent safety system has two key components: the *remote sensor* and the *processing computer*. The remote sensor is any device that collects data about real-world conditions. Some examples of remote sensors are radar, ultrasonic sensors, and cameras.

The processing computer receives data from the sensor as input[1], makes a decision, and sends commands to vehicle subsystems to help prevent an accident, mitigate its severity, or protect the vehicle occupants. In an example of an intelligent safety system, a processing computer might use the data from the sensor to decide that collision is imminent and send a command to the vehicle subsystems to apply brakes.

Technological advances in microprocessors and sensor technologies are making intelligent safety systems a reality. For example, advances in integrated chips now enable us to combine sensing with downstream processes, such as signal processing and data conversion, within a single compact device. Such embedded intelligence reduces the need for centralized data processing and greatly reduces the cost of intelligent systems. As these ad-

[1] The processing computer may receive data from multiple sensors and/or other sources of vehicle data, such as steering angle and speed.

vances accelerate, sensors that incorporate intelligence will become part of both passive and active safety systems.

In passive safety systems, advances in intelligent sensing will enable us to obtain information about a possible crash before the impact occurs and take steps earlier to mitigate the outcome. For example, a pre-crash sensor can detect an object in collision range and initiate a change in seat belt tension before impact. Or, a camera that monitors vehicle occupants can determine whether it is safe for an airbag to deploy.

In active safety systems, sensing intelligence will help to prevent an accident from happening, or mitigate the severity if an accident is inevitable. For example, a lane departure warning system uses smart sensors to monitor the road markings and determine if the car is moving outside of its lane. By alerting the driver of the lane change, the warning system mitigates a potentially hazardous condition. Eventually, such systems will become more sophisticated and will actually provide power assist to the steering in order to help the driver keep in the lane.

Together with the car's passive safety features, active safety systems help to provide optimum protection for all of the car's occupants. The ideal system is a marriage of intelligent active and safety systems that will provide a significant reduction in fatalities, injuries, and damages.

Figure 2 illustrates the developing market for advanced sensing and safety systems.

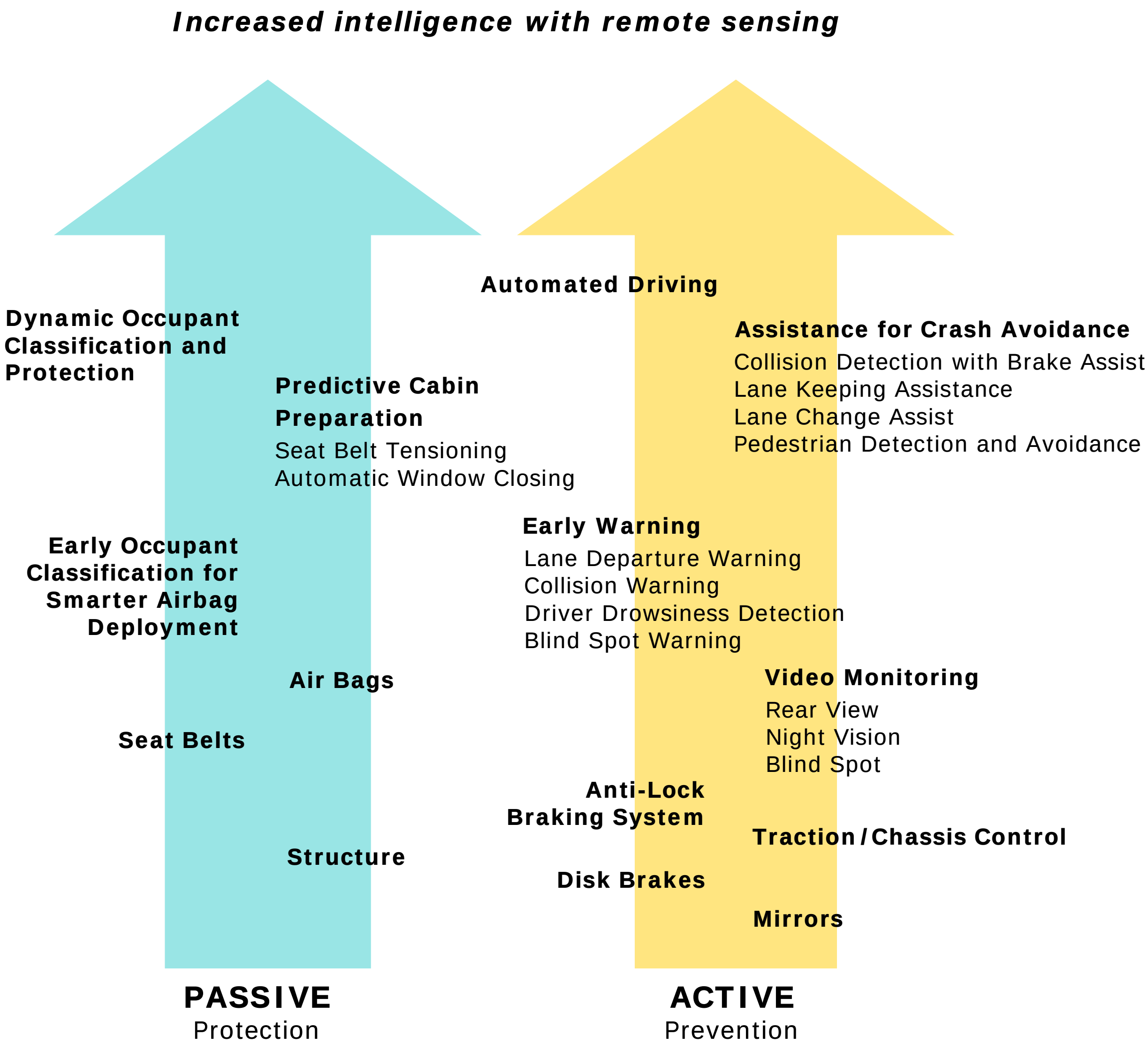

Figure 2 Developing market for advanced sensing and safety

Intelligent safety systems will require different types of sensors for different applications, and in some cases, multiple sensors types for the same application. The following are just a few examples of automotive safety systems that use different types of remote sensors:

- An adaptive cruise control system uses radar to determine the distance from other vehicles on the highway and uses the information to adjust the car's speed to maintain a safe following distance.

- A night vision system uses sensors that detect infrared light to see beyond the distance illuminated by headlights. The information can be used to produce a "heads-up display" that projects the image on the windshield to assist the driver. Affordable night vision systems will utilize sensors that respond to energy in the 700 to 950 nm range.

- An occupant classification system uses a pressure sensor to monitor the weight of the passenger seat's occupant. The information is used to classify the passenger as adult or child for safer airbag deployment.

- A pre-crash system emits laser light into the area just ahead of the vehicle and a sensor detects the light reflected from an object in the vehicle's path. In a process known as *ranging*, the system calculates the time between emitting and receiving the pulse. The information is used to determine the distance to the object and prepare for a collision.

Each type of remote sensor has advantages as well as disadvantages. Table 1 lists several current sensor technologies and compares their advantages.

Table 1 Comparison of remote sensor types

Sensor type	*Key Advantages*
Cameras (vision)	• Variable field of view (FOV), narrow to panoramic • High spatial resolution • Color data • Low unit volume costs • Non-emitting • Configurable for multiple applications
Radar	• Wide FOV • High range resolution • Operates in adverse weather conditions • Operates over significant distances
Laser (lidar)	• Wide FOV with angular resolution • Ranging • High accuracy
Ultrasonic	• Ranging for short distances • Low unit volume costs
Thermal cameras	• Passive/non-emitting • High temperature resolution

As Table 1 shows, vision cameras have several key advantages that make them uniquely suited for some remote sensing applications. Development of safety features using a fusion of available sensors, including vision-based systems, will provide the most robust solutions.

However, general-purpose cameras do not provide the performance required for critical safety systems. The next section examines performance requirements for cameras in intelligent safety systems and demonstrates the need for cameras that are developed specifically for automotive applications.

3. Camera Performance for Remote Sensing

Cameras play an important role in intelligent safety systems. Rear view enhancement is a common implementation of a vision-enabled application. A high-resolution vision camera assists a driver in parking and backing up by providing a clear view of the area otherwise not visible directly or in the mirrors.

Figure 3 shows just some of the many applications for cameras in automotive vision.

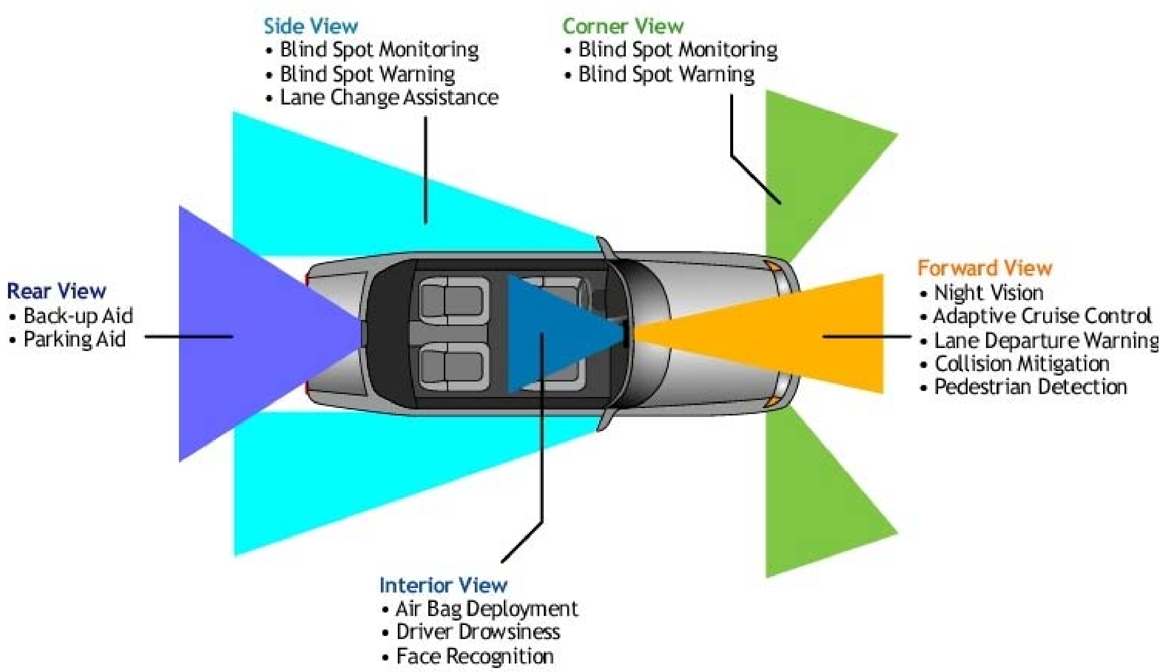

Figure 3 Applications of cameras in automotive safety

Low-cost digital video technology is widely available today from a variety of sources. Most of this technology has been developed for use in consumer devices such as digital cameras, camcorders, and cell phone cameras. Such general-purpose technology is not well suited for use in automotive intelligent safety systems. These existing technologies are not designed for the rugged automotive environment, nor are they developed with the rigorous automotive quality standards in mind. Furthermore, general-purpose cameras do not provide the performance levels such as wide dynamic range, extended spectral band, and low light sensitivity that are needed to make automotive intelligent safety systems possible. Clearly, there is a need for focused development of automotive-specific cameras.

For a camera to perform well in automotive applications, it must meet stringent requirements. The camera must outperform general-purpose cameras in all conditions of intensity and direction of illumination, wavelengths of light in the scene, and speed of motion of the object being detected. Also important are reliability and cost effectiveness. The automotive camera must be commercially available at volume costs and built to last for long life in a rugged environment.

Table 2 list the unique and most critical performance, quality, and cost requirements for automotive cameras.

Table 2 Requirements for automotive cameras

Property	*Description*	*Requirements*
Wide dynamic range	Performance under extreme variations of illumination. Ability to accurately capture visual information under conditions such as approaching headlights, glare from other vehicles, tunnel entrances and exits, and rising or setting sun. Ability to reduce exposure response time.	• Dynamic range of 100 dB minimum • Adaptability, programmability • Operation in day and night conditions • Monochrome and color processing
High imaging sensitivity	Efficiency in converting light to signal without producing excess noise. Higher sensitivity means less light is needed to produce a good signal-to-noise ratio (SNR) and thus useable images. A camera with high sensitivity can capture good pictures in low light.	• Low light sensitivity

Wide spectral range sensitivity including near-infrared	Sensitivity to near-infrared (NIR) wavelengths enables a camera to capture wavelengths that are present in the night sky. Near-infrared can also be projected by special headlights as additional lighting because it is invisible to the human eye.	• Near-infrared sensitivity • Broad spectral response (400 nm to 1100 nm)
Reliability and conformance to automotive quality standards	Cameras must be able to withstand the automotive environment. They should be manufactured and delivered under the ISO/TS16949 international quality management system for automotive parts manufacturers. High levels of product quality must be maintained.	• 15 year product life in extreme environmental conditions • Comprehensive validation testing • Stringent quality control in production • Process measurement and continuous improvement • Zero defects
Low overall cost of safety system	Systems incorporating automotive cameras must be available to the consumer at attractive prices. This is accomplished by controlling the cost of the camera component itself, as well as designing the camera to enable lower costs in the overall system.	• Camera is configurable for use in multiple applications • Cost-conscious design including Camera on a Chip (COC) when necessary • Common video format • Advanced features to reduce cost of other system components

The preceding table lists the most critical automotive-specific requirements. As intelligent safety systems become more sophisticated, additional requirements such as high frame rate and advanced region of interest control will also emerge as requirements.

General-purpose cameras do not meet the performance, quality, and cost requirements for automotive cameras listed in Table 2. What the automotive industry needs are automotive-specific cameras that meet the requirements for automotive safety. The next two sections of this paper compare current CCD and CMOS image sensors and identify the best technology to build upon as we focus on developing automotive-specific image sensors.

4. CCD Image Sensors

Until recently, charge-coupled devices (CCDs) were the only solid-state image sensors available for digital cameras. Invented in 1969 at Bell Labs, CCDs were originally developed as computer memory but quickly expanded into use in telescopes, video cameras, scanners, and other imaging applications.

CCDs are well suited to numerous applications, but have inherent drawbacks for automotive safety. Most CCD-based cameras do not provide the necessary wide dynamic range listed in Table 2. The most significant drawback, however, is economy of scale. CCD manufacturing requires specialized foundries, equipment, and processes, which prevents them from meeting the low cost/high volume production requirements for automotive cameras.

Furthermore, CCD architecture poses inherent limitations for automotive safety. Standard CCD image sensors are designed for serial readout, meaning that all previous pixels must be read out before the next pixels can be read (see the “Charge-Coupled Devices” sidebar). The readout architecture limits the *frame rate*, the number of images per second. This is a significant disadvantage in automotive safety applications, where capturing images rapidly will become a critical function.

Additionally, the typical CCD architecture imposes the following performance drawbacks that will become increasingly important as intelligent safety systems require more sophisticated and flexible image processing:

- Limited *subsampling*. Subsampling is useful when an application does not need to work with the full pixel resolution. The resultant image shows the same scene as the original image, but contains less detail and uses fewer pixels. With subsampling, less data is transferred, providing faster frame rates.

- Limited *subwindowing*. Subwindowing selects only a rectangular portion of the image, capturing only a region of interest to speed the data transfer without changing the resolution. Subwindowing is also a useful function in future applications that will require image processing to specific regions of the image.

Finally, CCD devices have a tendency toward *blooming*, an effect that happens when a pixel receives more light than it can handle and the extra charge spills into neighboring pixels. The highlight spreads in the captured image, causing an artifact like the one shown in Figure 4. Special circuits must contain the overload charge and these circuits are not generally designed into general-purpose imaging devices. Additionally, using circuits to control blooming in CCDs typically reduces the spectral response, particularly in the near-infrared wavelengths.

Figure 4

Optical blooming typical of commercial CCD performance

More about Charge-Coupled Devices

During integration, an image sensor captures light on a grid of pixels. After the integration, the charges are read off. Charge-coupled devices (CCDs) take their name from the way the charges are read from the grid.

To begin, the charges on the first row are transferred to a read out register. From there, the signals are fed to an amplifier and then to an analog-to-digital converter. Once the row has been read, its charges on the read out register row are deleted. The next row then enters the read out register, and all remaining rows advance by one row.

The charges on each row are thus "coupled" to those on the preceding row. When one row advances, the next row takes its place and each row is read—one row at a time.

---

5. CMOS Image Sensors

Complementary Metal Oxide Semiconductor (CMOS) is replacing CCD as the image sensor of choice in numerous imaging markets, including automotive. CMOS cameras are capable of meeting the requirements for wide dynamic range (see the Extended Dynamic Range with Autobrite® sidebar), imaging sensitivity, and wide spectral range.

CMOS image sensors are designed for fabrication in cost-effective commercial foundries, using the same high-yielding processes that produce other computing chips. The end result is an advantage over CCDs in economy of scale, with comparable image quality. This paves the way for producing high volumes that meet quality standards at lower overall cost.

CMOS image sensors have *random access readout*, meaning that pixels can be randomly addressed and a sub-frame quickly read out. As a result, CMOS image sensors overcome some of the disadvantages of CCDs described in this paper and are nearly unlimited in their ability to subsample and subwindow. Figure 5 shows the results of digitally zooming to a region of interest with CMOS image sensor subsampling.

In addition, CMOS image sensors are not subject to the same blooming effects as CCDs. Figure 6 shows the results of a CMOS image sensor containing the overload charge.

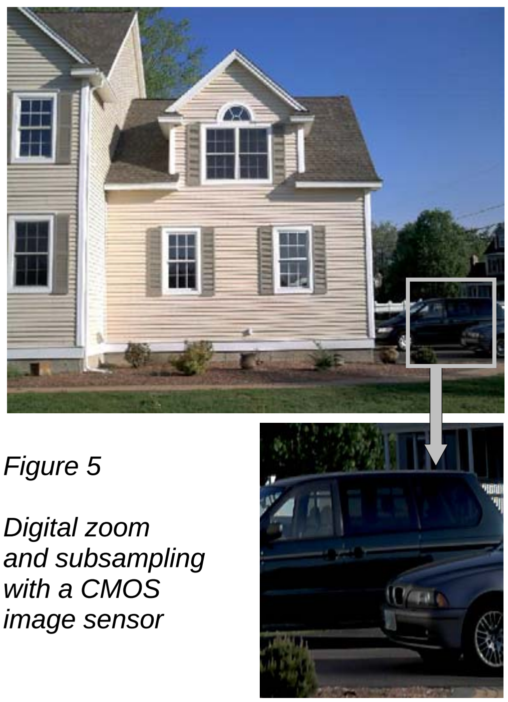

Figure 5

Digital zoom and subsampling with a CMOS image sensor

Figure 6

CMOS image sensor containing overload charge without blooming

CMOS is clearly the technology of choice as the automotive safety industry moves toward more advanced safety systems. The next section of this paper shows in more detail how designers focusing on CMOS technology will provide automotive cameras that meet all of the requirements in Table 2.

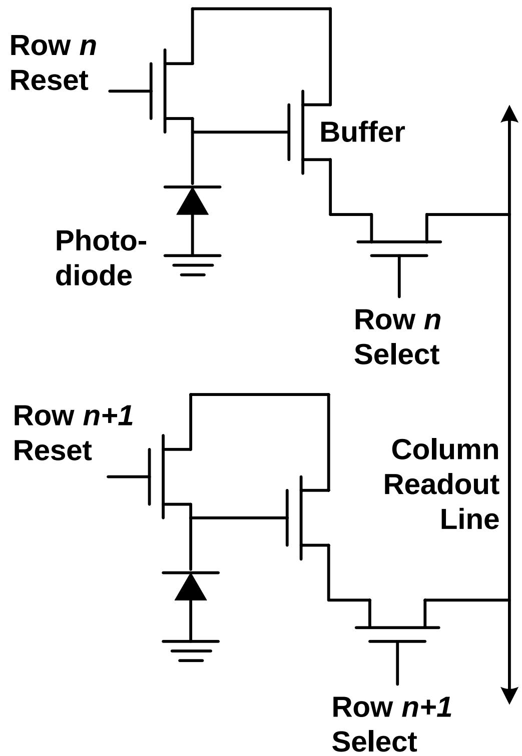

Figure 7 Diagram of CMOS active pixel

More about Complementary Metal Oxide Semiconductors

Complementary Metal Oxide Semiconductors (CMOS) active pixels (see Figure 7) consist of:

- *Photodiode to convert photons to electrons and store the integrated signal*
- *Reset to periodically return the photodiode to a state of reduced signal*
- *Buffer to drive the integrated signal to on-chip processing*
- *Row select to multiplex pixels on a common column read line*

Each frame comprises a reset of the pixel followed by an integration and readout of the charge.

6. Automotive-Specific Cameras

As the preceding sections of this paper have shown, the automotive industry must focus on developing automotive-specific cameras based on CMOS technology. These cameras will provide a higher level of performance in dynamic range and imaging sensitivity, while meeting automotive quality standards and providing low unit costs at high volume. This section describes the requirements in more detail and shows how cameras can be developed to meet the requirements of automotive vision.

Wide Dynamic Range

The dynamic range of a scene is the ratio of the highest to the lowest intensity of light. The real world has extremely wide dynamic range.

The dynamic range of a camera is the ratio between the darkest and the brightest area the sensor can capture at the same time. If the dynamic range of a camera is not sufficiently wide to accommodate the dynamic range of a scene, the resulting image will fail to capture details that the automotive safety system requires.

Figure 8 illustrates the challenge of capturing the dynamic range of scenes in the automotive environment. From a moonlit night to full sunlight, the range is 120 dB. For comparison, the dynamic range of standard camera is approximately 60 dB—inadequate for capturing both extremes of lighting in the same image.

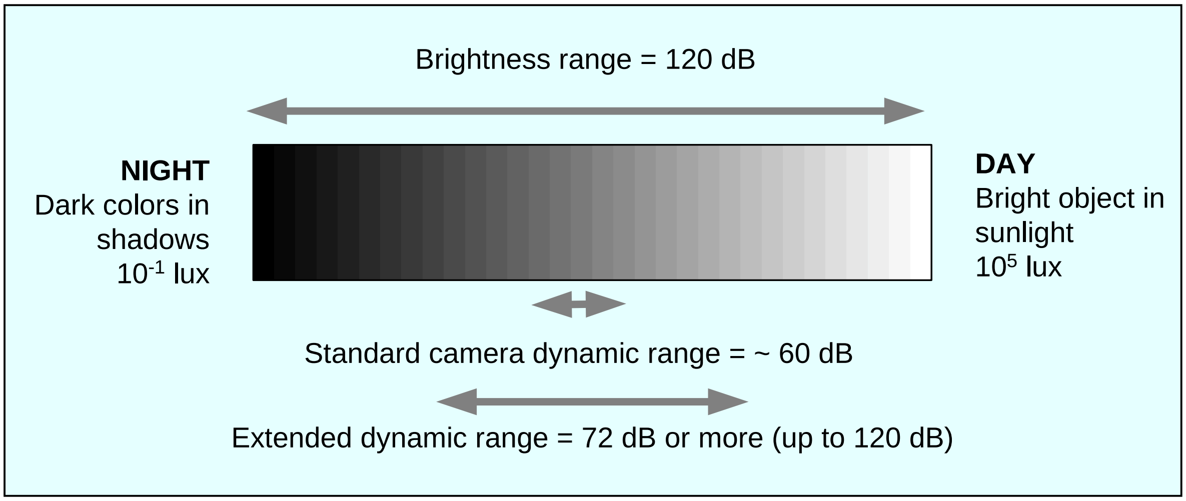

Figure 8 Typical values of dynamic range

Higher performance cameras with extended wide dynamic range provide 72 dB or more, in some cases achieving up to 120 dB. Higher dynamic range shows more details even in the darkest areas and avoids *saturation*, the "washed-out" effect in the brightest areas.

More about Dynamic Range

Expressed in decibel units (dB), dynamic range is a logarithmic ratio of light units measured in lux or candelas per square meter (cd/m2) according to the equation:

$$Dynamic\,Range = 20\,Log\,\frac{Signal\,(saturation)}{Signal\,(noise)}$$

At maximum brightness, the signal is limited by saturation, the point at which a pixel has accumulated its maximum charge and cannot process additional light.

At minimum brightness, the signal is limited by the noise floor. The noise floor represents the level of noise inherent in the imaging device, resulting from process technology limitations such as dark current and circuit design factors such as reset noise.

Figure 9 illustrates the difference between images captured with and without wide dynamic range. Automotive-specific cameras providing extended dynamic range are clearly required to capture the extremes of lighting in the automotive environment.

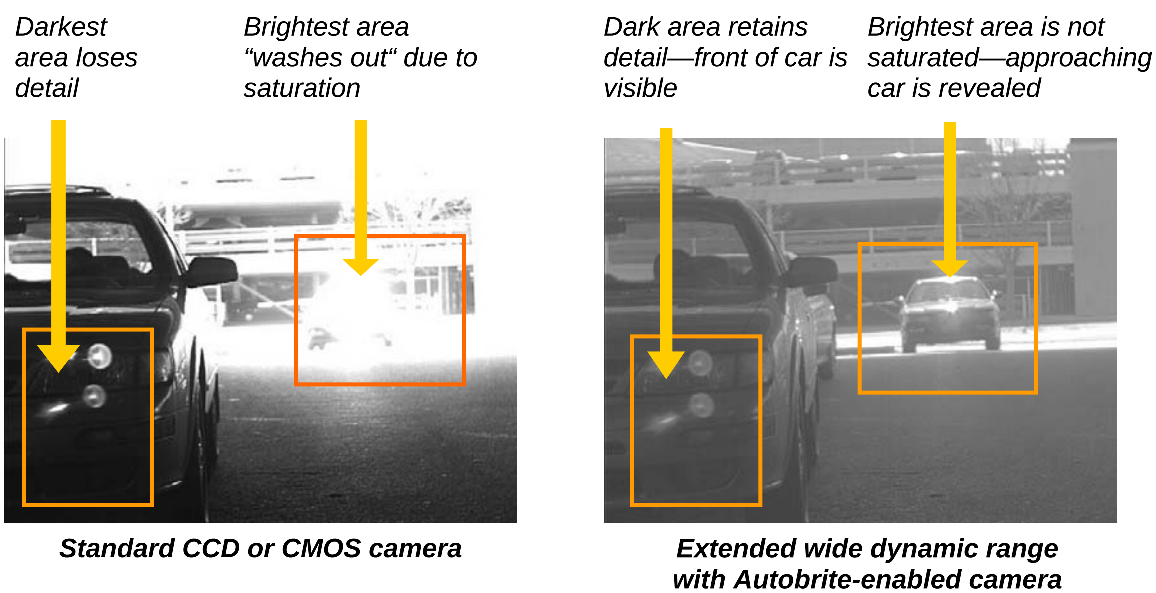

Figure 9 Comparison of automotive images

Extended Dynamic Range with Autobrite®

Autobrite® is a complete solution from SMaL Camera Technologies that provides extended dynamic range. Autobrite's wide dynamic range enables an automotive camera to capture critical visual information under challenging lighting conditions.

Autobrite's extended wide dynamic range improves differentiation, the ability of the automotive safety system to characterize objects even in the most difficult lighting conditions. Autobrite automatically adapts between night and day lighting conditions, adjusting every frame to ensure total data integrity.

For more information about SMaL's Autobrite technology, request a copy of our white paper "Autobrite® Imaging Technology: Wide Dynamic Range for Automotive Machine Vision".

High Imaging Sensitivity

The higher the sensitivity of an image sensor, the less light the camera needs to capture a good image. Figure 10 shows an example of the challenging lighting conditions in the automotive environment that require a camera with maximum sensitivity in low light.

Figure 10

Low-light scene requires a camera with high imaging sensitivity

An amplifier or gain can boost the signal output from the sensor, but doing so amplifies the noise as well as the data.

Maximizing sensitivity in the image sensor involves the following:

- Increasing light collection efficiency
- Reducing electronic noise such as read and reset noise
- Increasing the pixel's *fill factor*, the ratio of the light-sensitive area to the total area
- Lowering dark current

Designers of image sensors intended for automotive cameras are focused on improving these factors. For example, developments in new circuitry dramatically reduce pixel read and reset noise while maintaining high fill factors.

In addition, the latest CMOS manufacturing processes and pixel design techniques are resulting in much reduced dark current levels. Reducing dark current is critically important because dark current increases with the temperature of the image sensor. Therefore, in order to achieve high image quality at automotive temperature extremes, low dark current levels must be achieved.

Finally, designers focused on delivering high sensitivity image sensors for automotive cameras are developing new pixel architectures with reduced line widths and intelligent geometries to maximize fill factor and greatly improve light collection efficiency.

More about Sensitivity

Two factors critical to an image sensor's sensitivity are efficiency and noise.

Efficiency is the ratio of light energy incident on the photodiode to the photocurrent output. It describes how well the sensor changes photons (units of light) into electrons. High light collection efficiency means fewer photons are lost.

Every image sensor has a detection limit determined by noise. Captured photons that do not exceed the noise are not useful.

Sensitivity can be quantified as the light level incident on the chip that produces a signal-to-noise ratio=1. The lower this light level, the more sensitive the chip.

Wide Spectral Range with Near-Infrared Response

About half of all serious traffic accidents occur at night, even though there are fewer vehicles on the roads than during the day. Night-vision and other devices using near-infrared (NIR) light can help drivers and intelligent safety systems to see in the dark by collecting visual information under conditions of very low light. The collected information can be used to trigger a warning system or to project a "heads-up display" so the operator can see objects that would otherwise be obscured.

Enhancing near-infrared response requires automotive-specific image sensors that have been tuned to the spectral wavelength for much greater performance. Leading automotive CMOS image sensor and camera developers are designing pixels matched to the wavelength of the illuminant for highest clarity and sensitivity. Different wavelengths of light are absorbed at different depths in the image sensor's silicon. Blue photons are absorbed at 0.05 microns (µm) depth and near-infrared photons are absorbed at 1.6 µm depth. CMOS designers can use this fact to tailor pixel designs for specific wavelength response.

More about Infrared Light

Infrared is the region of the electromagnetic spectrum just out of the visible range of light. Infrared is divided into three sub-sections:

Near-infrared. Closest to visible light, with wavelengths ranging from 0.7 to 1.3 microns (µm).

Mid-infrared. Wavelengths ranging from 1.3 to 5 µm (although atmospheric absorption limits useful bandwidth to the 2.1 to 5 µm band).

Far-infrared. The largest part of the infrared spectrum, with wavelengths ranging from 3 µm to over 30 µm (although atmospheric absorption limits useful bandwidth to the 8–12 and 15–30 µm bands). Heat energy is considered to be far-infrared.

Although invisible to the human eye, infrared energy can be useful for various applications. Both near-infrared and mid-infrared are used by a variety of electronic devices, such as remote controls.

Night-vision systems use either near-infrared or far-infrared energies. A key distinction is that far-infrared is emitted by an object while near-infrared and mid-infrared are reflected off the object. Therefore, night-vision devices using far-infrared do not require a light source, while devices using near-infrared require illumination from headlights or another source. Near-infrared is detectable with standard CMOS sensors, while far-infrared requires specialized, expensive sensor types.

Reliability and Conformance to Safety Standards

Most of our motor vehicles are subjected to adverse conditions—extremes of weather, poor road conditions, and corrosive salts. The automotive environment is no place for unprotected electronics. The industry needs components that last for long periods of time under exposure to any conditions.

Well-known solutions exist for enclosing typical electronics modules in protective housings. However, the challenge of protecting a camera's optical path while maintaining accurate focus, at low cost and for fifteen years of life, is significant. Achieving this goal requires a host of integrated technologies and techniques.

These are some examples of the steps that must be taken to protect automotive cameras:

- During manufacture, the optical path of the camera must be precisely and automatically aligned and focused. This alignment must be held in place using advanced mechanical and adhesive techniques.

- The camera must maintain its focus even though it expands and contracts with heat and cold. *Athermalization*, a critical aspect of design, means the temperature of the camera must not affect the image focus. This is achieved through precise mechanical design and materials selection.

- The camera must be sealed against moisture.

- The camera must use low power and heat dissipation techniques. Heat buildup not only shortens a camera's life, but also reduces picture quality through increased noise.

The approaches listed here are critical to the performance and reliability of automotive cameras, but are seldom assigned high priority in the design of general-purpose cameras.

Low Overall Cost Of Safety System

Unlike CCDs, where processing circuits must be on separate chips, CMOS provides single-chip capability. With CMOS technology, both imaging and image processing functions can co-reside on the same device. Figure 11 illustrates a typical "camera-on-a-chip" package.

The combined features of cost-effective production and single-chip capability clear the path to developing automotive-specific image sensors with features such as:

- In-pixel processing
- Pixels tuned for an application
- Custom operation and interface

In-pixel circuitry can be used to share information with neighboring pixels for parallel processing, enabling processes such as high-speed motion detection, edge enhancement, multiple resolution, and recognition. On-chip circuitry can be used for more compact imaging systems, incorporating such modules as compression (JPEG, MPEG4, etc.), timing and control, computer interface, and uniformity correction. This advanced feature integration helps to lower overall system cost by reducing the processing burden on other components in the system.

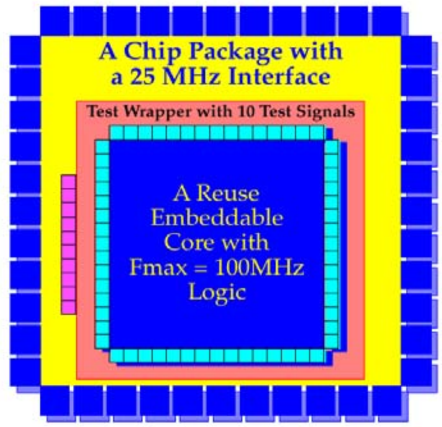

Figure 11

Mixed-signal "camera on a chip" with core base for design reuse

Finally, through programmability and wide feature availability, CMOS architecture permits *configurability*, a powerful attribute that provides the flexibility of using the same camera or image sensor for multiple applications. A vehicle with several safety systems may require multiple cameras, each performing a specific function under different conditions. Instead of deploying multiple specialized cameras, automotive safety systems developers will have the option to use the same camera technology throughout, configuring each sensor for maximum performance.

An immediate benefit of a configurable camera is reduced overhead. Stocking only one type of camera means a cost savings over maintaining multiple types of specialized units. Configuring a camera instead of producing a new one means less development time—and faster time to market for new applications.

7. What's Next for Automotive Vision?

As we have shown in this paper, vision-based cameras are increasing in importance as sensors for automotive safety and convenience. As the automotive safety industry looks ahead at the development of intelligent active and passive safety systems, we can predict the need for automotive cameras tailored specifically to these systems.

In the early stages of testing and deployment of this technology, we have learned that general-purpose cameras do not provide critical performance for automotive applications. Therefore it is important that the latest design efforts aim at producing automotive-specific cameras based on CMOS technology to meet the demanding environmental and operational requirements of automotive safety and convenience.

At SMaL Camera Technologies, Inc., our goal is to be a single source of supply for current and future automotive vision solutions. Because our cameras are designed specifically for the automotive market, they meet the demanding needs of intelligent safety systems. SMaL's Autobrite technology provides the wide dynamic range performance that is required. SMaL's advanced image sensor and camera designs also deliver high sensitivity and near-infrared response in combination with wide dynamic range. No other provider can claim such high performance on both these parameters in the same solution.

Finally, SMaL's configurable and flexible designs ensure that a single camera module can be used for multiple applications. SMaL automotive camera modules are configurable and programmable to enhance their flexibility.

Figure 12 shows that the rate of traffic fatalities has consistently decreased over the last decade with advancements in automotive safety. To further decrease the rate of fatalities will require robust solutions based on a fusion of active and passive safety systems working together as an integrated web. These will be smart systems, using advanced technologies in intelligent sensing, including vision, to prevent accidents, reduce severity of inevitable accidents, and protect effectively in the case of an accident.

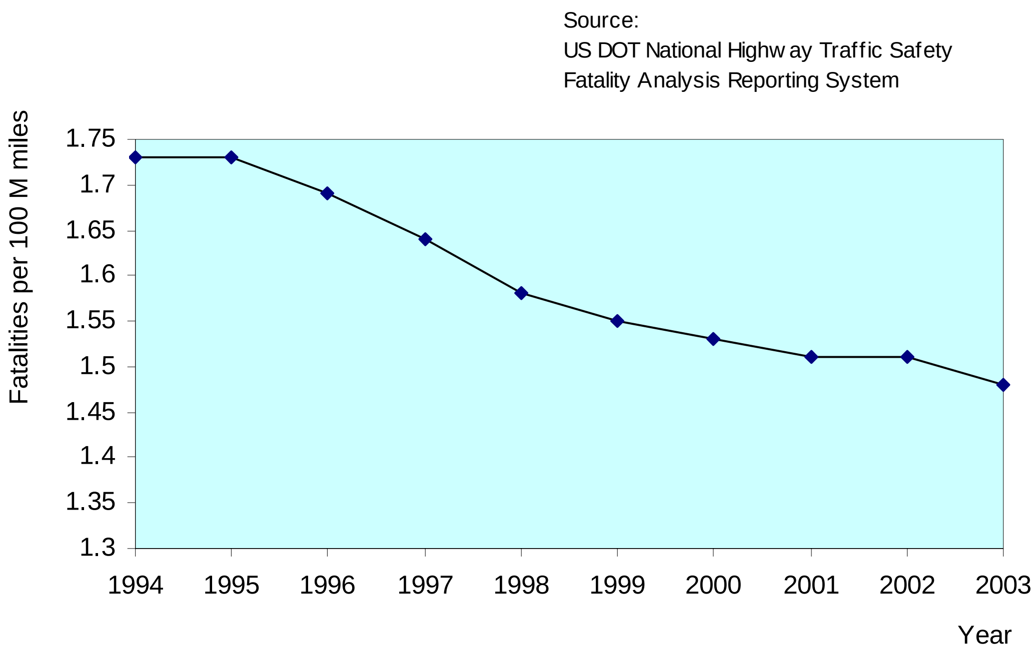

Figure 12 U.S.rate of fatalities per 100 million vehicle miles traveled

About SMaL Camera Technologies

SMaL Camera Technologies is an award-winning developer of high quality image sensors and digital imaging solutions for the digital camera, mobile phone, and automotive markets. SMaL's solutions are built around its proprietary CMOS image sensors, image pipeline, ASICs, and Autobrite® wide dynamic range technology. The result is industry-leading integration, high dynamic range, low-light sensitivity, low power consumption, and near-infrared sensitivity. SMaL was co-founded and launched in 1999 by leading electronic imaging experts at the Massachusetts Institute of Technology (MIT). SMaL is a privately held, venture-backed company headquartered in Cambridge, Massachusetts, USA.

For more information on SMaL Camera Technologies and its products, visit the company's web site at http://www.SMaLcamera.com.