Realisation of automatic correlation within a digital stereo plotter

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An essential component of every stereo plotter is to correlate homologue points within stereo image pairs. A digital plotter offers the particular feasibility of the automatic correlation. The realisation of the correlation block within a new digital stereo plotter will be presented. In particular there will be comments on
- the utilisation of several processors
- the availibility for different operations at the digital plotter

Synopsis of the system presuppositions

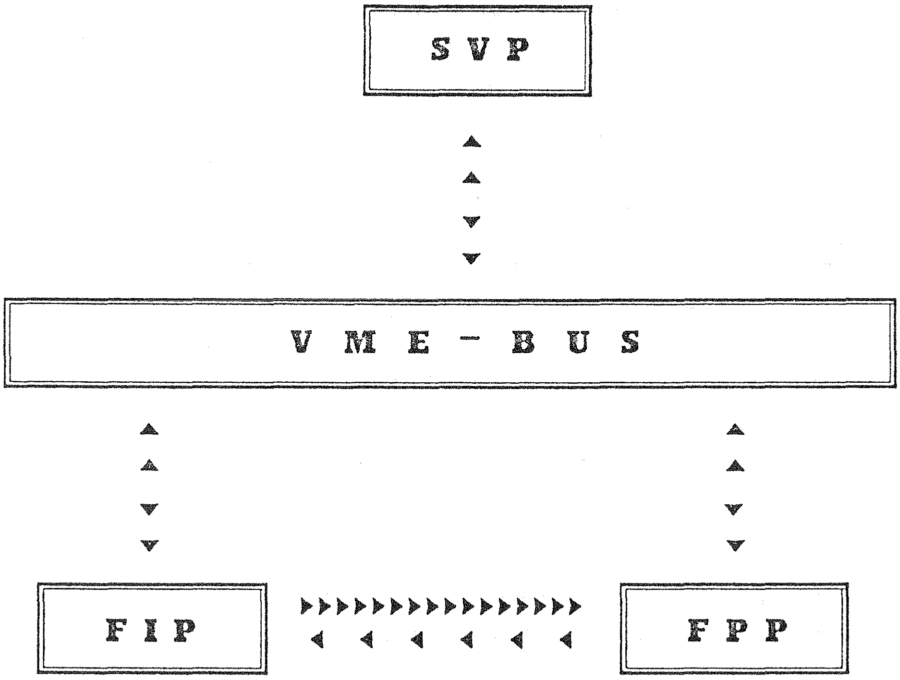
The correlation within the Stereo Work Station SWS1 is based on the so called CORRELATIONDRIVER. The CORRELATIONDRIVER consists on a system of functions using a triple of processors. These processors are:
1. Super Visor Processor(SVP)
2. Floating Point Processor(FPP)
3. Filter Processor(FIP)

The speed of the correlation is founded on the parallel and the optimal employment of these specially orientated processors.
Within the image processing system GOP302 of the swedish company Context Vision[1] it is compulsary to program in three different computer languages if you want to use these three processors. In the same order as above specified processors:
1. C
2. Gop Programming Language(GPL), comparable to PASCAL
3. Universal Micro Assembler(UMA)

The SVP is the coordinator of the employment of all available processors. Within the system there are even more processors integrated than used in the actual correlation. There are per example the Geometric Transform Processor(GTP), the Bit Orientated Processor(BOP) and two Display Control Units(DCU). Functions of the SVP are:
- Load defined image data
- Load FIP and FPP program codes in their memories
- Read and set flags sent to or received from FIP or FPP
- Load LOOKUP table for FIP
- Computing operations as usual

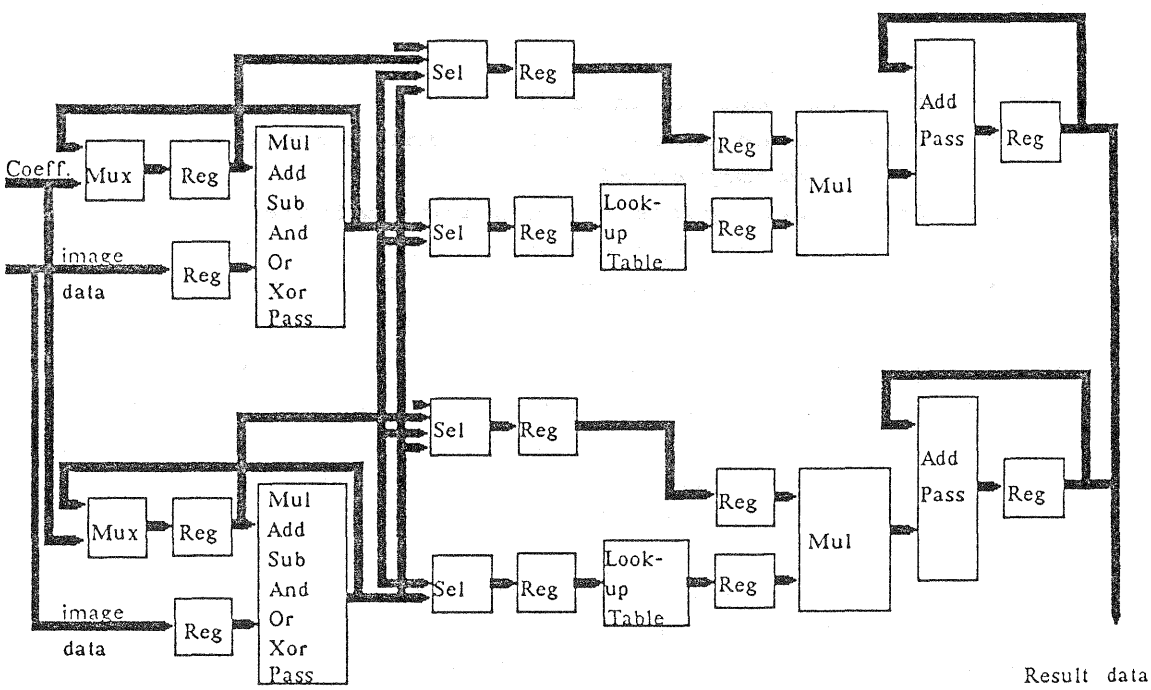
Graphic 1 shows the combination of the three processors. (next page)

The FIP does its work within the so called pipeline. This processor is mainly used to perform image filtering operations(convolutions) between images, and operators(kernels). The input images are held in the image segment memory, represented as complex valued 16+16-bit words. Seperatly the kernel data are stored in the same manner and in there own memory. Computations are performed in parallel in pipeline units, in order to produce the complex valued products. (see Graphic 2, next page)



Graphic 1: Combination of processors

The FPP is normally used for further computations on the convolution outputs from the FIP, taking e.g. contextual rule modifiers into account. The processor contains pipelined hardware units for floating point addition and multiplication, together with a special unit for calculations of transcendental functions.



Graphic 2: FIP - pipeline

The implemented correlation algorithm

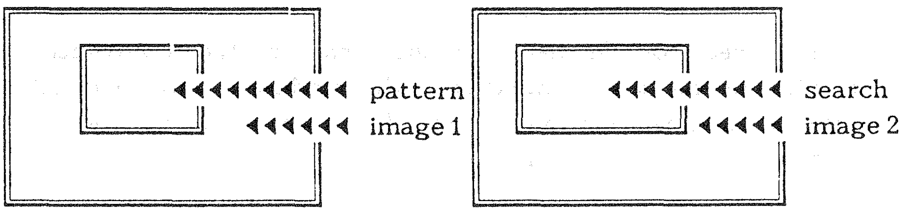
In principal the structur of the CORRELATIONDRIVER allows the implementation of any correlation algorithm. Concerning the actual version it is the algorithm of Pearson and Bravais[2] with subpixel interpolation. This is understood as an example. With the aid of it the schedule will be explained. The correlation function is:

$$\text{Coeff} = \frac{[\text{Pattern} \times \text{Search}] - [\text{Search}] \times [\text{Pattern}] / n}{\text{SQRT}\left(([\text{Search}\times\text{Search}]-[\text{Search}]^{2}/n)\times([\text{Pattern}\times\text{Pattern}]-([\text{Pattern}]^{2})/n)\right)} \tag{1}$$

with:

Pattern	=	element z,s of pattern matrice; z=1,zm; s=1,sm
Search	=	element z,s of search matrice section; z=1,zs; s=1,ss
[ ]	=	sum
n	=	number of elements within pattern matrice
zm/sm	=	number of pattern matrice rows/columns
zs/ss	=	number of search matrice rows/columns

The following situation is presupposed:



Graphic 3

Pattern as well as search matrice contain the object information.
There are three main tasks for the SVP:

1st main task = Load pattern matrice into kernel memory of FIP

2nd main task = Load pattern and search matrice into image segment memory of FIP

3rd main task = Load codes for FIP and FPP into their program memories and start them

The best explaination for the main task of the FIP is received by means of the correlation function. It is necessary to know that it is the strength of the FIP to have a the high through put of mass data additions and mutiplications. The following terms of the formular have these requirements:

- *[Pattern] = sum of pattern matrice elements(p.m.e.)*
- *[Search] = sum of search m.e.*
- *[Pattern*Pattern] = sum of square of p.m.e.*
- *[Search*Search] = sum of square of s.m.e.*
- *[Pattern*Search] = sum of products from pattern and search matrice elements*

Integrated in the flow of the FIP work there is an implicit variation of the image grey values by means of LOOKUP tables. After all this the main task of the FIP is defined. The results of the FIP are continuously transfered to the FIFO.

Because the actual correlation uses a pattern matrice which moves through the search matrice(variable step width) deriving the coefficient for every position, the FPP can function in parallel even if only one correlation is done. This situation is similar for iterative correlation processes.
There are two main tasks for the FPP:
The first is the computation of the lot of the correlation coefficients. The adjacent main task number two means interpolation for subpixel accuracy. This interpolation adjustment determines a two dimensional polynomial. The polynomial shall have the best fit within a window in the neighbourhood of the coefficient mountain top. The usage of the second main task is not compulsary.
At the end the FPP transfers his results to the SVP. Beside his control functions the SVP communicates with the world. The input parameters are sent to the SVP and the results are got from the SVP. The modular system of the CORRELATIONDRIVER needs the following input parameters:

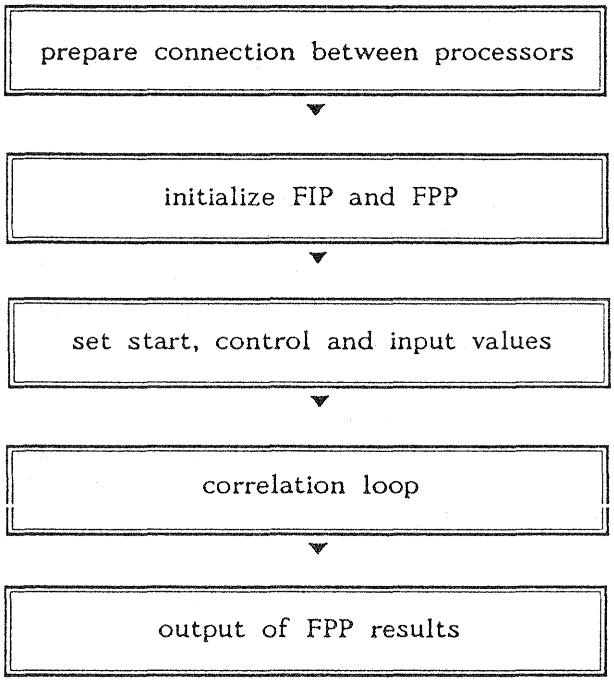
- image name 1
- image name 2
- number of rows of pattern matrice
- number of columns of pattern matrice
- number of rows of search matrice
- number of columns of search matrice
- step width in row direction
- step width in column direction
- size of interpolation window(square)
- row of pattern matrice. center within image 1
- column of pattern matrice center within image 1
- row of search matrice center within image 2
- column of search matrice center within image 2

The output parameters are:

- maximal correlation coefficient
- row of maximal correlation coefficient relative to image 2 (real value)
- column of maximal correlation coefficient relative to image 2 (real value)
- standard deviation of correlation coefficient from interpolation
- error code

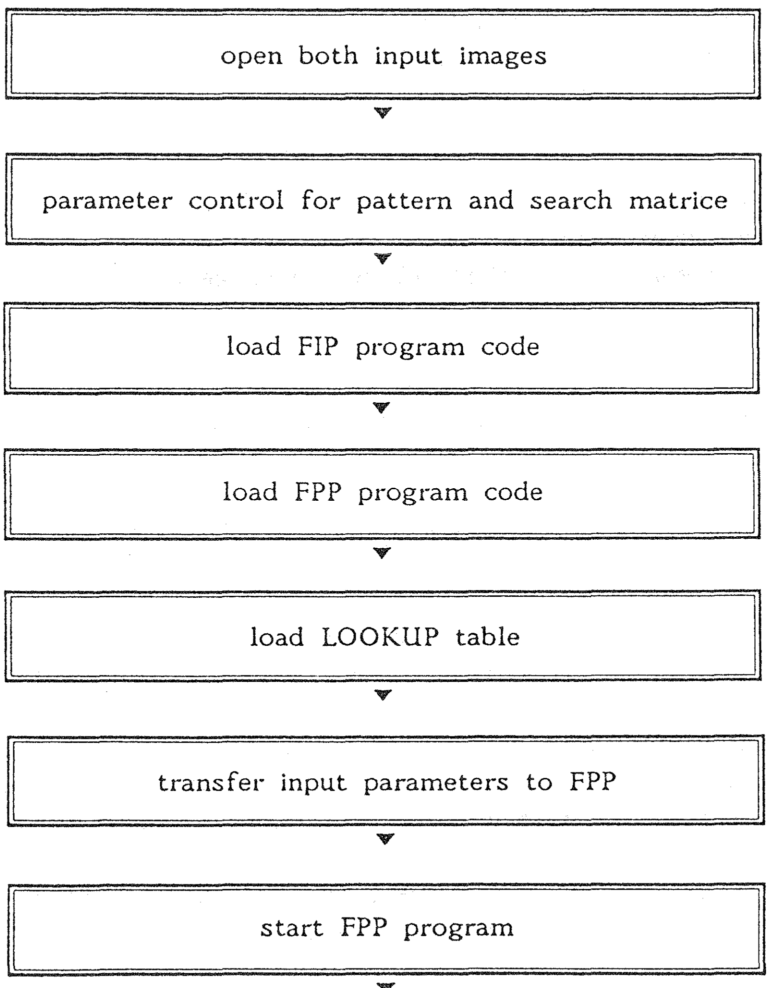
The communication takes place mainly via structures within specially defined files. Depart from this it is possible to define the last four input parameters (matrice centres) manually using the display and the mouse. With a view to the floating mark at the digital stereo plotter this will be a necessity.
Graphic 4 shows a global flow chart of the CORRELATIONDRIVER. (next page)

The internal communication between the processors happens with the help of flags. In this way parallel processes can be regulated. Furthermore pay attention to the circumstances that it is not necessary to repeat all of the ten named correlation steps again and again. If a measurement series is executed with constant correlation parameters the first 6 steps have to be done only once. This certainly implies an essential time saving.



Graphic 4: global flow chart of CORRELATIONDRIVER

To get a more detailed understanding of the correlation loop look at graphic 5.



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load pattern and search matrice for FIP

start FIP program

restore FPP results

Graphic 5: Loop

Hardware dependend limits

Two further aspects have an important meaning for the actual correlation:
- maximum size of correlation matrices
- speed of correlation

Concerning the size of pattern and search matrice four memories and their size have to be taken into consideration.

4 096 microwords <- program memory for FIP code
15 625 microwords <- data memory for FPP code
4 096 16+16Bit-words <- kernel memory
16 384 16+16Bit-words <- image memory

One microword consists of 64 bit.

For the computation of the maximal size we take into account
- *number of elements of pattern matrice -> ELEMENTS*
- *number of correlation coefficients -> COEFFICIENTS*
- *length of main program code for FIP, here constant 66 microwords*

The maximal pattern matrice size is derived on the basis of the criterias FIP program memory and kernel memory. The requirement of space within the FIP program memory illustrates the following formular(2):

$$\text{ELEMENTS microwords} \cdot 66 \text{ microwords} <= 4\,096 \text{ microwords} \qquad (2)$$

Table 1 illustrates that the pattern matrices size is mainly limited by the FIP program memory(see column 5). The number of ELEMENTS in column 4

example	maximums rows	columns	ELEMENTS	microwords
1	2	3	4	5
1	3	223	669	4080
2	25	26	650	3966

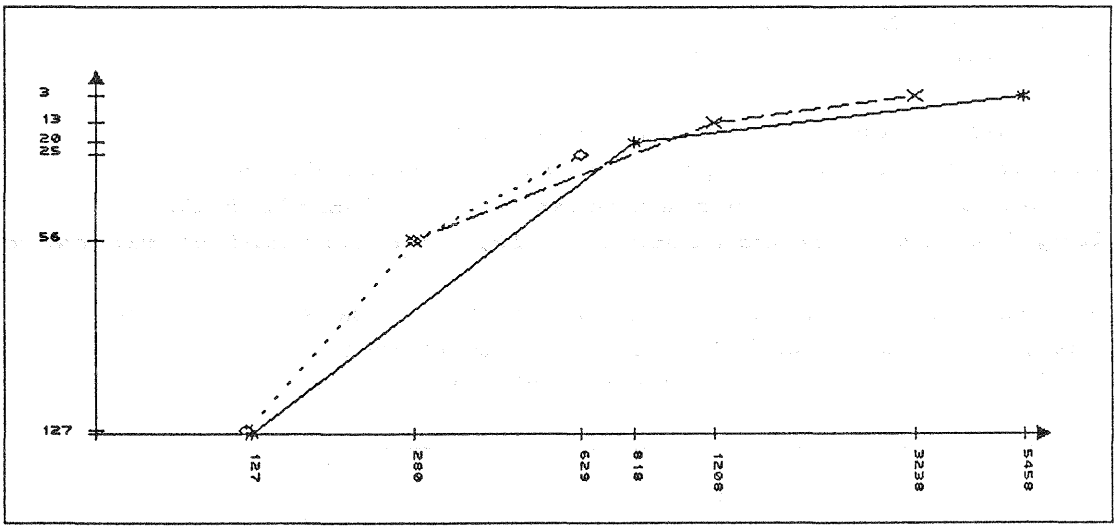
Table 1: maximal pattern matrice size

never reaches the kernel memory limitation.
The maximal search matrice size is found on the basis of the criterias FPP data memory and image memory.

			maximums			sum
	pattern	matrice	search matrice		COEFFI-	of
exam.	rows	columns	rows	columns	CIENTS	elements
1	2	3	4	5	6	7
3	3	3	3	5 458	5 460	16 383
4	3	3	20	818	14 688	16 369
5	3	3	127	127	15 625	16 138
6	3	223	3	3 238	5 016	16 383
7	3	223	13	1 208	10 846	16 373
8	3	223	56	280	2 132	16 349
9	25	26	25	629	604	16 375
10	25	26	56	280	8 160	16 330
11	25	26	126	124	10 098	16 274

Table 2: maximal search matrice size

As it is shown in table 2 the presuppositions for the correlation matrice sizes are entirely acceptable. To visualize the data of the table graphic 6 has been drawn. Of course row and column can be exchanged.



—— 3*3 pattern matrice
x— —x 3*223 " "
◇· · · ·◇ 25*26 " "

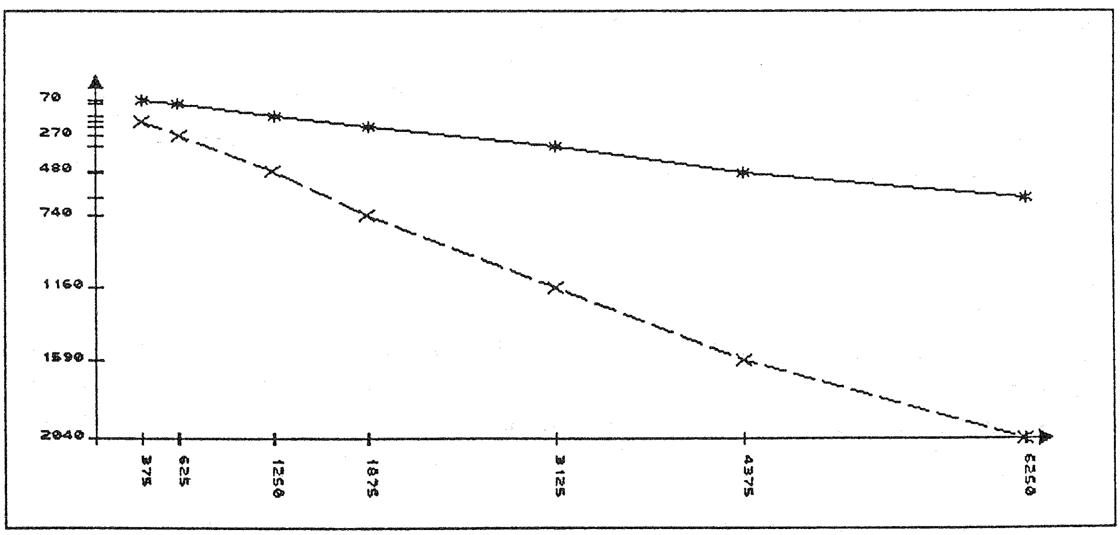
Graphic 6: maximal search matrice size

Speed of the correlation

If one talks about correlation one of the first questions will be that of the speed. Therewith the second characteristic of the correlation within the digital stereo plotter will be considered. The following data mean especially the time which is necessary to complete one loop(see above). The correlation investigations discern between matrice sizes and the dependend correlation coefficients. The subpixel interpolation is only a matter of some 10 milliseonds.

	pattern matrice		search matrice			time cons.
exa.	rows	columns	rows	columns	COEFFI-CIENTS	correlation [millisec.]
1	2	3	4	5	6	7
12	3	3	3	5 458	5 460	290
13	3	3	20	818	14 688	670
14	3	3	127	127	15 625	770
15	3	223	3	3 238	5 016	1 070
16	3	223	13	1 208	10 846	3 790
17	3	223	56	280	2 132	1 170
18	25	26	25	629	604	290
19	25	26	56	280	8 160	2 820
20	25	26	126	124	10 098	3 540
21	25	26	50	40	375	190
22	25	26	50	50	625	270
23	25	26	50	75	1 250	480
24	25	26	50	100	1 875	740
25	25	26	50	150	3 125	1 160
26	25	26	50	200	4 375	1 590
27	25	26	50	250	6 250	2 040
28	13	13	32	32	380	70
29	13	13	32	43	620	90
30	13	13	32	75	1 260	160
31	13	13	32	106	1 880	220
32	13	13	32	168	3 120	336
33	13	13	32	231	4 380	490
34	13	13	32	325	6 260	640

Table 3: time consumption



—— 13*13 pattern matrice

×— —× 25*26 " "

Graphic 7: time consumption

The examples from number 18 to 34 are additionally illustrated by graphic 7 to give an overview of expected time consumptions of correlation for predefined matrice sizes.
The linear dependency between the duration of correlation and the number of computed coefficients is unequivocal. As expected this means the better the approximation the quicker the correlation. Furthermore pay attention to the result, that multiplying the pattern matrice fourfold increases the time consumption from threefold up to fourfold dependend on the number of coefficients.

Possibilities of employment

The described CORRELATIONDRIVER has been implemented within the digital stereo plotter[3] within the following sections:
- interior orientation of aerial photographs
- interactive correlation of image pairs
- creation of digital elevation models(DEM)

The interior orientation of aerial photographs is kind of an exception, because in this case the real image 2, i.e. a section near to the fiducial marks, has to be correlated with a synthetic mask. The operator positions the floating mark approximately on the respective fiducial mark. And again as explained synthetic pattern will be correlated within a defined search matrice. This means a essential acceleration for the interior orientation of aerial photographs.
In the investigated example it needs only 0.26 seconds to correlate fiducial mark mask of the size 17*17 pixels with a 49*49 pixel search matrice. No operator will be able to surpass this speed. The accuracy is not a matter of this paper, because we handle a well known algorithm. Furthermore the operator is enabled to take the measurement of fiducial marks manually, if the accuracy results seem not to reach acceptable values for what reason how ever.
The correlation of image pairs can be done interactively. With the help of the mouse pattern as well as search matrice position are chosen and correlated.
For the creation of a DEM the following concept is valid. A number of optional image coordinates within a file A determines positions for the left image. The related file B contains the approximations for the right image. By the correlation the correct positions of the homologue points are found. Finally the program derives object coordinates with the additional help of the orientation data.

Summary

The actual presented CORRELATIONDRIVER explaines the special possibilities of a digital stereo plotter using different processors in parallel. Firstly, the work of the operator obtains an essential faciliation. Secondly, monotonous works can be done a lot faster. The assignment of homologue points takes places within tenth of a second.
The CORRELATIONDRIVER should be understood as an example. In a similar manner it is possible to implement other algorithms as developed in the last few years. The usage of the method of least squares suggests the additional integration of the geometric transform processor(GTP). With the

help of the GTP a high speed resampling can be realised[3]. Furthermore, under these circumstances a correlation method propagated in the last time should be taken in consideration, integration of image matching and object reconstruction[9,and other] or multiple image correlation.
Concerning other algorithms their expansion is offered via a consequent usage of the filter function ability called kernel. The combination of correlation and pattern recognition methods leads to the expectation of further profits with respect to speed(better approximations) and automatisation.
Therefore the digital stereo plotter offers a wide field of actions especially with regard to the correlation. The examplary CORRELATIONDRIVER proves the feasibility.

Literature

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