

## DSP BASED MEASURING LINE-SCAN CCD CAMERA

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**Abstract:** A simple, flexible and programmable line-scan CCD camera is presented in this paper. This camera is designed for measurement purposes such as dimension and position measurements. Camera enables implementation of various signal-processing algorithms as well as usage of various types of CCD sensors.

**Keywords:** - DSP, line-scan CCD camera, embedded signal processing

### 1. INTRODUCTION

CCD line-scan cameras are used in measurements e.g. for dimension measurement applications where the resolution (number of pixels) of cameras with area CCD sensors is not sufficient and the whole image of the measured object is not required. Following figures show block diagrams of two common line-scan camera concepts:

- camera with analog output (Fig. 1)
- camera with digital output (Fig. 2)

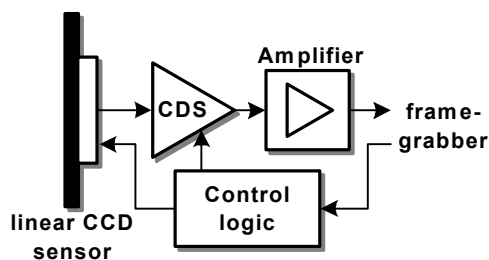


Fig. 1 – Block diagram of a common line-scan camera concept – camera with analog output.

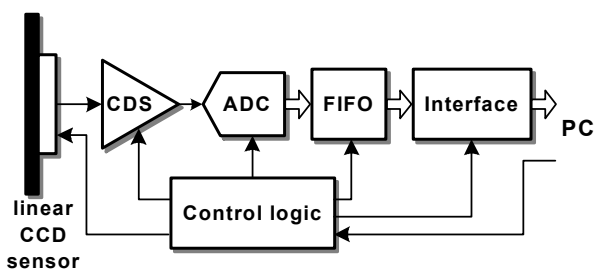


Fig. 2 – Block diagram of a common line-scan camera concept – camera with digital output.

In both cases the signal from the CCD sensor is in the camera only pre-processed using a sampler (CDS – Correlated Double Sampler) and an amplifier or an ADC. The signal-processing and measurement algorithms are implemented in some external unit such as PC.

Our goal was to develop a simple digital line-scan camera for measurement purposes that could work without additional peripherals. Further we wanted the camera to be re-configurable so it would be easy to change the signal-processing algorithm. Easy application of various types of CCD sensors was also required so it will be possible to use the most suitable sensor for different tasks.

### 2. CAMERA CONCEPT DESCRIPTION

Compared to the block diagram of a digital line-scan camera in Fig. 2, a stand-alone solution must also implement a signal-processing block (Fig 3).

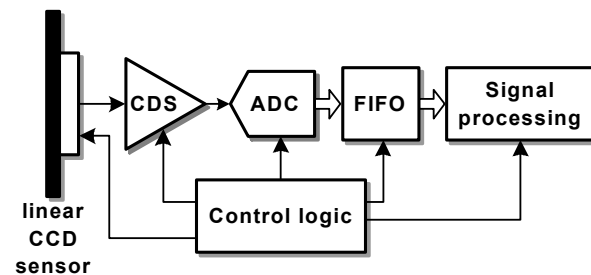


Fig. 3 – Block diagram of a stand-alone digital line-scan CCD camera.

The signal-processing block can be of course implemented using an embedded PC but more

simple and cost effective solution was required. Also a more flexible solution of the “control logic” block than the conventional solution based on logic gates or programmable device such as CPLD or FPGA was wanted.

This leads to a solution based on a single chip that would be able to perform all following tasks:

- generating CCD sensor control signals
- generating control signals for sampler and ADC
- storing measured data in memory
- performing various signal-processing algorithms

Requirements mentioned above led to a solution

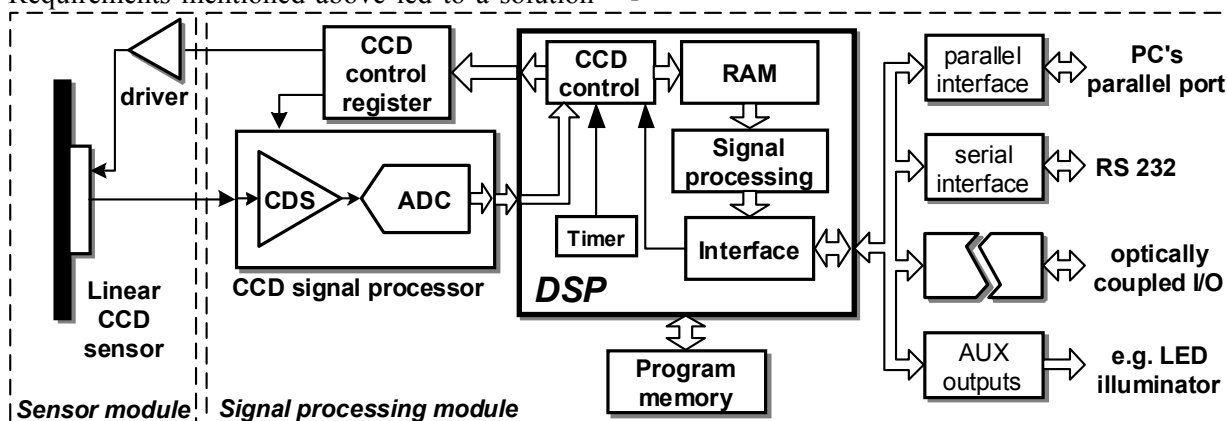


Fig. 4 – Block diagram of the designed camera.

contains a CDS (Correlated Double Sampler) sampling unit, a programmable amplifier, an offset correction DAC and an ADC. Namely the CCD signal processor AD9814 was used.

The camera is split into two modules (Fig. 4). The sensor module contains the CCD sensor and control signals driver (if necessary). The signal-processing module contains the rest of the necessary circuits: signal conditioning, control and communication circuits and the DSP. Splitting the camera into two modules enables to use various sensors with one multipurpose data acquisition and processing module.

When generating control signals the DSP has only small computational power left to perform real-time signal processing. Most algorithms must therefore work offline – after the whole image from the CCD sensor is acquired. This is only a small drawback since many applications and manufacturing processes allow to divide the measurement cycle into two steps:

- image acquisition,
- signal processing.

### 3. CONTROL SIGNAL GENERATING

To enable easy reconfiguration of the camera, the control signals are generated entirely by program. This is a more flexible solution than having the control generator realised using a programmable

based on a DSP (Digital Signal Processor) – see Fig. 4. Unlikely common DSP applications, where the DSP is used only for signal processing, in this application it also generates all necessary control signals and its internal data memory is used to store data before they are processed (no additional data memory, FIFO or dual-port RAM is therefore needed). The Analog Devices ADSP-2184 (or alternatively ADSP-2185) was used.

Further simplification of the camera design was achieved by using a so-called CCD signal processor (or CCD Analog Front End) for CCD sensor’s signal conditioning and digitising. The CCD signal processor

logic device (CPLD or FPGA) or logic gates. Control signals are generated by writing proper combination of signal levels to a register (CCD control register in Fig. 4) mapped in the I/O space of the DSP as an output port.

The DSP must generate all necessary signals needed to control the CCD sensor (Fig. 5) such as transfer gate pulse  $\Phi_{ROG}$ , shift register clock  $\Phi_{CLK}$ , charge detector reset  $\Phi_{RS}$  and shutter gate pulse  $\Phi_{SHUT}$  (if the used CCD sensor has one).

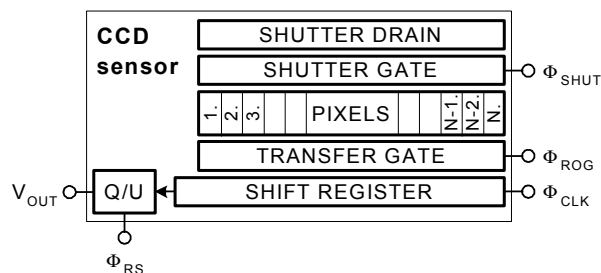


Fig. 5 – Block diagram of a linear CCD sensor with its control signals.

The program must also control the sampling of the sensor’s output signal  $V_{OUT}$  using the signals CDSCLK1 and CDSCLK2 (Fig. 6) and the A/D conversion using the signal ADCCLK.

The DSP’s internal timer is used to ensure constant integration time (i.e. constant period of signal  $\Phi_{ROG}$ ). This timer generates periodically

interrupts with a period equal to the period of the signal  $\Phi_{ROG}$ .

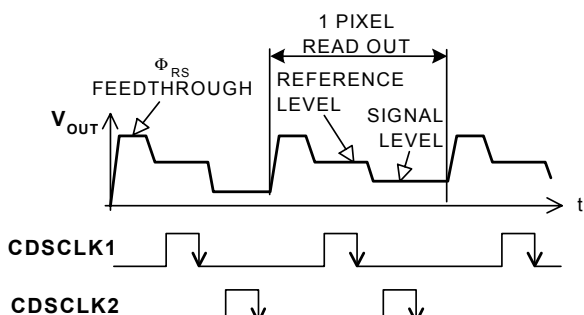


Fig. 6 – Typical waveforms of the CDS sampling signals.

In the timer interrupt service routine (see Fig. 7 for a routine flowchart valid for a sensor without electronic shutter) the  $\Phi_{ROG}$  pulse is generated first and then the image from the CCD sensors is read out. Finally, the acquired image is processed – e.g. multiplicative error is corrected, positions of edges in the image are found, distance between edges is determined and so on.

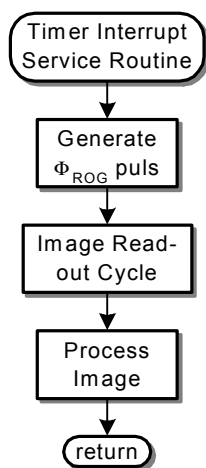


Fig. 7 – Flowchart of the timer interrupt service routine (CCD sensor without electronic shutter).

From Fig. 7 follows a limitation of this concept. The shortest integration time must be longer then the time needed to perform image read-out and image processing. This limitation can be overcome by using a CCD sensor with an electronic shutter.

Simplified flowchart of the image read out cycle is shown in Fig. 8. First the DSP's loop counter register (CNTR) is loaded with the number of sensor's pixels (N). Then the cycle of one-pixel read-outs is performed.

The number of instruction cycles needed to read out one pixel of the CCD sensor depends on the number and required waveform of control signals. For example when using a CCD sensor Sony ILX503A in the mode with external reset signal  $\Phi_{RS}$  it takes 17 instruction cycles to read out one pixel (one instruction cycle of ADSP-2184 with 20 MHz clock is 25 ns long) – see Fig. 9.

When using a Sony ILX551A sensor, which

generates the  $\Phi_{RS}$  signal internally, only 14 instruction cycles are needed.

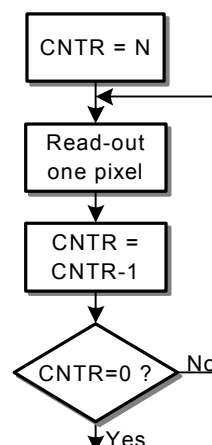


Fig. 8 – Flowchart of the image read-out cycle.

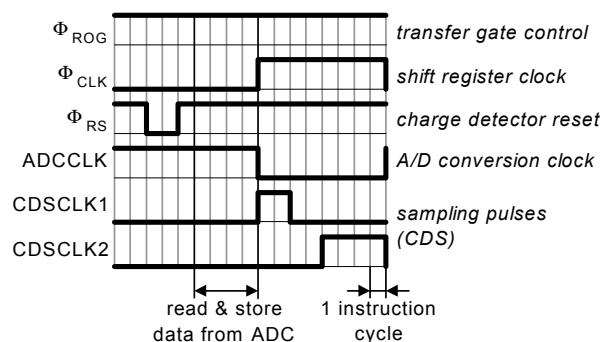


Fig. 9 – Example of waveforms during one pixel read-out (CCD sensor Sony ILX503A).

Thanks to DSP's *zero overhead* feature the decrementation and testing of the register CNTR and the jump from the end of the loop to its beginning (Fig. 8) takes no instruction cycle. This feature simplifies the read-out cycle design.

Complete image read-out cycle takes approx. 887  $\mu$ s for ILX503A sensor with 2087 pixels and ADSP-2184 with 25 ns instruction cycle.

#### 4. CAMERA'S INTERFACES

Although the camera is designed as a stand-alone device, it has interfaces to communicate with PC as well as with manufacturing process (Fig. 4).

The parallel interface working in the EPP (Enhanced Parallel Port) mode can be used for quick transmission of the whole image into a PC. E.g. algorithms can be then debugged and tested in the PC first and then implemented into the DSP. The serial interface (RS232) is suitable for transmission of small amounts of data such as results of measurement.

The camera is also equipped with two optically coupled inputs and one output and with an 8-bit general-purpose output port which can be used e.g.

for LED illuminator control that is necessary for some measurement methods.

### 5. CAMERA'S APPLICATIONS

The described camera was designed for both conventional and projection methods of measurement of position or dimension.

In case of conventional methods [1] the camera is equipped with lens (Fig. 10).

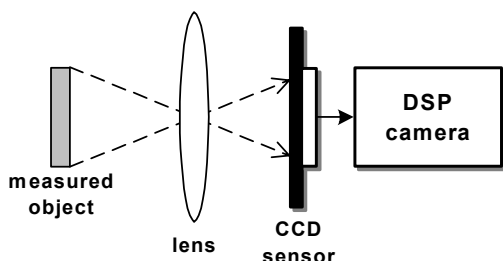


Fig. 10 – Measurement set-up – conventional methods of measurement.

For example the position of a measured object can be determined by calculating the center of mass of the image (Fig. 11):

$$x_C = \frac{\sum_{i=1}^N i y(i)}{\sum_{i=1}^N y(i)} \quad (1)$$

where  $y(i)$  is the illuminance level of  $i$ -th pixel.

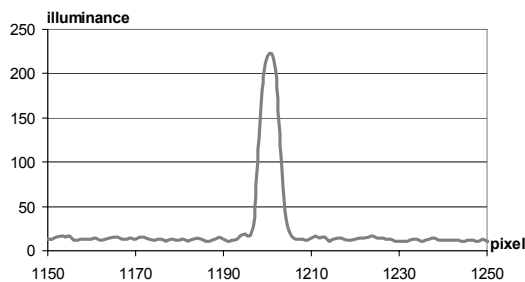


Fig. 11 – Measurement of position of a light track – example of measured illumination profile.

The projection (or so-called “shadow”) methods of measurement [2] use a shadow projected by a measured object on a CCD sensor without lens (Fig. 12) to determine the object’s dimension or position.

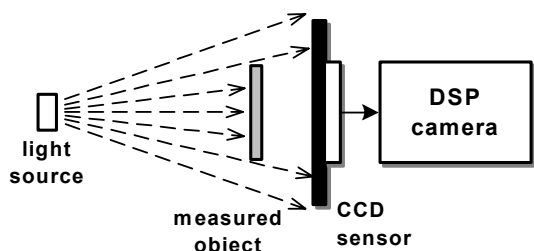


Fig. 12 – Measurement set-up – projection methods of measurement.

To determine object’s dimension the DSP must first locate the position of edges in the acquired image (illumination profile) – see Fig. 13.

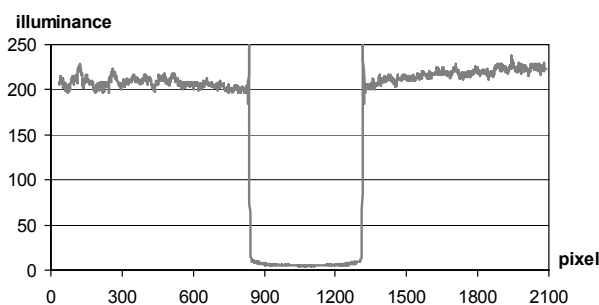


Fig. 13 – Dimension measurement using shadow projection - illumination profile.

The edges are always few pixels wide (Fig. 14) so some edge-detecting algorithm must be used for precise edge position detection.

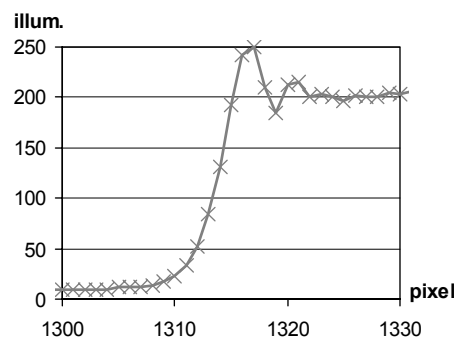


Fig. 14 – Dimension measurement using shadow projection – detail of an edge in the illumination profile.

The edge detection is usually done by comparing the illumination waveform with some threshold. To increase resolution of edge detection the interpolation between pixels is used. For example linear interpolation:

$$x_T = \frac{y_T - y(i)}{y(i) - y(i-1)} + i \quad (2)$$

where  $x_T$  is edge position;  $y_T$  is the threshold level;  $y(i)$  is the illuminance level of  $i$ -th pixel.

Both algorithms mentioned above require each approximately 210  $\mu$ s of computational time when using a CCD sensor with 2087 pixels and a DSP with 25 ns instruction cycle.

### 6. CONCLUSION

We designed and build a measuring digital line-scan CCD camera that enables implementation of

different measuring algorithms and methods. Camera is based on a DSP. Unlikely common DSP applications the DSP in the camera performs not only the signal processing but also other tasks such as CCD sensor and ADC control and data storage.

Using a single DSP for multiple purposes simplifies the design and enables easy reconfiguration of the camera. Disadvantage is that most measuring algorithms can't be performed in real-time (during image acquisition) because the CCD sensor control consumes a significant amount of computational power of the DSP. However, when fast scanning (short integration time) is not required, the computations can be performed in the interval between image read-out and end of scanning of next image.

The designed camera has a modular structure so various types of CCD sensors can be used with the same signal conditioning and control module.

Several measuring algorithms were implemented in the camera, e.g. algorithm of dimension measurement using the projection method was implemented and tested on objects with diameters from 100  $\mu\text{m}$  to 1 mm. The relative errors of measurement were in the range from 0.2 % to 2 % [3]. Resolution of measurement was 1  $\mu\text{m}$ .

## 7. REFERENCES

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## 8. ACKNOWLEDGEMENT

The results of the research project MSM 210000015 „Research of New Methods for Physical Quantities Measurement and Their Application in Instrumentation“ were used in this paper.

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