

THE WORK SYSTEMS PACKAGE - REMOTE WORK EXPERIENCE

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Abstract

The Work Systems Package (WSP), a 20,000 foot manipulative work system, has been undergoing operational testing at-sea and in the laboratory since 1976. It has been tested on the Navy's unmanned tethered vehicles, Cable Controlled Underwater Recovery Vehicle (CURV III), Remote Unmanned Work System (RUWS), and is presently undergoing testing on the Pontoon Impacement Vehicle (PIV). This paper will discuss not only the results of these tests but the difficulties encountered due to "Murphy's Law". It is hoped that this paper will provide the reader with a better understanding of the technological advancements obtained in the area of remote work from tethered vehicles and some of the more critical operational and design areas to be encountered.

1. Introduction

The primary intent of most papers given at symposiums is to present recent technological advancements. However, since writing the abstract for this paper, I have decided to use the author's poetic license and deal more with the operational experience gained during my past five years with the Work Systems Package & associated Programs. Although critical technological areas will be discussed and referenced as required, the intent of this paper is to take a step back to the basics that the engineer should be basing his at-sea designs upon. At times the engineer must return from chasing patents or new advancements in technology and go back to the building blocks that provide a successful system design, a design that can counter Murphy's first law: If anything can go wrong, it will, and at the worst possible moment. Therefore, I will discuss several subsystem design areas of undersea vehicles and work systems, areas where advancements in technology have resulted in greater undersea capability, and areas where engineering oversights could and have resulted in disaster. Although I will use the WSP as a primary example of technological advancement and design

applications, the comments in this paper are based on my experience in general and are not meant to reflect on the design or designers of any specific system. But first, some background on the WSP.

2. Background

The Work Systems Package (WSP), under the direction of the Naval Sea Systems Command, was designed, fabricated and is undergoing operational testing at the Naval Ocean Systems Center (NOSC) in San Diego (Reference 1). As part of the Deep Ocean Technology (DOT) project, the WSP program was initiated in February of fiscal year 1972, by NOSC working in conjunction with Battelle Institute, Civil Engineering Laboratory and the David Taylor Naval Ship Research and Development Center, Annapolis. The Work Systems Package (WSP) is designed to provide a versatile work capability when mounted as a unit on the Navy's Cable Controlled Underwater Recovery Vehicle (CURV III) or the Remote Unmanned Work System (RUWS) unmanned cable-controlled submersible vehicles, and the ALVIN, SEACLIFF, and TURTLE manned vehicles. In addition, it can be positioned and controlled by divers or operated independently from a surface support ship for operations at shallow depths without the need for a submersible.

The system was designed to accomplish a complete work task on the ocean floor without the necessity of resurfacing for tool interchange. Potential tasks include salvage, recovery, installation and repair operations. Basic components of the work package (Fig. 1) include two simple outer manipulator arms without elbow functions that act as "grabbers" or restraining/holding arms to steady the vehicle or hold small work pieces.

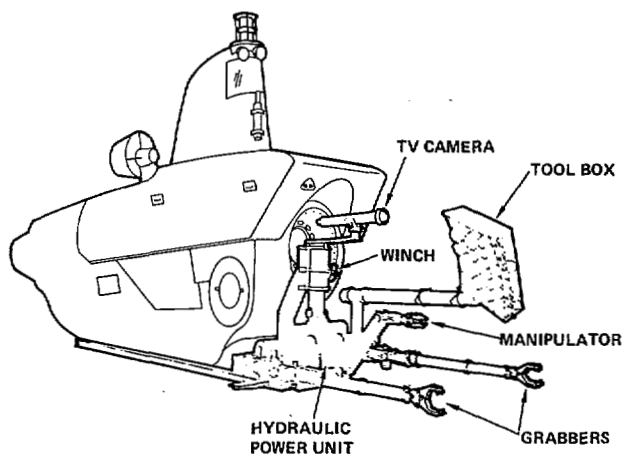
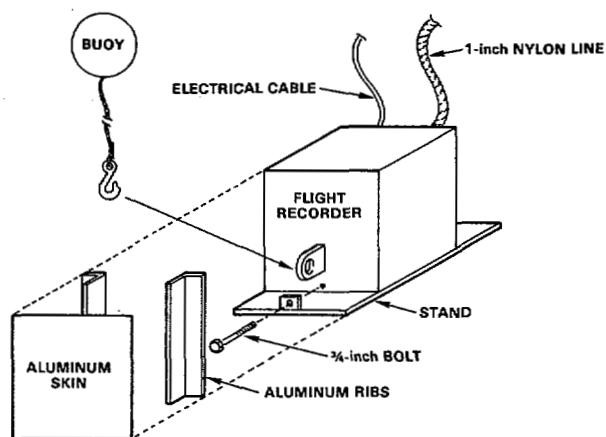


Figure 1. WSP as it would appear mounted to the manned submersible ALVIN.

A centrally located seven-function manipulator arm can select, interchange and operate a variety of hydraulically actuated tools. Included in the tool storage box are tools to perform cable cutting, synthetic line cutting, nut torquing, jacking, prying, wire brushing, sawing, grinding, drilling, tapping, and stud driving. An electrically-driven hydraulic pump unit supplies the power to most tools. Electric power is supplied to the system from a self-contained battery package. Control of all operations and functions is provided through a multiplexed telemetry circuit from the vehicle. Pressure tolerant electronic and hydraulic components operate at full ambient pressure in oil-filled, pressure-compensated enclosures.

Upon completion of assembly, checkout and preliminary tests, the WSP was mated to the CURV III for its first major in-water test. The WSP underwent six weeks of operational testing at the Navy's San Clemente Island test facility in fiscal year 1976. Such tests as underwater docking with a submerged test fixture, tool exchanges and operation, object identification and recovery, and a simulated flight recorder recovery were successfully completed.

The superior operability of the system, the short-time (2 to 2 1/2 minutes) required for remote tool exchanges underwater and the successful performance of a complicated recovery sequence requiring exchange and operation of nine different tools and bits in 2-1/2 hours, (Figure 2) achieved, and in many cases, surpassed original design goals.



SEQUENCE OF OPERATION

1. EXTRACT THE DRILL MOTOR AND A 1-INCH DRILL BIT
2. DRILL ACCESS HOLES IN THE ALUMINUM COVER TO ALLOW SPREADER INSERTION
3. EXTRACT THE SPREADER, INSERT INTO THE ALUMINUM SKIN AND OPEN THE SKIN TO ALLOW INSERTION OF THE JACK
4. REPOSITION THE VEHICLE TO ALLOW USE OF THE JACK
5. EXTRACT THE JACK, INSERT, AND SPREAD APART THE ALUMINUM RIBS ALLOWING REMOVAL OF THE "FLIGHT RECORDER"
6. EXTRACT THE IMPACT WRENCH AND SOCKET AND REMOVE THE 3/4-INCH BOLT FROM THE "FLIGHT RECORDER"
7. ATTACH A BUOY-LINE TO THE "FLIGHT RECORDER" AND REMOVE IT FROM THE TEST FIXTURE USING THE MANIPULATOR
8. EXTRACT THE CABLE-CUTTER AND CUT THE ELECTRICAL CABLE ATTACHED TO THE "FLIGHT RECORDER"
9. EXTRACT THE SYNTHETIC LINE-CUTTER AND CUT THE 1-INCH NYLON LINE ATTACHED TO THE "FLIGHT RECORDER" RELEASING IT TO FLOAT TO THE SURFACE

Figure 2. Simulated "flight recorder" recovery scenario

Following the successes at San Clemente Island, the WSP was flown to NOSC's Hawaii Laboratory for interface and testing with the Remote Unmanned Work System (RUWS). The WSP and RUWS were mated and operated in the RUWS test pool in preparation for support of the Large Object Salvage System (LOSS) operational demonstration at the Naval Coastal Systems Center (NCSC) during the fiscal years 1976 and 1977. The WSP/RUWS was flown to Panama City, Florida, where it successfully completed support of the LOSS operation. The systems easily performed such tasks as midwater docking, cable cutting, stud driving, messenger line attachment, and air hose attachment using quick-disconnects.

The WSP was then returned to San Diego where it was prepared for an extensive laboratory evaluation of the operating characteristics of the system. The laboratory evaluation resulted in a complete time motion baseline description of the Work Systems Package upon which any operational scenario can be simulated resulting in a projection of both operating time and power consumption by the baseline WSP design. With this baseline, subsystem parameters can be changed and the

sensitivity of these changes on the system can be determined providing the design engineer with an excellent tool for future work system designs (Reference 2).

Presently, the WSP is undergoing studies addressing the integration of it with the Pontoon Implantation Vehicle, in anticipation of testing which will deal with the area of Deep Ocean Recovery.

3. System Concept/Configuration

One of the hardest portions of the design problem is that of coming up with the proper concept or system configuration. This usually arises from the lack of a proper definition of the systems mission. For example, the range of missions in undersea work covers such areas as inspection of offshore drilling platforms with small remotely-controlled vehicles, recovery of downed aircraft or ordnance, up to recovery of entire submarines. Along with mission definition, the identification of the operating criteria is also essential. Changes in operational sea states, current velocities, depth requirements, maneuverability, and work capability, all have considerable impact on the initial design concept and should, therefore, be accurately identified in the early stages. For a successful design, these criteria must be realistically determined. The usual approach, that the system to be designed will be "THE SYSTEM" that will do everything, anytime, anywhere, cost nothing and be completed yesterday, is totally unsatisfactory. However, time and time again system designs begin with this "pie in the sky" attitude. Subsequently, a lot of time and money is wasted chasing totally unrealistic goals. The approach of being realistic and determining exactly what the operational criteria are, basing the system design around these criteria, and sticking to them is of the utmost importance. The laws of nature are not going to change for the design engineer, and he who enters the area of undersea design with the optimistic approach that this all-encompassing, general system will be able to do anything he desires, usually will end up with a system that compromises the mission and operational criteria, a system that instead of doing one thing very well, does a few things mediocre.

4. Operational Support/Handling

Although most aspects of this paper apply equally to both manned and unmanned submersibles, this section, more than others, will primarily address the tethered, unmanned system. Too often in system designs, tunnel vision results in the overlooking of several critical areas.

Areas such as:

- Identification of the operational platform.
- How will the system be transported to the operating location?
- How will the system be handled during the operation?
- Will the handling system keep the tether out of a critical dynamic range?

The Tether - The link which allows man to make his presence felt to the depths of the ocean, while he remains topside in an air-conditioned environment where he can control the operations below the surface in safety and comfort. The tether - the weak link of the unmanned submersible. With all the advantages associated with tethered submersibles, the tether design and its associated equipment is by far the most critical area of the entire system. Assuming you have a cable with the proper configuration and strength, is its termination capable of taking the stresses imparted on it by the cable dynamics? Has the handling system that you have come up with assured you that the cable will not enter a snap load region where it or the termination can be quickly damaged? You may say "this is only a design problem and can be overcome," and this is heard quite often when it comes to tethered design. You may be right, but if you are can you ensure that the pilot of the vessel you are operating from won't back over your cable and sever it? Once again, you may say "that will never happen to me," that your cable design is adequate, the dynamics have been taken into account, and you will operate from a ship that will not give you this kind of a problem. That is great on paper, but when you get down to the hard facts, life is not always a bed of roses, and several of those "it can't happen to me" problems are listed in Figure 3. The list in Figure 3 is only out of my background, and I'm sure it would grow considerably if it had been researched taking into account all of the offshore industry. In short, no matter how sophisticated and elaborate your submersible design is, if you lose your tether and can't communicate with it, it will do no one a bit of good. The engineer who takes a short cut in the cable dynamics design of the system because he sees a light at the end of the tunnel, may find out that the light is another train.

VEHICLE STATUS

FAILURE

Lost (1978)	Tether Termination
Lost/Recovered (1979)	Tether Termination
Lost/Recovered (1979)	Tether Entangled
Lost/Recovered (1979)	Tether Entangled/Broken
Severed/Recovered (1979)	Tether Severed by Ship

Figure 3. Five Recent Vehicle Catastrophies

Following closely behind the sea state induced cable dynamic problems is the problem of handling the vehicle system during launch and recovery. Quite often the system being designed will operate off ships of opportunity which may impose severe problems during launch and recovery in heavy seas. Since the designer cannot always be assured of the type of crane or system to be used to launch the vehicle, he must ensure that the method of rigging the vehicle for lift is fail-safe. For example, lifting hardware should be kept clear of critical system components, where during handling in rough seas damage to those systems is almost certain. Also, the lift points must be attached to a portion of the system which in no way can fail or come off either through overstressing or component or weldment failure. Expensive systems have often been damaged due to failure to properly integrate the handling system. This integration should be done very early in a system design and not done in retrospect. These failures cannot only cause loss of an entire vehicle or program, but can easily result in personal injury. Once again, as the following list indicates, Murphy has something for everyone who says "it can't happen to me":

-Figure 4 shows damage to the CURV III frame resulting from an accident that occurred during shipboard handling.

-WSP/RUWS dropped approximately two inches due to weldment failure at lift point in 1977 which resulted in over one week of down time during at-sea operations (Figure 5).

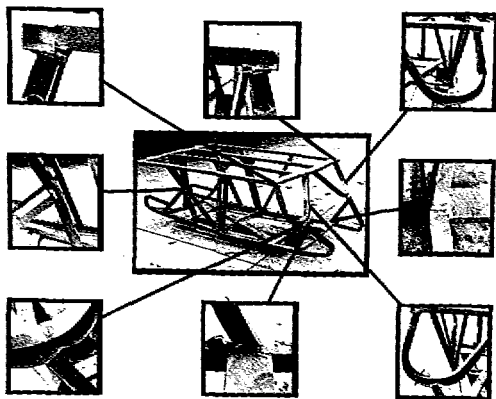


Figure 4. CURV III Frame Damage



Figure 5. Effect of a 2" drop of the WSP on 11 of its 16 mounting bolts.

In an effort to heed our own words, the upcoming operations with the WSP will utilize a handling system which remains on the vehicle and provides a single point for remote attachment, as opposed to the six point lift system previously used which required divers in the water to make the attachments. When you are placing a vehicle in the water next to a ship or taking it out, there is no time for mistakes, and the system that you are using should be failsafe, simple, remote, and quick, thus providing maximum safety to divers, the crew, and the vehicle.

5. Structure

Structure, the skeleton of the vehicle, the "bag" of the mechanical design engineer. What technological problem does there exist with the structure? None really, but how often did the sleek hydrodynamic vehicle which was presented in the early concepts end up being the cluge that is sitting on the laboratory floor? How often did improper system integration into the structure, problems with corrosion, or a poor design for maintainability hamper an at-sea operation? Unless you are relatively new in the field, then your answer is probably "more than one time." Let's look at these 3 areas more specifically: system integration, corrosion, maintainability.

Since most of the subsystems on a vehicle are relatively small compared to the overall size of the vehicle, the basic impact of poor systems integration, other than the effect of the overall vehicle design and efficiency, is the ease in which you can get to the subsystem and perform preventive maintenance or repair. However, one subsystem in tethered design stands out foremost, and that is the

buoyancy system. The buoyancy of a system is often considered late in the design; but in fact, it can have substantial impact on the system design and should be integrated in the initial stages. For example, the WSP buoyancy material, needed to provide neutral buoyancy while submerged, accounts for one-third of its in-air weight. The integration of a subsystem this substantial must take into account viewing requirements, manipulator movement requirements, accessibility to other subsystems, along with the structural integrity required to withstand the ocean environment. The affect of cable dynamics, wave-slap, and system dynamics during launch and recovery can impose severe loading problems on a large amount of buoyancy material, especially if this material is hanging on for dear life and not integrated properly into the vehicle itself.

The second area to be addressed concerning the vehicle structure is that of corrosion. "No problem," you say? "A good fresh water washdown after each operation should take care of it." In general this is a good philosophy; however, in reality, Mother Nature has another idea. Since I have become involved in undersea design, I have encountered two schools of thought on corrosion prevention. The first, and least used, is presented by those involved in long term undersea corrosion studies. This thought is that if you don't do anything to a large structure, i.e., don't paint or anodize it, then it will corrode slightly all over and you won't have corrosion concentrations which would cause failure. The second school of thought is that it's best to either anodize, passivate, or paint the structure thus protecting it from general corrosion problems, such as overall corrosion, but making it more susceptible to corrosion concentrations when this protective surface is damaged. However, both schools of thought miss one very critical aspect of corrosion. This aspect arises in the area of crevices or recessed locations which are usually hard to get to and entrap some salt water. As is usually the case these are the areas where stainless steel hardware or components are used in conjunction with the aluminum structure or housing. However, with the application of anodic coatings and adequate preventive maintenance, this problem can be dealt with. These anodic coatings also require application to those areas which are hard to get to for preventive maintenance. This includes all metal interfaces and not just those of dissimilar metals, since entrapped sea water along with areas of reduced oxygen due to tight interfaces can set up detrimental corrosion cycles. This became very apparent to those of the first school of thought upon retrieving large corrosion

test plates and finding that there was little corrosion on the plate itself, but severe corrosion below the teflon mounting washers used to insulate the test plate from the mounting fixture. Just remember, Murphy is always looking over your shoulder; he was looking over mine in 1977 when the WSP lifting failure was partially caused by corrosion. Therefore, I offer the third school of thought. You cannot overpaint, overanodize, overpassivate, apply too much protective coating, or perform too much preventive maintenance. If you don't apply enough protection to your system or keep that protection maintained you are going to have problems, even in the most sophisticated and well designed systems. Also, proper system design in the early stages to help eliminate areas conducive to corrosion and designing for easy preventive maintenance can help in solving the problem of corrosion.

Following along the path of preventive maintenance is the maintainability of a system. MAINTAINABILITY? What! You have never heard of the word maintainability? I would not be totally surprised. Unfortunately, too many of today's engineers have been stuck in an office designing systems for so long that they have forgotten what it's like out in the real world when this perfect design decides to no longer run. Repairing an inoperable system at-sea, in bad weather aboard a rolling ship, especially when you have just run out of dramamine, is not the most pleasant experience. What most engineers need, and I think should be required of any task team, would be spending a few weeks at-sea correcting the previous engineer's mistakes. Especially, when he can't quite get to the subsystem due to improper systems integration in the early design stages. Just because the innovative engineer managed to place a square peg in a round hole does not mean that the optimum design was achieved. Sarcasm you say? Possibly. But remember the following: Operating costs at-sea are phenomenal. When you are cutting 3 to 4 digit figures from your system design costs, sacrificing proper design and maintainability to achieve this, your daily losses while at-sea during failure of this system to operate may easily be in the 4 to 5 digit range, and if you are working for one of the oil companies, it may be pushing a 6 digit figure. Therefore, at all costs, design for preventive maintenance and maintainability of any given system and have enough spare parts on hand to complete the repair job. A beautiful system that does not work and cannot be easily fixed is of no use.

6. Manipulators

To a mechanical engineer the manipulator suit is usually the most dynamic and first addressed in the design of a more optimized undersea system. Shouldn't a more sophisticated, dexterous, advanced manipulator be used in your next vehicle system so that you can do your job much faster? Being a mechanical engineer, and therefore going against my basic design philosophy, I hope to refute this idea. In order to perform any type of work operations in the ocean, the work system manipulators must be capable of two things: (1) attach to and maintain the work system orientation at the work site, and (2) provide the manipulation required to operate tools to perform remote work tasks. The system must have this capability not only on the bottom, but also during mid-water operations.

In answer to the first requirement, the WSP design evolved into one requiring three manipulators. Previous submersibles had no more than two manipulators; one to hold the vehicle in position, the other to perform work operations. This configuration caused the system to be pushed away due to the reaction forces of the work manipulator, usually resulting in the breaking of tools or intolerable completion times of required tasks. To eliminate this problem the WSP uses two manipulators to act as grabbers or restraining arms while the third and more dexterous manipulator is used to perform tool exchange operations and the work tasks.

For the second requirement, let's address the grabbers and manipulators separately. The design of the grabbers should be relatively simple. Their primary function is to hold the vehicle in place, so they do not need the additional elements such as elbows or extensive movements in each joint. The critical point often overlooked in the design of grabbers to act as restraining arms is that not enough attention is paid to what they are actually restraining. The grabbers must be designed with enough strength to hold the entire vehicle in place in the maximum expected cross current. The drag forces imposed on the vehicle by the cross current can be quite substantial and can easily damage the grabbers. This factor, along with the following, resulted in breaking one of the WSP grabber wrists during at-sea operations. The second factor was a requirement to move TV cameras from one grabber to the other in order to view the undocking procedure. This resulted in the removal of the first grabber followed by the binding of the second grabber due to its bearing the entire vehicle load in the

cross current. To alleviate this problem, in future WSP operations, the system has been modified so that the activation of a single switch now opens and retracts both restraining arms of the system, therefore ensuring that no single arm is over-stressed during an undocking operation.

And now let's discuss the heart of the system, the dexterous work manipulator. When attempting to identify the desired characteristics of the work manipulator, the engineer is faced with several alternatives such as rate control, master/slave control, force feedback, or computer control. The optimum system will depend entirely on the critical tasks to be performed by the system. For example, if you are in space attempting to grab a satellite as it passes you, then you had better have a master/slave system incorporated into the design. If you are undersea attempting to disassemble and disarm a mine, you had better have a very dexterous manipulator with some force feedback capabilities. However, if your primary purpose is heavy duty undersea work, then the choice of a force feedback or master/slave manipulator system may not optimize the design, but quite to the contrary may subtract from it. For a more sophisticated manipulator a penalty must be paid in cost, reliability, and maintainability although certain tasks can be performed quicker. The design of the system must be addressed to that task which will occupy the greatest percentage of the work to be performed. After all, the manipulator that may do things twice as fast but only works half the time is not a very good trade-off. This is not to say that excellent sophisticated manipulators do not exist, but for certain jobs they may not be required. For example, when doing undersea tasks such as drilling, tapping, bolting, sawing, cable cutting, etc., such as the WSP has been designed to perform, it has been found that a more sophisticated master/slave design does not save that much time. In addition, if you are anticipating work at-sea with a tethered submersible where you have no time limit as to how long the task can and may take then you do not necessarily want to have your arm stuck in the master manipulator for an eight hour period. In this case, a simple rate controlled manipulator using a series of toggle switches is more than sufficient. In fact, recent studies have shown that designing a better manipulator is not necessarily the place to start in designing a more efficient system (Reference 2). Figure 6 shows that in operations without tools, the manipulator is used only 33 percent of the time, the cameras moved 17 percent of the time, while the operator requires 50 percent of his time to decide what to do on his next move. Therefore,

other areas, such as reducing operator decision time can have a great impact on the overall system design with a maximum payback of cutting the operating time in half, while installing a manipulator which can do its task twice as fast will possibly only reduce the overall operating time by around 16 percent. Although a more dexterous, faster operating manipulator may aid in reducing operator decisions, the primary effect will only be across the manipulator operation time.

OPERATION WITHOUT TOOLS (%)	OPERATOR DECISION	MANIPULATOR OPERATION	CAMERA PAN AND TILT OPERATION	TOOL OPERATION	LIGHT OPERATION (1)
AVERAGE OPERATION TIME	50	33	17		100
LOW SPEED PUMP IDLE TIME (2)	50				
LOW SPEED PUMP DUTY TIME (3)		33	17		
TOTAL POWER CONSUMPTION	32	27	14		27

OPERATION WITH TOOLS (%)	OPERATOR DECISION	MANIPULATOR OPERATION	CAMERA PAN AND TILT OPERATION	TOOL OPERATION	LIGHT OPERATION (1)
AVERAGE OPERATION TIME	37	30	11	22	100
LOW SPEED PUMP IDLE TIME	37			(22)*	
LOW SPEED PUMP DUTY TIME		30	11		
HIGH SPEED PUMP DUTY TIME (4)				22	
TOTAL POWER CONSUMPTION	17	18	6	(10) 26	23

(1) LIGHTING = 0.75 KW

(2) LOW SPEED PUMP IDLE = 1.55 KW

(3) LOW SPEED PUMP DUTY = 2.00 KW

(4) HIGH SPEED PUMP DUTY = 3.97 KW (ON-OFF ONLY)

*IT IS ASSUMED THE MANIPULATOR IS NOT BEING MOVED DURING TOOL ACTIVATION.

Figure 6. Operational Time Distribution of the WSP (percent)

Now, assuming you have a rate controlled manipulator and you wish a more sophisticated system, then the next recommended step would be only the installation of a position feedback system. With adequate position feedback available, computer control of the manipulator is easily achieved. After all, the most efficient operator is one who thinks instantaneously, i.e., a computer. The computer can easily be applied to repeatable tasks, thereby totally eliminating 50 percent of the operating time. Figure 7 shows the effects of a manipulator programmer on tool and bit exchanges on the Work Systems Package. It can be seen that in all cases, the experienced operator was outdone by the manipulator programmer. In the case of

those tasks performed at the work site which are only repeated a few times, program control can be used if the design is quite efficient. This requires that the operator needs only to push a button to begin recording the program and press a button to store the program, allowing the operator to recall the programmed path at any given time. This programmed path, which would of course include any operator errors; may not be the most efficient path to the work site; but, the fact that all decision time in making movements has been eliminated, it can be repeated in both the forward and reverse direction in considerably less time. The availability of this technology exists and has been demonstrated. Now, with the addition of the program control to the manipulator, it is an easy task to automatically program the pan and tilts to follow the manipulator and once again reduce the operator's overall time by 11 to 17 percent by not having to stop and move the TV cameras. Therefore, when requested to optimize a manipulator system on a limited budget, remember that a highly trained operator with a simple reliable manipulator may very possibly be the optimum design.

TASK	OPERATORS		PRO- GRAMMER	REDUCTION	
	INEXP.	EXP.		INEXP.	EXP.
ACQUIRE TOOL	5.18	2.12	0.90	82%	57%
REPLACE TOOL	3.24	1.42	1.31	59%	8%
ACQUIRE BIT	3.02	1.23	1.00	33%	17%
REPLACE BIT	3.56	1.30	0.74	79%	43%

Figure 7. Comparison of WSP task times (minutes) under direct operator control and computer control.

7. Viewing

"Viewing - no problem," you say, "We'll just throw a couple of cameras down there and see what we're working on." This may be easier said than done. Remember if you can't see it, you can't do it, and having a picture on a television monitor does not necessarily mean you can see what you want to do. The task at hand may be re-entering a small hole, for which a general overall view television camera may not be suitable, but one with a zoom lens would be optimum. But possibly the desired objective is to view the overall system so that the status of all manipulators or appendages may be known. This status may be required at more than just the forward operating point of the vehicle or system. Therefore, the engineer has the quandary of "Do I choose the wide angle camera, a zoom lens camera, a standard camera, or possibly a stereo pair?" The choice of any camera revolves around the basic fact that the water must be clear enough to view the operation. Granted, developments in technology have provided acoustic imaging systems which allow viewing through totally

opaque water and "touch and feel" manipulator systems which paint a picture of what they are feeling during any work operation thus allowing the completion of relatively simple tasks. However, these are exceptions to the rule and remember that your primary subsystem design should be based on that situation or operation that you will encounter the highest percentage of the time. Therefore, we are once again returned to the question of which camera do we use. The answer to this question is "use them all". If you have a wide angle or zoom requirement then install that camera in the proper position, i.e., use multiple cameras (Reference 3). A simple installation of several cameras and a few video switches will give the operator all the perspectives and fields of view required to perform the tasks effectively. Just because you can only view 1 to 2 monitors at a time when doing an operation does not mean that you are limited to that number of choices of pictures. You have never seen a football game with one man walking around with a camera trying to provide adequate coverage for television. There exists a control room with several video inputs in which the primary operator chooses the one to be presented, and undersea operations should be no different. This does not only pertain to the work area of the vehicle but to the status of the port, starboard, aft, top, and bottom areas of the vehicle. The two entanglement problems mentioned previously in Figure 3 may have been prevented with adequate viewing systems.

You may possibly come up against the problem that you do not have the bandwidth available in your cable to transmit that many TV pictures. Testing has shown that the operator can work easily with "quasi-real-time" television pictures, those being defined as providing a smaller number of TV lines at a slower rate. Although less data is being transmitted to the operator, for all practical purposes he sees no difference in the quality of the picture. With these types of processing of the television system, up to 4 quasi-real-time television pictures can be sent over a single coaxial cable previously capable of transmitting only one real time TV picture. And through the use of video switches the number of TV pictures available to the operator can be greatly increased.

8. Command and Control

As is usually the case in a paper or report written by an engineer of one discipline, areas relating to other engineering disciplines are usually covered in less detail. Not wanting to be an exception to the rule, this paper will be no different. When addressing the world of

electronics, it utterly amazes me that this field of engineers can keep up with a technology that is moving so fast. These engineers seem to have the capability of taking a myriad of black boxes and paint a portrait using a circuit board as a palette and a soldering iron as a brush. Although some of their achievements may seem remarkable, electronic engineers along with everyone else, easily fall prey to some of the critical design areas. Therefore, a few comments to those designing the electrical or electronic systems of submersibles follow:

- Maintainability, once again a dominating factor. Basic electronic design easily lends itself to modularity during repair or maintenance. Therefore, the design of electronics and their enclosures should keep in mind ease of accessibility and repair so that minimum down time results from any electronic component failure.

- Redundancy of an electronic system is a great asset for a successful operation. Along with the redundant system, a system which has the down link and up link signals unassociated will provide better feedback to the operator. It is hard to isolate a problem when the feedback data you are receiving is possibly being altered by the problem itself.

- The vehicle system should be simplified as much as possible, thus transferring as much sophisticated equipment as possible to a nondynamic, controlled topside environment.

Although the previous comments may be brief in outline, they are monumental in their effect if applied.

9. Conclusion

Design of a system for undersea use is easy, design of one that works is not. If you have read this paper and feel your intelligence has been insulted, you are one of the engineers to whom this paper was not written. However, if a single comment or point in this paper has opened your eyes or made you question your approach of design in any given area, then I feel the time spent presenting this paper was more than rewarded. The deep ocean is one of the few unconquered frontiers left, and engineers desiring this challenge will have an invigorating, frustrating, but fulfilling career. The conquest of the ocean is the greatest existing challenge to man. The challenge of beating Mother Nature at her own game. But one warning, it has been passed on to me by an unimpeachable source that Mother Nature's last name is "Murphy".

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