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THE IMPORTANCE OF SHORAN SURVEYING

By Carl I. Aslakson,[1] M. ASCE

Synopsis

During World War II many electronic devices were developed which were used subsequently in various fields of endeavor. One such device was shoran, a transceiver-transponder system by which radio-wave travel time is measured. Shoran has since been developed further and is a surveying instrument by which inaccessible terrain can be surveyed by combining shoran with photogrammetry with an accuracy comparable to third-order control. Horizontal control by the use of shoran is quite accurate, but vertical control leaves much to be desired; continued work in this direction is needed.

Shoran and photogrammetry are especially applicable to inaccessible terrains such as those which exist in the Southern Hemisphere. This application is needed because it has been found that the improvement of an area closely follows the surveying in that area.

Introduction

In 1944 the surveying and mapping engineer began to make strange additions to his vocabulary. Such words as "shoran," "raydist," "decca," "irrad," "moran," "geodimeter," and "electronic position indicator" have become common to the engineer. This is only a partial list; the surveyor is also concerned with "radio altimetry," "profile recorders," the "refractometer," the "dielectric constant of air," the "velocity of radio waves," and similar subjects. These additions to the engineer's vocabulary have been made necessary by the rapid development of electronic surveying, a method which is having a profound effect on the future of surveying and mapping.

Geodetic control on a unified continental datum is being established (as of 1954) throughout the island areas of the Antilles and in vast areas of the Canadian wilderness. Other important geodetic ties are being made throughout the world.

Many papers concerned with electronic surveying and related subjects have been published, and several of these are listed in the Appendix. The

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[1] Comdr., Coast and Geodetic Survey (U. S. Dept. of Commerce), and Air Force Missile Test Center Geodetic Officer, Patrick Air Force Base, Cocoa, Fla.

subsequent material is related, however, to a single instrument and its use. That instrument is shoran, a blind-bombing instrument (developed during World War II), which has been modified and adapted to surveying. Shoran is described because it is in more extensive practical use (as of 1954) than any other system. In restricting the investigation to shoran, it is not implied that similar instruments cannot be used to accomplish the same purpose after they have undergone extensive trials. Long-distance trilateration by shoran combined with shoran-controlled photography is of greater importance to South America, Mexico, Central America, and the Antilles than electronic-surveying instruments designed to compete with the conventional type. This greater im-

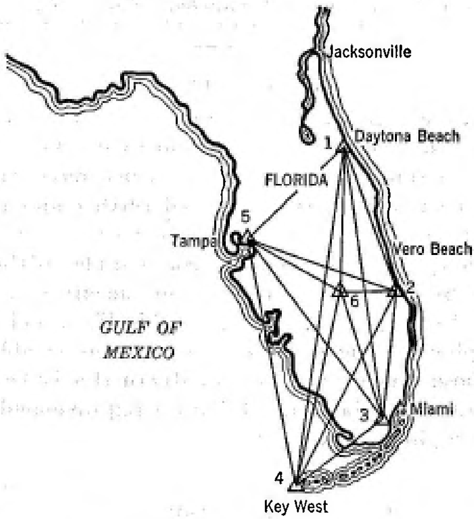

Fig. 1.—Shoran Net in Florida

portance exists because shoran will span the oceans for great distances, map difficult—and even inaccessible—terrain, and enable all of these maps to be placed on a single datum.

Shoran, a Surveying Instrument

Detailed descriptions of shoran design and operations are available (1).[2] Briefly, shoran is a transceiver-transponder system by which radio-wave travel time is accurately measured from an airplane to each of two antennas located at ground stations. This time measurement is translated directly into distance which is either read on dials or automatically recorded. These air-ground distances can then be reduced to geodetic distances by the application of corrections which involve certain instrumental corrections, meteorological factors, and the respective altitudes of the aircraft and ground stations.

Test of Shoran Accuracy.—Reports on tests of the accuracy of shoran have generally been classified, and only the results of that test performed in 1950

[2] Numerals in parentheses, thus (1), refer to corresponding items in the Bibliography (see Appendix).

(2) (3) will be presented. This test was performed in Florida (Fig. 1), where a total of fifteen distances were measured by shoran, and the results were compared with the distances obtained from conventional first-order triangulation. The distances varied in length from approximately 40 miles to 320 miles. Results of this test are given in Table 1. The maximum discrepancy with a

TABLE 1.—SHORAN RESULTS IN FLORIDA TEST

Line[a] (1)	Geodetic distance, in miles[b] (2)	Adjusted shoran distance, in miles (3)	Col. 2 minus Col. 3, in miles (4)	Proportional discrepancy, in parts per million (5)
2–6	40.6131	40.6123	+0.0008	19.7
3–4	96.7171	96.7147	+0.0024	24.8
5–6	100.3098	100.3105	−0.0007	7.0
1–5	118.9953	118.9951	+0.0002	1.7
1–6	133.0113	133.0122	−0.0009	6.8
2–3	134.9698	134.9685	+0.0013	9.6
2–5	139.1225	139.1250	−0.0025	18.0
3–6	145.8427	145.8420	+0.0007	4.8
1–2	145.8884	145.8913	−0.0029	19.9
4–6	190.5047	190.5060	−0.0013	6.8
2–4	199.1914	199.1912	+0.0002	1.0
3–5	226.9903	226.9893	+0.0010	4.4
4–5	235.5264	235.5241	+0.0023	9.8
1–3	277.0569	277.0572	−0.0003	1.1
1–4	320.1519	320.1521	−0.0002	0.6
Average			0.00118	9.1

[a] Points which are the ends of these lines are located in Fig. 1. [b] Results of first-order triangulation.

surveyed distance was approximately one part in 40,000; the average discrepancy was 0.0012 mile, or approximately 6 ft.

One of the most convincing results of this project was the discovery of a local surveying error (4) at Key West, Florida. In that instance, five shoran

TABLE 2.—VELOCITY OF LIGHT, IN KILOMETERS PER SECOND

Investigator	Year	Method	Velocity of light, in kilometers per second
C. I. Aslakson	1949	Shoran	299,792.4 ±2.4
W. W. Hanson and K. Bol	1950	Cavity resonator	299,789.3 ±1.2
L. Essen	1950	Cavity resonator	299,792.5 ±4.5[a]
C. I. Aslakson	1950	Shoran	299,794.2 ±1.4
E. Bergstrand	1951	Geodimeter	299,793.1 ±0.3
K. D. Froome	1952	Microwave interferometer	299,792.6 ±0.7
J. W. M. DuMond and E. R. Cohen	1952	Statistical[b]	299,792.9 ±0.8

[a] This probable error was assigned by J. W. M. DuMond and E. R. Cohen. L. Essen's limit of maximum possible error was 3 km per sec with a probable error of ±1 km per sec. [b] Based on a least-square adjustment of atomic constants.

measurements were made to this station from other shoran stations (Fig. 1), the shortest measurement being approximately 96 miles and the longest 320 miles (Table 1). On the basis of a computation which used the shoran-measured distances, it was predicted that a local surveying error of 35.4 ft having an azimuth of 39¾° was present. Several months later, triangulation by the

Coast and Geodetic Survey, United States Department of Commerce, revealed that the error actually was 36.4 ft in an azimuth of 37°.

A second convincing proof of the accuracy of shoran lies in the fact that measurements made by this method (2) (5) (6) (7) (8) (9) (10) (11) (12) have been accepted by physicists as a new and accurate determination of *c*, the velocity of light. Almost from the outset of research (1944), indications were found that the statistical value for *c* of 299,776 km per sec, determined by R. T. Birge (13) in 1941, was too low. The writer published (2) (3), in 1949 and 1951, two values for the velocity of light of 299,792.4 km per sec and 299,794.2 km per sec, based on shoran measurements in Florida. Other measurements of the

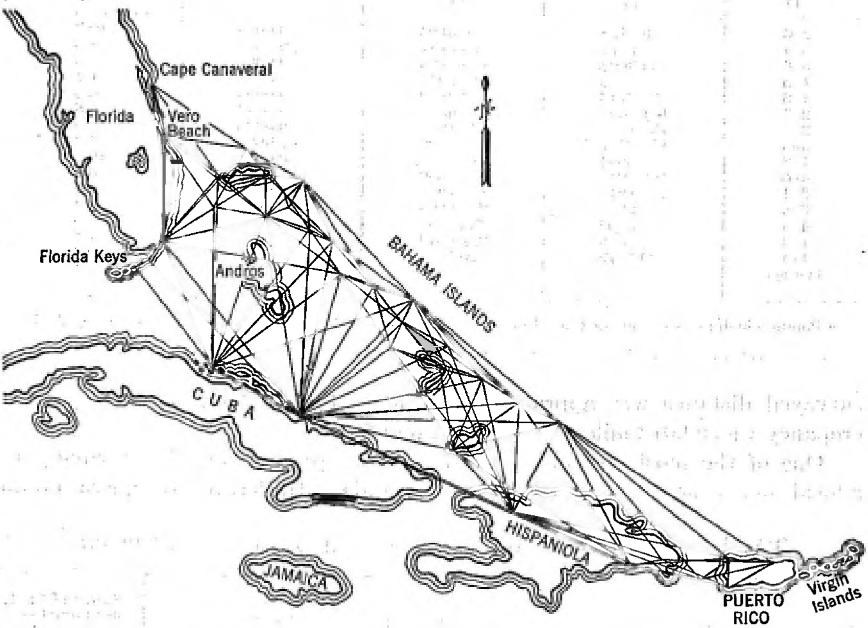

FIG. 2.—SHORAN NET OF AIR FORCE MISSILE RANGE

velocity of light are given in Table 2. Clearly, shoran measurements agree closely with the statistical value obtained by J. W. M. DuMond and E. R. Cohen.

What Shoran Can Accomplish.—The advantages of the shoran method of electronic surveying can be enumerated as follows:

1. Geodetic accuracy can be obtained over distances as great as 500 miles.
2. Errors are a function of time and therefore do not increase perceptibly with an increase in distance.
3. Aerial photography can be controlled by shoran distances, permitting accurate mapping of all areas within the range of the shoran ground stations.
4. Navigational devices, utilizing the shoran distance readings, permit flight-line navigation of great accuracy.

5. Shoran photographic techniques permit the establishment of control points of low accuracy without anyone touching the ground.

6. Vertical control of various degrees of accuracy are possible by shoran-photographic-radio-altimeter methods.

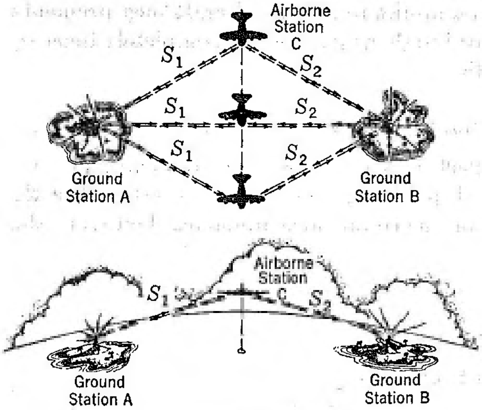

FIG. 3.—SHORAN LINE CROSSING

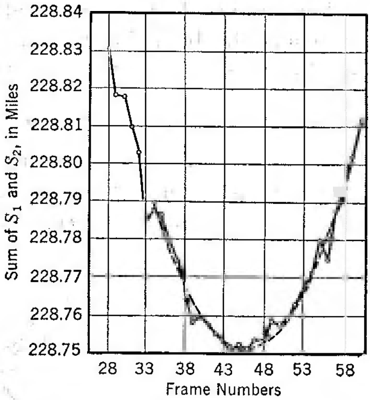

FIG. 4.—DETERMINATION OF MINIMUM SUM DISTANCE

Shoran Geodetic Surveying.—The survey of the United States Air Force Missile Test Center Range from Florida to Puerto Rico (shown in Fig. 2) is an excellent example of the use of shoran. Without these techniques, all the islands now (1954) being surveyed would remain geodetically isolated.

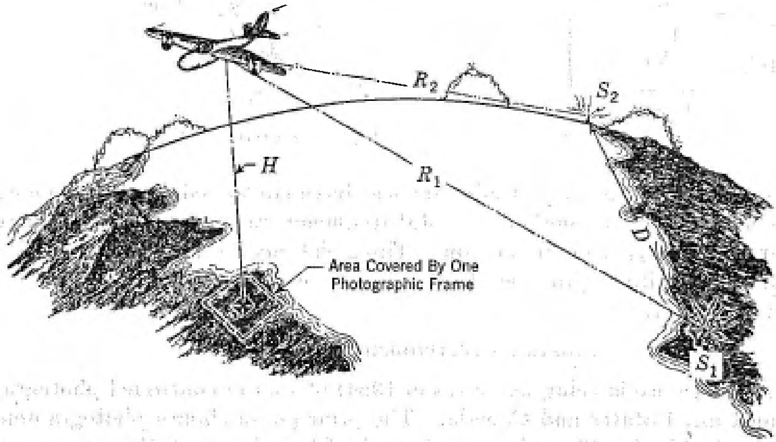

FIG. 5.—SHORAN-CONTROLLED PHOTOGRAPHY

By use of shoran, however, the Bahama Islands, Cuba, Hispaniola, and Puerto Rico will all have a unified datum. The distance measurements are accomplished by flying across the line joining two ground stations and making an analytical computation of the minimum sum of the distance from each station. This minimum is then reduced by the corrective terms to the geodetic distance (Figs. 3 and 4).

An important feature of shoran geodetic control is that, in general, the schemes can be situated so as to span mountain ranges or jungle areas. The ground stations may be situated in plains areas or on accessible rivers where the logistics problems are reduced to a minimum. The aircraft measurements are then made above the mountains or jungle which may be completely inaccessible to conventional surveying parties.

Electronic Measurement As Timing Measurement

There is another important aspect of electronic measurements; in conventional surveying, an erroneous tape length produces an error directly proportional to the distance. In an electronic measurement, however, the unit measured is time, and timing devices have controlled crystal frequencies. With modern (1954) methods, crystal frequency can achieve an accuracy of better than one part in one million. Thus, distances of hundreds of miles can be measured with approximately the same accuracy as distances of from 25 miles to 50 miles.

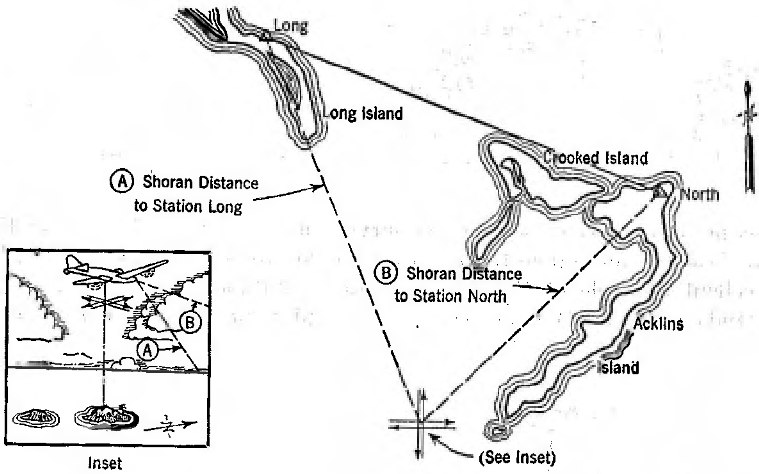

Fig. 6.—Shoran Photographic Pin-Point Control Method

Shoran-Controlled Photography

Extensive use is being made (as of 1954) of shoran-controlled photography by the United States and Canada. The principle of shoran photogrammetry is shown in Fig. 5. Two distances to each of two shoran stations are recorded simultaneously with the exposure of the picture. Several methods of photographic analysis have been developed to utilize these distances in controlling the compilation of maps. It has been concluded that 1:500,000 maps can be produced in this manner without other horizontal ground control. The efficiency of a combined shoran and geodetic-photogrammetric operation is therefore obvious. Geodetic measurements can be made under conditions—darkness, fog, or extensive cloud coverage—which prevent photography. Therefore, the higher priority can be allotted to photography, and the combined process can be operated very efficiently by utilizing the unfavorable weather to measure the distances for geodetic control.

Flight-Line Navigation.—At least four different flight-line navigational instruments have been developed in the United States, Canada, and Australia which utilize the shoran distance measurements to control the aircraft navigation. These instruments are simple in principle and highly successful; they make possible airplane navigation over unmapped terrain so accurate that gaps between adjacent flight lines are almost nonexistent. This makes shoran flight-line navigation most economical for side-lap can be kept to a minimum.

Secondary Photographic Control.—Main-scheme trilateration furnishes first-order control; shoran-controlled photography can be considered to be third-order control. If, then, it is desired to establish other points of n intermediate

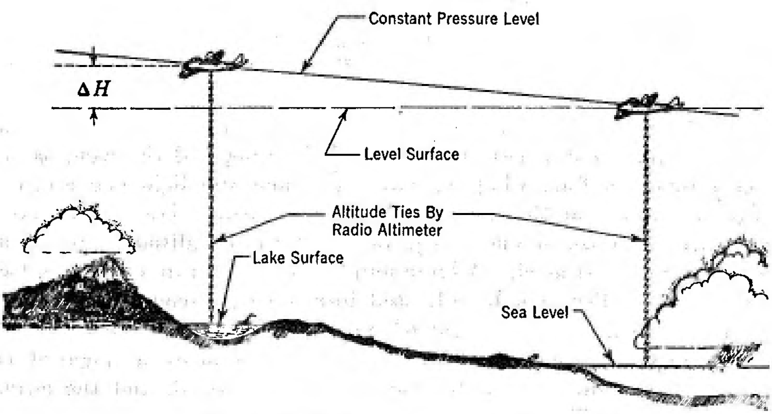

Fig. 7.—Establishment of Datum Planes

accuracy (second-order control), this operation can be performed by a shoran-photographic method.

In Fig. 6, there is shown an example of the method for establishing these intermediate-control points on two islands where no main-scheme shoran station is placed. Repeated flights in four directions (as shown in Fig. 6) with the camera operating at the minimum exposure interval—and with simultaneous pairs of shoran distances recorded for each picture—will furnish the data necessary to obtain the ground coordinates for a selected point, using any one of several methods of photogrammetric analysis. This procedure has been tested in the United States and in Canada and was used extensively in the Florida-Puerto Rico survey. It is concluded that a ground point can be positioned with an accuracy of from ±100 ft to ±25 ft relative to the two shoran stations used. This accuracy is dependent on the method of analysis and whether or not any local horizontal control exists in the area photographed. The important feature of this technique is that a geodetic position can be obtained in this manner in an inaccessible area without setting foot on the ground.

Vertical Control.—Radio altimetry has not kept pace with horizontal control developments, but some success has been attained. It has been reported (14) that vertical control with a relative accuracy of ±10 ft has been attained with a Canadian profile recorder. Certain narrow-beam radio altimeters have been developed in the United States, but their application has not been completely explored. The British have made tests with an instrument similar to shoran and with one of their radio altimeters from which it was concluded that an accuracy of ±10 m was possible (15).

A promising technique has been tested by Australia, Canada, and the United States. This process consists of the establishment of datum planes as shown in Fig. 7. If an airplane flies along a constant pressure level at a sufficient height so that the winds are geostrophic (winds caused solely by the rotation of the earth), the differential height between the constant pressure surface and a level surface can be computed from certain readily observable data when shoran navigation is used. This height difference is shown as ΔH in Fig. 7. The expression for ΔH is a simple one:

$$\Delta H = \frac{V\,S \sin\alpha \sin\phi}{K} \qquad (1)$$

in which ΔH is the change along the constant pressure level, V is the wind velocity, α is the angle between the aircraft heading and the wind, ϕ is the mean latitude of the line, S is the air distance along the flight line, and K is a constant depending on the units used. Thus, datum planes (for example, the lake surface shown in Fig. 7) can be tied by radio altimetry to a known elevation—such as sea level. A large number of these datum surfaces, locked together by cross ties, can be adjusted into a single scheme of elevations. These surfaces can then be bridged by photogrammetric methods. The Australians claim an accuracy of approximately ±10 m for a single observation (16). This figure should be considerably improved, and the adjusted datums should be still further improved.

Conclusion

The applications of shoran mapping have been described. Vast areas exist throughout the equatorial belt and in the Southern Hemisphere where only navigational charts exist, and many of these are of questionable accuracy because no unified datums are in existence. By this method of mapping large-scale maps can be rapidly produced, and these maps can all be compiled on a single datum. In the establishment of a datum for South America, a complete network of shoran trilateration can be established which covers the entire continent. This network can then be tied to existing triangulation. These ties serve a dual purpose: (1) They determine the scale for the shoran scheme and thus obviate any necessity for an exact knowledge of the velocity of propagation of radio waves. (2) They are controlled by Laplace azimuths and thus serve to control the shoran network in azimuth. Now, if astronomic positions are observed at all shoran stations, a least-square solution will determine a datum which will be the best fit for the entire continent. The practical and scientific value of such a project can hardly be overestimated.

A project such as previously outlined would require the cooperation of all the governments of South America and their surveying agencies. If this cooperation were secured, the individual cost to each nation would not be excessive. With efficient preparation the entire project could be consummated in from one year to three years.

History has proved that development follows good mapping. The small financial outlay required for this project would return its initial cost many times over in increased utilization of the natural resources of the cooperating nations.

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