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Digital Correlation Principles*

They were investigated by building an attachment to a photogrammetric instrument, an analytical plotter, to allow simultaneous density measurement of a stereopair of photographs.

INTRODUCTION

AUTOMATIC DETECTION of changes in an object may require the correlation of a number of photographs of the object. A practical example of this is the correlation of a number of satellite or aerial photographs.

Mapping, on the other hand, requires the correlation of a stereopair of photographs. As this is usually the situation in practice, the photographs are taken from different positions and with different tilts. This obviously results in a change in the geometry of patterns depicted on the photographs. Added to the changes in the photographic circumstances, this magnifies the problem of correlation.

This paper shows that the correlation is greatly simplified if we keep in mind the geometric relationships between the photographs, and between the photographs and the object. Based on this, two principles are explained here; one for change detection and the other for mapping.

The geometric relationships between the photographs and the object are considered in the photogrammetric plotters. The principles were, therefore, investigated by building an attachment to a photogrammetric instrument, an analytical plotter, to allow simultaneous density measurement of a stereopair of photographs.

The results indicate considerable simplification in the correlation of a stereopair of photographs, and, consequently, a reduction in the cost of a correlator based on such principle. Also, it appears that digital correlation is the simplest way of realizing the two principles.

ABSTRACT: *Two principles for digital correlation are: one is based on referring photographic densities to object points in an object coordinate system and can be used in change detection in the object; the other is based on scanning the stereo model in epipolar planes and can be used in mapping applications. The principles simplify the problem of correlation. A prototype incorporates the principles.*

The principles are first explained. The density-measuring attachment to the plotter is then described followed by some of the results obtained.

THE TWO PRINCIPLES

To illustrate the two principles, consider a stereopair of photographs which are relatively oriented in a photogrammetric instrument (Figure 1). Suppose that the density-measuring attachment to the instrument is built and calibrated so that if any point P is observed in the stereomodel space, the two densities at the image points p_1 and p_2 are measured. We can then relate the densities of the points p_1 and p_2 to the coordinates of the object point P. If densities from other photographs are related to the coordinates of P, the correlation of the different densities for the purpose of detecting changes in the object can be easily performed. We now introduce the first principle: to detect automatically changes in an object through the correlation of photographic densities, these are related to

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the object points in an object coordinate system.

The instruments used in realizing the principle (a densitometer or a photogrammetric instrument), and the density sampling (automatic or manual) depends on the accuracy and the purpose of detecting the changes.

The second principle becomes apparent if we consider the situation of sampling the densities if moving in the stereomodel space in epipolar planes. Any epipolar plane intersects the object in one profile and intersects the plane of each photograph in a line (L_1 and L_2 in Figure 1). The two lines are formed of the image points of the same object profile and are, consequently, corresponding. Accordingly, if this object profile is scanned, similar density values will be measured simultaneously. If, on the other hand, the scanning is performed along the line of intersection of the epipolar plane with the XY-plane, similar density values will not be measured simultaneously. The lagging between measuring the similar densities of one object point P, say, is a function of the Z-coordinate of P in relation to the plane of scanning XY. The search for similar density values and, consequently, corresponding image points, can thus be reduced to one direction—that of the scan line.

We may now introduce the second principle: to correlate automatically a stereopair of photographs the scanning is performed in epipolar planes.

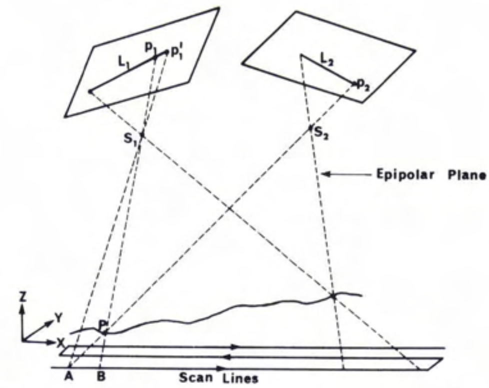

FIG. 1. The epipolar principle. Scanning is performed in epipolar planes, the densities are consequently measured along two corresponding lines L_1 and L_2.

PROTOTYPE

To test the above principles an attachment for measuring the density was built for an analytical plotter (model AP/2C). The analytical plotter was chosen mainly because of its computer control which allowed automatic scanning of the model and the synchroniza-

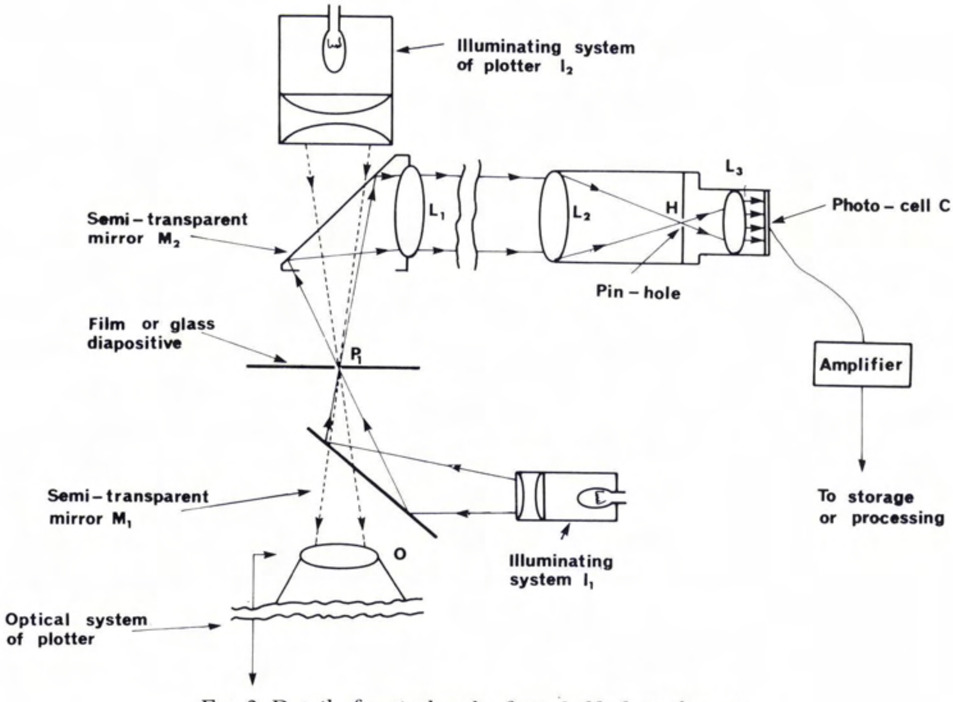

FIG. 2. Detail of optical path of one-half of attachment.

tion of the scanning and density sampling.[1]

The attachment consists of two identical halves; one for each photograph of a stereo-pair. Figure 2 shows the components of one half.

FUNCTION OF COMPONENTS

The illuminating system I_1 and the semi-transparent mirror M_1 illuminate the photograph for density measurement. The mirror M_2 and the lens L_1 form an image of the photograph at infinity. The mirrors M_1 and M_2 are semi-transparent to allow the photographs to be viewed also by the optical system of the plotter during the density measurements. The light source I_2 illuminates the photographs for this purpose. I_1, M_1, M_2, I_2, and L_1 form, together with the optical system of the plotter (whose objective is O), one unit which moves in X-direction. The photographs move in Y direction; thus any point on the photograph can be observed.

The lens L_2 forms an image of the photograph onto a diaphragm H with a pin-hole (fraction of a millimeter in diameter). The lens L_3 is placed with the pin-hole in its focal plane so that an image of the pin-hole is formed over the area of a photocell C. The photocell measures, therefore, the average light transmitted through the area of the transparency which is imaged to fill the pin-hole area. The signal from the cell is amplified and then stored or processed as explained below. The components L_2, H, L_3, C and the amplifier form one unit which is stationary. Figure 3 shows the plotter and the attachment.

Another arrangement of the components of the device is as shown in Figure 4. The principle of this arrangement is the same as that explained above. It is, however, more compact because it utilizes the illuminating system and objective of the plotter. It has also the advantage that the length of the optical path between the photograph and the photocell is constant for all the density measurements. This can give more accurate measurements. The first arrangement has been developed and tested. The second arrangement is now being developed.

It can be seen that the arrangement is simple. In addition, the components of the attachment are relatively inexpensive.

ADJUSTMENT OF THE DEVICE

Two types of adjustment are necessary:

- The device should be adjusted so that the photo point p_1 (Figure 2), observed at the measuring mark of the photogrammetric instrument, is imaged to be at the centre of the pin-hole H; and
- The outputs from the two amplifiers should be adjusted to be equal for equal densities observed.

These adjustments can be simply performed and are explained in more detail in an Appendix.

SYNCHRONIZATION OF DENSITY SAMPLING AND SCANNING

The outputs from the two amplifiers are in the form of continous analogue signals. At pre-selected intervals in the model these signals are read and stored. The control com-

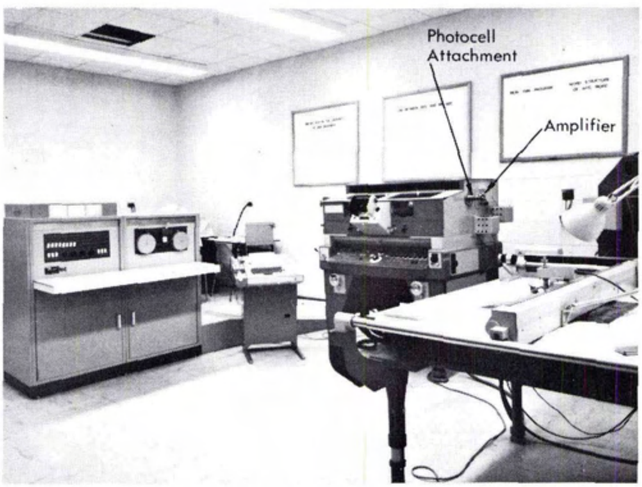

FIG. 3. The Analytical Plotter system showing the amplifier and photocell attachment of one-half of the prototype mounted onto the viewer.

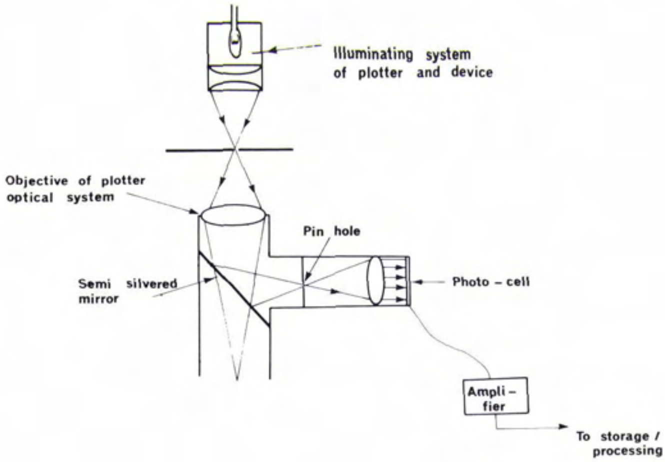

FIG. 4. Alternative arrangement of density-measuring device.

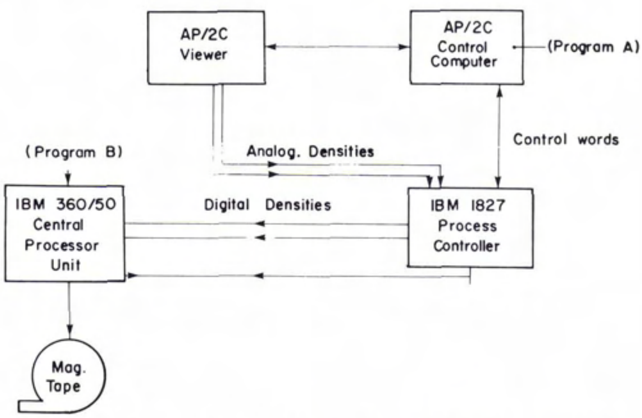

FIG. 5. Arrangement for synchronization of density sampling and scanning using two real-time programs.

puter of the plotter and an IBM 360/50 are interfaced[2]. The facility was used in the research in the reading and storage of the signals in a digital form. The synchronization of the scanning and density sampling was performed by two real-time programs which worked in conjunction with each other. One program (referred to hereafter as *A*) resided in the control computer of the plotter and the other (referred to as *B*) in the 360/50 computer. The arrangement is shown in Figure 5. The sequence of communication between the programs is indicated next.

At points of regular intervals in the model, program *A* sends one word to program *B*. This word is either the value of the *X*-coordinate in the model or an end-message, the difference being in the bit configuration. If it is a coordinate, program *B* reads the digitized densities and sends a word to *A* indicating that the densities are read. Upon its reception, program *A* drives the photo-carriages to the next point, and so on. If the word is an end-message, program *B* closes the storage file. The storage is performed by *B* on magnetic tape.

It may be noted here that it is possible to modify the control computer to perform the reading and storage operations. Alternatively, a small general purpose computer can be used for this purpose.

Practice and Results

The attachment was used in measuring the photographic densities of different aerial photographs. Figure 6 demonstrates the second principle. It shows two sample traces on a stereopair obtained by scanning while keeping the Z-setting of the instrument constant. The scale of the photographs was 1:10,000 and the size of the aperture was 100

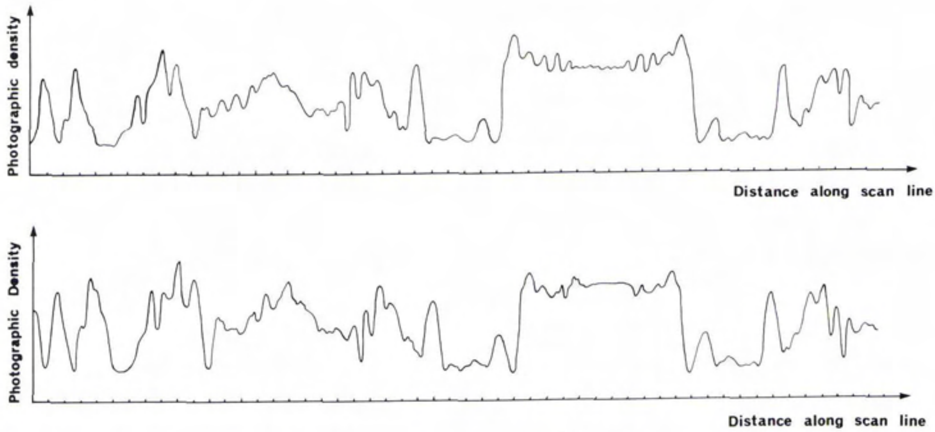

FIG. 6. Two density traces obtained by scanning a stereopair of photographs in an epipolar plane.

FIG. 7. Sample photograph displayed on a CRT after its digitization. Original photograph is shown in Figure 8. (The digitized photograph was displayed at a smaller scale).

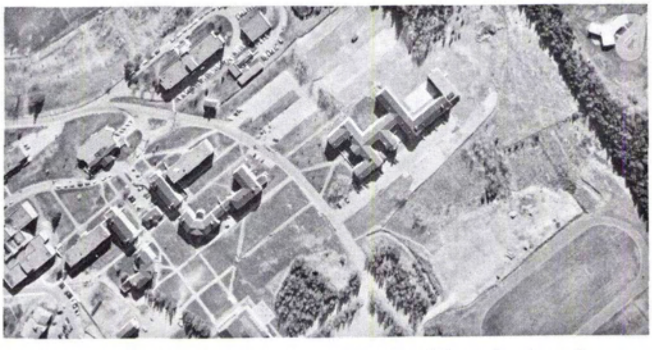

FIG. 8. Part of aerial photograph digitized and then displayed on a CRT (Figure 7).

micrometers. It can be seen that the two traces are quite similar. An algorithm was developed to correlate the density values and obtain the height profiles in the model. The results obtained will be presented in subsequent publications.

To test the performance of the prototype, the digitized density values of an area of an aerial photograph were displayed on a Tektronix 611 CRT interfaced with the IBM 360/50. This CRT model was not provided with means for dynamic change of the spot intensity. Different levels of gray were, therefore, obtained by writing each point on the screen a number of times proportional to the density. A time-exposure photograph is shown in Figure 7 and the original is shown in Figure 8.

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APPENDIX

ADJUSTMENT OF THE DEVICE

ADJUSTMENT A

The alignment of the pin-hole in relation to the measuring mark of the photogrammetric instrument was adjusted as follows. The photocell (Figure 2) is replaced by a light source. As a result, an image of the pin-hole is formed at the plane of the diapositive and observed by the optical system of the plotter. The position of the pin-hole is then adjusted so that its image becomes concentric with that of the measuring mark of the plotter. (This adjustment may be avoided if the image of the pin-hole is used as a measuring mark in establishing the stereo-model).

ADJUSTMENT B

Calibration of the outputs from the two amplifiers is obtained using a clear glass plate instead of the photographs. The output from the right amplifier, for example, is measured accurately. The right amplifier and photocell are then replaced by the left amplifier and photocell. The gain on the left amplifier is then adjusted to obtain an equal output. This ensures that for the same light intensity of two amplifier-photocell combinations give the same output. The intensity of the two light sources (I_1, Figure 2) are then adjusted to be equal by placing the amplifiers and photocells back in their positions and comparing the two outputs.