STEREOSCOPIC COMPUTER MEASUREMENTS OF MULTY-TIME IMAGES FOR INVESTIGATION OF MOUNTAIN GLACIER MOVEMENTS

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Abstract

The paper deals with the method intended for ice movement velocity determination of mountainous glaciers. It is based upon measurement of different time aerial photos. As only contact prints of the aerial photograms were available for researchers the version based on digital photogrammetry and relatively simple equipment has been chosen and developed. Processing results have shown that glacier movement could be estimated with sufficient accuracy and without using expensive photogrammetric plotters by using the suggested technique.

Introduction

Application of digital photogrammetry to study dynamical parameters of glaciers has not yet obtained wide representation in technical literature. As one of only a few examples, a paper on unsynchronized aerial photograms useg for ground shifts measurements, and glaciological objects in particular, may be mentioned (Crippen, 1992).

Several methods for determination of surficial velocity of glacier movement based on quasi-stereoscopic effect have been developed in the Moscow University Geographical Faculty, Laboratory of Aerospace Methods, following widely known Finsterwalder work (Finsterwalder, 1958). The most universal one known as the "Method of Horizontal Vectors" and is shown in the paper along with computeraided technique for repeated aerial photo processing made for Pamir glacier Medvezhy. This method provides for the daily detection of ice movement velocity and photogrammetric modeling to geometrically represent the glacier surface.The process is founded on relatively simple and widely distributed equipment and contact prints of aerial photos. It was considered that such data is often available for glaciologists and as such the use of high precision measuring devices is not prachcable. Otherwise, as it was correctly mentioned in literature, for example (Klaver, 1993) precision and cost of the measuring system are interrelated parameters, therefore a significant decrease in the working cost takes place if precision is limited to an acceptable minimum.

General grounds of the method

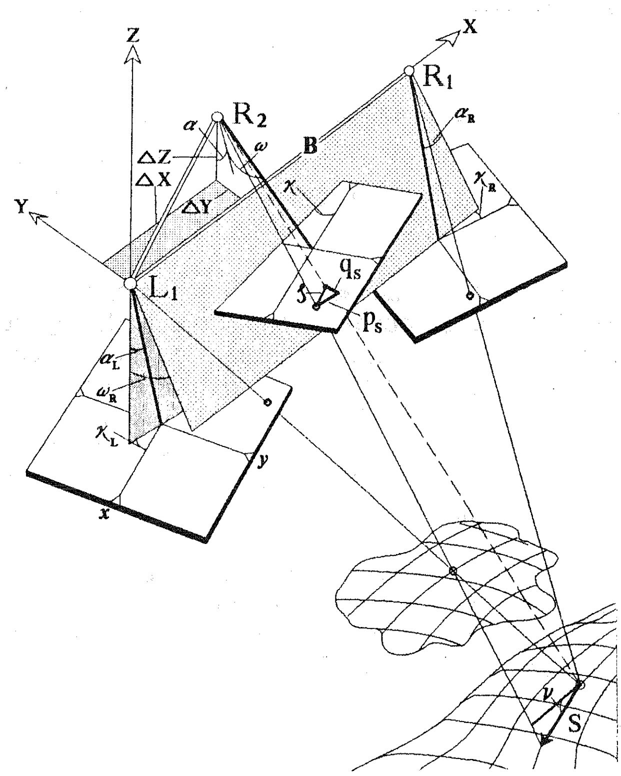

Fig.1. Geometric scheme of the method of the movement velocity measurement. Stereopairs of simultaneous aerrial photograms L1-R1 and different time photograms L1-R2 were used.The model koordinate system and the photos orientation elements are shown.

The method concept shown at the Fig.1 enables us to determine shift vector S belonging to an unmarked point on the glacier surface from measurements data obtained for simultaneous stereopair L1-R1 and different time stereopair L1-R2.

Methodological solution of the task includes two stages: a) detection of relative orientation elements for L1-R1 aerial photos in S1XYZ basic coordinate system and photogrammetric model construction; b) detection of exterior orientation elements for R2 aerial photo in the same coordinate system and shift values calculation.

Relative orientation is to be made on the basis of complanarity equations and following analytical conversion of the L1 and R1 aerial photos. Spatial X,Y,Z coordinates for all the points may be calculated by formulae:

$$X = \frac{\bar{x}_1 B}{\bar{x}_1 - \bar{x}_1'}; \qquad Y = \frac{\bar{y}_1 B}{\bar{x}_1 - \bar{x}_1'}; \qquad (1)$$

$$Z = f\frac{B}{\bar{x}_1 - \bar{x}_1'}$$

where B is the photography base; $\bar{x}_1;\bar{y}_1$ and $\bar{x}_1';\bar{y}_1'$ are converted coordinates of the points for L1 and R1 aerial photos accordingly; f - aerial camera focal length.

At first B is considered as an approximate value which has to be defined more precisely during the model orientation process using control geodetic points or cartographic data. A version using a free model without geodetic control is also possible .At the present time GPS-techique permits us to determine the photography base value during flight and photography.

Exterior orientation elements for the R2 aerial photogram may be calculated from resection using common stable points located out of the glacier area from the next equations:

$$-(f + \frac{x_2^2}{f})\alpha - \frac{x_2 y_2}{f}\omega + y_2\kappa - \frac{f}{Z+\Delta Z}\Delta X - \frac{\bar{x}_1}{Z+\Delta Z}\Delta Z = x_2 - \bar{x}_1 \qquad (2)$$

$$-\frac{x_2 y_2}{f}\alpha - (f + \frac{y_2^2}{f})\omega - x_2\kappa - \frac{f}{Z+\Delta Z}\Delta Y - \frac{\bar{y}_1}{Z+\Delta Z}\Delta Z = y_2 - \bar{y}_1$$

where α,ω,κ are angular and $\Delta X, \Delta Y, \Delta Z$ are linear exterior orientation elements;

x_2, y_2 are the points coordinates for R_2 aerial photo.

Initially, conversion of the R2 aerial photo using angular orientation elements is done. Then p_s and q_s differences are calculated with the help of the point coordinates on L1 and R2 rectificated photograms. These differences are shift vector components in the photo scale. The vector S is to be determined by the formulae:

$$p_S = \bar{x}_2 - \bar{x}_1 + \frac{f}{Z+\Delta Z}\Delta X + \frac{\bar{x}_1}{Z+\Delta Z}\Delta Z;$$

$$q_S = \bar{y}_2 - \bar{y}_1 + \frac{f}{Z+\Delta Z}\Delta Y + \frac{\bar{y}_1}{Z+\Delta Z}\Delta Z; \qquad (3)$$

$$S = \sqrt{p_S^2 + q_S^2}.$$

Values p_s, q_s for stable points have to be equal to zero in the frame of the accuracy limits. For moveable points these values show in the scale of the aerial photo shift of the point for period T between photography moments of L1 and R2 photograms. Vector S is calculated in basic coordinate system. For easy use it has to be converted into oxy coordinate system on the L1 photogram with the help of angle κ obtained during the relative orientation process. Natural value of the vector may be calculated after allowing for the model scale.

Value S determined by this technique is the projection of the movable point shift on the plane XY in the spatial coordinate system. It differs from tilted surface shift on the value described by formulae:

$$\delta S = S(1 - \cos\vartheta + \frac{x_1}{f}\sin\vartheta). \qquad (4)$$

where ϑ - angle of glacier surface tilt;

x_1 - abscissa of the movable point on L1 photogram.

When the angle of glacier surface tilt is less than 15° this correction does not usually exceed 10% from S. When it is necessary it may be calculated after determination of tilt angle with the help of spatial coordinates of the points on the glacier surface.

It is necessary to note once more common positive quality of the pseudo-parallax method: to identify the points on the stereopair photograms needs no their accordance to definite contours. The point positioning, both movable and stable, is defined by its coordinates on the L1 photogram, and comparison with positioning on the R2 photogram is done by stereoscopic sighting on stereomodel L1-R2 surface. When the glacier points are moveable this surface is pseudo-surface.

Conducted works and used equipment

Photos of Medvezhy Glacier (Fig.2) were made from repeated aerial surveying along the glacier lengthwise axis with time intervals from several days to several weeks. When repeated aerial surveyings were made, definite requirements as regards for aerial surveying strip direction, photography height and time were set. Said parameters have to be as similar as is possible for different aerial surveyings. Used aerial camera has a 200 mm focal length, 180x180 mm frame dimension and a 1:20000 average photography scale.

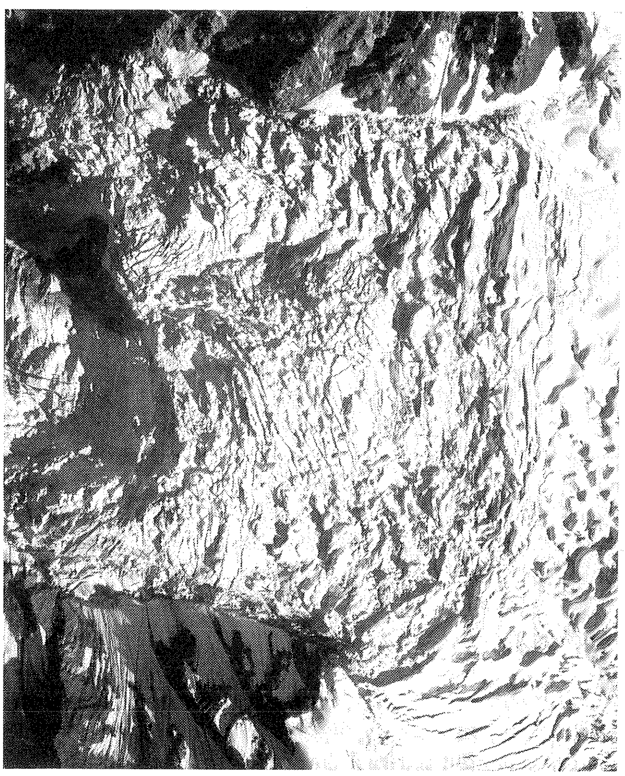

Fig.2. Fragment of the aerial photo of the main icefall of the Glacier "Medvezhy" in the scale of 1:14000. The photo central area is shown.

To digitize data by Desk Jet 3c Scanner with 600 dots/inch resolution contact photoprints from negatives were used. Because of significant deformation of the photoprints it is necessary to carry out detection and allowing for deformation during preliminary processing and to minimize its effect on the results. Two methods of deformation detection and allowing for were tested: with the help of fiducial marks on the photos and with the help of the crosses on the flattening glass of the aerial camera.

The first method is based upon off-line conversion of the photogram points. Coefficients of conversion are calculated with the help of fiducial marks measurements. This method is often recommended in literature when scanned imagery is measured (Fryer, 1993). The second method is based on the crosses measurement and corrections calculation with the use of the 2nd degree polynom.

Practice has shown that the first method lowers deformation to values of 2-3 pixels, the second one - to 1 pixel. This magnitude (0.04 mm in our case) may be considered as real accuracy of contact print measurements. Experimental estimation of obtained vectors accuracy has confirmed that fact. Such accuracy is able to solve different tasks taking place in application of measurements of aerial photograms. Therefore, it may be stated that scanning with a resolution more than 600 dots/inch is not reasonable because improved resolution could not be realized due to effect of residual errors of the photograms.

Measurements were carried out on IBM PC 486 equipped with stereoscopic spectacles on liquid crystals with 100 cycles per second working as a shutter. Design of the spectacles and their software for synchronized working with PC belongs to IBIK firm. Such a system provides for maximal use of the display area and has been tested for PC operations. As an example, publication (Nobuhico, 1992), may be mentioned. All stereoscopic measurements are carried out according to stereocomparator technique.

Software and forms of data representation

Software which has been developed in the Laboratory of Aerospace Methods enables us to provide stereoscopic measurements allowing for the photogram deformations, in order to reconstruct models using simultaneous and different time photograms, to calculate coordinates and shift of the movable point, to represent velocities field cartographically by vectors (Fig. 3) and by the newly developed graphical method, so called "strezhinel" lines. These lines (created from Russian word

"Strezhen" - axis of flow channel) visually illustrate direction and velocity of ice movement at given glacier areas (Fig. 4).

Drawing strezhinels is based on the preliminary constructed vector field. Beginning from the first point selected by operator vectors interpolation and automated drawing double line are made. Width of the double line is proportional to vector length in that point. Moving along flow motion with given step a double line of variable width is drawn, that visually describes the direction and speed of the flow.Velocity vectors and strezhinels are displayed on the monitor screen in given scales. A printer may be used for imagery printing.

A stereoscopic model constructed with the help of simultaneous photos permits us to obtain morphometric parameters of the object of interest, for example, to draw profiles, to determine slopes, to represent glacier surface in stereoscopic projection, and so on. It is to be noted, for said goals high precision exterior model orientation is not necessary.

Accuracy estimation and conclusion

All measurements carried out at different parts of pulsing glacier Medvezhy and at inaccessible icefall with height more than 4000m, in particular, have confirmed the high efficiency of the method.

Comparison of two versions of the reported method was made to estimate accuracy obtained from photoprint measurement results. The first version is measurement of negatives on a high precision stereocomparator. According to previous investigations the accuracy of this method equal to 0.02 mm in the scale of the photo. The second version is measurement of scanned photo prints at the monitor screen.

In both cases, velocity vectors were measured in fact at the same points. Results of comparison have shown that discrepancies, as a rule, do not exceed a value of 0.04 mm in the scale of the photogram.They agree to one pixel for given resolution. If we accept that error in the glacier velocity calculation does not exceed 10%, the method could be considered as reliable when ice shift value for period between two aerial surveyings is not less than 0.4 mm in the scale of the photos when contact photoprints were used.

Produced experiments allow us to make the following conclusions:

1. Based upon developed technique it is possible to carry out aerial photo measurements for studying glacier movement and its morphometry using contact photoprints from negatives and using relatively cheap and widely used equipment without expensive photogrammetric working stations.

2. It is possible to make stereoscopic measurements on unsynchronized photos with sufficient success, however, when glacier has to be processed high quality of pseudo-stereoscopic effect is provided only with rather small time intervals between different surveyings. One-two weeks interval may be considered as optimal. To carry out aerial surveying at the same time of the day, with similar parameters of flight is a very important factor.

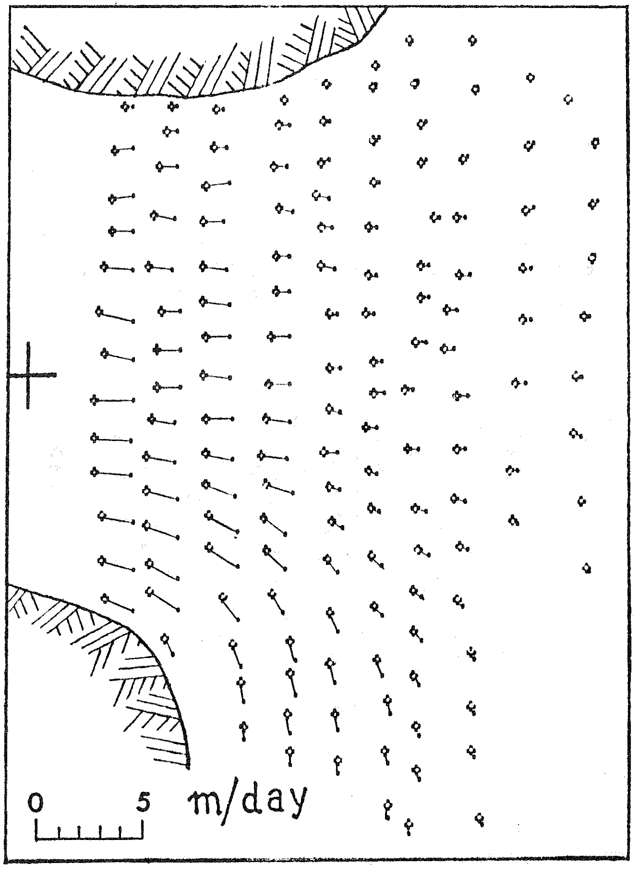

Fig.3. Vectors of the ice movement surficial velocity according to icefall part shown at Fig.2. Vectors scale in meter / day is shown.

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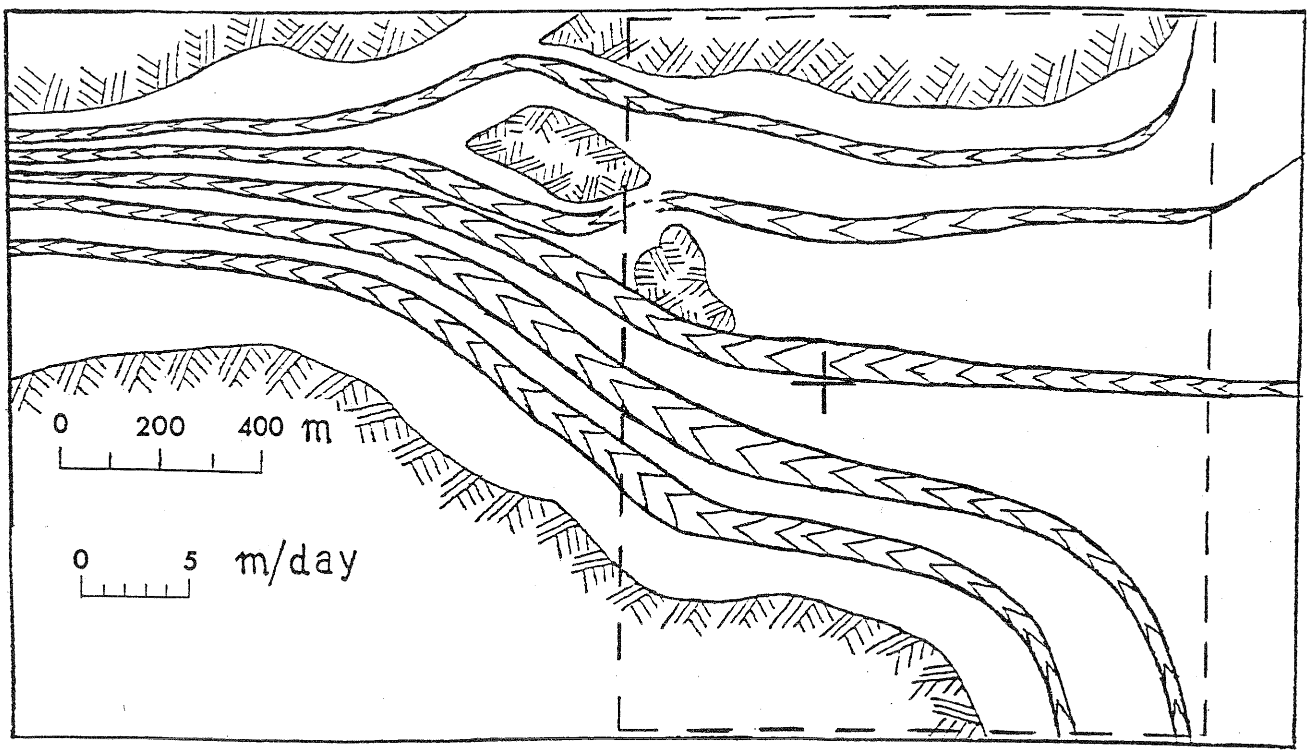

Fig.4.Schematic map of the Glacier Medvezhy part. Ice movement is drawn by strezhinels. Strrezhinels widht of the cross represents movement velocity in meter / day in drawn scale