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RESULTS AND EXPERIENCE OF 18 MONTHS' WORK WITH THE C-100 PLANICOMP

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1. Introduction

Up to this date, quite a few photogrammetrists have run practical tests on one of the two prototypes of the C-100 PLANICOMP analytical stereoplotting system, covering practically all types of problems normally encountered in photogrammetry. Even unconventional problems have frequently been solved offhand without any difficulty.

In a way, this paper might have consisted of separate contributions by several PLANICOMP users. However, it may be preferable at this time to give a general review of the results of the work performed with the instrument up to date. After a brief review of developments during the past 18 months, this paper will therefore first report about the results (general performance data), followed by experience with the PLANICOMP (procedure for certain types of work). In conclusion, an outlock will be given to assess the future perspectives of the PLANICOMP.

2. The PLANICOMP in retrospect

The C-100 PLANICOMP was presented to the general public in the form of a first prototype at the 13th International Congress of Photogrammetry held in Helsinki in July of 1976, after a development time of only 2 1/2 years. The actual phase of integration and testing had started only three months before the congress. April 23, 1976, may be considered to be the birthday of the PLANICOMP, the day on which the absolute orientation of a model was for the first time completed successfully in the prototype.

In Helsinki, not only orientation programs but even digitization and plotting programs were demonstrated and functioning flawlessly. At that time, the number of service programs available was about 40.

In the spring of 1977, a second prototype was finished. At the same time, the first instrument was presented in the United States. The number of available programs had meanwhile gone up to 55, after administrative programs for orientation and control data had been added.

Today, shortly before instruments from the first production batch are leaving the factory, the final number of programs (75) has nearly been reached, and testing of the software has almost been completed. In addition to numerous expansions and supplements, it is above all programs for the administration of general measurement data and for aerotriangulation that have been added.

3. Results

Important performance characteristics of a plotting system are its reliability, accuracy, versatility and operating speed.

Reliability

The PLANICOMP has proved to be very reliable. The first prototype failed only three times in 18 months. In one case, a photo carriage was damaged by a manipulation which is no longer possible in the production model, another time the power amplifier for a servomotor of the tracing table broke down, while the third failure occurred in the central processing unit of the computer. Two minor snags (occasional reading errors in the tape reader and transmission errors between computer and magnetic disk) had only a minor effect on the measurement work and could probably have been avoided entirely had the servicing interval recommended for the computer been observed.

Operation of the second unit was interrupted only once by a breakdown of the magnetic-disk unit during the first week after connection of the computer, and the machine has since been operating without any trouble for fully six months, except for some recent damage in transit. With the exception of minor trouble, the mean time between failures (MTBF) thus is about six months. Assuming a down time of 2 - 3 days per failure and 21 work days per month, this would bring the loss in productivity to about 2 %. In the long run, this failure rate should drop to less than 1 % (for comparison: the rate is 0.2 % for pure analog plotters and 10 % for large EDP systems with preventive maintenance).

Accuracy

The photo carriages are positioned with a resolution of 1 µm. Reproducibility of pointing for one operator is a function of point definition and viewing magnification and is about 2 or 1 µm for measurement of grid intersections, depending on whether 8x or 16x eyepieces are used. With natural, signalized or punched points, a lower pointing accuracy may generally be expected. Another accuracy standard is the so-called absolute measurement accuracy. By this we understand the real-time accuracy, that is the accuracy of the coordinates displayed directly during measurement. In analytical equipment, this quality characteristic is no longer determined exclusively by the measurement setup, but also by the software which corrects the picked-up data according to precisely defined numerical procedures. In the PLANICOMP, the coordinates measured and directly displayed are corrected only for first-order machine errors. In other words, allowance is made only for linear pitch errors of lead screws and a possible obliquity of coordinate axes (plane affine transformation).

Machine calibration is possible with the aid of a computer-controlled grid measurement, the residual errors after affine transformation to a nominal grid being the real-time accuracy, the so-called absolute measurement accuracy. In the first two prototypes, a standard deviation of 2 - 4 µm was obtained for the axes of the photo carriages and thus for the image coordinates.

Maximum values were 4 and 7 µm, respectively. Accordingly, grid-model measurements and measurements performed on excellent photography gave rms horizontal-position errors of 4 - 5 µm and rms heighting errors of 6 - 7 µm as referred to the image plane.

An enlarged transformation formula allows the compensation of all systematic error components of higher order. This would make it possible to increase absolute accuracy to the level of pointing accuracy of 1 - 2 µm. The PLANICOMP is therefore designed so that measured and stored image points can, if necessary, be corrected in an off-line operation by comparison with a correction matrix. However, this method will be used only if extremely high accuracy is needed, since with average photography the 5 µm threshold will hardly be exceeded.

Versatility

Central-perspective photography taken with fiducial-mark cameras of any focal length can normally be plotted in the PLANICOMP. This means that over 99 % of all mapping photography can be plotted directly. Additional, modified software would even enable the machine to plot dynamic photography, such as panoramic pictures or scanner images.

The machine is similarly flexible with respect to photographic configuration. Oblique photography can be plotted just as easily as convergent and inclined photography. Among the models measured up to date were photo pairs with a nadir distance of 60^g, a convergence of 40^g and a horizontal swing of 45^g. Even in these cases relative orientation with the usual distribution of parallax measurements was flawless without input of estimated approximate orientation data. Only if terrestrial photography is to be plotted as a model with a lateral tilt of roughly 100^g will $\omega \approx 100^g$ have to be input, since the RELATIVE ORIENTATION program is designed for a rotation of axes of up to 60 or 70^g only. The possibility of correcting methodical errors also contributes to the versatility of the machine. Film shrinkage and radial rotation-symmetric distortion as well as eccentricity of principal points can be corrected separately for the two photos. Model height can be referred to a spherical surface (correction for earth curvature), the radius and the position of the vertex being variable. Off-line procedures would permit any additional correction that can be described mathematically, for which in the normal case there is one definable correction matrix for each photo.

A description of the service programs /1/ bears out the machine's versatility with regard to plotting capabilities. Likewise noteworthy is the flexibility with which the machine can be converted from one plotting setup to another. Also, change-over between different models is almost as fast, above all, if the models have previously been measured or oriented: it is only necessary to call the model data from the magnetic disk, position the photos and measure the fiducial marks (interior orientation), a process which takes only about four minutes.

If the negative size is noticeably smaller than 240 mm x 240 mm (such as in the case of terrestrial or 35 mm photography), several models can be positioned simultaneously so that a single program start will accomplish switch-over from one model to another.

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Operating speed

In the PLANICOMP, the operating speed during orientation and measurement depends almost entirely on finding and setting the points to be measured or, in the case of dynamic measurement, on the travelling speed. The time required for computing orientation, computer-controlled plotting and data transfer is negligible. Even with a video screen as a terminal, the output of a large information volume is not found to hamper smooth work.

For an operator fully familiar with the machine, a typical average for complete orientation of a stereo model is 15 minutes, of which about 4 minutes correspond to positioning of the photographs and interior orientation, 6 minutes to relative orientation by 10 - 12 parallax measurements and 5 minutes to absolute orientation with about five control points. Erroneous point measurements can be quickly checked and corrected so that even additional measurements and computing operations required for difficult models will extend the orientation time to no more than 20 - 25 minutes. On the other hand, there are examples of complete orientation in as little as seven minutes.

During a project, the input of necessary data such as camera data, control coordinates or plotting parameters is limited to the designation of the new model, required exclusively for identification. For every camera employed, the camera data need be input only once so that later on, when work is resumed with new photography, only the corresponding "camera zero model" need be called. The control points can be completely stored in a control area on the magnetic disk before the project begins. The necessary points can then be transferred to the control area of the working memory within just a few seconds. If manual input of control points is necessary, about two points can be keyed per minute; a tape reader will read about 200 points per minute, and input from magnetic tape is another 100 times faster.

By comparison with analog equipment, the speed of the plotting operation proper is increased above all in areas where computer support relieves the operator of time-consuming controls, searches or checks. This is the case in triangulation work, special DTM measurements and large-scale mapping. This aspect will be discussed in greater detail in the following section.

4. Experience

The numerous test measurements made on the PLANICOMP have confirmed that an operator is capable of performing simple orientation and measurement operations independently after only a few hours' training and that he will be completely familiar with all important programs after a few days. Thus, visitors who worked on the machine were usually able to plot their own photography in the desired manner after two days.

On the basis of this experience, customers will be given a one-week training course when they receive the machine. Thereafter, operators should work on their own in order to become more fluent in the use of the different programs and to learn from their errors. Only after several weeks of intensive work will an operator have full command of all the different applications of the PLANICOMP and reach an operating speed typical of this type of machine.

During the 18-month period in which the PLANICOMP was tested, a number of new aspects were discovered, which had not always been fully expected when the system was conceived and the software plus the hardware developed. In the following, some of these aspects - both special capabilities and useful operating procedures - will be described.

For interior orientation, four fiducial marks are generally measured in order to define the position of a photograph on the corresponding photo carriage. In this case, a possible affine film shrinkage can be determined by comparison with the nominal fiducial-mark separation. However, if an affine transformation seems to be sufficient because film shrinkage, if any, is expected to be homogeneous, only two fiducial marks need be measured on opposite sides.

But the INTERIOR ORIENTATION program also offers a choice of which pair of the usually four fiducial marks should be measured, so that a photograph can even be oriented if one or even two fiducial marks are damaged or missing. In this case, the film shrinkage determined by comparison with the nominal separation is likewise considered to be homogeneous. This method allows plotting of partial photographs or of photos 240 mm x 480 mm in size that are occasionally used in the United States, provided that they are cut in such a manner that the portion to be plotted includes at least two fiducial marks.

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Practical use of the RELATIVE ORIENTATION program has shown that there will be a general tendency not only to measure the usual six points, but approx. 10 - 12 points, for instance double points or a regular array of marginal points. The mean parallax remaining after adjustment is then more representative for model generation than with only one overdetermination. With six points, the mean residual parallax will frequently be only 0 - 1 µm. Moreover, a possibly gross error can be located only if there is a sufficient number of overdeterminations.

Another advantage of relative orientation in the PLANICOMP by comparison with analog stereoplotters is the fact that an irregular distribution of parallax measurements, as in the case of large water bodies or terrestrial models, will hardly present any difficulty as long as the basic area surrounded by the parallax points is still sufficiently large. While in analog plotters the y-parallax should, if possible, be cleared at all image points affected by the different parameters so as to allow empirical orientation, the basic area in the PLANICOMP may be considerably smaller. An exact statement is, however, impossible without studies, since a reduction in the size of the basic area will also affect the accuracy of parallax measurement, the approximate values for the orientation parameters and the base-height ratio. Fig. 1 gives an idea of the parallax-point arrays that have still been oriented successfully.

The ABSOLUTE ORIENTATION program is likewise very dynamic. Gross aproximate values need practically be given only if extreme angles of orientation have to be expected, for instance, when changing over to oblique photography with lateral tilt exceeding 60^g or for plotting terrestrial photography with lateral tilt of approx. 100^g.

An interesting approach to absolute orientation with numerous overdeterminations is first to perform absolute orientation with just a few easily detectable points so that further control points can then be approached automatically on the basis of ground coordinates. This will eliminate the chore of finding the points, and the only thing required is precise pointing and storage of the image coordinates measured. Finally, computation of absolute orientation is repeated with all control points.

Another point in which the PLANICOMP promises considerable advantages is the different fields of application. A few remarks may therefore be appropriate regarding aerotriangulation, the measurement of digital terrain models and large-scale plotting.

Plotting

In large-scale maps - primarily cadastral maps, base maps and planimetric maps - regular shapes such as straight or smoothed lines, rectangular or circular patterns as, for example, standard symbols or lettering, are generally predominant due to the large number of artificial or defined objects. This is why in the direct mode a fair drawing can be derived from the original manuscript only in a second process. The software of the PLANICOMP, on the other hand, permits the direct plotting of straight lines, circular arcs and spline curves by computing spline functions over up to 144 points. In conjunction with the possibility of completing the fourth corner of houses and plotting symbols and text, special advantages are therefore secured, above all, for plans of industrial facilities, engineering projects and for cadastral purposes. This computer-supported plotting also allows direct fair drawing right in the plotting stage.

Digitization

Programs with flexible incremental recording capability and random scanning or scanning by profiles or in grid form are available for measuring digital terrain models. In the following, we shall only briefly mention the program for measuring cross-section, which in one form allows an application that was not hitherto possible with analog equipment and that is of considerable interest for traffic planning. At the beginning, we have to input either station data for the route or directly digitize the route in the stereo model or on a graphical draft on the on-line tracing table. Then the machine will automatically guide the floating mark along all the cross-sections of preset spacing and length, and the operator need only keep the floating mark in contact with the model surface.

Recording can be triggered individually or incrementally. In any case, however, a station recording is triggered as the route is crossed.

Due to the possibility of comparing the result with a nominal data set or a previous state directly after measurement of a surface in the PLANICOMP, the DTM programs should also be of particular interest for industrial photogrammetry and strip mining.

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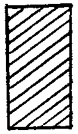
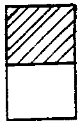
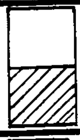
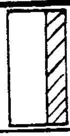
CASE		rms parallax (μm) at control points	rms residual error at control points (m)			Left g (gon)			Right g (gon)			Base mm	hg
			x	y	z	Ω	Φ	K	Ω	Φ	K		
1 Complete model		3	0,18 5	0,29 5	0,18 7	-0,21	-0,32	-13,51	-0,27	-1,01	-14,20	115,98	1854 m
2 Upper half		4	0,29 3	0,36 3	0,09 5	-0,18	-0,35	-13,51	-0,27	-1,04	-14,20	115,91	1853 m
3 Lower half		2	- 2	- 2	0,002 4	-0,21	-0,32	-13,51	-0,25	-0,99	-14,21	116,09	1859 m
4 Upper and lower edges		5	0,16 4	0,23 4	0,10 4	-0,22	-0,30	-13,51	-0,27	-1,00	-14,19	115,97	1856 m
5 Right-hand edge		8	0,58 3	0,39 3	0,12 4	-0,15	-0,38	-13,51	-0,19	-1,03	-14,24	116,13	1847 m

Fig. 1: Results of orientation of partial models in C-100 PLANICOMP

Focal length: 153 mm; photo scale: 12 000; end lap: 60 %.

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Aerotriangulation

The most striking advantage may be expected in the field of aerotriangulation. A report on a complete triangulation process in the PLANICOMP can be found in [2,3]. We here shall therefore discuss only the measurement process.

In the case of model triangulation, the designation of the new model is input before work on a new model is started, so that the records can be easily identified. The new photograph is then positioned and its location on the photo carrier determined by measurement of the fiducial marks. The old photo remains unchanged so that orthoscopic and pseudoscopic viewing are used alternately, as for instance in the PSK Stereocomparator. Next, the RELATIVE ORIENTATION program will accurately set the points known from the previous model in the retained photograph, set them approximately in the new photo and display the corresponding point number on the control panel. In other words, the operator need only fine-adjust all points at the left edge of the model (if triangulation proceeds from left to right) and confirm or erase the measurement. Since at this time the PLANICOMP is still used for comparator-type measurement, the operator may tentatively skip points that can be measured with greater ease in a model.

Next, the new points encountered for the first time have to be identified, found, set and stored after input of the corresponding point number. When the corresponding instruction is given, an adjusting relative orientation is then computed for bridging. A stereo model is thus formed after the residual parallaxes have been accepted by the operator. If all interesting points have already been measured, the model can be stored for subsequent adjustment. In practice, however, it is more likely that the ABSOLUTE ORIENTATION program will now be started, which in the bridging mode has essentially only a checking function. After all measured tie and control points have been displayed, points previously skipped will be approached automatically and can now be finally measured or erased, or they may remain skipped. The first step consists in determining the scale of the photo which up to now was coupled relatively, with the aid of the tie points to the previous model. For this purpose, all measured points were put into the control-point memory under their negative point number as tentative control points during "absolute orientation" of the previous model and may serve as a scale reference. If there are at least two tie points, residual errors can be output and thus allow checking on the tie.

If the tie is accepted, a search is made for control points that may have been measured, and their residual errors after tie-in are displayed. In strip measurements in the way of an aerial traverse, these residual errors will systematically increase above all in height. If the number of control points in the present model allows the computation of an independent absolute orientation, the latter will be performed. With overdetermination, the residual errors of the control points after such re-orientation will now be displayed, without the latter being effective yet. If these errors are likewise accepted, the operator may decide whether or not he wishes to repeat the leveling process. If at least the bridging or the re-leveling procedure has been accepted, the old "short-term" control points will be erased in the control memory and all newly measured image points will be stored as a new tie reference in the ground system that is now applicable.

The operator now has the chance to measure even further points before adding all measured points, together with the computed perspective centers in tentative ground coordinates in a special data file on the magnetic disk, to the other models measured, using a short auxiliary routine. In addition, he will generally trigger a print-out and transfer the model to the model bank so that he may later reproduce it in full detail.

According to present experience, the processing time per model will eventually be about 15 minutes for some 15 points per model or about 10 minutes for approx. 6 - 8 points.

Even in the case of bundle triangulation in the PLANICOMP, at least the measuring process will be performed as described above, so that a direct check is available. With the aid of another auxiliary routine, all measured points and the measured fiducial marks can then be independently stored in the data file in raw machine coordinates or in corrected image coordinates.

5. Outlook

Finally, a few capabilities of the PLANICOMP should be mentioned, which may gain importance in the future and which thus are important assets of the system. One of these is the fact that a model bank may be created, since the orientation data of all models ever measured can be stored. Checks or reruns are therefore possible with minimum cost and delay. However, the PLANICOMP system would also be suitable as a data source with decentralized access to models of local interest.

Another advantage results from the fact that in many types of work less than 50 % of the capacity of the computer will be used. In this case, connection of a second PLANICOMP to the first computer would make eminent sense. However, an automatic plotter or a graphic screen for interactive operation might also be connected. And last but not least, the computer may, to a certain extent, also be used for general data-processing work, depending on the peripheral units available.

For some users, the tremendous plotting flexibility of the PLANICOMP will open up new possibilities. In addition to the aforementioned dynamic photography, such as scanner or panoramic photos, two-media photogrammetry and the plotting of electron-microscopic images will one day be handled by PLANICOMP systems. In spite of this, the analytical equipment system may be excepted to have its greatest potential in the field of conventional photogrammetry.

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Abstract

Eighteen months of work on two prototypes of the C-100 PLANICOMP have by far exceeded all expectations. After only brief instructions, many visitors did practical plotting work on this analytical stereoplotter, generally managing even unconventional problems without a modification of software. Up to now, the greatest gain was found to be in aerotriangulation and civil-engineering work. However, graphical plotting and DTM measurements were likewise handled with greater ease in the PLANICOMP than in analog plotters. Apart from the direct increase in measurement speed, accuracy, versatility and flexibility, the interactive processing and checking of information as well as the high operator comfort offered by the instrument greatly contribute to the unusual productivity and economy of the system. Since less than 50 % of the capacity of the process-control computer is taken up by the PLANICOMP, it may be expected to be used for other types of work as well: independent computation as in a decentralized computer setup, plus connection to other process-controlled equipment.

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Ergebnisse und Erfahrungen aus 1 1/2-jähriger Arbeit mit dem PLANICOMP C-100

Zusammenfassung

Nach bisher 1 1/2jähriger Meßtätigkeit an zwei Vorseriengeräten des PLANICOMP C-100 sind die ursprünglichen Erwartungen weit übertroffen worden. Zahlreiche Besucher haben bereits nach jeweils kurzer Einweisung Auswertungen an diesem analytischen Stereoauswertegerät durchgeführt, wobei auch unkonventionelle Aufgabenstellungen überwiegend ohne Programm-Modifikationen bewältigt werden konnten. Der größte Gewinn zeigt sich bisher bei der Aerotriangulation sowie in der Ingenieur-Photogrammetrie. Aber auch graphische Aufgaben sowie DTM-Messungen werden am PLANICOMP vorteilhafter bearbeitet als an Analogauswertegeräten. Neben der unmittelbaren Steigerung von Meßgeschwindigkeit, Genauigkeit, Universalität und Flexibilität trägt auch die interaktive Informations-Verarbeitung und -Kontrolle sowie der hohe und praxisnahe Bedienungskomfort zur außerordentlichen Produktivität und Wirtschaftlichkeit bei. Da der Prozeßrechner durch die Steuerung des PLANICOMP zu weniger als 50 % ausgelastet ist, dürften diesem in der Praxis weitere Aufgaben zuwachsen: unabhängige Rechenarbeiten im Sinne einer dezentralen Rechenstelle, aber auch der Anschluß anderer prozeßgesteuerter Geräte.

Résultats et expériences après un an et demi de travail avec le PLANICOMP C-100

Résumé

Après la mise en oeuvre pratique de deux prototypes du PLANICOMP C-100 pendant un an et demi, les résultats obtenus dépassent de loin le prévisions les plus optimistes. A la suite d'une brève mise au courant, de nombreux visiteurs ont déjà exécuté des travaux avec cet appareil stéréorestituteur analytique. Des tâches inhabituelles ont pû également être accomplies, dans la plupart des cas sans modification des programmes. Le PLANICOMP C-100 a prouvé surtout sa supériorité pour les aérotriangulations et les applications de la photogrammétrie dans le domaine du génie civil. Il s'avère aussi plus bénéfique que les appareils stéréorestituteurs analogiques pour tous les travaux de nature graphique et pour la mesure des modèles de terrains réticulaires (mesure DTM). En plus des avantages directs, à savoir accroissement de la rapidité des mesures, de la précision, de l'universalité et de la flexibilité d'emploi, le traitement et le contrôle interactifs des données, ainsi que le confort de manoeuvre absolu se traduisent par un gain sensible de productivité et de rentabilité.

La commande du PLANICOMP C-100 ne requérant que moins de 50 % de la capacité du calculateur, ce dernier peut remplir d'autres tâches, p.ex. opérations de calcul autonomes et commande d'autres appareils à régir en fonction de processus.

Resultados y experiencias obtenidos al cabo de año y medio de trabajo con el PLANICOMP C 100

Resumen

Un ano y medio de mediciones en dos prototipos del PLANICOMP C 100 han sobrepasado en mucho las expectaciones originales. Numerosos visitantes ya han trabajado en este estereorrestituidor analítico después de sólo breves instrucciones, resolviendo incluso tareas no convencionales generalmente sin modificación de programa. La mayor ganancia hasta ahora se manifiesta en la triangulación aérea, así como en la fotogrametría de ingeniería. Sin embargo, el PLANICOMP también resuelve más ventajosamente que los instrumentos analógicos las tareas gráficas, tales como mediciones DTM. Además del aumento directo en velocidad de medición, exactitud, universalidad y flexibilidad, el procesamiento y control interactivos de informaciones, así como el alto confort de manejo contribuyen decisivamente a la productividad y economía extraordinarias del nuevo sistema. Como el PLANICOMP sólo aprovecha menos de un 50 % de la capacidad de la computadora de procesos, esta última podría desarrollar otras labores: trabajos de cálculo independientes en el sentido de un centro de cómputo descentralizado, pero también trabajos en conexión con otros instrumentos controlados por procesos.

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