Optica Applicata, Vol. XIX, No. 2, 1989

CCD scanner element in some optical measurements*

Z. Chorvatova, T. Furda

Department of Experimental Physics, Faculty of Mathematics and Physics of the Comenius University, Mlynska dolina, 842 15 Bratislava, Czechoslovakia.

The program-controlled camera based on a CCD scanning element senses the optical signal which is then digitalized and stored in the computer memory, displayed on the monitor and treated with the aid of suitable programs. The camera can be utilized in the studies of optical phenomena where information on the cross-section of the optical image is sufficient, e.g., in most of the diffraction and interference phenomena, as well as in spectroscopy.

1. Introduction

The use of computer technology for contemporary experiments in optics is inevitable. For the control of the experiment, registration of the image and treatment of the optical signal, the use of a camera based on CCD (Charge Coupled Devices) is of some advantage [1].

2. CCD camera

We had the opportunity to use the CCD TS 110 scanner (made by Tesla, Piestany) composed of 256 light-sensitive elements (13 by 13 micrometers) in a two-register configuration. The control impulses for the CCD element were generated from the clock pulse of the PMD 85-2 microcomputer. The CCD output signal is adjusted in the camera output circuits and in this way a digitalized analogue signal is produced [2].

The speed of processing the image signal sample is 40 kHz. This speed was chosen with regard to the requirement according to which the storage in the memory should be accomplished in real time. The analogue-digital converter is 8-bit, the conversion of one light-sensitive cell takes 8 microseconds and the theoretical accuracy of conversion is 0.54%.

The camera has the possibility to change the operating regime with the aid of the computer and to set in this way the optimum regime for the given optical experiment. The accumulation time (the time needed for charge integration and for reading the videoregisters) is set by the program, the minimum value being 9.5

---

* This work has been presented at the VIII Polish-Czechoslovakian Conference, Szklarska Poręba (Poland), September 13–16, 1988.

milliseconds. Higher values, if desired, may also be set, but then the sensor noise occuring during the registration must be taken into consideration.

The so-called pair–impair effect caused by the different characteristics of input circuits treating the signals produced in two videoregisters was eliminated in the camera.

The camera is controlled with signals started by the computer with a program written in machine code. The videosignal which is read by the control program and stored in the computer memory with the aid of the converter, is at the same time displayed on the screen. It can be stopped at any time and the values of the last recording remain stored in the memory.

The software package comprises also a program written in machine code which makes the storage of any number of readings (limited only by the capacity of the memory) possible. A program written in BASIC which deducts the values of parasitic noise from the results obtained by measurement and draws the registered optical signals may be also used. The above-mentioned standard software pack contains also programs for the evaluation of individual optical measurements (interference of two or more bundles, measurements of the wedge layer angle, of the Gaussian section of optic bundle, etc.).

It is evident that the software may be completed with new programs regarding the scanning and processing of other optic signals, e.g., spectra including Fourier's trasformations and also other methods.

3. Results

Some samples of scanning basic optic phenomena which do not require a flat CCD scanner, but for which a sequential CCD element is sufficient, are shown. Figure 1 shows the interference bundles produced by the reflection from a wedge glass plate.

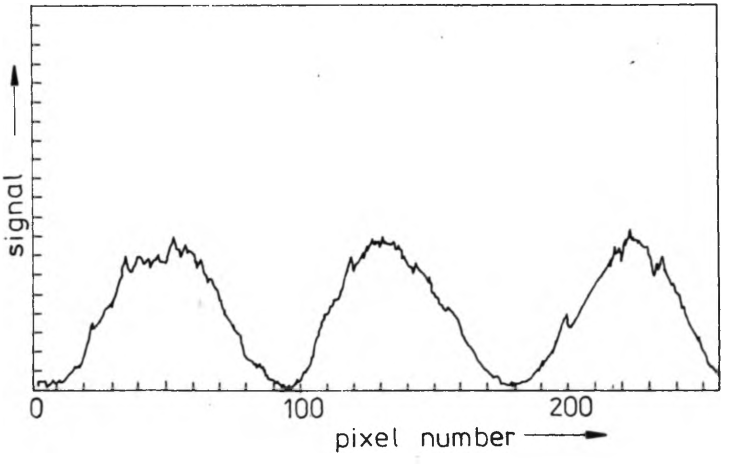

Fig. 1. Wedge interference

The wedge angle can be calculated from the signal, but this procedure requires the determination of the localization of maxima and minima, respectively. Both courses, being not identical, must be approximated with a theoretical function. The most convenient is the approximation using the method of least squares with a function describing the division of intensity I in the interference image

$$I = I_0 \frac{\sin^2\left(N\frac{\varphi}{2}\right)}{\sin^2\left(\frac{\varphi}{2}\right)} \tag{1}$$

where N is the number of interfering bundles, their phase difference, and I_0 the constant of proportionality related to the maximum intensity. As in our case the interference is a two-boundle one, the relation (1) can be also written as

$$I = 4I_0 \cos^2(\varphi/2). \tag{2}$$

The determined correlation is the function $I(x)$, i.e., the dependence of intensity on the position x of the CCD element. Since the scanned image cannot be exactly positioned into the defined coordinates, its description by a direct theoretical function is not possible. Therefore, vertical (Q_0) and horizontal (T) image shifts and the theoretical function

$$I = Q_0 + 4I_0 \cos^2 \frac{m_0(x+T)}{2} \tag{3}$$

must be considered, m_0 being the transform constant at the transformation $x \to \varphi$. The approximated values superimposed over the measured values are shown in Fig. 2.

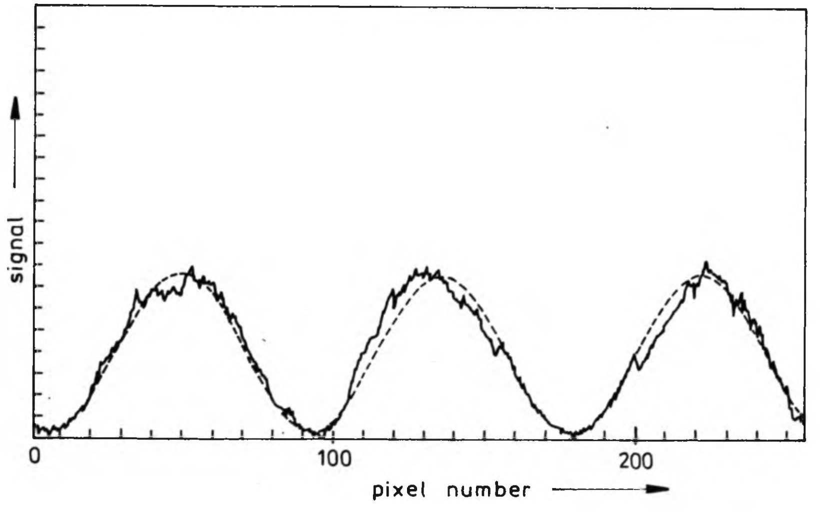

Fig. 2. Wedge interference and approximation

The approximation program is completed with a program for the calculation of the wedge layer angle on which the interference takes place.

Figures 3 and 4 show Fraunhofer's and Fresnel's diffractions on circular aperture, respectively. Similarly as in the case of evaluating the interference phenomena, also these values obtained by measurements can be superimposed over the theoretical

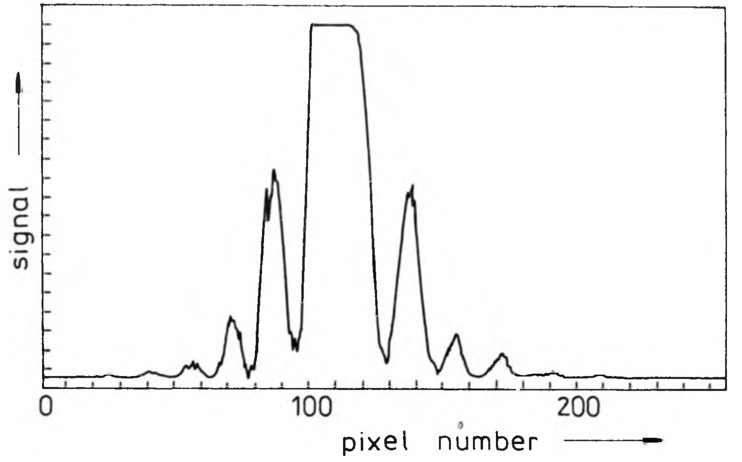

Fig. 3. Fraunhofer's diffraction on circular aperture

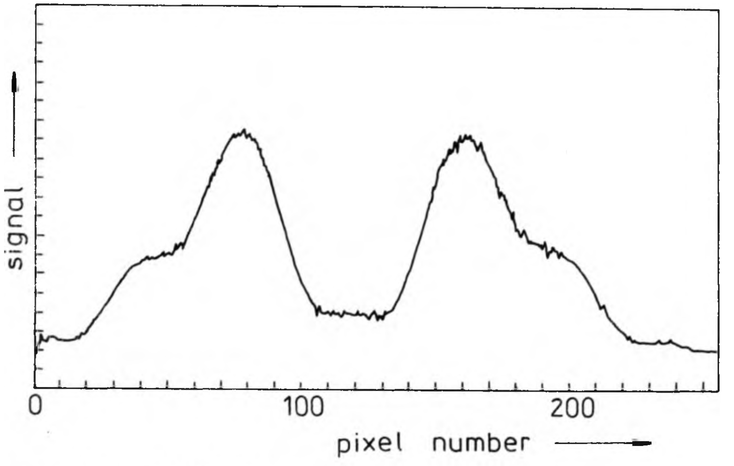

Fig. 4. Fresnel's diffraction on circular aperture

curve. In this way, by analysis of this curve, the variables can be computed with the aid of a program. By showing the samples of diffraction we would like to stress that in scanning diffraction effects the zero maximum is usually supersaturated. The reason is that the dynamic range of the CCD element does not allow us to display both of these maxima at the same time, because of large differences between the intensity of the zero and first maxima. (In the case of the sample in Fig. 3, the CCD element is not located in the middle of the diffraction image.) In case of scanning the maximum diffractions of higher order with the CCD element located in the middle of the diffraction image, the zero maximum should be significantly supersaturated. In this situation, however, there occur a large accumulation of charge in the CCD elements as well as a passage through the potential barriers, demonstrated by the dissipation of the charge among individual cells. This is illustrated in Fig. 5 which was taken at the diffraction by the slit.

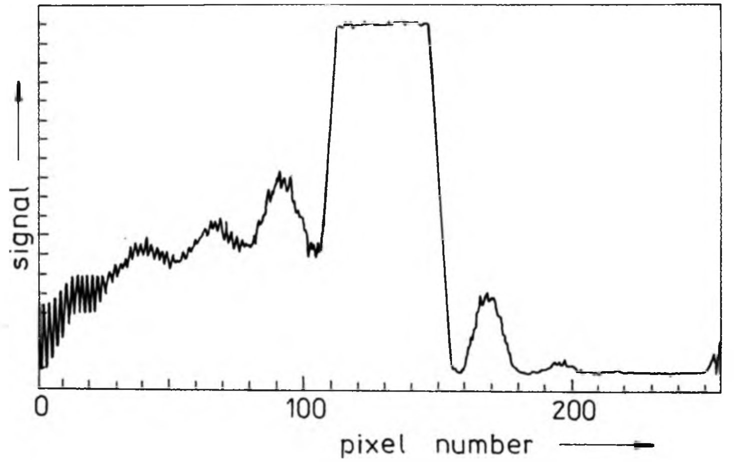

Fig. 5. Fraunhofer's diffraction by the slit at significantly supersaturated zero maximum

When scanning diffraction phenomena, the CCD element must be placed so that it dissects the produced diffraction rings exactly in the middle (to avoid a distorted image of their diameters), and at the same time the supersaturation of zero maximum must be avoided. This can be achieved by decreasing the intensity of the light bundle with the aid of a polarizer. The CCD detector is then placed in the position with the maximum intensity value of zero maximum. After the polarizer is removed, the program enables us to calculate, for instance, the distances of mutually corresponding diffraction maxima or minima of even higher orders.

The other samples (Figs. **6a** and **b**) show the recordings of interference fringes produced by the interference of He-Ne laser radiation in Michelson's interferometer, in which the screen was replaced by a CCD detector. We have registered images in two wavepath differences (18 images each) which in time immediately followed one another, the scanning time of each being 48 milliseconds.

Figure **6a** shows 6 readings taken at a path difference of $\Delta l = 2$ cm. Figure **6b** shows the same images at a path difference of $\Delta l = 46$ cm. The contrast V was calculated from the values obtained by measurements with the aid of the well-known

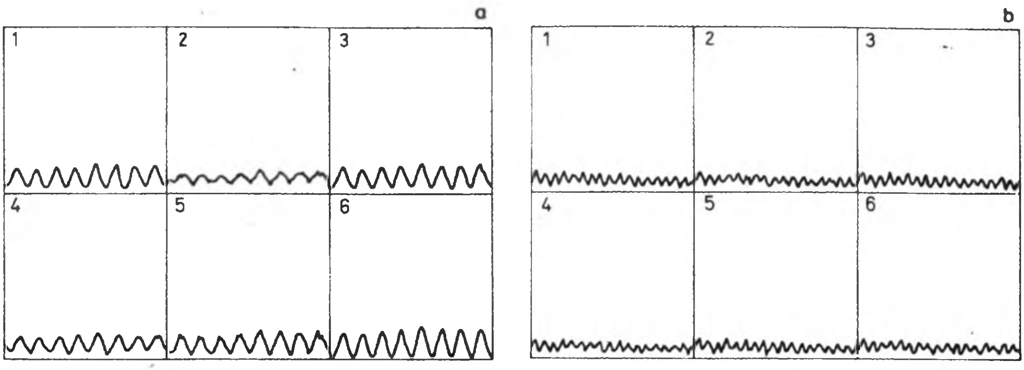

Fig. 6. Interference fringes in Michelson's interferometer at a path difference of: $\Delta l = 2$ cm (**a**) and $\Delta l = 46$ cm (**b**). Depicted are 6 recordings

relation

$$V = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \tag{4}$$

where E_{max} and E_{min} are the illuminations in the interference maximum or minimum, respectively.

The V dependences for individual readings are shown in Fig. 7. It can be seen that the contrast V is larger in the case of a smaller wavepath difference of bundles.

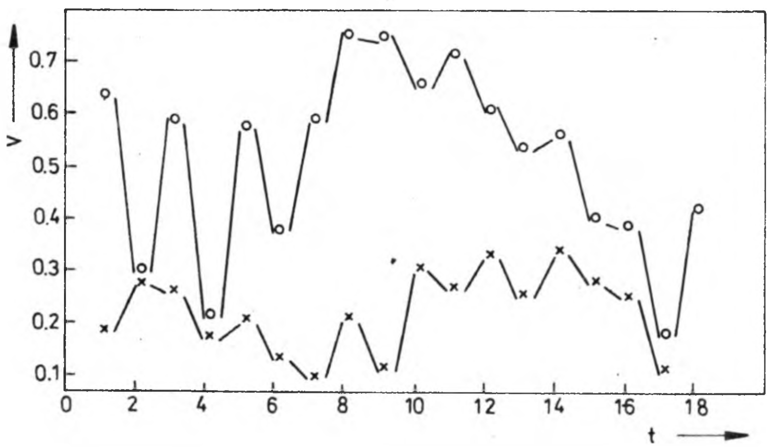

Fig. 7. Contrast (V) time change of interferograms in Michelson's interferometer in 18 consecutive recordings (one recording takes 48 milliseconds) at $\Delta l = 2$ cm (o) and $\Delta l = 46$ cm (+)

A large dispersion variance in values obtained by measurements, which are due to certain reasons, is also significant. It is obvious that the CCD camera reacts very sensitively to the fluctuations of the interference image as well as to the fluctuations of the contrast V. For this reason, in order to gain the possibly most accurate information, new mathematical methods must be applied in the evaluation of the results of such measurements.

We have also studied experimentally the radial distribution of intensity in the cross-section of He-Ne laser bundle in a plane perpendicular to the bundle axis (Fig. 8).

We have merged the Gaussian function with the signal (Fig. 9) that helps us to evaluate the extent to which a Gaussian section laser bundle can be generated.

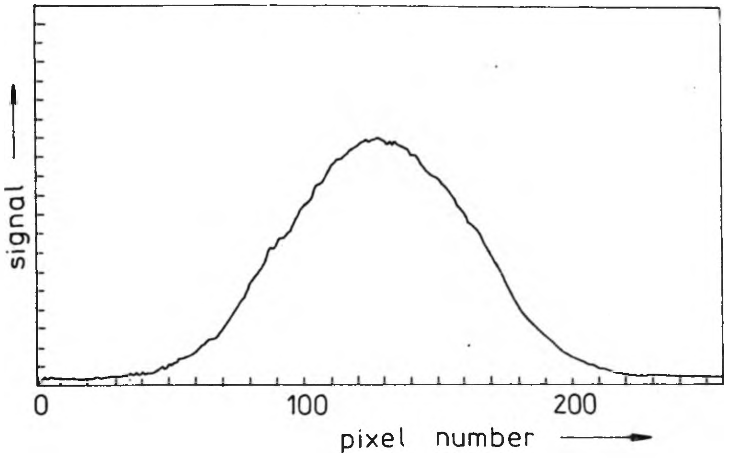

Fig. 8. Radial intensity displacement in the He-Ne laser bundle cross-section

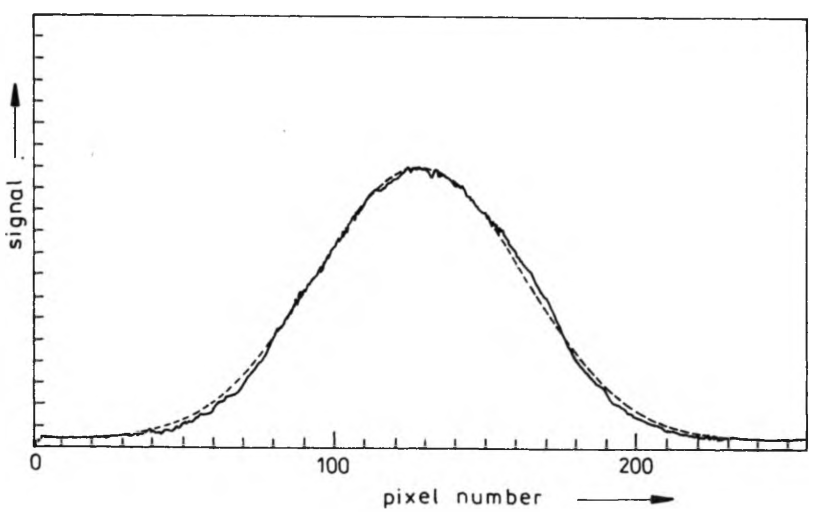

Fig. 9. Comparison of the signal from Fig. 8 with Gaussian course

4. Conclusions

We have scanned some elementary optical phenomena with the aid of a camera based on a CCD scanning element. We have been able to show that the CCD camera enables the evaluation of optical signals with the aid of suitable programs and that it is its largest advantage. The optical measurements are performed faster and in some cases also more accurately. When using a CCD camera for scanning, a very sensitive registration of all instabilities and inaccuracies of the equipment must be taken into account. This presents not only a possibility but in some cases also the necessity of studying the possibility of producing new methods for the evaluation of optical signals.

The characteristics of the camera designed by our team can be improved in some ways. One of them is to increase the accuracy of the conversion by using a fast analog-to-digital converter of 12 or more bits as well as to use a more sophisticated programming language and a computer with a larger memory.

References

[1] BARBE D. F., Proc. IEEE **63** (1975).
[2] STRBA A., FURDA T., CHORVATOVA Z., PANCIK J., [In] 6th Federal Conf. *Lasers in Research and Industry*, Rackova dolina (Czechoslovakia), October 1988.

Received September 19, 1988

Использование линейного элемента с зарядной связью (CCD) для некоторых оптических измерений

Камера на основе линейного элемента с зарядной связью, управляемая посредством программного обеспечения, снимает оптический сигнал, производит его дигитализацию, укладывает его в память вычислительной машины, переводит на монитор и обрабатывает при помощи подходящих программ. Можно ее использовать для изучения таких оптических авлений, где достаточна информация о сечении оптических картин, напр. при большинстве дифракционных, интерференционных явлений и в спектроскопии.