CANADIAN SHORAN PROJECT

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INTRODUCTION

In 1949 following two years of experimentation with Shoran electronic equipment, Canada initiated a trilateration survey of its regions to the north of the then existing triangulation system. In the period 1949-1957, except for 1954, the system was gradually extended until its completion in 1957, with its farthest north station at Lake Hazen, Ellesmere Island, 600 miles south of the north pole. The magnitude of the completed operation may be appreciated best by a comparison of the area thus controlled with that of the total area of the five countries greater than that within the Canadian Shoran Project, i.e., Australia 2 900 000 square miles; Brazil 3 300 000; Canada 3 300 000 (Shoran control 2 500 000); China 3 759 000; United States with Alaska 3 548 000; U.S.S.R. 8 548 000.

The vast northern region had previously been sparsely controlled by precise astronomic determinations of latitude and longitude with the greatest density of stations along the 60th parallel of latitude. In addition, about 1 040 second-order astronomic stations were scattered quite generally over the northern mainland and the southern fringe of the Arctic Archipelago. These stations had been determined for control of small-scale aerial mapping. Most of the vertical photography has now been completed. To satisfy the demands of larger-scale mapping, the trilateration had to be conducted in such a way as to secure a much greater accuracy than that obtainable by astronomic means. There was no intention that the system should be made to approach first-order geodetic accuracy, although it was fondly hoped that this might result. Nor was it, nor is it now, considered that the geodetic triangulation operations are replaced; in fact, the necessity for them in the near future is more apparent.

At the outset it was decided that the trilateration should cover the entire area, as this would make possible the maximum use of the available geodetic control, and supply an immediate basis for Shoran-controlled photography.

It is profitable to consider, although somewhat briefly, some of the details of interest to geodesists and also to mention other functions for which the Shoran system is now being used.

I

The Shoran net consists of 143 stations (18 fixed) with 502 measured interlacing lines of which the longest is 367 miles. The average length of line is 230 miles. The net has been adjusted in two parts : *a*) the work of 1949-1955 and *b*) that of 1956-1957 with the addition of 3 stations noted later.

The part south of the Arctic coast *a*) above, which was adjusted by the U.S. Army Map Service in 1956, consists of 116 stations with 384 interlacing lines. It is attached to 18 triangulation stations along its western, southern, and eastern limits. The triangulation control stations are widespread with the northerly terminal stations 4 500 miles apart by the shortest triangulation route, although they are only 2 400 miles apart through the Shoran net. It is thus improbable that the terminals are spaced correctly within a few feet, so some distortion must arise in the Shoran net from this source. Four Laplace azimuths are included in the net and, in addition, the Greenland Hiran connection has imposed a length and an azimuth condition.

The results of this adjustment and further information now available allow us to give the following as a fair assessment.

The Shoran trilateration is indicated as having an average line-measurement accuracy of 1 in 56 000. The average correction for a line is 21.4 feet.

Two Shoran stations, since connected by triangulation, indicate errors in placement by Shoran within error circles of radii 18 feet and 30 feet. A comparison of inverse triangulation lengths with Shoran adjusted lengths for the common stations of both systems indicates that Shoran lengths agree with triangulation lengths on the average to better than 1 in 60 000.

If the systematic errors of calibration in the various years' work were eliminated by the adjustment, and the tendency to swing, which contributes distortion of various amounts and direction in the net, was maintained within narrow limits, it is estimated that northern stations should not be in error by more then an 80-foot radius of absolute position. This would apply to stations in an area some 800 miles from the present first-order control. We know that the factors of systematic error and swing cannot be correctly assessed until chains of first-order triangulation are projected northward. When this has been done the present Shoran placement may be improved by the use of more triangulation values as basic control. Two such chains of triangulation are now being projected and by the end of 1959 there will exist more accurate values for 3 more Shoran stations. In the course of time the Shoran net will be divided into sections, each containing a relatively small number of Shoran stations. Local adjustments will then provide the knowledge which we now lack of systematic length errors and distortion in position.

The inter-station lengths in local areas are maintained to an order of 1 in 56 000, irrespective of whatever error in station position may now exist.

The accuracy of length measurement and the position of stations are assessed as of second-order accuracy and thus the trilateration is amply sufficient for the purpose for which it was designed, that of control for Shoran photography in the production of large-scale national maps.

Geodesists with an engineer's educational background are able to draw an analogy between the Canadian system and the problems of bridge design. The minus and plus corrections of the measured lengths as given by the adjustment indicate the compression and tension members of the trilateration. They represent the push and pull required to correct the measurements to a point-to-point system. Their values will remain static until there is a change in loading. As far as trilateration is concerned, a change in loading will be brought about by Shoran stations being incorporated within the proposed triangulation northward. This will introduce a foundation of new and more accurate values of geodetic position for control. The Shoran stations common to new triangulation stations will not then be free to adjust themselves to the strains of local measurements. The errors of these measurements will be forced in the area where they occur and their effect upon the system as a whole will be greatly diminished. This is a process of obtaining better geodetic positions for the Shoran stations similar to successive approximations.

For the part north of the Arctic coast, 3 stations of the southern net, which were strengthened by more measured lines in the extension northward in 1956, were readjusted with the 1956-1957 part. This adjustment was based on the values as given by the 1956 adjustment for the northern stations of the southern net. In this, the position of Shoran station Thule was held fixed to a value supplied by the U. S. Army Map Service.

A summary of the results of this adjustment follows :

1956 averages :

Line correction : .... 34.4 feet
length of line : .... 237 miles

$$\frac{\text{correction}}{\text{line length}} = \frac{1}{36\,500}$$

$$\text{worst ratio} : \frac{1}{7\,400}$$

1957 averages :

Line correction : .... 15.1 feet
length of line : .... 222 miles

$$\frac{\text{correction}}{\text{line length}} = \frac{1}{77\,000}$$

$$\text{only two values exceeding } \frac{1}{30\,000}$$

The corrections for six lines of the new portion directly connected with 2 central stations of the southern work indicate a distortion or swing in relative position of these stations. These corrections are the largest obtained in the entire system, are also concentrated in a local area and may therefore be considered not to arise from mismeasurement. If these six lines are excluded from the 1956 summary above, the average ratio becomes 1/46 500 for the 1956 work and for the two years 1/60 000.

In 1956 and 1957 all Shoran equipment had been replaced by improved equipment, designated Hiran. It was therefore somewhat of a surprise to get an indication of less accuracy for the northern than for the southern work. No doubt the excessive corrections noted above are in large part due to distortion of the southern work in the vicinity of the attachment used in the northern adjustment. These stations being on the edge of the southern net are geometrically less strongly placed than interior stations. It is also fair, however, to point out that other factors also operate and I quote from *The Canadian Surveyor*, July 1958, A. C. Hamilton :

" With this equipment, the gain-riding technique as developed by the USAF was introduced. This is a system whereby the errors due to variation in pulse strength are minimized by manual gain controls at each receiver. The maintenance and servicing requirements are exacting, and a high degree of coordination is required between all the operators. The equipment must not be merely in working order. It must be at peak efficiency. It is well known that it is many times more difficult to keep electronic equipment at peak efficiency than just to keep it in working order. Most of the period allocated to training (of RCAF personnel) during the winter of 1956 was required by the technicians to get the new equipment working and there was little time to strive for optimum performance. The 1956 season was hectic. Churchill, our main base, was 1 000 miles from the center of the net; aircraft and crews were away at advance bases for days at a time. Operations were started in May; temperatures of minus 20° F prevailed at the ground stations. From our experiences this season it was quite apparent that a training period of at least six months, and preferably a year, is needed for the technicians to become sufficiently familiar with the complex equipment to get first-order accuracy from it. Fourteen stations were positioned by measurement of 57 lines in 1956 ".

The theoretical geodesist may express surprise and even disappointment that an electronic survey of this magnitude does not produce results of greater apparent accuracy. The practicing geodesist feels differently because of several vital factors. One of these is the necessity of accurate heights for the Shoran stations and for the plane during line-crossing operations. Basic elevations were not available in the area, so resort had to be made to barometric determinations correlated with the synoptic weather maps. This method is practical but does not lead to the most precise values of elevation. Also, the equipment initially was wartime material and used during a period when replacement of defective parts was hard to obtain. Service personnel had to be trained in duties foreign to their former fields and unfortunately for our purposes a rotation of personnel was in vogue. Generally when the technicians had obtained their maximum of efficiency and knowledge, they were seconded to other duties, and the training of others had to be done mostly under operating conditions with only a nucleus of former personnel left to guide them. That the results are of as high an order of accuracy as indicated is a tribute to the interest, faithfulness, and capability of all and especially to the few who served for lengthy periods under conditions sometimes far from pleasant to complete a major task.

There is no question now as to the suitability of the electronic method and to its use in trilateration over vast remote areas devoid of horizontal control. It is timesaving, economical and can be used to secure various degrees of accuracy. The Canadian system will be steadily strengthened by attachment to future triangulation and thus in course of time will be vastly improved in accuracy because it will be subject to more control in geodetic position, i.e. through length and azimuth from the triangulation. What is not so clear is how many lines per station would have been necessary to obtain, under the requirements of the Canadian operation, a substantial increase in accuracy. To have increased the number of lines per station would first require the introduction of many more stations within the present framework, so that lines would be shortened and thus make the framework more rigid by the measurement of extra interlacing lines. To obtain an accuracy of 1/100 000, Hiran requires a factor " Total lines to those required for fixation " at the least in the ratio 3 to 1, while in Canada for Shoran the ratio is 2 to 1. The increase of stations and lines to secure greater accuracy in position thus constitutes a serious economic problem.

II

USE IN MAPPING

As mentioned earlier, the trilateration was projected primarily as a mapping control. During the course of the work northward local areas were broken down by additional stations and Shoran-controlled vertical photography flown over grid lines.

Shoran may be used to determine the position of the aircraft at each exposure station. These positions, plotted on the base sheet, are nadir points directly above which each corresponding projector should be oriented. There are a number of devices which indicate the plumb ray from each projector lens, such as vertical collimators and plumb bobs. Because of random errors in the determination of individual positions by Shoran, it is best to scale the strip as a unit, selecting the best average scale and position. This procedure of using the plumb rays of the projectors requires that the models be carefully levelled; therefore, allowances must be made for the slopes of some models due to the vertical bow of the strip.

The extent of the concurrent use of the trilateration in mapping is indicated below :

For the period 1952-1956 auxiliary stations had been selected within the primary framework, lines measured, and photo-fixes established as follows :

Year	Stations Fixed	Lines Measured	Photo-Fixes
1952	1	4	2 105
1953	5	15	6 248
1954	6	30	7 135
1955	2	10	3 135
1956	4	19	2 543
	18	78	21 166

There are now available more than 30 000 photo-fixes based on the 1956 adjustment. Of the total area in the net, 743 000 square miles have been covered with Shoran-controlled photography and an additional 270 000 square miles have been broken down by Tellurometer and conventional topographic survey methods.

In this auxiliary work the longest line measured is 325 miles and the shortest 97 miles. The improved instrumentation with gain riding was not used on any of this work.

The pattern of photo-controlled flights in general approximates a grid of rectangles with sides in the cardinal directions. Along the Arctic coast and among the Arctic islands this grid pattern is not suitable, and the control is varied with the coastal outline.

The average dimensions of a grid unit are 35 miles in an east-west direction and 23 miles in a north-south direction. Expressed otherwise the grid is 30 minutes of arc in longitude and 20 minutes of arc in latitude. Every third east-west line falls on a parallel of latitude expressed in degrees only and as many as possible of the north-south lines fall on the meridians expressed in degrees.

To obtain a balance of the factors inherent in the Shoran-controlled photos, the following procedures have been employed :

a) A minimum of four successive photographs oriented in stereoscopic plotting equipment, such as the Multiplex and the extension is scaled to the values of the outside plumb points. If the internal agreement is within approximately twenty metres (between the projected and computed plumb points) the setup is acceptable. If there is wide disagreement, the scaling is continued until there is a rough balance between the projected and computed plumb-point positions.

b) Several points of detail which can be easily recognized and identified on other flights of photography are chosen, and the positions of these points are plotted and coordinated from the plotter setup. These points are then used as control.

This procedure was used with success on an emergency 1/50 000 mapping program and it has since been employed in standard 1/250 000 mapping in normal working procedure. The number of groups of Shoran photos used varies with the scale of map required. The advantage lies in the fact that it can be handled with ease by experienced plotter operators with a minimum of mathematical background in a relatively short period of time. The disadvantage from a theoretical viewpoint is that it only uses a small proportion of the total information available and the solution might be termed a crude rather than a precise one. With multiplex equipment, a seven-projector bar is quite adequate.

III

TELLUROMETER SURVEYS

It now appears that the 1959 season will see the displacement of Shoran-controlled photography in Canada due to the ease with which traverses can be measured with the Tellurometer. Areas are divided in block fashion, traversed and connections made to Shoran stations. With few exceptions, the traverse closures on Shoran have been very good. The method gives further control stations on the ground and permits a greater density where needed for specific purposes.

IV

GEOIDAL STUDY

The astronomic values of many of the Shoran stations are available from exploratory fixation, and from these the components of deflection are known. This information was submitted to the U. S. Army Map Service and permitted Irene Fischer (*) to construct from the assembled deflection data a map of geoidal contours in North America. The arbitrary datum is 10 metres at Calais, Maine. The map shows a depression extending from the Great Lakes region to Hudson's Bay near Churchill and then westward attaining a minimum contour of some 22 metres. Mrs. Fischer has continued a study of this depression on the basis that it is associated with the Ice Age and that the earth's crust is not yet compensated for the release of the ice loads. Much evidence exists in this region as to the present rate of rise of the land. The map is subject to personal interpretation because of the relative scarcity of deflection data in the north, but there is no doubt that the major features of the geoid are as presented. The trilateration project has thus contributed to a valuable research not visualized earlier in its full impact.

V

CONCLUSION

Through the Shoran trilateration Canada now has a complete coverage of the area north of the present triangulation system. The Arctic islands are integrated with the mainland and all results are upon a uniform datum. The standard of accuracy in length is assessed as 1 in 56 000 and this value has been confirmed by a limited number of Shoran stations since incorporated in the triangulation net. Variations in position of some magnitude are bound to be revealed because while length is maintained on the average to a high degree, random mismeasurement does occur and has remained undetected during the operation. The effect of mispositioning a station is to introduce a local twist or swing in the net and this, in turn, is imposed on the succeeding work. Due to the location of the 18 basic triangulation stations, the distortion in position cannot be removed now, but it cannot exceed certain limits because of the confinement of the work by these stations. An improvement in positioning and general accuracy will be obtained through the projection of first-order triangulation northward, and the geodetic value of the trilateration will then be correspondingly increased.

The Shoran trilateration has served its original purpose during the period of projection and also for a further two years. The embracive control

(*) *A Map of Geoidal Contours in North America,* Irene FISCHER, U.S. Army Map Service.

coverage now permits a coordinated breaking down of the net in local areas by newer and shorter-range electronic instruments. Shoran, replaced by Hiran, which, in turn, will perforce give way to other instrumentation, has given Canada one of the essential bases for accurate mapping.

The trilateration has provided an important link in the connection of continents and thus aided in the comparative study of datums, and perhaps will contribute to the selection of a world spheroid and datum.

Many examples exist to show how some facts are brought by demonstration from controversy to accepted truth. In 1951 following the Brussels Conference of the IUGG, Dr. Eric Bergstrand invited J. L. Rannie and myself to observe geodimeter trials at the Arctic Circle near Overtornea, Sweden. The results of length measurement were most satisfactory. It is interesting to note that these geodimeter trials were conducted by Dr. Bergstrand in the same area where the famous Oblate Hypothesis of the earth's figure was confirmed by triangulation observations in 1736. This degree measurement of 1736 established a truth and settled a long-standing controversy. Now electronic length measurement has been pioneered with Shoran, Hiran, and the Geodimeter. In the early use of these instruments there was considerable skepticism as to their utility, accuracy, and economy over well-known established methods. This feeling has now disappeared because of the extensive applications made by many organizations with the results proving satisfactory to the purpose. The scope for each is now well demonstrated. But is there still a reluctance to accept newer approaches to geodetic progress ? The experience of the last 15 years furnishes an emphatic NO. We have been granted the boon of new types of instrumentation amply proved as to accuracy in certain fields. These modern devices are acceptable in present form to geodetic practice. They show promise of improvement in application and in accuracy. It would indeed be a retarding step if geodesists would not support their immediate use wherever practical. At the same time the geodesist should be constantly on the alert for new ideas in instrumentation and application and thus share in and contribute to progress.

The Canadian Shoran project is now completed. Therefore, I should like to include here my appreciation of the friendly spirit and cooperation of Mr. Carl Aslakson and other persons of the United States organizations, such as the Coast and Geodetic Survey, Army Map Service, U. S. Air Force, who assisted the Canadian Shoran Project in many ways; also, my thanks to the officers and airmen of 408 Photo Squadron of the Royal Canadian Air Force to whom were entrusted the logistics, installation of stations, and line-crossing operation.