Shipboard Monitoring and Control Systems: Selection, Design and Installation Criteria

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ABSTRACT

This paper provides an overview of shipboard monitoring and control systems. The objective is to describe the capabilities and components of such systems and provide design and installation guidelines. This information should be useful for individuals responsible for selecting, installing and operating such systems.

INTRODUCTION

A Shipboard Monitoring and Control System (SMCS) can monitor various system parameters and it can alarm based on specified alarming setpoints. It can also integrate with other systems on board the yacht providing both monitoring and control capabilities from Operator Interface Terminals (OIT) and user-friendly computer based Graphical User Interfaces (GUI) that can be installed at different locations on the yacht. This paper will provide a description of some of the capabilities and components of a SMCS. Due to differences in requirements as well as in equipment from one yacht to the next, many of the large SMCS applications are custom-built. This paper will attempt to offer insight into selecting, designing and installing such systems. This information, though applicable to a standard SMCS, will be more relevant to custom-built systems.

CAPABILITIES

The use of a SMCS for monitoring and control provides increased efficiency due to automation of routine tasks. It offers a consistent and easy to use interface to different systems and the ability to control and monitor from any desired location on the yacht. With current computer technology, it is possible to monitor and control most systems on a yacht. Some of the SMCS capabilities and the systems often interfaced with are described below.

1. **Monitoring:** A SMCS can monitor and display parameters from the engines, generators, AC and DC electrical systems, tanks and bilge levels. It can monitor fuel consumption and estimate future fuel needs based on the consumption rate. It can also generate alarms to notify the operator if any of the monitored values stray outside of their normal operating ranges as defined by setpoints. Various types of setpoints can be specified on a parameter-by-parameter basis such as high, high-high, low, low-low, and Rate Of Change (ROC). All alarms and events can be historically logged with time and date stamps. A SMCS can also historically log and chart parameters being monitored providing a powerful troubleshooting and forensic tool.

2. **Fire detection:** Interfacing a SMCS with a stand-alone fire detection system makes it possible to provide graphic indication of the fire location using actual deck layouts. This can also be displayed throughout the yacht on televisions which can be automatically switched to the appropriate channel in case of a fire alarm.

3. **Security:** Integration with a security system makes it possible to graphically show the location of a security breach and also track the intruder using the actual vessel layout. The GUI/OIT can display the armed/disarmed status of zones. In the unarmed state, movement around the yacht can be monitored. A SMCS can also be used to integrate the security system with the exterior deck lighting to automatically turn lights on and off based on activity in an area.

4. **CCTV cameras:** It is possible to control camera functions such as pan and tilt in addition to displaying the camera image in a GUI screen.

5. **HVAC:** Better monitoring and control capabilities are possible with a SMCS than those offered by the stand-alone controls of a standard HVAC system. These include the ability to record and display zone temperatures over a period of time and alarm in case of setpoint deviation. A SMCS can be designed to memorize and easily recall the temperature setpoints of the entire yacht. This allows for recalling the owner's favorite settings with just one button or restoring to more energy efficient settings with another button.

6. **Lighting:** Lights can be grouped into zones based on location, type or functionality. For example, lights used while underway can be one zone while starboard gangway lights can be another zone. Zones can be easily configured and reconfigured with software without needing to change actual wiring. An entire zone of lights can be controlled by a single push-button in a GUI/OIT or automatically made to turn on or off at designated times using timers. The same can be done for curtains and blinds.

7. **Navigation:** A SMCS can collect data from navigational equipment such as the GPS, speedlog, echosounder and gyro and display it on a single easy-to-read GUI screen. This image can also be displayed on televisions making viewing possible by guests throughout the yacht. Interesting information such as current heading, speed and location can thus be made available to the guests. This information can also be automatically entered in an electronic logbook. This serves as an electronic backup of the ship's log and also provides quick and accurate trip and crew watchtime information.

8. **Pagers:** The SMCS can be integrated with an onboard pager system to provide a simple method of sending

alphanumeric message pages from a GUI screen. This makes it possible to page either an individual such as the captain or a group such as the deck crew. Certain critical alarms such as engine, fire and security can also be automatically sent to designated crew members.

9. **Remote access:** Using a modem, it is possible to dial in to a SMCS from a remote location and perform monitoring and control tasks. Additionally, the SMCS can be configured to dial-out to specified phone/pager numbers in case of alarms.

COMPONENTS

The components and architecture of a SMCS depend largely on the systems being interfaced to as well as the desired functionality. However, there are some basic components that a SMCS must have in order to monitor parameters pertaining to the engines, tanks, bilges etc. These components include sensors, Input/Output (I/O), a Central Processing Unit (CPU) and GUI/OITs.

1. **Sensors:** Sensors are installed in engines, generators, tanks, etc. and they make it possible to electrically measure parameters such as temperature and pressure. Sensors can also be referred to as senders, transducers or talkers. Sensors can be classified as analog if their output signal can vary between a specified current range (for example, 4-20mA) or voltage range (for example, 0-10VDC) or as digital when their output can only be on or off. Analog sensors can be classified based on their wiring requirements (such as two wire and four wire) and also based on whether they supply or require voltage/current (source or sink). A four wire sensor has its own voltage/current source while a two wire sensor offers a variable impedance to regulate the current based on the measured parameter. Sensors have to be carefully selected based on the parameter being measured and the operating range. Usually, 4-20mA current sensors are preferred over voltage based sensors due to better immunity to noise and lower signal degradation over longer wire runs due to a balanced signal. They also offer better fault detection since a defective 4-20mA sensor, a wire-break or a blown fuse is likely to result in an output below the normal operating range (i.e. <4mA). A defective 0-10V sensor, on the other hand, may continue to output 0V which lies within the valid range for this type of sensor. The industrial controls world is also seeing the advent of smart addressable sensors that can be individually queried over a sensor level network. Such networks offer savings through reduced sensor wiring, but have not yet made their way into SMCS applications. It is also becoming possible to acquire data from electronically controlled engines and generators through communication protocols being implemented by engine manufacturers such as Detroit Diesel (with the DDEC engines) and Caterpillar (using Catlink). This offers substantial savings by not having to install, troubleshoot and maintain spares for an additional set of sensors just for the SMCS.

2. **Outputs:** Annunciation devices such as alarm horns and strobes are often used, specially in engine rooms, to indicate the presence of an alarm condition. Actuators and solenoids are other kinds of output devices.

3. **I/O:** Sensors and outputs are wired to hardware referred to as I/O that can either be in the same rack as the CPU (local I/O), or can be distributed around the yacht (remote or distributed I/O). In local I/O, information is normally exchanged between the CPU and the I/O via a backplane. With remote I/O, the I/O stations are typically daisy chained together in a master-slave I/O network with the CPU as the master. The function of I/O is to interpret the electrical signal from the sensors and convert it to a form that the CPU can understand. It also converts output commands from the CPU to the appropriate electrical signal before sending to the output field devices. The type of sensor or output dictates the type of I/O required. For example, a digital 24VDC sensor would be wired to digital I/O while an analog 4-20mA sensor would wire to the appropriate 4-20mA analog input. Analog input modules can be classified as differential (where the difference between two signal levels is measured) and single-ended (where a signal level is measured with respect to a common reference). Differential inputs tend to be more expensive with inputs in the same module being usually isolated. In single-ended input modules, the inputs are not isolated and instead share a common reference. Analog input modules convert the electrical signal from sensors to a binary representation through an analog to digital converter (A/D converter). The reverse happens for analog outputs. The speed and accuracy of the A/D conversion process should be considered when selecting analog I/O. The accuracy or resolution depends on the number of bits used to digitize the analog signal.

4. **CPU:** The CPU runs a program in an endless loop that reads the values of the parameters being monitored from the I/O and performs necessary tasks such as filtering and scaling. It alarms if the monitored parameters are outside the normal operating range and also writes to the necessary outputs such as horns and lights. It also makes the values of the monitored parameters available to the GUI/OIT for display to the operator. The CPU can also be programmed to perform complicated control functions such as ballast or generator control. The execution time for one complete CPU program loop is referred to as the scan time. The longer the program, the slower the scan time as more instructions have to be processed. The scan time should be fast enough to not miss an input that may pulse for a very brief duration. The CPU traditionally is a rugged industrial computer called a Programmable Logic Controller (PLC). The programming language of the PLC varies with the brand with some of the common ones being relay ladder logic, statement list and control flowcharts. With PCs becoming faster and less expensive, the PLC may be replaced with a PC. Such a system is referred to as a Soft PLC and offers the advantage of combining the control aspects of a PLC program and the GUI on a single PC. An international standard called IEC 1131-3 has emerged and offers to standardize the programming of PLCs and Soft PLCs.

5. **GUI/OIT:** A GUI/OIT makes it possible for a crew member to interact with the SMCS. An OIT typically has an alphanumeric LCD or LED display which can range in size from a single line to multiple lines. Membrane type buttons are used for navigating through menus and for user interaction. An OIT displays alarms with the ability to acknowledge them and offers limited monitoring and control capability. Graphic capabilities, if any, are mainly limited to displaying bar graphs. A GUI, on the other hand, offers extensive graphical capabilities and runs on a PC. A GUI can also be referred to as a Man Machine Interface (MMI) or the more recent, Human Machine Interface (HMI). The display units for GUI PCs are either CRT or LCD flat panel displays which are larger than an OIT display. A touchscreen interface or a mouse is commonly used with such displays. Flat panel displays are popular due to smaller space requirements and they come primarily in two types - active matrix and dual scan. The more expensive active matrix displays offer much brighter images with a wider viewing angle. Touchscreen interfaces for flat panel or CRT displays include resistive, capacitive, infrared and guided acoustic wave. Resistive touchscreens are probably the least expensive and involve a plastic film overlay. The plastic film, however, can get damaged and also reduces the image brightness and sharpness. Capacitive touchscreens use a glass overlay and are more durable but have the drawback that they cannot be operated with a gloved hand. Acoustic wave interfaces have the highest cost, do not require an overlay and can be operated with gloved hands. However, they are affected by dust, grease or water on the screen. Infrared interfaces are quite rugged, yet are not suited for very high ambient light applications.

6. **Printer:** This is used for printing alarms and events with time and date stamps. It can also be used to print values of monitored parameters at regular intervals.

SELECTION CRITERIA

When selecting a SMCS supplier, the most important items to consider include system capabilities, price, warranty, size and reputation, installed customer base and references. Some additional items to consider when selecting a SMCS supplier are:

1. **Factory testing:** All SMCS hardware and software components should have gone through properly documented factory test procedures. This is important to prevent problems such as premature hardware failure once the yacht leaves the yard.

2. **Software:** In case a computer fails while underway, current backups should be available so as to restore the system using a spare computer. All PLC and non-PC based systems must have the program in some sort of non-volatile memory such as Erasable Programmable Read-Only Memory (EPROM) or Electrically Erasable Programmable Read-Only Memory (EEPROM). Systems with battery-backed memory for program storage should be avoided due to the likelihood of having to reload the program when the battery fails. Another thing to consider is ownership of the software source code. Many suppliers will not provide the source code since it represents their intellectual property and all they are really selling is the right to use a runtime version. However if source code is required, then it should be negotiated.

3. **Year 2000 problem:** This is also referred to as the millennium or Y2K problem and has to do with the fact that a lot of hardware and software is designed around the principle that years are represented by only two digits. When the year 2000 comes, affected systems will be faced with the year "00" which may be interpreted by the system as the year 1900 causing the system to crash or malfunction. All SMCS software and hardware components must internally use a full four digit year representation and the supplier should be willing to provide a warranty that will cover any year 2000 problems even after the regular warranty may have expired.

4. **Language localization:** It is possible that the crew may prefer a language different from what the GUI/OIT is originally designed to display. Some SMCS suppliers may be able to provide GUI/OIT screens in which the user can toggle between two or more languages such as English and Portuguese. The same applies to the units in which parameters are displayed such as gallons or liters for tank levels.

5. **Support:** Knowledgeable technical support should be available day or night. For example, if the SMCS were to lock up while underway, the ability to promptly receive technical support via SATCOM can make a significant difference in the duration that the engines and other systems may have to operate without adequate monitoring and alarming capability.

6. **Remote diagnostics:** This capability helps save both time and money since a SMCS engineer does not have to be flown in to fix a minor problem or to perform system updates. These savings, specially after the warranty has expired, far outweigh the initial cost of such a feature.

7. **Spares:** The SMCS supplier should provide a list of spares. In case the SMCS supplier is simply reselling parts, then it can be helpful to know who the original manufacturer/source is if parts are unavailable from the SMCS supplier. It is important that adequate spares are supplied with the original system in case there is a problem while underway.

8. **Certification:** It is best to make sure from the SMCS supplier if their system has been approved by the desired regulatory agency such as ABS or Lloyds. If not, and this approval is required, then the supplier may be able to get it. However, the time and expense involved need to be discussed.

9. **Drawings:** Ideally, the SMCS supplier should state in the contract exactly what they will provide. This should include as-built drawings, preferably also in electronic file form. Getting the drawings in electronic form makes it possible to easily reprint or update drawings in the future.

10. **Liability insurance:** The SMCS supplier should have adequate liability coverage to deal with potential situations

such as a subcontractor getting hurt during installation or damage associated with faulty wiring.

SYSTEM DESIGN

There are many aspects that must be given adequate consideration when designing and implementing a SMCS. Some of these are discussed below.

1. **Setpoints:** Setpoints and allowable ranges should be properly selected. Using bad setpoints can lead to false or nuisance alarms. In addition, appropriate alarm permissives should be used to prevent alarming when it is not desired. For example, to prevent a low engine oil pressure alarm on engine startup, engine RPM can be used as a permissive to allow this alarm only if the RPM are above a certain value. Setpoints should be retentive so that in the absence of an Uninterruptible Power Supply (UPS), a power cycle would not cause the setpoints to go back to their default values. In the case of multiple GUI/OITs, the setpoints should be global and a change at one location should automatically be reflected at all other locations. Individual alarm enable/disable capability is helpful for silencing recurrent alarms that the operator is aware of, for example, due to a bad sensor. This capability should be password protected so that only authorized personnel can access it. Based on the type of sensors being used, the system should also be able to distinguish between sensor faults and actual alarms.

2. **Filtering:** Parameters such as tank levels that can fluctuate due to the fluid sloshing around in the tanks, must be adequately filtered before being displayed or alarmed.

3. **Control philosophy:** Common sense must be used when implementing control capabilities in a SMCS. For example, though it may be technically feasible, it should not be possible to control the navigational lights from any location other than the wheelhouse. When controlling lights from a SMCS, there is always the possibility that one could accidentally turn off the lights in another zone while there is someone in that zone. The worst case impact of simple mistakes like this must be considered when deciding how much control to implement.

4. **Stand-alone systems:** Try and keep systems stand-alone from a control standpoint to eliminate the possibility of finger-pointing between system suppliers. For example, if the SMCS could arm or disarm the security system (assuming the security system supplier would allow it) and that there is no alarm during a security breach, then it may be difficult to determine which system was at fault. To avoid problems of this nature, control such as arming/disarming should be possible only from the original system. Annunciation, however, should be possible from both the original system and the SMCS.

5. **Redundancy:** The SMCS architecture should be studied to identify the existence of any single point of failure that could cripple the entire system. Based on the level of fault tolerance required, redundant systems may be designed to overcome the impact of such a failure. For example, if the main PLC were to fail, then the entire SMCS would become non-functional. To prevent this, a backup PLC can be used to function as a hot backup to the primary PLC. This backup PLC should take over immediately, if the primary unit fails. Depending on the level of redundancy desired and the budget, it is possible to have redundant networks, redundant sensors, redundant I/O and redundant PLCs.

6. **Expandability:** System design should allow for future expansion. This can be achieved by using modular components, leaving spare I/O, leaving spare room in the I/O cabinets and having adequate network bandwidth. This expansion capability may come at a higher price, but will probably be worthwhile in the long run.

7. **Operating systems:** Amongst the currently available PC operating systems, Windows NT offers the most secure and reliable platform for a GUI. Depending on the GUI, even Windows 3.11 or Windows 95 may be suitable. The choice of operating system is often dictated by the software being used, for example, if the SMCS GUI software is 32bit, then a 32bit operating system such as Windows 95 or Windows NT will be required. For Soft PLC applications, add-on software may be required to make Windows NT more robust and deterministic for fast and consistent scan times.

8. **System administration:** The SMCS software should be intelligent enough to automatically perform routine tasks such as deleting/backing up historical data files and alarm log files after a user specified time duration. Without this capability, the hard disks will eventually run out of room.

9. **System security:** It is important to have passwords to prevent users from loading games or other non-essential software on SMCS PCs. These PCs should be totally stand-alone. This is necessary to prevent system slowdowns and also to reduce the risk of the system configuration being corrupted or a virus being introduced.

10. **Serial communications:** A SMCS is often interfaced with other stand-alone systems such as CCTV cameras, navigational equipment, fire and security systems via digital serial communication links in which data is sent in a stream of ‘1’s and ‘0’s. Common methods of serial communications include RS-232, RS-422 and RS-485, each of which has different electrical characteristics and capabilities such as the ability to multidrop devices. The cable length limitations of the type of serial communications being used should be considered. These lengths depend on both the data rate as well as the cable type. RS-232 uses an unbalanced signal and is recommended for distances under 50 feet (15 meters) while RS-422 and RS-485 use balanced signals and can be used for distances up to 4000 feet (1200 meters).

11. **Speed:** The slower the speed of serial or network data communications, the better the immunity to noise. Thus, it is better to acquire valid data at a slower speed than meaningless data twice as fast. When selecting components based on speed, a faster component such as a PLC should be selected only if it will actually make an

improvement to the overall speed of the system. A faster PLC may not help when the speed bottleneck is in the PC.

12. **Response time:** An operator should not have to wait for more than a second to get a response after pressing a button. It is important to have instant gratification whenever possible, else the operator may be inclined to press the button again. Doing so, the operator may even unknowingly cancel the original request. It is important to study the network design and get a feel for the data path and time delays that are involved in actions such as pressing a button in a GUI/OIT and having a light turn on in a room.

13. **Protocols:** It is important when the SMCS is being interfaced to systems supplied by other vendors, that the protocol for communications between all the systems is well thought out in advance. There have been situations where, for example, a fire system supplier may say that they can provide fire alarms to the SMCS via a serial link and not learn until late in the project that the installed fire panel does not have that capability or that it uses a proprietary protocol.

14. **Entertainment systems:** On yachts with large scale entertainment systems, the volume should lower automatically in case a critical alarm is sounded. In addition, one should be able to hear the general alarm from any location on the yacht.-

GUI DESIGN

GUI design is probably the most subjective part of a custom SMCS and user preference often plays a significant role in the final outcome of the GUI screens' appearance. Here some suggestions are provided for things to consider when designing GUI screens.

1. **Readability:** The GUI screens should provide the ability to toggle between different color and intensity combinations (such as day and night modes) to provide the best combination based on ambient light as well as night vision requirements. Colors should be used consistently throughout the GUI, for example, red should be used only for indicating an alarm condition throughout the GUI. When using colors such as red, color blindness issues must also be addressed. Text should be large enough so that it is easily readable. The ISO 8468 standard[1] specifies that character height (in mm) should not be less than 3.5 times the reading distance (in meters) and the width should be 0.7 times the height. The size of the characters is not only a software design issue, it also depends on the size and resolution of the display screen.

2. **Display resolution:** The screen resolution should be such that the information presented is easily readable. Graphics normally look better at higher resolutions. However, the displays selected should be large enough, so that running at high resolution such as 1024x768 does not make the characters too small to read.

3. **Gauge design:** Similar to an aircraft's cockpit, gauges in a SMCS GUI should be designed to provide the operator with the desired information quickly and efficiently without unnecessary clutter. A gauge needs to provide the parameter's current value, allowable range, alarm regions as specified by the setpoints and the parameter's rate of change. Gauges should be designed to best fulfill these requirements. A digital readout is easy to read, provided the data is not rapidly changing. A gauge design with a needle type index moving relative to a graduated circular or linear scale, effectively conveys information about current value, alarm setpoints as well as allowable range. It is also easier to get a feel for the rate of change with such a design than with a purely digital readout. A combination of a needle based gauge with a digital readout seems to offer the best of both designs. For consistency and ease of interpretation, orientation of all gauges should be similar and increase in a parameter's value should result in the needle moving in a clockwise direction.

4. **Push-button behavior:** The desired behavior of push-buttons in a GUI should be to allow users to press down anywhere on the screen (with a mouse, or a finger in the case of touchscreen displays) and release (lift up) at the desired location. This is important while underway in rough seas where it is not always possible to easily touch the desired push-button accurately on the first attempt. Furthermore, the shape, color and tactile response of elements like push-buttons that are controllable (rectangular) should be different from elements that are primarily indicators (round).

5. **Alarm acknowledgment:** An alarm is usually indicated by an audible horn and a strobe light in the engine room along with an alarm description on the GUI/OIT. If the operator acknowledges the alarm, the audible and strobe should be canceled and there should be some indication on the screen that the alarm condition still exists but has been acknowledged. If the alarm condition was to occur for a short period of time and then disappear as in an intermittent alarm, it should still be visible on the screen until it is acknowledged and should be historically logged. In the case of multiple GUI/OITs at different locations, some users prefer global acknowledgment of alarms where acknowledgment at one location results in the alarm being automatically acknowledged everywhere. Others may want only local acknowledgment capabilities.

INSTALLATION

Here I am going to touch on some installation related issues that I have encountered over the course of several yacht projects involving custom SMCS applications.

1. **Wiring:** All suppliers should follow consistent labeling, color and naming conventions for wires, devices and enclosures. This can make the job of the electrical engineer that eventually has to track down problems, a lot easier. It is also important that the correct kind of wire is used based on the application. Stranded wire should almost always be used in a SMCS over solid core wire, which can easily break after being subjected to some

flexing. Proper attention should be paid to the shield as well as to insulation flammability properties. Cables, specially fiber, should not be bent tighter than their recommended minimum bending radius. A light pass through test with signal loss measurement should be performed on all conduit run (i.e. pulled) fiber optic cables. Furthermore, enough slack should be left when running cables until all devices have been hooked up. Spare cables should be run to allow for future needs as it is much easier to do this during the initial build than later on. It is important to maintain adequate separation between sensor and I/O wiring for the SMCS and power cables, preferably using different cable trays.

2. **Computer networks:** Adequate shielding should be a major factor in the selection of a network cable. Length limitations of the type of cable being used should be considered. For example, when using Category 5 Unshielded Twisted-Pair (UTP) in a 10BASE-T Ethernet network, the maximum allowable cable length is 100 meters (Thinnet or 10BASE2 is good for 185 meters, 10BASE5 or thick Ethernet is good for 500 meters and 10BASE-F or fiber is good for 2000 meters). Connector selection and installation with proper tools is equally important. For example, in a 10BASE-T Ethernet network, installing RJ-45 connectors, meant for solid core wire, on stranded wire will lead to intermittent connections. The terminations must be checked with appropriate test equipment. The correct color standards and sequence should be followed. This is critical with RJ-45 terminations in a 100base-T (Fast Ethernet) network. This ensures that the twisting of the wires is correct and noise, which can make high speed communications impossible, is eliminated.

3. **Fuses:** It is advisable to use fuses wherever possible in order to localize and limit damage. One can either spend the money up front and extensively protect individual circuits with separate fuses or pay a lot more in extensive equipment damage as well as longer time to diagnose and locate problems. The temptation to simplify and speed up wiring by using a single fuse on the common side for a few inputs/outputs should be resisted for important systems such as fire detection. When using a single fuse for a group of inputs/outputs, an input should be used to monitor or readback the status of the fuse, providing an alarm in case of a blown fuse.

4. **Ground loops:** Ground loops are due to a difference in potential between two grounded points. If the potential difference is high enough, the resulting current can cause equipment damage. Serial connections between a SMCS and other systems are susceptible to ground loop problems. The best protection is to use optical isolation and fiber optic cables for the serial link if possible. It is also necessary to ensure that the same ground runs throughout the yacht and that devices are grounded only at one end. For consistency, the talker end should be selected for this purpose.

5. **Noise immunity:** There are various sources of Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI) on a yacht that can pose a problem to the validity of data displayed by a SMCS. EMI/RFI poses a much larger problem in fiberglass yachts since electromagnetic and radio frequency energy can pass through fiberglass unimpeded. On a recent fiberglass yacht project, operation of the sideband radio produced unwanted effects such as the crane lurching, the HVAC fan coming on in the wheelhouse and it also caused the SMCS to display invalid values for engine parameters before going into alarm. The best insurance against such problems is to use adequately shielded wire and to properly ground the shields during installation. If EMI/RFI problems exist, in spite of good installation techniques, ferrous beads are often used but their correct application may require a trial and error approach. Special metals such as Invar can also be used for housing or enclosures to make them more impervious to EMI/RFI. The use of fiber optic cable, which is completely unaffected by EMI/RFI, is another option.

6. **Power:** All hardware should be clearly labeled to indicate rated voltage and frequency to prevent damage. Always check to make sure the hardware can handle the voltage/frequency being applied. Step-down transformers do not change the frequency and some devices with electronic circuits can be damaged or malfunction if the correct frequency is not supplied. Most computers and monitors these days are auto-adjusting but it is a good idea to check before powering up. In addition to providing the right kind of power, it is essential that the power is clean and is available at all times. To ensure availability, a UPS should be used for critical SMCS components. The impact of a power outage on system performance should be considered when determining UPS needs. For example, if a power cycle causes a PLC controlling the HVAC system to return to default setpoints, then this PLC should be on a UPS. Additionally, there can be many types of electrical noise and distortion on a yacht such as high voltage spikes, high frequency components riding on top of the normal AC sine wave and harmonic distortion. This can be caused by power converters, switching power supplies, certain types of lights, etc. and can damage electronic components including transformers and even raise the neutral current in three phase systems. To protect equipment from such disturbances, it may be necessary to use passive or active filters, power conditioners and surge protectors.

7. **Sensors:** For a monitoring system to function satisfactorily, it is crucial that the sensors are accurately calibrated. This is particularly relevant for tank level sensors, which should be incrementally calibrated while completely filling an empty tank. This is necessary due to the non-standard shapes of most tanks on a yacht which result in non-linear sensor output to fluid volume relationships. It is also important to use separate power supplies for analog and digital sensors. This helps prevent the likelihood of problems where the digital signal can influence the analog signal through a common power supply. Analog inputs in the same I/O module must be isolated when wiring to analog sensors driven by different power supplies. This prevents damage due to ground loops arising from a potential difference between the

power supplies. Additionally, the total loop impedance should be considered when selecting a power supply for a sensor. For example, using Ohm's law (R=V/I), if a 24VDC power supply is used for a 4-20mA sensor, then the total loop impedance should be less than 1200 ohms for it to be able to supply 20mA when required. Fail-safe considerations should be taken into account when wiring digital I/O as Normally Open (NO) or Normally Closed (NC). This means that a fire alarm input should probably be wired as NC and a motor starter output as NO.

8. **Heat and noise:** It is important to give proper consideration to the heat generated by electronic equipment. I have seen installations of stacks of Audio/Video (A/V) equipment in tight fitting cabinets in guest staterooms where heat build up posed a potential fire hazard. The noise created by cooling fans in A/V equipment in owner and guest staterooms should also be considered when designing enclosures to ensure that the noise of the cooling fans does not keep occupants awake.

9. **Access:** Space is always at a premium on a yacht. However, an attempt should be made to mount components in such a way that they are easy accessible for diagnostic/reprogramming purposes. This particularly applies to distributed lighting controllers like Litetouch and Lutron which have scene programming capabilities.

10. **Vibration:** All computers and critical electronic hardware should be mounted on vibration isolating mounts to protect against hardware damage caused by vibration. The use of rugged industrial computers, whenever possible, is also recommended.

11. **Displays:** Readability of displays can be affected by various items. Attention should be paid to proper orientation in order to reduce reflections on the displays, specially in the wheelhouse. Use of anti-glare coatings and flat screen displays helps but not as much as proper orientation and the use of non-reflective dark colored materials for all possible reflecting surfaces such as the wheelhouse ceiling. In the wheelhouse, orientation of the windshield plays a significant role and the ISO 8468 standard[1] recommends that bridge windows should be inclined from the vertical plane top out, at an angle between 15° and 25°. This may not be aesthetically pleasing, but it helps reduce reflections. Glass that can electrically be made opaque or transparent can also be effectively used for interior panels in the wheelhouse to hide light sources that cause reflections on displays. When selecting CRT/flat panel displays, only displays with easily accessible dimming controls should be installed. Degauss buttons on CRT displays are also important since the image and colors can get distorted due to magnetic fields on a yacht. Only displays with adequate masking against magnetic fields should be installed. These should also have accessible power switches so that they can be easily turned off when required without having to hunt for the appropriate breakers. It helps to install displays on one circuit and computers on another. By doing so, if the yacht is in harbor for extended periods, the displays can be shut down from the breaker independently of the computers, which may be left running.

12. **Navigational equipment:** The NMEA 0183 standard[2,3] should be followed when interfacing a SMCS to navigational equipment and all serial communication links should be optically isolated. Terminating resistors in RS-422 serial communications should also be properly selected. This is applicable if a converter is being used to convert the RS-422 signal from the navigational equipment to an RS-232 signal, commonly required by a PC. Proper selection of this terminating resistor based on the cable impedance can reduce the likelihood of noise and framing errors.

13. **HVAC:** One of the most significant items with HVAC systems is the location of temperature (and humidity if applicable) sensors. It is important that these be located intelligently, so that they measure the temperature/humidity in the same area as where it needs to be controlled. For example, mounting the sensor under the console in the wheelhouse, where it can get quite hot due to all the equipment, makes it impossible to properly control the temperature in the actual wheelhouse. Aesthetics should not be allowed to compromise the functioning of the HVAC system by influencing sensor location.

14. **Lockout:** It is important that proper lockout procedures for electrical equipment are in place and these are strictly followed while working on equipment, both during and after the yacht construction phase.

REFERENCES

1. International Standard ISO 8468, 1990, "Ship's bridge layout and associated equipment - Requirements and guidelines".
2. International Standard IEC 1162-2, 1995, "Maritime Navigation and Radiocommunication Equipment and Systems - Digital Interfaces".
3. National Marine Electronics Association Standard NMEA 0183 V2.02, 1994, "Standard for Interfacing Marine Electronic Devices".