

CURRENT & FUTURE TRENDS IN MACHINE VISION

Research Scientist Mats Carlin
Optical Measurement Systems and Data Analysis
SINTEF Electronics & Cybernetics
Box 124 Blindern, 0314 Oslo, NORWAY
E-mail: Mats.Carlin@ecy.sintef.no
<http://www.sintef.no/ecy/7210/>

Introduction

Our definition of a machine vision system is a system for measurement, inspection or surveillance based on connecting an electronic camera to a computer.

To be able to build successful machine vision systems one must control the following technologies and parts of a machine vision system.

- Lighting
- Optics
- Camera sensor
- Electronics
- Image processing
- System integration

The purpose of this paper is to provide an overview of current trends within each of these fields and their impact on machine vision applications.



*Fig.1: Machine vision systems.
(Photo: Jan D. Martens)*

Lighting

It is a main issue in machine vision to have full control of the lighting to achieve the proper image quality. The lighting should be designed to enhance the measurement of the wanted physical

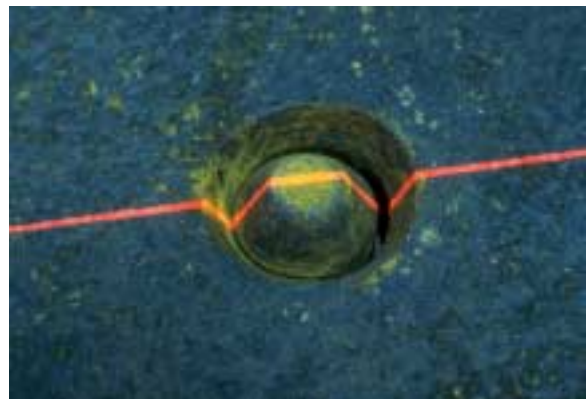
or geometrical properties. There are a number of important design factors for lighting:

- Intensity
- Spatial distribution
- Spectral distribution
- Temporal variation
- Temperature sensitivity
- Shielding against unwanted light

Without the proper images, we may spend awful amounts of time and money to obtain reliable measurements.

The emergence of specific equipment for even illumination is the major trend in lighting. Fiber pads provide even back light illumination, half domes provide even diffuse front light illumination, ring lights, pits and fiber probes provide even side light illumination and beam shaped lasers provide even pattern illumination. The light intensity can often be controlled directly from the computer over an RS-232 connection and long-term temporal variation can be adjusted.

The impact of this equipment is that prototyping is performed much faster without rigorous lab testing. Standard off-the-shelf equipment is used to solve the most common machine vision tasks.



*Fig.2: Laser plane projection onto a steel bolt.
(Photo: Jan D. Martens)*

Optics

The optics is crucial for many machine vision systems. The optics is designed to collect and focus the incoming light on the sensor. Important effects of the optics are:

- Geometric aberrations
- Colour aberrations
- Collimation
- Optical transfer function (spatial resolution)
- Projections
- Special effects (filters, gratings, mirrors, beam-splitters, micro lenses etc.)

To obtain high-precision measurement some of the optical effects must be corrected either by calibration or by expensive optics.

It is a trend to use diffractive optic elements for a range of light shaping tasks, such as laser beam forming, diffusers, large-scale telecentric lenses and tailored spectrometric measurements. The diffractive optic elements can be produced in plastics using much of the same technology as in Compact Disc (CD) production.

Small-scale telecentric lenses are becoming state-of-the-art for most measurement applications with a field-of-view up to 30-50 mm. A telecentric lens collects only light rays within a small angle to the optical axis of the lens system and provides larger depth-of-field than ordinary lenses.



*Fig.3: Inspection of air-brake fittings at Raufoss AS using a telecentric lens.
(Photo: Jan D. Martens)*

Camera sensors

The semiconductor camera sensors are based on arrays or matrices of light sensitive elements called pixels. Silicon is light sensitive in the visible (VIS) to near infrared (NIR) part of the electromagnetic spectrum (300-1000 nm). Other semiconductors are sensitive in other parts of the spectrum, ultraviolet (UV), mid infrared (MIR) and far infrared (FIR). Using special layers called scintillators the semiconductors can even be made sensitive to X-ray radiation. Since applications in the visible part of the spectrum proliferate, silicon sensors are the most common ones.

Charged Coupled Devices (CCD) are most common today, while Charge Injection Devices (CID) and Metal-Oxide Semiconductors (MOS) are used for special purposes. The CCDs allow efficient transfer of the electronic charges from the sensor elements to the read-out electronics by a principle called bucket brigade where the charges are shifted from sensor element to sensor element on the chip itself. CCDs are today produced on special semiconductor process lines.

The current trend is towards CMOS sensors that can be produced by the same production process as ordinary microchips, allowing cheap sensors with the possibility of integrating processing power directly on the sensor chip. CMOS sensors allow direct access to selected pixels, a principle called active pixel access.

The market for camera sensors is already divided in several segments; the machine vision cameras are better suited than standard surveillance and analog TV-quality cameras, but are more expensive. We believe that the price difference will diminish in the future, since the new progressive-scan digital video broadcasting standards are based on much of the same camera technology.

In the future we will also see special-purpose CMOS sensors with special types of image processing performed on the chip itself. We will also see integrated sensors with several different measurement principles operating concurrently.



Fig. 4: Parquet-floorboard inspection by smart camera (Photo: Jan D. Martens)

Important camera sensor characteristics are:

- Pixel ratio and area
- Pixel sensitivity, gain and saturation
- Fill factor (percentage of light sensitive area)
- Pixel-to-pixel variation
- Dark current (background electronic noise)
- Smear and blooming
- Electronic shuttering (controlling exposure)
- Sensor alignment with the optical axis
- Progressive-scan digital output

Some of these objectives are not possible to combine. 100% fill factor sensors do not allow electronic shuttering, but require mechanical shuttering or strobe (pulsed) lighting, as an example, due to the architecture of the sensor itself.

Electronics

After exposure each pixel in the sensor has an electronic charge corresponding to the total intensity of the incoming light during exposure. This electronic charge must be read out from the sensor, amplified and digitised, converting the analog electronic charges to digital signals that can be stored and processed on a digital computer.

The trend is to put more and more of the electronics into the camera. CMOS sensors allow integration of the camera specific electronics directly on the chip. Several machine vision cameras offers digital output and even frame-buffers which allows storage of several to a few hundred images before transfer to the computer. We believe that digital cameras soon will make

the frame-grabber obsolete, each PC will soon have a plug-n-play digital video connection.

The next giant step is to move general-purpose processors into the camera, making them into real "smart cameras". Several producers offer such solutions today based on special-purpose processors, but we believe the trend will be towards general-purpose processors.

In the future the machine vision camera will contain a self-sustained PC, allowing transparent application development and system integration.

The electronics introduce many new effects that we must be aware of and control.

- Dynamic range of the digitisation
- Gamma-factor (non-linear corrective gain)
- Digitisation noise
- Synchronisation of read-out and exposure
- Jitter (line-to-line synchronisation)
- Transmission noise
- Automatic gain control
- Automatic white balance
- Automatic colour correction

To date everything that is automatic is avoided in most successful machine vision applications since processing gets more complicated when using for example automatic gain. Fixed thresholds are only fixed for a specific gain.



Fig. 5: Days of the past? A frame-grabber for machine vision with special-purpose processors. (Photo: Jan D. Martens)

Originally the pixels do have a linear light response function, but the electronics may distort the signal from the sensor. These distortions should carefully be avoided in high-precision measurement systems. Many machine vision cameras are specially designed for this task and avoid the greatest pitfalls.

Image processing

The images from a machine vision measurement system must be processed to extract the specific measurement information. The main task of the image-processing module is often to transform a digital image to a set of invariant measurements. It is of utmost importance to keep the image processing as simple as possible to make it work in real applications.

The concept of what can be done in real-time is expanding rapidly as the seemingly ever-increasing amounts of computer power become available. There is a trend from simple greyscale measurements, thresholding and edge detection towards utilising high-level shape, colour, texture and spatial information in machine vision systems. We are able to perform tasks that were unimaginable a few years ago. This leads to larger research and development projects, since more valuable tasks can be solved by machine vision systems.

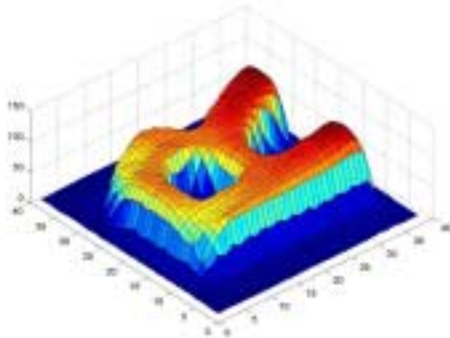


Fig.6: Height plot of the letter R on a cellular phone display window from IPlast.

Prototyping will be done in high-level languages with mathematical capabilities. Because of the boost in computer power, less time will be spent on optimising software code for speed, more time will be spent on user interface and ease of use. The main limitation to many problems is no longer computer power, but our knowledge and understanding of methodology, mathematics, physics, statistics and perception.

One possible step forward in image processing will be to leave the sampled digital image domain and reconstruct the original continuous intensity distribution to obtain better shape, colour and texture information about the images, avoiding many of the effects of quantisation and sampling

noise. The curves with zero second directional derivative of the intensity distribution is for example the correct physical locations of the edges of an image if we assume symmetric smearing in the optics and image formation process. These curves can be reconstructed with a much higher precision from a surface representation using geometrical operations than from a pixel representation using thresholding techniques.

Advantages of machine vision

- 100% inspection and control
- Objective measurements
- Non-contact measurements
- High accuracy
- High capacity
- High flexibility, reprogramming is possible
- Traceability
- Scalability
- System duplication is straightforward
- Mass production is relatively cheap

Theoretical foundations for shape, colour and texture are developing currently, but there are many remaining problems to be solved. The development of a consistent shape theory will require knowledge of geometry, physics and perception, colour will require knowledge of spectrometry and perception, while texture will require knowledge of the interaction between light and matter, physics and perception.

Object recognition is an important factor in many machine vision systems. The current trend is towards flexible templates, discarding fixed templates. We believe the largest challenge in object recognition is to make the systems automatically or semi-automatically configurable by allowing the systems to learn the template shape and allowed deviation of the template from real samples or by specifying a template for measurements manually in a user-friendly graphical user interface.

We believe there will be a trend towards modelling the physics of image formation in future machine vision systems. We will also see a trust towards understanding human perception more thoroughly.

