UNH SEA GRANT PROGRAMS

A STUDY OF THE COST EFFECTIVENESS
OF REMOTE SENSING SYSTEMS FOR
OCEAN SLICK DETECTION AND CLASSIFICATION

by Glen C. Gerhard
Associate Professor, Electrical Engineering

Report to the Office of National Sea Grant Programs

April, 1972

UNIVERSITY of NEW HAMPSHIRE
DURHAM, NEW HAMPSHIRE. 03824

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1.0 Introduction

This report has, as its main objective, the selection of a method of determining the cost effectiveness of present and future proposals for detecting and classifying oil slicks by remote sensing. A figure of merit called the effective "cost per slick" is computed using data obtained from a number of sources, especially the United States Coast Guard which is primarily responsible for slick detection. Implicit in this study are several assumptions which must be set forth.

This report, as well as oil slick surveillance programs which it discusses, is based on an assumption that the demand by the public for increased enforcement of anti-pollution laws and for the prosecution of violators will increase during this decade. Thus the identification of oil slicks and the determination of accountability for them will be a major goal of any Coast Guard surveillance program. A second assumption is that the increased likelihood of the development of oil resources in the northeastern United States, especially in the Gulf of Maine, makes this problem a particularly sensitive one in the New England states. The expansion of surveillance flights along with increased oil slick detection and identification ability could prove especially critical to this cold-water region. The third assumption is that while the effective "cost per slick" is an artificially created figure of merit at this moment, these costs will become quite real as the proposed Coast Guard program becomes operational and public demands become increasingly translated into programs and hence, costs.

Therefore the measure of effectiveness for an improved remote sensor system is how many additional slicks it may allow to be correctly identified for a given fixed operational cost, causing the cost per slick to be reduced. As the need for slick identification increases, the differential savings "per slick" as set forth in this report will become actual savings.

2.0 Summary and Conclusion

This report sets forth the results of a study made over a five-month period concerning the uses of, and the need for, remote sensing devices and techniques to be applied to the oil slick detection and classification problem. In addition to a comprehensive literature survey to assess both the current state of remote sensing technology, and the application of this technology to current problems, a number of personal contacts were made with individuals in private industry and in the government, notably the Department of Transportation. Conferences with both operational and research and development personnel of the U. S. Coast Guard provided an outline of the current status and needs of that organization in this area.

Specifically, the Coast Guard has documented a need for airborne remote sensor packages designed to detect and identify oil slicks on the ocean surface with a maximum allowable error of 10 percent. A request for proposals for an operational prototype airborne oil surveillance system has been issued. At the present time, the Coast Guard surveillance system consists of daytime visual spottings by patrol helicopter pilots. This is a highly subjective and limited surveillance technique with an estimated 50 to 75 percent error probability - not including small films less than 100 feet diameter - dependent upon the observer. The plans for instrumenting overflights and an estimate of the resulting effective cost to detect a slick is discussed in this report. It is shown that a sensor system which allows only a 1 to 5 percent improvement in detection capability can in a one-year period justify reasonable costs for technical feasibility studies and prototype development work. Other needs such as improved oil slick thickness monitoring capabilities and nighttime identification techniques warrant further study and development to realize significant improvements in the cost effectiveness of sensor packages.

The type of instruments and sensor packages based on Coast Guard requirements and availability as well as the best obtainable cost estimates are reviewed. Much of the information cited in this section was obtained from conversations and meetings with Coast Guard personnel, especially those with operational responsibilities.

From the following discussions, it is clear that if even small reductions in slick classification errors can be effected (1 to 5 percent), then the increase in cost effectiveness provides an argument for developing improved sensor technology. A technical feasibility investigation concerning emissive infrared oil slick signatures in the 3 to 14 micron region was proposed to the Office of National Sea Grant Programs. Little work has been done or is being done in this region, especially for the 8μ to 14μ region, except for broad band thermal measurements and some index of refraction measurements. USCG and industry personnel expressed interest in evaluating such a system if it were shown to be feasible; several offered to attempt to fly a prototype package in their aircraft. The Marine Research Group of the USCG offered assistance in ground truth investigations if time schedules could be coordinated. It is concluded that from the standpoint of cost effectiveness and potential user interest the technical feasibility of this approach merits further investigation.

It is also clear that system improvements to allow determination of quantitative factors such as oil slick thickness are necessary from both a legal and economic viewpoint if remote sensing is to provide any impact in pollution control monitoring. Hence, sensor system work should be directed towards this goal.

Finally, sensor information from routine patrol flights, once the prototype USCG system is operational, could be available to other agencies and workers outside USCG on a timely basis. It is time to begin planning for a mechanism to disseminate this information, maximizing the benefits of the new systems.

3.0 The Current Surveillance Program

The current USCG surveillance program consists of overflights with visual observation of areas such as the Gulf of Mexico (based in Mobile), helicopter coverage of the Galveston and Miami areas, as well as coverage of major harbor and bay areas such as Chesapeake Bay, New York City, Boston, Los Angeles, San Francisco, and Seattle. A total of 3,000 aircraft hours per year is allotted exclusively for this purpose, all in fair weather daylight conditions. Additional spill monitoring is done on flights of opportunity. The current cost effectiveness is an elusive quantity because cost records are not compiled in any fashion to facilitate the calculation of a "dollars-spent-per-slick-classified" or "per-case-successfully-prosecuted" basis. Indeed, when one views the problem as it presently exists, it is easy to see the difficulty of performing such a task on any meaningful basis.

It has been observed that as surveillance of critical areas increases, the frequency of observed spills, accidental or otherwise, often decreases. Two cases in point were cited for this deterrent effect. When money is available, the offshore patrolling over the Gulf of Mexico is increased. When the more intensive partols are not run, the frequency of observed spills is relatively high. Within a few weeks of the resumption of the extra patrols, the number of spills is drastically reduced (this could be referred to as the "policeman" or the "big brother is watching you" effect). In another case, a pilot program was instituted in the Seattle area whereby a ground-based roving patrol monitored 90 percent of all oil transfer operations. The total number of spills investigated remained constant, but the number from unknown sources dropped essentially to zero in a four-month period. The estimated reduction in spill rates was between 20 and 25 percent. The initial six month program cost less than $100,000 with a $10,000 cost for each additional month. Obviously there was a positive effect and there was a cost; the measure of the effectiveness in dollars alone does not give the complete story in either case.

The current pilot-observer technique has a typical aircraft reporting between 500 to 600 spills per year. Of these, 25 to 50 percent are pursued. However, the pilot actually sees many times that number and subjectively classes many of them as being too small to be troublesome or worth following up. In the Gulf of Mexico, one pilot may observe several hundred assorted "slicks" per flight. He subjectively decides which ones are worth reporting. In the New York City harbor area, he might sight several thousand slicks, but it is difficult to visually pinpoint the type, let alone the source, of most of these. Therefore, if one counts all the small slicks observed, the Coast Guard estimates that only 1 percent are actually followed up at present.

In order to demonstrate the possible cost effectiveness of better sensing and classifying systems, the current plans for the next few years with respect to USCG sensor system procurement presents a basis for estimation.

4.0 Sensor System Planning: The Immediate Future

In order to reduce the error and increase the probability that a given oil slick can be (1) detected and, (2) classified as to general type of oil and severity of spill and/or violation, the Coast Guard is undertaking development and testing of a prototype Airborne Oil Surveillance System. The exact sensors to be used are not known since this contract (under Notice of Request for Proposals CG-22, 170-A, dated 23 November 1971) has not yet been awarded at the time of writing. (The date set for award is 21 April 1972.) However, interviews with USCG technical personnel and also one potential contractor indicate that possibly ultraviolet, visible, near-infrared, and thermal (broad band) infrared imaging systems along with limited (and probably specialized) spectrophotomic and radiometric instruments, primarily for the shorter wavelengths (with the possible exception of a microwave radiometer) will be used. This is to be a prototype system for evaluation by the USCG and it is set forth under the following tentative timetable:

<u>Phase I:</u> Comprehensive analysis of oil slick sensing problem with detailed design of operational prototype airborne oil surveillance system along with development of work breakdown structure for fabrication flight evaluation (to be completed 23 October 1972).

<u>Phase II:</u> Fabrication and beach testing of prototype system; USCG acceptance of beach system and related documentation and plans (to be completed 30 November 1973).

<u>Phase III:</u> Full flight test and evaluation program of prototype system, with modification, retest, and design specification acceptance (to be completed 1 June 1974).

Thus this program will require two years to obtain just one operational prototype system.

In addition to calling for the development of a complete system for the remote detection of oil films on the sea surface, the Request for Proposals calls for establishment of the credibility of each particular proposed sensing concept as well as justification for using such a concept in the proposed overall system. All problems anticipated in the development of the proposed system must be identified, including those concerned with obtaining a significant probability of detection, the ability to discriminate against false targets, and the effects of sea state and oil aging on detection capability. For this sensor acquisition program, extending through fiscal years 1972 and 1973, the Coast Guard has budgeted some $290,000.

Additionally, the Coast Guard plans to spend $900,000 for reactivating several HU-16E twin engine amphibious aircraft to use these new sensors when they are developed. Once flying, these craft require about $115,000 per craft per year for direct aircraft and personnel operating costs; support personnel costs are an additional $150,000 per craft per year giving a total operational cost of $260,000 per aircraft per year. Plans call for flying each aircraft for 4,000 nautical miles (nmi) per year. These craft have a cruising speed of about 150 knots; a 3.5 to 4 hour flight will usually cover a total path length of 500 to 600 nmi.

One of the major requirements specified for this all-weather day/night proposed system is that the false target rate for oil slick detection not exceed 10%. The primary areas of interest are rivers and harbors, and the coastal waters (up to 50 nmi from the coast). With the emphasis on the primary coverage area, a single 600 nmi total flight path will not cover any great total length of the coastal environment if the detection sensors require too narrow a swath width to reach the required 10% (or even a 25%) false target rate. While side looking radar (SLR) could provide general observation capability over the 50 nmi path width, an initial investment of several million dollars would be needed to properly set up such a wide swath coverage system. Along with the indicated higher aircraft costs (a HU-16E is apparently not large enough for a powerful SL-RADAR), the heavy investment precludes using this approach for the USCG command at the present time even though some of the operations personnel favor the SLR approach because it has shown a significant promise in several oil slick experiments, including some of those run under the auspices of the U. S. Navy. Because of such financial restraints, the USCG personnel responsible for this system feel that their interim sensors will continue to require a great deal of interpretation and subjectivity on the part of the operator, and that they will initially have to accept a greater than 10 percent error until an operator becomes sufficiently experienced or more sophisticated sensor systems are developed. They feel that they are still several million dollars away from an automatic classification system. Since the HU-16E aircraft will be flying to altitudes of 4000 to 5000 feet, they would like swath widths which will allow 100 percent of all slicks - 100 feet or more in diameter - to be resolved from such altitudes. They optimistically hope for a 50 to 75% positive rough identification capability.

5.0 A Cost Analysis

In order to properly assess the cost effectiveness of any existing or proposed system for airborne surveillance and remote sensing of oil slicks, one must attach some dollar value on each slick which is detected, identified, or is successfully prosecuted. There are several sets of statutes. One sets forth harmful discharges as those producing a film, sheen, or discoloration. Another convention makes it an offense to cause an oily discharge with greater than 100 ppm of oil. Civil penalties may be imposed up to $10,000 maximum per discharge; criminal penalties can be up to $2,500 and/or one year in prison. Failure to report a spill under the Water Pollution Control Act can bring a fine up to $10,000 and/or one year in prison. Since the difficulty of prosecution varies with the particular statute involved - the distance from the coast, and other factors - the fines and penalties cannot really be used in computing cost effectiveness for remote sensing. Furthermore, remote sensing as a diagnostic tool is such a new technique that courts do not presently have confidence in evidence of this type.

The HU-16E aircraft to be recommissioned will provide additional area coverage and, when equipped with sensor packages, greater slick detection and identification ability. Each of these factors contributes to the overall cost effectiveness of the combined airborne surveillance system. If one looks at the $260,000 per aircraft year cost and assumes that because of the greater speed and distances flown by these craft, an increase in the number of spills sighted by the pilot-observer would be produced, one may also readily assume that the percentage of spills or slicks positively identified by the pilot (without the use of the new sensor system) will not significantly increase. Thus the 25 to 50 percent of all sightings over 100 feet in diameter, the upper current limit, may be maintained.

It is currently planned to put a total of six HU-16E aircraft on patrol using oil surveillance systems. Initially, two such craft will be recommissioned with four more to be added. (It is of special interest to this institution that eventually there may be two of these aircraft based at Cape Cod.)

Even if one assumes that the $900,000 budget for reactivating the HU-16E aircraft now in storage will cover the refurbishing cost of all six planes, the investment will be $150,000 per craft. Amortizing this initial cost over a five-year period and adding $260,000 annual operating cost per aircraft gives an average annual cost of $290,000 per craft. These figures and the discussion which immediately follows are summarized in Figure 1.

In addition to the $290,000 prototype sensor package acquisition program discussed in the previous section, another five sensor packages will be required to make the system fully operational. Therefore, a $500,000 sensor acquisition cost is a reasonable assumption. Because of technological obsolescence and increasing future operational requirements, a five-year linear depreciation for these six initial sensor packages was assumed in Figure 1, indicating a pro-rated sensor cost of $16,700 per aircraft per year. The addition of another $3,300 per aircraft for detector coolants, photographic supplies, and processing for legal follow-up for a total sensor cost of $20,000 per craft per year does not appear to be unreasonable. Thus, based on the prototype system - an admittedly interim package - the minimum total operational cost is the sum of the $290,000 annual cost per aircraft and the $20,000 annual sensor system cost or $310,000 per aircraft per year. Note that this does not allow for the acquisition of new aircraft (estimated by USCG personnel at two million dollars per plane).

In order to calculate the cost effectiveness on any meaningful basis, the total cost of a surveillance system and aircraft must be allocated on a

FIGURE 1: Estimate of Annual Cost

of Aircraft and Sensor Package

Item 1:	Reactivation Investment Cost (6 craft)	$900,000
÷ 5	(Assume 5 year write-off period): Per year	$180,000 per year
÷ 6	since six HU-16E craft are included:	$ 30,000 per craft per year
Item 2:	Annual Operating and Personnel Cost per craft	$260,000 per craft per year
Item 3:	Total Annual Cost Per Craft	$290,000
Item 4:	Total Acquisition Cost (including R&D) for sensor packages	$500,000
÷ 5	(Assume 5 year obsolescence write-off)	$100,000 per year
÷ 6	(Divide cost equally among 6 craft)	$ 16,700 per craft per year
	Add for coolants, film, etc.	$ 3,300 per craft per year
Item 5:	Total Sensor Annual Cost Per Craft	$ 20,000 per craft per year

Total annual cost for one operating craft/sensor unit is the sum of Items 3 and 5: $310,000 per craft per year.

"per slick" or other such basis. The figures cited here are averages and estimates gathered from interviews with USCG personnel having responsibility for oil slick surveillance on an operational basis. Based on the presently operating visual surveillance system, some 2400 "slicks" may be visually sighted by each aircraft in one year. Of these, up to 600 may be reported. Of these 600, 25 to 50 percent are deemed important enough to be pursued. Allowing (optimistically) the upper quantity, 300 "slicks" per craft per year are currently pursued in some fashion or other - either by additional overflights, surface vessel, or observer tracking during regular patrol flights. Since the expected mileage of the new craft will be some 33 percent greater than the 3000 nmi per craft per year currently flown, one may assume an equal percentage increase in the total number of slicks to be spotted or a total of 3200 slicks per craft per year. Assuming (although with greater certainty because of the new sensor systems) that the same 25 percent deserve to be reported, a total of 800 slicks per craft per year require some sort of additional decision-making capability.

At present, 25 to 50 percent of those "slicks" which are reported are followed up in some fashion. Based upon the 800 "slick" figure, 200 to 400 of these would require some action. Making a conservative estimate that the lower number or 200 "slicks" should definitely be followed up would mean that the remaining 600 "slicks" should not be pursued. These include "slicks" caused by natural phenomena and those not a threat because of insufficient oil concentration or rapid diffusion. This reasoning is set forth in Figure 2, demonstrating how a cost effectiveness (i.e., a relative effective cost) may be calculated for the proposed six aircraft-sensor package operating units.

FIGURE 2: Example of Cost Effectiveness Calculation

For Six Aircraft-Sensor Package Operating Units

1. Number of Estimated "slicks" spotted per craft per year: 3200 "slicks"

2. Assume 25% of these are worth reporting: 800 "slicks"

3. Assume 25% of these require action: 200 "slicks"

Item 6: Effective Cost Per Slick = $\frac{\text{Total Cost per Operating Unit Per Year}}{\text{Number of Slicks Requiring Legal Action Per Year}}$

$= \frac{\$310,000 \text{ (per Figure 1)}}{200 \text{ (per 3 above)}} = \$1550$ per slick (per craft per year)

4. Assume a 75% confidence level of sensor system, i.e., a 25% error probability.

800 "slicks" worth reporting

(a) 200 "slicks" requiring action
x.25 error
50 erroneous decisions possible

(b) 600 "slicks" not requiring action
x.25 error
150 erroneous decisions possible

5. Assume that 150 + 50 = 200 "slicks" were incorrectly classified

6. Assume 50% of the 150 erroneous decisions (b) required follow-up:

.50 x 150 = 75 "slicks"

7. Then the corrected total requiring action (per craft) should be the sum of 3 and 6 or: 200 + 75 = 275 "slicks"

Item 7: New Effective Cost Per Slick = $\frac{\$310,000 \text{ (per Figure 1)}}{275 \text{ (per 7 above)}}$

= \$1127 per slick (per craft per year).

The increase in cost effectiveness then per slick requiring action is the difference between Item 6 and Item 7 or (\$1550 - \$1127) = \$423 per slick.

FIGURE 2: (Continued)

Item 8: The total increase in cost effectiveness due to 75 more slicks being properly classified for legal action/follow-up is:

275 slicks/craft/year x 6 craft x $423/slick = $698,010/year

Thus, $698,010 (which was to be spent anyway) now buys increased effectiveness at $423/slick for identifying, at no increased cost, an additional 450 significant slicks.

Taking the cost figure as derived in Figure 1 of $310,000 per aircraft and sensor system per year and dividing it by the 200 slicks requiring immediate attention as set forth above, one arrives at the effective cost per slick of $1550 as shown in Item 6 of Figure 2.

It is unreasonable to assume that prototype airborne oil surveillance system will have the 90 percent correct slick location and identification capability suggested as the goal in the original request for proposals. A figure between 50 and 75 percent is much more realistic. Assuming the higher of these two figures, there exists an excellent chance that 25 percent of those 200 slicks will either not be oil or will be oil of such a nature that no law enforcement is needed or possible. Likewise 25 percent of the other 600 slicks not selected for follow-up may indeed have required it if the proper identification had been made; hence the possibility of a wrong decision involving some 200 slicks exists. In order to make a reasonable comparison for cost effectiveness studies, assume that an additional 200 slicks (25% of 600 plus 25% of 200) were incorrectly classified as shown in lines 4 and 5 of Figure 2. From the 25% of the 600 slicks not deemed significant, 150 such "slicks" may be considered improperly classified. Of these, 50 percent or 75 slicks should have been investigated as shown in line 7. Then on the basis of 275 slicks, the cost per slick would drop from $1550 to $1127 per craft per year as in Item 7 in Figure 2.

As shown, this effective savings may be used as a measure of cost effectiveness by observing that this incremental unit "savings" of $423 per slick, when multiplied by the 1650 slicks that will be followed up in one year, results in a maximum effective annual "savings" of $698,010

(Item 8, Figure 2), based upon a 100% effective identification system. Such an ideal figure is not actually saved in the sense of reduced spending but it is an indication of the level of cost effectiveness increase which could be achieved by eliminating all 25 percent margins of error on a pre-selected sample of slicks. Since the total elimination of such error is not feasible, an example based on a reasonable estimate of sensor effectiveness may serve to illustrate how a significant increase in cost effectiveness could still be obtained by sensor system improvements, possibly realized in the next few years.

Figure 3 sets forth a cost effectiveness calculation based on an improved sensor capability resulting in elimination of 5 percent of the errors in classifying the total "slicks" spotted. As set forth in the figure, of the 800 slicks per craft per year originally assumed significant, 600 were assumed to be such that they went unclassified or unpursued. If an improvement could be made in a sensor system to effect just a 5 percent increase in classification ability, then these 20 properly identified slicks (per craft) would cause the per slick cost to decrease from the $1550 previously cited to $1348 as set forth in Items 9 and 10. This $202 differential multiplied by the 230 identified slicks gives an increased cost effectiveness of $46,460 per craft per year for the same operating and acquisition budget. When again multiplied by the number of craft to be involved (6), a total increase in cost effectiveness of some $278,760 per year is realized as set forth in Item 12. Over a five-year period, a total increase in cost effectiveness of some $1,393,800 could accumulate.

FIGURE 3: Cost Effectiveness Improvement Due

To a 5 Percent Increase in Sensor

Classification Ability

From Figure 2, (1), (2), & (3):

1. Number of Estimated "slicks" spotted per craft per year: 3200 "slicks"

2. Assume 25% of these are worth reporting: 800 "slicks"

3. Assume 25% of these require action: 200 "slicks"

Thus 800 - 200 = 600 "slicks" were deemed "not significant".

Now assume an additional 5% of these original 600 "not significant" slicks are determined to be worthy of further action because of positive identification due to improvements in sensor system. .05 x 600 = 30 "slicks"

plus original group (3) 200

Item 9: Total requiring action: 230 "slicks"

Item 10: New Effective Cost per Slicks = $\frac{\$310,000 \text{ (per Figure 1)}}{230 \text{ slicks from above}}$

= \$1348 per slick/craft/year

Compare this with previous \$1550 per slick/craft/year based on only 200 slicks:

Item 11: \$1550 - \$1348 = \$202 per slick (per craft per year) differential

Total annual increase in cost effectiveness is given by:

Item 12: \$202/slick x 230 slicks/craft x 6 craft = \$278,760 per year

Thus, at no increase in operational costs, an additional 180 slicks requiring follow up could be properly classified per year.

In a five-year period, this is equivalent to \$1,393,800

Thus, moderate investments leading to improved sensor system discrimination ability can easily be justified on purely economical grounds. Moderate cost improvements giving only 1 percent error reductions, can pay for themselves in increased cost effectiveness over a period of time even if deterrent and other effects are not considered.

6.0 Other Economic and Operational Considerations

There are several significant advantages with respect to both enforcement and cost considerations if sensors can be developed or improved to meet specific needs. When ground or "sea" truth becomes sufficiently established and recognized by the courts, and the use of information gathered from remote sensors becomes admissible evidence, operational remote sensor systems can effect further increases in cost effectiveness. At the present time, collection of verifying water/oil samples as well as direct observation must be made using surface vessels. Even if one assumes the ship investment is necessary for other Coast Guard responsibilities, there is an added cost due to fuel consumption, engine wear, etc. each time a vessel puts to sea to evaluate a slick. If one assumes an added direct cost of $1000 per slick to pursue it with a small vessel or cutter, perhaps sometimes using spotting aircraft to relocate a drifting slick,a cost of $300,000 is involved. This is if the use of vessels for such purposes are required only 300 times a year (25% of the anticipated slicks needing follow-ups). Cutting this by even 10 percent results in an increase of cost effectiveness of $30,000 per year. Admittedly this is a very crude estimate. Data to accurately calculate this differential cost was not known to USCG operating personnel interviewed. However, it is possible to measure the cost of not being able to adequately classify a "slick" from a patrol aircraft. One large apparent "slick" off Nantucket required the use of a cutter, two additional small boats, and three aircraft at a cost of some $25,000. It turned out to be a natural phenomenon!

Nighttime and foul weather capability could also greatly influence cost effectiveness. While passive microwave and broad band infrared radiometers and thermal imaging systems will provide some spotting capability, they will be insufficient for classification work. Actually, side-looking radar imaging systems would possess a definite advantage here if the initial overall costs, of both the radar and an aircraft of sufficient size and range, were not so apparently prohibitive. It is difficult to estimate the increase in cost effectiveness of improved night sensor systems because the use of systems with reasonable observation and classification capability would have a definite deterrent effect on such violations as nighttime bilge pumping. There is also no information concerning the number of violations occurring under the cover of darkness since the USCG ability to make such observations does not now exist.

7.0 Present and Future Remote Sensing Technology: A Suggested Approach

The general application of remote sensing systems for oil slick location and identification has already been discussed. It is the purpose of this section to set forth the instruments and sensor systems which currently offer the greatest promise for this application and to suggest a direction for future sensor development which would be directed toward providing the greatest improvement in 24 hour slick classification ability and assisting with other current problems.

Proposed sensor systems being considered by the Coast Guard include ultraviolet, visible, and near infrared monochromatic, panchromatic, and color photography; ultraviolet, visible and thermal infrared (broad band) scanner systems; infrared and microwave radiometers; derivative, and conventional spectrometers; artificial illumination (laser) systems (including fluorescence); side-looking imaging radar; wide range image spectrometry; Fraunhofer line discrimination; and correlation spectrometry. An evaluation of some of these methods has been published.[1] A number of studies and reports on multibrand color photographic coverage have been made.[2] An evaluation of the other results shows that both the ultraviolet and the infrared regions contribute significant information with respect to general oil slick determination.[3] The infrared regions favored generally are the near infrared extending from the visible red spectrum at 0.6μ to about 1μ, and the thermal infrared in the atmospheric window between 8μ and 14μ. Useful radiometry may also be done in the 3μ to 5μ region.

A number of the proposed techniques are applicable to daylight hours only. These generally involve reflected natural illumination and include nearly all systems involving ultra-violet, visible, and the near infrared spectrums with one exception which will be discussed. Because of the

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[1] C. T. Wezernak and F. C. Polyn: "Technological Assessment of Remote Sensing Systems for Water Pollution Control", Annual Report, Contract No. 16020FOY, University of Michigan, 30 April 1971.

[2] Pollution Control Branch, USCG Applied Technology Division: "Remote Sensing of Southern Calif. Oil Pollution Experiment", Project 714104, July 1971.

[3] R. Horvath, W. L. Morgan, and S. R. Stewart: "Optical Remote Sensing of Oil Slicks: Signature Analysis and Systems Evaluation", Final Report, Project 724104.2/1, Willow Run Labs., University of Michigan, October 1971.

daylight limitations of systems employing these wavelengths, it is felt that future efforts in these spectral regions should be directed toward solving particular problems with the sensors themselves, their application in gathering information useful in classifying the "slick", and for following up such classifications with legal action when necessary.

One area where improved sensor system development could bring additional direct benefits involves the use of passive measurements to provide quantitative information in both the emissive infrared and the microwave regions of the spectrum. Limited experiments have suggested that the emissivity of oil films on sea water will vary as a function of wavelength according to the spectral absorption qualities of the film. At least one prominent worker[1] has noted spectral fluctuations in the 8 to 12 micron portion of the spectrum when observing emitted radiation. But he feels that the fluctuations are mainly due to changes in the index of refraction. While the signal to noise ratios obtained in these experiments were insufficient for a rapid scan imaging system, they may be quite sufficient for a small area point measurement. Likewise Hollinger has shown that passive microwave measurements are useful for both identifying oil slicks and determining their thickness using a two wavelength band approach. Both of these techniques, the emissive infrared and the microwave radiometric readings are passive and are useful during the hours of darkness. An instrument package using such sensors would greatly enhance oil slick classification and identification during the hours of darkness.

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[1]R. Hovath, Willow Run Labs, University of Michigan, private communication.

Other current instrument possibilities for dark conditions include broad band thermal infrared scanning systems and radiometers, and artificially illuminated fluorescence systems.[1]

The latter offers perhaps the only method currently under investigation which will provide quantitative measurement data from nighttime classification of spills and identification of oil type. The thermal infrared spectral signature system suggested would greatly enhance the classification ability of any day/night system once the technical feasibility is fully evaluated and exploited. Obviously a significant increase in cost effectiveness could be effected since there currently exists no operational nighttime system for identifying oil slicks.

Better methods of determining oil film thickness and concentrations need greater attention. While ultra-violet infrared and microwave measurements can give some thickness indications, highly variable sea and air conditions cause temperature differential measurements to be inconsistent indication of film thickness. This inaccuracy is especially important if remote sensing measurements are to develop the measure of reliability necessary to constitute evidence in a legal trial concerning oil spills or bilge pumping. There is again the economic issue involved here. In order to prosecute at the present time, surface vessels must be used to obtain water/oil samples for analysis. Runs to make these sample grabs involve both time delays and costs. However, additional capability in these areas would serve to increase the overall cost effectiveness of any airborne oil surveillance system.

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[1]J. F. Fantasia, T. Mittard, "An Investigation of Oil Fluorescence as a Technique for the Remote Sensing of Oil Spills", Final Report, Project No. 71410/A/003, Transportation Systems Center, Cambridge, Mass., June 1971.

There is an additional opportunity to increase cost effectiveness. Sensor packages on USCG aircraft will be producing a great deal of potentially useful information including ocean surface temperature, spectral reflectance, etc. This could be made available to other users if the proper channels were set up. Certainly temperature information is potentially useful to commercial fishermen: Oregon State University researchers have been providing this service to fishermen for some time. Thus, an overall cost effectiveness of any sensor package could be greatly increased if the results are shared.