THE COMPUTER IN LAND SURVEYING

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Introduction Few technological innovations during the past several years have made such an impact on the public imagination as the development of high speed electronic computers. Nevertheless, it is probably true to say that the subject of computers and their attendant automated systems have remained something of an enigma to the public as a whole.

Sensational and exaggerated newspaper and television reports have been very misleading in their delineation of computer applications and the esoteric approach prevalent in the majority of articles written on the subject, have undoubtedly created the impression that the skills required to use and understand computers are beyond the average comprehension.

Little has been done to overcome such impressions. The status of the computer as a useful tool for many potential users, has, perhaps, suffered from its initially glamourized image as a relentless "super-brain", epitomized by frequent glossy advertisements showing wildly attractive young women surrounded by many pieces of highly complex machinery.

The surveying profession, no less than any other, has in recent years been flooded with requests and exhorted to use the facilities of a variety of computing companies both in Canada and the U.S.A. Unfortunately, the results were often less than satisfactory. The reasons for this were many and varied. Frequently the program or set of computer instructions, were merely reproductions of existing manual forms of calculation and as such, failed to utilize the computer to its fullest capacity. They thus became extensions of the electric or manual calculator. In apposition to this lack of full utilization, computers were used whose capacities were totally inadequate to handle the complexity of the problems encountered. Furthermore, there was often complete failure on the part of the programmer to develop a program orientated towards the practical problems of the surveyor. To compound the difficulties, the application of the program was not infrequently carried out by personnel totally unfamiliar with the art of surveying.

In many cases, the inadequacy of the programs produced some fundamental misconceptions. The format for the input preparation was sometimes so intricate, that the engineer or surveyor found it required more time to prepare the input than to obtain the solution manually. Moreover, the complicated nature of the input permitted greater leeway for error, which in any computer operation must be minimized if it is to be successful. Finally, the cost of the calculations was generally the same, and in some instances more than the manual costs.

The conclusion in certain areas that the computer, as an adjunct to the surveying profession, was impractical, costly and unsuitable for the majority of surveying problems was therefore not entirely surprising. Although some excellent programs for land surveying and ancillary calculations have come into being during the last two or three years, a considerable degree of scepticism and suspicion as to the practicality of this method of calculation still exists in many minds.

It is hoped that this article, written from an intimate experience gained over the past two years in the development and application of computer programs, will dispel for the reader, some of the misconceptions formed from past experiences. It may help to illuminate the topic for those surveyors who already use the computer and for whom the computer will become an increasingly more important asset in the performance of their day-to-day surveys.

The Computer Having outlined some of the misconceptions of the subject, it remains to clarify the topic. Before discussing the development of a computer program the question as to what precisely is a computer should be answered.

Basically, the computer is an electronic device designed to handle massive amounts of data rapidly, accurately and efficiently. Normally computers are made up of three basic units:-

(1) Input units which feed or introduce data into the system;

(2) The Central Processor which controls the processing routines, performs the arithmetic and maintains a quickly accessible memory. The memory is, in effect, an electronic filing cabinet, completely indexed and capable of storing large amounts of data during processing.

(3) Output units which serve two functions: (a) to create records and reports, and (b) to create new data which can be utilized in further automated processes.

There are of course many variations in these units but in any computer system, there are one or more input units, a central processor, and one or more output units. Although the development of a computer program is concerned with the total system, it is primarily concerned with the operation of the central processor, since it is here that all the calculations are performed and the information stored.

The basis of the computer's number system is the binary system, that is, with a base of two as opposed to our decimal system with the base of ten. The reason for this is that the computer being electronic, the components controlled by the electric current may be considered as either "on" or "off". This "on" or "off" characteristic means that the best number system for a computer has a base of two. The two digits in this number system are zero and one. Zero means the current is off. One means the current is on. The binary representation of the decimal values 0 through to 9 is illustrated below:

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Although the computer uses binary numbers and performs all its computations in binary numbers, both the input and output of the computer is done in ordinary decimal numbers. That is, all of the information and data fed to the computer through the input units are decimal in nature. The computer can automatically convert these decimal numbers to binary numbers. After the computations are performed, the computer converts the binary numbers back to decimal numbers. The answers, printed out from the output units are thus in decimal form that can be easily read.

In spite of the computer's tremendous ability to handle enormous amounts of data rapidly and accurately, it is not a brain. It does only what it is instructed to do. It is capable of making "decisions" as to how to handle particular kinds of data, but it must be instructed exactly what decisions to make and specifically, when these decisions are to be made. It has a memory but it is nothing more than electronic filing cabinet. The computer must also have detailed instructions on precisely where to "look" to find the information it needs.

<u>The Program</u> Giving the computer instructions is referred to as "programming the computer", or more exactly developing a program, which is the act of preparing the necessary instructions telling the computer what you want it to do, how you want the job done, and in what sequence you expect it to perform the various operations. In order to prepare these instructions, the programmer must know what information must be produced and what data is available to feed the computer. Having decided on the input and output information, the programmer can commence to write the program.

Instructions to the computer may be in several forms. They may be coded in the machine language, or written in a program language which is either machine orientated or procedure orientated. Machine languages vary from computer to computer and are often complex and difficult to learn, indeed with large computers programming by this method is impractical if not impossible. On the other hand, a programming language provides the means whereby the instructions may be written in a form which transfers much of the clerical work of writing the program to the computer.

There are several languages in operation, e.g., Algol, Cobol, Fortran, etc., for different machines and systems. The one with which most technical people are familiar is Fortran developed by the I.B.M. It is a mathematical language which closely resembles the ordinary language of mathematics. A simple example of mathematical expression written in Fortran is illustrated below:

EXAMPLE OF FORTRAN INSTRUCTIONS TO CALCULATE $X = \frac{A + B}{B}$

FORTRAN ST	EXPLANATION
50 READ (5, 10) A, B	READ VALUES
10 FORMAT (F7.2)	
T = (A+B)	CALCULATE NUMERATOR
IF (T) 15, 20, 15	IF ANSWER = 0, STOP
15 IF (B) 30, 40, 30	IF DENOMINATOR = 0 WRITE ERROR
30 X = T/B	CALCULATE EXPRESSION
WRITE X (5, 10)	WRITE ANSWER
GO TO 50	GO BACK AND READ VALUES
40 PRINT 11	WRITE ERROR
11 FORMAT (12H$_b$ INPUT $_b$ ERROR)	
GO TO 50	GO BACK AND READ VALUES
20 CALL EXIT	STOP

The present surveying program with which the writer is familiar is written in Fortran. The basis of this program is two-dimensional co-ordinate geometry or analytic geometry, a system of mathematics familiar to the surveying profession but little used manually because of its unwieldly nature. This indicates immediately the basic difference between manual concepts and computer concepts of calculation. Because of the computer's ability to perform hundreds of thousands of calculations very rapidly, that which is inconceivable manually, not only becomes feasible with the computer but in fact is sometimes the only correct way.

In any approach to programming for the computer two of the most important considerations are flexibility and versatility. A co-ordinate geometry system provides the means whereby an infinite variety of geometric problems can be solved by defining the geometry in terms of co-ordinates, from which may be extracted the required information in familiar surveying terms, i.e. bearings, distances, curve data, area and of course, the co-ordinates of every point.

The application of co-ordinate geometry to surveying mathematics reduces 90% of all problems to the "repetition" of four basic solutions.

The co-ordinates of a point may be defined by:

(1) A distance and direction; or
(2) The intersection point of two lines;
(3) The intersection point of a line with a distance (i.e. a line with a circle);
(4) The intersection point of two distance (i.e. the intersection of two circles);

The last two solutions provide, of course, two answers from which the correct one may be selected by the inclusion of a reference point.

This, therefore, is what constitutes the "input" for the computer; the definition, in various forms, of the geometry of the problem in terms of the four basic solutions for co-ordinates. From the co-ordinates thus calculated are extracted the required information for the "output", which is in a format familiar to most surveyors and engineers. It will be noted that input consists of the four basic calculations repeated many times. This emphasis on repetition is important to the computer operation. In evaluating a computer's ability to provide a comprehensive solution, it is necessary to reduce the problem to simple repetitive elements. If this cannot be done it is not generally a problem for the computer.

The effect of this change in emphasis from trigonometric to geometric solutions with the computer, introduces a far greater degree of flexibility than has heretofore been permitted in surveying calculations and relieves the surveyor or technician from the burden of many detailed and laborious calculations, while at the same time ensuring him of a far higher degree of accuracy in the final results. A vast amount of detailed information can be obtained with comparatively little effort and many more or less complex problems can be solved by defining the geometry in a few lines of input.

Program Application

It is one problem however to produce a comprehensive program, but an altogether different problem to relate the computed values to practical surveying. Difficulties have arisen in establishing in the field, the absolute values computed by the machine, because of the limitations of the survey equipment and personnel. This perhaps more than any other single factor, has contributed to the reluctance of the surveyor to make the fullest possible use of the computer. Moreover, in order to apply a computer form of calculation properly, a complete re-thinking of the existing methods of doing certain types of surveys is often required.

It also became apparent that a completely versatile system of adjustment was necessary to reconcile the natural accumulative errors inherent in any type of survey.

Subdivision Application

To date, the biggest use that has been made of the computer has been in the area of subdivision calculations. Experience in this area has indicated that without the implementation of proper control procedures either physical or computed, it is indeed very difficult to layout large areas of development. Without control the accumulation of error frequently becomes difficult to reconcile with the computed data. Although there are those who advocate the simple expediency of accepting field measurements over computed, this does in effect nullify the calculations and where specific information must be supplied to Townships to indicate compliance with the by-laws, aborts the whole purpose of the calculation.

There are a variety of ways to establish control. In the past, a grid system or set of control lines laid out in the field has proven sufficient except that the surveyor had to adjust them manually prior to providing the information to the computer. Now, of course, such lines can be adjusted according to surveyor's instructions in any way desired. A more successful method however, has been the establishment of a precalculated control generally in alignment with the anticipated position of the road lines. This is based upon an adjusted boundary survey, or in the case of an irregular boundary, three or four control lines properly adjusted. The philosophy behind this system is one of proportioning and is of course, predicated on the assumption that the boundary or control has been surveyed to a reasonably high standard of accuracy that is consistent with the size of the development.

The precalculated control lines are established in the field, the measurements compared with the computer data and, if reasonable, simple proportioning is employed to establish the positions of intersecting and emergent lines. The distribution of the error in this fashion enables the road fabric for a large tract of land to be established within a considerable degree of accuracy. Thereafter, the computed information for the lots and blocks must fit without any significant error, in fact, from the experience of several surveyors, with almost negligible error.

Right-Of-Way and Road Widening Application

In the field of road widening and easement surveys, there are once again a variety of approaches contingent upon the nature of the survey. A basic traverse control or centre line, into which are tied either by production, right angle or random ties all existing property lines and evidence governing the position of the lines, may be employed as the basis for the calculations to establish the dimensions of the widening limits, together with the area of the parcels to be acquired. The limits of the widening may then be established in the field from the computer data.

This is suitable for widenings where the road limits are irregular and the lines between the properties abutting on the road run at varying angles to the limits. In simple parallel widening strips, however, it is generally easier to establish the widening limits as the survey proceeds and use the computer calculations as a check against the field survey data.

In some surveys it is necessary to precalculate irregular and curved widenings or highway right-of-way strips through several parcels. This poses a different problem - the proper adjustment of the various properties or parcels through which the widening or right-of-way proceeds. For the sake of compatibility with deeds or old surveys, it is also necessary in many cases to adjust the surveys retaining specific information.

By using a recently developed iterative adjustment with a quadratic convergence these problems can now be easily solved using a co-ordinate geometry program. Indeed, if required, an adjustment for more precise surveys with identical results to the least squares, can be obtained with the minimum of effort by such procedures.

The principle involved is again repetition in the computer operation, for to iterate is precisely this - to repeat again and again certain basic data. A basic formula for adjustment is taken and by feeding back the information it is required to hold, the desired result is obtained. This may entail ten or a thousand repetitions of the formula depending on the problem and the degree of accuracy required, but since it harnesses the computers ability to process enormous numbers of calculations with tremendous speed, it is an immaterial consideration.

<u>Disadvantages</u> Having covered some but by no means all of the practical applications of the program, it remains to enumerate some of the advantages and disadvantages of the system to the practising surveyor.

It is perhaps convenient to discuss first the disadvantages. Foremost of these, is the problem of processing small jobs in a large scale computer operation. Although from the production aspect they present no problem, they do tend to become expensive for the computing firm to process if they cannot be incorporated into larger runs, since the machine costs naturally decrease in proportion to the volume of data being processed. Furthermore, by the time they have reached the computing firms, are computed and returned, it is probable that some could have been done quicker manually. Jobs which can be done by a draftsman in one or two days are generally not problems large enough to justify the use of a computer.

Experience has indicated, however, that when an excessive work load occurs and the surveyor is faced with working overtime or hiring additional staff, the opportunity to pass off the excess on to the computer, even if it consists of small jobs, is of great value in providing his client with rapid service.

From a technical viewpoint, the preparation of the input is a sensitive area. Although this may not be of too much interest to many surveyors, since they anticipate the computing firm preparing the input, it is worth mentioning in order to dispel any notion that it is a simple pushbuttom operation. Since the job often involves computing a subdivision or right-of-way survey in its entirety, the person preparing the input not only has to be thoroughly conversant with surveying and its attendant geometry, but has to have a retentive memory combined with a high degree of clerical accuracy. It is in fact true of any computer operation that the leeway for input error is around two percent if it is to be an economical proposition. Therefore, for those surveyors intending to have personnel trained in the preparation of input, these factors should be borne in mind in the selection of suitable people.

<u>Advantages</u> Before describing the various advantages from a technical and survey operation viewpoint, it is perhaps worth examining the question of errors, which appears to be an obsessive point with people recently acquainted with computers.

Computers are not reliable enough that the possibility of error need never be considered. They have, however, been designed to be far more reliable than their least reliable component and as a consequence are sufficiently reliable that in locating errors the last consideration is the computer. Generally, when computer errors do occur they are of such a magnitude and form as to be only too obvious.

Other errors came under the category of input errors and geometric errors. Input errors may be of two types, either data incorrectly entered or data cards incorrectly punched. The majority of programs have built in checks which enable the computer to locate and describe a variety of errors in this category, together with their source.

In addition, there may be produced at the end of each job a listing of the input data from which the calculations were completed. This may be checked with the output so that transcription errors in input of the nature 25.96, instead of 25.69 become easily discernible.

Lastly, the advantage of cost is significant. It would appear that the computer costs are on the average about twenty percent lower than it would cost the surveyor to do the calculations. However, there is by no means unanimity on this subject. It is the contention of some that they can do an adequate job for the same costs, but it is felt that if time is money, then this in itself is a saving, irrespective of the fact that the information supplied to the surveyor is often considerably more than he would contemplate calculating himself.

Conclusion For those surveyors who have yet to explore the services offered by the various computing companies, it is hoped that the following opinions will assist them in evaluating the quality of the services.

1. The magnitude and complexity of the average surveying problem requires a program of such a size that the only machines suitable are large general purpose computers. They provide a memory large enough to facilitate the development of a program sufficiently sophisticated that the input preparation can be done with the minimum of effort and time. In addition, they are capable of accommodating the vast amount of detailed information it is required to store.

   The adequacy, therefore, of a small computer operation is questionable. Although a small computer can theoretically do anything the large one can do, given enough time, practical considerations preclude this. Further, any program developed for a small computer must of necessity be limited in its scope and ability to provide the most satisfactory solution.

2. The only satisfactory type of program for the solution of surveying problems is a co-ordinate geometry program. It is a system of mathematics easily adapted to a computer operation. Traverse type programs with trigonometric solutions have proven to be too rigid both from a programming and input preparation viewpoint. They also lack flexibility and are incapable of being used in the comprehensive manner required for the majority of surveying projects.

3. It is axiomatic that any firm engaged in providing computer services for land surveyors, should retain on their staff personnel professionally qualified in land surveying who are fully conversant with the problems. Any firms who do not, unless they have a proven record of performance in this field, should be approached with caution. It is difficult for other professionals no matter how competent in their own fields to understand and appreciate the surveyors' problems.

Since a thorough knowledge of law is of paramount importance in the execution of his duties, the land surveyor has perhaps been inclined to consider the mathematical aspects of land division of secondary importance. His pre-occupation and rightly so, with the extent of title in all its ramifications has obscured the fact that there is already a large body of people of a variety of professions encroaching on his professional responsibilities. With the advent of the computer, highly refined photogrammetric methods and now digital plotters there is a tendency, albeit unconscious at times, to pre-empt the surveyor's position and relegate him to the status of a technician. It is therefore essential that to justify his title of professional, the land surveyor keep abrest of the scientific and technological developments of the surveying field, even if at times his sphere of activities appear to be restricted to much that is mundane.

In this context, it is urged that those surveyors who have not yet explored the field of computing services, do so. There is no doubt that considerable benefit would be derived from the knowledge acquired. It is to the advantage of the surveyor and his client that he becomes aware of the new techniques which would improve the quality and speed of the surveys he performs.

Geometric errors are sometimes the most difficult to locate, since in large jobs the large amount of output may look perfectly correct until detailed examination proves otherwise. Quite frequently, however, the incorrect definition of the geometry produces weird results, which become immediately apparent in an automatic or manual plot of the data. These are mostly the result of inexperience in preparing input and cease to occur with increasing knowledge of the technique employed in using the program. Errors of this nature are also, of course, directly related to the competence of the person preparing the input.

This then, is one of the major advantages of the computer calculation, that on an average a far higher degree of accuracy can be expected than presently exists in manual methods - there are too many checks and counter checks to permit otherwise.

From the viewpoint of fieldwork, it would appear that the possibility of gross errors is eliminated and indeed the incidence of small errors is also greatly reduced, since the surveyor must fit the computer data or conclude that there are larger inaccuracies in his fieldwork than warranted. To reiterate a point, this does not mean that the computer operation is infallible, but experience has shown that the majority of errors exist in the field and generally can be rapidly located before any damage is done. The effect of this is to raise the standards of fieldwork and in subdivisions the availability of good control enables the work to proceed more rapidly, especially in the final stages of lot stakeout.

It is true of course, that initially a higher standard of fieldwork is required in the boundary and control surveys which are to be used as the basis for the precalculation. This may mean a little more time and trouble than is normally expended, but is in the opinion of the writer well worth the effort considering the advantages to be derived.

It has been argued that precalculated systems can only work on the assumption that the error is accumulative and this is true, but the problem of large compensating errors, or accidental errors lying in one or two lines, is just as acute a problem to reconcile in manual calculations, as it would be in computer calculations, in fact more so. Given the corrected information which may mean the revision of one or two data input cards, the complete subdivision or road survey may be recalculated within seconds and returned the same day, at a cost far less than would be necessary for a draftsman to spend time trying to correct the calculations or adjust the survey manually.

An integrated precalculated co-ordinate system properly established, provides the means whereby the use of co-ordinates for additional control and retracement becomes feasible, in that the tolerances within which each point is established are sufficiently high to permit the redefinition of lost corners and lines with considerable accuracy. In this context, for those unaccustomed to working with the co-ordinate system, it has the added advantage of introducing them to the co-ordinate system in an effective way. Problems in control and especially retracement may be minimized through the use of the co-ordinates provided in the calculations.

There are of course, more obvious advantages. In subdivisions the ability to guarantee full compliance with the by-laws in regard to frontage and area, is a feature which in some sections of the Province make the use of the computer essential, so acute have become the problems of interpretation which appear to vary from Township to Township and City to City. The element of time is often of critical importance. It is now possible to turn out in about two weeks that which previously took two months of manual calculations. This advantage may result in considerable savings to the surveyor's clients and in the case of subdivisions, the engineers can proceed to expedite their designs and plans for services.