ENERGY EFFICIENT LIGHT MODULATION FOR MULTISPECTRAL IMAGING

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ABSTRACT

In the following paper an approach for cost-effective multispectral imaging system is given. For the spectral separation the special characteristic of LEDs were used in combination of an optical band-pass filter. Therefore standard LEDs were evaluated in order to wavelength distribution, availability on standard distributors. For the use of this LED setup a special 24 channel light controller were developed and evaluated. The second major part was the efficiency of the controller, especially in the state of low light requirement. In this case normally a lot of electric power will be lost in the electronic. The developed control unit uses a special combination between analog and digital electronics which leads to high system efficiency. The complete setup was tested and optimized using a reflection normal. The paper ends with a multispectral application detecting safety features of a bank note.

Index Terms **–** Multichannel -LED-controller, multispectral illumination, multispectral imaging

1. INTRODUCTION

Multi-channel-imaging is already a challenging task. Actual strong developments in the field of 3D-Multi-View-Imaging and Spectral-Imaging were done. Gained by the development of fast processors a lot of new possibilities are given for the applications in science and industry. With a combination of the state of the art knowledge and new technologies in terms of digital signal processing as well as sensor technologies various systems were described. The approach of this paper is the use of standard elements to realize a cost effective space-saving multispectral imaging system. Furthermore the aspect of energy efficiency is one of the major objectives of this system.

To achieve the spectral separation of the single channels a various range of apparatus were developed in the past. Principally this can be done in two ways, filtering the reflected light in front of the sensor using gratings, filters and other technologies or modulating the illumination. An overview about the latest developments is given in [1]. Mostly the spectral imaging systems are very complex and expensive systems having high power consumption. For example the One Light Spectra system uses a digital light processing module combined with a gas discharge lamp working as broad band illumination. The power consumption of this system is 500 Watt and the costs are approximately 15T€. Furthermore the size of the system is also not applicable for some use cases.

A better way is the use of semiconductor sources which have a defined spectral distribution. In the past a lot of investigations were done to maximize the light output of light emitting diodes. In terms of object illumination these systems are optimized for the visible range. But nevertheless there are some manufacturer focuses on colored illumination as well as for special LED with dedicated wavelengths. The resulting properties of the emitted light like light ratio and spectral distribution, strongly depend on the used materials and technologies.

2. LED SELECTION PROCESS

The choice of LEDs has been made regarding to the filter wheel of the camera that was already available in the department of the Quality Assurance and Industrial Image Processing of the Technische Universität Ilmenau. The goal was to find two LEDs for each filter in the wheel. One is supposed to emit a wavelength that lies below the wavelength of the filter and the other should lie above this border, in order to duplicate the sampling rate. With this approach, duplicating the sampling points leads to a spectral resolution that is twice as high as the original resolution of the used camera. In case of a DUT which has a characteristic absorption or reflection characteristic. For self-emitting objects this approach doesn't work.
The transmitted wavelength is supposed to cover half of the transmission window of each filter, which leads to a FWHM of ± 25 nm. In order to cover the whole area of transmission, the center of each LED wavelength needs to lie 12.5 nm below and above the wavelength peak of each filter.

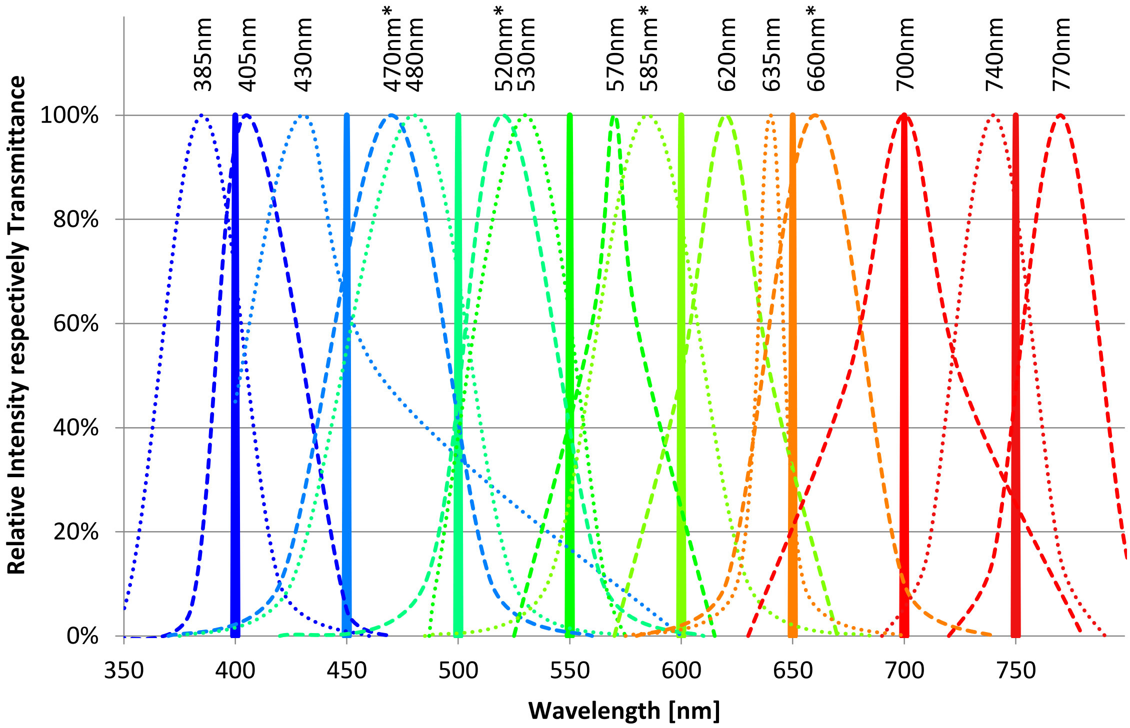

Figure 1: Filter wavelength and LED-spectra in the region from 350nm up to 800nm (the * marked spectra were modeled for the reason of no manufacturer information)

Due to the fact that the emitted wavelength is directly dependent to the semiconductor material, it is not possible to meet this exact condition for each LED. Figure 1 shows the range of semiconductors with their corresponding filter wavelength that are available within the visible spectrum.
The spectral characteristics were not available for all LEDs. Therefore all unknown graphs are marked with a star and considered to behave like a standard Gaussian-shaped curve. All of this leads to an overview of the available LED spectra within the visible spectrum. For clarity the filter spectra are not shown in figure 1. It shows only the peak wavelength of each LED. The radiance and transmittance was normalized to 100% for comparison. In fact the spectra of the filter wavelengths are also Gaussian-shaped with a FWHM of 50nm.

With the combination of different spectral light sources which can be pulsed in synchronization with an image sensor system, a sequential spectral imaging system is realizable. As mentioned the objective is to make the system cost effective. Therefore standard LED types were evaluated and used for this system. At the end 20 different LED light sources with well-balanced distribution beginning with the near ultra violet and ending with the infrared region can be found. With this wavelength distribution most of silicon based image sensors are usable for the imaging task.

2. LED CONTROL UNIT

Beside the advantages of spectral separation of LED light and the low amount of power consumption, the LED circuits have a non-linear behavior. Therefore a current control has to be applied for these devices. The design of the current source should be also considered under the energy saving aspect. The energy loss in controlled current sources is mainly influenced by two parts: the shunt resistor (R_SNS) and the power transistor (Q1) (figure 2). To minimize the energy loss in this circuits a pulse width modulation with a lot of converter principles are available today. Most of the converters are designed for continuous operation mode, so synchronization to an image sensor system is complicated. Only a few converters are offering the option to add a PWM signal to its output. With this option an additional energy loss can be avoided as well as the synchronization for the imaging system can be done.

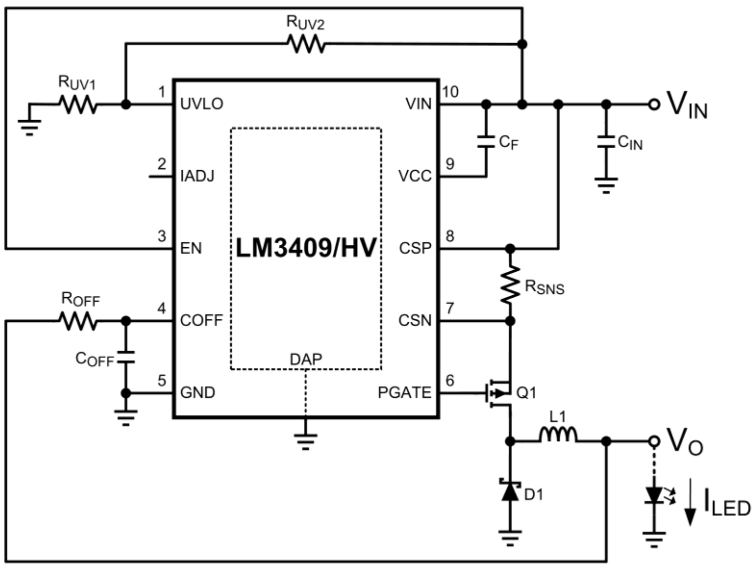

Figure 2: Standard schematic of the LED-driver-circuit-ICs LM3409 fabricated by Texas Instruments [3]

The LED driver circuit LM3409 from Texas Instruments is shown in figure 2. This circuit was used as a driver that supports an analog and a PWM-based control. It offers up to three different ways of controlling the LED:

- To dim the PWM by using the enable-pin
- To dim analog by use of the potentiometer between the current adjust-pin and the ground
- To dim analog by a range of 0V to 1.24V using the current adjust-pin

In order to get multispectral images with this setup, the light has to be formed and displayed on the sample as well as the modulation of the single channels must be realized in synchronization to a camera system. According to the demands a design for a 24 channel light controller is needed. For that reason a modular layout were designed which can control 24 channels simultaneously. An embedded controller which is connected to the universal serial bus controls two digital to analog converters via Inter-Integrated-Circuit-Bus. These devices are giving the input control value for the current control.

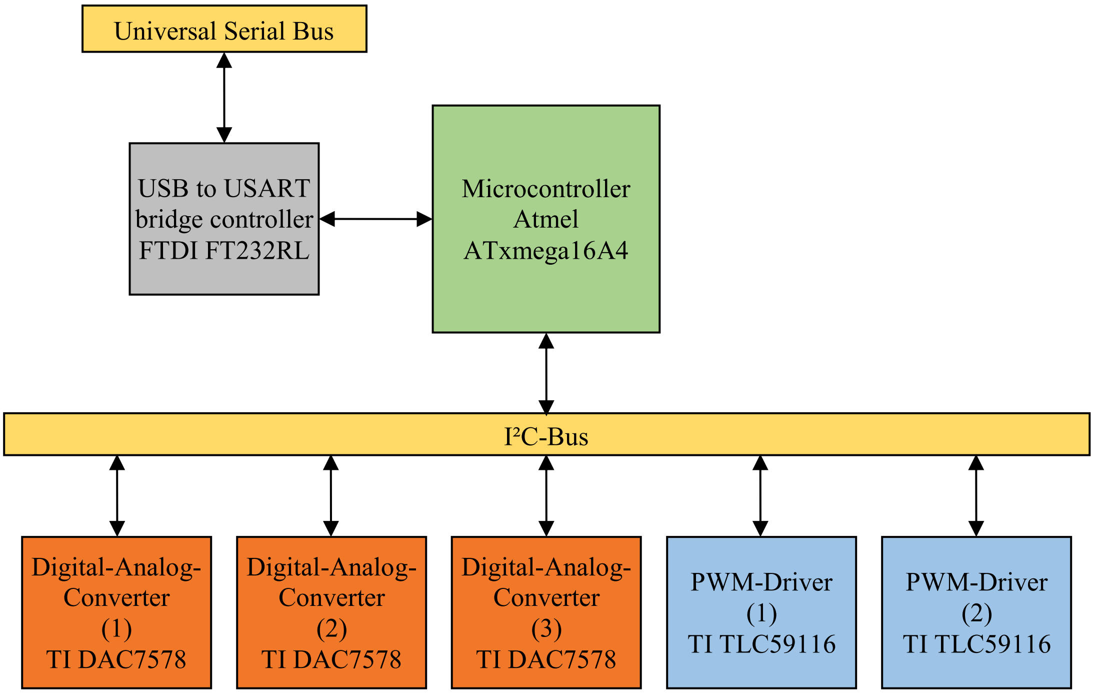

Figure 3: Illumination controller block diagram with microcontroller and I²C bus system

With this light control system, depicted in figure 3, a printed circuit board with the mentioned LED sources were realized and tested with the light control system. With this solution it is formally possible to capture multi spectral images. Nevertheless for aspects of homogeneity of object illumination, the light was mixed using a milky glass as a diffusor. The light output of the optical surface is connected to an optical beam-splitter which gives the possibility of a coaxial incident light illumination.

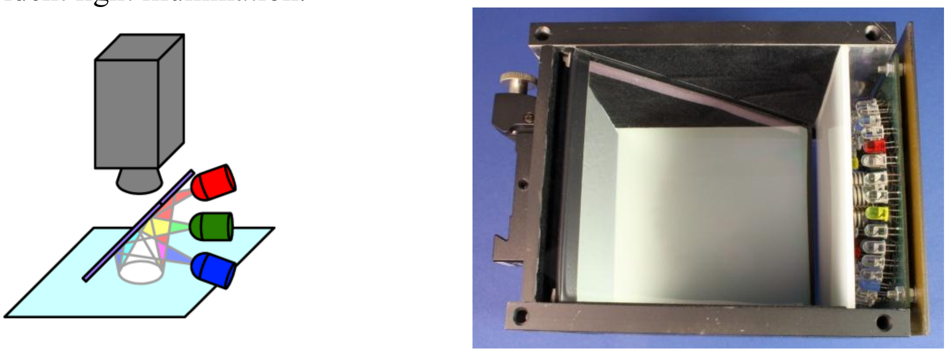

Figure 4: Principle of the developed incident light illumination unit (left), assembled incident illumination system with beam splitter and LED array (right)

For the evaluation of these system concerning multi-spectral imaging possibilities a filter wheel camera system was mounted in the coaxial illumination system figure 4 [2]. Any other CCD or CMOS camera depending on the focused application is also suited. The illumination setup is producible for less than 1T€ including a medium class CMOS camera. Therewith a cost-effective and also an energy-efficient multi spectral imaging system was realized.

For the evaluation of this system firstly the linearity of the controlled current were measured. The linearity of the analog controlled current varies in dependence of the different loads, it is less than 10 % over the full range. Therefore by using this system a high grade of repeatability for experiments can be guaranteed (figure 5).
In comparison to the DAC-controlled graph, the slope of the PWM- controlled LED signal is much more irregular. Therefore this method will only be used for switching on and off of the LED and synchronization of the camera.

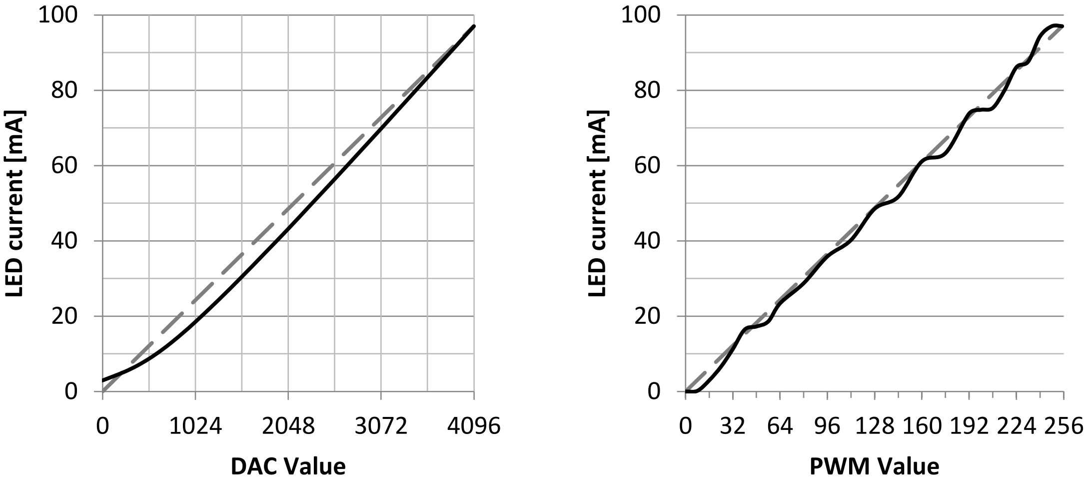

Figure 5: Comparison between the linearity of the LED current (channel 16, 830nm) with analog control (left) and PWM controlled (right), the dashed line illustrates the ideal system behavior in the working range.

In order to minimize the power dissipation of the developed control of illumination the loss of power was measured and monitored the whole time. In case of an increasing control value the dissipation of power grows as well. One reason for this are the 20 down converter and the conducting paths. At the same time the energy demand of the microcontroller and control elements stays the same.
On the contrary the effective capacity increases continually and fast until its ratio of the total power reaches a value twice as big as the ratio of the power dissipation.
Due to the high power and voltage of the serially connected IR-LEDs, the useful power output decreases to half of its value at their output channels. The remaining power spreads to the 15 channels of the LEDs operating in the visual area that are only using small amounts of power and voltage.
The system efficiency reaches up to 65% and decreases non-linear at small DAC values caused by the increasing influence of the dissipation power.

3. EVALUATION OF THE LED ILLUMINATION

For the characterization of the spectral characteristics of the illumination a spectrometer was used to sample the spectra. The full width half maximum ranges and the amplitude of the single LED chips differ in a wide range. But with the information of the spectrometer and the knowledge of the working points of the single sources a correction can be calculated and set up in the illumination controller.
The used light emitting diodes are connected together in two subgroups. One subgroup covers the upper wavelength region of the metal interference filters and the other subgroup the lower wavelength region of the metal interference filters. First step of the investigation was a test setup with a calibration normal which had an homogeneous reflection behavior in the required wavelength range. Therefore firstly the lower subgroup were evaluated, the lower subgroup

were evaluated and at the end the complete set of LEDs were evaluated with the calibration normal. Therefore a fiber-coupled spectrometer was used to get the wavelength distribution from the mixed light. Figure 6 illustrating the achieved wavelength distribution.

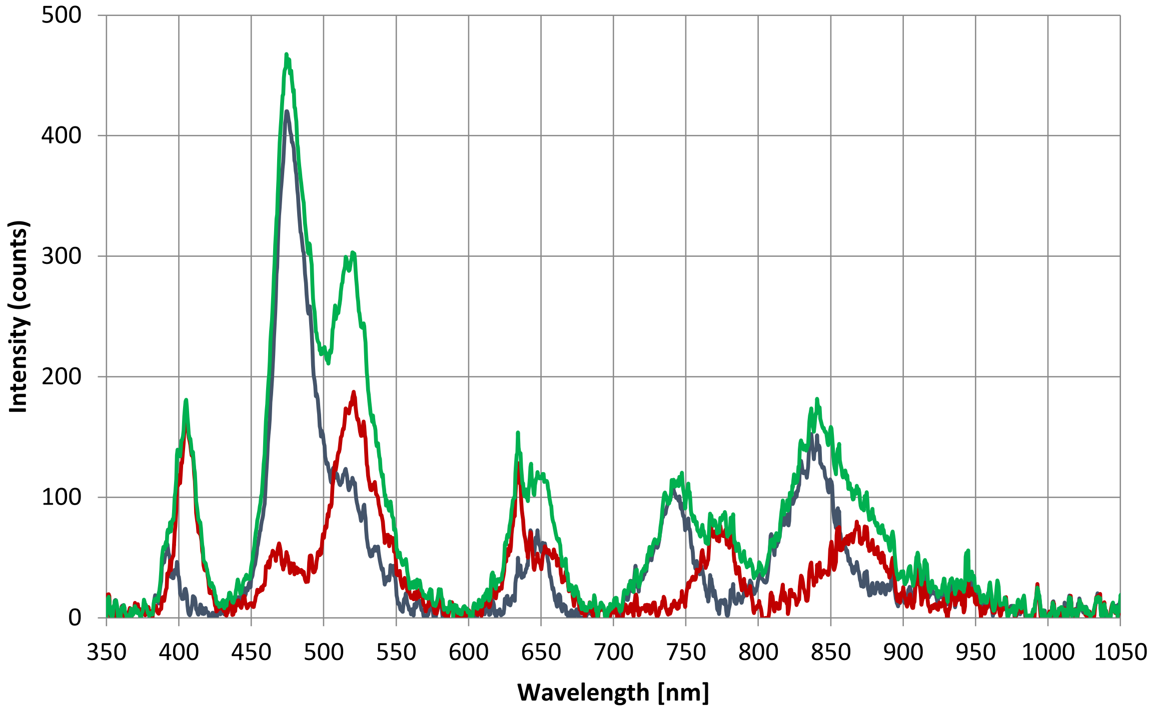

Figure 6: Reflected spectrum of the used white calibration normal, lower LED subgroup(blue), upper LED subgroup(red), both subgroups mixed (green)

The diagram clarifies that the peak wavelengths of the single LED sources were clearly detectable. In contrast to regions (for example 600nm) where the intensity is roughly zero. The strongest amplitude emits the LEDs in the wavelength region of 500nm. Other LEDs which delivers more light intensity in the single transmission measurements during some pre-evaluations were now strongly damped. Especially in the boundary wavelength regions the attenuation is very strong. One reason for this effect is the light diffusor material which is made of acryl glass. Apparently the absorption within the UV and NIR region is stronger than for the VIS region. Nevertheless also the reflection normal has a minor influence due to the spectral transition function of the optical system. The main reason for the achieved wavelength distribution can be traced back to the single intensity distributions of the single LEDs. But the approach was to use standard LEDs from standard distributors to achieve a cost effective design.

Beside the generated illumination spectrum the homogeneity in the illuminated field were also evaluated. Therefore for every LED-wavelength a single picture was captured. With the use of the greyscale-value distribution of the illuminated field, which was captured with the filter wheel camera, a spatial distribution can be recorded. The distribution is depicted in figure 7. The emerging circle on every picture is the shape of the calibration normal. Furthermore the LED had also a ring-light shape and is focused on the diffusor. That leads to an additional increase of intensity in the middle of the object field. The spatial distribution error which occurs can be corrected in the middle of the field. For better results in the homogeneity distribution more LEDs have to be used.

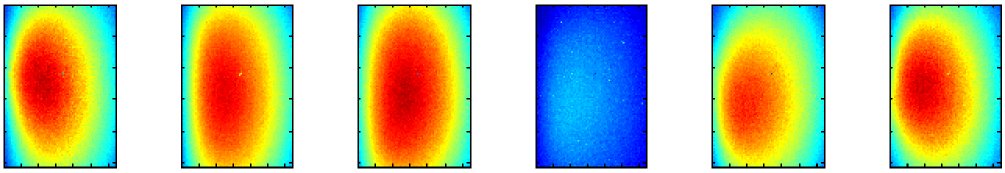

Figure 7: Spatial intensity distribution of the calibration normal with the illumination system, (385nm & 405nm @ filter center wavelength 400nm), (430nm & 470nm @ filter center wavelength 450 nm), (480nm & 520nm @ filter center wavelength 500nm), from left to the right;

Finally the system was tested on a bank note which was captured to demonstrate the working principle as well as an application for this system. The results are displayed in figure 8. A counterfeit note can separated on different features in the spectra which is not possible with normal RGB imaging.

Figure 8: An 5-€uro banknote captured with 480nm (left), 620nm (middle), 830nm(right), With the increase of the wavelength special safety features were gained.

4. OUTLOOK

For the future it is planned to capture further industrial samples which needs a space resolved multispectral image to detect different quality features. An additional use case for this system is by using the possibility to linearize the silicon spectral characteristics of silicon based image sensors (figure 9). Therefore it is used as a light mixing device.

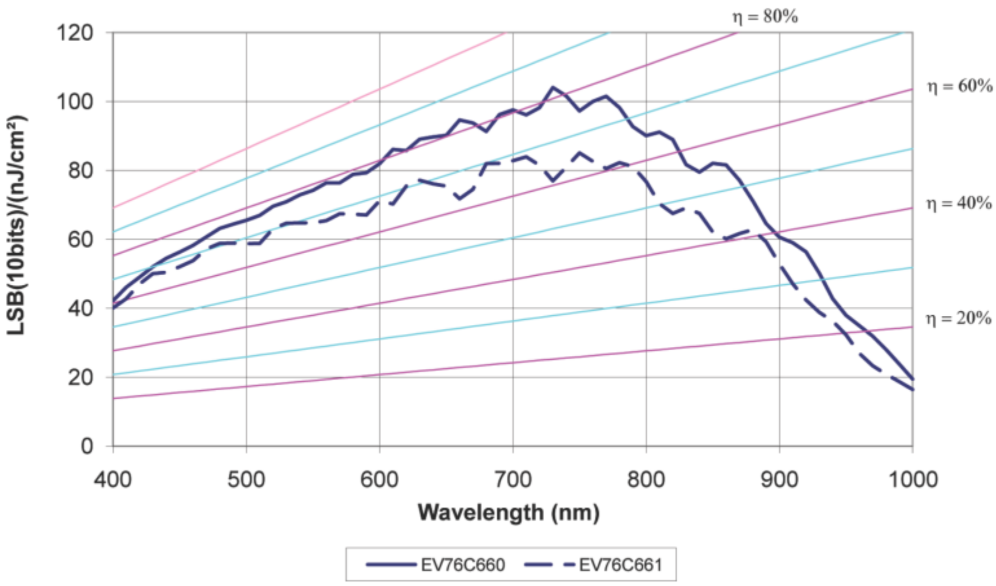

Figure 9: Spectral sensitivity of the CMOS image sensor integrated in the filter wheel camera [4]

To correct the characteristics of the CMOS image sensor the power of every LED- Channel should be adapted with the LED light control unit. That leads to a decrease of emitting light power in the regions where the CMOS has a high sensitivity and an increase of emitting light power in the regions where the CMOS has a lower sensitivity. The goal should be an optimal adaption of the spectral output power of the light source in respect to the spectral sensitivity of the imaging sensor. This leads to a constant integration time for every spectral channel during the capturing of the DUT.

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