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Hardware-in-the-loop Testing of DP systems

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Return to Session Directory

Hardware-in-the-loop testing of DP systems

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1. Introduction

Systematic testing of DP system functionality, performance, and failure handling is increasingly important as the software and hardware complexity of DP system installations grow. Hardware-in-the-loop (HIL) simulation testing is widely used in other industries in order to test the hardware and software of computer-based control units. This paper reports on a pilot study on HIL testing of DP systems.

A DP-HIL vessel simulator is a real-time simulator which is directly interfaced to a DP computer system. It calculates the vessel motion in response to simulated environmental conditions, failure modes injected by the user, and thruster commands received from the DP computer system. Based on the calculated motion of the simulated vessel, it also simulates on-board systems and equipment such as the power system, thrusters, sensors and position reference systems and transmits the corresponding sensor and status signals back to the DP computers. Compared to a built-in training simulator, a DP-HIL vessel simulator is distinguished by capability of significantly more detailed simulation of failure modes. The benefit of such as test setup is that the DP control system can operate in closed loop during Factory Acceptance Test (FAT) and commissioning. The level of DP computer system testing at FAT and commissioning will therefore be comparable to a sea trial as the DP control system will be exposed to a wide range of operational modes, complex failure modes and sea states already at FAT.

A hardware-in-the-loop FMEA simulator can be interfaced to the DP computer system installed on-board the vessel, in order to test failure handling and alarm functions of the integrated DP system. During a dock or sea trial, the FMEA simulator can modify the original signals and insert dirty signals at the input or output of the DP computers. The benefit of this test setup is that systematic Failure Mode and Effect Analysis (FMEA) of a wide range of integrated software and hardware functions can be tested efficiently with increased test coverage and with non-destructive and complex hardware failure simulation.

The CyberSea Simulator is an advanced integrated system simulator for HIL testing of DP systems (DP-HIL). The real-time vessel simulator is based on state-of-the-art models of hydrodynamics, thrusters, power system, sensors, and position reference systems, including more than one thousand of single point failure modes in addition to common mode and multiple failures. This paper present the new DP-HIL simulator concept and technology, and reports how practical testing of DP computer system hardware and software can be carried out.

2. HIL Simulator Concepts

The purpose of a HIL simulation may be to test the functions, performance and failure handling of an isolated sub-system or the complete integrated DP system, see Skjetne (2005) for a general overview of HIL simulation in marine control systems. Typically, at FAT the test scope is limited to a stand-alone test of the DP computer system, while at CAT the scope is extended to the integrated DP system. Different HIL simulators can be configured to meet these test scope requirements.

Consider for example a DP system as illustrated in Figure 1. At FAT (or dock trials during commissioning or after a DP computer system upgrade on a sailing vessel) the HIL vessel simulator may be configured to simulate the vessel motion and all relevant systems onboard the vessel, see Figure 2. This means that the DP computer system communicates only with the HIL vessel simulator and not with the true sensors, position references systems, thrusters, and power system.

During sea trials there may be no need to simulate the vessel, power system, thrusters etc. since they may be available for test. An FMEA simulator, see Figure 3, can then be configured to facilitate efficient and detailed failure mode testing of the installed DP system. The FMEA simulator allows failures to be simulated by modifying any signals in or out of the DP computers, at any point in time. This greatly extends the test scope since more complex failure modes than loss of signals can be simulated. This includes rate of transmission errors, integrity errors in NMEA telegrams, high levels of noise, wild points, out of range errors, checksum errors on NMEA telegrams or network messages, signal freeze, signal drift, signal bias, etc.

Some of the key benefits of HIL testing are

- Closed loop realistic testing of the DP computer system can be carried out at FAT, commissioning, at dock, etc.
- The environmental and weather conditions can be set arbitrarily, such that performance and function can be systematically verified over a wide range of conditions.
- A wide range of typical and complex failures can be simulated on each signal and tested, greatly expanding the scope of conventional FMEA testing.
- Simulator testing is non-destructive, and one can simulate failures in e.g. power and propulsion systems that will be difficult or undesirable to simulate physically.

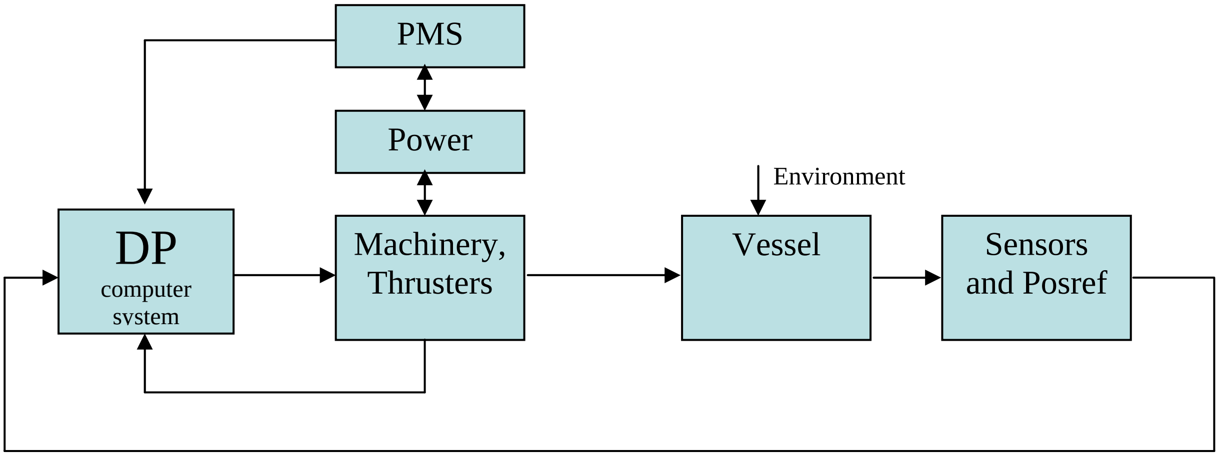

Figure 1: Overview of DP system

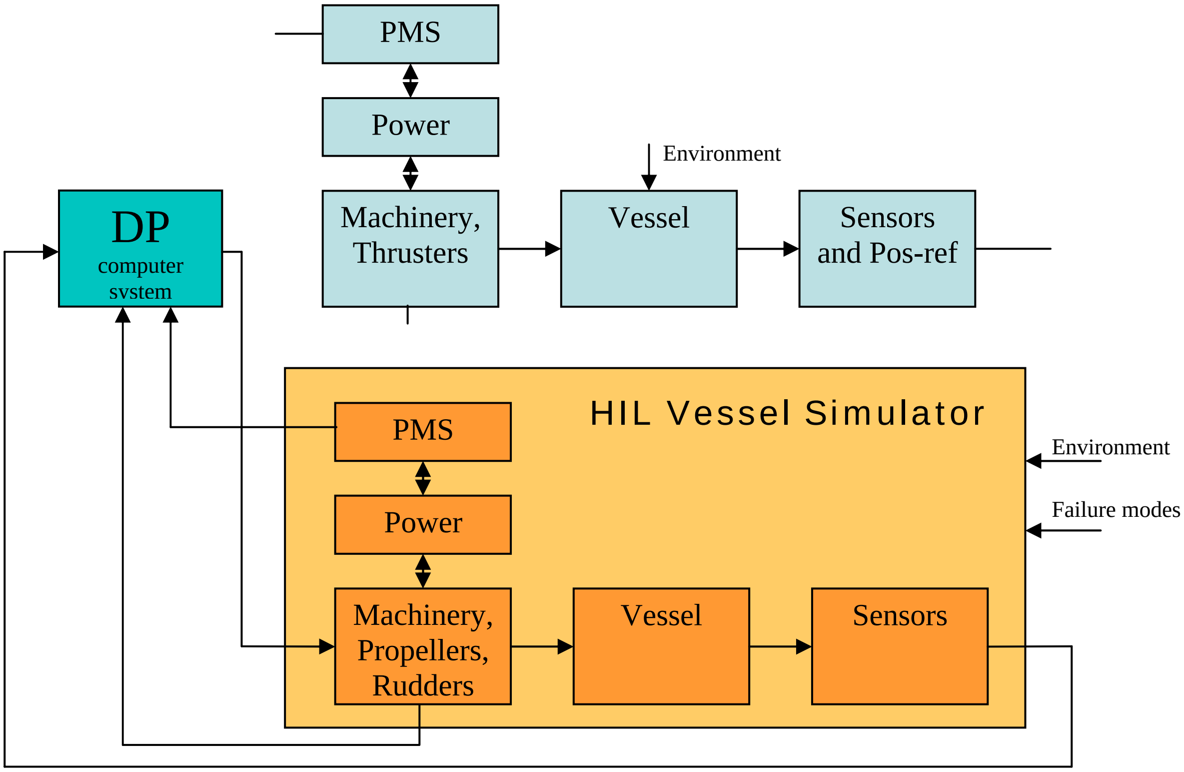

Figure 2: HIL vessel simulator test configuration

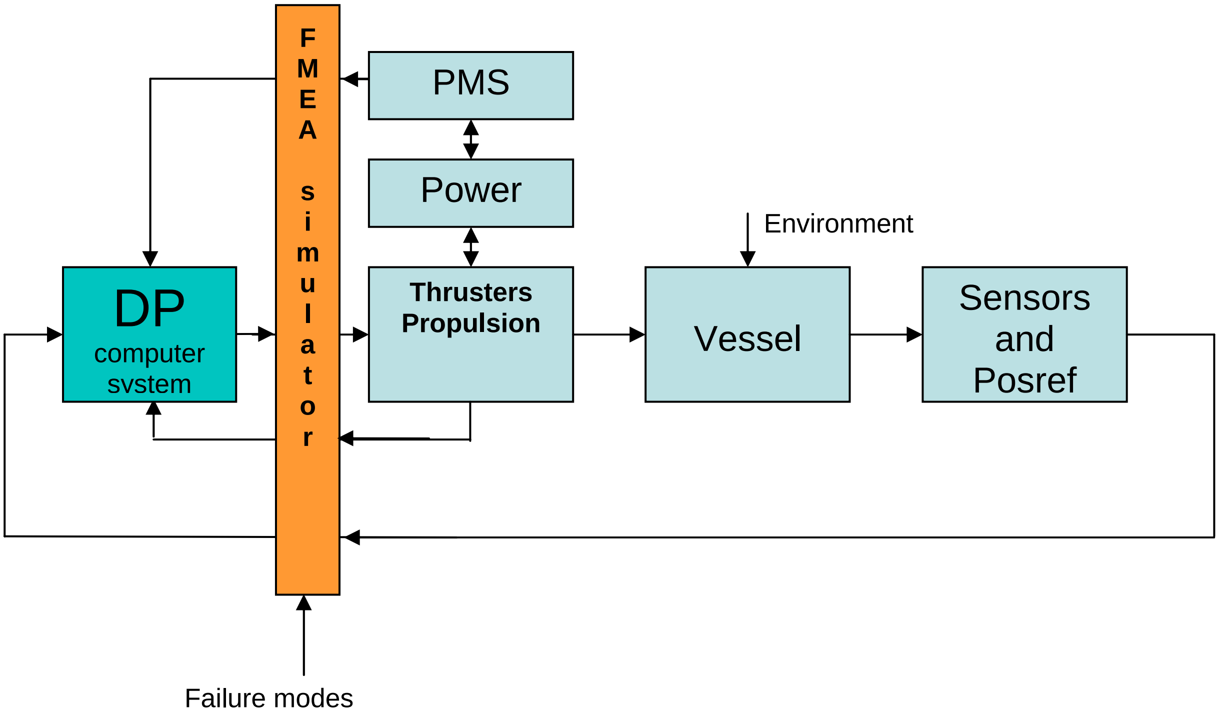

Figure 3: FMEA simulator test configuration

3. DP-HIL Vessel Simulator

3.1 Hardware-in-the-loop simulator architecture

The vessel simulator simulates the motion of the vessel, and the behavior of the DP system hardware not included in the closed loop (such as the power system, thruster system, sensors and position reference systems), see Figure 2. The DP computers, operator stations, and data network are usually included in the closed loop and are subject to testing. The real-time simulator program is embedded in a computer external to the DP system such that all test equipment is removed after the test, and the HIL simulator test equipment can be made independent of the DP vendor.

Such a HIL vessel simulator must facilitate testability of the DP computer system. This means that the simulator should be capable of simulating the necessary range of failures in equipment and signals according to a test program. It should be an integrated system simulator where the interactions between the different equipment modules are correctly and accurately simulated, and allow the vessel environmental conditions (such as sea and wind loads) to be defined.

The HIL vessel simulator has capabilities for data logging and real-time presentation of simulation results, such as trend plots and statistical properties, such that test completion and test result can be witnessed and verified in a transparent manner. It is essential that the vessel and equipment is modeled to sufficient accuracy and correctly configured for the actual vessel in order to give realistic interaction with the DP control system and accurate predictions of performance within the full expected operating envelope of the DP system.

3.2 Interfacing to DP computer system

The DP-HIL vessel simulator could be interfaced to the DP computer system signal input/output (I/O), through

- the normal hardware I/O interface of the DP computer system (analog, digital, serial/NMEA protocol), or the normal network protocol of the DP computer system, or
- a dedicated test I/O interface built into the DP computer system.

These options are illustrated in Figures 4 and 5. The I/O interface allows simulated position reference, sensor, thruster feedback and power feedback signals to the DP computer system to be transmitted, and all thruster command signals sent by the DP computer system to be received by the simulator.

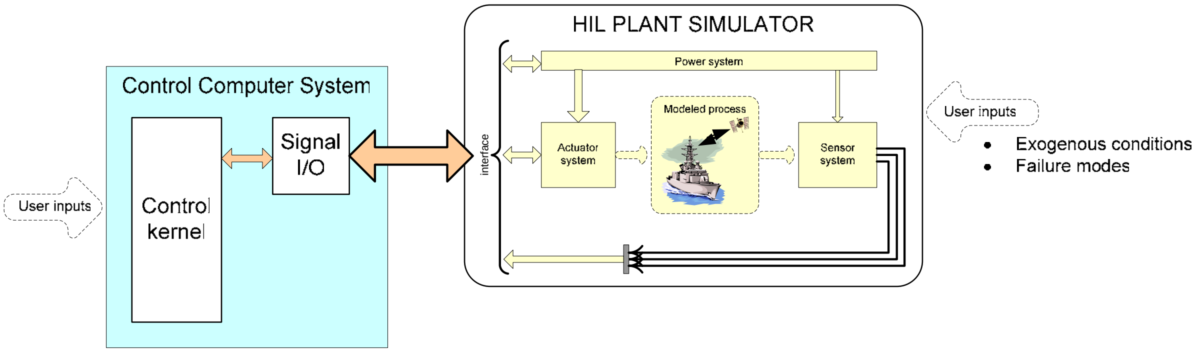

Figure 4: HIL simulator interfaced directly to the DP Computer system Signal I/O.

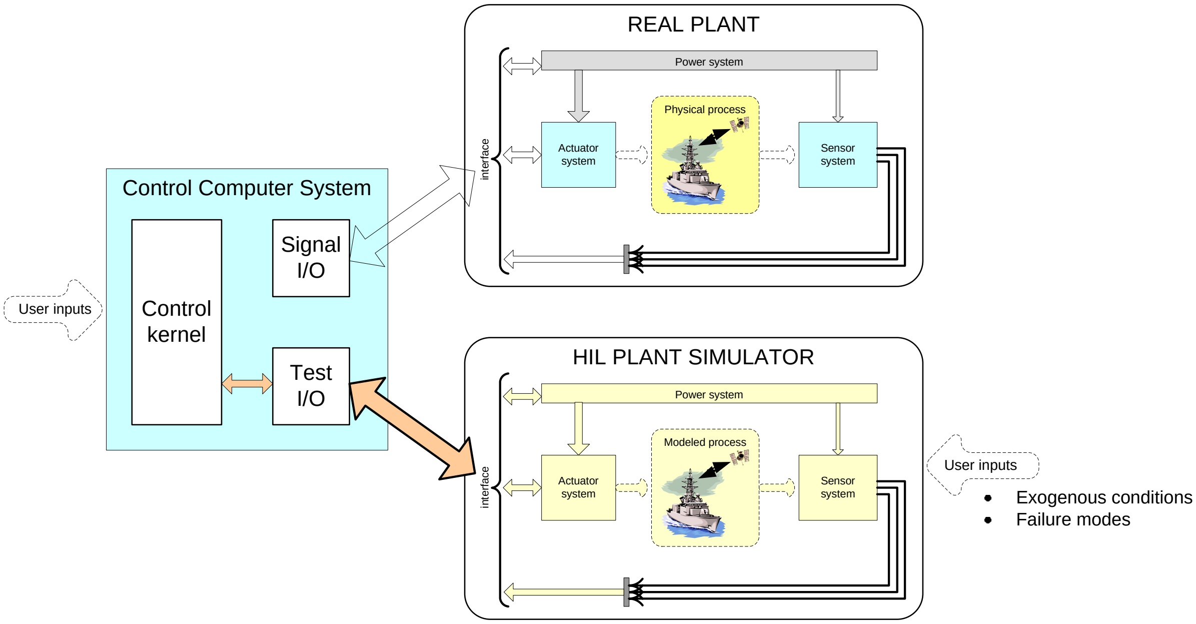

Figure 5: HIL simulator interfaced to the DP Computer system via a built-in test I/O interface.

3.3 Vessel motion, sea and wind loads

The vessel motion is simulated in six degrees of freedom (surge, sway, heave, roll, pitch, and yaw) using a nonlinear rigid-body model of the vessel.

Damping and restoring forces

For station-keeping and low-speed maneuvering up to 3 knots, 2D or 3D potential theory or equivalent is used for numerical computations of six degrees of freedom frequency-dependent potential coefficients (including added mass and damping) and restoring forces. For maneuvering at moderate speed, that is speeds below:

$$U = Fn\sqrt{Lg}$$

where L is the length of the vessel, g is the acceleration of gravity, and $Fn = 0.3$ is the Froude number, the frequency-dependent potential coefficients are computed using 2D potential theory (strip theory). Frequency-dependent linear skin friction are represented as exponentially or linearly decaying functions in the frequency domain while viscous quadratic damping is modeled using the cross-flow drag principle in sway and yaw. Quadratic drag or added resistance in surge is modeled using the ITTC skin friction formulation with modification for friction resistance, including wave making resistance. Fluid memory effects due to frequency dependent coefficients are converted to a representation suitable for time domain simulation. The equations of motion are solved in the time-domain using the recent methods of Kristiansen and Egeland (2003), Fossen and Smogeli (2004), and Fossen (2005) where fluid memory effects are represented by state-space models and integrated in the body-fixed reference frame. In the original work of Cummins (1962) and Ogilvie (1964) retardation functions were used whereas time-domain simulations where limited to the use of the hydrodynamic (equilibrium) frame representation.

First- and second-order wave loads

The wave loads are computed for different incoming wave directions, wave frequency, and significant wave heights using 2D or 3D potential theory programs. This includes computation of six degrees of freedom first-order *Froude-Krylov* and *diffraction* forces and second-order wave drift forces in surge, sway and yaw. First-order wave loads are represented by force transfer functions. Random time-domain wave elevation at each position on the hull can be simulated using standard wave spectra like ITTC, PM, Torsethaugen, or JONSWAP depending on the operating condition of the vessel.

Wind loads

The wind loads in surge, sway and yaw can be computed using the standard quadratic wind resistance formulae Fossen (1994, 2002) together with one of the following methods for wind load coefficients:

- Wind load coefficients are computed by scaling the data of a similar vessel Blendermann (1986), Isherwood (1972), OCIMF (1977), Wagner (1967), De Kat, J. O. and E. W. Wichers (1991).

- Wind load coefficients based on experimental data.

- Wind load coefficients in surge, sway, roll, and yaw are computed using Helmholtz-Kirchhoff's equation and curve fitting to experimental data (Blendermann 1994).

Random time-domain horizontal wind direction and speed can be simulated using spectra such as NORSOK or Harris, including wind gusts.

Current loads

The current loads in surge, sway and yaw can be computed using the standard quadratic current load formulae, Faltinsen (1990) or Fossen (1994, 2002), together with one of the following methods for current load coefficients:

- Current load coefficients are computed by scaling the data of a similar vessel, OCIMF (1977), Van Berlekom (1974), De Kat, J. O. and E. W. Wichers (1991)
- Current load coefficients based on experimental data.
- Current load coefficients in surge, sway, and yaw are computed using the skin friction formulation with corrections for residual and additional resistance whereas the cross-flow drag principle is applied in sway and yaw; Faltinsen (1990), Aarsnes (1986), Beukelmann (1988), Beukelman and Journée (2001), Golding, Ross and Fossen (2006).

3.4 Power system

The power balances of each high- and medium-voltage power bus, including the main generator sets and main consumers, are simulated. The power loads on the consumers correspond to the simulated time-varying loads on the thrusters and other large consumers. The simulator transmits the relevant power system signals to the DP computer system, such as status signals, thruster power consumption and generator power consumer feedback signals. It is possible to simulate all operational configurations of the power system by changing the positions of the switches, status flags, circuit breakers, and bus-ties during simulation.

Interaction with the thruster system and power management system is simulated, e.g. that the available power is limited by the instantaneous loading of the power buses. Power management functionality like pitch reduction can also be simulated.

It is possible to simulate relevant power system failure modes, with respect to single point and common mode failures, and if relevant, multiple failures. This includes loss of diesel generators, partial blackout on medium and high voltage switchboards, UPS failures influencing available position reference systems, sensors and computers, increased loads on other consumers, and various signal failures on status, command and feedback signals between power system and DP computer system.

3.5 Thrusters and propulsion

The propulsion system is modeled by various propeller types and rudders, such as fixed and controllable pitch tunnel thrusters, ducted and non-ducted fixed and controllable pitch main propellers and azimuths, podded propulsion units, and normal and high-lift rudders. The models provide thrust production and power consumption for 4 quadrants of operation (positive and negative thrusts and advance velocities), and encompass relevant thrust loss effects such as cross-coupling drag, the Coanda effect, thruster-thruster interaction, ventilation and in-and-out-of-water effects, including disturbances due to current, waves, and 6 degrees-of-freedom (DOF) interaction between the vessel and each thruster. Lift and drag forces generated by rudders and podded propulsion units are simulated.

The control interface to the DP system and the local thruster control strategies are simulated, e.g. shaft speed control, pitch control, consolidated control, and thrust force control. It is possible to override the DP system and control each thruster individually by manual thruster control.

Various relevant thruster failure modes can be simulated, and physically correct behavior is modeled when the failures are activated. Simulated failure modes include failures in thruster system equipment, local thruster control unit, and signal transmission errors. In particular, relevant sensor/signal failures can be included in the feedback signals to the DP system.

3.6 Sensors and position reference systems

The HIL vessel simulator generates the sensor and position reference signals transmitted to the DP computer system. These signals are contaminated with the typical noise level that is characteristic for each particular sensor and position reference system type installed on the vessel under the simulated environmental conditions. In addition it is possible to add signal failure modes of various kinds.

Several sensor and position reference system units have protocols (such as NMEA) that include one or more indicators of quality or integrity of the unit that has produced the message. Nominally, these indicators are simulated consistently with the failure mode of the sensor. In addition, it is possible to simulate errors (lack of integrity) in these messages.

Some position reference systems have inputs from specific sensors, such as a gyro compass or VRU. In such cases the correction functions within the position reference system can be simulated based on the simulated output from the sensor.

Redundant sensor and position reference systems (e.g. three different gyro-compasses on the same vessel) are simulated independently with uncorrelated noise and independent failure modes, with possible exception of redundant position reference systems (such as GNSS and multi-user hydroacoustics) that may share common components.

GNSS (Global navigation satellite systems)

GNSS systems consist of several components, the space segment, transmission medium, antenna, receiver components, and usually differential correction. All components can experience failures that degrade or completely destroy positioning performance. Some errors are correlated between receiver outputs, and some are not, and it is therefore important that independent GNSS signals can be simulated. The effect of the following GNSS errors are simulated:

- Satellite clock and position errors.
- Ionospheric and tropospheric errors.
- Multipath and receiver clock and noise errors.
- Errors in differential link and differential correction.

A detailed description of the different error sources of GPS, most of which also applies to other GNSS systems, are given in Parkinson et. al. (1996). Almost all of the error sources give errors in the measured range, and in order simulate realistic ranges at an arbitrary point on the surface of Earth at a given time, the entire satellite constellation is simulated based on the almanac (or ephemeris if extra accuracy is required) which is valid for the given time. This also allows for simulation of poor satellite geometry due to satellite outages or shadowing.

Hydro-acoustic position reference systems

The hydro-acoustic systems can be divided into several components: Transponders, transmission medium, and transducers. The following components can be simulated according to the philosophy of the hydro-acoustic positioning system (such as Long Base Line (LBL) and Super Short Base Line (SSBL)/Ultra Short Base Line (USBL)):

- Transponder power and directivity.
- Signal absorption.
- Transducer directivity and bandwidth.
- Thruster noise based on thruster settings and distance to transducers.

A description of these components can be found in Faugstadmo (1998). It is possible to apply a wide range of signal failures to all measured ranges and bearings.

Other position reference systems and sensors

The output of other position reference systems, such as taut-wire, laser, radar or radio based navigation systems, can also be simulated with relevant failure modes. The output of the following sensors are simulated with a wide range of failure modes: Gyro-compasses, VRUs, wind sensors, thruster feedback (pitch and RPM), power feedback from thrusters, switchboards and generator sets.

4. DP-FMEA Simulator

The DP FMEA simulator, see Figure 3, can be interfaced to the DP computer system signal I/O, either through

- the normal hardware I/O interface of the DP computer system (analog, digital, serial/NMEA protocol), or the normal network protocol of the DP computer system, or
- a dedicated hardware-in-the-loop test I/O interface built into the DP computer system.

These options are illustrated in Figures 6 and 7. The I/O interface allows the following signals (including status signals) to be received, modified and transmitted by the DP FMEA simulator:

- Position reference system data
- Sensor signals
- Thruster feedback signals
- Thruster command signals

- Power system feedback signals

The simulator is able to simulate the following general failures for all signals:

- Random signals: White noise, correlated noise (Markov process), random walk (Wiener process).

- Deterministic signals: Wild points, signal freeze, bias, drift, constant output independent of input, scale-factor error, flags.

- Signal communication (NMEA and vendor specified serial or network protocols): Erroneous rate of transmission, checksum errors, and empty fields.

- Power failures: Simulated failures in a UPS or low-voltage power system module should cause a simulated loss of power of the units connected to the module.

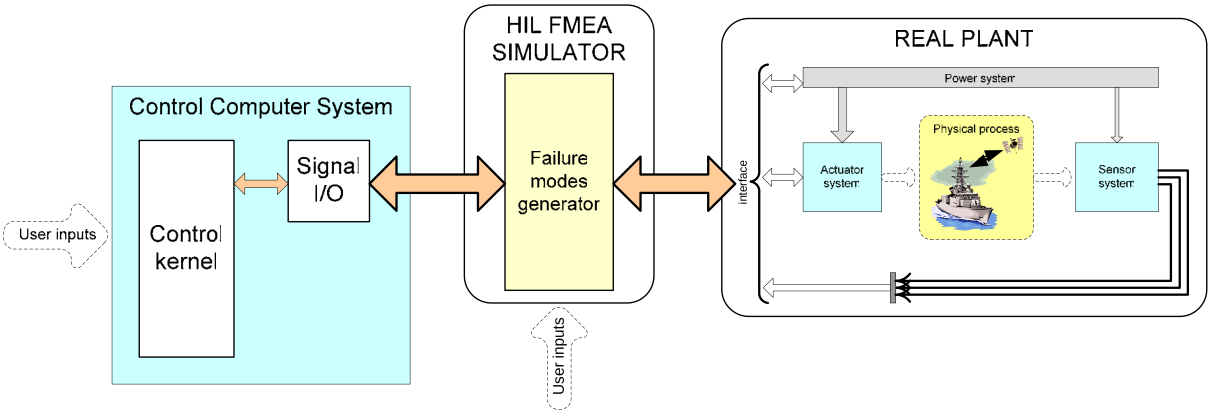

Figure 6: FMEA simulator interfaced through the normal DP computer signal I/O system

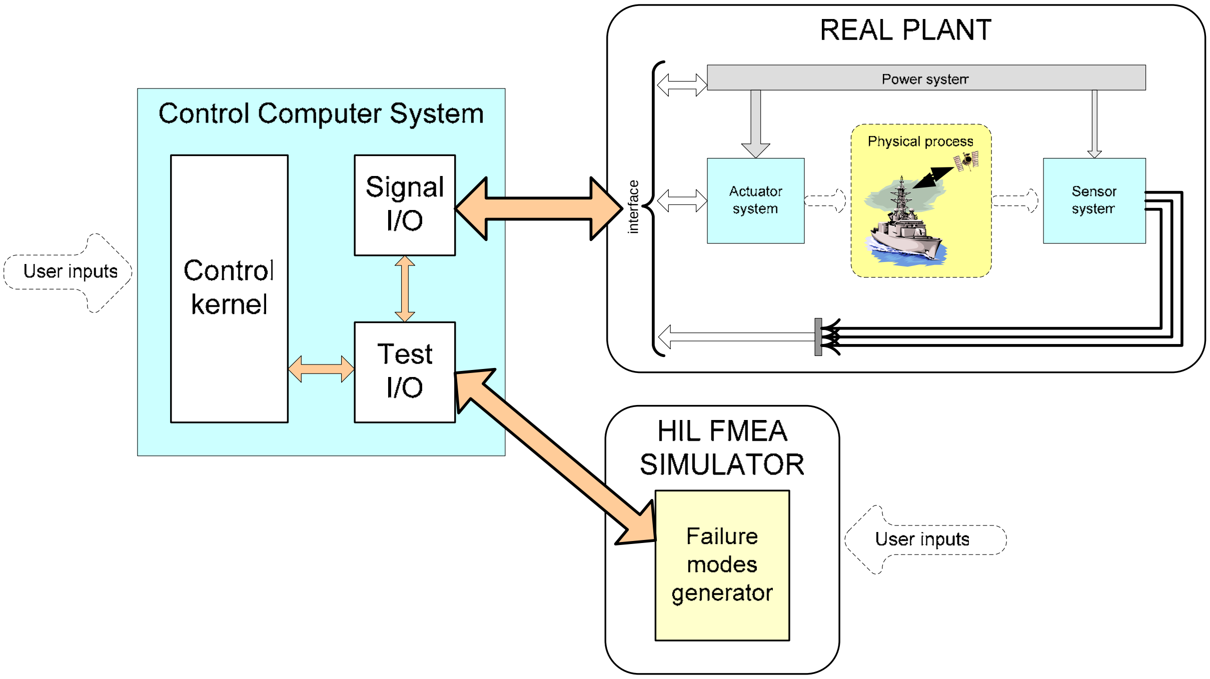

Figure 7: FMEA simulator interfaced through a dedicated test I/O interface.

5. Test program, test coverage, and DP system life cycle

In this section we provide an overview of a DP-HIL test program, life cycle activities, and some experiences from a pilot project.

Different tests can be categorized as

- Functional tests, i.e. verification of availability and correct operation of the specified functions of the DP system
- Performance tests, i.e. testing the capabilities of the DP system and how well it behaves when operating under different environmental conditions
- Failure tests, i.e. testing the availability and correct operation of failure detection and handling functions such as alarm system, redundancy and voting mechanisms, signal quality assurance etc.

Some more general considerations and requirements regarding HIL testing can be found in (Skjetne, 2005) and (DNV, 2005).

A DP-HIL test program might be compiled in a different manner for FAT, commissioning/CAT, annual trials, and after upgrades. The HIL simulator tools used at the different phases in the DP system life-cycle are illustrated in Table 1.

	Factory Acceptance Tests (FAT)	Commissioning	Customer Acceptance Test (CAT)	Annua trials and after upgrades	Performance and capability verification
DP-HIL Vessel Simulator	√ (vendor/yard)	√ (dock)	√ (dock/sea trials)	√ (dock/sea trials)	√
FMEA Simulator		√ (dock)	√ (sea trials)	√ (sea trials)	

Table 1: HIL Simulator tools for different test scopes and life cycle activities

A significant part of the test scope may be completed during the FAT, since there is usually most time available for extensive testing. At FAT the focus is on testing of the following aspects:

- Basic hardware and software configuration testing, including DP computers, and operator stations.
- I/O system hardware and software interface, failure handling, barriers to data transmission buffer and interrupt overload
- DP and joystick basic modes / functions and mode switches, including thrust allocation modes, forbidden sectors, rotation points and thruster configuration
- Power and propulsion system configuration. Verification of the correct devices, their location, ratings, that each device can be selected and deselected without reducing the DP performance. Verification of consequence analysis, power limitation and blackout prevention functions.
- Position reference and sensor system configuration. Verification of the correct devices, their location, that each device can be selected and deselected without reducing the DP performance.
- Alarms and warnings, verification that all simulated single point failures give the expected alarms or warnings, and that correct handling in the DP computer system is made in terms of disabling the faulty device and automatically switching to a correct redundant device if available. A typical test scope may include hundreds of single point failure tests (involving sensors, position reference systems, thrusters, power system etc.) and would give a thorough testing according to the rules and guidelines of class societies, e.g. (DNV, 2004; ABS, 2005)
- DP controller tuning, including gain settings, state estimator performance (model / Kalman filter), feed-forward from wind sensor, dead reckoning performance, wave filtering performance, dynamic capability verification, extreme weather performance.

Such extensive testing may give useful indications of performance that should contribute to reducing the time needed for tuning and testing during sea trials.

- Multiple failures testing, and testing of relevant reported incidents.

At commissioning and CAT the test scope should be limited to focus more on the items that have been influenced by the installation and commissioning, i.e. re-tuned, upgraded, or re-configured after FAT. In addition, the focus is moved more towards testing of the integrated DP system, rather that the isolated DP computer system. Additional items to be tested include:

- Testing of integrated network functionality and barriers. This may include network storm testing, monitoring of traffic, robustness to partial loss of network and messages etc.
- Testing of physical segregation in the case of redundant DP system, in particular class III operation.
- Testing of mode switch between DP, joystick, manual thruster control, vessel management, bridge systems, transfer of command between operator stations.
- Testing of interfaces and propagation of failures between DP computer system, and power and propulsion system

Many of these tests can be completed at dock using the HIL vessel simulator. As indicated in Table 1, some tests may involve the use of the FMEA simulator for testing of failure handling and alarms functions.

The test scope during annual trials or after upgrades should be reduced to focus on the most relevant tests, depending on the upgrade history and previous testing history of the vessel.

At commissioning / CAT and annual FMEA trials, HIL should be considered a complement to conventional testing methods in the sense that it cannot replace some of the normal test, while it can make the testing more efficient by allowing tests to be moved from sea to dock, destructive testing may be avoided, and the test scope can be increased. It should be kept in mind that DP-HIL testing, as presented here, is most ideally suited for testing of software and hardware functions in the DP computer system and therefore should be complemented by conventional FMEA testing that is more ideally suited for testing of integrated hardware functions and physical segregation.

Human factors often play an important role in DP system design, and are essential in some cases to avoid incidents. HIL simulation provides a realistic setting for DP operators, and a unique chance to get to know features and weaknesses of the DP system that are otherwise apparent only during incidents or other rare occasions. A HIL simulator developed during the new building phase could be a valuable tool for training and operational simulations during the entire life cycle of the vessel.

A pilot project involving a ROV/intervention vessel with a class II DP system has been completed (Statoil, 2004). The pilot project involved both an FAT and CAT where several hundred sub-tests were completed using a HIL vessel simulator and FMEA simulator. The pilot study reports greatly increased test coverage, and DP-HIL is introduced in new buildings by oil companies such as Statoil and Hydro.

References

ABS (2005) Rules for building and classing of steel vessels, Section 4.3.5.15: Dynamic positioning, American Bureau of Shipping, June 2005

Aarsnes, J. V. (1984). Current Forces in Ships. Dr.Ing. thesis, Department of Marine Technology, Norwegian University of Science and Technology.

Blendermann, W. (1986). Die Windkräfte am Schiff. Bericht Nr. 467, Institut für Schiffbau der Universität der Hamburg (in German).

Blendermann, W. (1994). Parameter Identification of Wind Loads on Ships. Journal of Wind Engineering and Industrial Aerodynamics, vol. 51, no. 3, pp. 339-351.

Beukelman, W. (1988). Longitudinal Distribution of Drift Forces for a Ship Model. Delt University Report no. 810.

Beukelman, W. and J, M. J. Journée (2001). Hydrodynamic Transverse Loads on Ships in Deep and Shallow Water. Proceedings of the 22nd International Conference on Hydrodynamics and Aerodynamics in Marine Engineering (HADMAR).

Cummins, W. E. (1962). The Impulse Response Function and Ship Motions. Technical Report 1661. David Taylor Model Basin. Hydromechanics Laboratory, USA.

DNV (2004). Rules for classification of ships, Part 6, Chapter 7: Dynamic Positioning Systems, DNV, January 2004

DNV (2005). Standard for Certification of HIL Testing, DNV, 2005

De Kat, J. O. and E. W. Wichers (1991). Behavior of a Moored Ship in Unsteady Current, Wind, and Waves. Marine Technology, vol. 28, no. 5, pp. 251-264.

Faugstadmo, J. E. (1998), Acoustic Positioning in Deep Waters, MTS Dynamic Positioning Conference, Houston TX

Fossen, T. I. (1994). Guidance and Control of Ocean Vehicles, John Wiley & Sons Ltd. ISBN 0-471-94113-1.

Fossen, T. I. (2002). Marine Control Systems: Guidance, Navigation and Control of Ships, Rigs and Underwater Vehicles, Marine Cybernetics AS, ISBN 82-92356-00-2

Fossen, T. I. and Ø. Smogeli (2004). Nonlinear Time-Domain Strip Theory Formulation for Low-Speed Maneuvering and Station-Keeping. Modeling, Identification and Control, MIC-25(4), 201-221.

Fossen, T. I. (2005). A Nonlinear Unified State-Space Model for Ship Maneuvering and Control in a Seaway. Journal of Bifurcation and Chaos (ENOC'05 Plenary), 2005.

Golding, K., A. Ross and T. I. Fossen (2006). Identification of Viscous Damping Coefficients for Marine Vessels, IFAC Conference on System Identification (SYSID’06), Newcastle, Australia.

Isherwood, R. M. (1972). Wind Resistance of Merchant Ships, Trans. RINA, vol. 15., pp. 327-338.

Journée, J. M. J. and W. W. Massie (2001). Offshore Hydromechanics. Delft University of Technology, 1st edition.

Kristiansen, E. and O. Egeland (2003). Frequency-Dependent Added Mass in Models for Controller Design for Wave Motion Damping. In: IFAC Conference on Maneuvering and Control of Marine Systems (MCMC'03). Girona, Spain.

OCIMF (1977). Prediction of Wind and Current Loads on VLCCs. Published by the Oil Companies International Marine Forum, London, UK, pp. 1-77.

Ogilvie, T. F. (1964). Recent Progress towards the Understanding and Prediction of Ship Motions. In: 5th Symposium on Naval Hydrodynamics, pp. 3-79.

Parkinson, B. W. and J. J. Spilker Jr. (1996), Global Positioning System: Theory and Applications Volume I and II, American Institute of Aeronautics and Astronautics, Washington DC

Skjetne, R., and O. Egeland (2005), Hardware-in-the-loop testing of marine control systems, SIMS2005, Scandinavian Conference on Simulation and Modeling, Trondheim, Norway, 2005

Statoil (2004), http://www.statoil.com/STATOILCOM/SVG00990.nsf?opendatabase&lang=en&artid=41256A3A0055DD31C1256F43002A62DA

Wagner, B. (1967). Windkräfte an Uberwasserchiffen. Schiff und Hafen, Heft 12, pp. 894-900 (in German).