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Innovative Technologies for Coast Guard Marine Inspectors

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Abstract

The Coast Guard is required to conduct inspections of merchant vessels. The structural phase of these inspections consists of an initial screening of the outside of the hull, decks, superstructure, and internal spaces. This is followed by a close-up visual inspection and conventional nondestructive techniques (NDT) of suspect areas. NDT methods are employed at the vessel owner's expense. Structural inspections of tankships are particularly difficult due to large spaces with limited accessibility. The U.S. Coast Guard Merchant Vessel Inspection and Documentation Division is sponsoring several projects through the Coast Guard's Research and Development Center to investigate alternative technologies to improve the effectiveness of tankship structural inspections. A review has been conducted of other industries to identify those techniques which may be adaptable. The focus is on identifying safe, simple, and practical ship inspection methods and technologies that cover the maximum amount of area in the minimum amount of time while providing a complete and accurate picture of the structural condition of the vessel. This paper will present an overview of projects associated with improving the structural reliability of merchant vessel tankships. Promising technologies that will be of interest to the shipping industry as well as ways to improve the way Coast Guard marine inspectors conduct their business will be presented.

Introduction

In recent years the U.S. Coast Guard has initiated several efforts designed to enhance the effectiveness of its marine inspection (MI) program. Several of these initiatives have been the direct result of studies commissioned in response to structural failures or the potential for such failures. Most notably was the occurrence of severe structural cracking in tank ships engaged in the Trans-Alaska Pipeline service (TAPS). These problems, described by Sipes, et al. [1] occurred as a result of a combination of factors including harsh environment, high strength steel, and minimum scantlings. It was reported that TAPS tankers accounted for 59 percent of structural failures yet comprised only 13 percent of U.S. flag vessels over 10,000 gross tons. One of the study's major findings was that "poor design of details and poor weld workmanship, particularly on those vessels constructed with high tensile steel, appear to contribute significantly to the occurrence of structural failures." The report went on to recommend that all tank vessels should be required to have critical area inspection plans (CAIPs), and that the Coast Guard should form joint industry work groups to address design and maintenance of tank vessel structures.

The above recommendations supported an earlier Coast Guard study known as the Bell study after the study group chairman Admiral Bell [2]. This study recommended that the Coast Guard Research and Development Center evaluate means for internal inspection techniques in large tanks and the development of high technology equipment for use in such tanks, including high intensity lights, high definition video equipment, or any other devices that may be suitable for use by the industry. In his M.S. thesis, Holzman [3] has outlined an experiment in which a single tank can be used to evaluate many of these alternate inspection technologies. These studies have essentially identified most of the major structural problems and inspection needs confronting the Coast Guard today. Structural problems are:

- cracking associated with the use of high strength steels and associated welding
- reduction in overall ship scantlings allowed by classification societies
- out of date structural details which had been developed for mild steel
- failures of coating and corrosion protection systems

Inspection issues are:

- inability to safely inspect upper areas of large tanks
- marine inspector safety especially in confined tanks
- marine inspection data management, or the need for modernized information systems
- limitations on time to actually accomplish inspections
- human factor issues such as an excessive marine inspector workload and lack of experience

The tasks placed before an inspector can be monumental, if not impossible, given current inspection tools. For example, Exxon has provided some statistics for VLCC's which were summarized in a recent National Academy of Sciences report "Tanker Spills, Prevention by Design" [4]. Table 1 below shows just how much structure there is. Clearly, it would be impossible to expect that all of this structure could ever be visually inspected. These data demonstrate the need for innovative inspection procedures which use novel technologies to optimize the inspector's time.

vertical height to climb for survey	35,000 ft
tank selection area	74 acres
total length of welds	750 miles
flat bottom area	2.6 acres
source: Exxon Corporation, 1992	

Table 1
Extent of VLCC Structure

In this same report the statement is made that "Coast Guard inspection efforts are not sufficient to ensure structural safety of oil tankers... The Coast Guard spends between 11 and 36 person-hours for each inspection of hull structure related to hull examination, inspection for certification, or reinspection. This effort is only a small fraction of the time needed to conduct a thorough examination of a tank vessel."

As the Coast Guard's only research and development organization, the R&D Center was aware of these studies and in 1990 had completed an overall assessment of the marine safety program to identify research needed over the next decade. In this assessment which is documented by Reese, et al. [5], a plan was laid out to accomplish several MI projects which would contribute to the overall effectiveness of the Coast Guard inspection process.

The objective of this paper is to provide an overview of those MI projects which have been initiated in the last two years in response to these developments. Not all of the projects identified in the Reese report could be started at the same time due to funding constraints. The highest priority projects have been funded first and these are the ones discussed here. Figure 1 outlines these projects, where they are broken down into general areas of Marine Inspection Technology, Data Management, and Personnel Safety. Some of these areas will be discussed in more detail in this paper.

Execution of these projects is accomplished by R&D Center staff in the Marine Engineering Branch using contractors with expertise in specific areas. In general, the first year of these projects involved technology surveys and field visits to observe marine inspections and talk to marine inspectors. Surveys of inspection procedures used in related industries such as aerospace, building and bridge construction, etc. were done to identify promising technologies. In their final report of this first year effort, Goodwin and McClave [6] have summarized the state of the art in inspection procedures and technologies. Ayyub and White in [7] have proposed an experiment using several approaches including expert elicitation to evaluate the effectiveness of alternative tank inspection technologies. In the current year, prototype technologies are being procured or leased for field testing and evaluation during actual marine inspections.

There are several other related marine inspection projects which are currently ongoing and supported by the Coast Guard. The Ship Structures Committee (SSC), of which the Coast Guard is a member along with ABS, MARAD, the Navy, and industry, has sponsored several projects which address marine inspection, including very practical guidance summarized in its "Guide for Ship Structural Inspections" [8].

The SSC projects provide specific technical background for designers, builders, and operators of all vessels. The effects of corrosion, fatigue, and age upon vessels are addressed with practical guidance provided for marine inspection.

Another related effort is the Joint-Industry Project (JIP) at the University of California at Berkeley "Structural Maintenance for New and Existing Ships: Overview, Fatigue Cracking and Repairs" [9]. In this JIP various technologies including structural reliability, human error analysis, fatigue cracking assessment, and repair methods are combined to develop durable designs and maintenance procedures.

Present Procedures of US Coast Guard Marine Inspection

The Basic Coast Guard Structural Inspection

The objective of a Coast Guard structural inspection of a merchant vessel is to obtain an overall impression of the structural integrity in a relatively short time. Ideally, 100% of the spaces should be inspected. However, this is nearly impossible with present techniques and methodologies. A 100% structural inspection, especially on the larger tankships, is difficult because the Coast Guard inspector is limited to a few simple tools that he or she carries, administrative workloads, safety restrictions, limited manpower, physical barriers on the vessel, and the desire not to impose costly downtime to shipowners.

The inspection of a vessel has evolved into four distinct phases. The first phase of the inspection is a screening inspection which may involve looking at the outside hull and bottom for clues to possible defects. This also includes a visual screening examination of the internal space. The second phase is a close-up visual examination of structural areas identified in the screening phase as warranting additional attention or of those areas that have a history of failures. The third phase consists of nondestructive testing of areas identified as having problems. This is conducted by an independent non-destructive testing (NDT) contractor at the owner's expense usually at the request of the Coast Guard marine inspector. The final phase is the reinspection of the repairs made as required by the Coast Guard.

Information Requirements

Information requirements can be viewed from two perspectives. The industry perspective is to maintain and document defects and repairs of its fleet so as to avoid costly structural failures and to meet Government requirements. The Coast Guard perspective is the legal requirement by Title 46, U.S. Code to conduct periodic inspections of certain vessels to verify seaworthiness and to learn enough about the structural history of a particular vessel to be able to certify that the vessel is operationally safe. This has naturally lead to the need for close mutual cooperation and sharing of information.

Before a marine inspector goes to the inspection site he must first collect background data from the Marine Safety Information System (MSIS) which is the Coast Guard's computerized inspection database. Usually, the inspector assembles a package of reference material applicable to the inspection and acquires a printout of the Marine Inspection Pre-Inspection Package (MIPIP) from MSIS prior to the inspection. Data collection on the inspected vessel is usually done with a small pad of paper and pencil. CG-840 series inspection booklets may be filled out during or after the inspection. Back at the office the information is coded and entered by administrative personnel into MSIS.

Delays can occur in the present information system and there is a need to streamline the data collection process. The workloads imposed upon the inspectors, unavailability of workstation terminals or time needed for administrative interpretation, coding and transcription of field notes makes it difficult for inspection data to be entered quickly. It is possible that as a result of this delay between the physical inspection and eventual MSIS system-wide availability that a ship may be inspected by another inspection zone without the benefit of detailed information from the previous inspection.

Industry has already taken the initiative to develop their own critical area inspection plans (CAIPs) such as Chevron Shipping Company's Computer Aided Tanker Structure Inspection and Repair (CATSIR*) or ARCO Marine's Hull Fracture Database (HFDB) to track the performance of structural elements on tankships. The Coast Guard has recently provided guidance in the development, use, and implementation of CAIPs in a Navigation and Vessel Inspection Circular No. 15-91. In general, the methods used to document structural defects range from sophisticated computer programs to personal knowledge retained by the individual who periodically performs the structural inspections. In light of the information management technology explosion of the 90's, there is an opportunity to develop industry wide standards in handling of vessel structural inspection data collected. There exists a need to determine how best to organize that information to optimize the ability to track recurring problems.

Technology Descriptions

Inspection Technologies Identified

In the Goodwin and McClave [6] survey there were three phases to the work effort: a Coast Guard field survey, Government agencies and industry survey, and a technology evaluation. The survey covered two broad areas, NDT techniques and access enhancement techniques. Figures 2 and 3 summarize the technologies surveyed in 1992 and

* The use of trade names in this paper does not constitute endorsement of any one product over another. It is merely stated here to provide the reader with an example.

identifies those technologies which are worth further developmental effort by the Coast Guard as reported in [5]. Many of the methods listed as needing no additional study are useful for shipboard inspection but are already well developed or are continually being improved by industry.

Visual Techniques

Inspectors unanimously agree that lighting is their primary concern, especially in the performance of cargo tank internal inspections of large tankships. The predominant inspection method is to walk the tank bottom to view structural members. The size of the tank, the rough, dark nonreflective surfaces, and the types of lights available make it difficult to see very far, especially the underdeck structure. The inspector's flashlight is probably his or her most important piece of gear for a visual inspection.

Two fundamental needs for these types of inspections are adequate lighting in cargo tank spaces and lighting in restricted entry areas such as double bottoms. Lighting in large cargo tank spaces where the inspector walks the bottom and scans the side shells and underdeck requires the greatest light performance. Portability is still important but maneuverability is not as difficult once down in the tank. For lighting in restricted entry areas such as in double bottoms, portability is extremely important because of the difficulty in climbing through numerous athwartship and fore/aft lightening holes. The general performance of the inspector's flashlights is usually adequate for these small spaces. Some inspectors carry the flashlight on a strap across their chests while others carry them in their side pockets. In these confined spaces, carrying anything is a burden and can impair safety.

The inspectors' portable flashlight arsenal usually consists of a variety of different off-the-shelf models as a result of trial and error attempts to find the best lighting source. For example, MSO Portland has a few rechargeable MAG-LITES, ORECKXL police cordless rechargeable spotlights, 6-volt Eveready lanterns and a couple of low power head lamps. The flashlight most commonly used at this office is the MAG-LITE. Much of this equipment is purchased by conscientious inspectors with their own money in an attempt to improve their inspection capability. The R&D Center brought a portable Xenon arc spotlight to MSO Portland which is being used in Coast Guard law enforcement detachments. This spotlight puts out 6 million candlepower and will focus from a 40 degree flood light to a 2 degree spot light. This is far better than the typical hand-held flashlights with candlepower ranges from 14,000 to 40,000. The performance of this light was far better than anything the inspectors had ever seen before. However, the trade-off for improved performance is increased cost and weight. Although some inspectors felt that it was a little too bulky and heavy, they did agree that if the power supply could be repackaged to be carried in a vest worn under coveralls it would be a valuable inspection tool.

Manufacturers specifications for portable lighting systems (flashlights) rarely contain photometric data other than beam candlepower. Many of the flashlights surveyed in [6] did not even have candlepower values associated with them. Even so, brightness between market available flashlights can't be compared because the manufacturers don't use common testing practices. Without additional descriptors, such as average, mean spherical, distribution curve, or peak, the candlepower is next to useless. Depending on the outcome of follow-on technical evaluations in 1993 the Coast Guard may need to develop its own performance requirements for a portable lighting system. While, this may not be considered as an innovative method it does represent a piece of marine inspector gear that can be optimized to provide short term benefits to improving visual inspections.

Very little ambient light enters tanks and the little that does is absorbed by the dark colors of the ship bulkheads and protective coatings. The illumination available from one 12 inch tank cleaning opening for a center tank of a 70,000 d.w.t. tanker, on an overcast day, is estimated as being 0.1 foot-candles in [6]. This is equivalent to the amount of illumination in a theater during a movie. Night vision equipment allows viewing at low light levels using the visible and near infrared regions of the spectrum.

Night vision systems generally produce a green monochromatic image. The image quality varies as a function of available ambient light and can be degraded significantly with high levels of light. Generally, night vision systems can inhibit depth perception and reduce visual acuity to no better than 20/40. The R&D Center tried a small, lightweight, hand-held Night Vision Equipment, Inc. 500 pocket night vision scope illustrated in Figure 4 and AN/PVS-7A aviator's night vision imaging system inside a cargo tank. The pocket scope weighs 15 oz. and has a battery life of 40 hours. The figure also illustrates other options for mating to a 35mm camera or 5X magnifier.

The units permitted the inspector to view structural details with the only ambient light coming from the ladder hatch (no butterworths were opened). Without the night scope and any additional illumination it would have been too dark to maneuver safely. The scopes had more than enough ambient light to work effectively in viewing the underdeck details. With the added illumination of a common flashlight the effectiveness of the night vision equipment improved by an order of magnitude. The only drawback to using this would be the lack of color definition which can provide the inspectors with clues as to the types of defects.

A relatively new inspection technique that has been used in the aerospace industry is Diffracto Sight (D-Sight). The technique is used for visualizing surface distortions, depressions, or protrusions, and is adaptable to the detection of any phenomenon leading to a change in surface topography greater than 10μm. Figure 5 illustrates the basic setup and typical results. This apparatus can detect stress cracks and corrosion under paint films. The D-Sight process can be viewed as a slope-detecting technique, with positive surface slopes looking dark and negative slopes looking bright relative to the background. The surface being inspected needs to be reflective; rough surfaces can be made reflective by wetting with a fluid. This technique has the potential of inspecting large surface areas in a short amount of time.

Moving a remote video camera might be more desirable than making provisions for humans to gain access to the underdeck of a large tankship. The equipment necessary to package together a corrosion proof video system is commercially available for about $50,000 as described in [6]. This idea is already being employed by Ronald Nisbet Associates, Inc. with their RemoteView$_{TM}$ shown in Figure 6. This is a remotely operated video system designed to perform visual inspections of cargo tanks. It can be deployed through butterworth openings or one inch holes drilled through the deck to access desired areas. The holes could be made permanent for future inspection access by sealing them with a threaded plug. RemoteView$_{TM}$ is a good example of the commitment of independent surveyors to improve the inspection business on their own initiative.

Approaches to conducting a visual structural inspection will differ and current procedures have advantages and disadvantages in terms of ease-of-exercise, cost, quality, safety, and effectiveness. Ayyub and White in [7] developed options for evaluating visual inspection methods to allow for more effective use of inspection resources. Documented quantitative measures of inspection qualities could be used by both industry and Government to select the best method. Evaluation methods considered include a statistically-based experiment using a fixed test tank or from out-of-service vessels, performance monitoring, or expert ellicitation as described in [8, 9]. Expert elicitation is a formal process of collecting expert judgement through the elicitation of probabilities to evaluate risks for policy and decision making. Although, this technique is more qualitative, it could be used to evaluate the best inspection practices for particular tank configurations as well as the potential of new methods before embarking on costly quantitative studies.

Vibration and Acoustic Methods

Two methods under consideration, vibration and acoustic emmision testing, offer novel means to quickly survey large areas of ship structure and identification of questionable members. These methods may have the potential of identifying significant defects which may otherwise go undetected because they are hidden by paint, corrosion, and dirt.

The concept behind vibration testing recognizes that the dynamic characteristics of a structural member are dependent on stiffness and mass. Any significant flaw which develops in that member will alter the stiffness, which in turn will be reflected in its vibrational behavior. By measuring the dynamic characteristics of a member and comparing them to a previously established baseline, it is possible to identify the presence of significant flaws. The feasibility of vibration monitoring for the nondestructive evaluation of structures has been demonstrated for highway bridges by Mazurek and DeWolf [10]. The application of this approach has also received considerable attention for offshore platforms, for which Rubin [11] gives a number of citations.

Structural vibration tests are commonly performed by applying a measured force excitation at one point and measuring the response at one or more other points. The force and response signals are inputted to a spectrum analyzer, where they are digitized and transformed to the frequency domain. Using the analyzer it is possible to derive frequency response function (FRF) curves, which relate response to excitation input as a function of frequency. Computer processing of the FRF's permits extraction of the dynamic characteristics of interest, such as resonant frequencies, mode shapes, and damping factors. Ewins [12] provides extensive details for this type of testing.

There are several different structural vibration testing methods which might be employed. The technique under investigation for ship inspection is the impact method, where an instrumented hammer is used to impart a measured force. The response transducers are typically accelerometers, although other types may also be used. Vassilopoulos [13] has already used this type of testing to troubleshoot shipboard vibration problems. If impact testing is implemented in ship inspections, it is envisioned that the inspector would tote a small system which contains a computer and signal processor. He would mount an accelerometer at a prescribed point, impact the member at a second point, and the computer would evaluate the resulting FRF. After comparing this FRF to an accepted baseline, the computer would indicate whether a flaw was suspected.

To test this concept, an aluminum model of a section of hull structure is being assembled. The model, depicted in Figure 7, consists of four rows of longitudinals and five transverse sections. The purpose of the model is to evaluate how severe a defect must be in order for it to be reliably detectable in the vibrational response. The model will also be used to evaluate the consistency of the response for members of the same geometry, fixity, and degree of integrity. This will provide some indication as to whether the baseline response obtained for one member can be used for all members of the same type. Preliminary tests were conducted on one of the longitudinals, with the resulting FRF's shown in Figure 8. The first test was with three edges of the longitudinal secured, and the second with one of the short edges released (roughly emulating a very severe crack). In addition to the distinct contrast evident between the two spectral patterns, it is interesting to note the apparent fundamental mode of vibration, with a resonant frequency of about 210 Hz for full constraint, dropped to about 67 Hz when one edge was released. Although they are preliminary, these results do indicate that this method shows promise for future ship inspections.

The second method being considered for survey inspections is acoustic emission (AE) testing. As cracks develop in a structure, elastic acoustical stress waves are released by the crack and transmitted through the structure. A portion of these stress waves are converted to surface waves which travel along boundaries. The concept behind the AE technique is to monitor these surface waves as a means for detecting new cracks and observing the growth of existing cracks (Wood and Harris [14]). There are certain conditions which must exist in order to effectively implement the AE method. Since a crack must be growing before it will release acoustical energy, the structure must be loaded dynamically, and the loading must be such that it is causing the crack to open and close. Because of this, the AE method does not appear to be well suited for port inspections. However, the technique shows particular promise for operational monitoring of ships underway. It is anticipated that the hull structure model described previously for the vibration testing will also be used to test the AE method in the laboratory.

Classical NDT Techniques

As shown in Figure 2, there are a variety of, for the purposes of this paper, classical NDT techniques employed by industry. These include dye penetrant, ultrasonics, multiprobe ultrasonics, magnetic particle, eddy current, ACPD & ACFM, radiography, weld surface micro structure, and shearography. These are all local NDE methods and are fairly well developed. These methods could be called for in the third and fourth phases of the structural inspection. The reader should refer to [5] for descriptions of these methods. Although Coast Guard inspectors do not use these traditional NDT methods in the course of their work, they are trained to know enough about many of these to make appropriate recommendations to the ship owner and to interpret test results. While these close-up NDT techniques are important it is believed that the greatest short-term benefit can be derived from the development of those methods that will improve the first two phases of the structural inspection process.

Thermography

Infrared thermography techniques have been widely used on land to produce maps of infrared emissions from a target area. The basic principle is to use infrared thermography cameras to locate temperature differences which may indicate an area where corrosion or cracking has taken place. This technique has recently been applied to Glass Reinforced Plastic (GRP) composite vessels by Jones et al. [15] in work sponsored by the Coast Guard R&D Center. It appeared to be effective in identifying a number of discontinuities within the composite laminate assembly of the Steam Yacht Medea. To date as reported by the contractor in [15], there has not been any application to tanker hull inspections. Since this technique has the potential to inspect large surface areas in short amounts of time its potential should be explored.

Installed and Portable Systems

Naturally, built-in access to all structural members such as adequate ladders, walkways, handholds, and extended longitudinals would be ideal. Unfortunately, these provisions are not always cost effective to the shipping business and, although some access in the form of permanent ladders is provided, the majority of a cargo tank remains inaccessible. Without any help, i.e., safety equipment, the marine inspector is reduced to walking the tank bottom or to climbing the side shells. Because of safety considerations the inspector is limited to climbing ten feet without safety devices.

To improve access ladders can be used. Marine Inspection products of Bath, United Kingdom have a ladder system called "Framewalk" designed for dry bulk carriers with transverse framing. It requires assembly by two persons in about 20 minutes and weighs about 420 lbs. Fixed staging is another way of providing access but this is normally setup to effect repairs rather than for inspection purposes because of the high costs involved. An alternative to fixed staging is using work platforms suspended from the underdeck structure similar to those used by window washers for large buildings. Spider Staging Corp. has several portable staging systems that can fit through butterworth openings such as the ST-26 Mini-Spider. Another portable staging system belongs to Stageaway Vessel Support Services. An articulated work bucket such as the Portable Work Platform developed for Shell International Marine which is pneumatically operated and can fit through a tank opening could also be employed.

Rafting is another alternative and can be performed while at sea. Water ballast levels are varied to provide for visual inspection of the upper tank areas. However, safety considerations require the highest water level not to exceed three feet below the opening in the web frames. A complete inspection of the underdeck may still not be possible when there are deep web frames.

Robotics & Underwater Systems

Robotics technology lends itself to controlled and repeatable inspections, eliminating human subjectiveness and the potential of eliminating the need for an inspector in the tank. Robotics has penetrated a number of industries to varying degrees, including the automotive, electronics, and aerospace to name a few. There have not been many formal developments of robotics for the purposes of tank inspection. However, one such program involved a remotely operated vehicle (ROV) called the Remote Tanker Inspection System (ARTIS). Figure 9 illustrates this system. This system was developed in the mid-eighties for Mobil Oil for the close-up inspection of ballast tanks for corrosion and structural damage. The design approach was to make the vehicle intrinsically safe by using an underwater generator that used water from the firemain to turn a water turbine and fiber optics in its umbilical cable. While the proof of concept tests of the system were reported as being successful. no further development has been completed to date.

The concept of using underwater remotely operated vehicles (ROVs) to inspect the insides of a ballasted tank or hull is not a new one. It has been attempted as described above. However, due to the large size of the vehicles, lack of a suitable navigation system, cost, and poor automatic control over the inspection, these programs were terminated. Over the years ROV costs have decreased significantly and high accuracy ranging and dynamic positioning systems have been developed.

Application of this technology has been demonstrated in a number of areas. Marquest Group, Inc. is developing an in-service inspection capability for above ground petrochemical storage tanks. Precise position data combined with inspection data allow the creation of thickness contour plots and photomosaics of corrosion hot spots of the tank internals. An underwater vehicle is also being developed by the Naval Surface Warfare Center, Bohlander, et al. [16], to perform a number of tasks including inspection, paint/hull plating thickness gauging, hull electropotential monitoring, and to conduct marine fouling removal. It is anticipated that this would reduce maintenance costs in dry-dock and improve the quality of paint maintenance. Figure 10 illustrates the tethered automated hull husbandry vehicle (AHHV) of [16] as it performs its hull inspection chores. The contour lines represent the presence of varying marine fouling thickness.

Although, diver inspection is nothing new, the improvements in diver navigation being exploited by the Ship Shape program, Eastport International, Inc. [17] sponsored by Supervisor of Salvage, US Navy are new. They have interfaced a computer mapping system to a diver navigation system UT gauging capability, and diver's helmet video camera. Diver location data is recorded and mapped to the vessels geometry along with the collection of significant thickness gaugings and video. The two diver navigation systems used were Marquest, Group Inc. EXACT and Sonardyne Diver Locator Systems. The data collected would then be used by the NAVY to prepare bid packages for hull repair work.

Recent advances in control hardware and software have resulted in extremely stable platform control for inspection tools such as ultrasonic thickness devices, visual and acoustic imaging systems. These platforms can be guided through a tank collecting thickness data in a hands-off mode through dynamic positioning and automatic control. If the underwater inspection industry continues advancing along this path and the technology costs come down it won't be long before it would be worth a re-visit to this area for application to commercial tankship inspection.

There is a number of general considerations to be addressed in the development of any form of robotics capability for tank inspection. The physical constraints such as the tank sizes and accessibility is one such consideration. Tanks on VLCCs can be up to 200 feet long by 110 feet deep and 170 feet wide while a typical 70,000 d.w.t. ton tanker could be 105 feet long by 55 feet high and 45 feet wide. Access can be made available through Butterworth openings, roughly 18 inches in diameter, that are situated every sixteen to twenty feet near the centerline of the tanks. Ease of use and portability is important. Safety in terms of use inside tanks carrying petroleum products must be considered and level of desired detection capability will greatly affect the sophistication of design.

Concepts being evaluated by Battelle Pacific Northwest Laboratories under contract to the Coast Guard R&D Center include a deployment system utilizing a long reach manipulator arm. This might be implemented by using a full arm of proximity sensors or computer model of the tank geometry in conjunction with a kinematics model of the arm. Battelle has been developing long reach manipulator inspection systems for condition surveys of large underground nuclear waste storage tanks for the Department of Energy Hanford site. These tanks are up to 75 feet in diameter. An example of one of the systems looked into for these tanks was the Stemlite unit manufactured by the

ZUMRO company of the Netherlands illustrated in Figure 11. This system uses a two inch stowable mast formed from strips of heat treated steel and resembling a retractable metal measuring tape to move a pan and tilt camera inside a tank. The mast is retractable into a top-side unit by wrapping around a drum. Battelle feels that a fully robotic inspection system may ultimately be developed but the initial robotic inspection system will be telerobotic and require interaction with an inspector.

A long reach manipulator inspection system is also being developed for the Federal Highway Administration to perform scour inspections under bridges. This is illustrated in Figure 12. The trailer mounted device deploys a telescopic arm to position a sonar probe just below the river surface up to 50 feet.

Information Technologies

Functional requirements were developed in 1992 for a Coast Guard specific portable data entry inspection tool in McClave and Goodwin [18]. These requirements were developed based on extensive surveys and interviews with practicing marine inspectors and administrative personnel. The basic concept consists of a mobile unit in the form of a pen based computer with a resident menu-driven, vessel-specific program which the inspector carries during a ship inspection. The mobile unit will offer on-line access to important reference material and will allow for the recording of comments, sketches, and digital photographs for incorporation into an inspection diary. A desktop unit will be used to expand the capabilities of the mobile unit. It will have a floppy disk, hard drive, a portable printer, and a CD-ROM unit which will support a desktop computer capability on-site in a temporary office. The information collected becomes part of a permanent inspection record that is stored in an inspection file. This file can be downloaded into the new Marine Safety Network replacing the old MSIS without administrative re-transcription. This is conceptually illustrated in Figure 13.

In surveying and interviewing Coast Guard marine inspectors in (18) information was gathered in the form of what types of inspections were conducted, environmental constraints, human factors, communication needs, reference information needs, etc. When presented with descriptions of some available data recording technologies in the survey including notebook computers, pen-based computers, digital dataloggers, and voice recorders the inspectors chose a pen-based system as the most suitable platform.

A pilot program being sponsored by Coast Guard Headquarters (G-MVI-1) to evaluate the concept and strategies proposed in the developed functional requirements of [18] will be initiated in 1993. This will allow inspectors to evaluate the concept of computerized inspection, the hardware, and impact it will have on their mobility. The assembled marine portable inspection unit (MPIU) will have an inspection and reference database with only Category Level 1 of 3 reference materials as defined in [18].

A project is being sponsored in '93 and '94 by the Coast Guard through the Maritime Administration's National Maritime Enhancement Institute to develop practical guidelines for a computerized Ship Structural Integrity Information System (SSIIS). This will support the evolution of the computerized CAIPs into a PC based industry standard. This project will evaluate approaches to computerized inspection data entry, archiving, and analysis that can be used by industry, Government, and classification societies.

Benefits may be derived by both the MPIU and SSIIS information systems being developed for the Coast Guard and industry, respectively. It could lead to better and more effective information sharing. Data collected on a particular ship by industry could be downloaded into the Coast Guard's MPIU to facilitate the inspection process.

Conclusions

In summary, the Coast Guard R&D Center is looking at innovative inspection technologies which will benefit Coast Guard inspection in both the short term and long term. Short term technologies such as lighting, night vision glasses, remote video, and access enhancement technologies have been identified which can be put to immediate use. Over the next year prototypes of these technologies will be evaluated during actual marine inspections.

Long term technologies are also being evaluated. For the not too distant future marine inspectors may use Diffracto Sight, vibration and acoustic methods, thermograqphy, ROVs, and robotics to aid in his or her inspection.

And finally, the area of information management has been evaluated and several prototype systems, most notable the pen based computerized "Marine Portable Inspection Unit" will combine one time data entry, background inspection data, and preparation of inspection reports to reduce inspector paperwork and add to data integrity.

Ultimately, the final judge of the worth of all of these technologies is the marine inspector. The goal of our research is to identify those technologies which will be accepted by the marine inspection community because of obvious improvements in mission performance for reasonable costs associated with equipment procurement, maintenance, and operator training.

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