Light Emitting Diode Illuminators for Video Microscopy and Machine Vision Applications

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Illumination system as the part of an imaging system

Illumination is one of the most important issues in machine vision. Most imaging systems usually include an optical system, illumination system, camera censor and data analyzing system. Any of these systems can be a bottleneck in the imaging process. The best diffraction limited optical system will not supply good image quality without the correct illumination. The illumination system can either enhance or diminish some features of a monitored object. Furthermore, poor illumination can even create artifacts.

Fortunately, many of these problems can be avoided with the correct lighting. When considering illumination for an imaging system, the numerical aperture of the optical system, camera sensitivity, light spectrum, light intensity and angular distribution are the key parameters to keep in mind.

Fiber optics illumination system concepts

Let's consider one of the best illumination system concepts, the diffused day skylight. In this system, the object of interest is illuminated from many angles at the upper half of the sphere. This is the most appropriate illumination system for the human eye because it illuminates microscopic objects in a way that is very similar to the day light illumination that we are used to for macroscopic objects.

An attempt to duplicate the range of illumination angles of the day skylight is the simultaneous use of multiple fiber optic illuminators, including a ring light, coaxial illuminator and double bundles (Fig. 1). Unfortunately, the discrete character of illumination is the weak point for almost any fiber optic system. For example, the fiber optic illumination system described above has very large angular illumination halls between every single illumination unit (Fig. 1).

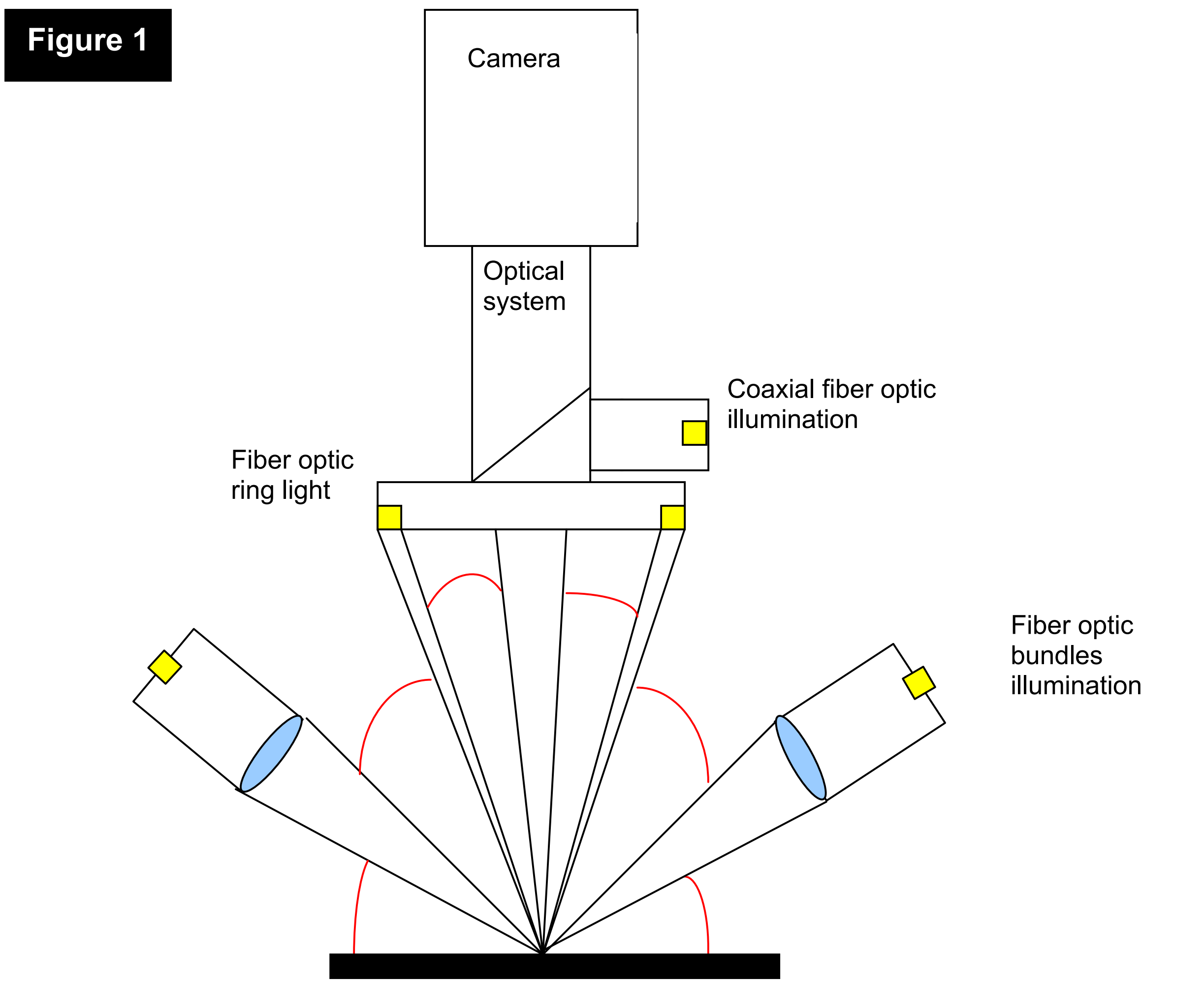

Figure 1: *Schematic diagram of the typical fiber optic illumination system for video zoom microscopy. Red lines show the angular illumination halls in this system.*

There are many approaches that attempt to reach day skylight illumination using fiber optic techniques. One example is the Fostec and Lumitex produced Front-light (or panel light) illuminator (Fig. 2). This illuminator covers the entire range of illumination angles from approximately 5 degrees up to 25 degrees to the normal. This approach dramatically increases the image quality of some machine vision applications and appears to be very successful. However, even with Front-light illumination, the system has a significant amount of angular illumination halls. Other weak points of this system are the low brightness of the Front-light unit and very bad mechanical stability of the plastic fibers.

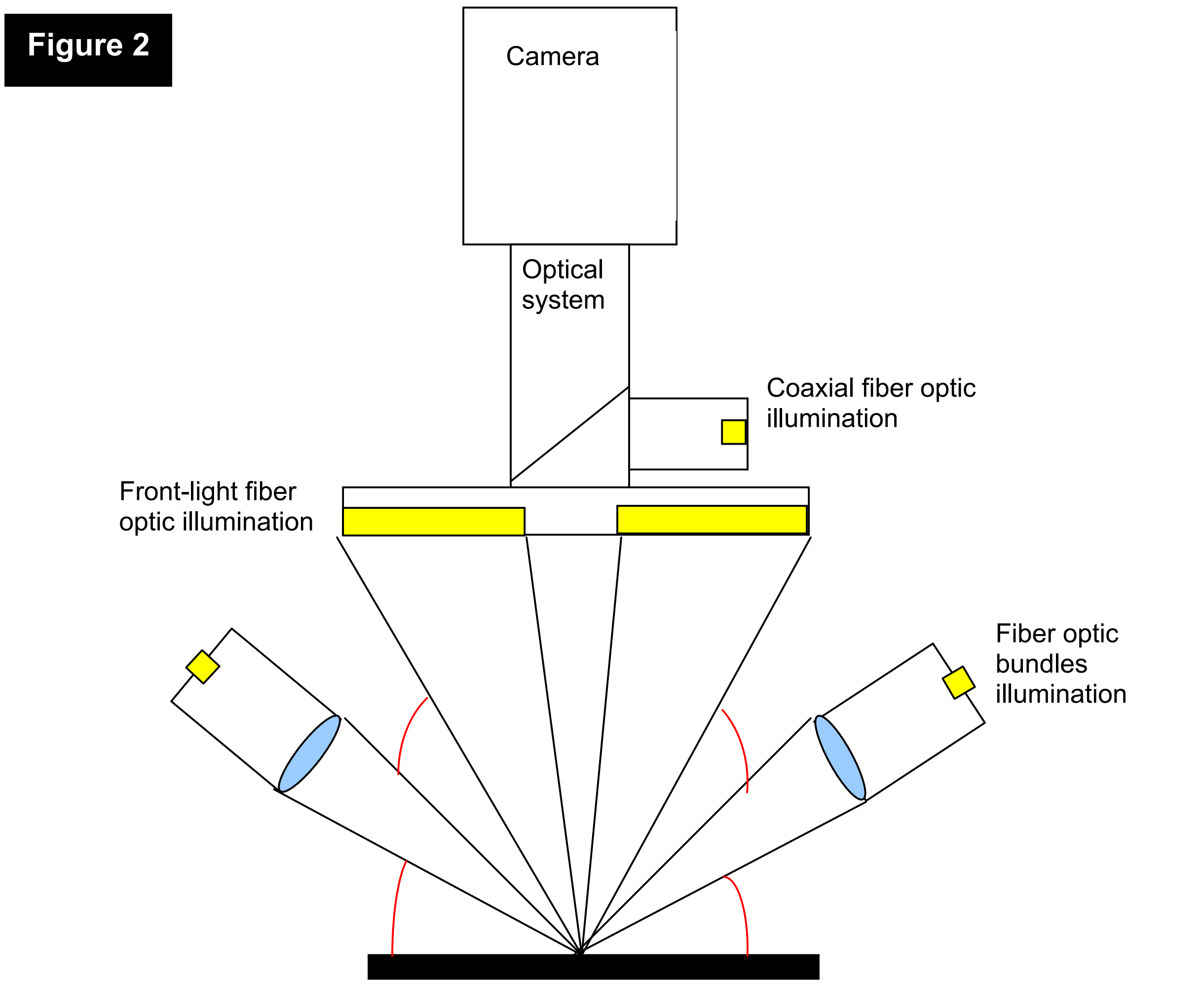

Figure 2: *Schematic diagram of the typical front panel fiber optic illumination system for video zoom microscopy. Red lines show the angular illumination halls in this system.*

Another very popular approach is the fiber optic Diffused Dome type illuminator. In this type of illuminator the optical fiber ring light is placed at the bottom part of the hemisphere. The light is diffusively reflected from the dome walls and completely covers all angles of the hemisphere. The weak points of this illumination system are not only intensity, which is usually insufficient for microscopic applications with less than a 2mm field of view, but also the inability to change the angular distribution of light intensity. Uniform light angular distribution is not always the best for non-diffusive objects.

Model of the ultimate illumination system

The ultimate, most versatile illumination system is the Dome type (or hemispherical) LED illumination system with the ability to change the light intensity from any immeasurably small area in the hemisphere (Fig. 3). To better visualize this type of system, imagine that the night sky, completely filled with stars, is the dome type LED illumination system and you have the ability to change the intensity of any star in the sky. In the actual illumination system, instead of a night sky filled with stars, you have a dome filled with LEDs. Each LED can be adjusted to change the light intensity to get the best possible illumination.

Figure 3

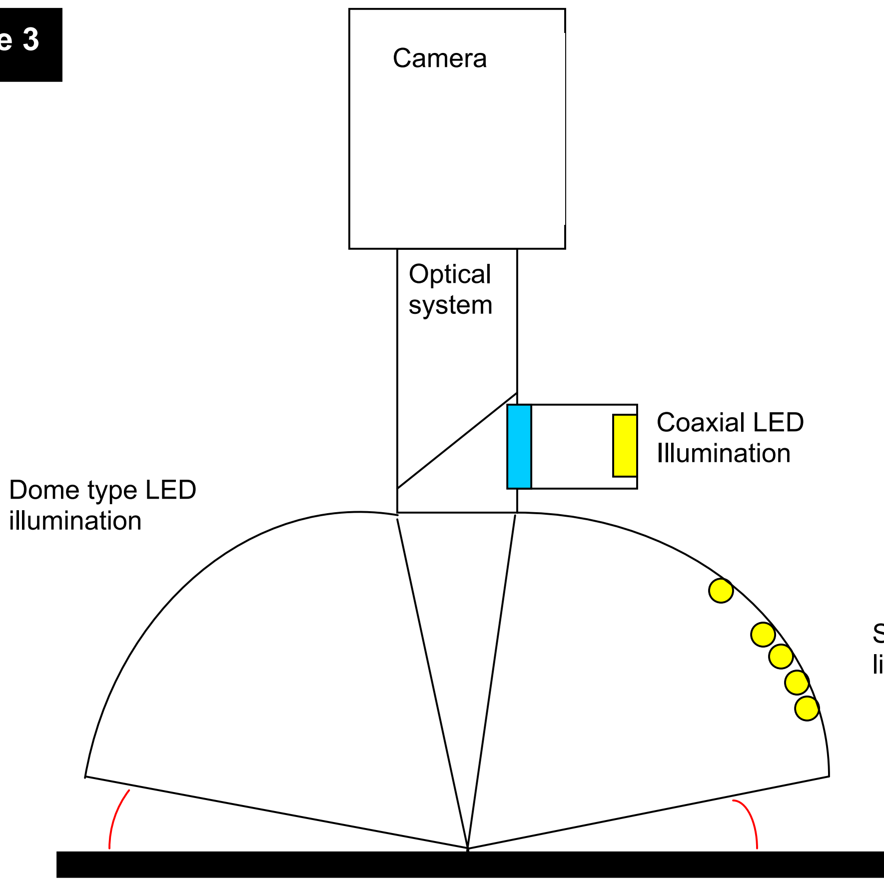

Figure 3: *Schematic diagram of the dome type LED illumination system for video zoom microscopy. Red lines show the angular illumination halls in this system.*

The dome type LED illumination system works very well for reflective, diffusive, flat and rough objects. Any illumination problem can be solved using this ideal system. However, to properly operate such a complicated illumination system, you must know how to set the intensity and angular illumination of the each LED. The angular illumination, which can be time modulated, allows the system to receive important three-dimensional information about the object.

The building of such an illumination system from conventional light sources and fiber optic illuminators is completely impractical for several reasons: the relative large size of conventional light sources, heat dissipation problems, and the very high cost of fiber optic illuminator systems. It is, however, relatively easy to achieve this ultimate illumination system by using LEDs as the light source. LEDs have the unique ability to be building blocks in the ultimate illumination system because of their small size and relatively low heat dissipation.

I would like to emphasize that the main appeal of LED illumination is how easily it fits into the model of the ultimate illumination system. Small single LEDs, like stars in the sky, perform excellently for any very complicated illumination problem.

Comparison of LED and conventional light sources

a. Spectrum

The spectrum of a conventional quartz halogen light source is very similar to black body radiation (Fig.4). The effectiveness of the quartz halogen lamps is low and further reduced by an additional 50% with fiber optic coupling.

Figure 4

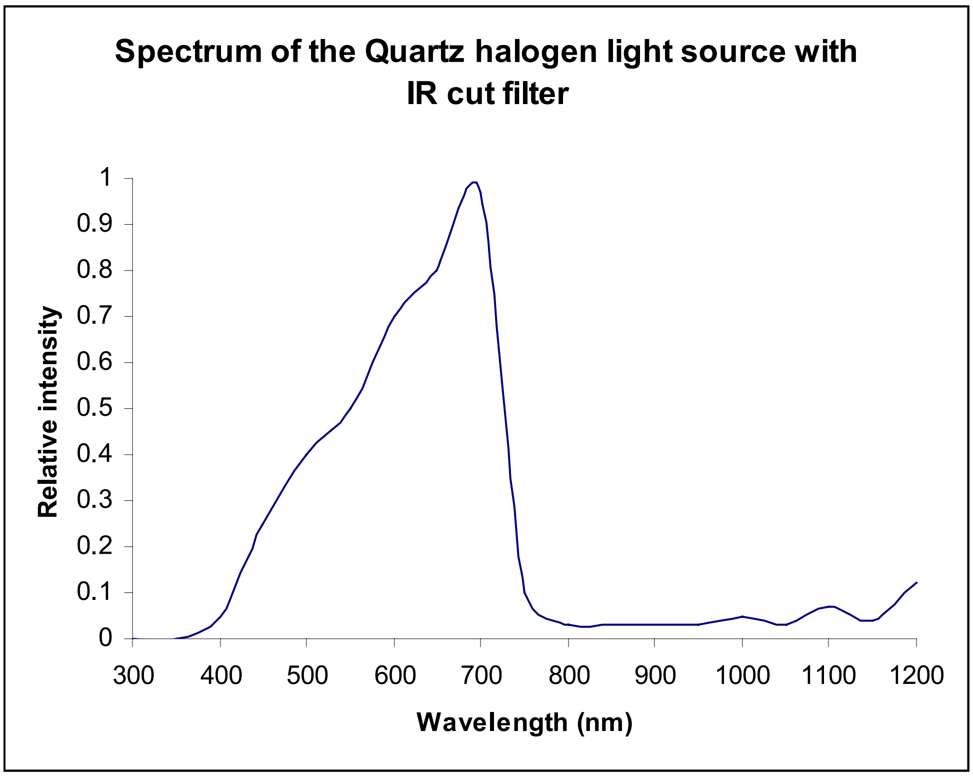

Figure 4: *Typical spectrum of the Quartz halogen light source with infrared cut filter.*

LEDs are solid-state semiconductor devices that convert electrical energy directly into light. The light generation efficacy is very high because most of the energy radiates within the visible spectrum (Fig. 5, Table 1).

Figure 5

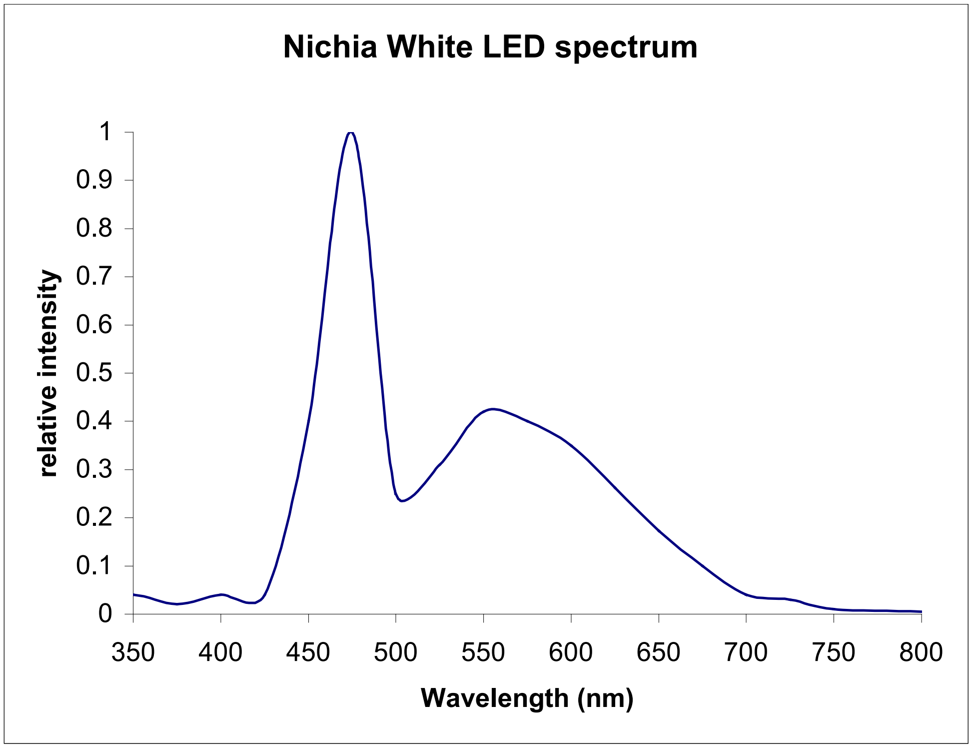

Figure 5: *Typical spectrum of the white Nichia LED.*

Table 1

Quartz halogen Tungsten lamp	15 Lumen/watt
Fluorescent Lamps	70 Lumen/watt
Super Bright LED	60-80 Lumen/watt

Table 1: *Summarizing the light efficacy of the major light sources:*

In addition to low efficacy, the light output of the QH lamps is very much in infrared and red portions of the spectrum. The combination of the "red" QH-light source from the machine vision system and the "white-blue" light from the ambient fluorescent light makes it impossible to properly adjust the white balance of the sensitive camera. The combination of white LEDs and fluorescent light has very good match.

b. Lifetime

The lifetime of some QH lamps does not exceed 40 hours. This can be very problematic for machine vision applications. For example, the machine will need to be shut down to replace the bulb an average of every two days. The lamp can also die in the middle of the operation process, making it necessary to stop the machine, change the bulb and recalibrate the machine before restarting it again.

Reliability is the most important feature of the LED. The expected lifetime for each LED is around 100,000 hours. This equals nearly 11 years of continuous operation. However, it is important to consider the thermal condition of the LED operation, which does change over the lifetime of the light. Under normal operation conditions (25 degrees C and 20mA) the light output drops off 2% for every 1000 hours of operation. The results are much less promising for white LEDs where the light LED intensity drops off 10% for every 1000 hours of operation. It is possible to reduce the percentage drop off per 1000 hours to a very small amount by operating at reduced power settings.

c. Mechanical Stability

LEDs are mechanically very stable. If you look at an LED bulb closely you will see that there are some wires and a little block of material completely encapsulated in clear plastic. It is almost impossible for the LED bulb to fail because of mechanical damage unless the plastic is smashed with a hammer. The mechanical stability of the LED illumination unit makes it the preferred choice for applications where lighting is attached to moving parts. Fiber optics illumination, on the other hand, is not as mechanically stable as LEDs and can break over time, reducing illumination intensity.