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LIQUID CRYSTAL TELEVISION BASED JOINT TRANSFORM CORRELATOR FOR CUNEIFORM INSCRIPTION RECOGNITION

NAZIF DEMOLI[a], UWE DAHMS, BERND HAAGE, GÜNTHER WERNICKE and HARTMUT GRUBER

Institute of Physics, Humboldt University, Berlin, Germany
[a]*Institute of Physics of the University, 10000 Zagreb, Croatia*

Dedicated to Professor Mladen Paić on the occasion of his 90th birthday

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An optoelectronic joint transform correlator system for recognizing cuneiform inscription signs is described. Real-time correlation experiments are carried out with the help of liquid crystal television (LCTV) type of addressable spatial light modulators. The in-class and out-of-class sensitivities as well as the effects of preprocessing of input signals taken from an original clay tablet are discussed.

1. *Introduction*

Character recognition by means of character-reading or font-characterizing has been often the matter of concern in the field of optical pattern recognition. Among numerous applications, starting from an early demonstrative one [1] and later dealing with real problems such as the handwriting recognition [2,3], the recognition of cuneiform inscription (CI) signs using a multifunctional extended optoelectronic correlator (MEOC) device has been recently reported [4-6]. Let us briefly outline the problem. A total database of clay tablets that carry messages from the ancient times in the CI form comprises about half a million pieces spread all over the world [7]. In present conditions, the world CI database is endangered by natural or man-made destruction so that the fine-structure information from many tablets is already hardly interpretable. Therefore, a high-resolution archival storage, that would allow retrival and processing at later times, is required [5]. On the other hand, an efficient method for characterizing, identifying and classifying of the CI signs is of interest, too. Although cracks, scratches, fractures and other frequent unwanted artefacts can make reading very difficult, the CI sign fonts can also differ considerably due to different writers, writing tools, or periods of writing. Furthermore, as in handwriting, the CI sign samples vary in appearance even on the same tablet. Thus, the use of character recognition methods for minimizing the sensitivity of an in-class group of objects while maximizing the discrimination against other objects, usually called out-of-class objects, has been shown to be indispensable [5,6].

In this paper, an experimental device that utilizes a real-time joint transform correlator (JTC) architecture [8] and liquid crystal television (LCTV) type of addresable spatial light modulators [9] is described. The correlation experiments conducted on several preprocessed CI signs illustrate the discrimination ability of the device (in-class sensitivity vs. out-of-class sensitivity) as well as the effects of preprocessing of input signals on the output energy distribution.

2. *Experimental setup*

The correlation experiments were realized using the optoelectronic setup schematically shown in Fig. 1. To work in real time, two optical axes were organized. Vertically polarized HeNe laser light ($\lambda = 632.8$ nm) was spatially filtered

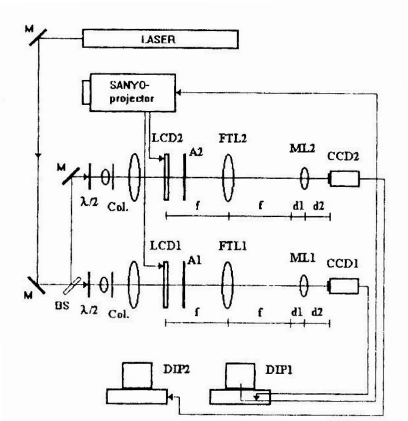

Fig. 1. Scheme of the experimental setup; M: mirror; BS: beam splitter; Col.: collimator; LCD1, LCD2: liquid crystal displays; A1, A2: polarizers; FTL1, FTL2: Fourier transform lenses; ML1, ML2: magnification lenses; DIP1, DIP2: digital image processing systems.

and collimated with a maximum input aperture of 50 mm. Two twisted nematic liquid crystal display (LCD) panels were separated from a disassembled Sanyo video projector (type PLC 300/ME), introduced into the input and Fourier transform

(FT) planes of the experimental setup, and driven with the original highly integrated electronics. The panels have 62.72×47.04 mm effective display size and 640×480 pixels, with a center-to-center spacing of 0.098×0.098 mm (see Fig. 2). Note that the active area is only 25%. We replaced the four poor-quality polarizers, originally attached to the LCD panels by two higher-quality rotatable polarizers and two $\lambda/2$ plates. These elements were rotated to give the best contrast at the CCD1 camera and the optimum correlation output at the CCD2 camera. The lenses FTL1 and FTL2 were used as Fourier transform operators, while the lenses ML1 and ML2 were added to enlarge the images taken by the CCD cameras. The magnification $d2/d1$ was optimized for the resolution requirements of the LCD panels, CCD cameras, and the output correlation signals.

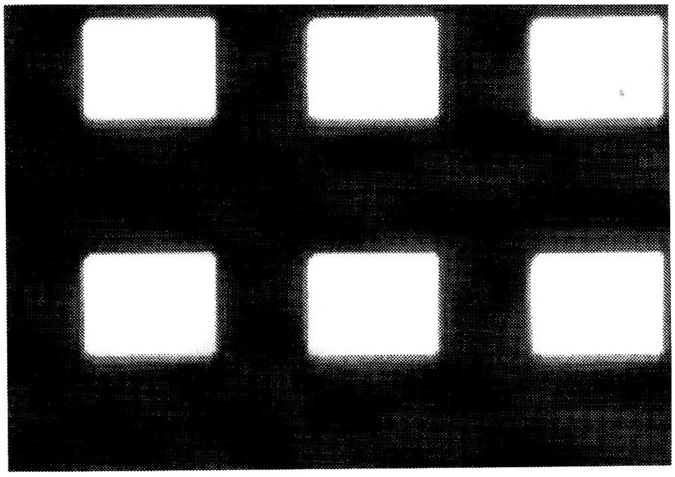

Fig. 2. Pixel structure.

3. Joint transform correlator principle

Consider two signals, a reference signal $r(x, y)$ and an arbitrary signal $s(x, y)$, displayed side by side on the panel LCD1 and thus forming the input distribution $f(x, y)$,

$$f(x,y) = r(x,y) \otimes \delta(x, y-b) + s(x,y) \otimes \delta(x, y+b), \tag{1}$$

where $\otimes$ represents the convolution operator, and 2b is the mean separation of two signals. The joint power spectrum (JPS), $|F(u,v)|^2$, captured by the CCD1 camera is given by

$$|F(u,v)|^2 = |R(u,v)|^2 + |S(u,v)|^2 +$$

$$+ R(u,v)S^*(u,v)\exp(-\mathrm{i}4\pi b\nu) + R^*(u,v)S(u,v)\exp(\mathrm{i}4\pi b\nu), \tag{2}$$

where capital letters denote the Fourier transform of a function, and the asterisk denotes a complex conjugate. The JPS is then displayed on the panel LCD2. By performing an additional FT operation using the lens FTL2, the CCD2 camera detects the output distribution $g(x, y)$

$$g(x,y) = r(x,y) \bullet r(x,y) + s(x,y) \bullet s(x,y) +$$

$$+[r(x,y) \bullet s^*(x,y)] \otimes \delta(x, y+2b) + [r^*(x,y) \bullet s(x,y)] \otimes \delta(x, y-2b), \qquad (3)$$

where $\bullet$ denotes the correlation operation. The operations indicated in Eqs. (1) and (3) are described in more detail in Ref. 10. From Eq. (3), it is obvious that the output plane consists of three spatially separated terms. The on-axis term corresponds to the overlapping auto-correlations of $r(x, y)$ and $s(x, y)$, while the two off-axis terms correspond to the cross-correlation between $r(x, y)$ and $s(x, y)$. The similarity between $r(x, y)$ and $s(x, y)$, can be qualitatively estimated by observing the correlation signals, and quantitatively determined by measuring the correlation peak values. Thus, the discrimination ability DA is given by

$$DA = \frac{\frac{1}{N}\sum_{i=1}^{N} I_{cp,i}}{\max\{I_c(x,y)\}}, \qquad (4)$$

where the numerator represents the average peak intensity of the in-class objects and the denominator is the maximum correlation value of the out-of-class object.

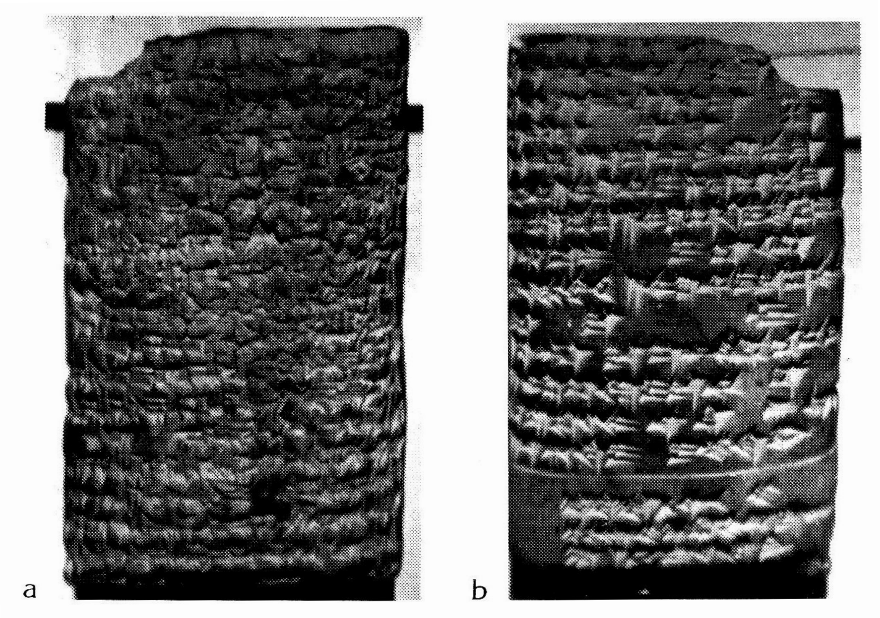

Fig. 3. Holographic reconstruction of the original tablet HS 158b, from Nippur, 1329 BC, a) front side, b) back side.

4. *Experimental results*

To demonstrate a holographic storage, Fig. 3 shows a holographic reconstruction of the original CI tablet HS 158b (Hilprecht-Sammlung Vorderasiatischer Altertümer Jena), from Nippur, 1329 BC. It is visible that the front side of the tablet is rather damaged containing crack and noise.

Several areas of interest on the original tablet were vertically illuminated, captured by a CCD camera, preprocessed digitally, and further processed, as illustrated in Figs. 4–7. Two sets of in-class objects were selected, one consisting of "I" sign samples and the other of "DI" sign samples, and two training sets were defined.

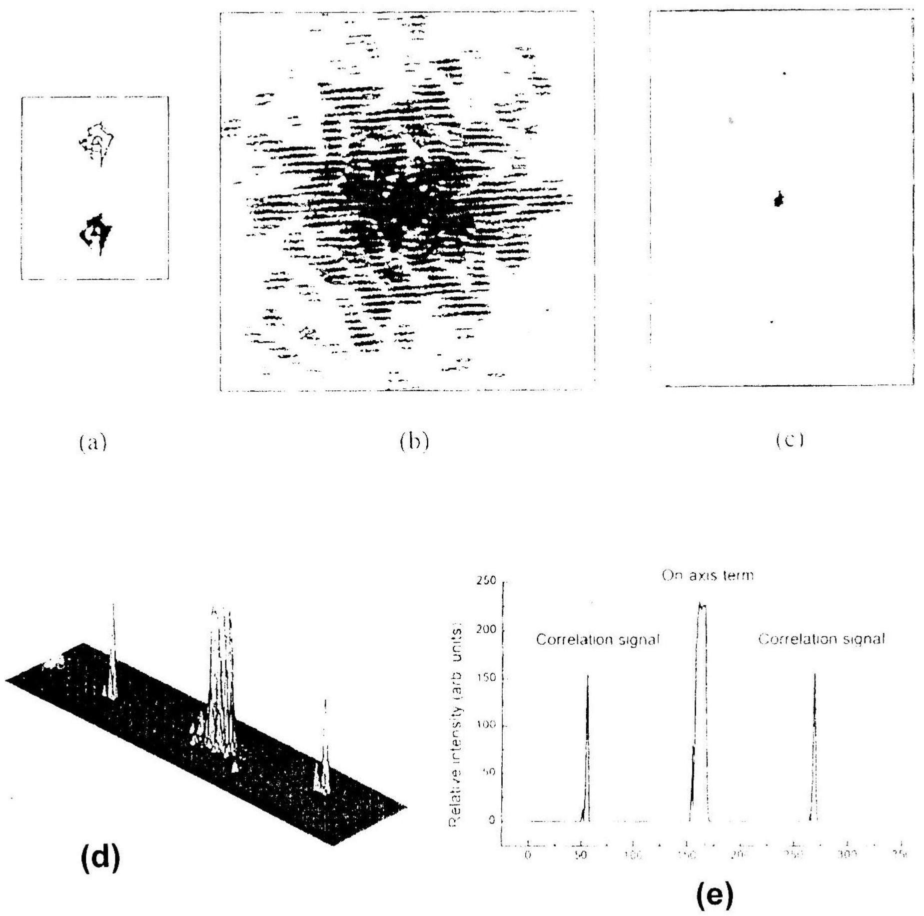

Fig. 4. JTC results: edge-extracted identical objects, a) input image, b) JPS, c) correlation output, d) 3-D perspective of c), e) cross-section of c).

TABLE 1.
Average normalized output correlation peak values.

Input objects	Full objects	Edge extract.	Mixed objects
Identical	0.61	1.00	0.74
In–class	0.48	0.49	
Out–of–class	0.04	0.07	

The selected samples were then isolated and normalized to give the same total power. From the training set, the average signs "I"-av and "DI"-av were synthesized by means of optical and digital procedures [5], to represent our reference signals. The average correlation peak power for various inputs is summarized in Table 1.

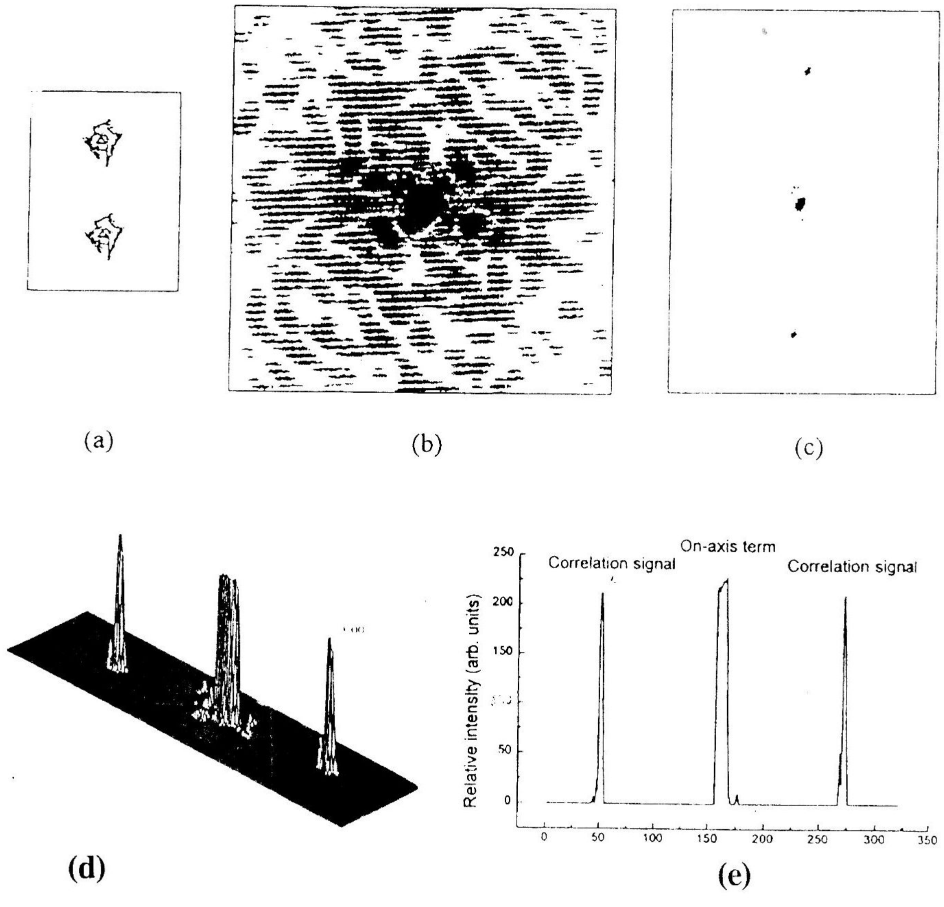

Fig. 5. JTC results: edge-extracted in-class objects, a) to e) the same as in Fig. 4.

The values are normalized to the maximum correlation peak power obtained for the identical edge-extracted input objects. Note that the out-of-class correlation peak values are one order of magnitude lower than the in-class correlation peak values. From Table 1, we can easily calculate the value of DA (Eq. (4)), which is equal to 12.0 for the full-objects case and 7.0 for the edge-extracted case. Some of the results from Table 1 we illustrate in Figs. 4–7.

Figure 4a shows two identical edge-extracted "DI"-av signs as an input image. The JPS and the resulting correlation outputs are shown in Figs. 4b and c, respectively. Furthermore, the output light distribution is shown in three-dimensional

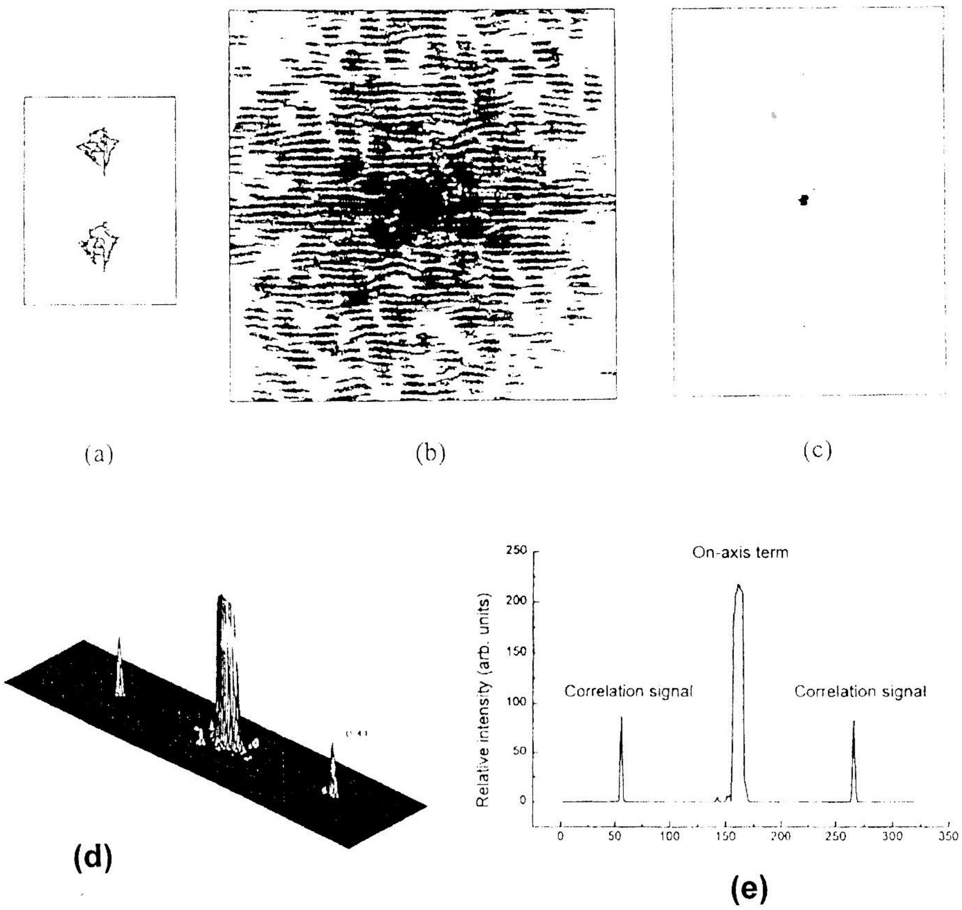

Fig. 6. JTC results: mixed identical objects, a) to e) the same as in Fig. 4.

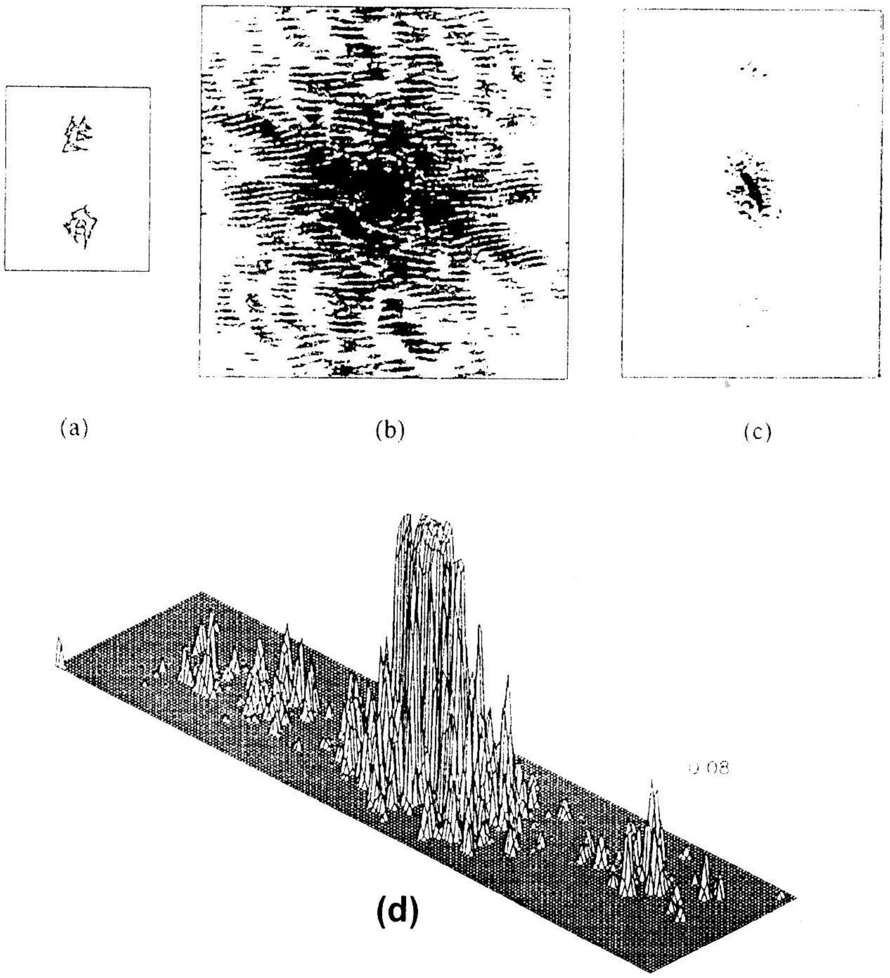

Fig. 7. JTC results: edge-extracted out-of-class objects, a) to d) the same as in Fig. 4.

perspective in Fig. 4d, while its cross-section is given in Fig. 4e. The correlation of one in-class sign with "DI"-av sign is shown in Fig. 5. The correlation of objects, edge-extracted "DI"-av with full "DI"-av, is shown in Fig. 6. In the mixed objects case, the correlation peak value is lower than in the edge-extracted case, but higher than in the full objects case. Finally, the correlation of one out-of-class sign (in this case "I"-av represents an out-of-class sample) with "DI"-av sign, is shown in Fig. 7, where the cross-section is not given because of the spreading of the correlation signal. We see from these figures that sharp correlation peaks are obtained for all in-class correlations, whereas a broad correlation peak is obtained for the out-of-class correlation.

5. *Conclusions*

We have demonstrated the use of an optoelectronic JTC device for the CI sign recognition. The basic advantage of the proposed system to the previously reported MEOC system [5,6] is in the real time operation and programmability due to using LCTV spatial light modulators. The latter advantage, however, was not utilized completely. We are currently characterizing the LCTV panels in order to use them as numerically addressed spatial light modulators.

By performing correlation experiments, the in-class and out-of-class sensitivities were calculated for differently preprocessed inputs. The average correlation peak power values for full patterns were compared to edge-extracted patterns. For identical input patterns, the edge-extracted case gives a higher diffraction efficiency. However, full patterns give a better discrimination ability. Finally, sharp correlation peaks are obtained for all in-class correlations, whereas broad correlation peaks are obtained for all out-of-class correlations.

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PRIMJENA KORELATORA S PREKLOPLJENIM FOURIEROVIM TRANSFORMATIMA I PANELIMA S TEKUĆIM KRISTALIMA ZA RASPOZNAVANJE KLINASTOG PISMA

Opisana je primjena optoelektroničkog korelatora s preklopljenim Fourierovim transformatima na problem raspoznavanja znakova klinastog pisma. Provedeni su korelacijski eksperimenti u realnom vremenu uz pomoć adresabilnih prostornih modulatora svjetlosti s tekućim kristalima. Raspravljane su korelacijske osjetljivosti objekata unutar i izvan definirane klase te utjecaj prethodne obrade ulaznih signala uzetih s originalne glinene pločice.