Smart Cameras as Embedded Systems

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Abstract. A "smart camera" is basically a video camera coupled to a computer vision system in a tiny package. This communication begins stating the main differences between smart cameras and standard smart vision systems. A smart camera architecture is described whereby a combination of an on-board microprocessor and PLD's allow for the embedding of image processing algorithms in the camera. A static thresholding algorithm is presented which demonstrates the ability to track non-uniformity in the inspection target. A multi camera inspection system application is presented where a maximum of twenty smart cameras may be networked together to a single host computer. Finally, a prediction is made of technological and applicational future evolution on smart cameras.

1   Introduction

The smart camera – a whole vision system contained in one neat housing – can be used anywhere, in any industry where image processing can be applied. Companies no longer need a cabinet in which to keep all their computing equipment: the computer is housed within the smart camera. In the pharmaceutical industry and in clean rooms – when not even dust is allowed – this can be a big advantage. A single square metre of space can be comparatively very expensive – if there is no need for a component rack or cabinet, simply a smart camera, then this could save a lot of money. In particular, there would not be the usual cabling involved for other vision systems, and set-up is simple [1]. Later in this communication are stated some advantages of using smart cameras or PC-based systems in vision applications.

In usual vision systems scenarios, only a small fraction of a picture frame will be the region of interest (ROI). In fact, often no visual image of the ROI is even required. The object of a vision system, after all, is to make a decision: "Is there a blob"? "Where is the blob"? "Is this a defect"?

What if all that pixel pre-processing and decision-making could be done within the camera? If all the processing were done inside the camera, the blob analysis of a gigabit image might result in only a few hundred bytes of data which need to be sent somewhere. Such compact packets of data could be easily transmitted directly to a machine control without even passing through a PC.

Information should be processed where the information occurs – i.e. the brain should be behind the eyes!

The answer to the problem stated earlier is a stand-alone, smart camera [2].

To illustrate this, a smart camera's embedded system architecture is shown along with an example of a hardware embedded image processing algorithm: *"Static Gray Scale Thresholding"*.

Many global companies including Glaxo and Ciba-Geigy, and motor companies such as Ford and Volkswagen are users of smart cameras. Others include Sony Music and 3M; the

latter has in place up to 150 smart camera systems [1]. A small example of a vision system for web inspection is shown where twenty smart cameras are connected together.

Many changes are yet to come concerning smart cameras as in technology as well as in there future applications. An overview, concerning these issues, is made closing this communication. We have to recognise however that smart cameras will not be the answer for all vision applications.

2 Smart Cameras vs. Standard Smart Vision Systems

The question often comes up as to what is the most appropriate approach to take in implementing a vision system - using a smart camera or using some sort of PC-based approach. There is no question that as the microprocessors, DSPs and FPGAs are getting faster and, therefore, more capable, smart cameras are getting smarter. Therefore, they are a challenge to more "traditional" approaches to vision systems. Significantly, however, "traditional" approaches are also taking advantage of the advances and so, too, are faster and smarter.

Traditional approaches usually mean a PC-based implementation. 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 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. Because this format resembles the format of many intelligent sensors, these products are often referred to as "vision sensors."

However, a vision sensor often 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 recognised as having the greatest flexibility and, therefore, capable of handling a wider range of applications.

2.1 PC-Based Vision Systems Advantages

The PC-based vision systems advantages include:

- 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 vision systems.

2.2 Smart Cameras Advantages

The smart cameras advantages include:

- Cost - Smart cameras are generally less expensive to purchase and set up than the PC-based 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.

In general the performance of the smart camera will continue to increase. This will mean that the smart camera will be used for more difficult applications, slowly displacing the PC approach [3].
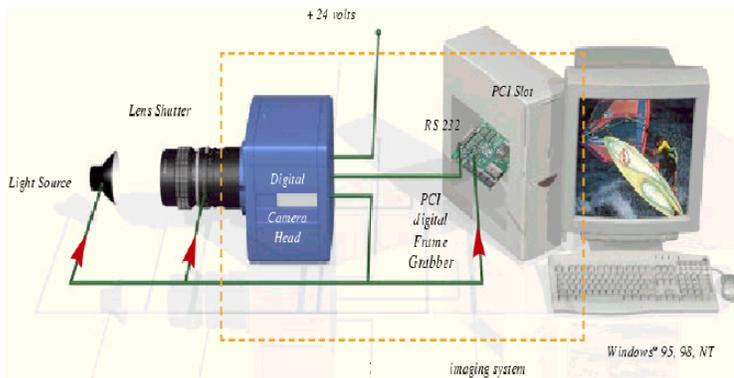

Fig. 1. Standard Smart Vision System (Image courtesy of Atmel Grenoble) [4]

Fig. 2. Smart Camera System. (Image courtesy of Vision Components) [5].

3 Smart Camera Architecture

The smart camera presented in this communication reduces the amount of data generated to the *'data of interest'* by making use of embedded image processing algorithms. The data of interest might be, for example, defective areas of the product being inspected. Multiple cameras can route their data to a single frame grabber and computer due to the reduction of data stream, thus dramatically reducing system cost and increasing inspection bandwidth capability. This smart camera also makes use of an on-board microprocessor for communication with the inspection systems' host computer and for internal control functions [6].

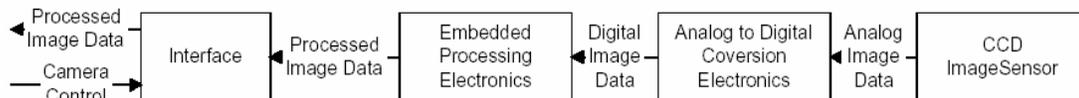The following block diagram illustrates the camera architecture.

Fig. 3. Smart Camera Architecture Block Diagram

A detailed explanation of the camera architecture follows, starting with the image sensor.

3.1   Image Sensor Basics

In this smart camera, a CCD (Charge Coupled Device) image sensor converts photons (light) into electrons (charge). When photons hit an image sensor, the sensor accumulates electrons. This is called charge integration. The brighter your light source, the more photons available for the sensor to integrate, and the smaller the amount of time required to collect a given amount of light energy.

   Finally, the sensor transfers its aggregate charge to readout registers, which feed each pixel's charge from the image sensor into an output node that converts the charges into voltages. After this transfer and conversion, the voltages are amplified to become the camera's analog output [6].

3.2   Analog to Digital Conversion Electronics

The analog output of the CCD is converted to a digital output for further processing. The camera presented here sub-divides the CCD analog output into eight channels of 256 pixel elements each. Analog to digital conversion is performed at a 20 MHz data rate for each channel thus yielding an effective camera data rate of 160 MHz. The digital data is then passed along to the image processing electronics for processing and analysis [6].

3.3   Image Processing Electronics

Image processing is performed by embedded algorithms on a per channel basis. The following block diagram illustrates the basic processing architecture for each channel.
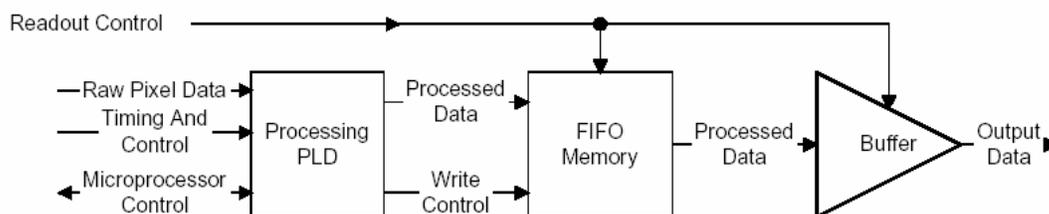

Fig. 4. Image Processing Architecture Block Diagram

   The processing algorithm is embedded in the processing PLD. The microprocessor has a bidirectional path being able to randomly access the algorithm parameters, as well as program a new algorithm into the PLD as required by the user. Raw pixel data and associated timing and control signals are also connected to input pins into the processing PLD,.

   For storage and subsequent readout, algorithm processed data is output along with a write control signal to FIFO memory. 8:1 multiplexing of the data is achieved by using FIFO memory. Readout control is accomplished by the microprocessor/FIFO readout control card whose architecture is shown below.
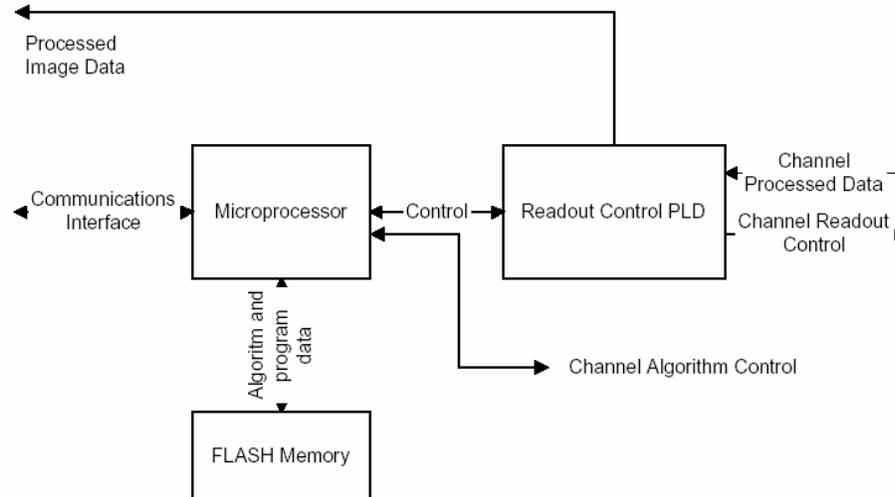
Fig. 5. Microprocessor/FIFO Readout Control Circuit Board Block Diagram

The Microprocessor/FIFO readout control circuit board acts as the master controller for the smart camera. FLASH memory is used to store microprocessor code and PLD algorithm code. In-system programmability is achieved because all PLD devices in the image processing section of the camera are SRAM based [6].

4 Image Processing Algorithms

Many types of image processing algorithms can be embedded within the camera, since the video processing modules are completely in-system programmable. As an example, a static grey scale thresholding algorithm is presented below.

4.1 Static Grey Scale Thresholding

In static thresholding, an upper and a lower bound are established around what is considered a normal value. Image data that falls within the boundary window is considered normal non-interesting data. Image data that falls either above or below the boundary window is considered data of interest. Considering we are dealing with an 8-bit digital camera, the normal, upper and lower boundary values are seen to be digital numbers (DN) on a scale of 0 to 255 "Gray scale". Imagine that a product is being inspected for defects and the grey scale level of non-defective product is 85 DN, and the upper and lower boundary values have been set to +/- 15 DN. All image data that fell within the bounds of 70 DN to 100 DN would be considered non-interesting and would not be transmitted out of the camera.

Image data that fell below 70 DN and above 100 DN would be considered interesting and would be transmitted out of the camera. Substantial data reduction is achieved since only some of the data will fall outside of the established boundaries.

It is important to note that all of the *'data of interest'* is transmitted out of the camera and thus data reduction is achieved where all of the grey scale information is preserved. This type of algorithm is illustrated by the image shown in figure 6 [6].
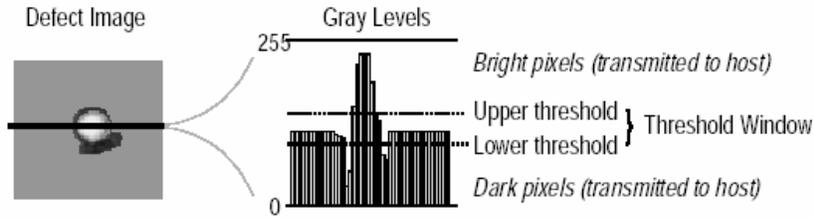
Fig. 6. An Example of Static Thresholding

For later display and analysis each pixel must be given an address such that an image can be reconstructed by the frame grabber since an algorithm of this type produces non-continuous data. The static thresholding algorithm requires three parameters as follows an upper bound, a lower bound, and a centre value. The determination of the centre value is essential to this type of algorithm, and the acceptable band between the upper and lower bound. The static thresholding algorithm is expressed as follows:

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IF (PIXEL GRAY IS > (CENTER + UPPER)) OR (PIXEL GRAY IS < (CENTER –
LOWER) ) THEN

        TRANSMIT PIXEL

ELSE

        IGNORE PIXEL
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4.2 Embedded Image Processing Algorithms

The algorithms are embedded in hardware with a PLD/microcontroller combination and operate at a 20MHz data rate per channel. The effective processing rate is 40MHz because each image processing PLD can process two channels of image data. With dedicated DSP controllers such data processing rates could be difficult to achieve. Microcontroller also can directly control the algorithm without host computer intervention, since it has access to the image data [6].

5 Smart Camera System

A vision system for web inspection is presented below where a maximum of twenty 2048 pixel high sensitivity line scan smart cameras are networked together to a single host computer and frame grabber. A block diagram of the system is shown in figure 7 [6].

5.1 System Overview

The system shown consists of up to twenty 2048 pixel high sensitivity line scan smart cameras housed within a camera enclosure mounted above the web. Transmissive illumination is provided since illumination source is mounted beneath the web. Routed through two cabinets are the data, control, and power lines to/from the cameras. The system makes use of fibre optic technology for transmission of data and control signals thus allowing the inspector station to be located remotely at a distance of up to 100m.
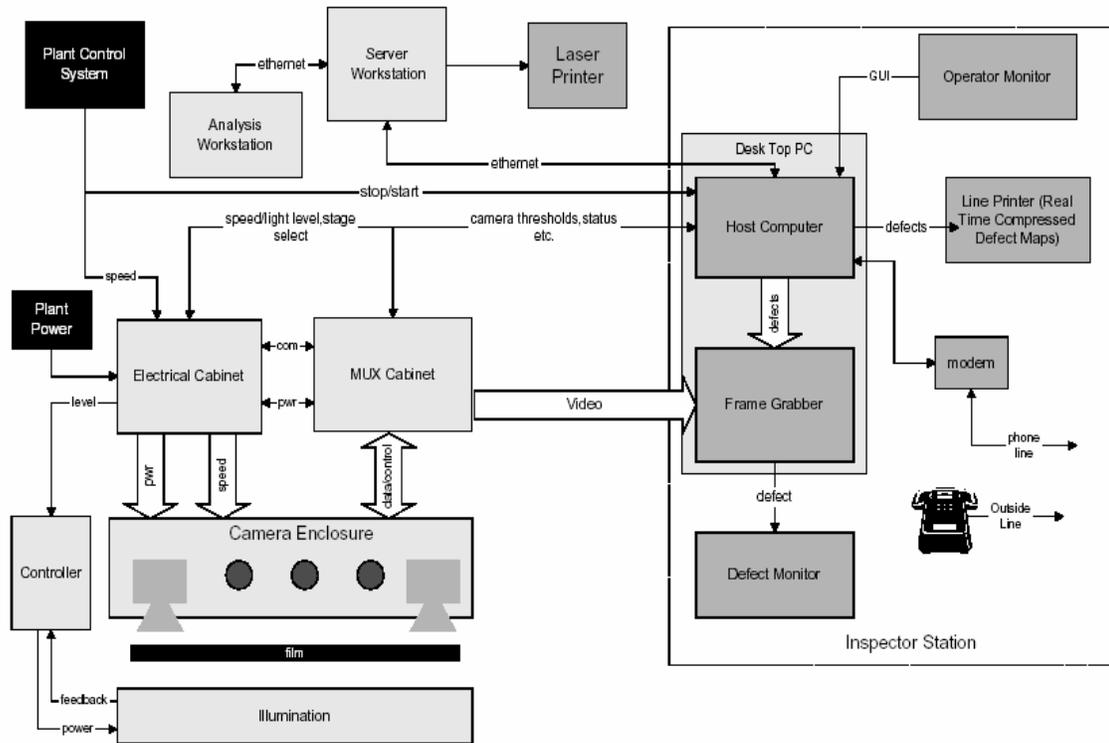
Fig. 7. System Block Diagram

The system also provides input and output to the plant control system. Data from the cameras is acquired by the frame grabber, assembled into images, and then transferred to the host computer real time display on the defect monitor, and stored to a database residing on the file server via an Ethernet connection. Subsequent analysis of the data is performed at the analysis workstation with analysis software that allows extraction of data from the database for creation of reports. All system and analysis software is multithreaded and provides real time data access and display. Via a modem connection the system is also operable remotely. To ensure smooth and constant illumination of the web the system software also controls the illumination source with a fuzzy logic control scheme [6].

6 Looking Ahead

The vision industry is rapidly moving away from the video camera/frame grabber systems of the twentieth century to a new generation of smart-camera-based systems for the 21st century. These 21st century smart-camera systems will perform real-time, pixel-data extraction and processing operations within the camera at extremely high speeds and at a cost, which is considerably less than required today for comparable capabilities. Eventually, complete vision-processing-systems-on-a-sensor-chip will be available [2].

Components in smart cameras will undoubtedly change due to the push from semiconductors and new microprocessors coming onto the market. The trends for the next year will be towards megapixel sensors, higher resolution, faster processing power, and colour. A typical standard CCD based camera has a matrix of 480,000 pixels, however the new megapixel cameras offer at least 1,000x1,000 pixels – or 1 million pixels. Some manufacturers already offer cameras of 2 million pixels [1].

6.1 Future Applications

To date, exploitation of smart camera technology has been mainly for industrial vision systems, but a crossover is just starting to take place. Smart camera technology will begin to enter new applications, for example, in the security and access control markets, in the automotive industry, for collision avoidance, and even – one day – for the toy industry [1].

Even our automobiles may soon be outfitted with miniature eyes. Built into a cruise control system, for instance, such a camera would suddenly alert the driver if it noted a rapidly decelerating vehicle. The cameras could also take the place of the rear view and side-view mirrors, thereby eliminating dangerous blind spots and - in the event of an accident - recording the seconds prior to a collision [7].

Another example would be with intelligent lifts. An office block, with many lifts and floors, may see a lot of people travelling up and down between floors, particularly at high-traffic times such as early morning or end of the working day. At the moment, lifts are called by somebody pressing a button and putting in a request for the lift to stop at a particular floor. Connected with smart camera technology, lifts could be routed on demand, working intelligently, stopping only when there was a pre-set number of passengers waiting at a floor – and missing out a floor if too many people were waiting to meet the maximum capacity of the lift.

Looking into the future, we can foresee an infinite number of applications for the smart camera; in fact, as many as there are potential image processing uses [1].

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