INVESTIGATION OF ACCURACY OF COMPUTATIONS IN GEODESY USING AN OLIVETTI P 101 COMPUTER

By

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An Olivetti P 101 electronic desk-top computer was used for test computations, investigations of accuracy in problems of survey calculations. The aim was primarily to establish what an accuracy could be achieved within the limits of the computer capacity, entering numbers of a given size and sharpness. In course of the test computations also the time required for the computation was recorded.

The type of survey computations suiting a P 101 is determined by the number and the size of stores for both arithmetic operations and numbers. The range of problems fit to the computer is somewhat extended by the use of the magnetic card, as in this way computation of a problem can be divided. The multi-card program often necessitates repeated entering of variables or of part-results. This may be considered unfavourable, but use of the mentioned possibilities makes nearly all survey computations accessible to the P 101.

For the computations, such programs are suitable which consist of as few instructions as possible and have the least time demand possible; this is also true to the available collections of programs. Such programs are called optimum programs. Of course the extent of the program has to be increased if thereby the accuracy of the solution or the permissible range of numbers entered can be usefully increased. This is why basically different programs can be found in different collections of programs for a certain problem, though each is an optimum program for the respective task.

Investigations invariably concerned that program alternative which involved the practically widest range of values for the sake of accuracy and utility.

In order to generalize and simplify programs of survey computations the problems involving angle or direction input or output are formulated so as to enter or get these values in the system of 400 grades of arc. Therefore the values of degree-minute-second of arc are turned by special programs into grades and vice versa before or after the computations. The conversion and reversion operation could be incorporated into the program of the problem, though at a loss of generality. besides, the computer capacity is rather low, so that in many cases a single-magnetic-card computation would become a two-card or multi-card program, making the computation cumbersome and lengthy. Conditions and accuracy of the separate conversion and reversion operations will be discussed below.

1. Conversion of degree-minute-second of arc into grades

Numbers entered in: degrees — minutes — seconds of arc.
Output: grades
Relationship between decimal numbers and accuracy is shown in Table I.

Table I

Number of decimals	5	6	7	8	9	10
Accuracy	$1''$	$0.1''$	$0.01''$	$10^{-3}{}''$	$10^{-4}{}''$	$10^{-5}{}''$

Number of cards: 1.
Entering of variables: single
Number of instructions: 31
Time requirement:

a) entering the data: 10 seconds,
b) computation: 3 sec. (Running time does not depend on the number of decimals.)

2. Conversion of grades into degree-minute-second of arc

Numbers entered: grades
Output: degrees—minutes—seconds of arc
Relationship between number of decimals and accuracy is shown in Table II.
Number of cards: 1
Entering of variables: single
Number of instructions: 27

Table II

Number of decimals	5	6	7	8	9	10
Number of decimals of the grade value	4	5	6	7	8	9; 10
Accuracy	$1''$	$0.1''$	$0.01''$	$10^{-3}{}''$	$10^{-4}{}''$	$10^{-5}{}''$

Time requirement:

a) entering the data: 8 sec.

b) computation: 6 sec. (Running time does not depend on the number of decimals.)

Note: Accuracy of the angle values in Table II is obtained only by rounding up.

Further investigations were extended to programmed computations of the following survey problems.

3. Computation of bearing and distance

Scheme of the problem is shown in Fig. 1

Numbers entered: y_1, x_1, y_2, x_2

Output: t_{12}, δ_{12}

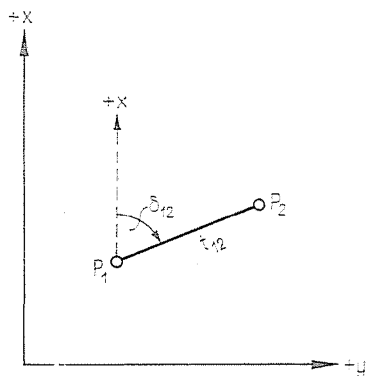

Fig. 1

Relationship between number of decimals and accuracy: Table III

Number of cards: 1

Entering of variables: single

Number of instructions: 107

Table III

Number of decimals	7	8	9	10
Maximum distance or co-ordinate [m]	10^8	10^6	10^4	10^2
Accuracy of bearing	1″	0,1″	0,01″	10^{-3}″
Accuracy of distance [mm]	10^{-3}	10^{-4}	10^{-5}	10^{-6}

Time requirement:

a) entering of data: 23 sec.
b) computation of the distance: 3 sec.
c) computation of bearing: 35 sec. as an average.

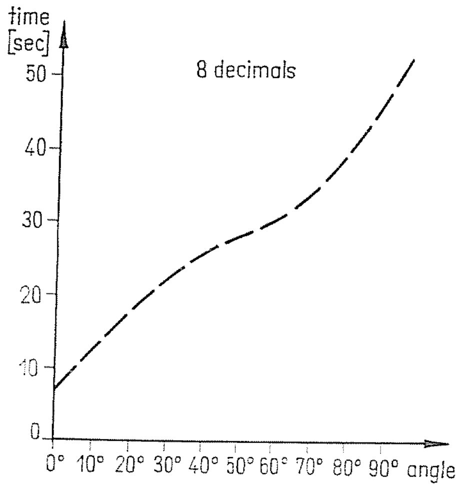

Fig. 2

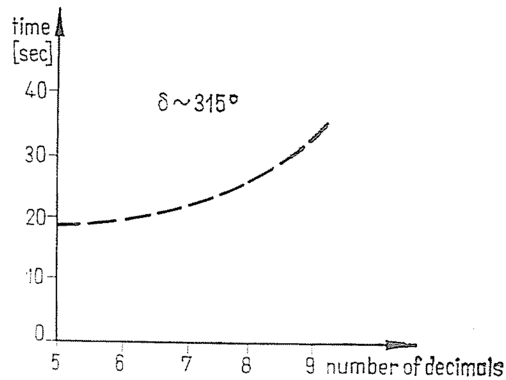

Fig. 3

Running time of computation of bearing depends:

a) on the angle data (Fig. 2),
b) on the number of decimals (Fig. 3).

4. Computation of co-ordinates of the polar point

Scheme of the problem: Fig. 4
Numbers entered: y_K, x_K, δ_{KT}, β_{TP}, t_{KP}
Output: y_P, x_P
Accuracy: Table IV
Number of cards: 1
Entering of variables: single
Number of instructions: 72
Time requirement:

a) entering of data: 35 sec,
b) computation: 12 sec. as an average.

Time requirement depends on:

a) bearing data,
b) number of decimal places (Fig. 5).

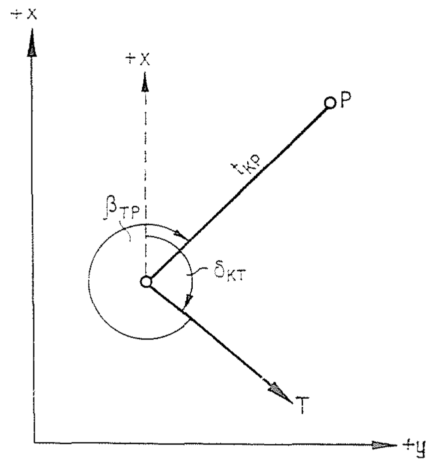

Fig. 4

Table IV

Number of decimals	4	5	6	7	8
Maximum number of integers in the co-ordinate and in the distance	7	6	5	4	3
Accuracy	dm	cm	mm	10^{-4}m	10^{-5}m

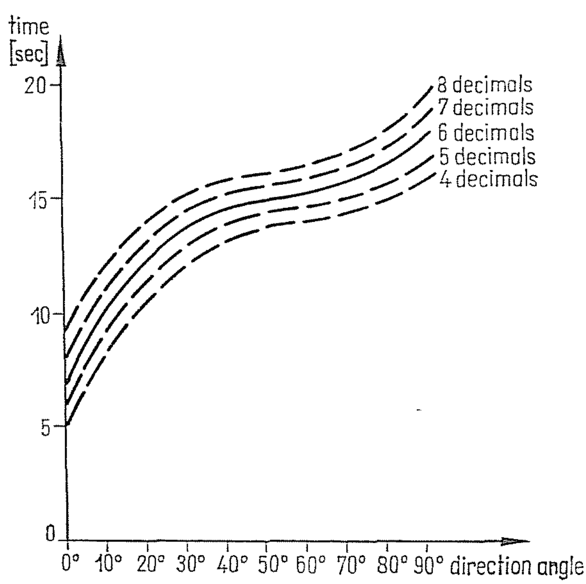

Fig. 5

5. Area computation from co-ordinates

Numbers entered: $y_1, x_1, y_2, \ldots, y_i, x_i, \ldots, y_1, x_1$
Output: area (T)
Accuracy: the output is exempt of neglect if twice the number of decimal places of the co-ordinates are entered.
Number of cards: 1
Entering of variables: single
Number of instructions: 48
Time requirement:
a) entering of data: 14 sec. for each pair of co-ordinates,
b) computation: 7 sec. (Running time is independent of the number of decimal places.)
Note: a pair of co-ordinates entered erroneously can be corrected in the course of computation.

6. Intersection by interior angles

Scheme of the problem: Fig. 6
Numbers entered: $\alpha, \beta, y_1, x_1, y_2, x_2$
Output: $\operatorname{cotg}\alpha$, $\operatorname{cotg}\beta$, y_P, x_P
Accuracy: Table V
Number of cards: 1
Entering of variables: single
Number of instructions: 94

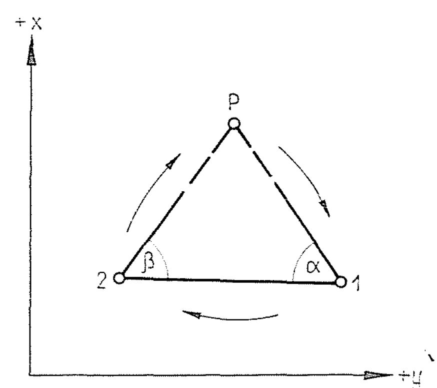

Fig. 6

Table V

Number of decimals	5	6	7	8	9	10
Decimals after calculation of cotg values	4	5	6	7	8	9
Maximum distance [m] of determining points	10^6	10^5	10^4	10^3	10^2	10
Accuracy [m]	100	1	10^{-2}	10^{-4}	10^{-6}	10^{-8}

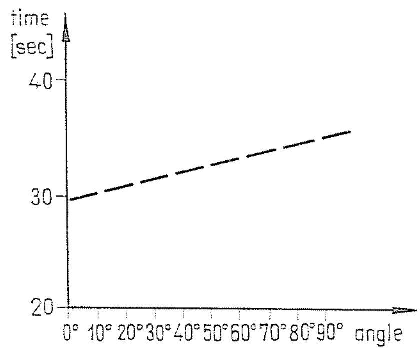

Fig. 7

Time requirement:

a) entering of data: 32 sec.

b) computation: 75 sec in average.

Running time: computation of the cotg-s of the angles depends on the angle data (Fig. 7).

7. Intersection by bearings

Scheme of the problem: Fig. 8

Entering of variables: δ_{1P}, δ_{2P}, y_1, x_1, y_2, x_2

Output: tg δ_{1P}, tg δ_{2P}, y_P, x_P

Accuracy: Table VI

Table VI

Number of decimals	5	6	7	8	9	10
Number of decimals in computation of tg values	10	10	10	10	10	10
Maximum distance [m] of determinant points	10^6	10^5	10^4	10^3	10^2	10
Accuracy [m]	10	10^{-1}	10^{-3}	10^{-5}	10^{-7}	10^{-9}

Number of cards: 1
Entering of variables: single
Number of instructions: 88
Time requirement:

a) entering of data: 32 sec.
b) running time: 54 sec. in average.

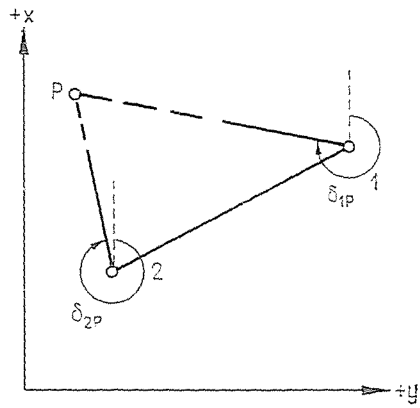

Fig. 8

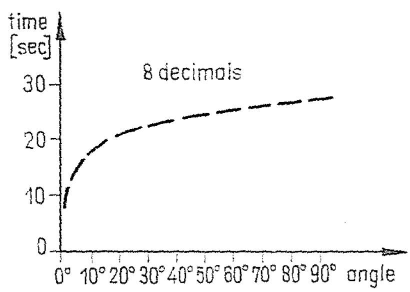

Fig. 9

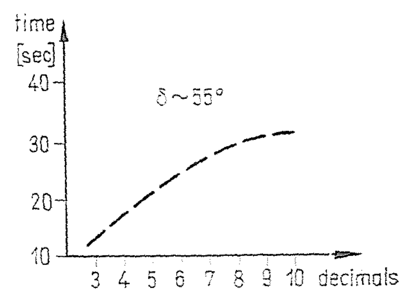

Fig. 10

Computation time of tg *values* is a function of:

a) the angle data (Fig. 9) and,
b) the number of decimal places (Fig. 10).

8. Sizes of rectangular staking out

Scheme of the problem: Fig. 11
Numbers entered: y_1, x_1, y_2, x_2, y_3, x_3
Output: t_{10}, t_{30}, y_0, x_0
Accuracy: Table VII

Number of cards: 1
Entering of variables: single
Number of instructions: 96
Time requirement:

a) entering of data: 25 sec.
b) running time: 15 sec. (independent both of decimal places and of stake spacing).

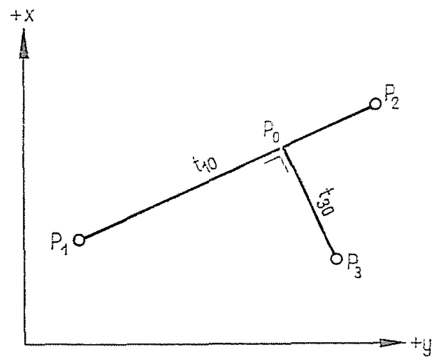

Fig. 11.

Table VII

Number of decimals	4	5	6	7	8
Maximum distance [m] of points	5000	2000	800	200	50
Maximum number of integers	7	6	5	4	3
Accuracy	dm	cm	mm	10^{-5}m	10^{-5}m

9. Three-point resection

Scheme of the problem: Fig. 12
Numbers entered: α, β, y_1, x_1, y_2, x_2, y_3, x_3
Output: y_P, x_P
Accuracy: Table VIII

Table VIII

Number of decimals	5	6	7	8
Maximum distance [m] of points	5.10^5	5.10^4	5.10^3	5.10^2
Accuracy	10 m	dm	mm	10^{-5}m

Number of cards: 2
Entering of variables: single
Number of instructions: 179

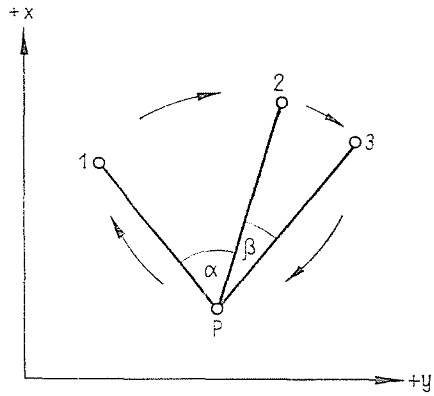

Fig. 12

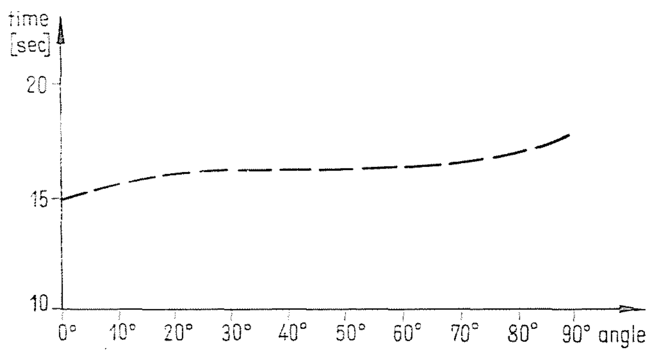

Fig. 13

Time requirement:

a) entering of variables: 31 sec.

b) running time: 41 sec. in average.

Running time for the cotg *depends on angle values* (Fig. 13).

10. Traverse oriented at both ends with distribution of angle misclosures

Scheme of the problem: Fig. 14

Numbers entered: $\delta_A, \delta_B, \beta_A, \beta_1, \ldots \beta_n, \beta_B, t_1, t_2, \ldots, t_n, y_A, x_A, y_B, x_B$

Output: misclosure of angles ($\Delta\varphi$), $\delta_1, \delta_2, \ldots, \delta_n$, projections of polygon-sides ($\Delta y_1, \Delta x_1, \Delta y_2, \Delta x_2, \ldots, \Delta y_n, \Delta x_n$), preliminary co-ordinates ($(y_1), (x_1) \ldots, (y_n), (x_n)$), projection misclosures (dy, dx) sum of polygon-sides $[t]$,

final co-ordinates $(y_1, x_1, \ldots, y_n, x_n)$.
Accuracy: Table IX
Number of cards: 2
Entering of variables: multiple entering of variables and of part-results
Number of instructions: 227

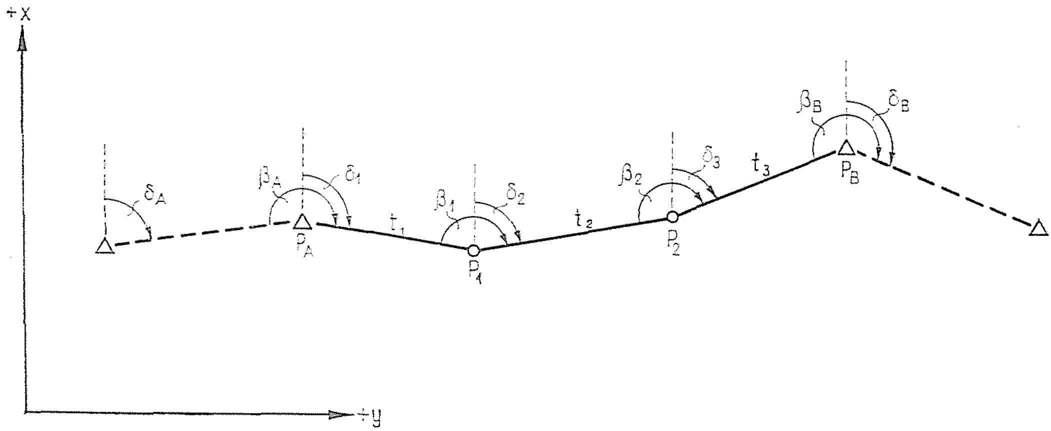

Fig. 14

Table IX

Number of decimals	5	6	7	8
Maximum number of integers in co-ordinates	6	5	4	3
Accuracy	dm	cm	mm	mm

Time requirement:
a) entering of data: for each point 40 sec.
b) computation: for each point 1 minute 20 sec. in average.
Running time: increase of the number of decimal places demands 3 sec. more time for each point.

*

Notice that the time data given with the output types represent the neat running time. For mass computations the preassessed times have to be increased by a given basic time and repetition times, for faulty computations.

The P 101 lends itself to solve a much wider range of problems than outlined here. Rather than to aim at completeness, our accuracy analyses affected various program types listed by Roupp [1] and the most frequent problems. Analysis of all survey problems suiting a P 101 computer still demands considerable amount of work.

Summary

Results of accuracy investigations of ten computation problems most frequent in geodesy are discussed.

In Tables I to IX accuracy data are given as a function of the entered number of decimal places as well as other conditions to obtain the required accuracy.

The recorded time requirement for each problem is indicated together with factors of the running time. Functional relations are shown in diagrams.

References

1. ROUPP, M.: Ein neuer Kleincomputer und seine Einsatzmöglichkeiten im Vermessungswesen. Allgemeine Vermessungsnachrichten 1968.
2. FÖLDVÁRY-VARGA, M.: Olivetti P 101 and its uses in geodesy.* Geodézia és Kartográfia 1971.

* In Hungarian.

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