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Characterization of a system for digital ultra-high speed recording

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A system for digital ultra-high speed recording consists of the Imacon 790, ultra-high speed electronic converter camera, a video camera and personal computer with a video board. The paper shows the procedure for system characterization including dynamic range, linearity and dynamic spatial resolution. The characteristic curve of the video camera is determined through calibration. Verification of the video camera resolution and evaluation of the video system linearity are performed.

Key words: **ultra-high speed camera, video camera, dynamic range, dynamic spatial resolution, characteristic curve.**

Used marks and symbols

D – optical density
T – transmission
n – number of line pairs per millimeter registered by a system for digital recording (lp/mm)
n_{test} – number of line pairs per millimeter on the test chart (lp/mm)
n_{US} – number of line pairs per millimeter registered by the Imacon camera (lp/mm)
k – image/object reduction factor
o – object hight (mm)
l – image hight (mm)

Introduction

THE Imacon 790 ultra-high speed converter camera (US camera) is used for recording high speed processes or transient events in the fields of ballistics, detonics, electrical discharge, corona, plasma, laser emission, photo chemical kinetics, impact, fracture, fluid mechanics, aerodynamics, etc. Records are used for qualitative and quantitative phenomena analyses. Up to now images were recorded on a high speed film. For data acquisition and further analysis records were subsequently digitized [1]. The digital recording technique gives images in a digital form during recording [2]. This technique has been successfully applied in plasma recording and investigation [2,3,4], as well as in initial experiments in detonics physics. In consideration of future use of this technique as film substitution it was necessary to determine characteristics of a system for digital recording. In this paper the obtained results are shown and compared with film characteristics.

System for digital recording

The Imacon 790 is an electronic converter camera with a high light gain [5]. Image is formed on the output phosphorus screen P11 with a persistence of 80 μs. In the framing mode, 8-16 successive frames arranged in two rows are produced on the screen. In the streak mode, time continual record is formed on the screen. Up to date images were recorded on the high-speed Polaroid film type 667 or type 47 placed in direct contact with the Imacon output screen. Due to a lack of films and need for digital recording, a system for digital recording was developed, including video camera, personal computer and video board [2]. The video camera is placed on a support bracket mounted on the Imacon. The camera is optically coupled to the Imacon output screen and together with the screen fitted inside a dark chamber at the back of the Imacon. The video camera is Mintron model OS 45 D with the characteristics: TV standard - CCIR; scanning system: 625 lines, 25 frames/s; picture elements: 795 (H) x 596 (V); geometric linearity: no camera distortion; resolution: 600 TV horizontal lines; gamma correction: 0.25, 0.45 or 1. A black and white video camera is used for two reasons: 1. image on the Imacon output screen, which is recorded, is monochromatic; 2. a monochromatic camera has better characteristics than a color camera (higher resolution, better signal/noise ratio and higher sensitivity and contrast) [6].

The video camera works in the standard TV mode – interlaced mode, in which a picture (frame) is formed by alternative displaying of two fields. Because of a short camera sensor exposure, image from the Imacon output screen is shown in one field only. The consequence is a halved number of effective TV lines in the recorded image. Exposure duration of the video camera sensor is not critical and short light exposure is possible at any moment during the framing period without decay of information [7].

An analog output signal from the video camera is fed to the miro VIDEO DC30 video board. The video board performs digital processing of input signals and storage of digitized data into the memory. A film processing software is used for further data manipulation.

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Experiment set-up

Verification of the video camera resolution, evaluation of the video system linearity and determination of the video camera characteristic curve are made by the use of the Teletest chart set [8]. The set consists of four standard test cards for all color and monochrome video system testings. In our experiment three cards were used (the fourth one is intended for color cameras):

1. the resolution chart – test chart for use in checking video system resolution. The chart consists of sets of converging vertical and horizontal lines, and numbers at the sides of the resolution wedges refer to the number of TV lines resolved at that point. The converging black and white lines in appropriate chart areas are observed. A value at which lines become indistinct is read and that number defines limiting resolution of the video system;
2. linearity chart - test chart for linearity i.e. shape distortion evaluation. The chart consists of a rectangular grid of black lines on a white card with circles in the centre and corners;
3. grey scale test chart (Fig.1) – test chart for black and white video camera calibration. The chart consists of two optical wedges – two arrays of nine neutral grey patches with known optical density values *D*, shown in Table 1.

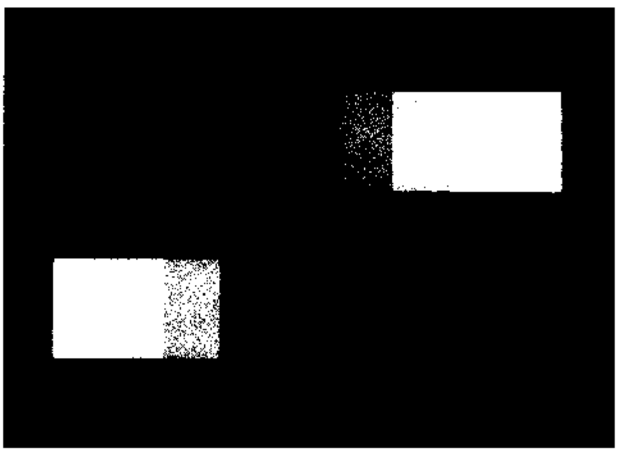

Figure 1. Grey scale test chart

Table 1. Optical density of the tele–test grey scale

Segment	Optical density
1	0.22
2	0.32
3	0.43
4	0.56
5	0.70
6	0.87
7	1.08
8	1.34
9	1.70
Background	0.80
Black patch	2.25

By the use of this chart the video camera characteristic curve is obtained, necessary for nonlinearity introduced by video camera to output signal elimination, what is particularly important in quantitative analysis. The video camera transfer characteristic is a dependence diagram of the camera output, expressed in terms of grey scale levels of optical wedge segments on the camera recording, as a function of input intensity, determined by optical densities of relevant wedge segments.

For these three tests the video camera is mounted on the camera stand model RF 25410, manufactured by KAISER, USA, equipped with four lamps. The camera is used with a blue filter to simulate the light emitted by the Imacon output screen phosphorus P11. The video camera is used with the following parameter settings: γ correction 1; automatic shutter speed off; automatic gain control –AGC off.

Characterization of the digital recording system includes determination of dynamic range, linearity and dynamic spatial resolution of the system. During these measurements the video camera is mounted on the support bracket at the back of the Imacon camera for the optical coupling with the US camera screen.

The measurement of the system dynamic range and linearity is made simultaneously and refers to the transfer characteristic relating input optical power or intensity to the output of the video camera. Dynamic range is the measure of the maximum span between the measured maximum and minimum signal levels achievable under linear input-output characteristics. The Imacon camera is used with the streak optics and the vertical slit. The image of the streak slit illuminated with flash unit falls on the photochatode. Neutral density filters – ND, inserted in front of the Imacon camera objective, are used for input optical power change. The Imacon camera works in the framing mode. The output image containes 8 frames with the vertical light strip – the slit picture. The delay generator is used for synhronization between the Imacon camera and the flash control unit; the camera is triggered 70 μs after the flash. The input intensity level, as relative, is represented in a form of the filter.optical density. The output intensity, as a grey scale level, is determined by digital image analysis. On the diagram representing the output intensity level as a function of the optical density of the filter – *D*, linearity range is observed and dynamic range calculated.

Spatial resolution of the system is determined by the use of the transparent resolution test chart (Fig.2) with known black and white lines densities, i.e. number of line pairs per millimeter (lp/mm) - n_{test}, depicted on the same figure. The resolution test chart is placed in front of the lamp window. The US camera is adjusted so that the chart image fills the screen. The Imacon camera records the flash of the lamp.

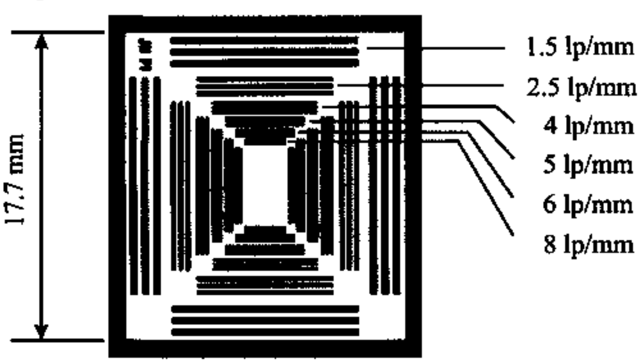

Figure 2. Resolution test chart

The US camera is triggered by the delay generator 70 μs after the flash control unit. Spatial resolution is measured for both modes of US camera – framing and streak. Maximum resolution for each used camera unit is determined. The experimental set-up for spatial resolution measurment is schematically presented in Fig.3.

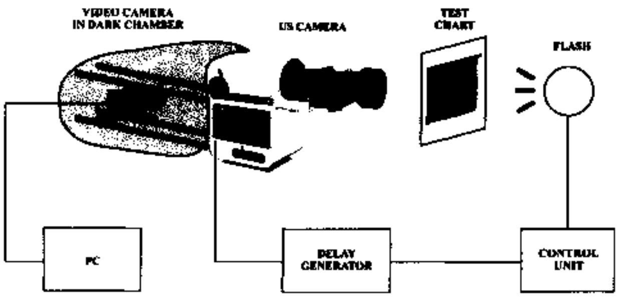

Figure 3. Experimental set-up for spatial resolution determination

Results

Verification of the video camera resolution is performed by the resolution test chart recording with the camera Mintron and by visual control of the camera output on a 17 " monochromatic monitor with 800 TV lines horizontal resolution. 600 TV lines resolution is confirmed through the observation of distinct black and white lines on the vertical edges.

By means of the linearity chart recording, preservation of black lines grid linearity is established, as well as the fact that the video camera does not introduce shape distortion.

The video camera characteristic curve is obtained by the grey scale test chart recording and the grey scale levels of the optical edge segments measurement on the record. Expanding of the input intensity range is archieved by the use of three video camera apertures, considering that change of one f- stop equals to 0.3 optical density increment. For F22, the optical densities shown in Table 1 are used. The closing of camera aperture for one f-stop is achieved by adding the 0.3 optical density ND filter in front of the camera objective; this corresponds to the optical density increases for 0.3. For F16, the optical density decreases for 0.3. For optical density values D shown in Table 1 and the given recording conditions, the input intensity is expressed by means of the optical edge segments transmission determined from relation (1):

$$T = \frac{1}{10^D} \tag{1}$$

The video camera grey scale level denotes output quantity.

The video camera characteristic curve is shown in Fig.4 in the lin-log coordinate system. It is evident that the camera can be used over an intensity range of about 100. The segment of the transfer characteristic with linear change of the grey scale level as a function of T is shown separatelly in Fig.5 in the lin-lin coordinate system, with a linear fit line drown. The linearity of the characteristic exists at T range from 0.07 to 0.5 which corresponds to the camera dynamic range of about 5.

Dynamic range and system linearity were examined for framing units $1 \cdot 10^5$, $2 \cdot 10^5$, $5 \cdot 10^5$ and $2 \cdot 10^6$ frames/s. First, for each unit the lamp flash was recorded with the maximum Imacon aperture and without the filter. Then the ND filters were added in front of the Imacon camera objective untill a completely dark image was obtained; for each filter, a grey scale level value was measured from the record. The curve representing dependence of the registered grey scale level on the input optical intensity, expresed in terms of the filter optical density - D, was determined for each camera unit. Characteristic curves are shown in Fig.6.

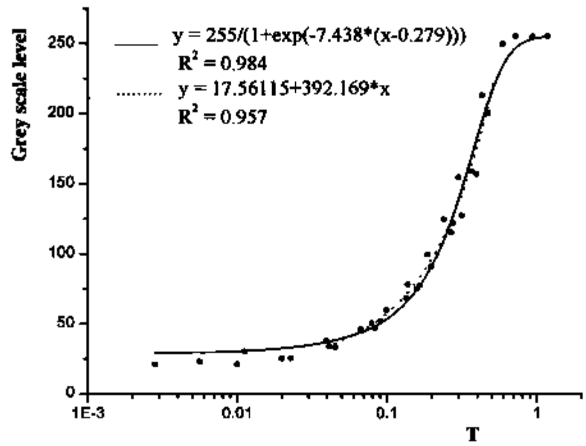

Figure 4. Video camera characteristic curve

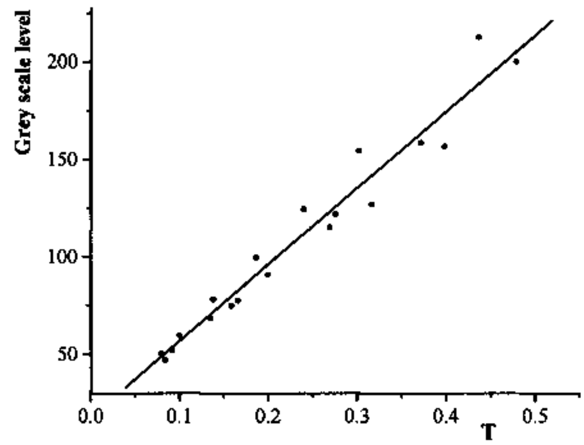

Figure 5. Linear part of the video camera characteristic curve

The dynamic ranges, based on the curves shown in Fig.6, are: 7.5:1 at $1 \cdot 10^5$ frames/s, 6:1 at $2 \cdot 10^5$ frames/s, 5:1 at $5 \cdot 10^5$ frames/s and 4:1 at $2 \cdot 10^6$ frames/s. The Imacon camera, according to manufacturer data, has the dynamic range with a maximum of 400:1 at 10^4 frames/s to a maximum of 50:1 at $2 \cdot 10^7$ frames/s achieved for a negative film under optimum conditions [9]. It can be noticed that the system for digital ultra-high speed recording, has a short dynamic range. This is the consequence of a narrow dynamic range of the video camera (Fig.5), which severely limits the overall system dynamic range.

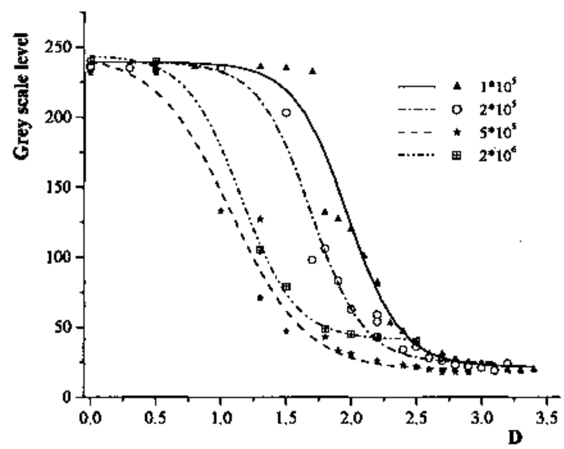

Figure 6. Dynamic range

Dynamic spatial resolution is determined as resolution on the Imacon camera photocathode. The following units were used for dynamic spatial resolution determination: framing $1\cdot10^5$, $5\cdot10^5$, $1\cdot10^6$, $2\cdot10^6$, $5\cdot10^6$ and $2\cdot10^7$ frames/s and streak – 10-100 μs/mm (streak speed 10 and 100 μs/mm), 1-10 μs/mm (streak speed 1 and 10 μs/mm), 100-1000 ns/mm (streak speed 100, 500 and 1000 ns/mm), 10-100 ns/mm (streak speed 10 ns/mm) and 1-10 ns/mm (streak speed 1 ns/mm). For each framing and streak unit, the maximum order of the distinct line pair on the resolution test chart, n_{test}, is determined. For n_{test} values shown in Table 2 the maximum resolution on the US camera photocathode which can be registered by the US-video camera system is determined from relation (2):

$$n=\frac{n_{test}\cdot 2}{k} \quad , \quad k=\frac{l}{o}. \qquad (2)$$

The coeficient k is calculated from the known test chart hight and the test chart image hight measured from the static record. In Table 2 the results of US-video camera system spatial resolution determination are shown. Data for the resolution on the Imacon camera photocathode according to the US camera manufacturer documentation are presented in the same table [9]. It should be emphasized that the values for n_{US} refer to a negative film which is more sensitive than a polaroid film.

Spatial resolution of the system for digital ultra-high speed recording is lower than the resolution obtained for a polaroid film. This is expected since, instead of a high sensitive film (3000 ASA) in direct contact with the screen, the video camera is used for recording the US screen from a certain distance (about 300 mm). Thus a digital system cannot register the same number of line pairs as a polaroid film. Moreover, the video camera quality also influences spatial resolution decrease.

Table 2. Spatial resolution of the US video camera system and the spatial resolution of the Imacon camera

US camera mode	n_{test} (lp/mm)	k	n (lp/mm)	n_{US} (lp/mm)
framing $1\cdot10^5$	2.5	0.787	6.35	10
framing $5\cdot10^5$	2.5	0.787	6.35	
framing $1\cdot10^6$	2.5	0.787	6.35	
framing $2\cdot10^6$	2.5	0.787	6.35	
framing $5\cdot10^6$	2.5	0.847	5.9	
framing $2\cdot10^7$	1.5	0.847	3.54	5
streak 10 – 100 μs/mm	4	0.842	9.50	12
streak 1 – 10 μs/mm	4	0.842	9.50	
streak100–1000 ns/mm	2.5	0.842	5.94	
streak 10 – 100 ns/mm	2.5	0.893	5.6	
streak 1 – 10 ns/mm	1.5	0.893	3.36	

Conclusion

In this paper the procedure for characterisation of the system for digital recording using the Imacon 790 ultra-high speed camera is described. The characteristics of the video camera, which serves as a film supstitution, are verified: horizontal resolution and linearity preservation i.e. no shape distortion. In relevant system characteristics determination, the obtained values are lower than those for film recording. This is the consequense of the video camera insufficient quality, the way of the image transfer from the Imacon screen to the video camera sensor, as well as the usage of 256 grey scale level luminance quontization (8-bits) during digital image processing. The obtained values were expected for previously mentioned reasons and they are in accordance with literature [10,11,12]. A professional video camera with a wider transfer characteristic range, which uses progressive scanning instead of interlaced mode and with direct coupling from the Imacon camera screen to the video camera sensor (e.g. fiber optic coupling) would represent a better film supstitution, with characteristics closer to those for film recording.

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Karakterizacija sistema za digitalizovano ultra-brzo snimanje

Sistem za digitalizovano ultra-brzo snimanje čine ultra-brza elektronska konvertorska kamera Imacon 790, video kamera i personalni računar sa video karticom. Prikazan je postupak za karakterizaciju sistema, kojim su određeni dinamički opseg, linearnost i dinamička prostorna rezolucija sistema. Kalibracijom video kamere određena je njena prenosna karakteristika. Izvršena je verifikacija rezolucije video kamere, kao i provera linearnosti video sistema.

Ključne reči: **ultra-brza kamera, video kamera balistika, dinamički opseg, dinamička prostorna rezolucija, prenosna karakteristika.**

Характеризация системы для цифровой верхбыстродействующей записи

В состав системы для цифровой сверхбыстродействующей записи входят: сверхбыстродействующая электронная преобразовательная камера "Imacon 790", видеокамера и вычислительная машина со видеоплатой. Здесь показан поступок для характеризации системы, которым определены динамический диапазон, линейность и динамическая пространственная резолюция системы. Калибровкой видеокамеры определена ее кривая характериситики. Тоже сделана верификация резолюции видеокамеры и контроль линейности видеосистемы.

Ключевые слова: **сверхбыстродействующая камера, видеокамера, балистика, динамический диапазон, динамическая пространственная резолюция, кривая характериситики.**