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MARINE PHYSICAL LABORATORY

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RUM III VEHICLE CONTROL SYSTEM

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ABSTRACT

The hardware and software design of a control system for the RUM III vehicle project is described. The functional requirements, design constraints, and system configuration are first examined. A description of the hardware systems and their corresponding software components follows.

INTRODUCTION

RUM III is a tethered, remotely operated submersible vehicle capable of operating in both deep towed and bottom crawling modes at depths of up to 6000 meters. This report describes the peripheral hardware currently scheduled for inclusion on the vehicle including a manipulator boom, camera and sonar systems, thrusters, and various sensors along with a description of the software necessary to allow full operator control over these systems and others that may be included. Also described is a shipboard software development system that may be used to aid both vehicle software development and any ancillary scientific projects.

FUNCTIONAL REQUIREMENTS

There are four functional requirements which are the basis for the RUM III Vehicle Control System design. They are described in the following paragraphs.

1) Format and Transmit Operator Commands to the Vehicle.

This includes commands for the operation of the basic vehicle and its sensor systems, and for the operation of whatever mission related devices may be mounted on the vehicle during a particular operation.

In the present implementation all commands are entered via the Operator CRT. Eventually an Operator Console with joysticks and other dedicated control input devices will be provided.

2) Format and Transmit Sensor Information to the Operator Displays.

Sensors include video and sonar systems as well as transducers for vehicle status (positions, speeds, voltages, etc.), for environmental parameters, and for the mission related devices.

3) Provide Fail-Soft Capability.

This will allow reduced-capability operation in the event of partial system failures, with particular attention to the safe recovery of the vehicle and its scientific payload. Emphasis is on providing alternate data paths for critical command and sensor information, alternate microprocessor control of various functions, and on returning the vehicle controls to a safe state in the event of a loss of all command channels. This includes providing the capability of stowing the manipulator and experimental devices for safe vehicle recovery.

4) Incorporate Computer-Aided Operator Control.

Operator aids will include graphic displays to aid in navigation and manipulator control, automatic positioning of television cameras to follow manipulator actions, implementation of high level operator commands (e.g. move the manipulator to a specified position), automatic repetition of a stored sequence of commands executed once by the operator, etc. In the initial system, the Operator Console functions will be carried out by the Operator CRT. The Operator Console functions will be added as operating experience indicates what features and functions will be most useful. The system will be designed so that extented functions can be included through modular additions to the software and hardware.

DESIGN CONSTRAINTS AND GOALS

a) Cable Bandwidth Limitation.

Only a limited amount of information may be transmitted between the vehicle and the shipboard Console Telemetry Processor per unit time. This limitation is most important with respect to the video data and to a somewhat lesser extent to the sonar systems. The other sensor data to the shipboard system and command information to the vehicle do not require a large fraction of the available bandwidth and so are not limited in this way. Much of the design effort has been directed at making the best use of the available bandwidth by providing a flexible format for the video and sonar data, in order to allow tradeoffs based on particular operating conditions.

b) **Expandability and Modularity.**

The design approach separates the system into functional modules with carefully defined interfaces. This will facilitate the design and checkout of the first, minimal system and will allow an orderly inclusion of enhancements. It will also simplify the design of devices required for particular missions and experiments. This philosophy applies to both the hardware and software aspects of the system design.

SYSTEM CONFIGURATION

The RUM III vehicle control system consists of a network of several microcomputer sub-systems and telemetry links providing for transmission of command, status, and other data between the microcomputers in the vehicle and those on board the ship. Each computer fills a particular role in the organization of the system. The major components of the system are described in the following paragraphs and in Fig 1.

a) **The Software Development Computer (SDC).**

The primary purpose of the software development computer is to provide an efficient environment for the software design and implementation of the RUM III control system. In order to achieve this goal the system must be able to support high level and assembly language program development along with the support functions necessary to compile, assemble, link and download the resulting products to the target systems. It may also be used for data analysis, navigation and engineering support, and as a general computational tool for any scientific tasks that may arise during a mission in the field.

b) **The Console Telemetry Processor (CTP).**

The CTP interfaces the Operator Console and Operator CRT to the system along with providing a bi-directional path from the SDC to the Telemetry Link and the vehicle, which is needed for program downloading, video and sonar uploading and similar functions. The control software that corresponds to each Vehicle Peripheral Processor will reside here along with all system software necessary to interface with the telemetry interface to the vehicle data node, the operator console, and the monitor system.

c) **The Command and Status Link (CSL).**

This bi-directional link carries commands from the shipboard CTP system to the Vehicle Data Node on the vehicle to be distributed to the VPPs and carries data up the link in the reverse direction.

d) **The Vehicle Data Node (VDN).**

The VDN is a central switching point for communications between the CTP, the VPPs and the VTP. It is responsible for coordinating the bi-directional data flow between vehicle systems and the shipboard systems.

e) **The Vehicle Peripheral Processors (VPPs).**

The actual control of the various physical devices of the RUM III control system is done by the VPPs. Here commands received from the shipboard system are translated into the outputs necessary to control the manipulator, thrusters, TV and sonar systems, TV scanner, the tracks , and the on-board VTP processor.

f) **The Vehicle Telemetry Processor (VTP).**

The VTP serves a dual purpose. First, it may be used to pre-process wideband data such as video and sonar signals for more efficient uploading to the CTP over the limited bandwidth High Speed Telemetry Link. In addition, it may be used as a more powerful on-board processor for the VPP control functions. This latter function gives the system some built in redundancy as the VTP is able to take over the functions of the VDN if a hardware failure is encountered.

g) **The High Speed Data Link (HSDL).**

The High Speed Data Link carries information from the vehicle video and sonar systems to the shipboard CTP system.

THE SOFTWARE DEVELOPMENT COMPUTER (SDC).

An Integrated Solutions Inc. Q-Bus compatible MC68000-based CPU board is used as the CTP. This CPU card allows the use of the Motorola MC68000 processor with the large variety of peripherals available on the Q-bus. The board chosen will operate at 12 Mhz with no wait states out of the on-board and local bus expansion memory. Forty Mbytes of hard disk storage and a tape drive are also supported.

The principal software development tool is the UNIX* operating system. UNIX provides a powerful program development environment which includes many utilities useful for software design and implementation and document preparation. The C language compiler and other utilities provided with UNIX may be used to prepare programs which are then downloaded into the CTP and the VTP. A cross-assembler for the 6502 is used to generate software for the VDN and the various VPPs.

THE CONSOLE TELEMETRY PROCESSOR (CTP)

A second Integrated Solutions Inc. MC68000 based CPU board running at 10 Mhz is used as the CTP. This board contains 256k of on board RAM and 128k of EPROM memory. The CTP is interfaced to the Operator Console and through the telemetry, to the VDN and the VTP. The Operator Console is the primary interface between the operator and the RUM III Control System. From this device, the operator is able to control all hardware and software systems. In addition, the operator may choose from a selection of formatted displays that provide information on the status of all systems. When implemented, the Operator Console will accept operator inputs from pushbuttons, joysticks, etc., and format commands to the vehicle. Status information from the vehicle will be interpreted and the console's displays updated as required.

In the initial configuration, the Operator Console is simulated in software using a video terminal. This has allowed early testing of the system without a major console hardware effort being undertaken before the actual needs of the system are known. When the requirements of the Operator Console are adequately defined, the console hardware will be built. The simulations will then be available as a backup console, if needed, due to a hardware breakdown.

* UNIX is a trademark of Bell Laboratories.

THE VEHICLE TELEMETRY PROCESSOR (VTP)

The VTP has been selected and procured but has not yet been integrated into the system. It consists of a set of boards designed and fabricated at the Marine Systems Engineering Laboratory of the University of New Hampshire. Like the SDC and the CTP, it is based on the MC68000 microprocessor. The VTP boards are designed for installation in a seven inch inside diameter pressure case.

OPERATING SYSTEM

The CTP and the VTP are provided with the VRTX/68000** "Versatile Real-Time Executive", a silicon software component for embedded microprocessors donated to the Regents of the University of California by Hunter and Ready Inc. of Palo Alto California. A silicon software component is an executable version of a microprocessor program that can be delivered in Read-Only Memory (ROM). For the RUM III application, VRTX has been copied onto EPROMs along with the TRACER** real-time debugging utility also from Hunter and Ready.

The VRTX executive provides a set of mechanisms necessary to support real-time systems. The RUM III control system builds on these mechanisms to produce an operating system that is both flexible and extendable. The modularity of the system allows it to be easily modified to adapt to future changes in hardware or applications goals.

The features include:

a) **Multitasking support.**

The RUM III control system is designed to support real-time systems by utilizing a set of VRTX mechanisms for implementing multitasking.

The design of real-time systems allows them to perform a number of different functions in a seemingly parallel environment. A characteristic situation that can benefit from multi-tasking involves servicing hardware devices while continuing with normal processing. The RUM III control system contains a number of such situations and benefits greatly from existing in a multitasking environment. The Operator CRT and Operator Console must be serviced quickly to provide adequate operator control over the system, but this may be done efficiently in parallel with the transfer of data over the telemetry links. The physical operation of various devices such as the focusing of a TV camera, the moving of the manipulator boom, and activation of the sonar system may proceed without host CPU time while being adequately serviced on an interrupt basis.

b) **Intertask communication and synchronization.**

In a multi-tasking environment, it is often necessary for tasks to communicate with each other. The RUM III control system builds on VRTX inter-task communication mechanisms to provide a full set of multi-tasking message passing functions. The messages may contain the information in themselves or they may be pointers to larger messages in agreed upon buffer areas.

Synchronization between tasks can also be implemented by causing tasks to pend and unpend at a specified location while waiting for a message from another task or device.

** VRTX and TRACER are registered trademarks of Hunter and Ready Inc.

c) **Real-time responsiveness.**

The RUM III control system must be able to respond quickly to real-world generated interrupts. VRTX provides the mechanisms by which the interrupt environment may alter the state of the multi-tasking environment. Interrupt driven events from the external world may initiate the rescheduling of tasks by raising or lowering the priorities of various tasks. The Operator CRT for example may be serviced by a high priority task so that characters will not be lost from the keyboard, while the downloading of a command to the manipulator boom will not be adversely affected by a short wait possibly produced by running at a lower priority than the keyboard.

With these features, the RUM III control system using VRTX/68000 provides a basic environment for real-time, multitasking applications. One of the major aims of the system design is to allow future designers to concentrate their efforts on applications software by providing them with a set of well defined multi-tasking functions to use as building blocks to create more complex systems.[1]

APPLICATIONS SOFTWARE

The RUM III Control System must integrate a large number of processes occurring in real-time. In one case, the CTP may coordinate the various parts of the system by monitoring and controlling the actions of several VPPs doing local data acquisition or control tasks. The CTP uses commands to the local systems to make changes in the activities of those systems and request data from them. It may use the retrieved information to start, stop, and modify a process, detect malfunctions, implement adaptive control, etc. In another situation, the operator may wish to exercise some control over the CTP or take over its functions entirely.

In order to facilitate this design, the CTP applications software is organized as a set of processes operating in a multitasking environment for efficiency of operation and ease of control.

The basic tasks are:

a) **The Console Command Interpreter (CCI).**

The CCI is the user-interface between the operator and the RUM III Control System. It accepts input from the Operator CRT and displays formatted output on the screen. As each line of input is decoded, various functions are performed. The CCI may format and send a message command to a device directly, or it may fill a channel buffer belonging to another task and activate the selected task to do the processing. The CCI is menu driven and will prompt the user at all levels for the proper response. Information about each command and its use is available interactively on line. The user is protected against potentially destructive input, warned, and re-prompted for a selection of proper inputs. In this way, the new user is led by the system to a full understanding of what functions are available to him and their proper use while the more experienced operator has at his disposal a fast memory aid. These functions are especially useful in the field under difficult working conditions where it may not be possible to make effective use of written documentation.

A list of available commands may be found in *Appendix I*.

b) **The Operator Console Task.**

There are two Operator Console Tasks that may be implemented depending on the hardware used in the Operator Console. For those devices that are read on an interrupt basis, the method used for the Operator CRT is used. That is, the task is activated when a buffer related to it is flagged as ready to be processed and is pended when the processing is completed. For those devices that must be continually polled for output, their task is given a higher priority than all other tasks and allowed to run continuously. When other tasks of a lower priority need to be activated, their priorities are raised to that of the Operator Console Task, causing them to run in parallel with it on a time-sliced basis.

Both types of tasks must format the information read from the hardware devices in a way that can be transmitted to both the Operator CRT to provide feedback to the operator on the status of the Operator Console outputs and to the Command and Status Telemetry link for downloading to the VDN.

c) **The Manipulator System Task.**

The Manipulator System includes the Manipulator itself and the Manipulator Boom. The RUM III manipulator boom and its hydraulic systems are mounted on a rotating turret which provides for azimuthal movement. The boom consists of three articulated arms with the joints rotated by hydraulic linear actuators acting on compound linkage mechanisms.

This task is responsible for processing the operators command to, and reading and processing sensor information from the Manipulator System. The processing done by the task is determined by which of five basic control modes for driving the manipulator system is engaged.

The five control modes are:

1) **Operator control of the boom end position.**

In this mode, the operator supplies control input by means of a joystick on the Operator Console or by keyed input at the Operator CRT. The input determines the direction and rate of movement of the manipulator boom tip in r, z, theta coordinates. The desired rate and direction in r and z coordinates of the command is converted into rates for the three boom joint angles by the boom VPP. An approximate conversion is carried out by use of a stored matrix of conversion vectors, one vector for each of the one foot square access cells. The conversion algorithm constrains the arm in a least mean square error sense to the stored preferred shape defined at the center of each access cell while transitioning along the trajectory.

2) **Operator control of each boom actuator's rate of change.**

In the second control mode, the operator supplies control input by means of the Operator CRT or four rate control switches on the Operator Console which individually control the rates of the manipulator boom hydraulic actuators. In this mode there is no preferred configuration constraint. This mode is useful for moving the boom in unusual ways.

3) **Operator control of each pilot valve.**

Here the operator controls on-off switches which actuate the hydraulic pilot valves. This is the most primitive mode useful only for emergency movements should some component malfunction.

4) **Computer control of a pre-programmed movement.**

This control mode is very useful for repetitive tasks. Here, pre-programmed or learned movement sequences are stored in the ship-board computer memory and recalled with a single command by the operator.

5) **Computer control to a given boom end destination.**

Finally, this control mode is a ship-board computer controlled movement in which the operator inputs a command to move to a particular location and the computer calculates and executes the best boom movement to complete the command. The "best boom movement" is software definable.

In all control modes, the computer system is programmed to:

1) Warn or prohibit intended movements into inaccessible or restricted areas.
2) Limit movement of the actuators if necessary to keep movement rates in the proper requested proportion.
3) Stop all movement if unable to move any component as requested.
4) Stop all movement if other RUM III subsystems request it.[2]

d) **The Command and Status Telemetry Link Task.**

This task activates when a buffer sent from the VDN is ready to be processed and when a buffer is ready to be sent to the VDN. It is responsible for distributing the received data to the proper channels and setting up the downloading buffer and initiating interrupt driven output. The VDN is a 6502 based microprocessor system dedicated to transferring data between the shipboard CTP through the Command And Status Telemetry Link and the ADLC of each of the VPPs and the VTP contained in the vehicle. The Command and Status Link provides a two way interprocessor communications link, ship to vehicle and vehicle to ship, capable of accommodating simultaneous two way transmission of binary coded signals at a bit rate of 20 Kbps up cable and 10 Kbps or greater down cable.

e) **The High Speed Telemetry Link Task.**

Most of the usable cable bandwidth will be occupied by the high speed data transmission signal (approximately 200 Khz to 1.25 Mhz) using a delayed modulation - mark, or "Miller" coded waveform. The down-cable interprocessor link will be a frequency shift modulated (FSM) signal centered at 1.5 Mhz. This task is responsible for sending, receiving, and buffering TV and sonar data being transmitted over the data link.

f) **The Sonar Task.**

Four basic sonar systems are considered essential for the initial RUM III Control System:

1) **Surface echo**: Used to measure depth below surface.
2) **Bottom echo**: Used to measure height above bottom.
3) **Side-looking**: For mapping, especially in tow mode.
4) **Transponder, navigation**: Take ranges and compute position.

The Sonar Task processes input and output buffers in the normal way. It also converts sonar data read to a form that can be displayed and understood more easily by the operator.

g) **The TV Task.**

The operator may select individual TV cameras and may change the following settings:

1) **Focus**: Near, Far.
2) **Zoom**: In, Out.
3) **Pan**: Left, right.
4) **Tilt**: Up, Down.
5) **Scan**: 512, 256, 128 line resolution.

The operator will also have a choice of three scan modes:

1) **High resolution, slow scan.**

   This will provide 512 line resolution at approximately 1.17 frames/sec.

2) **Medium resolution, medium scan.**

   256 line resolution at 4.69 frames/sec.

3) **Low resolution, fast scan.**

   128 line resolution at 18.77 frames/sec.

i) **The Thruster System Task.**

The Thruster System is a constant speed, two thruster underwater device that provides for variable thrust in either direction along its axis of rotation and/or variable torque around any line perpendicular to its axis of rotation. By varying the pitch of each of the four blades of the two thrusters, various combinations of directional thrust and torque may be produced.

This task also treats buffered information in the standard way described above. There are four basic modes of addressing the Thruster System:

1) **Auto Heading.**

The Auto Heading mode may be engaged in parallel with the other modes of operation. The operator instructs the Thruster System to maintain a selected magnetic heading. The task reads the compass status, calculates the needed thruster pitch for each of the two thrusters and sends a formatted command to the Thruster System.

2) **Directional Control.**

The operator selects one of eight directional commands and a power. The calculations are done to produce the proper thruster instructions to create the desired effect and the command is sent to the Thruster System.

The commands are:

a) **Forward.**
b) **Backward.**
c) **Slide Right.**
d) **Slide Left.**
e) **Rotate Right.**
f) **Rotate Left.**

3) **Individual Thruster Control.**

The operator may select an individual thruster and set the direction and power of its thrust.

4) **Individual Rod Control.**

The operator may individually power each of the three Pitch Rods for each of the two Thrusters.

j) **The Accumulator System Task.**

The Accumulator System is designed minimize the effect of the tether cable on the RUM III vehicle. It acts to insulate the movement of the ship from the vehicle which may either be on the sea floor in "bottom mode" or in "tow mode" above the surface at some depth. This task controls the selection of the two modes, the amount of cable collected by the vehicle and the amount of tension on the cable.

CONCLUSIONS

The RUM III vehicle was successfully tested at sea to a depth of 3000 ft. in January 1985 off the coast of San Diego and the control system functioned as designed. The basic design and much of the original software have since been ported to another instrumentation project at the Marine Physical Laboratory fulfilling the original design goals of adaptability and extensibility.

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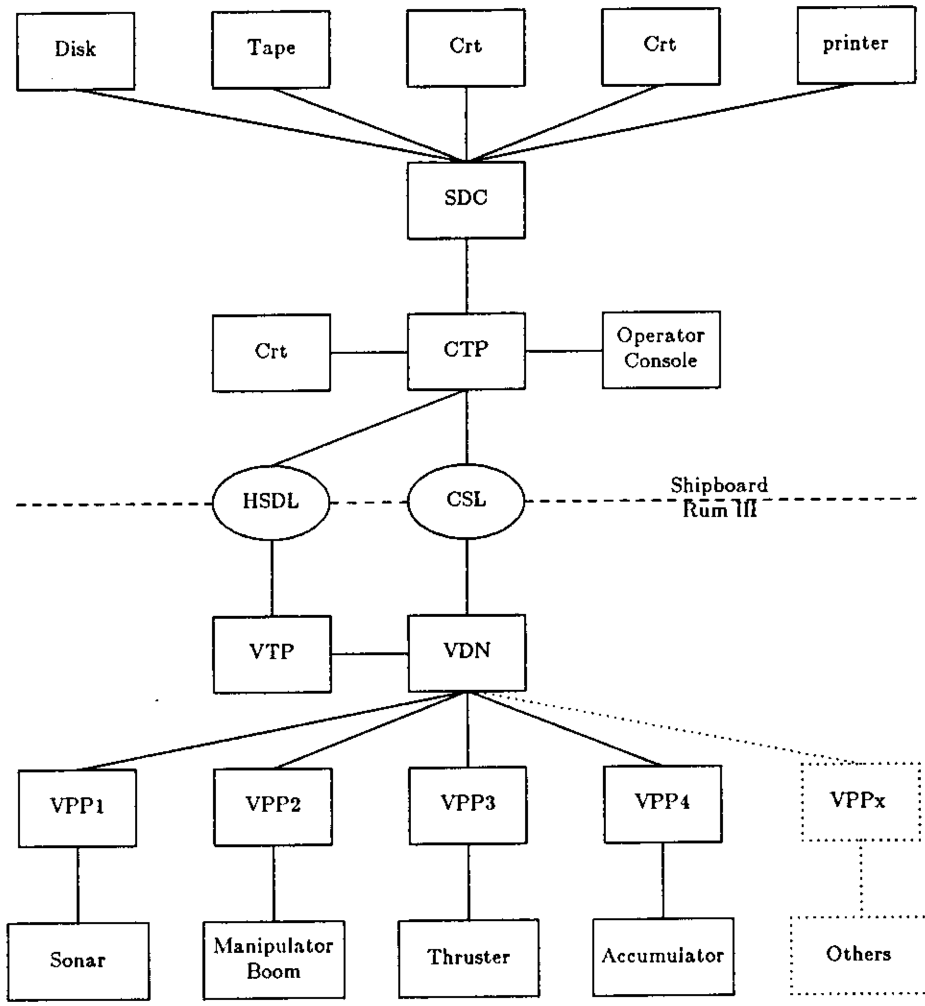
1. *VRTX/68000 Users Guide,* Hunter & Ready Inc, Palo Alto, CA.

2. Horn, Ronald C., Anderson, Victor C, and Madsen Bruce, "Seawater Hydraulic Manipulator Boom For Rum III", ROV '83, MTS, San Diego, 1984.

APPENDIX I

Summary of Rum III System Commands

1) <"help">	<"help">				Print this menu.
	<"thrust">				Print thruster menu.
	<"tv">				Print TV menu.
	<"manip">				Print manipulator menu.
	<"tele">				Print telemetry menu.
	<"console">				Print console menu.
	<"sonar">				Print sonar menu.
	<"sensor">				Print sensor menu.
2) <"boom">	<"manu">	<#>			Execute pre-programmed maneuver "#".
	<"switch">	<#>	<rate>		Set control rate switch "#" "0-MAX".
	<"valve">	<#>	<"on">		Pilot valve "#" on.
			<"off">		Pilot valve "#" off.
	<"move">	<r>	<z>	<Θ>	Move boom to position "r,z,Θ".
	<"stop">				Stop all manipulator boom motion.
3) <"head">	<deg>				Maintain heading "0-360 deg".
4) <"veh">	<"for">	<pwr>			Vehicle forward "0-MAX".
	<"bac">	<pwr>			Vehicle backward "0-MAX".
	<"sta">	<pwr>			Vehicle slide starboard "0-MAX".
	<"prt">	<pwr>			Vehicle slide port "0-MAX".
	<"lft">	<pwr>			Vehicle rotate left "0-MAX".
	<"rht">	<pwr>			Vehicle rotate right "0-MAX".
	<"stop">				Stop thrusters.
5) <"thrus">	<#>	<"f">	<pwr>		Set thruster "#" forward "0-MAX".
		<"b">	<pwr>		Set thruster "#" back "0-MAX"
		<"s">			Stop thruster "#"
6) <"rod">	<#>	<"i">			Move pitch rod "#" in.
		<"o">			Move pitch rod "#" out.
		<"s">			Stop pitch rod "#".
7) <"tv">	<#>	<"on">			Turn camera "#" on.
		<"off">			Turn camera "#" off.
		<"focus">	<"i">		Focus in.
			<"o">		Focus out.
		<"zoom">	<"i">		Zoom in.
			<"o">		Zoom out.
		<"pan">	<"r">		Pan right.
			<"l">		pan left.
		<"tilt">	<"d">		Tilt down.
			<"u">		Tilt up.
		<"scan">	<n>		Scanrate at "512", "256", "128"..
8) <"acc">	<"on">				Turn acoustic sensor on.
	<"off">				Turn acoustic sensor off.



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Tape
Crt
Crt
printer
SDC
Crt
CTP
Operator
Console
HSDL
CSL
Shipboard
Rum III
VTP
VDN
VPP1
VPP2
VPP3
VPP4
VPPx
Sonar
Manipulator
Boom
Thruster
Accumulator
Others

Figure 1.

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