Camera Performance Considerations for Automotive Applications

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Vision systems in cars?

• Availability of low-cost high-performance electronics has increased the feasibility of automotive vision systems.

• Several different applications are currently being evaluated by research groups including:
  – Collision avoidance and intelligent cruise control
  – Enhanced night vision
  – Driver recognition
  – Occupant detection
Automotive vision system Applications

• Externally mounted cameras could be part of a vision system to
  – Maintain a safe distance behind leading vehicle
  – Identify pedestrians and avoid them
  – Track road edges
  – Provide enhanced night vision using HUD
Automotive vision system Applications
(continued)

• Cameras mounted in the passenger compartment could be used to:
  – Detect a drowsy driver and sound an alarm.
  – Identify occupant in passenger seat for proper airbag deployment.
  – Monitor the vehicle for unauthorized entry and/or driver verification.
The Automotive Environment

• Automotive products must be able to withstand extreme environmental conditions.
  – Temperature range from –40 to +85 °C
  – Extreme Vibration
  – Dust and dirt
• In many ways the automotive environment is not all that different from military requirements except cost must be very low!
• Worse yet, lighting is totally unconstrained!
The case for CMOS sensors

• The need for low cost places significant constraints on camera design in automotive applications.
• CCD sensors have traditionally been used for machine vision applications.
• CMOS sensors have become increasingly popular because of their low cost and improving performance.
• CMOS sensors can be integrated with a significant amount of on-chip processing circuitry.
CMOS vs. CCD

• Historically, CCD sensors have had substantially better performance than CMOS sensors.
• Substantial progress with CMOS sensors has greatly reduced the performance gap.
• There seems to be some consensus that CCD still provides better performance when highest quality imaging is needed, especially for very low light levels.
Active pixel sensors

• A substantial improvement in CMOS cameras is provided when a transistor is used to buffer the pixel voltage.

• Three transistors are now required instead of one.
Important considerations

• Dynamic range needs to be large because of unconstrained lighting. Issues here include:
• Sensor needs to respond efficiently to available light for nighttime situations.
• Sensor must have sufficiently high data rate (frame rate) to capture rapidly changing scenes accurately.
Dynamic Range

• Because of unconstrained lighting, camera must be able to capture an image of a scene with very bright and dark regions accurately.

• Integration time can be shortened to prevent saturation in bright areas.

• At the same time, dim regions may be too corrupted by noise to provide useful information.

• A typical camera SNR of 45-50 dB is inadequate for automotive applications.
Camera Sensitivity

Camera sensitivity is a complex topic with a number of issues including:

- Spectral response of sensor
- Spectrum of available illumination
- Amount of noise
- Integration time
- Pixel size
- Fill Factor
Sensor Spectral Response

Spectral response varies due to a variety of factors including:

– Type of photodetector (photodiode or photogate)
– Shallowness of implantation (typical CMOS processes provide poor red/IR response)
– Circuit elements or connections over photosites may have variable attenuation as a function of wavelength
Spectrum of illumination sources

- Sunlight closely approximates a black body source at ~5500 K
- The peak radiation is in the yellow-green (~500 nm) portion of the spectrum but there is substantial radiation at longer wavelengths.
- Incandescent sources operate at a temperature around 3000K with peak radiation in the near IR around 1000 nm.
- Near-IR LED sources typically have peak output around 950 nm.
HID Headlights!

- Some newer vehicles use HID (Xenon gas discharge) sources.
- HID sources are much more efficient than incandescent lamps.
- Most of the radiation is in the visible spectrum with little output in the near IR.
- Camera output may well be less for this type of illumination source.
Quantum efficiency and wavelength

- Quantum efficiency is the probability that a photon will result in a corresponding signal increment.
- An ideal detector would have 100% quantum efficiency.
- Watt for watt, red and near-IR photons produce about twice the signal level as blue photons because they only have less energy.
- The net result is that silicon detectors produce a larger output at longer wavelengths even with uniform radiation.
Noise Issues

Both CMOS and CCD performance are degraded by noise. Sources include:

– Fixed pattern noise (FPN) is relatively easy to minimize

– Photon shot noise (uncertainty of photon arrivals) is a fundamental limitation

– Amplifier (1/f) noise

– Reset noise (and FPN) can be minimized with correlated double sampling technique
Correlated double sampling

With CDS, a pixel is sampled before and after integration and the difference is calculated using a differential amplifier.
Fill factor and pixel size

• The need for additional circuitry in every pixel of an APS sensor reduces the fill factor.
• The use of microlenses is one way to overcome this problem but is not effective for low-f optics and wide angle optics.
• Big pixels don’t necessarily help given that the camera lens really determines how much light is focused on the sensor.
Shutter considerations

- Electronic shutters are used to control the integration interval
- Rolling shutters are the simplest to implement but cause significant distortion in rapidly changing scenes.
- Global shutters require additional circuitry that reduces fill factor.
Passenger Compartment Sensors

- Cameras need to respond well out to about 1000 nm since IR illumination is required at night.
- Dynamic range on the order of 70 dB may be adequate.
- Resolution requirements are fairly modest.
- The camera should be small and unobtrusive.
External cameras

• Very wide dynamic range required
• Excellent immunity to blooming required
• In at least some applications camera spectral response should be optimized for headlight spectra.
• Relatively high resolution needed to deal with complex real-world scenes.
Conclusions

A CMOS sensor for automotive applications should:

– have excellent dynamic range
– match the spectral response of relevant illumination sources
– have a global shutter
– have low noise levels
– have a high fill factor