FIRST RESULTS FROM THE NEW GSU CCD SPECKLE CAMERA

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ABSTRACT: The CCD speckle camera now in use at Georgia State University has brought about considerable improvement in limiting magnitude and photometric accuracy over the old photographic system, but has also necessitated considerable changes in data storage and reduction. These new data handling techniques are outlined, with a few words about overall accuracy and a brief description of new equipment which should further improve our speckle program at GSU.

In the previous paper, McAlister described several of the speckle interferometry projects planned or in progress at Georgia State University. In this paper I will describe the equipment now in use for data acquisition and storage, as well as the method of reduction currently being developed.

The old speckle camera, used for all our published binary star work to date, was a photographic system, recording data on 35-mm film. A typical observation would consist of about 50 individual exposures per star, each of perhaps 1/50 second. (As a reminder to us of the photographic speckle camera, we now have approximately 100,000 feet of used 35-mm film in our lab.) Reduction of these data involved as many as 4 additional photographic steps in order to arrive at the final images to be measured, either by hand or using a Grant-type machine. The major drawbacks of this system were (1) a limiting magnitude, using the Kitt Peak 4-meter telescope, of only about 7, and (2) the loss of any real photometric accuracy through these many photographic steps.

The new speckle camera has been in use at Kitt Peak and Lowell Observatories for about two years, and is clearly able to overcome many of the problems inherent in the photographic system. It has improved our limiting magnitude to about 15, and allowed us to preserve photometric information as well. It has also, however, necessitated a completely different approach to data handling and reduction.

In brief, the new system consists of a proximity-focus, dual

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microchannel plate intensifier, coupled via a fiber optic plug to a two-dimensional CCD. The entire system is described in detail by McAlister et al. (1982), except for a recently-added cooling system. The CCD is read at standard video rate using a modified RCA video camera, with data being displayed on a video monitor and stored on video tape using a modified video recorder. All observations are made using either a hand paddle or, more frequently, a minicomputer which stores our observing lists and can automatically calculate appropriate Risley prism settings, move optical components, start and stop observations, and the like.

A quick calculation at this point will indicate the major constraint we face in reducing the speckle data we now obtain. A typical observation consists of about 60 seconds of data accumulation. At 30 frames per second this corresponds to roughly 1800 video frames per star. Each such frame has 256 x 240 pixels, and on a good night we can observe upwards of 200 stars. On a three-night run, then, we accumulate over 5×10^{10} pixels of information (about 17,000 computer tapes' worth). Digitizing and processing this information in any standard fashion would require months of computer time per observing run, so is clearly out of the question.

The technique we are using to reduce our data is based on the determination of the vector autocorrelogram. Each frame of data is read from video tape and sent to a hard-wired vector autocorrelator, designed and constructed by Digital Television Imagery, Inc. The autocorrelator digitizes the video input, then keeps only the addresses of those pixels exceeding an adjustable threshold. Address differences are determined between all pairs of bright pixels and added to an Bautocorrelogram array. The procedure is repeated for each frame of data in order to build up the final autocorrelogram.

An alternate way of visualizing the autocorrelation process is shown in the following example.

Figure 1a shows a single frame of data for a hypothetical binary, consisting of just 5 pairs of speckles (thresholding has reduced these 10 points to 1's and all other points to zeros). The vector autocorrelation process can be thought of as shifting the array such that the first nonzero pixel is at the origin and mapping these 1's and 0's onto the autocorrelogram array, then shifting the array so that the second bright pixel is at the origin and adding these values, etcetera.

The final result in as shown in Figure 1b - a large spike at the origin of the autocorrelogram corresponding to the sum of the 10 pixels, smaller spikes on either side at separations and angles corresponding to the true binary star separation, and many smaller spikes scattered over the array. A cross-sectional cut through the three major spikes is shown in Figure 1c.

Over many frames of real data, the background of points around

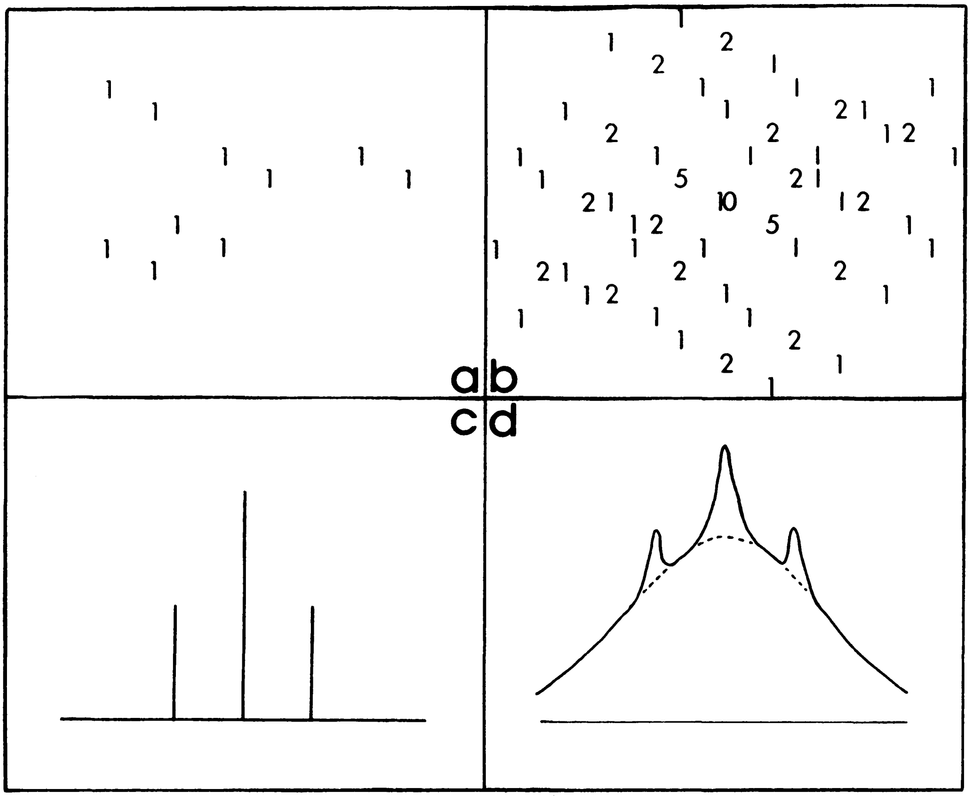

Figure 1. Autocorrelation of a hypothetical binary star.
1a. Single frame of data, showing 5 pairs of speckles. Thresholding has reduced these 10 speckles to 1's, all other points in the array to zeroes.
1b. Autocorrelogram of the data in 1a.
1c. Cross sectional cut through the three major peaks in 1b.
1d. Cross sectional cut through a more realistic autocorrelogram. The binary star peaks are now broadened and superposed on a broad seeing disk profile.

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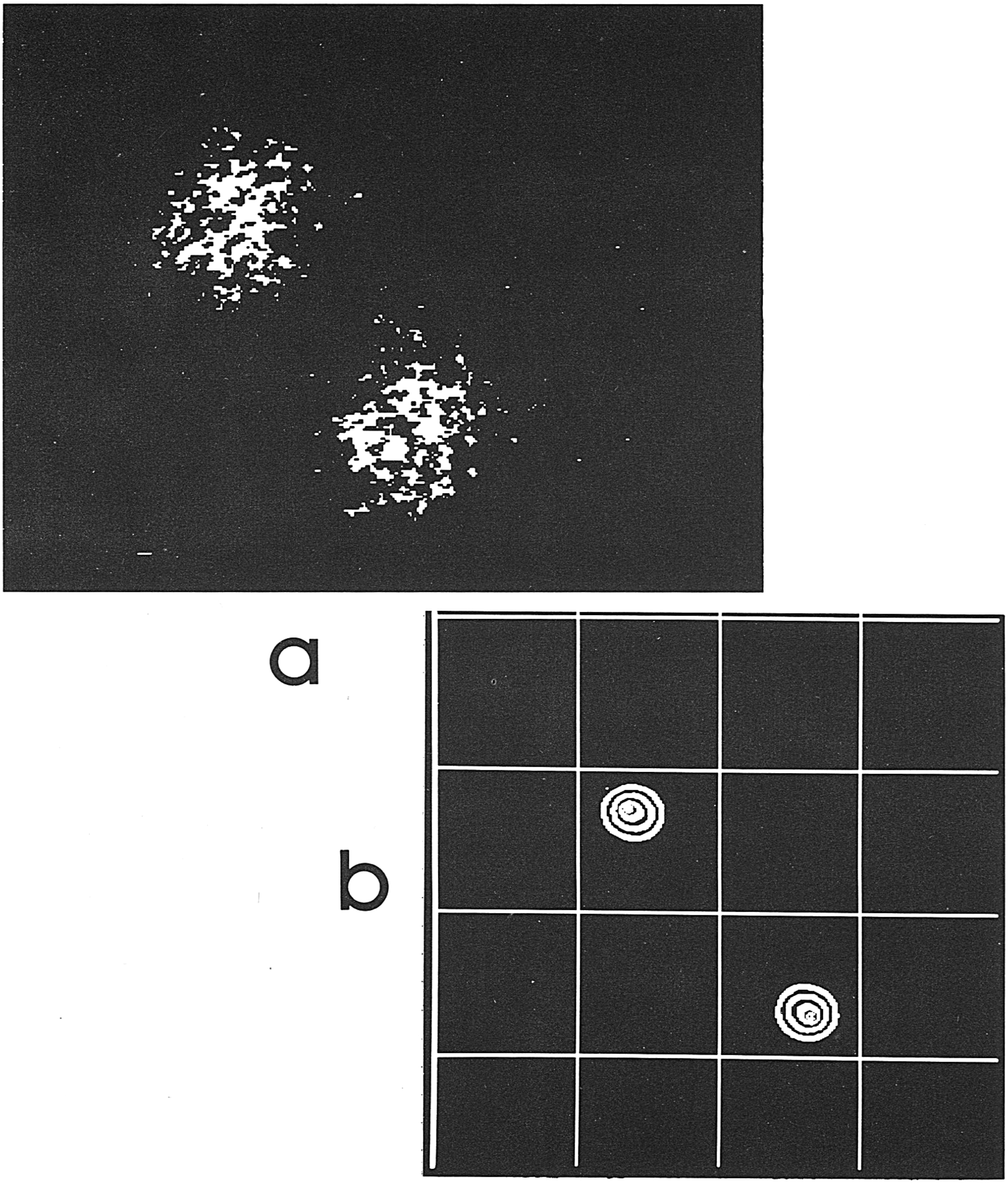

Figure 2. ADS 10345, separation 2".1.
2a. Single CCD frame of data (10 msec exposure)
2b. Autocorrelogram of approximately 20 seconds (600 frames) of data. Asymmetry in the contours about each of the binary peaks indicates the presence of the broad seeing disk.

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these three spikes forms into a smooth "seeing disk" profile, and the cross-sectional cut through the autocorrelogram would look more like Figure 1d.

Let us now look at some real data.

Figure 2a shows a single video frame for a binary star of separation 2". The autocorrelogram of some 20 seconds worth of observation is shown in Figure 2b, where the central peak has been windowed out. Although the binary peaks appear very distinct, a look at the contours about these peaks shows that they are noticeably asymmetric. Even for a wide binary, then, the overall seeing profile must be removed before the binary peaks can be accurately fitted.

The problem is much more apparent in the case of a closer binary. Figure 3a shows a single frame of data for a binary of separation 0"3. The autocorrelogram of about 1000 such frames is shown in Figure 3b. The binary star peaks here are so strongly affected by the seeing profile that they are barely visible in the contours.

Our method for removing the seeing profile begins by taking a set of radial cross sections through the autocorrelogram, one at an angle which passes through the approximate position θ of the binary peak, and several others at angles $\theta+2\alpha$, $\theta+\alpha$, $\theta-\alpha$ and $\theta-2\alpha$, where α is typically 10 to 20 degrees. These cross sections are displayed in Figure 3c, with radial distance from the autocorrelogram origin increasing to the right.

A least squares polynomial fit is then made to the top and bottom profiles ($\theta+2\alpha$, $\theta-2\alpha$) over the range in r of interest. An interpolation of these polynomials is subtracted from all points in this wedge of the autocorrelogram. The top, middle, and bottom profiles, with polynomial fits removed, are shown in Figure 3d. This corrected binary peak is finally fit by either a two-dimensional Gaussian or polynomial to determine the position of the secondary peak relative to the primary.

Early repeatability tests indicate that our positional fits are good to about 1 milliarsecond for a single observation. Several improvements have been made in our reduction procedure since these tests were made, so 1 m" is probably a rather conservative estimate at present. As mentioned in the last paper, mean accuracies of a few tenths of a milliarcsecond are necessary for our planet search program, and we feel that we are now approaching such a value.

Postscript: A recently-awarded DOD grant will in the near future allow us to improve significantly upon our current reduction scheme. An International Imaging Systems Model 70 image processor will be coupled to a dedicated VAX 11/750 computer and associated hardware to give us much better graphics and greater computational capability. High resolution color contouring will allow us to detect much fainter

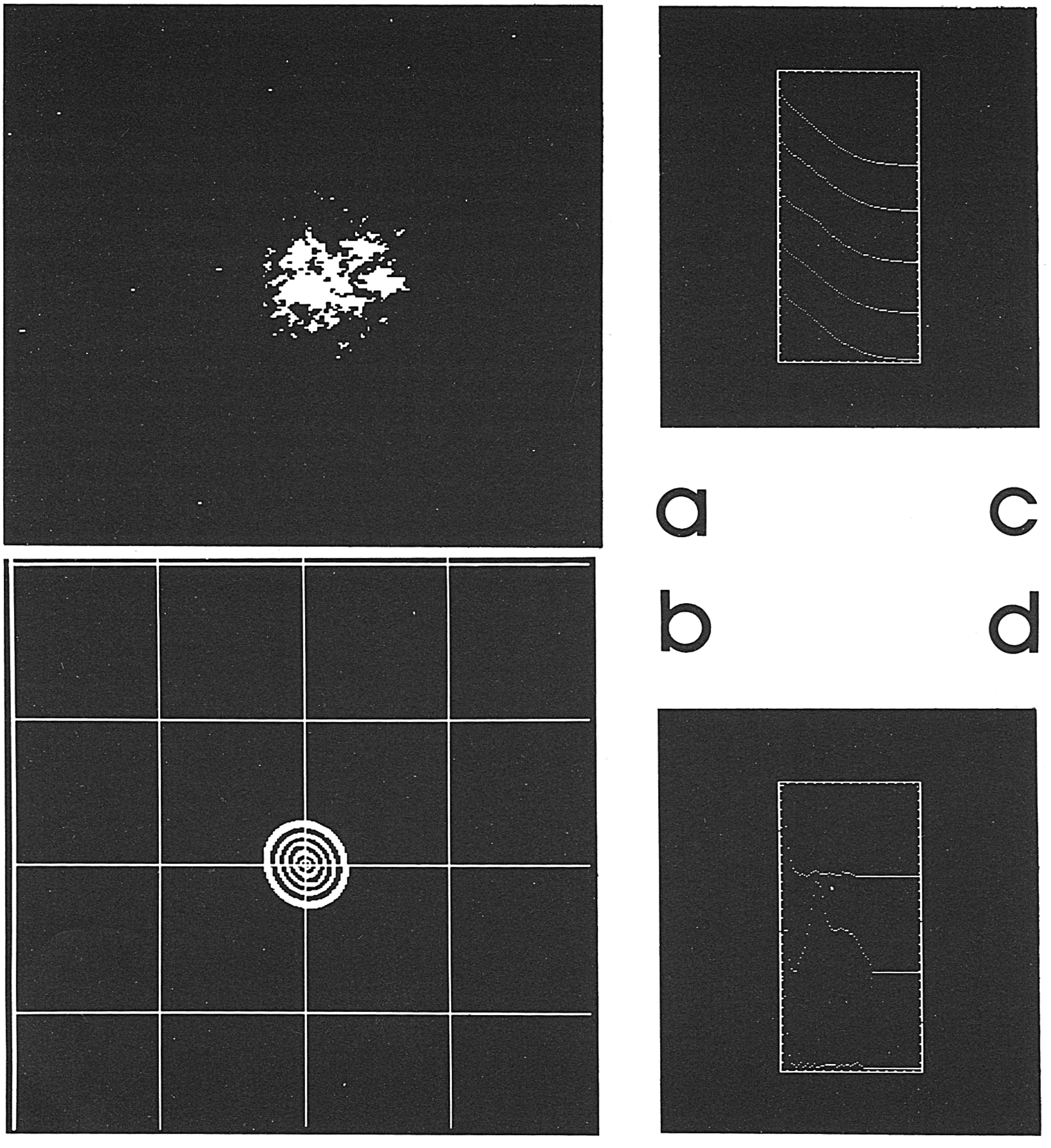

Figure 3. Cou 114, separation 0".3.
3a. Single CCD frame of data.
3b. Autocorrelogram of 30 seconds of data. Binary star peaks are barely visible at angles 150° and 330°.
3c. Radial cross sections through the autocorrelogram in 3b, cut at angles 110°, 130°, 150°, 170°, and 190°. Radial distance increases left to right, starting at the origin.
3d. Cross sectional profiles at angles 110°, 1550°, and 190°, after removal of 3rd order polynomial fits. Curves are fit to the top and bottom curves and interpolated at all points in the enclosed wedge of the autocorrelogram.

secondary peaks, thus increasing the range of Δm over which we can detect binary components. More involved reduction algorithms can be used in order to determine relative magnitudes and colors of each component of close systems, thus allowing us to determine better spectral classifications. Lastly, the greater computational speed should finally give us the ability to reduce data at a rate approaching that at which we can now collect it.

REFERENCE

McAlister, H. A., Robinson, W. G., and Marcus, S. L. 1982. Pub. S.P.I.E. 331, p. 113.

Discussion:

STRAND: If your limiting magnitude is 15^m, I suggest observation of GL 107-70, a white dwarf double for which we have a good orbit but need accurate separation for obtaining well determined masses. The separation is presently about $0\overset{''}{.}6$.

HARTKOPF: Give us the coordinates and we will do it.

JEFFERYS: You have impressed us with the amount of digital tape required to store your data. How much video type is required to store a night's data?

HARTKOPF: Video tape is a convenient way to store huge amounts of data. A typical night results in one or two video tapes. We have 60 to 70 tapes sitting in a pile waiting to be processed with a new program.

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