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OPTICAL JOINT CORRELATION USING THE DEFORMABLE MIRROR DEVICE

Final Report

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ABSTRACT

An experimental investigation of the Deformable Mirror Device (DMD) developed by Texas Instruments at Dallas for use in object identification was completed. The DMD was tested as a joint correlator. The DMD was used as a spatial light modulator on which the squared modulus of the Fourier transform of test object pairs was written. The squared modulus was phase encoded on the DMD after it had been thresholded and rewritten as a binary phase function. The thresholding was found to produce a sharp peak in the autocorrelation when the test objects were matched and no significant peak in the case of distinct objects. It was concluded that the use of the DMD as a joint correlator looks promising and further studies should be carried out.

INTRODUCTION

The location and recognition of objects belonging to small well defined sets (e.g., handtools drifting in space) or objects belonging to large less well defined classes (e.g., boulders on the surface of Mars.) are typical parts of mission requirements on several NASA programs including the planned unmanned expedition to Mars, the EVA (Extra Vehicular Activity) retriever program and autonomous rendezvous and docking. In most cases the speed of the recognition process must rival that of the human eye-brain. This is difficult competition. Even the fastest available digital computers would not be able to process data fast enough to keep pace with human vision. An interesting alternative to digital computing is optical computing. Optical computing takes advantage of massive parallel processing. Within the last 10 years, optical processing techniques have matured to the point that they are worthy of consideration in tasks where speed is a premium. Although it lacks the flexibility of digital processing at the present, it can perform certain fixed tasks, such as Fourier transforms in two dimensions, almost instantaneously (i.e., essentially in the length of time it takes the light to pass through the optical processing system.) At present, the Tracking and Communications group at NASA is studying the use of a hybrid system that exploits the best of both digital and optical processing for artificial vision problems. The key element in this approach is the Deformable Mirror Device (DMD), a new type of integrated optics device under development by Texas Instruments (TI) in Dallas.

The DMD consists of a 1/4" square array containing 128 x 128 mirror elements. Each mirror element consists of a set of four individual cantilevered mirrors arranged as in a 2 X 2 matrix (roughly in the form of a cloverleaf.) Each of the mirror elements can be deflected as a group using the electrostatic forces determined by capacitatively stored charge between a mirror and the array back plane. The charge stored, and thus the deflection, is determined by on-chip electronics and addressing. The DMD is, in essence, a deformable mirror surface whose shape can be digitally controlled. The mirror is also fast. Each element can be deflected at an 8 kHz. rate, although the current experimental setup operates the DMD at 50 Hz. to maintain compatibility with a 50 Hz. European standard video.

At the present, the DMD is being studied for use as an optical correlator. Correlation strength measures can be a key feature in vision identification tasks [2]. Correlation, however, has not been normally used in practical vision systems since it is computationally intensive and slow. This is not the case using the DMD where correlation using optical processing is attractive. The two classical approaches to correlation using optical processing are Vander Lugt Filtering (VLF) and Joint Correlation (JC). The use of VLF has been one of the prime thrusts of previous research on the DMD and is described elsewhere [3]. The JC approach was developed and studied this summer as a part of research conducted under the ASEE summer faculty program. The key results of this work are described here.

The basic approach to JC involves two Fourier transform operations and one square law (intensity detection) operation. First two objects to be correlated are optically Fourier transformed in the same operation. This is done by placing the objects side by side in front of a lens and transilluminating them with coherent light. The lens produces a joint Fourier transform of the objects in terms of the electric field [5]. The field is then detected with a square law detector. The squaring operation produces crossterms containing the Fourier transform of the joint correlation of the objects. An additional Fourier transform of the squared field (using another lens) will yield two crosscorrelation terms. Optically this results in autocorrelation peaks in the form of intense points of light when the objects are matched. The degree of correlation as well as the details of the object structure determine the "sharpness" of the correlation point. The implementation of the JC process on the DMD required some modifications of the traditional JC process. In conventional optical implementations the square law operation is usually carried out by detecting the intensity of the joint Fourier transform on photographic film. A positive transparency of the transform then serves as an input for the second Fourier transform operation using a lens that yields the JC. In the approach used here the film is replaced by the DMD. The DMD is not primarily an amplitude modulating device; it is for the most part, a phase modulating device. In this case, the intensity was phase encoded.

In previous research, using a computer simulation [5], it was shown that directly writing the intensity as a phase would yield good quality correlations. This was attempted initially by writing the squared Fourier transform patterns, calculated by a computer, directly on the DMD. The DMD was then illuminated with collimated light from a helium neon laser. The reflected light was then Fourier transformed with a 50 cm. lens. The resulting inverse transform was then imaged on a CCD array camera and observed on a monitor. These first attempts were negative and no correlation peaks were observed. The process was reviewed for flaws. One of the major problems in the previous computer simulation is the assumption that the DMD could be accurately modeled using simple reflecting surfaces whose mechanical deflection was directly proportional to the charge pattern written into the DMD. In the real device, this does not appear to be the case. Based on data obtained by TI [6], it appears that there is a nonlinear relation between charge patterns written on the DMD and the resulting pattern of mechanical deflection. Therefore, an alternative approach was tried that appeared to be much more robust.

The key identification feature in the NASA tasks is a sharp autocorrelation peak that shows strong correlation between an object to be identified and a reference object. A sharp peak is due primarily to a strong single frequency sinusoidal component occurring in the joint Fourier transform. The strength of this single frequency component is proportional to the number of equally spaced point pairs on the objects being correlated. If this sinusoidal component can be emphasized in the case of a good match, then the correlation spot will be bright. A simple approach that appears to accomplish this, and completely avoids the nonlinearity of the DMD, is to threshold the modulus squared of the Fourier transform and rewrite the squared transform as a binary object. If the sinusoidal component is present, it will be emphasized as the fundamental component of a square grating. Typical results using this approach are described next.

FINDINGS

The use of JC on the DMD was tried using thresholding. The Fourier transform of test object pairs were calculated, squared and then thresholded by replacing intensities above a constant value (the threshold) by a 1 and intensities below the threshold by 0. In the cases studied, the threshold was set at one percent of the peak value. The resulting pattern was written on the DMD. Then an inverse Fourier transform was carried out optically and the resulting "correlations" were recorded. Quotes are used here to indicate that correlation is used loosely since a nonlinear mapping has replaced the joint Fourier transform intensity with a binary object.

Figs. 1 and 2 show two sets of objects that were used to test the DMD as a recognition correlator. Fig. 1 shows the pair SS and Fig. 2 shows the pair ST. In this case, the S and T can be considered as reference objects that are being compared with a test object, i.e., another S. A sharp

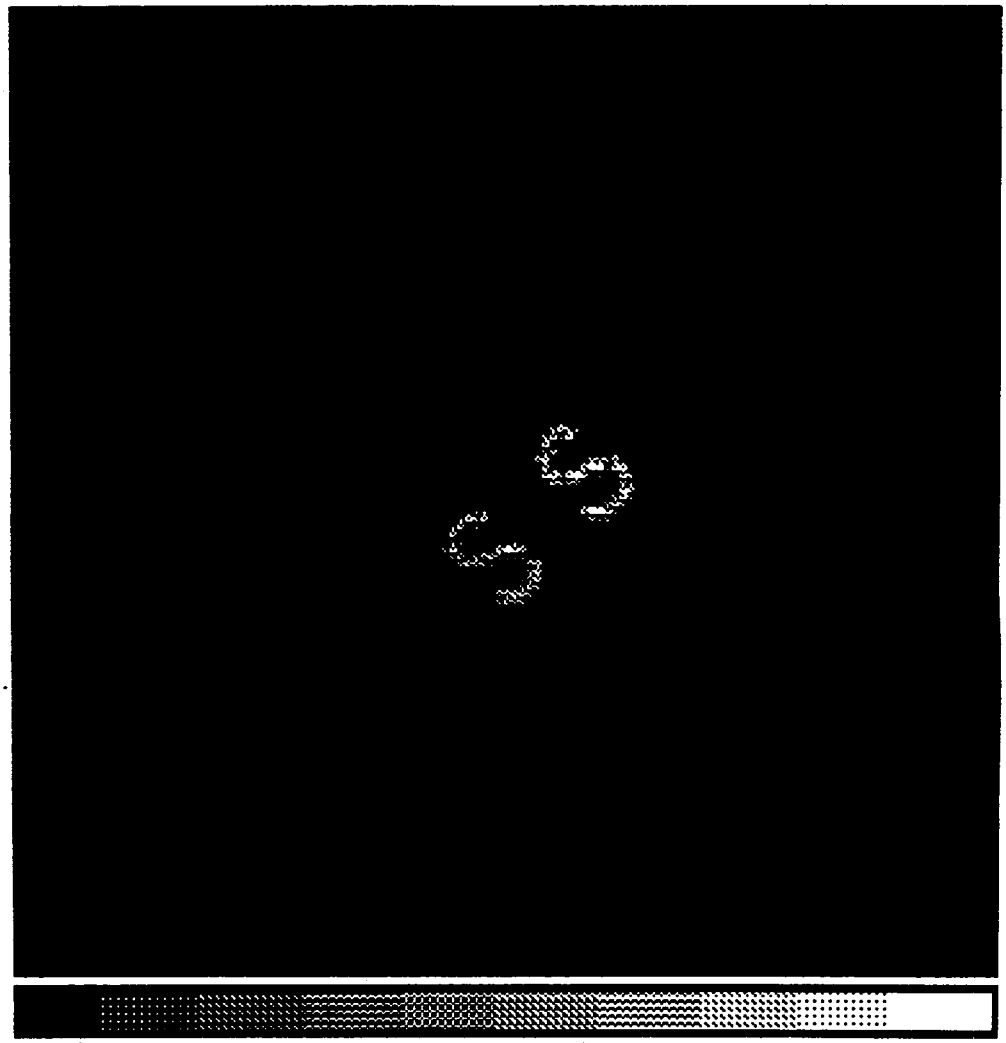

Fig. 1. The test pair SS.

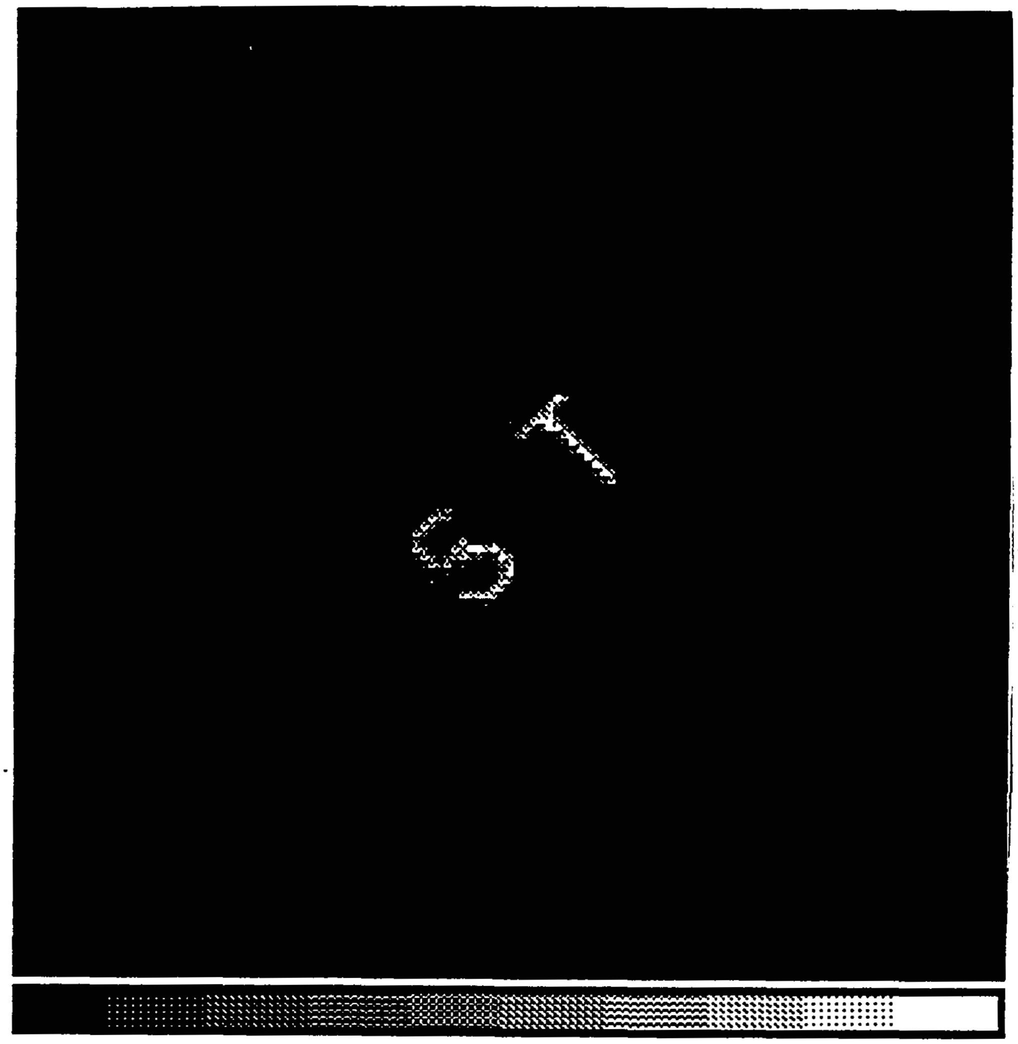

Fig. 2. The test pair ST.

correlation peak is desired when the objects are matched to indicate recognition. However when the objects are not matched then a weaker peak (or a peak too weak to observe) is desired.

Figs. 3 and 4 show the computer generated Fourier transforms after threshholding and converting to binary images for the SS and ST pairs, respectively. Note the strong single spatial frequency component for the SS transform in the diagonal direction. This frequency corresponds to the separation between the objects and will determine where the correlation peak will appear in the output plane. Figs. 5 and 6 show respectively, the resulting correlations made using the DMD. The images were taken from a CCD array camera and stored using a frame grabber. Note the presence of strong off-axis correlation peaks in the case of a match as shown in Fig. 5 and the lack of distinct peaks in Fig. 6. It should be pointed out that all the figures shown are only crudely grey scaled using a 10 level grey scale plotter in conjunction with a laser printer. The grey scale code is shown below the figures.

CONCLUSIONS

The results presented suggest that the DMD can be used to correlate images for identification with good results provided that proper thresholding is used. Since only a small set of objects was tried it is not possible to offer a general scheme for thresholding. It is not known how well the particular threshold scheme used here will work in general. Furthermore, more testing is needed to evaluate scaling, rotation and noise effects using a more interesting object set.

Also, the similarity between the thresholding approach used here and in optical neural networks has not gone unnoticed. Indeed, the only element missing to convert this system to an optical neural net system is a feedback mechanism. This is being considered in future studies using a system the author is presently developing [7].

ADDITIONAL COMMENTS

During the preparation of this final report, but after the author's ASEE summer epoch, some further results were obtained on the JC during a joint "overnight research adventure at NASA JSC " involving Richard Juday and a summer intern student from The University of New Hampshire ,Joe Bailey. The DMD was tested using photographic transparencies as the correlator input. The squared Fourier

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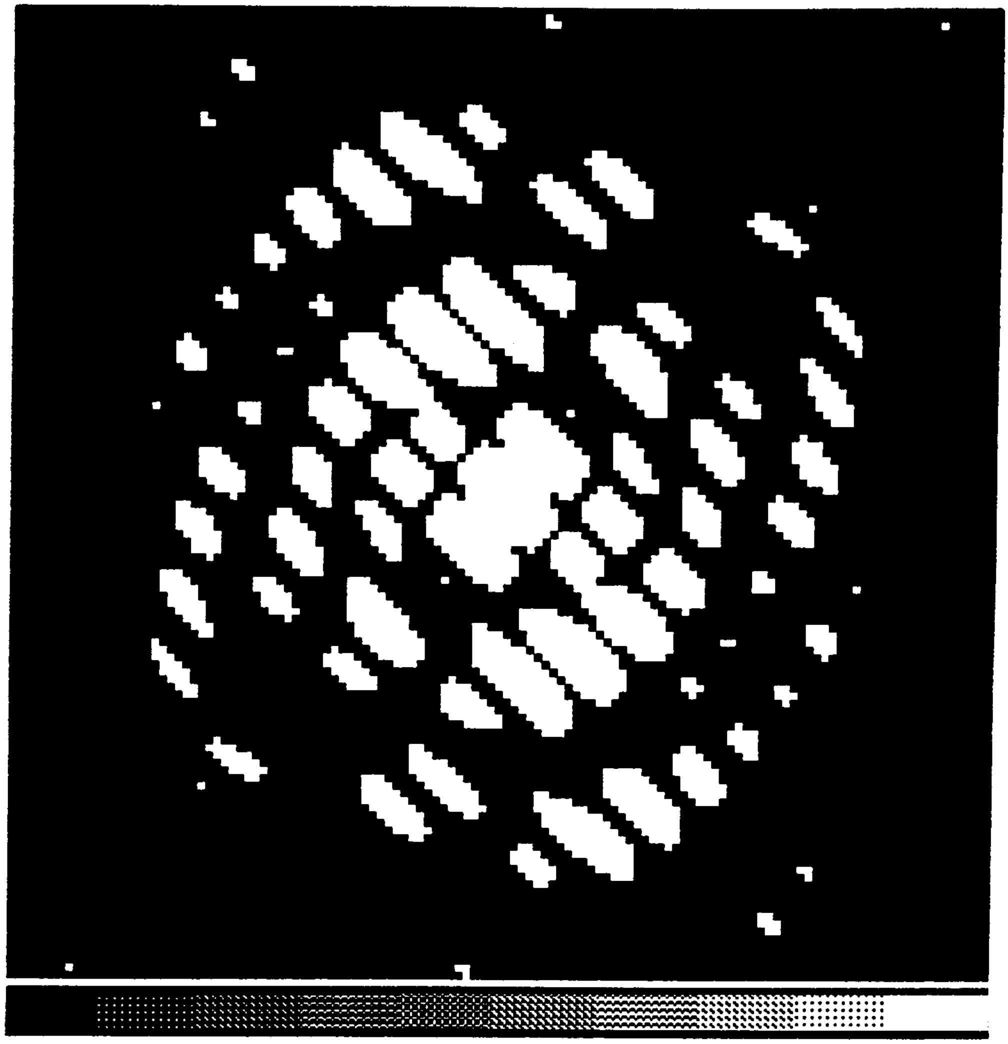

Fig. 3. The computer generated Fourier transform of SS after thresholding.

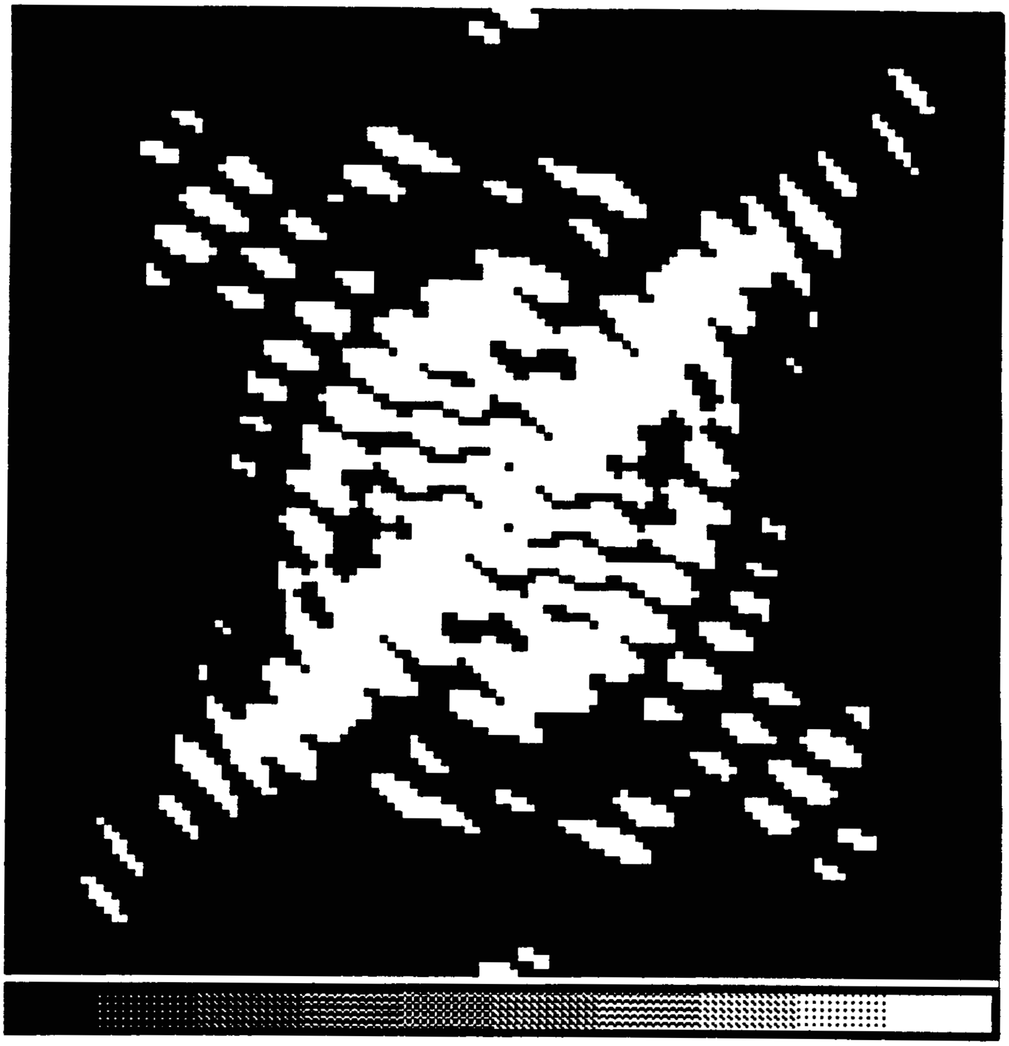

Fig. 4. The computer generated Fourier transform of ST after thresholding.

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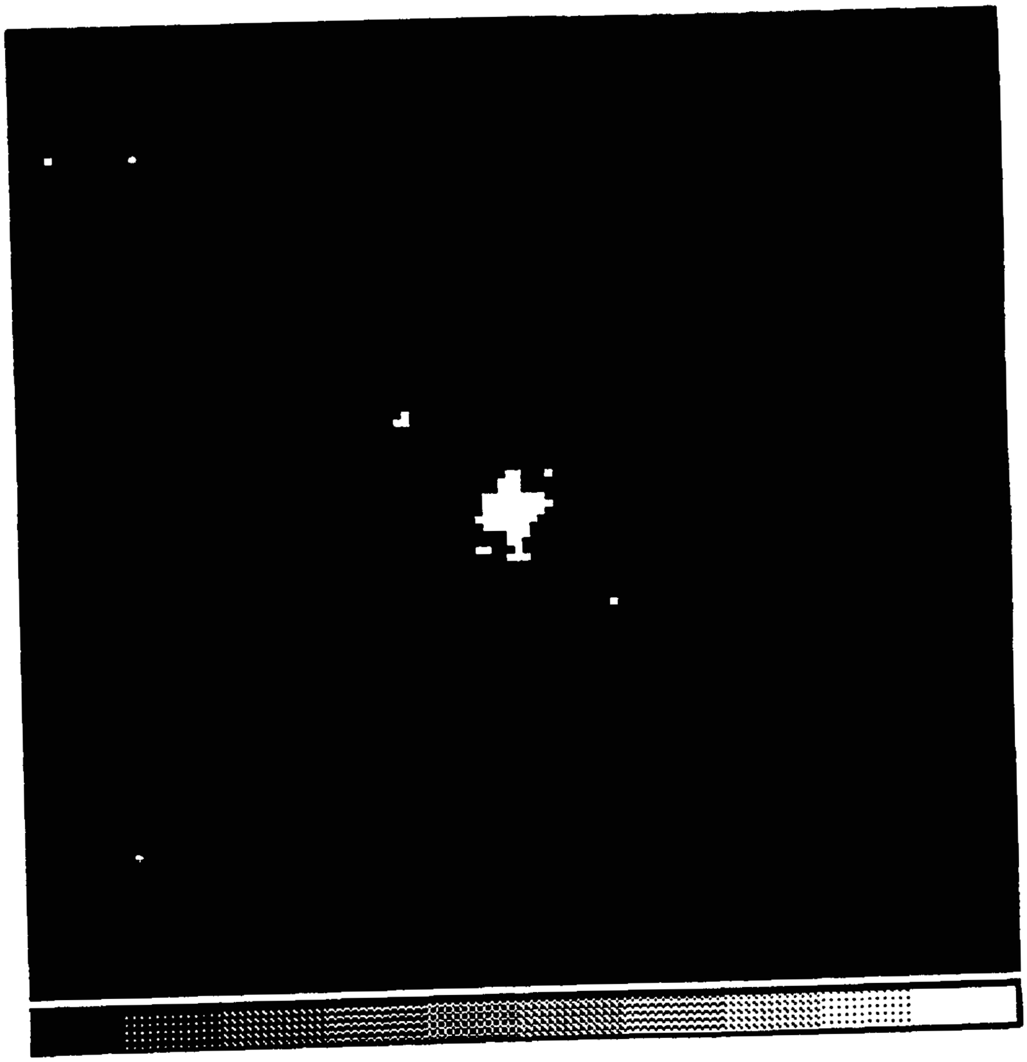

Fig. 5. The joint correlation of the SS pair.

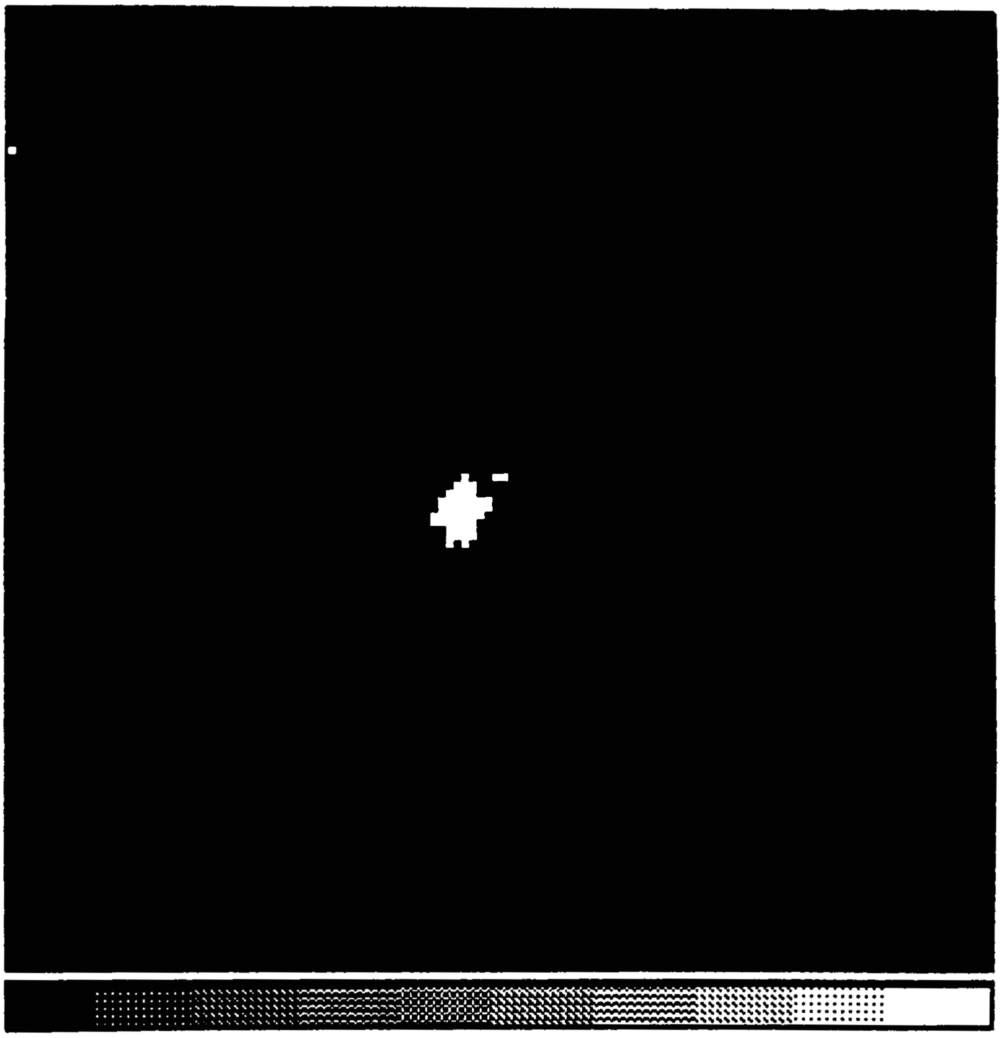

Fig. 6. The joint correlation of the pair ST.

transform was obtained optically using a lens and directly recorded on a CCD camera. The camera image was written into the DMD using a frame grabber. Good quality correlations were obtained. These results will be reported in detail at a later date. It would appear that real-time JC is possible provided a fast spatial light modulator (SLM) is used as an input to the DMD correlator. Such a real-time device is in the process of being installed. The only additional requirement is a fast frame grabbing routine for transferring the Fourier transform intensity to the DMD. This should not be a problem at the 50 Hz. frame rate now being used to write to the DMD.

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