PARALLEL SPACE-TIME STRUCTURE FOR COMPUTER VISION SYSTEMS

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Abstract. In the Jasinevitchius (1991) we have introduced the new approach to the parallel space-time computing structures (PASTICS). This paper deals with the further elaboration of the concept and synthesis of a particular architecture dedicated to the computer visions systems.

A dynamic pattern recognition problem has predetermined the functional organization of the newly developed architecture. A gist of the paper lies in a methodology of the synthesis and in the vitality of the obtained structures.

Key words: computer visions, parallel processing, space-time structure.

1. **Introduction.** According to the parallel space-time computer architecture concept, called in the Jasinevitchius (1991) as PASTICS, the functional description of the real problem predetermines the structure, dedicated to the problem's solution. Each problem in general case is described in space-time co-ordinates. That is the reason why the corresponding computer structures must perform all operations with time or/and space dependent variables.

Here an attempt is made to synthesize the PASTICS dedicated to the computer vision systems dealing with the dynamic pattern recognition problems.

2. **Description of the problem.** Let us assume that the field of observations with the two-dimensional forms on it or characters to be recognized by the computer visions system, or even abstract patterns describing the situation to be evaluated and classified, is presented by the set of measurable parameters. For each particular

object the parameters can be given as a cortege or a row vector $\vec{x} = (x_1, \ldots, x_i, \ldots, x_j, \ldots, x_N)$. Let us also assume that the unknown object must be dedicated to one of the s classes $p = 1, 2, \ldots, r, \ldots, s$. This dedication procedure is based on the evaluation of a degree of similarity

$$\Phi(\vec{K_p}, \vec{x}) \text{ for } \forall_p, \tag{1}$$

where $\vec{K_p}$ is a some sort of generalized pattern of the p-th class, and the final decision must be made according to the $\max_{\forall_p} \Phi(\vec{K_p}, \vec{x})$, i.e., the maximum of the similarity. The most important peculiarities of the problem under the discussion are following:

1) descriptions of objects such as $\vec{x}$ are presented in space domain, i.e., in space co-ordinates, and all kind of preprocessing operations as well as the evaluation of the degree of similarity also must be performed in space co-ordinates at the one particular given time moment;

2) the generalized pattern $\vec{K_p}$ (for $\forall_p$) changes in time domain, i.e., $\vec{K_p} = \vec{K_p}[n]$, where $n = 0, 1, 2, \ldots$ – are the moments or the points of the time co-ordinate axis. These changes are caused by the space-time alterations in the data base where the characteristic representatives of all classes are locates. For example, let us assume that each class r is represented by arbitrary chosen characteristic patterns $\vec{a_r^l}[n] = (a_{r1}^l[n], \ldots, a_{ri}^l[n], \ldots, a_{rj}^l[n], \ldots, a_{rN}^l[n])$, $l = 1, 2, \ldots, k, \ldots, L$ and the same can be stated for $\forall_r$. It is ease to imagine that preprocessing of each $\vec{a_r^l}[n]$ must be fulfilled in space domain, but all changes of the $\vec{K_p}[n]$, caused by the changes of $\vec{a_r^l}[n]$ in time, must be fulfilled by time operations whilst evaluation of their similarities are obliged to be combined space-time operations.

For the simplified case (Jasinevitchius, 1988) the preprocessing procedure for each x_i can have, for example, the following form

$$\overset{o}{x_i} = x_i - 1/N \sum_{j=1}^{N} x_j; \tag{2}$$

the generalized pattern of the p-th class can be expressed as

$$\vec{K_p}[n] = \left(K_{p1}[n], \ldots, K_{pi}[n], \ldots, K_{pN}[n]^T \right); \tag{3}$$

where $0 \leqslant K_{pi}[n] \leqslant 1$ for $\forall_{pi}$ and T is for transpositions: these last restrictions simplify the hardware as well as software implementation of the PASTICS for computer vision. The proper $\vec{K}_p[n]$ can be found as the space-time solution of the problem consisting of the maximizing of the

$$\Phi(\vec{a}_p^k, \vec{K}_p[n]) \to \max \tag{4}$$

under the set of restrictions

$$\Phi(\vec{a}_p^l, \vec{K}_p[n]) \geqslant \gamma \Phi(\vec{a}_p^k, \vec{K}_p[n]), \quad l = 1, 2, \ldots, L, \tag{5}$$

$$\Phi(\vec{a}_p^k, \vec{K}_p[n]) \leqslant \varkappa \Phi(\vec{a}_p^k, \vec{K}_p[n]), \tag{6}$$

$$l = 1, 2, \ldots, L, \quad r = 1, 2, \ldots, s, \; \neq p, \; \gamma > \varkappa > 0,$$

$$0 \leqslant K_{pi}[n] \leqslant 1 \quad \text{for} \quad \forall_i. \tag{7}$$

Here $\vec{a}_p^k$ – is an arbitrary chosen pattern from the set of representatives of the p-th class and two positive coefficients γ and $\varkappa$ guarantee a proper level of distinguishability between the k-th representative of the p-th class and the know representatives of the concurrent class $r = 1, 2, \ldots, s, \; \neq p$ and certain level of similarity among all the representatives of the p-th class. It must be emphasized that the part of the PASTICS for computer vision system in which the time-variant $\vec{K}_p[n]$ for $\forall_p$ are to be computed is destined to solve in parallel s problems described by (4) – (7) for $\forall_p$.

3. Implementation of the PASTICS. The parallel space preprocessing structure acting according to the (2) can be built as it shown in the Fig. 1 where corresponding PASTICS is presented and where each summer of the σ-type calculates $\vec{Y}_i[n] = 1/N \sum_{m=1}^{i-1} x_m[n] + 1/N x_i$ and the summer of the $\varkappa$-type calculates the expression (2).

Evaluations of similarities of the given and preprocessed $\vec{x}$ to the each generalized pattern of the class for $\forall_p$ can be computed by the parallel space structure presented in Fig. 2. Here

$$\tilde{y}_{pj}[n] = \sum_{m=1}^{p-1} K_{pm}[n] \cdot \overset{o}{x}_m[n] + K_{pj}[n] \cdot \overset{o}{x}_j[n].$$
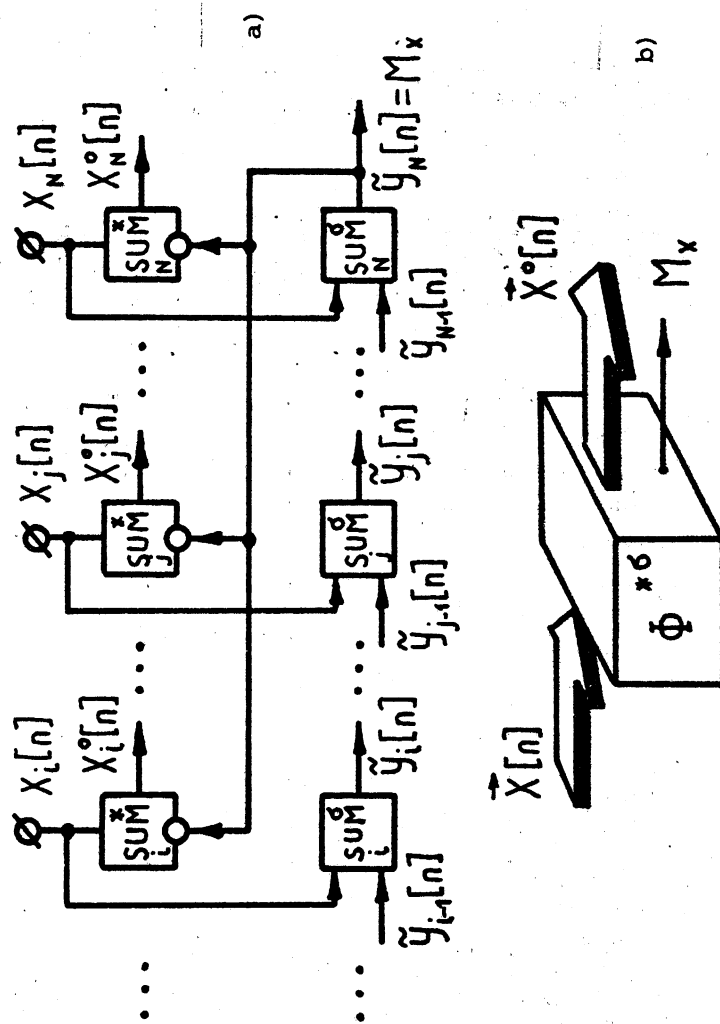
Fig. 1. Parallel space preprocessing structure:
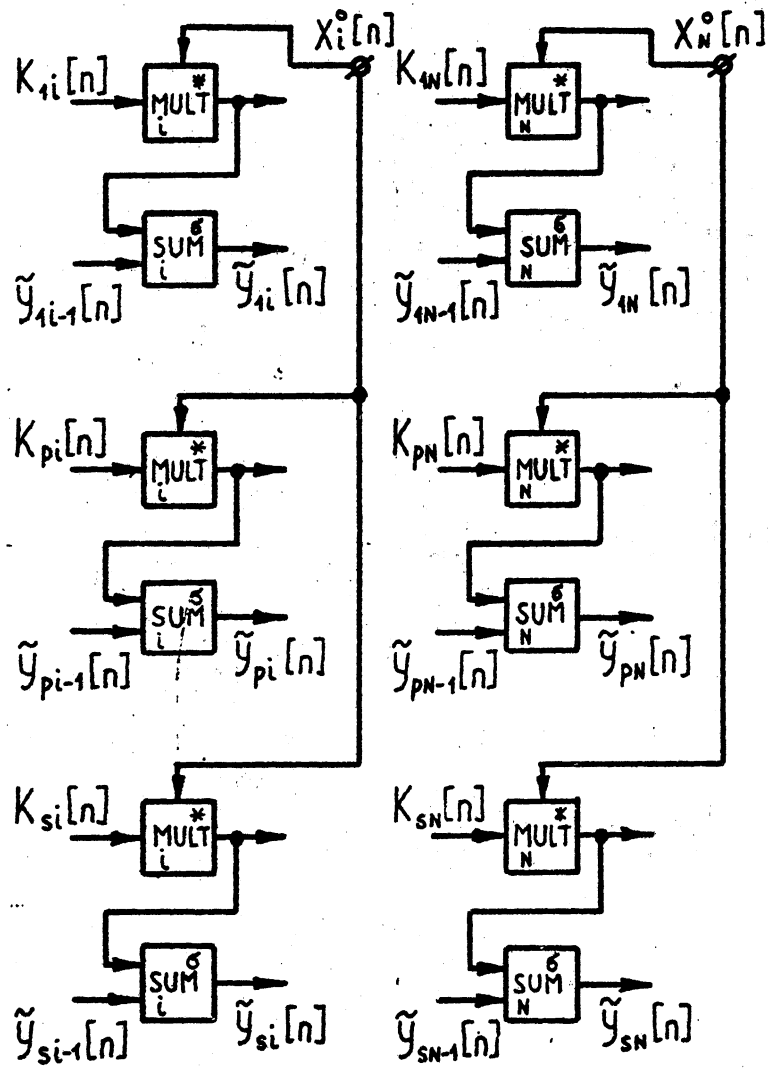   a) detalized,
    b) generalized case.

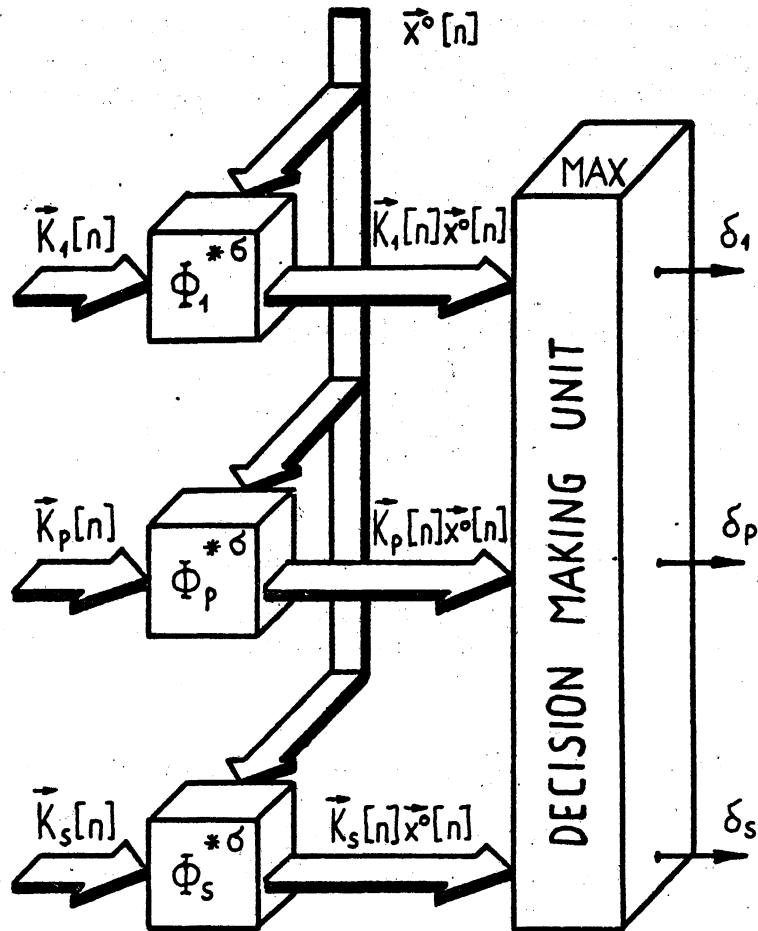**Fig. 2.** Space evaluation of the similarity.

Fig. 3. Generalized space structure for similarity evaluation and dynamic decision making.

And the PASTICS as a dynamic decision making unit acting according to the $\max\limits_{\forall p} \Phi(\vec{K}_p, \vec{x})$ and expressing it's decision in the form of vector δ with the component 1 in the output of the channel, corresponding to the maximal value of a similarity, and zeros in all other channels is presented in Fig. 3.

The parallel space-time structure for dynamic correction of generalized patterns is developed as an implementation of an iterative algorithm for (4) – (7) solving. This algorithm can be derived as Pyne algorithm to solve the linear programming problem and can be written in the scalar form as

$$K_{pi}[n] = K_{pi}[n-1] + h\Delta_i^p[n-1], \tag{8}$$

where

$$\Delta_i^p[n-1] = c \cdot a_{pi}^{ok} - \sum_{l=1}^{L} \delta_{pp}^l[n-1](\gamma \overset{o}{a}_{pi}^k - \overset{o}{a}_{pi}^l)$$

$$- \sum_{r=1}^{s,\neq p} \sum_{l=1}^{L} \delta_{pr}^l[n-1](\overset{o}{a}_{ri}^l - \varkappa \overset{o}{a}_{pi}^k) \tag{9}$$

and

$$\delta_{pp}^l[n-1] = \begin{cases} 0, & \text{if } H_{pp}^l[n-1] \leqslant 0, \\ 1, & \text{if } H_{pp}^l[n-1] > 0, \end{cases} \tag{10}$$

$$\delta_{pr}^l[n-1] = \begin{cases} 0, & \text{if } H_{pr}^l[n-1] \leqslant 0, \\ 1, & \text{if } H_{pr}^l[n-1] > 0, \end{cases} \tag{11}$$

and

$$H_{pp}^l[n-1] = -\sum_{i=1}^{N} \overset{o}{a}_{pi}^l K_{pi}[n-1] + \gamma \sum_{i=1}^{N} \overset{o}{a}_{pi}^k K_{pi}[n-1], \tag{12}$$

$$H_{pr}^l[n-1] = -\sum_{i=1}^{N} \overset{o}{a}_{ri}^l K_{pi}[n-1] - \varkappa \sum_{i=1}^{N} \overset{o}{a}_{ri}^k K_{pi}[n-1], \tag{13}$$

(see, for example, Korn (1972) or Jasinevitchius (1988)).

The PASTICS for the parallel matrix dot products $\vec{a}_p^{ol} \vec{K}_n[n-1]$ we need to compute the expressions of the type (12) and (13) is shown in Fig. 4. They are used to compute the $\delta_{pr}^{(l)}$ for $V_{p,r,l}$ in the PASTICS presented in Fig. 5. The parallel space-time structure for the dynamic correction of the whole system of generalized patterns $\vec{K}_p[n]$ ($p = 1, 2, \ldots, S$) is shown in Fig. 6. The corrective quantities $\Delta_i^p[n-1]$ for $V_{p,i}$ can be computed by the structure presented in Fig. 7.
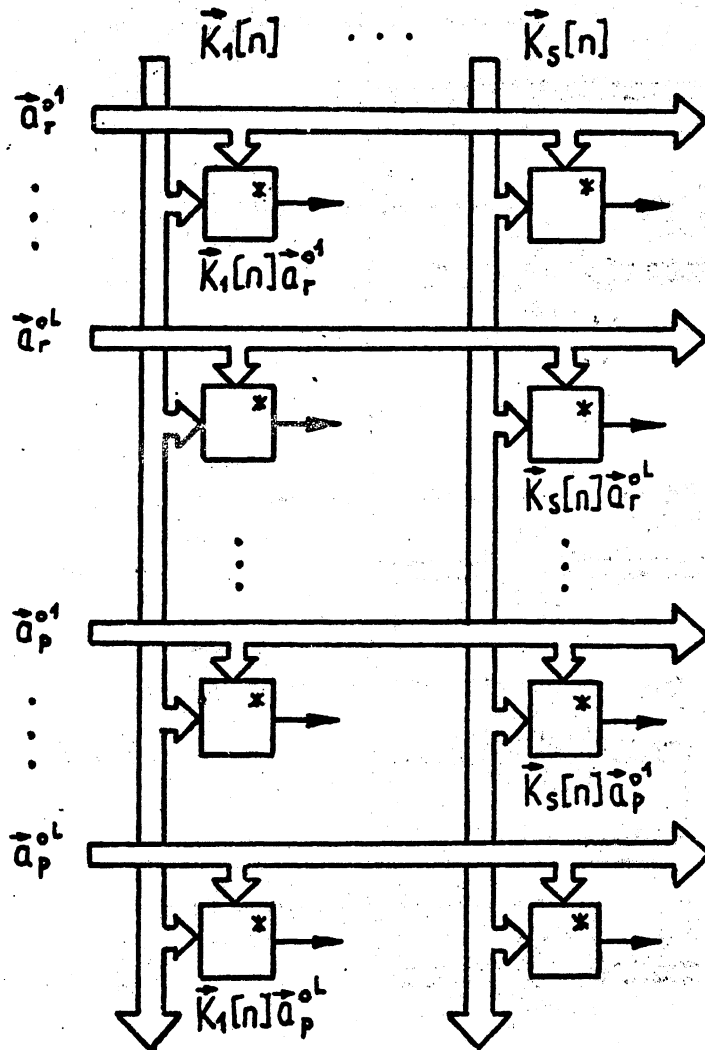
Fig. 4. Space evaluation of the parallel matrix dot products $\vec{a}_r^{ol}\vec{K}_p[n]$ for $\forall_{p,r,l}$.
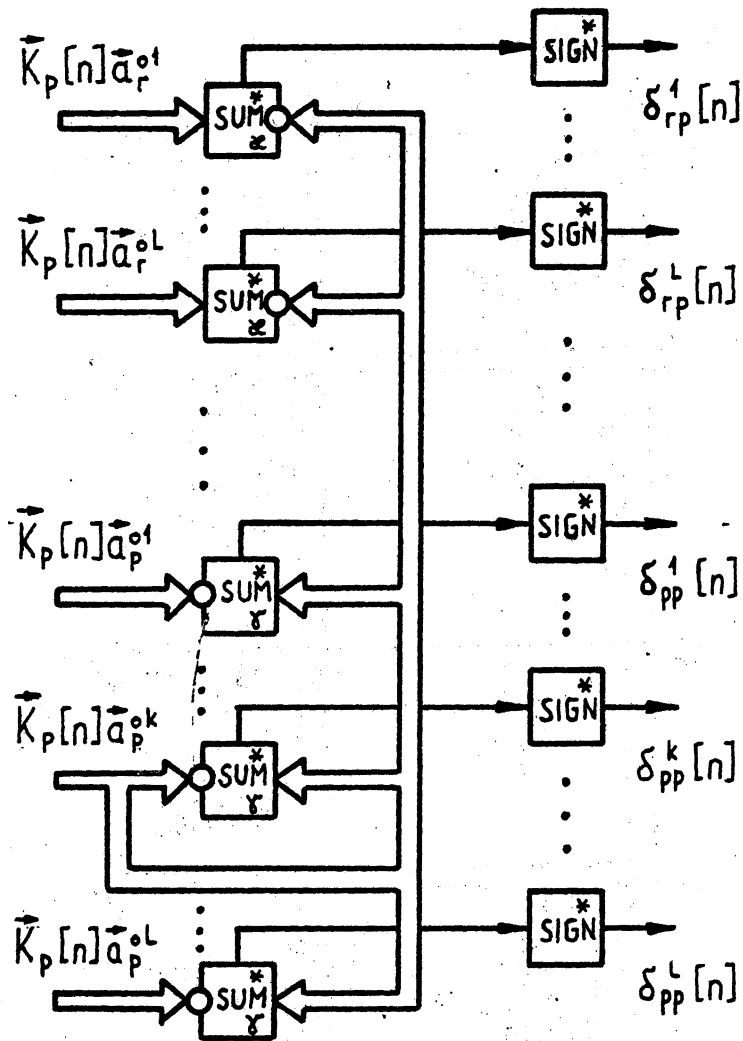
Fig. 5. Space structure for the operations to compute conditions $\delta^l_{pr}[n]$ for $\forall_{p,r,l}$.
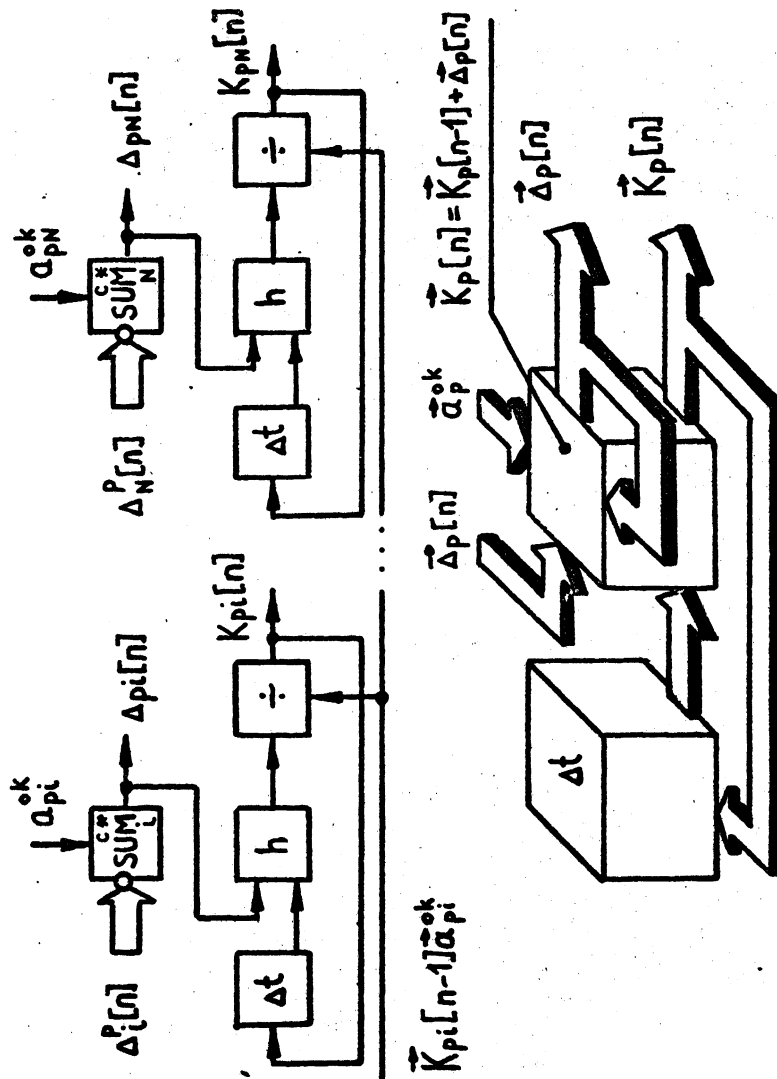
Fig. 6. Parallel spece-time structure for the dynamic corrections of $\vec{K}_p[n]$ for $\forall_p$.
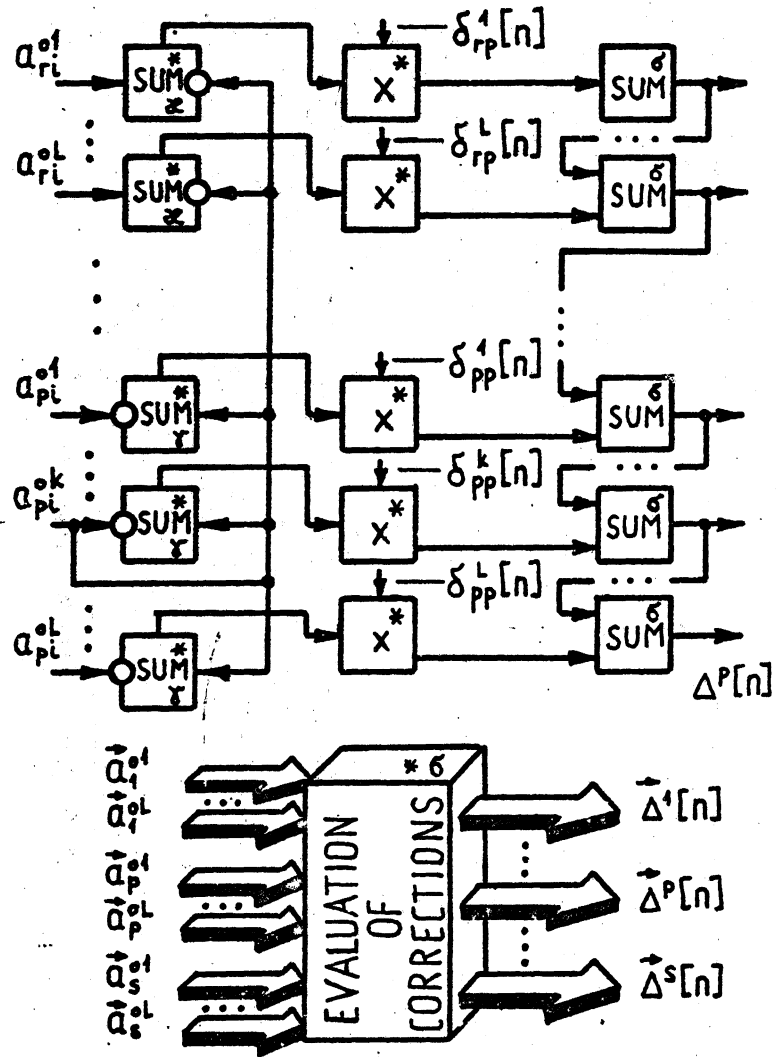
Fig. 7. Parallel space structure for the evaluation of the corrections $\Delta_i^p[n]$ for $\forall_{p,i}$.
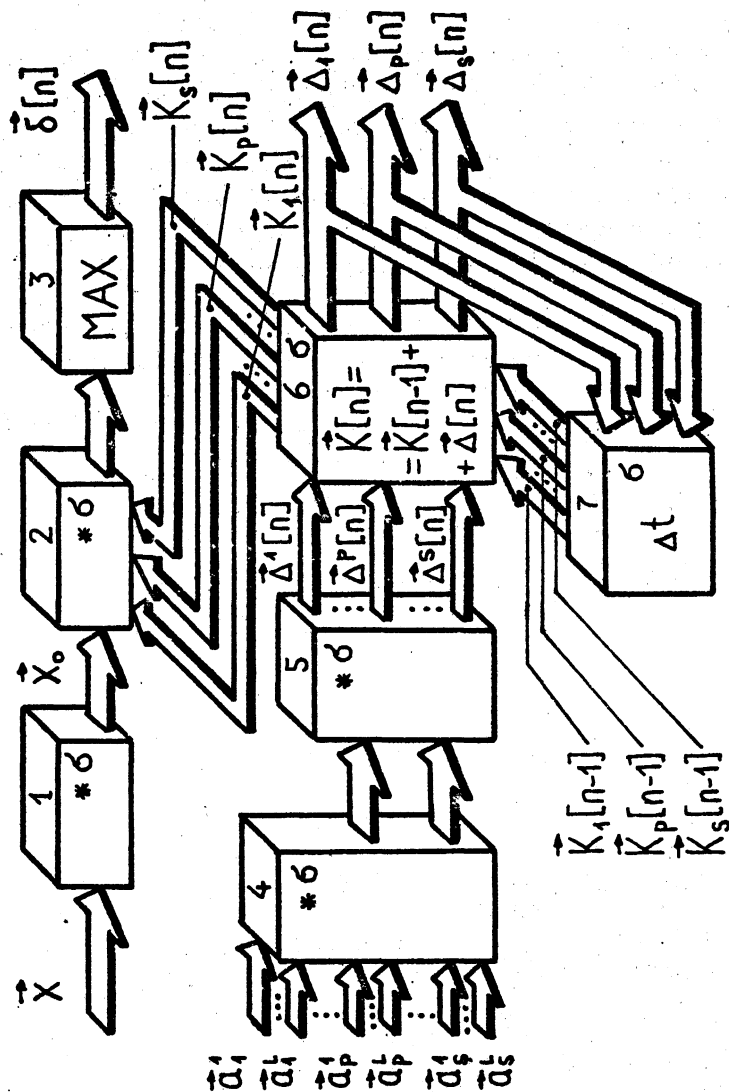
Fig. 8. Generalized block-diagram of the space-time structure
for dynamic computer vision. 1. Space processing.
2. Space similarity evaluation. 3. Decision making.
4. Matrix dot product. 5. Evaluation of corrections.
6. Space-time dynamic correction. 7. Time delay.

So the generalized block-diagram of the PASTICS for the dynamic computer vision system can be presented as it is shown in Fig. 8. Having in mind parts of the PASTICS shown in Fig. 1–7 it is ease to conclude that the PASTICS for the computer vision consists of several neural-type strata processing in parallel space and time dependent information while some of the operations have a space as an independent variable, some operations have a time as independent variable and some – both of them.

4. Concluding remarks. In the paper we discussed in detales the new approach to the synthesis of a dedicated parallel space-time computing structure for computer vision systems. The result obtained can be considered either as an architecture of a certain specialized hardware or as a flow chart of the program to solve the dynamic character recognition problem lying in the base of the computer vision process.

Must be emphasized that the same approach can be used to develop various expert systems and other systems with elements of artificial intelligence.

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