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A Comprehensive Market Analysis on Camera and Illumination Sensors for Image Processing and Machine Vision Applications

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***Abstract*—In the present industrial application space, conventional inspection techniques using manual intervention are getting replaced by automated inspection using image sensors. Image sensors have empowered machines with vision and that has led to increased levels of process automation which used to be manually exhaustive. This paper mainly focuses on the comparative study of Machine Vision hardware aspect specifically on cameras and lighting- the technologies in use and their application across different industry verticals.**

***Keywords*-Sensors; Camera; Illumination; Machine Vision**

I. Introduction

Machine vision inspection applications, by their nature, are very diverse - covering an extremely wide assortment of applications. Machine Vision finds application in Automotive, Electronics, Pharmaceutical- industries characterized by zero tolerance for defects. This in turn has reduced the exclusive dependence on error prone human vision in different industries requiring high accuracy levels. A basic machine vision system consists of (i) illumination (ii) cameras (iii) part sensor (iv) camera-computer interface and (v) inspection software. A generic machine vision system is shown in Figure 1. Illumination ensures that the feature of interest becomes visible and prominent. Camera sensors create an image from the focused illumination and convert it to an analog or digital signal. Camera-computer interface converts the signal into an image in the processing unit. Finally, the Image processing software extracts the meaningful information from the image and takes decision specific to application. In machine vision, one of the most important factors that should be considered while developing an application is to identify and evaluate the correct hardware requirements. In this paper the focus is on the camera sensors keeping in view their advantages and disadvantages. Different illumination sources have also been studied across different parameters. The purpose of this study is to help machine vision application developers to identify the correct hardware to suit a particular application. In the current document, an attempt had been made to compare the two most commonly used camera sensors viz. Charge-couple-device (CCD) and Complementary-metal-oxide-semiconductor (CMOS). An insight into the illumination systems used for machine vision applications has also been provided. The comparative analysis can serve as a guideline for selecting the appropriate sensors and illumination for a particular application.

II. State of the art

Selection and placement of camera and lighting system is the most essential part in a machine vision system as this can reduce the complexity of the algorithms to a great extend and hence can reduce the computational complexity . There are two types of sensors used in machine vision camera system: Charge-couple-device (CCD) and Complementary-metal-oxide-semiconductor (CMOS). These two different camera types have diverse application. Both technologies have their own competency and neither can be called superior over the other. According to Dave Litwiller there has been a significant shift in the image sensor marketplace over the past 10 years more so for CMOS than CCD technology. Carlson compared the CD and CMOS sensors for low resolution imaging and concluded that for low resolution imaging (VGA and below) CCD and CMOS sensor technologies are converging to practically indistinguishable solutions in terms of performance, size and cost. Another important component of a machine vision system is the illumination. There are different types of sources for machine vision illumination system. But the most preferred light sources used by the machine vision system integrators today are light-emitting diodes (LEDs). According to Hassaun A. Jones Bey , LEDs are the most preferred light sources. He explained that due to recent major improvements in brightness, LEDs are emerging as important illumination sources for machine vision because they offer an order-of-magnitude greater life expectancy than halogen and emit much less heat. Nick Trevis reports that consistency is also another factor for choosing LEDs over other light sources. According to him, for many years, fibre-optic lighting combined with a halogen light source provided the best solution. However, LEDs have evolved and their price or performance attributes have improved, leading to even more reliable and more consistent performance in machine vision applications. Shang Ping Ying et al. explained the approaches for generating white lights, which are very

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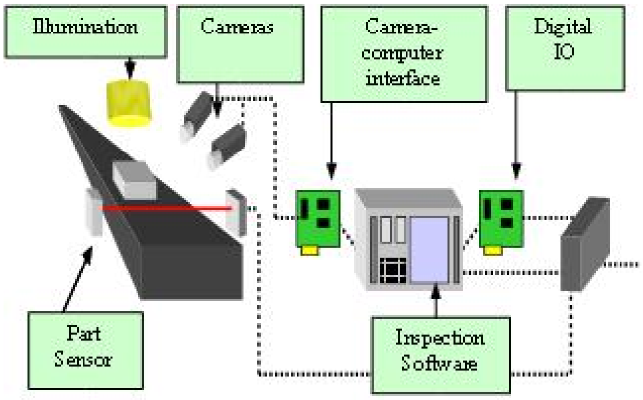

Figure 1. A Generic Machine Vision System

important for some applications, using LEDs. They also analyzes the optical and color characteristics of the mixture of colored LED light source. Sunil K Kopparapu explained of external light source for machine vision applications. He identified that the problem of uniform distribution of light is posed as a minimization problem and proposed a scheme based on simulated annealing algorithm to determine the optimal position of the light sources. However, none of the papers suggested any comparative study amongst the different illumination sources and camera sensors. This paper targets to bridge this gap and serve as a quick reference to machine vision application developers for selecting the adequate hardware depending on the target environment.

III. Machine Vision Camera Systems

Cameras are the essential and the most important part of a machine vision system. Choosing the correct camera for the correct application is the fundamental decision for designing a vision system. The camera performs the task of capturing the image and translating it to information which is processed either in the camera itself or transmitted to a host for processing. The most important component of the camera is a digital sensor. In machine vision camera systems, two main sensor technologies used are CCD and CMOS technology. The basic principle of these two technologies, their comparison and market share of CCD and CMOS in machine vision applications is given below.

A. CCD Technology

In CCD technology, the photo effect is used to generate electrons from incident photons, this charge is collected and is held in the form of individual picture elements (pixels). This charge is moved towards the output of the device using various gating clocks where it is converted to current or voltage.

Table I
Comparison of CCD and CMOS Sensor Technology

CCD	CMOS
Noise is very low	Noise is high
Slower read out	High speed read out random addressing
High power consumption	Low power consumption
No co-integration logic	Co-integration of logic smart sensors

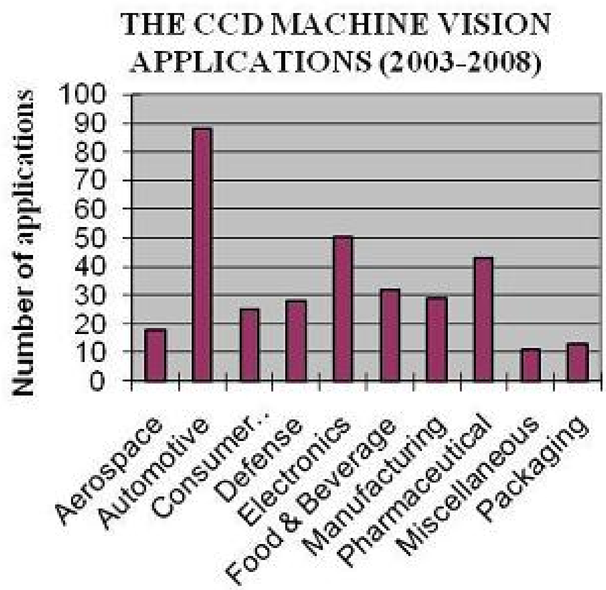

Figure 2. CCD machine vision applications across different industries

B. CMOS Technology

In CMOS technology, again the photovoltaic effect is used. But instead of transporting the charge of the photo-diodes sequentially to a readout register, the CMOS sensor converts the charge to voltage already in the pixel. Neither technology has a clear cut edge over the other. A comparison between the two technologies is given in Table 1. However, both the sensor technologies have their own market share depending on the type of applications and the industries where they are deployed. Table 2 and shows the industry wise share of the CCD sensor technologies. Table 3 and depict the share of CMOS sensor technologies deployed across different industries. Figure 4 shows the cumulative share of the CCD and CMOS sensor technology across all industries.

IV. Machine Vision Illumination

Proper lighting is one of the most important components for designing a machine vision system. Mathematically, in the image processing context, the brightness value between the object of interest and the background should differ. Contrast, brightness, textures, reflexes are done which can be achieved by proper lighting. That is precisely why experts

Table IV
COMPARISON BETWEEN DIFFERENT ILLUMINATION SOURCES

Light Source	Operating voltage	Lifetime	Color temperature	Effect of Aging
Halogen	Operate with low-voltage(starts with 1.5V)	300-2000h	3000-3400K	Large fall off in brightness over time (drift)
Metal Vapor	High voltage (upto 30KV)	10,000h	3500-5900K	Large fall off in brightness
Xenon	Use high voltage of (around 250V)	1000000 thousand flashes	5500-12000K	50 percent down after few million flashes
Fluorescent	Use high voltage	5,000-12,000h	3000-6000K	After 12,00h approximately 50percent of brightness
LEDs	Low voltage (aound 12V)	20,000-100,000h	2700 8000K	Changes color coordinates

Table II
INDUSTRY WISE APPLICATION OF CCD MACHINE VISION PRODUCTS (CAMERAS AND LIGHTING)

Industries with CCD MV products	Number of applications
Aerospace	18
Automotive	88
Consumer Products	25
Defense	28
Electronics	50
Food and Beverage	32
Manufacturing	29
Pharmaceutical	43
Miscellaneous	11
Packaging	13
Total	337

Table III
INDUSTRY WISE APPLICATION OF CMOS MACHINE VISION PRODUCTS (CAMERA AND LIGHTING)

Industries with CMOS MV products	Number of applications
Automotive	63
Defense	6
Electronics	19
Food and Beverage	21
Manufacturing	10
Pharmaceutical	9
Robotics	17
Packaging	12
Solar	21
Wood industry	16
Total	194

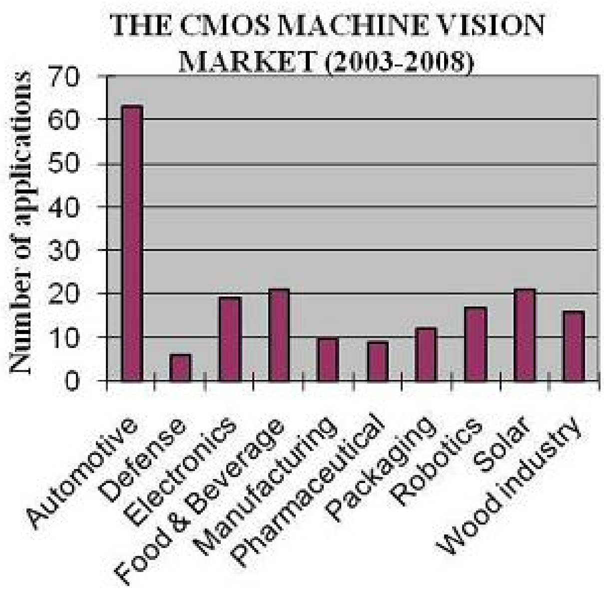

Figure 3. The CMOS Machine Vision applications across different industries

harp on the fact that lighting constitutes two-third of a machine vision solution. The basic elements of lighting components are light sources. Our study concentrates on the different light sources and their use in the machine vision applications.

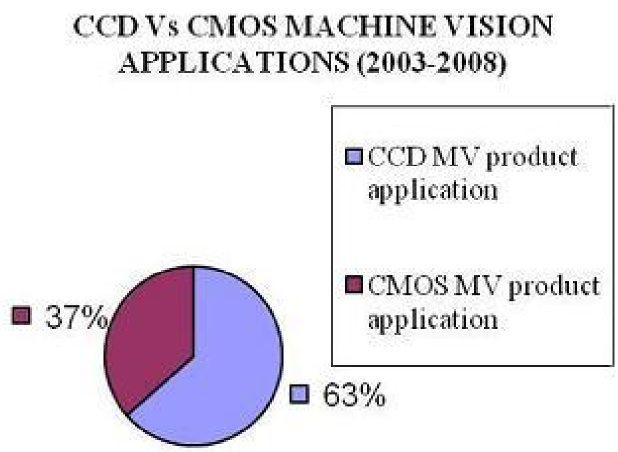

Figure 4. Segregation of the Machine Vision product application on the basis of the two prime technologies CCD and CMOS [source of data- table 1 and 2]

A. Incandescent light

These are the lamps that use tungsten filament for incandescent emission. The performance of a typical incandescent (halogen) lamps is measured by its Lifetime, Luminous flux and Color Temperature.

B. Metal Vapor Lamps

These are the gas discharging lamps that use the metal vapor inside to produce a vapor pressure that is necessary for the gas discharge.Metal vapor lamps are seldom used for machine vision applications.

C. Xenon Lamps

These are the lamps used for continuous as well as flash operations. Xenon flash lamps use glass tubes in a housing filled with xenon gas and has an expensive control circuitry. These lamps are useful for color image processing where much light is required and are particularly useful in fast running applications.

D. Fluorescent Lighting

Fluorescent lamps are driven by alternating current (AC). The change in current direction is converted into a flickering of light with the double frequency of the supply voltage. These lamps are usually operated with HF-ballasts to avoid brightness interferences between fluorescent light and image acquisition frequency. Fluorescent lighting is usually used in machine vision applications which require illumination of large areas and are usually low cost solutions.

E. Light Emitting Diodes (LEDs)

LEDs or Light Emitting Diodes are nowadays the standard lighting of machine vision applications. LEDs are small and very robust light sources and emit almost monochromatic light. The different sizes, long lifetime and the monochromatic nature of the LEDs inspire experts to use LEDs in large variety of applications. LEDs find its application in almost all type of machine vision applications due to its small size, low maintenance cost, low voltage requirement and longer lifetime.

F. Lasers

Laser light source are not very frequently used in machine vision applications. Some of the characteristics of the laser light source are emission of coherent light, monochromatic light and point shaped origin of light. Reservations of using lasers are mainly due to their danger for man. However, lasers are used for some specialized 3D applications in industries like automotive, electronics etc.

Table 4 shows the comparison of the different illumination sources considering some key parameters which can be taken into account while designing a machine vision system.

V. Conclusion

Like most other technologies, machine vision technology has also evolved with time. From the above study, it is evident that amongst Machine Vision cameras, CCD still enjoys a greater share (63percent) than CMOS (37percent) at present. However, this picture might change in the near future as seen from the trend of CMOS eroding CCDs market share. Machine vision cameras - both CCD and CMOS are used in a variety of industry verticals ranging from automotive to electronics and Food and Beverage to Pharmaceutical. External lighting is one of the major factor for the success of a machine vision application as it is required to maintain a uniform and non-varying illumination in case of real time vision applications. However selection of the proper pair of illumination sources and camera is very much application specific and depends on the target environment. For example, if there is adequate cooling facility in the target environment and if the target object to be inspected is colored in nature, then normal incandescent illumination can be used with CCD camera. In the contrary, if the target environment demands low heat generation from the illumination sources, LEDs should be used. Therefore, selection depends on the application type and the target environment. LEDs are currently the most preferred source due to their longer life and lower costs. In certain cases proper filters can be used with the illumination sources depending on the application. For example, as CCD and CMOS sensors are sensitive to infrared light, an infrared cut filter is often useful to avoid color changes in the image. However, the selection of lighting filters is very much application dependent and is out of scope of this study

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