CRITERIONS OF SELECTING OPTO-ELECTRONIC COMPONENTS OF SYSTEMS INTENDED FOR CONTACTLESS AND TRUE TO GEOMETRY MEASUREMENT

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ABSTRACT

People developing opto-electronic systems for contactless and true to geometry measurement not in any case have the appropriate conditions of being sure, that they selected the most suitable opto-elctronic components for their task from a great variety of components offered on the market. On the example of CCDs and frame grabbers interesting measuring problems - e.g. linearity errors of CCD measurement of lateral pixel sensitivity and pixel geometry, investigation and verification of true to geometry imaging features of frame grabbers as well as quality investigations of video pick-up channels of frame grabbers - and measuring results gained on electronic components of different producers are presented and discussed.

Keywords: Accuracy, Camera, Photogrammetry, Sensor, Standards

INTRODUCTION

During the conceptional development phase of opto-electronic instruments intended for solving measuring, testing and automation tasks an optimum selection of opto-electronic components - for example CCD and frame grabbers for such systems - is of decisive importance.

They determine quality and use value . In consideration of the variety of opto-electronic components with their partially most different features offered on the market and the entirely insufficient comparability of the informative material about them for high sophisticated image processing tasks it is absolutely necessary to measure their parameters or to test them under future application conditions (spectral range, dynamic range, optical and electronic resolution).

Within the scope of the development of non-contact metric measuring and 2D-3D image pick-up systems in the laboratory of Rheinmetall Jenoptik Optical Metrology GmbH a lot of different sensible opto-electronic units were tested and certificated accordingly.

We would like to demonstrate here a selected number of the most interesting measuring problems .

The measuring results gained on most different components of different producers under equal conditions and measuring methods illustrate the topical importance and brisance of an approach like that.

Thus a decision you have to take for a system conception will be effective and possible at the earliest possible moment of the development.

2. LINEARTY ERROR OF CCD COMPONENTS

CCD components' linearity is investigated by taking their characteristic curves ($U = f(E \cdot t)$, U - video signal, $E \cdot t$ - irradiation) when they are illuminated by a steady source. Irradiation can be altered or by changing irradiance or by varying integration time. For solving complicated measuring tasks you have to find a quasi-linear range in case of non-linear characteristic curves and to define it for the dynamic range permitted later on in the measuring system. If the dynamic range limited in this way is insufficient correction algorithms have to be applied based upon these measuring results.

The basic idea of the interpretation method of quasi-linear range determination consists in the fact that a characteristic curve is approximately linear when its rise change tends to zero. This means that in case the characteristic curve is indicated as an analytic expression (polynom) the second derivation must disappear.

The principle of this method is shown on figure 1. Besides giving the quasi-linear range with the aid of the second derivation the first one supplies an additional information about differentiated sensitivity in this range.

3. MEASUREMENT OF LATERAL PIXEL (SUBPIXEL) SENSITIVITY - PIXEL GEOMETRY

Lateral single pixel sensitivity is investigated with monochromatic light irradiation (for example: 436 nm; 55Ø nm; 626 nm) by imaging a diffraction-limited light spot (diameter: 1.1 μm; 1.3 μm; 1.5 μm) on to a pixel of the CCD to be investigated. During the measuring procedure the light spot step-by-step is moved over the chosen pixel and its environment in column and row direction. The characteristic curve of lateral sensitivity is obtained by recording the videosignal at every approached position. In case of an extremely high spot positioning accuracy (±2Ø nm) it is possible to determine the real pixel geometry from the lateral sensitivity characteristic curve [1].

It can be stated that the expected trapezoidal shape of the lateral sensitivity characteristic curve will often not appear.

In the following I would like to demonstrate a few examples on the figures 2 ... 9.

It can be established that no significant differences could be found in the shape of the lateral sensitivity characteristics of the measured pixels within one CCD component under constant conditions of measurement.

But obvious differences in the lateral sensitivity curve shape appear under constant measuring conditions on different CCD components

- components of one and the same type but of different producers (WF, F79/F89)
- components of one and the same producer but different batches (F79, F89)
- different component types (WF, F79, F89, matrix)

and also in the scope of one CCD when sampling direction or wavelength were changed (WF, F79, F89, matrix).

Analogous measurement was carried out on sensors of different operating modes (for example: CID arrays), too.

The presentation of the special results caused by the operating principle would go beyond the scope of this discussion.

4. SPECIAL INVESTIGATIONS ON FRAME GRABBERS

For tasks in measuring image processing it is of essential importance how imaging of light-sensitive pixels is realized on frame grabbers . Such a measurement is realized by moving the spot image mentioned in item 3 over the whole matrix along the rows or columns and by interpreting the CCD video signal and the occupation of the frame grabber memory simultaneously (see figures 1Ø; 11)

On the figures (1Ø; 11) you can see that not all light-sensitive pixels of the matrix were imaged on to the frame grabber memory.
Additionally a displacement of the geometric centre of the matrix relatively to the memory centre occurs on such an image.

In imaging pixels on to the frame grabber memory the operating mode (pixel-synchronous, non-pixel-synchronous) is of great importance.

From the non-pixel-synchronous operating mode it follows that a single pixel irradiated in accordance with the method described in item 3 statistically can occupy several adjacent memory locations of a row in the frame grabber memory.

Furthermore in the non-pixel-synchronous mode the space between two matrix pixels can be imaged differently within a row of the frame grabber memory.

That means, in the extreme case a circle imaged optically on to the matrix can appear on the frame grabber as an ellipse. Pixel-synchronous mode excludes effects of such kind and thus ensures an image pick-up true to the geometry. This is an unavoidable condition for measuring image processing [2].

During the investigations of the pixel synchronism the following essential feature of frame grabbers becomes obviously.

The analog channel located in the input unit of the frame grabber causes a type-specific smearing of spot or edge images within a row of a frame grabber memory over several pixels (figure 12, figure 13).

5. QUALITY OF FRAME GRABBERS' VIDEOSIGNAL INPUT CHANNELS

In the videosignal input channels of every frame grabber analog amplifiers, clamping stages, reference power supplies and analog-to-digital converters (ADC) are installed which are necessary for converting videosignals into a digital image. Within this process additional errors are joined to the videosignal which are caused by the real properties of the mentioned components:

- All analog circuits are noisy and thus add a non-correlated failure part to the signal.
- Amplifiers have an additional bandwidth and slew rate limitation and thus falsify signal dynamics and even signal shape.
- ADCs have non-linear characteristics which are difficult to describe and besides that are influenced by the signal change velocity.
- ADCs also add noise to the signal which cannot be defined by means of the simple distribution function of the amplifier's noise .

Quality measurement should be best done in complex: instead of the videosignal a testsignal is supplied which goes through the channel till storing the digitized signal image in the memory, and in the following interpretation of the digital signal differences between (a priori known) the features of the analog testsignal and the digital image are identified as errors of the channel.

Measuring methods are of a great variety and generally not able to identify all possible errors in the same manner well and to describe them in the form of error parameters. That is the reason why generally different tests have to be done in order to get a complete as possible picture of the real performance of the videochannel. Even in the last years a considerable number of papers has been published on this topic, and we have been engaged intensively in testing such measuring methods, too (see /3/, /4/).

Unfortunately, till now it has'nt existed any standard for carrying out such measurement uniformly. At present only in the field of general purpose digitizer channels (e.g. inside electronic measuring instruments) such a proposal is elaborated which will not contain a reference to video-typical signal features. One reason for this is that time-periodical black level clamping stages usually applied in video channels prevent the usage of sinusoidal signals as testsignals. But such kind of signals is the most suitable because it is a test-signal which can be generated easily, is of high quality and can be described in simple mathematics. Thus only two ways are open:

1. variant: The influence of the clamping stage in itself is considered as inessentially. If it is possible to eliminate clamping (at least temporary) and thus to generate the wished operating point on the ADC methods based on a sinusoidal signal, however, could be used. This way also ensures the comparability of the results with the typical data sheet values given by ADC producers (signal-to - noise ratio, to differentiate non-linearity).

2. variant: Special video-test signals with an enclosed reference level are used as a test-signal. Highly precise generation of such signals is expensive and, in any case, requires signal sources which are not available in any laboratory. It exists only a small number of known interpretation methods and they are far away from arriving the evidence of the above mentioned methods (to differentiate gain, to differentiate phase).

Measurement of the existing input channels of frame grabbers is certainly not an academic pastime, even this area is lagging behind in its progress. Who of the frame grabber producers generally gives any quality parameters of its frame grabbers? Furthermore, on the base of such measurement it becomes possible to improve future frame grabbers or to distinguish suitable ones from non-suitable ones.

Still a few words about a consideration of selected error properties. While in general video technology a limitation of the frequency path of video channels even is required, in measuring image processing using the pixel-synchronous sampling mode this leads to horizontal edge smearing which are by no means wished. You need such a high bandwidth (and slew rate) that the videosignal will not be falsified additionally to the width of the edge junction given by the optics. Unfortunately, noise will increase at a high bandwidth but, it should'nt be more than the noise of the optical signal and the "quantization noise" of the ADC. Frame grabbers with only one amplifier stage will meet this requirement better than those with more or even programmable amplifier stages. Besides that video ADCs used in frame grabbers differ in their properties. Till now ADCs made in bipolar technology have dominated over the CMOS types. With the trend to place more and more circuit elements into the video ADC (reference power supplies, amplifiers, clamping elements, output look-up tables) extremely complex devices will come into being which must not be better in their performance than devices of a lower integration step (an example is the BFP frame grabber with a Brooktree ADC).

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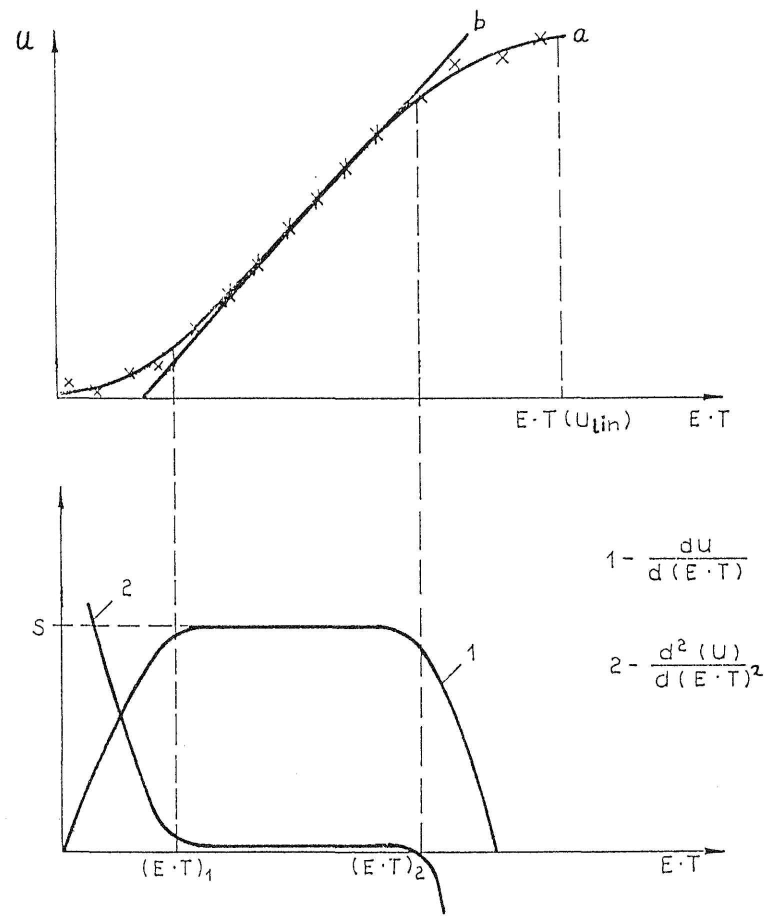
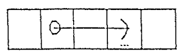


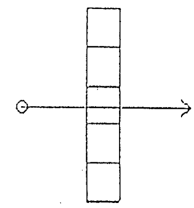
Figure 1 Principle of the method for describing the linearity error of CCD elements

Top figure: x - real measured values
a - polynom belonging to it
b - row adapted to linearity behaviour

Bottom figure: First and second derivation of the polynom and the quasi-linear range



- sampling directions
- CCD pixel sizes according to the producer's data (13 μm * 13 μm)



Line type WF

λ = 550 nm

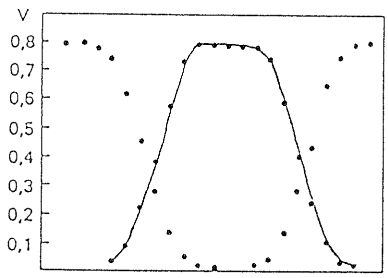


Figure 2a

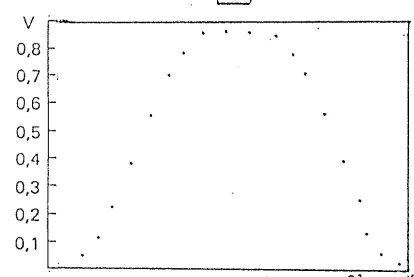


Figure 2b

λ = 626 nm

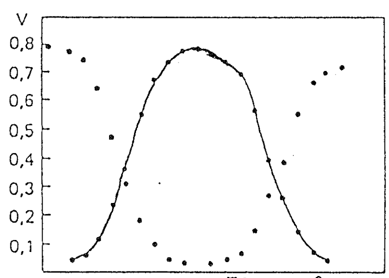


Figure 3a

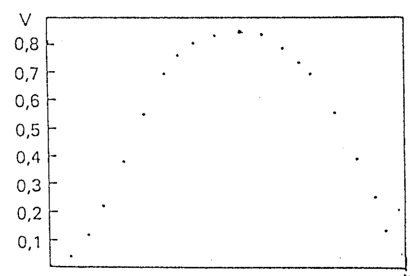


Figure 3b

Line type F 89

λ = 550 nm

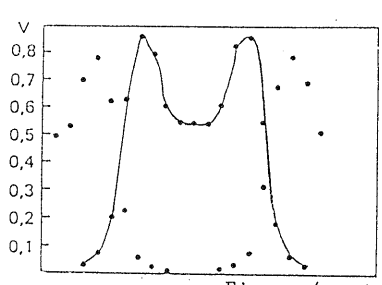


Figure 4a

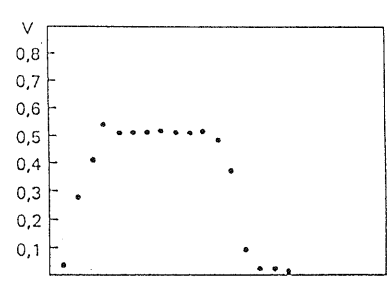


Figure 4b

λ = 626 nm

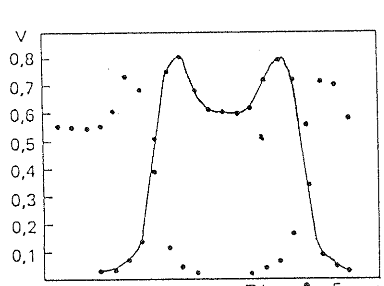


Figure 5a

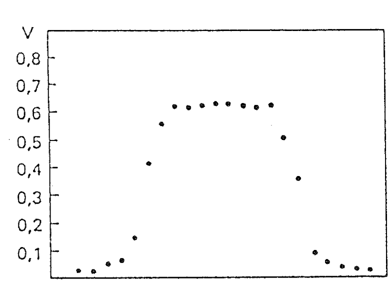


Figure 5 b

Line type F 79

λ = 550 nm

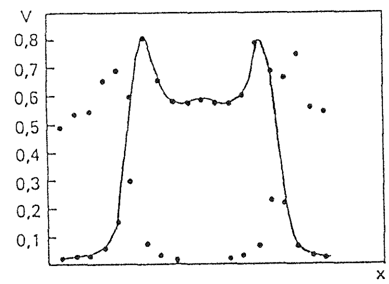


Figure 6a

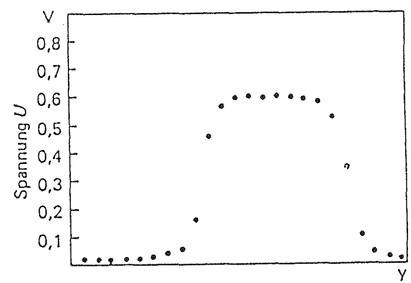


Figure 6b

λ = 626 nm

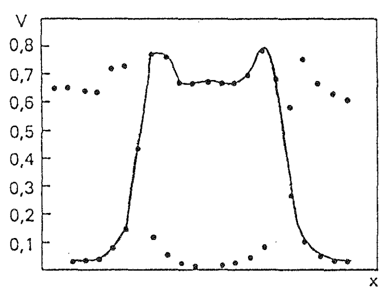


Figure 7a

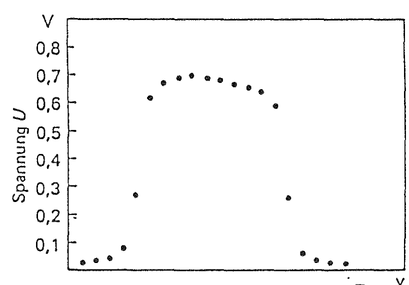


Figure 7b

Schematic representation of pixel junctions

λ = 55Ø nm

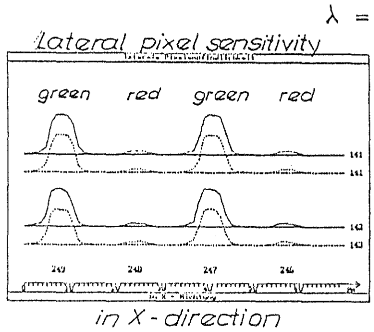


Figure 8a

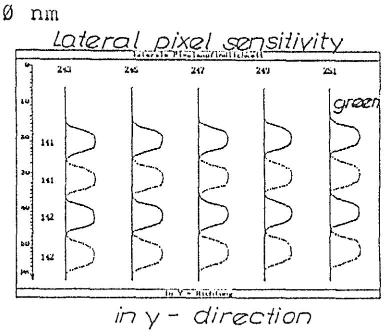


Figure 8b

λ = 626 nm

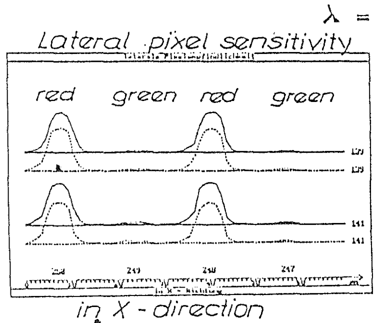


Figure 9a

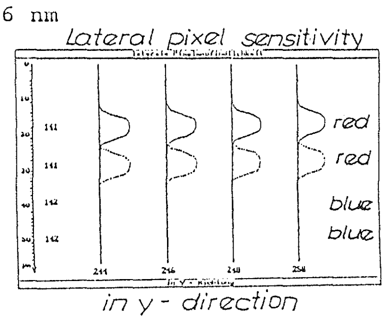


Figure 9b

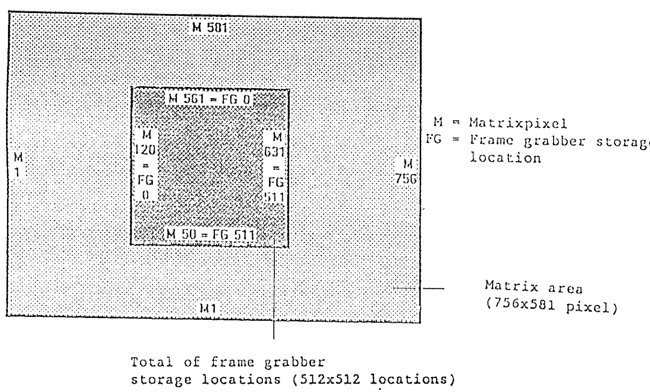


Figure 10: Position and number of matrix pixels accepted in the frame grabber memory

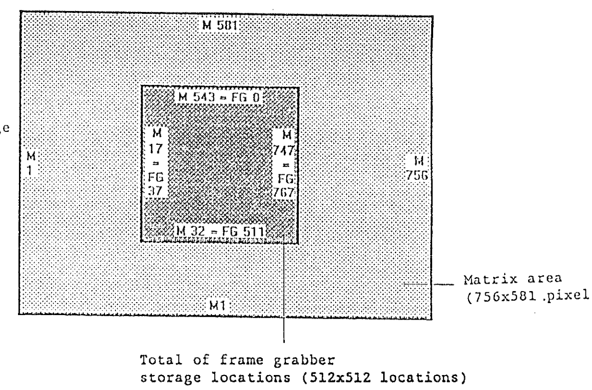


Figure 11: Position and number of matrix pixels accepted in the frame grabber memory

Frame grabber type 1

	Column :	226	227	228	229	230	231	232	233	234	235
Row :	272	9	11	11	11	10	12	5	7	9	10
	273	7	8	9	86	235	40	21	18	14	11
	274	10	10	9	9	11	9	8	10	9	7

Figure 12 Spot image smearing of a matrix pixel within a frame grabber row (frame grabber type 1; representation in grey values)

Frame grabber type 2

	Column :	368	369	370	371	372	373	374	375	376	377
Row :	254	1	2	2	2	2	1	2	1	2	2
	255	1	13	79	64	31	16	8	4	3	2
	256	1	1	1	2	1	1	2	2	2	2

Figure 13 Spot image smearing of a matrix pixel within a frame grabber row (frame grabber type 2; representation in grey values)