SHORAN IN HYDROGRAPHIC SURVEYING (*)

by

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It is obvious that the remarkable wartime developments in electronics are resulting in major changes in some of our surveying and mapping methods and no doubt will render some of them obsolete. While the ultimate uses of these devices can be only partially estimated at present, they are certain to bring about a definite improvement in the quality of our surveys, as well as a decided acceleration in their rate of performance.

You have heard how Shoran—SHOrt Range Navigation—can be used in geodetic surveys. Another class of work which will receive major benefits from this new electronic device is hydrographic surveying. In war, Shoran made it possible for a bomber to determine distances rapidly and accurately from known positions on the ground and thereby to plot its course unerringly to any target designated for destruction. In peace, with substantially the same equipment, it is possible for a hydrographic surveying ship to determine distances from two or more known positions either on shore or afloat, and thereby to plot positions rapidly and accurately as it proceeds along a sounding line.

Nature of the problem.

Greatly oversimplified, the process of mapping or charting may be described as consisting of two problems : " What it is " and " Where it is ". The " what " in mapping is obviously, a mountain, house, highway, or the ground elevation. The corresponding " what " in nautical charting is generally the depth below the water surface. The determination of the " where " is by a system of measurements of one kind or another from basic central points. Over the sea, the position determination, or fixing of the sounding, is done by a process analogous to triangulation using basic control points ashore. The actual plotting of points is usually a graphic process. When within visible distance of points, horizontal sextant angles have been used for the protractor-solution of the well-known " three-point problem ".

RAR Method of Hydrographic Control.

Years ago, to extend our range beyond sight of shore points and to permit work during darkness or fog, a method of indirect distance measurement at sea was developed which utilized underwater sound transmission and radio. This system became known as Radio Acoustic Ranging, or RAR. Briefly, it consists of the following procedure : A bomb is thrown from the moving survey vessel. Its explosion, which is recorded instantly on a chronograph aboard the vessel, causes sound waves to register on a hydrophone attached to a sono-radio buoy established in a predetermined position. The buoy receives the sound impulse and automatically returns a radio signal to the ship. We know the velocity of sound in sea water. We have a chronograph measure of the elapsed time between the bomb explosion and return of the radio signal from the buoy. We can now compute the distance.

While RAR has been used effectively for many years in controlling offshore surveys, it has certain inherent weaknesses and limitations. The very nature of the sound wave, which may travel in an almost unlimited number of paths, causes reflections and refractions due to varying temperature and irregular configuration of the ocean bottom, which interfere with its transmission. Another objection is that it is necessary to know the temperature and salinity of the water to determine sound velocity, necessitating repeated observations over the water area to be surveyed.

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Shoran Method of Hydrographic Control.

Shoran constitutes no new principle in hydrographic surveying but it does apply a new and more effective method for the determination of distances from known control points. Shoran does the job more quickly, more accurately, and more simply, under conditions of atmosphere and sea which will not permit the use of Radio Acoustic Ranging.

Shoran is based on the fact that radio waves travel through the atmosphere at a very nearly constant velocity of approximately 186,000 statute miles per second. Success of the method is due to the accomplishment of electronic engineers in devising means for accurate measurement of the remarkably small time intervals involved in the travel of radio waves to a target and back. In the familiar Radar, dependence is placed upon the reflection of radio waves from natural objects encountered. Shoran strengthens and specializes this principle by use of responding radio stations set up at known points, which return intensified signals from the specific positions of the responding stations. (See : fig. 1.)

Similarity to RAR.

There are certain similarities between Shoran and RAR. An installation called an *interrogator,* on the vessel, takes the place of the bomb used in RAR. The interrogator sends out radio impulses to (or interrogates) a *transponder,* or *ground station,* which corresponds to the sono-radio buoy. The ground station returns the impulse to the interrogator, in much the same way that the sono-radio buoy receives the sound waves and returns a radio signal to the vessel. As in the case of the RAR buoy, the position of the ground station must be determined in advance. Since a known distance from the ground station would give only a " line of position " for the ship, two or more ground stations are established, and the distances are measured simultaneously by the ship equipment.

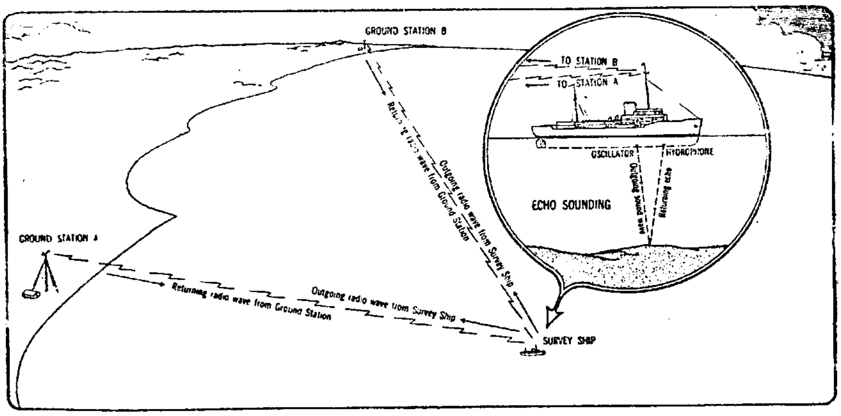

Fig. 1
Echo Sounding and Electronic Position Determination.

Instrumental Equipment.

The instruments are very compact and light in weight, a necessary consideration since they were designed for use on airplanes.

The interrogator is the heart of the Shoran equipment. It contains a transmitter and a receiver-indicator unit.

The transmitter is designed to transmit on two frequencies. It initiates the interrogations to the ground stations, sending them out on the frequencies to which the ground stations are tuned. The signals are actually very high frequency pulses of extremely brief duration, there being 930 pulses per second.

The receiver-indicator receives and separates the replies from the two ground stations and measures very accurately the time elapsed between the outgoing impulses from the transmitter and the return impulses from the ground stations.

This measurement of time intervals between radio impulses is the fundamental function of Shoran. It is done by means of a cathode ray tube wherein a stream of electrons is manipulated with a speed and facility so remarkable that time intervals of hundred millionths of a second are registered by " pips " on the fluorescent screen of the tube at a scale permitting

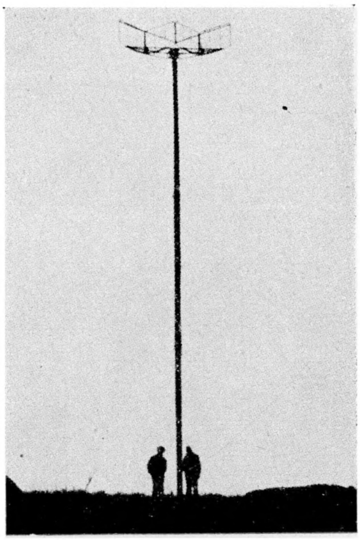

Fig. 2
Mast and antenna system for Shoran ground station.

easy measurement. A circuit called a Variable Calibrated Phase Advance is manipulated to remove instrumental lags and constants, and the operator reads true distance from the vernier. The trace shown on the fluorescent screen of the indicator tube is circular with a reference pip at the top, and the two distance pips showing somewhere else. In making the distance measurement, the two distance pips are aligned with the marker pip. When operating on the 1-mile scale, this sweep makes 93,109 " revolutions " per second, corresponding exactly to 1 statute mile per revolution. The sweep length, with a diameter of about 2 inches, is approximately 6 inches. It is a simple matter of using the verniers attached to the calibrated phase advance circuits to divide this 6-inch sweep into hundredths or even thousandths of a mile.

The transponder on shore is a self-contained unit designed to adjust itself to the ship station in all the various timing and control elements necessary to receive and return the radio waves.

Figure 2 shows the mast and antenna system for the ground station. The mast is about 50 feet high and consists of six sections of telescoping tubing made of plywood. Several sets of guys support the mast so that it is strong enough to withstand as much as a 100-mile-an-hour wind.

Power for the ground station is supplied by a small gasoline-driven generator set.

Shoran Investigations in Alaska.

The first experimental work on Shoran for hydrographic surveying was carried out in the Aleutian Islands in the summer of 1945 by the Coast and Geodetic Survey Ship *Explorer*. (See : fig. 3.)

Station SHOR was established on the easternmost of the Semichi Islands, during two working days, at a ground elevation of 220 feet, making the antenna height 270 feet. Station RAN was established on Attu Island on a low knoll 105 feet in elevation, making the antenna height 155 feet. Work on this was completed in about 10 hours. After triangulation locations of these two stations, their distance apart was computed as 41.382 statute miles.

Preliminary Tests.

Test runs were made to check the operation of the stations and the distance measurements. Having determined the correct vernier setting for station Shor, with some accuracy, the factor of error of distance readings from Ran, with the same setting, was determined.

This was accomplished by running along the base line, taking simultaneous readings of the two distances at short intervals, holding the ship on the proper course by running ranges or by control with sextant fixes. The line was run on two different days with comparable

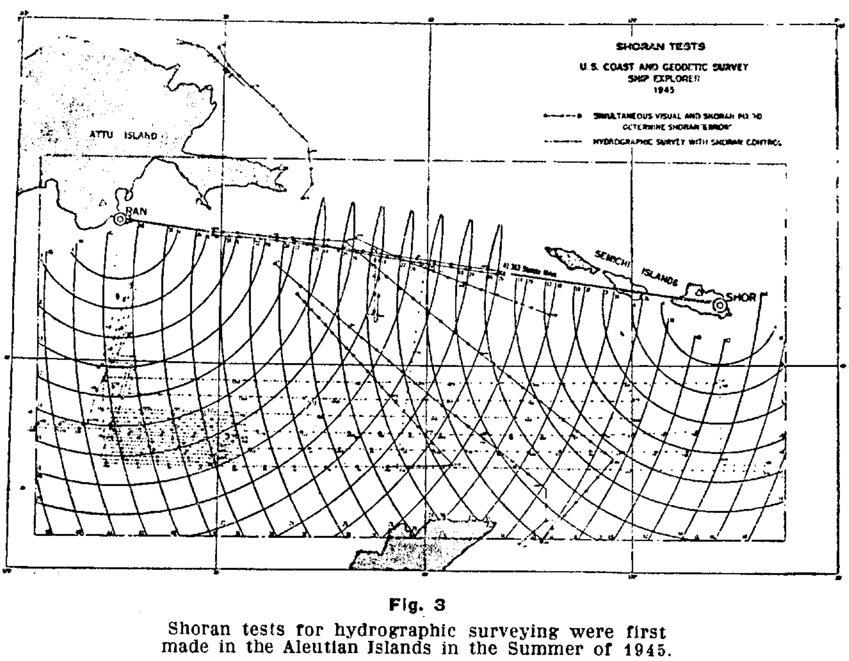

Fig. 3
Shoran tests for hydrographic surveying were first made in the Aleutian Islands in the Summer of 1945.

results. They showed that the two ground stations did not react alike, and the indications were plus 0.002 mile to Shor and plus 0.016 mile to Ran. During the operational tests about 750 comparisons were available between the Shoran distances and the scaled distances from station Shor and about 500 from station Ran. Even with this large number of comparisons, the errors cannot be considered to have been completely eliminated. In the first place, the absolute length of the base line is not known, since it was determined through several related schemes of second-order unadjusted triangulation. The computed length was 41.382 statute miles as against the uncorrected Shoran length of 41.363 miles, a difference of about 100 feet. Some of this difference must be expected to be in the computed length. Secondly, the same weight has been given to a sextant fix as to triangulation, whereas an error of one minute in a sextant angle can give a position error of from 12 to 75 feet, depending upon the size of the angle and the distance from the signals. Probably the larger part of the error is in the Shoran measurement, though the magnitude is not deflnitely proved by these tests.

Hydrographic Surveys.

Actual hydrographic surveys were conducted for about 4 1/2 days, during which somewhat more than 400 statute miles of sounding lines were run. During 2 of these days runs were made to determine the maximum distance over which return signals were useful; that is, where they became too weak to give good returns. The results of these runs were highly satisfactory, distances over 47 miles being read with ease. Both stations gave about equal range, though there was a difference of 120 feet in their antenna elevations. The indications are that the Shoran range is nearly twice the line of sight distance as calculated for ship and ground station antenna heights, up to 270 feet elevation.

A portion of the hydrographic survey includes a small area of close development where the lines were spaced at about 350 yards. Control of the ship was perfect at all times. This spacing of 350 yards could be materially reduced where necessary for closer development.

Systematic and Random Errors.

As with any device which measures distances, directly or indirectly, there are certain errors which are always present in Shoran. These are generally classified as systematic and random errors. The systematic errors are of two kinds: (1) That due to the difference between the Shoran distance and the map distance, and (2) that due to variations of velocity of the radio waves due to changes in barometric pressure and so on. The first is caused by the difference in elevation between the ship and ground station antennas; this causes the Shoran distance to be somewhat longer than the great circle distance between the two points referred to sea level, or the map distance. The Shoran path can be very closely approximated by a circular arc with a radius of about 15,000 statute miles (or more closely as 3.91 times the radius of the earth). For the purposes of hydrographic survey control, the elevations of the ground station will be relatively small—generally about 500 feet as a maximum,—and the ship antenna will be of the order of 100 feet, so that the combined systematic errors will not exceed 0.015 statute mile, or about 25 yards.

The random errors may be classified as follows : personal errors in reading and setting the verniers; non linearity of the calibrated phase advance circuits; the inability to standardize the ground station exactly to its predetermined value. These random errors will, if all accumulative, amount to as much as 0.01 statute mile, or 16 or 17 yards; and so will cause a position uncertainty dependent upon the angle with which the distance arcs intersect.

Advantages of Shoran.

This short period of experimentation with Shoran indicated that it is an ideal system for the control of hydrographic surveys. Shoran ground stations can be located accurately by triangulation; two or three stations will control a large area, and the survey will be completely homogeneous. The total margin of systematic and random errors is small—considerably smaller than those encountered in Rar—and well within the accuracy requirements for offshore surveys. The potential accuracy of the system is such that any distance can be measured with a probable error of not more than 5 yards, regardless of the length of the line, up to the limiting range of the equipment. Positions as determined by the intersection of two simultaneous distance arcs will have an accuracy better than 15 yards in the area where the angle of arc intersection is greater than 30 and less than 150 degrees. Once the correct settings are determined for each set of equipment, it is probable that an accuracy of about 1 : 10 000 can be secured—thus raising the position fixing afloat from fourth-order to third-order accuracy.

The range of the system is such that very accurate surveys can be made in areas as far offshore as 40 to 50 miles. Three stations on more or less a straight line and separated by 35 to 40 miles will control an area about 100 miles long by some 45 miles in width along one side of the base line.

The rapidity with which Shoran fix can be taken and plotted makes development of critical areas very simple, and it should be very easy to run closely spaced lines and "splits" wherever necessary. Actually, fixes can be taken at any interval desired with a possible minimum of 30 seconds. In the system developed, the time required to take and plot a Shoran fix was about 15 seconds from the time of "mark" to the time the position was plotted. This is in sharp contrast to the time necessary to plot a sextant fix, sometimes as much as 90 seconds. Small changes in course are immediately apparent to the navigator, for the Shoran position is actually more accurate and consistent than sextant fixes—the entire area is controlled by one set of stations or signals, a condition which is never met with in any visual control system.

Another advantage of the Shoran method is its flexibility. It can be applied to the measurement of base lines at sea, thus permitting the establishment of precisely fixed floating responder stations where circumstances require. A station can be easily installed on a ship. This would be advantageous in carrying control into an area far outside that available from land stations. The velocity of radio waves through free space is almost constant under any of the conditions likely to be met with during hydrographic surveys. Therefore the sum of two Shoran distances measured along a base line will be the length of that line. Or, if it is not possible to run along the base line, the ship can make several crossings at very slow speed, at the same time taking Shoran fixes at even time intervals, from which the length can be deduced by a method of least squares. By development of this process, preliminary triangulation can be carried by Shoran far in advance of the regular triangulation. Shoran would also be valuable in supplementing triangulation where the lines are very long, and the angles small, or where fog, haze or smoke interfere with seeing over long periods of time.

The effectiveness of the system is in no way impaired by darkness, fog or rain. Static is scarcely noticeable; even the effect of high-powered radio equipment is negligible.

Conclusion.

The tests in Alaska proved that Shoran can be easily adapted to the control of hydrographic surveys. The system is rapid and economical, and the limits of accuracy are well within the requirements for offshore control. The errors inherent in Shoran are lesser and more easily determined than in the old method of Radio Acoustic Ranging.

The successful application of Shoran to hydrographic surveying opens up a new field of electronic techniques which promises to increase our range, facility and accuracy.