Colloquium on
„Illumination for High Speed imaging“

The last words of Germany's most famous writer –
Johann Wolfgang Goethe – were: "**more light**!"

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Author: Chris Seger, VP Marketing & Sales
AOS Technologies AG, Switzerland
www.aostechnologies.com

Content:

Introduction

While digital cameras for high speed imaging have become easily available and affordable, they seldom solve the problem for the user. Beside optics and data management, illumination is in many cases the critical subject. Often, it's the illumination which decides between an insufficient image and one necessary to have the problem solved or the test completed. Beside "classical" high speed imaging applications like Vehicle Impact Testing, new applications in the industry and in research get now access to high speed cameras. While the user in the automotive industry will has his illumination systems, less experienced users often struggle to select an adequate light source for their application or fitting their budget.

The following is an attempt to describe possible illumination systems commonly used to illuminate high speed camera applications. Its whether a physical explanation of various light sources nor a marketing tool to favour the one or the other product.

Starting point

Why is illumination such a critical issue in high speed photography? Can't we just use our good ol' desktop lamp?

High speed imaging means that we get many "pictures" (correctly called "frames") per second – often a thousand or even hundred thousand. Even the most modern digital high speed camera follows strictly the rules of photography! A light sensitive area – nowadays almost exclusively a solid state image sensor – gets exposed to light, regulated by a shutter and an iris.
The shutter, no longer a mechanical device but a function which controls how long the image sensor accumulates light, can not be open longer than for the time of a single frame. While your still camera offers shutter times between typically 1/1000 sec to 30 sec, it is evident that a high speed camera running with 1'000 frames / sec ("fps") has a maximum possible shutter time of 1/1000 sec (to freeze very fast moving objects, this shutter time is further reduced to 50, 20 or even less percent of the maximum possible time, resulting in an actual shutter time of a 10^{th} or 20^{th} thousand of a second!
Now imagine you could select such a fast shutter time on your SLR camera (which is not possible, by the way)! To get a well lit image, you would either have to use a faster film (not possible on your digital high speed camera) or to get more light (let's suppose the iris is already set to its maximum setting).
The very same applies for high speed cameras: the shorter the shutter time (due to a higher frame rate or reduced shutter time), the more light we need.

Conditions

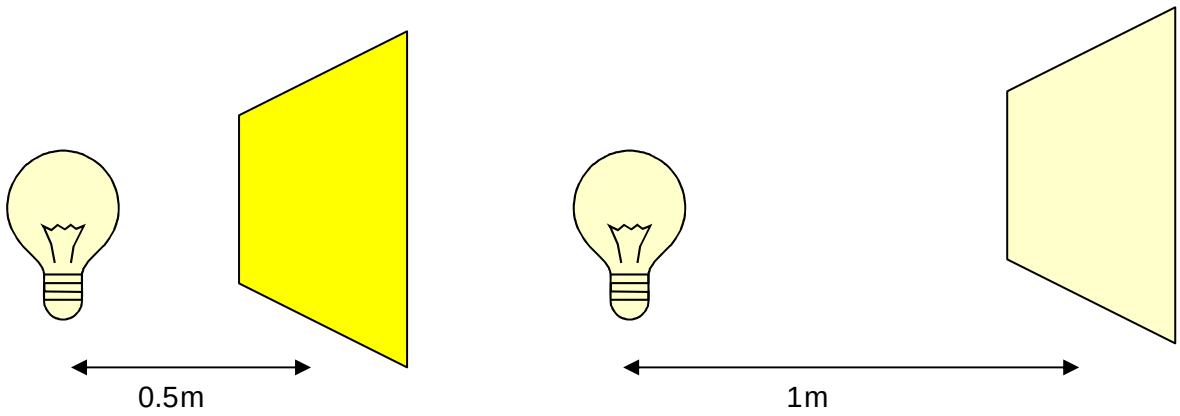
Despite tons of illumination formulas, there is unfortunately no formula to calculate the "correct" illumination. Factors for a correct illumination are (not complete):

- distance between light source and object
- field-of-view
- type of light source
- intensity of light source
- contrast between object and background
- reflection of object surface
- color and tone of image
- image sensor type (monochrome or color)
- camera setting (frame rate, shutter time, gain)

Distance light source – object

The closer the light source to the object, the brighter it appears. Doubling the distance results in 25% of brightness! Tripple distance = 1/9th of the original brightness. But also: reducing the distance results in a brigher object.

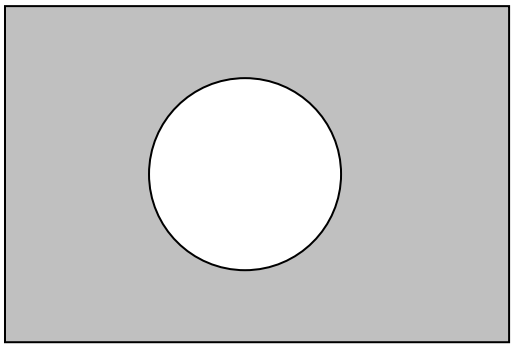
➔ always position the light as close as possible to the object



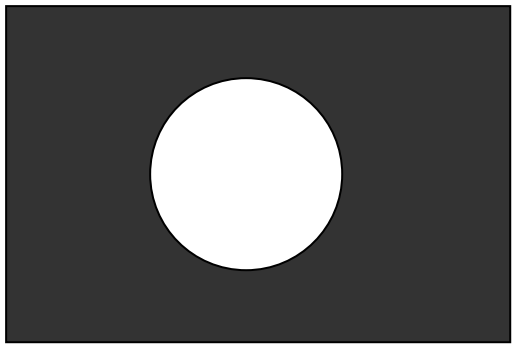
Field-of-view

Closely connected to the above. Light sources have to placed wider from the scene when the complete field-of-view needs to be illuminated, or can be closer if only the object needs to be illuminated

- ➔ carefully select the necessary field-of-view (not too large)
- ➔ does the background really be illuminated as well?



Background illuminated
(needs lot of light)



Background not illuminated
(needs less light, object
contrast even better)

Type of light source

Some light sources are by their nature brighter then others, i.e. sunlight is brighter then LED light. Instead of setting up tons of light sources of a certain type, maybe a different type of light would be smaller, better and probably less expensive

- ➔ carefully select the appropriate type of light

Intensity

A 500W light bulb is brighter then a 60W bulb. Instead of arraying ten 60W bulbs, better use a 500W lamp.

- ➔ go for the most powerful light suitable and available
- ➔ take care not to overheat your object (i.e. live animals, chemicals)

Camera type

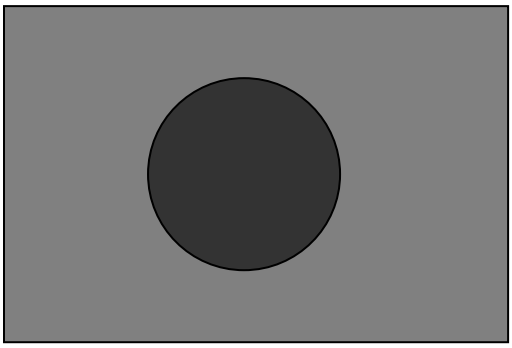
Color cameras need about 2 to 4 times more light then monochrome cameras due to their color filter in front of the image sensor.

- ➔ does it REALLY need to be color?

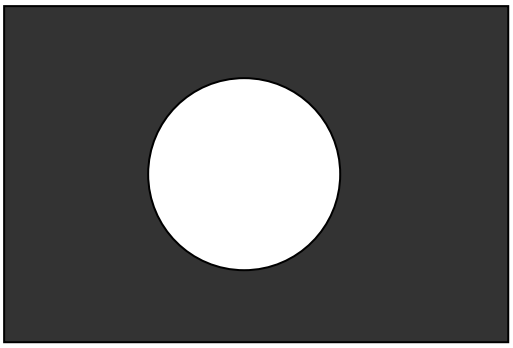
Contrast

Illuminating a mate black object in front of a mate black background needs obviously more light then a shiny white object in front of a black background. Improve the object contrast when needed (apply white color to the object if possible)

➔ try to achieve a high contrast



Dark object in front of a dark background:
- lots of light necessary
- poor contrast, making motion analysis difficult



Bright object in front of a dark background
- less light needed (object ony)
- high contrast, making motion analysis easier

Reflection of object

Closely related to the above. Try to get a bright, shiny object (white, glossy).

But: metallic surfaces often reflect too much light, creating a halo and disturbing the image. In such cases the light intensity needs to be reduced. In some cases, a mating spray can help (available in pro photo shops).

➔ try to get a good, reflective object surface

Color and tone of object

Closely related to the above. White is more reflective then black.

➔ Try to get a bright object

Camera setting

Optimize the conditions for a well exposed image by using the minimum frame rate and shutter time needed, and try to boost the image using the image controls of your camera control software. Open the lens iris as far as possible (often limited by the necessary depth-of-field).

➔ go for the best camera setting

Light sources for high speed imaging

- daylight / natural sunlight
- electric light bulbs
- Tungsten light bulbs
- HMA lights
- Cold light / Fibre optics
- LED light
- Laser
- Argon bombs
- Others

Daylight / natural sunlight

Only possible with certain applications (outdoor).

Subject	- -	Rating	+ +
Intensity			
Color temp.			
Cost			
Heat			
Flickering	no		

! white reflectors can help to improve illumination

Typical applications:

- outdoor vehicle testing
- range / ballistic tests

Electric light bulbs

Here our old desktop light comes in. Rarely suited for high speed imaging for its low intensity and low color temperature (typically around 3200K / orange).

Subject	- -	Rating	+ +
Intensity			
Color temp.			
Cost			
Heat			
Flickering	yes		

Setting: 60W light bulb

! use 100W bulbs instead of 40 or 60 W light bulbs, which provide a very orange light.
! Light flickers in the mains frequency

Typical applications:

- none

Tungsten light bulbs

As above, its still a light bulb with all that disadvantages. However, has a higher efficiency, higher color temperature (3600K) and can be run on DC power to avoid flickering.

Subject	- - Rating + +
Intensity	
Color temp.	
Cost	
Heat	
Flickering	no (if powered with DC voltage)

Setting:
Tungsten light 100W
DC supply (no flickering)

! tungsten light bulbs are cheaply and widely available in ratings between 5 and 250W
! use DC power (power supply / battery) wherever possible to avoid flickering

Typical applications:

- Vehicle impact testing (on-board)
- Industrial or research applications with a small field-of-view

Xenon light bulbs

Xenon light bulbs are a rather modern light bulb and used in automotive headlights and image beamers. They run on high voltage / high frequency and need therefore a control device.

No test image available

Subject	- -	Rating	+ +
Intensity			
Color temp.			
Cost			
Heat			
Flickering	around 20kHz		

! Xenon light bulbs are very bright and intensive
! Their point-like source is prone to create disturbing reflections on objects and backgrounds

Typical applications:

- Vehicle impact testing (on-board)
- Industrial or research applications

HMI lights

Widely used despite its costs and complexity. Automotive test centers use large light panels to illuminate the crash area. Small light systems are available too.

Subject	- -	Rating	+ +
Intensity			
Color temp.			
Cost			
Heat			
Flickering	no		

! HMI light heads need a power and control device (“load”) to be operated
! HMI lights need a starting time to get to their full intensity
! HMI provide daylight type light (5500K)

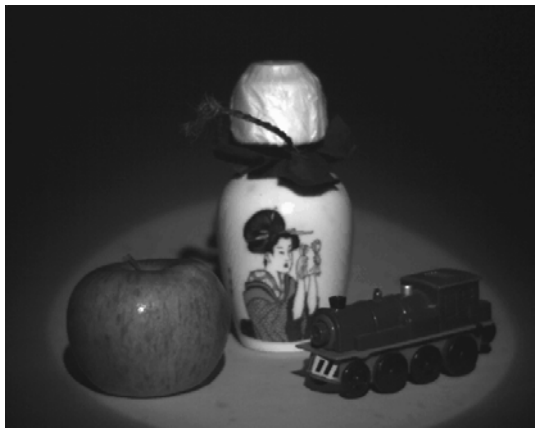
Typical applications:

- Vehicle impact testing
- Industrial or research applications

Cold light / Fibre optics

"Coldlight" is created for close-up applications by a light source (typically tungsten, xenon or HMI) and fed to the head by a flexible light conductor (a bundle of glass fibres).

Setting:
60W tungsten light
Fibre Optic light bundle



Subject	- -	Rating	+ +
Intensity			
Color temp.			
Cost			
Heat			
Flickering	no		

! Cold light is suited for close-up application with a small field-of-view (some centimetres / inches diagonal)
! most light sources allow to have multiple light conductors connected for a flexible illumination

Typical applications:

- Close-ups of living animals, bio-medical objects or on chemicals

LED light

Widely available for machine vision applications in many different shapes. Usually not intensive enough for high speed applications

Subject	- -	Rating	+ +
Intensity			
Color temp.			
Cost			
Heat			
Flickering	no (if used with a good DC power s		

! if you use LED lights, go for a high quality DC power supply to avoid flickering
! various shapes (panels, ringlights, domes) allow many different illumination (darkfield, brightfield, side illumination etc.)

Typical applications:

- Close-ups with low frame rates (less then 250 fps)

Strobe light (in general)

A strobe light (flash tube or LED) creates a highly intensive light flash per frame. Needs therefore be synchronised with the camera.

2 types are available: LED-based or flash tube based, the later higher in efficiency but less controllable.

Flash tube strobe light

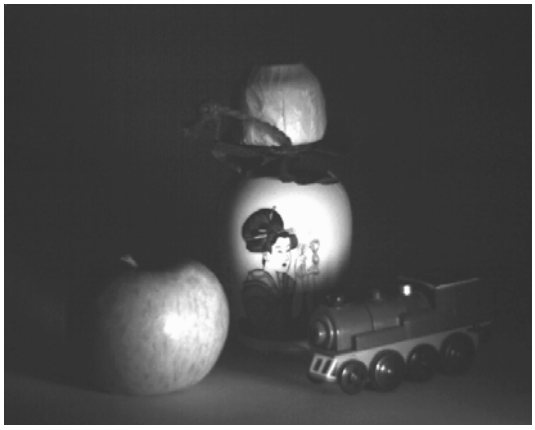
Subject	- -	Rating	+ +
Intensity			
Color temp.			
Cost			
Heat			
Flickering	synchronised with the camera		

! high energy flash creates often electromagnetic noise which can disturb the application or the equipment
! the flash practically eliminates motion blur

Typical applications:
- Close-ups with a need for light
- Ideal for very fast moving objects

LED strobe light

Setting:
StroboLED V3 white / 100usec pulse



Subject	- -	Rating	+ +
Intensity			
Color temp.			
Cost			
Heat			
Flickering	synchronised with the camera		

! no electromagnetic noise
! versions available with white, umber or IR LED's
! the flash practically eliminates motion blur
! simple control of light burst duration

Typical applications:
- Close-ups with a need for light
- Ideal for very fast moving objects

Laser

Lasers could be used to illuminate many different kind of objects and applications, depending on their type and intensity.

Due to their wide span of characteristics, an experienced supplier should be contacted to select the most appropriate system

Argon bombs

An explosive system which generates a single, ultra-bright light flash – what limits its application to range testing and similar military type applications.

Test Setup:

Setup:
Object size: 20 x 20cm
Field-of-view: 30 x 30cm
Distances
Camera-object: 40cm
Light-object: 50cm
Lens: 25mm/f1.4

Color cameras are less sensitive

Monochrome image

100W light bulb
Image is well lit.
Objects are clearly visible

Color image

Same setting, same illumination
Image is remarkably darker.
Objects difficult to observe.

When lighting conditions are difficult, prefer to use a monochrome camera if a color camera is not a must!

Color temperature:

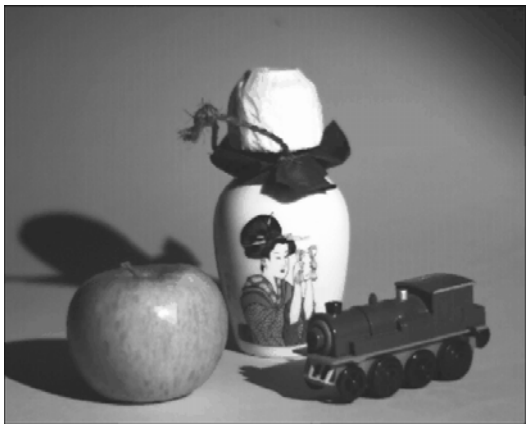
Color image with 60W light bulb
no or wrong white balance.

Color image does not show natural colors, but a distinctively orange.

Color image with 60W light bulb
and correct white balance.

Color image shows almost natural colors.

Same image taken with a monochrome camera



To get real natural looking color images, the use of either a light source with a daylight spectrum (i.e. Xenon- or HMI-light) is necessary. Alternatively, color correction filters in front of the camera lens are recommended (i.e. KODAK 80B)

Considerations:

To select the most suitable light source, the following questions need to be answered:

Power:

- do you have enough power available?
- Voltage: 120, 230 ? AC or DC?
- Amperage
- Power equation: W = V x A
- Power cable: can you provide power by a cable?

Heat:

- is the object sensitive to heat (living animal, bio-medical object, chemicals)?
- Will the heat affect the camera operator / test person?
- Note: the efficiency of a light bulb is around 3% - out of 1000W consumption, only 30W will create light, 970W create heat!

Size:

- how much space you have available?
- Does your preferred light source fit into that space?
- Can the generated heat escape from that position?

Money:

- what budget is available?
- Can you rent or lease a sophisticated light systems for certain tests?
- If you cannot afford the best: are there less expensive alternatives?

Useful links:

www.aostechnologies.com
Highspeed cameras, tungsten lights, Crash light systems, LED stroboscopes

www.visinst.com
Lights, stroboscopes

www.oxfordlasers.com
Laser illumination systems

www.dedolight.com
Tungsten lights

http://www.schneiderkreuznach.com
Color correction filters

http://www.khslight.de
HMI light systems