



**International Conference**  
1ST International Conference on Innovations, Recent Trends and Challenges  
in Mechatronics, Mechanical Engineering and New High-Tech Products  
Development  
**MECAHITECH'09**

Bucharest, 8-9 October 2009

---

## Intelligent Vision sensors Integration In Machine Vision Systems

Eng. Anca Atanasescu, eng. Sorin Sorea  
National Institute of Research and Development for Mechatronics and Measurement Technique  
6-8 Pantelimon Road, 2<sup>nd</sup> District, 021631, Bucharest, ROMANIA; E-mail: [irinelanca@yahoo.com](mailto:irinelanca@yahoo.com);  
incdmtm@incdmtm.ro

### ABSTRACT

Machine vision is a relatively new technology that advanced dramatically in the last 10 years. The latest generation of vision systems has been dominated by the rapid evolution of Smart Cameras that in many cases combine the intelligence of PC with the image quality of a high end industrial camera. This presentation will explore current trends in Smart Camera technology. It will also discuss Smart Camera benefits and limitations compared to PC based vision systems. In the process of comparing the two, criteria such as performance, system architecture and cost effectiveness will be discussed.

### INTRODUCTION

Machine vision is an image-processing technology that enables automated devices to scan objects within a limited field of view, interpret their orientation, and react according to preprogrammed sequences.

Intelligent vision sensor is a complete or nearly complete vision system contained in the camera body itself.

Usually intelligent vision sensor are called "intelligent cameras" and "smart cameras". From now on, we will use the term „smart cameras”.

The traditional smart camera is a single box that houses a sensor and processing element. Communication lines were secondary and limited at best. However, as we'll see, many of the industrial leading manufacturers offer unique combinations of input, output, sensor and processor to provide unique smart camera solutions.

Lighting and optics may or may not be integrated. At a minimum an intelligent vision sensor combines a camera with image processing and MV-related programs within the same housing.

Smart cameras often support a machine vision system by digitizing and transferring frames for computer analysis, but some smart cameras can also serve as self-contained vision systems without relying on external processing equipment.

A smart camera cannot "see" with the complexity of a human eye, it can approximate vision by examining pixel clusters through pattern recognition software and drawing simple conclusions based on programmed knowledge.

The components used to accomplish this include:

- Sensors: Image detection equipment, such as a charge-coupled device (CCD) or a complementary metal-oxide-semiconductor (CMOS), that converts lens projections into a voltage sequence, which can then be digitized or stored in memory.
- Digitization circuit: A conversion device that maps a set of points onto an image and translates them into pixels to create a digital representation.



**International Conference**  
**1ST International Conference on Innovations, Recent Trends and Challenges**  
**in Mechatronics, Mechanical Engineering and New High-Tech Products**  
**Development**  
**MECAHITECH'09**

Bucharest, 8-9 October 2009

- Central processing unit: A CPU, or in some cases a digital signal processor (DSP), that executes algorithmic programs for interpreting a digital image code.
- Storage hardware: Primary and secondary memory, such as RAM or Flash, used to run CPU programs, or to record and store images for future use.
- Communication technology: A method for connecting cameras to external devices. An Ethernet or RS232 signal transmits encoded images to a computer for analysis, or delivers instructions to reactive equipment.
- Lighting Device/LED: An illumination apparatus for clearer image captures.

Smart camera capabilities typically vary from model to model. Some types may incorporate all of the listed components, while others retain only the sensors, digital circuitry, and communication interface necessary for supporting a larger machine vision system.

Smart cameras are capable of running:

- a single application software
- a single vision library
- a variety of vision libraries or custom software.

**Different approaches to smart cameras**

Global markets demand the highest quality levels with regard to homogenous, patterned, printed, coated, or colored complex surfaces. Even the smallest deviations or defects lead to production interruption and decline. A smart cameras can be integrated in industrial process cycles as well as proving, fully automated, inspection solutions for the following complex surfaces, surface forms, and production methods:

Technical Surfaces	Surfaces types	Production methode
Film, foil	Homogeneous	Piece goods
Glass	Patterned	Bulk goods
Plastics	Coated	Roll goods
Painted finished parts	Colored	
Non-wovens	Printed	
Paper	Painted finishes	
Print products		

Smart cameras are also used for a number of automated functions, whether complementing a multipart machine vision system, or as standalone image-processing units. Due to their cost-efficiency and relative ease of use, smart cameras may be an effective option for streamlining automatision methods, or integrating vision systems into manufacturing operations.

In industrial production, manufacturers often use smart cameras for inspection and quality assurance purposes. A smart camera can be programmed to detect structural or component flaws, missing parts, defective or deformed pieces, and other deviations from an



**International Conference**  
**1ST International Conference on Innovations, Recent Trends and Challenges**  
**in Mechatronics, Mechanical Engineering and New High-Tech Products**  
**Development**  
**MECAHITECH'09**

Bucharest, 8-9 October 2009

---

intended design. If networked to the proper automated equipment, such as a robotic arm or retractor, a smart camera with processing capabilities can signal the instrument to remove a defective product. Alternatively, the camera can flag a deformed product for later removal.

Smart cameras are also used for industrial measuring. Using sensors, the camera can determine and record a component's physical dimensions without making direct contact. Depending on the vision system's level of sophistication, these measurements can involve high precision analysis and incremental scanning. The ability to verify a product's dimensions is also used in quality assurance to check for adherence to design specifications.

Smart cameras are also used for code reading and identification. Code reading and authentication require less processing capacity than product inspection, so relatively simple smart camera models can perform such operations. A barcode provides machine-readable data that can be quickly scanned by a smart camera, thereby enabling a high volume of code-imprinted products to be authenticated at a comparatively rapid pace. Smart cameras can verify that a barcode has been applied to the appropriate product, or determine if a code contains the correct data.

Optical character recognition is a more complex form of code reading that requires smart cameras to identify typewritten text. The rate of authentication may be slower than that of barcode reading, but with adequate processing power, a smart camera can analyze text to a high degree of accuracy. This can be useful for ensuring that printed materials display correct spelling and word order, and that product labels conform to design.

A smart camera can provide movement correction and repositioning data when working in conjunction with an automated tool. Through a network, the camera can communicate with a robotic device to assist it with sorting or identifying parts. This process helps improve the efficiency of automated services by increasing the accuracy of part manipulation.

Since a smart camera's functionality chiefly depends on its image-processing capacity, the device is adaptable to numerous requirements. Smart camera users can develop or purchase custom software programs to meet specific machine vision needs, which can range from product quality assurance to law enforcement support.

Some machine vision systems form a visual sensor network, which uses multiple smart cameras positioned at specific locations to capture images of a single object or area from several angles. This method is applied under circumstances in which numerous images fused together are more useful than the individual image each camera obtains. Sensor networks can effectively monitor environmental conditions, track objects in motion, or simulate three-dimensional representations of images.

The technology used in a smart camera has also been applied to biometric recognition systems. Retinal, facial, or fingerprint scanning are used for security purposes. A smart camera's processor can execute programs that use recognition algorithms to verify a person's identity or trace his location.

## **Market Segmentation**

Today, smart cameras are expanding to encompass a larger section of the vision market. We're seeing a migration of the functionality of what was once only PC based systems down to the smart camera level.

A smart camera seems to fit almost any system that doesn't use a PC, shoots for plug-and-play compatibility and comes relatively cheap. Starting at just over US \$1000 and ranging upwards of US \$6000, smart cameras are hitting the fabled price points while

delivering the processing power that many experts have said will take machine vision out of the specialist field and into the commodity market.

There are two market segments of applications:

- applications based on PC-aided Machine Vision Systems;
- application based on smart cameras, vision sensors, or compact vision systems.

There are also three market segments based on product features (**fig. 1**):




Vision Sensors (Lower End)	Smart cameras Intelligent cameras Vision Sensors (Higher end)	Embedded Vision Processor Embedded Vision computer Compact Vision System
		

Fig.1

The three segments are based on 7 segmentation criteria, see **fig.2**:

	Vision Sensors (Lower End)	Smart cameras Intelligent cameras Vision Sensors (Higher end)	Embedded Vision Processor Embedded Vision computer Compact Vision System
<b>Form Factor</b>	Integrated	Integrated	Less Integrated
<b>Price</b>	Lower-End of Market	Higher- End of Market	Higher- End of Market
<b>Flexibility/Programmability</b>	Lower	Higher	Higher
<b>I/O</b>	Simple	More Complex	More Complex
<b>Processing Power</b>	Less	More	More
<b>Memory Configuration</b>	Low	Medium	Highest
<b>Resolution</b>	Lower	Higher	Higher

Fig. 2

Smart Camera are benefits and limitations, compared to the other vision systems. In the process of comparing the three segments, criteria such as performance, system architecture and cost effectiveness can be discussed (fig.3).



**International Conference**  
 1ST International Conference on Innovations, Recent Trends and Challenges  
 in Mechatronics, Mechanical Engineering and New High-Tech Products  
 Development  
**MECAHITECH'09**

Bucharest, 8-9 October 2009

<b>Competitive Advantages</b>		
<b>Segment "1"</b>	<b>Segment "2"</b>	<b>Segment "3"</b>
<ul style="list-style-type: none"> <li>▪ Lower Cost</li> <li>▪ Ease of use</li> <li>▪ Integrated Lighting</li> <li>▪ Smaller form factor than "3"</li> </ul>	<ul style="list-style-type: none"> <li>▪ Less maintenance than "3"</li> <li>▪ Direct access of processor to sensor unlike "3"</li> <li>▪ More flexibility &amp; programmability than "1"</li> <li>▪ Can handle more advanced applications than "1"</li> </ul>	<ul style="list-style-type: none"> <li>▪ Can use more than one camera</li> <li>▪ Camera flexibility in some cases (can use different cameras)</li> <li>▪ Improved processor performance</li> <li>▪ Can handle more advanced applications than "1"</li> </ul>
<b>Competitive Disadvantages</b>		
<b>Segment "1"</b>	<b>Segment "2"</b>	<b>Segment "3"</b>
<ul style="list-style-type: none"> <li>▪ Less programmability (can only handle a limited number of simpler functions)</li> <li>▪ Les configurability</li> </ul>	<ul style="list-style-type: none"> <li>▪ Harder to use than "1"</li> <li>▪ More expensive than "1"</li> </ul>	<ul style="list-style-type: none"> <li>▪ Harder to use than "1" and "2"</li> <li>▪ More expensive than "1"</li> </ul>
<p><b>Segment "1" - Vision Sensors (Lower End)</b>  <b>Segment "2" - Smart cameras; Intelligent cameras; Vision Sensors (Higher end)</b>  <b>Segment "3" - Embedded Vision Processor; Embedded Vision computer; Compact Vision System</b></p>		

Fig.3

**Smart Camera benefits and limitations compared to PC based vision systems**

The question often comes up as to what is the most appropriate approach to take in implementing a machine vision system - using a Smart Camera or using some sort of PC-based approach.

When developing a machine vision solution to an industrial problem, the system integrator usually does not exactly know where the problem analysis will actually take him.

The PC-based solution offers an immense set of potential resources, in terms of computational or interfacing performance. The PC platform is essentially open, and it became so popular that its cost to performance ratio is unbeatable.

The low-cost argument is particularly true for the desktop PC, but it is sometimes claimed that the mechanical weakness of a mainstream desktop PC is not compatible with the industrial requirements of a serious machine vision application. However, compared to the more expensive industrial PCs, the low-cost desktop PC offers the latest CPUs and associated components, offering the highest performance at the lowest cost.

All in all, when considering all trade-offs to be made in its design, the machine vision developer reaches the conclusion that the PC-based system is the most cost-effective solution.

Secondly, some vision problems belong to a well-defined, special purpose class, identically found at numerous user sites. A good example of such an application consists in decoding Datamatrix codes.



**International Conference**  
**1ST International Conference on Innovations, Recent Trends and Challenges**  
**in Mechatronics, Mechanical Engineering and New High-Tech Products**  
**Development**  
**MECAHITECH'09**

Bucharest, 8-9 October 2009

---

In those cases, the computational and interfacing resources to solve the problem are predictable. It makes a lot of sense to pack the required resources into a single unit, and this is a definition of a Smart Camera. If (and only if) the quantity involved in this special application is significant, the cost can be reduced to a level that makes the product competitive with a PC-based solution.

"Traditional" approaches more often than not today mean an implementation based on a PC. This could be either using a camera with the capability to interface directly to the PC (IEEE 1394/Firewire, CameraLink, LVDS, USB, etc.), or a system designed based on a frame grabber or other intelligent image processing board or vision engine that plugs into the PC. In this latter case, more conventional analog cameras are used as the input device.

A Smart Camera, on the other hand, is a self-contained unit. It includes the imager as well as the "intelligence" and related I/O capabilities. More often than not, however, a vision sensor has a limited and fixed performance envelope, while a Smart Camera has more flexibility or tools, inherently capable of being programmed to handle many imaging algorithms and application functions. A PC-based vision system is generally recognized as having the greatest flexibility and, therefore, capable of handling a wider range of applications. One significant difference is that vision sensors/Smart Cameras are essentially single socket units, while PC-based vision systems can generally handle multiple camera inputs.

Another style machine vision system that falls somewhere between the PC-based vision system and a Smart Camera/vision sensor is what some call an "embedded vision computer." This type system is essentially a stand-alone box with frame storage and intelligence. It generally has limited flexibility and comes with a number of fixed application-specific routines. These are distinct from Smart Cameras in that the camera is tethered to the unit rather than self-contained. They often have the ability to handle multiple camera arrangements, which can be useful for many applications.

All these systems can be found with high-resolution imagers (up to 1000 X 1000) and/or color imagers. Interestingly, versions are often competitively priced. Some smart cameras and virtually all PC-based imaging capabilities can handle applications that require line scan cameras as well.

Concerning to advantages/disadvantages of PC-based machine vision versus Smart Camera-based machine vision, these are really two different technologies targeted predominately at two different customer segments. The PC based technology is largely focused on what one would call an OEM customer. The Smart Camera technology is largely focused on the end user.

In the process of comparing the two, criteria such as performance, system architecture and cost effectiveness will be discussed.

PC Based Machine vision advantages:

- Flexibility - The PC offers greater flexibility in the number of options that can be selected. For example one can use a line scan versus an area scan camera with the PC. One can use third party software packages with the PC approach (Smart Cameras tend to be single source software).

- Power - PC's tend to offer greater power and speed due in large part to the speed of the Intel processors used internally. This power in turn means that PC's are used to handle the "tougher" applications in machine vision.

- Expandability, easier to configure other types of I/O, communications, upgrades



**International Conference**  
1ST International Conference on Innovations, Recent Trends and Challenges  
in Mechatronics, Mechanical Engineering and New High-Tech Products  
Development  
**MECAHITECH'09**

Bucharest, 8-9 October 2009

---

- Ease and accuracy of calibration, a Smart Camera based robot system is rudimentary when it comes to calibration.

Smart Camera Advantage:

- Cost - Smart Cameras are generally less expensive to purchase and set up than the PC solution since they include the camera, lenses, lighting (sometimes), cabling and processing.

- Simplicity - Software tools available with Smart Cameras are of the point-and-click variety and are easier to use than those available on PC's. Algorithms come pre-packaged and do not need to be developed, thus making the Smart Camera quicker to setup and use.

- Integration - Given their unified packaging, Smart Cameras are easier to integrate into the manufacturing environment.

- Reliability - With fewer moving components (fans, hard drives) and lower temperatures, Smart Cameras are more reliable than PC's."

Comparison PC based vision systems/ Smart cameras:

- PC-based machine vision systems are generally more capable than Smart Camera based systems. They have more computational power to be able to handle much more sophisticated software algorithms. The Smart Cameras are great for simple tasks using general edge detection or binary tools; however, they do not have the computational power or memory to handle more sophisticated application specific algorithms. They will be limited to how fast and how complex the inspection performed will be.

- Smart Camera has a processor at each inspection point. This gives a network of Smart Cameras a distinct speed advantage over a single processor system. Ethernet allows the cameras to be easily managed from a single PC on the factory network and eliminates problems with PC hardware compatibility and operating system bugs.

- Smart Cameras are compact units, whereas a PC system comes with a lot of "baggage". In a PC solution you put together your system of components, frame grabber, camera, PC etc. These system components work together through standard interfaces. The camera, the frame grabber and the PC come from three different manufacturers, bringing compliance, driver and partially implemented feature set problems.

- Many Smart Camera applications today are networked. In several cases Smart Cameras are connected to PCs, PLCs etc. Smart Cameras perform the repetitive image processing functions providing only the results to the PC. The PC does the record keeping reporting administrative tasks it was originally designed for. Smart Cameras fit well into today's fashionable concepts of distributed computing, distributed control etc."

- Cost of a multiple camera system: Typical PC based vision systems can handle up to four cameras per frame grabber. In applications that require multiple cameras, the cost of a PC based system should be compared with the cost of multiple Smart Cameras.

- Communications overhead: Smart Cameras communicate with robot controllers via serial interface (RS-232) or Ethernet. Communication overhead adds a delay in robot to camera communication. In contrast, in the case of an integrated motion and vision system the communication overhead is miniscule since all hardware and software is on the same platform.

- Seamless integration of motion and vision: In order to use Smart Cameras the customer has to select and link separate off-the-shelf products. With off-the-shelf controller-based vision system the customer is investing in a pre-engineered and pre-configured system.



**International Conference**  
 1ST International Conference on Innovations, Recent Trends and Challenges  
 in Mechatronics, Mechanical Engineering and New High-Tech Products  
 Development  
**MECAHITECH'09**

Bucharest, 8-9 October 2009

- **Size and weight:** Typical analog cameras are approximately 44 x 29 x 71 mm in size and weigh 140 grams. Smart Cameras require additional electronics, which increases their size and weight. This may be an important selection criterion for applications that have limited camera-mounting space and for arm-mounted cameras where the momentum of the arm or mechanism is critical.

- **Power Consumption and Heat Generation:** Smart Camera consumes more power for the additional electronics and this results in higher heat generation. Heat can deteriorate camera performance over time.

Summarized these criterias with the following table (fig.4):

	<b>PC-based vision system</b>	<b>Smart Camera</b>
<b>Flexibility</b>	Excellent	Poor
<b>Ruggedness</b>	Poor	Excellent
<b>Size</b>	Multiple-box system Imaging head can be very small	All-in-one box Not necessarily very small
<b>Functionality</b>	Expandable	Limited
<b>Performance</b>	Expandable	Limited
<b>Ease of use</b>	Needs computer skill	No computer skill needed
<b>Configuration</b>	Expandable	Fixed
<b>Computational Power</b>	Expandable	Limited
<b>Scalability</b>	Excellent	Poor

## REFERENCES

- [1] W. Wolf, B. Ozer, and T. Lv, "Smart cameras as embedded systems," *Computer*, vol. 35, no. 9, pp. 48–53, 2002.
- [2] "Proceedings of the Workshop on Distributed Smart Cameras (DSC '06)," B. Rinner and W. Wolf, Eds., Boulder, Colo, USA, October 2006.
- [3] B. Heyrman, M. Paindavoine, R. Schmit, L. Letellier, and T. Collette, "Smart camera design for intensive embedded computing," *Real-Time Imaging*, vol. 11, no. 4, pp. 282–289, 2005.
- [4] A. Rowe, C. Rosenberg, and I. Nourbakhsh, "A second generation low cost embedded color vision system," in *Proceedings of IEEE Embedded Computer Vision Workshop (ECVW '05) in conjunction with IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR '05)*, vol. 3, p. 136, San Diego, Calif, USA, June 2005.
- [5] S. Fleck, F. Busch, P. Biber, and W. Straßer, "3D surveillance—a distributed network of smart cameras for real-time tracking and its visualization in 3D," in *Proceedings of IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR '06)*, p. 118, New York, NY, USA, June 2006.
- [6] M. Bramberger, B. Rinner, and H. Schwabach, "A method for dynamic allocation of tasks in clusters of embedded smart cameras," in *Proceedings of IEEE International Conference on Systems, Man and Cybernetics (SMC '05)*, vol. 3, pp. 2595–2600, Waikoloa, Hawaii, USA, October 2005.