A SPECKLE IMAGING CAMERA

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Abstract

A new camera for use in high resolution imaging on large telescopes has been constructed. It is designed to be used with photon event detectors (such as the PAPA) although other types of detector may be used as the system is modular.

Introduction

Considerable achievements have occurred in the field of interferometric imaging in optical astronomy since Labeyrie invented the technique of speckle interferometry [1]. There has been continuous progress because of the developments of both image reconstruction algorithms and imaging detector systems. According to the way image data are recorded, speckle imaging systems have evolved through the following three generations in the past 20 years:

1. Film Camera: film was used to record and store individual intensified frames for later use in an analog optical processing system. More accurate data analysis required frame digitization with either a microdensitometer or a TV camera. Examples of this type are given in Refs.[2] and [3].

2. Time Framed Device: images amplified by an intensifier are recorded by a TV camera[4, 5,6]. The major disadvantage of this type of device is that its temporal resolution is currently limited to video rates and the arrival times of the individual photon events within the frame are not known.

3. Time Tagging Device: each photon event detected is recorded with both spatial and temporal co-ordinates. There are several different types of devices, such as resistive anode[7], PAPA[8] and MAMA[9]. The distinguishing feature between them lies in the way a detected photon event is read out.

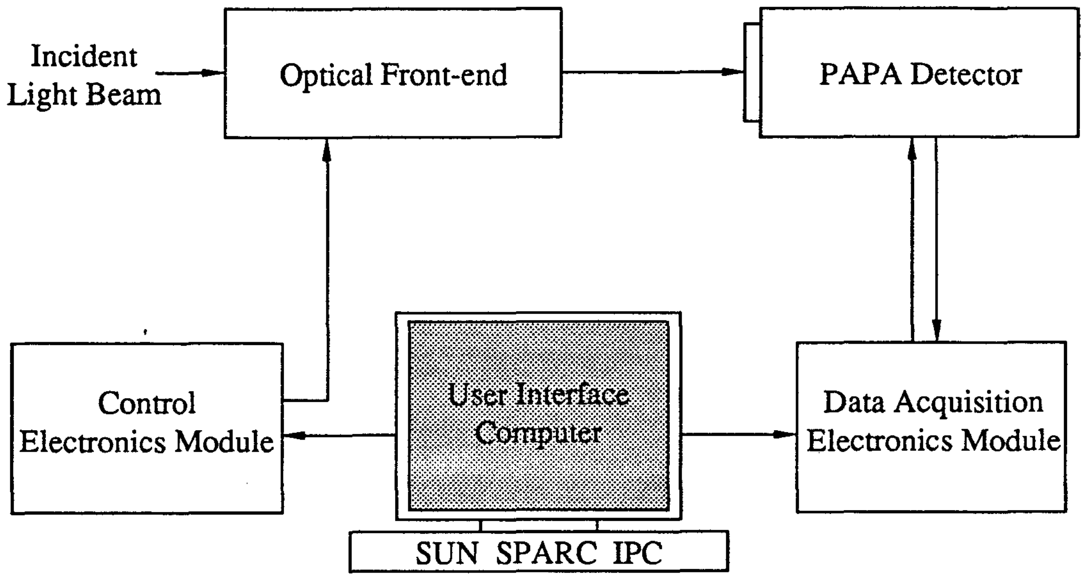

Fig. 1 Block Diagram of Speckle Imaging Camera

We have built a speckle imaging camera designed to be used with a PAPA detector, although the camera can be used with other photon event detectors since the system is modular. The camera consists of five sub-systems: a) optical front-end; b) control electronics module; c) user interface computer; d) PAPA detector; e) data acquisition electronic module. A block diagram of their relationship is shown in Fig.1. In this paper we present the technical details of design which describe the optical front-end (a), the control electronics module (b) and the user interface computer's facilities (c), together with an outline of the other two subsystems (d) and (e).

1. Optical Front-end

The layout of the optical front-end is given in Fig.2. The function of this unit is to present an enlarged, dispersion-corrected, stable, spectrally filtered image to the detector. All these are achieved by the following components:

Acquisition System

Mirrors M1 and M3 serve to align the optical axis of the instrument to that of the telescope. The "guiding" mirror is situated at the telescope focus, splitting the incident light into two parts: a central image spot of 3mm diameter (roughly 13 arc-sec at the f/11 focus of the 4.2m WHT) and the remainder of the field which is reflected into an intensified TV imaging system showing a sky background of about 1 arc minute around the object on a TV monitor.

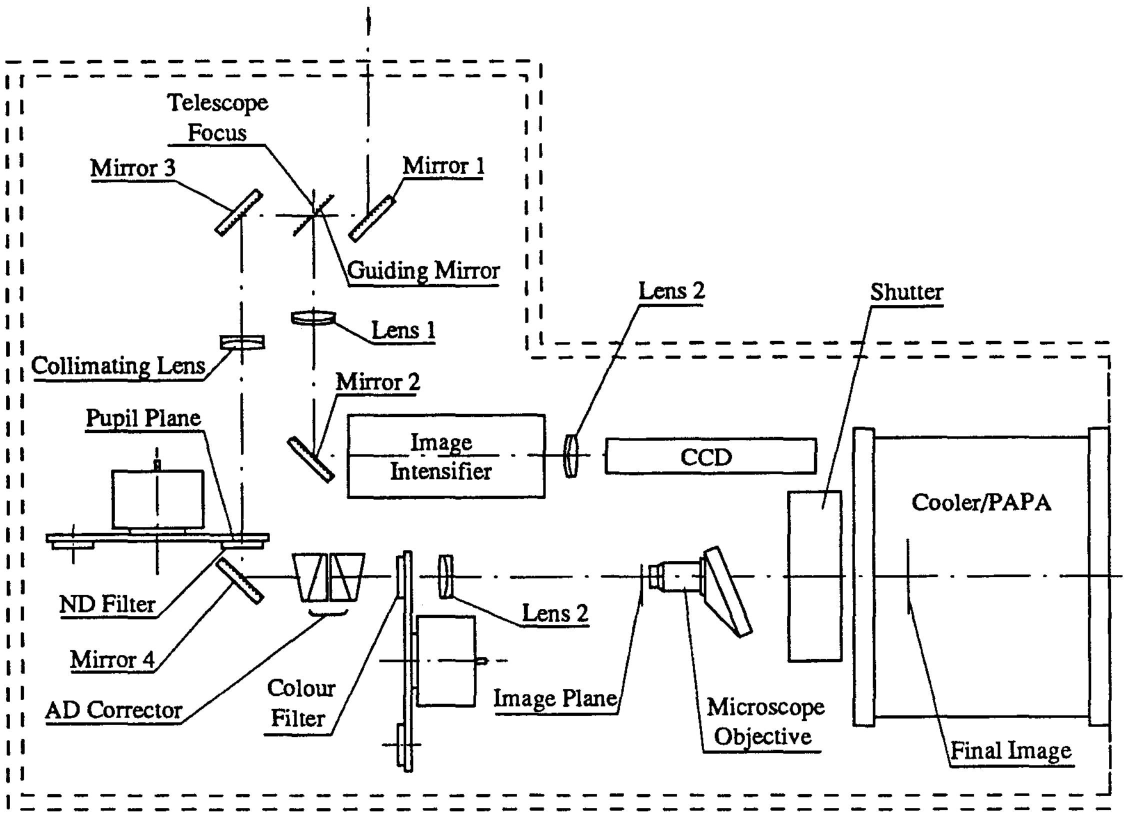

Fig. 2 Optical Front-end

Automatic Stabilizing Mirror

A tip-tilt mirror (mirror 4 in Fig.2), driven by piezo-electric actuators, centroids the image when a time-tagging detector is used. When the detector is acquiring data, one transputer continuously calculates the center of the image with a time constant on the order of 1 second. Error signals are fed back to the piezo as a voltage to drive the mirror, with a maximum velocity constraint to maintain the object centroided in the field-of-view. The mirror has ± 5 arc-sec movement range.

Filter Wheels

Neutral density filters and aperture masks are placed in the first 16-position wheel, the mounting plate of which is situated exactly in the exit pupil plane so that pupil plane interferometry (aperture synthesis) could be carried out when an aperture mask is used. There are 11 neutral density filters of the following ND values: 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0 and 3.0.

There are 15 interference filters situated in the second 16-position wheel. The 15 spectrum-selecting positions currently provide the following mean wavelengths, mainly with a 10 nm

bandwidth: 400, 423, 427, 450, 500, 548, 550, 600, 620, 640, 656, 694, 704, 715 and 751. The last working position is left clear for whole spectrum imaging. Filter selection can be done either automatically or manually.

Atmospheric Dispersion Corrector (ADC)

The ADC is composed of two identical prism doublets from two types of glass, which form a Risley prism pair. The magnitude of the atmospheric dispersion is a function of spectrum bandwidth and also proportional to the tangent of the zenith angle[10]. Setting the following values as initial conditions, maximum zenith angle $\varsigma_{max}= 60^{\circ}$, λ_0=550 nm for zero deviation, λ_1= 400 nm, λ_2= 800 nm and M= D/d = 300 for magnification, glasses LaF21 and KF9 were found to be two good candidates whose combined dispersion most closely matched that of air. By minimising residual lateral color over the range of 400~800 nm, their angles were determined to be $\Theta_1=38^{\circ}16.5'\pm1'$(for KF9) and $\Theta_2=24^{\circ}45.5'\pm1'$(for LafN21)

Under typical environmental conditions at La Palma (altitude 2366 m, temperature 0 centigrade, humidity 10 percent) and for a zenith angle of 60°, the residual lateral colour after compensation by our ADC is shown in Fig.3. It can be seen from Fig.3 that the residual lateral colour is quite small throughout the whole visible spectrum ($\approx$ 10 mas) and for a typical bandwidth of 10 nm it is negligible.

The ADC works in a collimated beam so it produces no extra aberrations. It is driven by stepper motors under the control of the Electronics Module. The relative rotation of the

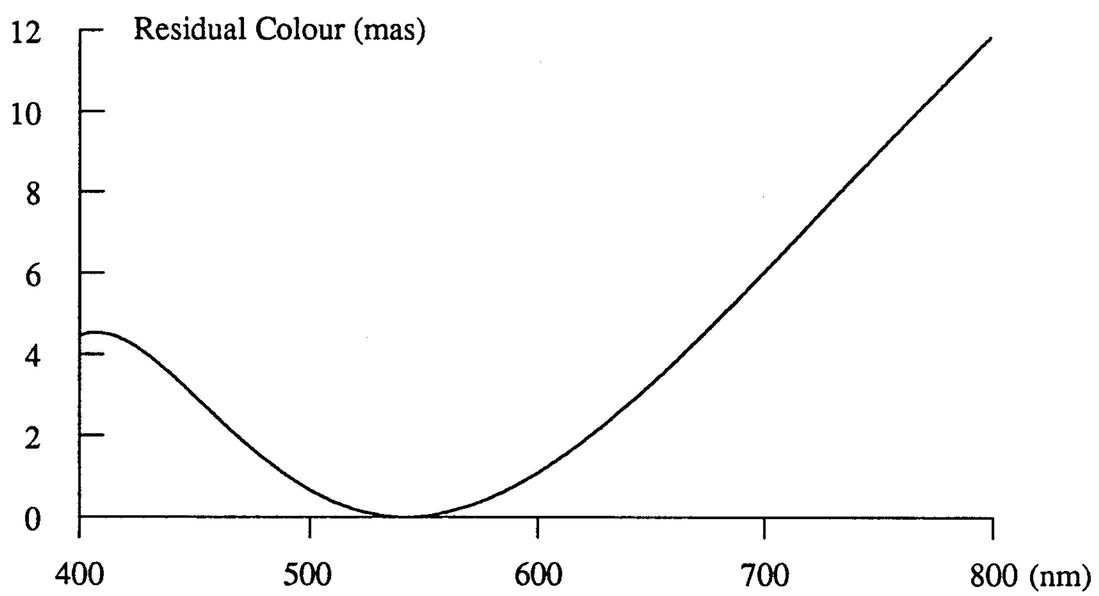

Fig. 3 Residual Colour After Dispersion Compensation

two prism doublets changes the effective dispersion of the ADC to compensate the magnitude of dispersion. Their absolute rotation about the hardware zero position will make their combined dispersion vector follow the opposing direction of the atmospheric dispersion, which changes with time.

A programme for dispersion correction was written and has been incorporated into the system control software. It calculates air dispersion and makes a comparison every two seconds between the current correction and the required correction. The prism doublets' positions are updated when the residual dispersion is beyond the error limit (typically 0.05 mas/nm).

Microscope Objective

A microscope objective provides a magnified image. It is mounted on a standard rotatable plate where three objectives of different magnification, e.g. 40×, 25× and 16×, may reside so any one of them can be easily chosen (manually) for use.

2. Control Electronics Module

The function of the Control Electronics Module (CEM) is to act as an interface between the user interface computer (i.e. remote host) and the Optical Front-end. The five devices controlled by the CEM are: (i). Intensified TV Camera System(ITV); (ii). Two 16-position Filter Wheels; (iii). Atmospheric Dispersion Corrector(ADC); (iv). Shutter; (v). Alignment laser and its interlock. The CEM hardware composition is shown as a block diagram in Fig.4.

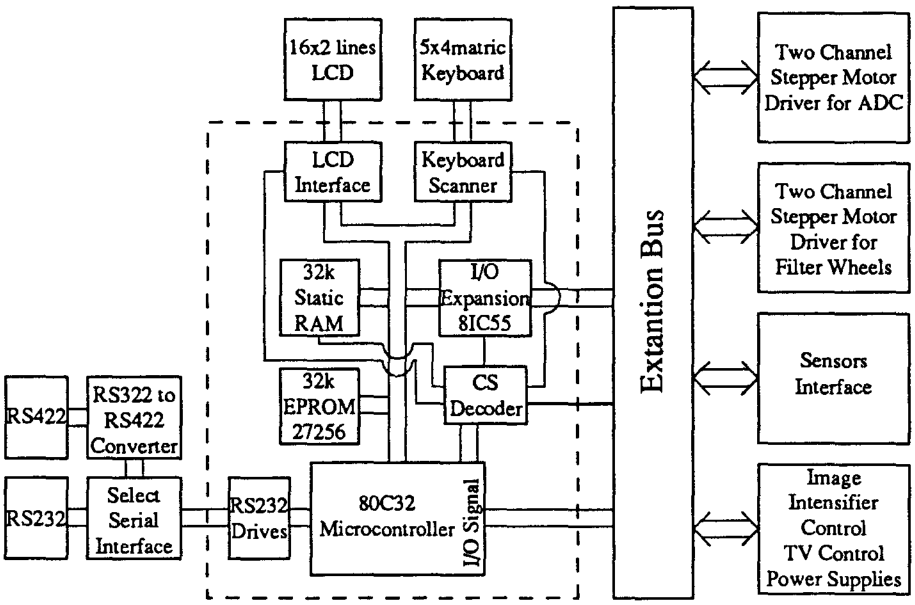

Fig.4 Block Diagram of CEM Hardware

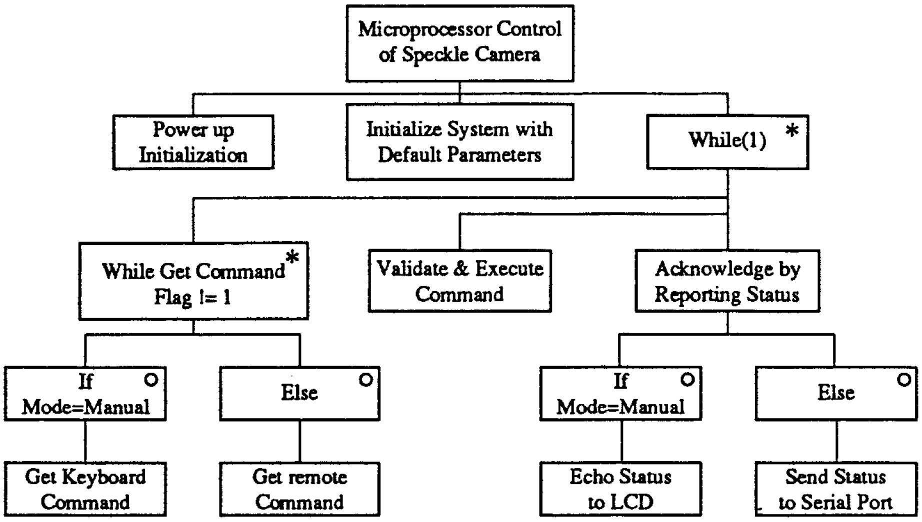

Fig. 5 Software Structured Diagram of CEM

It has a microprocessor which receives commands and sends status information via an RS422 link up to 100m. The CEM is housed in a 19-inch rack which is to be located within 3m of the camera. Users have the option of direct control over the subsystem devices since the CEM also incorporates a keyboard and LCD for this purpose. It is powered from 240v-50Hz nominal and contains all the required power supplies.

Fig.5 displays the flow chart of the CEM software. When it is switched on, the system is initialized with default settings which are: prisms of ADC and filter wheels zeroed, shutter closed, TV camera off, image intensifier off and its gain set at minimum value. When the CEM receives commands from the user interface computer, each command is validated prior to execution. After each command is successfully executed, the CEM updates the status registers and sends the status message with zero error code to the user interface computer, otherwise any detected error is reported along with the status message.

3. User Interface Computer

The user interface computer (UIC) is a SUN IPC workstation with 24Mb of memory, a 327Mb disk and a 15"colour monitor. This computer controls both the speckle camera system, via an RS422 serial link to the control electronics module, and the data acqusition unit, via a transputer card on the IPC's S-Bus.

The software system running on the UIC consists of three separate communicating processes. The major process is a graphical user interface; this process, shown as a block diagram in Fig.6, starts up the other two processes, initialises the graphics and windowing system then

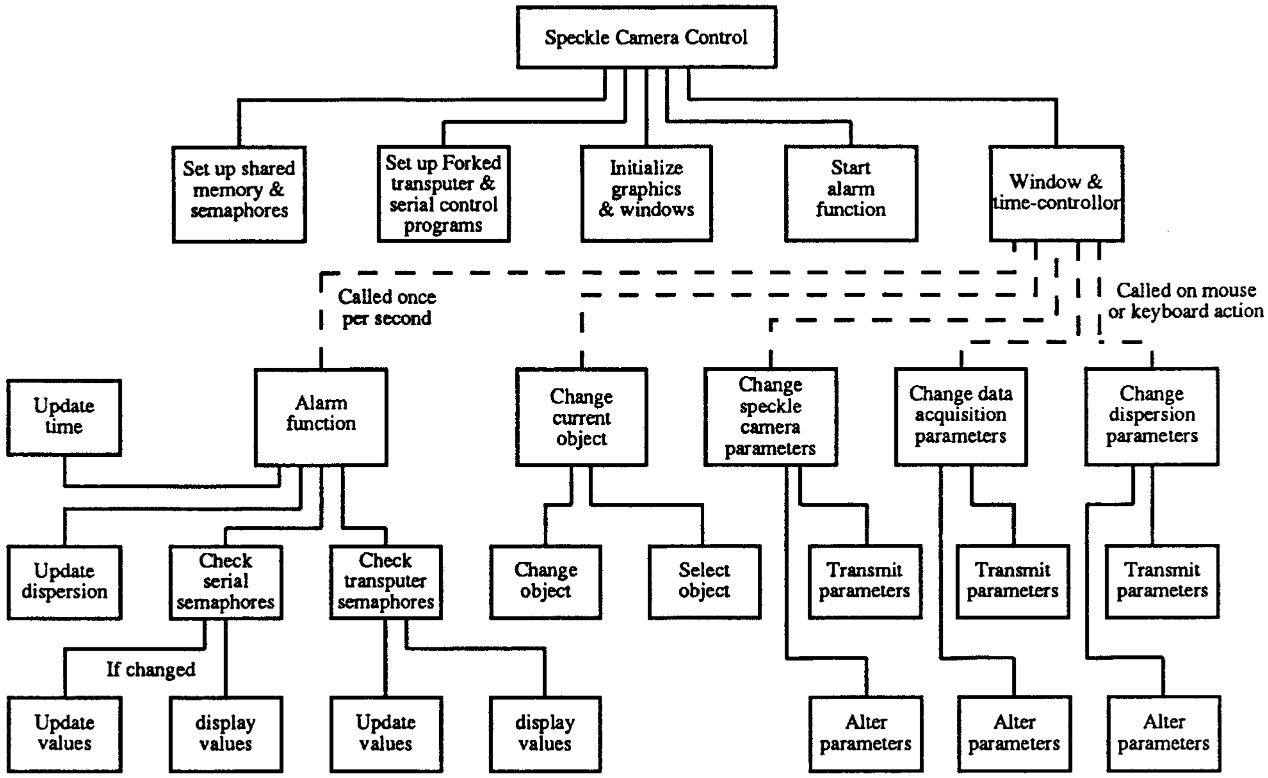

Fig. 6 Block Diagram of User Interface Software

goes into a timer and user interuptable loop. In the loop the dispersion is recalculated and the data acquisition and speckle camera system are checked every 0.1 seconds. The user can also generate an event with the mouse or keyboard and so can alter any of the configurable system parameters.

The second process simply 'listens' to both the major interface process and to the transputer system [via UNIX fifos]. Similarly the third process 'listens' to the interface and control electronics module.

The reason behind splitting the code into three semi-independent processes is to prevent deadlock whereby the transputer or serial links could lock up the whole computer. For portability to other host UICs the software is written in K&R C with the graphics interface in X11/XView.

4. Detector

The system has been built with the intention of using it with a PAPA detector[8]. As delivered by the manufacturer, this detector did not function and is currently (Nov. 1991) being re-built.

5. Data Acquisition Electronic Module

This is described in detail in an accompanying paper in the volume[11].

Acknowledgement

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References

[1] A. Labeyrie, Astron. Astrophys., **6**, 85 (1970)

[2] A. Labeyrie, "High-Resolution Techniques in Optical Astronomy", Progress in Optics, **XIV** (1976)

[3] J.B.Breckinridge, H.A.McAlister and W.G.Robinson, App. Opt. **18**, 1034 (1979)

[4] A. Boksenberg, 1978, Proceedings of ESO Conference "Telescope of the Future" (Geneva, Dec. 12-15 1977), 497

[5] J.L.A. Fordham, D.A.Bone and A.R.Jorden, SPIE vol.**627**, "Instrumentation in Astronomy VI", 206 (1986)

[6] J.L.A. Fordham, D.A.Bone, T.J.Norton and P.D.Read, SPIE vol.**1235**, "Instrumentation in Astronomy VII", 636 (1990)

[7] D.Rees, I,McWhirter, P.A.Rounce, F.E.Barlow and S.J.Kellock, J. Phys. E: Sci. Instrum., **13** 763 (1980)

[8] C.Papaliolios, P.Nisenson and S.Ebstein, App. Opt. **24**, 287 (1985)

[9] J.S.Morgan, Proceedings of ESO Conference and Workshop, 381 (1988)

[10] E.P.Wallner and W.B.Wetherell, Proceeding on "Telescope of the 1990s", vol. **2** 717, A.Hewitt Ed. (Kitt Peak National Observatory, Tucson, 1980)

[11] R.M.Redfern, P.O'Kane, C.O'Byrne, R.Wouts, B.D.Jordan, and N.Wooder, "High Speed Data Collection System for Speckle and Other High Resolution Imaging Techniques", this Proceedings.