SPECTROPOLARIMETRIC VIDEO SYSTEM FOR OPTICAL INVESTIGATIONS OF THE ATMOSPHERE

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Computer–controlled spectropolarimetric video system has been developed for investigations in atmospheric optics. This system allows one to obtain polarized images of objects formed by scattered optical radiation in passive and active modes. The receiving optical system comprises a set of changeable lenses with the angular apertures from 2 to 100 degrees. The photoreceiving modules form four optical channels on CCD matrices and on a supervidicon for low signals. The spectral intervals are isolated with a set of bandpass filters. The time–dependent signal structure is analyzed in the optical channel with a PMT as a detector. The system comprises a Nd:YAG laser equipped with a beam decollimator. The system control, data processing, and construction of the polarimetric images are being done with an IBM PC/AT.

1. INTRODUCTION

The development of devices for atmospheric optics investigations has attracted an increased interest due to the necessity of monitoring the dynamics of atmospheric processes and estimating the influence of various factors on the environment. The above-mentioned problem and other similar problems involve many parameters. Solution of these problems needs for investigations using devices for parallel recording of information about a combination of indications on contribution from different effects of the interaction of optical radiation and the atmosphere. Thus, for remote control of natural object parameters the use of scattered optical radiation as a source of information appears to be effective only if synchronous recording and analysis of its angular, spectral, polarization, and temporal structures is provided.

Such complex distributions of scattered radiation field appear to be more sensitive to physico-chemical and structural changes of investigated objects compared to their usual images representing an angular distribution of intensity.[1–3] In such cases the air, its gas and aerosol components, the interface, water surface layer, cloud and ground covers may be the objects of investigation.

The Institute of Physics, the Central Design Office and EP of the Academy of Sciences of Belarus have developed the computer–controlled polarimetric system (CCPS) for investigations in atmospheric optics. This system allows one to obtain complex images of the investigated objects formed by scattered optical radiation taking into account its polarization.

2. DESCRIPTION OF THE SYSTEM

Figure 1 shows the block diagram of the CCPS. The system comprises a photodetector PD, orientation device OD, data converter DC, power supply module PSM.

The receiving optical system OS comprises a set of changeable lenses with the angular apertures from 2 to 100 degrees and is equipped with polarization elements installed using a symmetric scheme. Optical system rearrangement with respect to the wavelengths is accomplished by bandpass spectral filters. The photoreceiving modules of the system form four optical channels on CCD matrices of FPPZ–1ZM type with the number of elements being 128×128. The nominal thermal regime of matrices is provided with a thermal regulator TR. Electronic module of PD comprises a level converter LC, a corrector C, a synchronous generator SG, modules of analog processing MAPs. The level converter produces continuous and pulsed control signals needed for CCD matrices. The MAP comprises a buffer amplifier, low–frequency filter, double-correlated sampler. The synchronous generator forms a sequence of clock pulses providing matrix videosignal formation. Videosignals from each of the four PD channels come to the data converter in which the analog–to–digital converters ADC_1–ADC_4 digitize input signal. RAMs allow the system to store four successive image frames from each channel. The data converter comprises module for extracting frame and string synchro pulses MESP and testing signal generator TSG. This allows any TV camera having a standard video–signal to be connected with the recording system.

To record the time behavior of a signal, an amplitude channel based on PMT FEU–84 is used. It also provides the triggering of recording system at the input of the signal reflected from the object investigated. It comprises the photodetector having the computer–controlled gain factor, synchro pulse generator SPG, measurer and subtracter of the background MSB, and signal gain comparators. PMT signal after subtraction of the background and amplification is converted with analog–to–digital converters ADC_5 and is put into RAM_5. To fix the starting point of the recording, either digital or analog comparators are used, the choice is performed by the computer. The time range of the signal recording is governed by the number of samples (1024) and variable frequency of sampling (maximum frequency is 10 MHz). The recording being finished, the synchro pulse generator produces corresponding signal and then comes to a storage regime.

The power supply module PSM comprises a thermal regulator module TRM, controlled–current generator CCG, optical calibration module OCM, stepper driver SD, high–voltage power supply HVPS for the PMT.

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The orientation device together with the steppers S_1 and S_2 provides the required orientation of PD assigned by polar θ and azimuthal φ angles. The steppers are controlled with the computer via the controller SC placed in DC. The orientation device design provides manual orientation of PD also. The control over the system is made using an IBM PC/AT via decoder D and PC controller PCC.

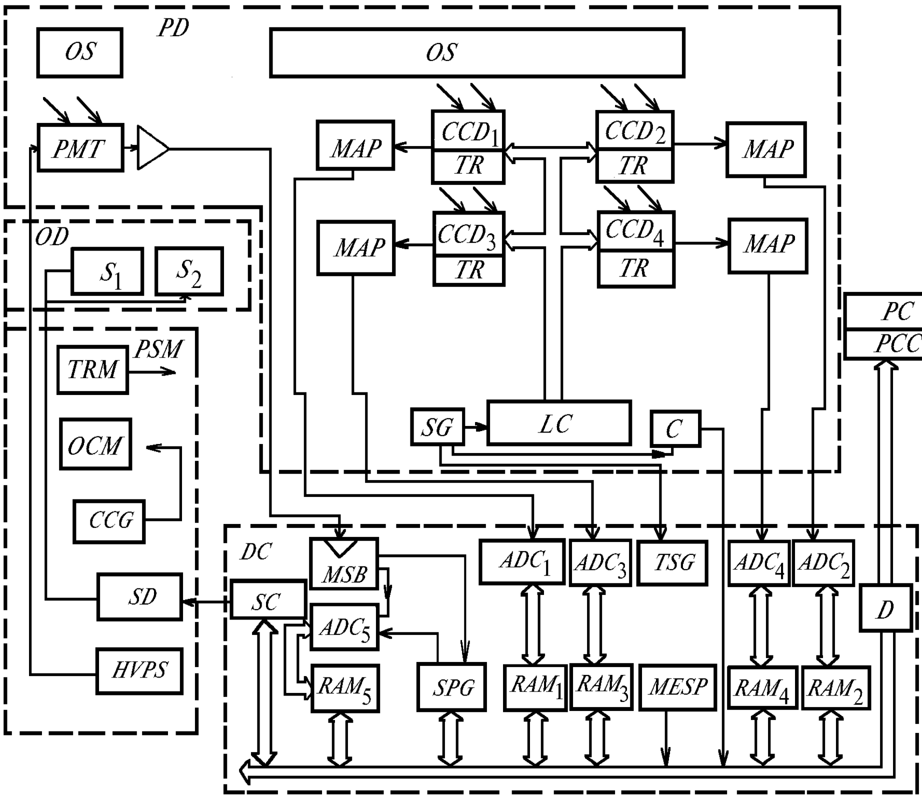

FIG. 1. Block diagram of the CCPS.

3. CAPABILITIES FOR REMOTE CONTROL

In the presence of sunlight and in passive mode the recording of the image is accomplished with the external triggering. In the pulse recording mode the image construction starts at the moment of triggering the system by the first quanta scattered by the object investigated.

To provide active irradiation, the system is equipped with a Nd:YAG laser and a beam decollimator having a wide range of angular apertures. The emitter is not mechanically connected with the recording system and those two taken together form a bistatic circuit. The area controlled with the system in nonstationary mode is of ellipsoid shape, in one focus of which there is an emitter while in the other one there is the recording system.

The size of the area under control substantially depends on the emitter power, photodetector sensitivity, and the value of the angular, spectral, and time intervals within which the signal accumulation is accomplished.

For low signals in the test system the recording system is equipped with the supervidicon which accomplish the reception (detection) when the illumination intensity is about $5\cdot10^{-3}$ lx. Each of the image elements (i, j) depending on the lens aperture determines the fixed sighting direction $(\theta_{ij}, \varphi_{ij})$. A system of coordinates used is connected with the photodetector. For the visual control of the size of the area investigated the sighting device connected mechanically with photodetector is used.

The distance l to the controlled volume along the direction $(\theta_{ij}, \varphi_{ij})$ depends on the distance d_e to the emitter, eccentricity ε of the ellipsoid, orientation η of its axis in the vertical plane and is estimated with t against the time scale

$$l(t) = (1 - \varepsilon)^2\, d_e / [2\varepsilon\, (1 + \varepsilon \cos \eta)]\,, \qquad (1)$$

where $\varepsilon = \varepsilon(\theta_{ij}, \varphi_{ij}, t)$ is found geometrically. The optical characteristics of the medium are estimated from the signals coming from the four matrix channels. This imposes enhanced demands on the mutual matrix orientation. Special orientation system provides unambiguity of spatial consistency of each element in all matrices with the accuracy of 0.5 element.

Polarization characteristics of the light scattered by an object at a symmetric analyzer is estimated from I_1, I_2, I_3, I_4 signals detected in each of the four channels. The intensity can be calculated from the formula:

$$I = \frac{2}{3}\,(I_1 + I_2 + I_3). \qquad (2)$$

Omitted hereinafter are the factors determined from calibration which allow for not ideal quality of the polarization elements at different wavelengths within the region of spectral sensitivity of the photodetector.

Polarization azimuth, which assigns the orientation to a large axis of the polarization ellipse, takes the form:

$$\chi = \frac{1}{2} \arctan \frac{U}{Q} + \frac{\pi}{4} (1 - \text{sign } Q) \text{ sign } U, \quad (3)$$

where $Q = \frac{2}{3} (2 I_1 - I_2 - I_3)$; $U = \frac{2\sqrt{3}}{3} (I_2 - I_3)$ and the term $\frac{\pi}{4} (1 - \text{sign } Q) \text{ sign } U$ allows for the extension of the definition of χ.

The degree of polarization may by written in the form:

$$P = (Q^2 + U^2 + V^2)^{1/2} / I, \quad (4)$$

where $V = (I + Q \cos 2\chi - 2 I_4)/\sin 2\chi$ is found using signal I_4 in the fourth channel with the phase compensator.

The ellipticity angle is

$$\beta = \frac{1}{2} \arcsin \frac{V}{I} . \quad (5)$$

In the formulas given we omitted for simplicity i, j, l, λ indices indicating the correspondence to the fixed sighting direction, the distance to the investigated object, and the radiation wavelength. The terms entering in Eqs. (2)–(5) form the Stokes vector $\mathbf{I} = \{I, Q, U, V\}$ which is a comprehensive characteristic of the scattered radiation. Since the system involves a personal computer there is an opportunity to create complex polarized images around the above–mentioned characteristics. Ordinary images may come from those as implementations with reduced volume of information.

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