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AIRBORNE LASER HYDROGRAPHY

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ABSTRACT

Airborne laser hydrography is an emerging technology which has the potential of performing large amounts of bathymetric surveys rapidly and inexpensively. The accuracy, applicability, and economics of laser bathymetric surveying are discussed. The characteristics of a scanning laser bathymetric system being developed under direction of the United States' Defense Mapping Agency are presented.

INTRODUCTION

The National Ocean Survey (NOS) has been investigating the potential of airborne laser bathymetry for several years. This technique can potentially collect large quantities of bathymetric soundings more rapidly and less expensively than existing sonar methods. The resultant soundings are intended for use in the production of marine charts. The NOS investigations have been aimed at determining the performance of the technique, estimating where it could be used, quantifying the economic advantages it offers, and projecting its impact on other parts of NOS. Based on such information, developed both by Navy organizations and NOS, the Defense Mapping Agency (DMA) has concluded that airborne laser bathymetry is technically and economically feasible for their requirements. DMA is proceeding to develop an operational system employing current technology and designing it such that improved components can be substituted as new technology emerges.

Principle of operation

The laser bathymeter is an aircraft-mounted, scanning beam, pulsed laser system which measures depth in a manner analogous to sonar. Some energy from each laser pulse is reflected from the sea surface and some energy is reflected from the sea bottom. The sea bottom reflection, however, occurs at a later time because of the extra distance the light must travel. The difference in the arrival time at the laser system receiver of the two reflections is proportional to twice the depth.

Accuracy of soundings

The airborne laser bathymeter must be able to make soundings which meet the NOS accuracy standards. Those standards allow 0.3 metres of error in depths from 0-20 metres, 1 metre of error in depths from 20-100 metres, and an error of 1 % of the depth in depths greater than 100 metres.

The ability of laser bathymetry to meet the accuracy standards is being determined through a theoretical experimental program. The experimental program is designed to measure the effect of system and environmental parameters on performance and uses a prototype laser system belonging to NASA as an experimental tool. The theoretical program is designed to explain the experimentally observed behaviour, to model system performance, and to extrapolate the observed performance to that of an optimally designed laser bathymeter. Preliminary results on accuracy (precision, bias, and repeatability) are available from these two programs.

Precision is a measure of system noise and is, therefore, a fundamental limit on accuracy. A model of precision for the NASA prototype system has been successfully developed. That model predicts poor precision at low signal-to-noise levels and improved precision as the signal-to-noise increases. Experimental results are in excellent agreement with the theory, and imprecision as little as ± 5 cm RMS has been observed.

Bias is a constant offset between a measured depth and the actual depth. A high density, NOS sonar survey of the test area was used as the most readily available approximation of true depth. Consequently, what was actually determined is not true bias, but the disagreement between laser depths and sonar depths. Experimental results show differences between the two techniques on the order of ± 0.3 metre. The theoretical and data analysis efforts are still investigating this difference. It is interesting to note that except for the offset, the laser and sonar depth profiles agreed to within ± 7 cm RMS.

Repeatability is the capacity of measuring depth in one location on two different days, under different conditions and getting the same answer. Two profiles of laser bathymetry over one flight line have been compared and were found to agree to within ± 15 cm RMS. Considering the slope of the bottom this error is consistent with that caused by the uncertainty in position.

These preliminary results on accuracy are extremely encouraging, with an explanation of the laser/sonar disagreement being the most important remaining problem. Work still needs to be done, though, to ensure that accurate soundings can be made in a routine manner.

Areas suitable for laser bathymetry

The areas which could be surveyed by laser are established by three factors : the penetration capability of the system, the water clarity, and the depth. Penetration capability is defined in terms of a system extinction coefficient αD, where α is the beam attenuation coefficient and D is the depth. Extinction coefficients of 10 to 15 have been demonstrated with the NASA prototype system. At the Chesapeake Bay test site, where $\alpha = 2\ \mathrm{m}^{-1}$, this means a depth capability of 5 to 7.5 metres. Clearer waters of the Atlantic Ocean ($\alpha \simeq 1\ \mathrm{m}^{-1}$) and the Caribbean ($\alpha \simeq 0.2\ \mathrm{m}^{-1}$) will allow proportionately greater penetration. Based on a theoretical extrapolation from the demonstrated αD capability, it is felt that $\alpha D = 20$ is an achievable goal.

Given a value for the system extinction coefficient, the surveyability of different geographic areas can be determined using local values of depths and water clarity. NOS is using two sources of water clarity data in assessment of surveyable areas — digital data banks and aerial photography. Water clarity measurements from the digital data banks are combined with depth measurements and then contoured. The area enclosed by a specific αD contour is considered surveyable by a laser system whose extinction coefficient equals that value of αD. Aerial photographs of shallow water are manually scanned to determine "photographic penetration". This area is then extrapolated to deeper water using the estimated relative capabilities of laser and photo techniques.

Early results from this water clarity investigation show that a significant amount of area could be surveyed with a laser system of extinction coeffcient $\alpha D = 20$. For example, in the southern half of the Chesapeake Bay 80 % of the area could be surveyed with depths of 12 to 13 metres being reached, and 50 % of the northern half of the Chesapeake Bay could also be surveyed. Although quantitative values are still being computed, it appears that significant amounts of Lakes Erie, Ontario, Huron and Superior should be surveyable by laser. Based on extrapolation from aerial photos, depth up to 30 metres should be achievable in the Gulf of Mexico, and all of Nantucket Sound, Massachusetts, is expected to be surveyable.

There is a large uncertainty in the basic water clarity data being used. However, even with such uncertainty, a laser bathymeter is expected to be able to survey large amounts of the turbid U.S. coastal waters.

Cost-effectiveness of airborne laser bathymetry

NOS motivation for being involved in laser bathymetry is the potential for increased production of high-quality bathymetric data at significantly lower cost than with the existing sonar systems. Because economics are so crucial, several studies are being done on the cost-effectiveness of laser surveying.

A cost model has been developed to study the economics of laser surveying. This model parameterizes the cost per square kilometre of laser surveying in terms of capital or non-recurring costs and operating costs. Estimates of the model's parameters have been made, the model has been exercised, and the cost per square kilometre determined. The resulting cost estimate was approximately \$ 100 per square kilometre of laser surveying when the system is used at its maximum capacity of 6600 square kilometres per year. This cost includes operating costs and annualized capital costs.

At \$ 100 km^{-2}, laser surveying is estimated to be 1/8 the cost of conventional sonar surveys. There is a concurrent manpower and time savings achievable by using the laser, and its magnitude is presently being quantified. It is felt that this computed savings is large enough that, at high annual rates of surveying, potentially significant savings can be realized.

Defense Mapping Agency Program

The Defense Mapping Agency has an urgent need to increase its rate of hydrographic data collection. An airborne laser system is regarded as a means by which this can be accomplished. It has also been concluded that a scanning laser system, installed in helicopters assigned to the Navy coastal survey ships, can be integrated into an aircraft-launch-ship survey operation such that the helicopters can relieve the small launches of time-consuming close inshore work. Such a system can increase the data collection by 30 % to 40 % at no increase in ship time cost. The principal reason for use of the ship-based helicopters is that survey operations are frequently conducted in areas too remote to permit use of shore-based fixed-wing aircraft.

HYDROGRAPHIC AIRBORNE LASER SOUNDER (HALS)

The DMA system is referred to as the Hydrographic Airborne Laser Sounder (HALS). HALS will be small, light-weight, rugged and will require minimal power. Because the full capacity of the helicopter must frequently be used for logistics, the laser system will be capable of rapid installation and removal. (Six hours is taken as an allowable time). The optimum ground speed of the helicopter is about 50 m/sec. At this speed, and an altitude of 150 m, a laser pulse rate of 400 Hz and a scan angle of 624 mrad from the vertical are required in order to optimize data collection and area coverage within the international charting accuracy requirements.

To be cost-effective, HALS must be capable of detecting a bottom signal to depths of at least 20 metres in typical mid-latitude coastal waters where the coefficient (K) of attenuation of diffuse light is about

0.15 metres^{-1}. Depth accuracy will meet International Hydrographic Bureau standards : $\pm$ 0.3 metre in water depths of 20 metres or less, and $\pm$ 1 metre in greater depths. Horizontal positioning, to be provided initially by standard short or medium range precise radio navigation aids, and later by the satellite Global Positioning System, must meet the IHB accuracy requirement of 1.5 mm at the scale of the published chart. Thus, HALS positioning by standard radio navigation aids will be sufficiently accurate to permit its use in surveying to a development scale of 1:7 500 for production of a 1:15 000 scale chart. This will suffice for all but the most detailed harbour charts.

The computer in the aircraft will have sufficient capacity, within allowable physical size and power available, to accommodate the high data rate of return laser pulse, and orientation and position information, and will be compatible with the ship/launch computer systems for data processing. The entire ship/launch/aircraft system will be capable of producing completed charts in the field.

HALS SYSTEMS DESCRIPTION

The following is a description of how HALS is expected to be configured.

Laser transmitter

The neodymium doped yttrium-aluminium-garnet laser (Nd:YAG) has a very favourable power to size and weight ratio and transmits at a wavelength of 1060 nanometres. With the laser frequency doubled, a wavelength of 530 nm is produced which is excellent for penetration of most coastal water. A peak power output of 350 kW is envisioned and every attempt will be made to produce a pulse no longer than 10 nsec in order to maximize the signal-to-noise ratio, resolve shallow depths and minimize pulse digitization requirements.

Scanner

The scanner arrangement will likely be similar to the nutating mirror with a constant rotation rate which was satisfactorily demonstrated in the NASA prototype system. The simplicity of the design is advantageous, and the elliptical scan pattern provides both the necessary data coverage and a means of tracking the aircraft attitude and sea surface.

Receiver

In general, the receiver component will be an arrangement whereby the return laser pulse is reflected from the nutating mirror into a telescope, the receiver field of view being automatically controllable between 0 and 30 mrad to allow for variable ambient light and signal-to-noise conditions. The pulse will be directed by telescope into an optical delay sufficient to allow activation of gating circuitry in the pulse waveform detection photomultiplier tube (PMT). The gating reduces the initial response of the PMT, preventing its saturation by the large pulse from the sea surface and the suspended particulates just below. Spectral and spatial filters will be included in the optical path.

Preprocessor

The function of this component is digitization of the voltage waveform output of the photomultiplier. There are a number of means of doing this. The most promising is a technique of storing the wide bandwidth signal from the PMT at discrete clock intervals in a semiconductor device. When the stored signal is recalled, at a lower rate, a replica of the original signal, reduced in bandwidth by the ratio of the two clock rates, is generated and recorded.

Orientation sensing techniques

The direction of the laser beam relative to the aircraft will be recorded for each pulse by a shaft encoder on the mirror mechanism. Aircraft attitude will normally be obtained by analysis of the elliptical pattern of slant ranges to the surface as measured by the laser. Heading will be taken from the aircraft reference system.

Horizontal Positioning Systems

Initially, the HALS aircraft will be positioned using the same type of medium or short range shore-based radio navigation aid used for the present boat/ship survey operation in either a hyperbolic or range-range mode. When the NAVSTAR Global Positioning System (GPS) becomes operational in a few years, the very restrictive shore stations will be eliminated. HALS, as most survey systems, will then be navigated by GPS.

Clock

A clock is required to produce time of day as a data label, a 400 Hz strobe to activate the laser transmitter and data sensors, plus strobes to activate the waveform digitizer and aircraft positioning systems. A precision timer/counter will precisely record the time interval between the transmitted pulse and initial return pulse for calculation of slant ranges to the surface.

Recorder

A digital tape recorder of the necessary capacity will be used to record the return waveform and all associated data.

Computer

The computer must perform both arithmetic and data acquisition functions. Its primary arithmetic task is to identify the surface and bottom return pulses by means of a centroid algorithm and calculate the time difference between them, the value being stored in memory for subsequent recording on magnetic tape. Additionally, it must provide navigation information to the pilot and monitoring displays for the system operator. Requirements for the computer are based on the complexity of the real time algorithms and the speed at which they must be executed; HALS will generate data at a very high rate. It is planned also that the computer be capable of performing post flight data reduction, including quick look, analysis and production processing. The selection will probably be a high speed minicomputer, such as DEC 11/60.

Development schedule

Delivery of the operational system is expected by early 1983. HALS is being developed by the Naval Ocean Research and Development Activity at Bay St. Louis, Mississippi.