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ADVANCES IN TECHNOLOGY

Development of a Coordinated Control System for Tandem Offloading Vessels

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Abstract

As part of its program in Offshore Engineering Technology, the Institute for Marine Dynamics, a division of the National Research Council of Canada, is currently pursuing research in the area of Marine Control (Dynamic Positioning) of vessels. Aspects of this research program are being carried out in collaboration with Memorial University of Newfoundland's Instrumentation, Control and Automation (INCA) Laboratory and with Intrignia Solutions Inc.

Firstly, we propose the concept of a supervisory controller that coordinates all control systems and vessel resources within a single DP vessel and across multiple vessels. Secondly, we are investigating methods of analyzing and proving that such a controller design will work for all ranges of conditions that the systems may be expected to encounter. One instance of a multi-vessel system that we are investigating is that of the tandem offloading of an FPSO to a shuttle tanker. Coordination of the various resources on board each of the vessels should lead to improved reliability and better control performance overall.

This paper describes the coordinated control concept in greater detail and the possible benefits of such an approach. An upcoming scale model test will serve as proof of concept. The techniques for model testing are described in some detail.

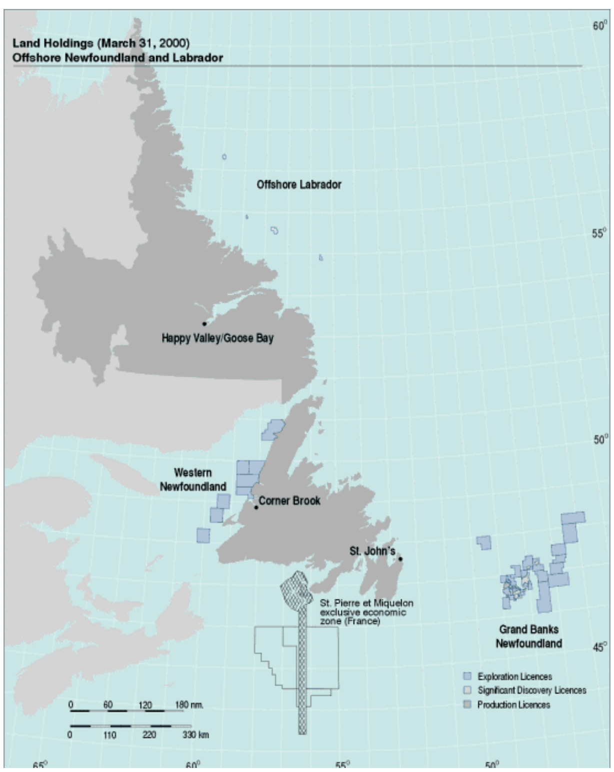

Figure 1. Offshore Newfoundland Production and Exploration

Introduction

Current projections indicate that by 2005, 40% of Canada's conventional oil will come from offshore Newfoundland (see Figure 1). Most of this oil is likely to be exploited by use of FPSO technology, since gravity-based structures are less favorable economically and jackets are unusable due to the presence of pack ice and icebergs. Existing discoveries and producing fields lie on the eastern Grand Banks in water depths of less than 200 meters. At this time, exploration is already progressing into deeper water depths (greater than 2000 meters) off the edge of the continental shelf. As the focus moves further out into the North Atlantic in the future, there will be a need for additional floating production systems that are capable of surviving the unique and extreme environmental conditions of this area. The aim of our research is at improving the reliability of such systems, and thereby the safety of DP operations where multiple vessels may be involved. The techniques that we use may also yield improvements in the system integration aspects of a single vessel.

The Case for Coordination

At last year's Dynamic Positioning conference, many papers were presented on the topics of reliability, and vessel designs that integrated various systems with the DP in an effective manner.

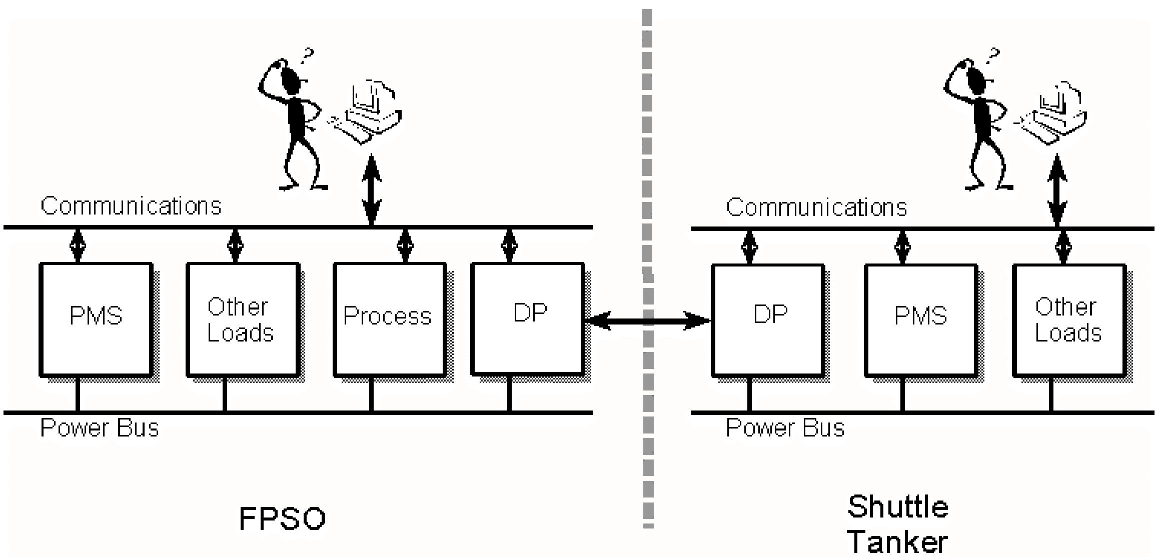

Figure 2. Autonomous Vessel Control Scenario

A ship such as an FPSO contains many systems working together and sharing a common power system (see figure 2). On the power bus, there is competition for the available power resources between the DP system and the production and other systems on board the FPSO vessel. The Power Management System is designed to manage the generation and distribution of power amongst the competing systems on the vessel. The DP, PMS, and other controllers and loads operate on a peer-to-peer relationship, communicating amongst each other. The PMS reacts to increases and decreases in loading from the various competing sources. On the Shuttle Tanker, a similar situation exists, with the communication between DP systems confined primarily to positional and heading information exchange. The shuttle tanker is "slaved" from the FPSO, tracking the stern connection point. At the top of each control system is ultimately the DP operator, who is attempting to keep on top of things; he acts as a supervisor: provided with large amounts of information on numerous systems operating across the vessel, he oversees the operation of these systems. The operator is provided with a multitude of tools to simulate various scenarios. He can use these to prepare himself to change the behavior of the underlying controllers on his vessel, or to step in should a system failure occur. The operators' role is to supervise and to a lesser extent, coordinate the systems on board his vessel. The various vessel systems, due to this lack of coordination, are more or less left to "fight-it out" amongst each other.

As autonomous entities, these control systems are optimized to do their own jobs. For example, the DP system utilizes an optimal controller strategy that is designed to minimize position and heading excursions, while the PMS is optimized say, for reduced power consumption, by control over power generation and distribution. Unfortunately, the optimal strategy for one system may cause it to compete with others, thereby producing undesirable (i.e. competitive) behavior when they are brought together in a single system. For example, a desire to reduce power consumption on the FPSO, may lead to more movement of the vessel (due to lower available thrust for the DP), which in turn affects the motions of the shuttle tanker, possibly leading to a disconnect if the situation gets severe. The results of one controller's decision may cause a ripple effect throughout both vessels. Predicting what those effects may be and whether they lead to undesirable or unsafe outcomes is a challenge. If a coordinated control scheme could be employed, perhaps, an improvement in overall performance may be achieved.

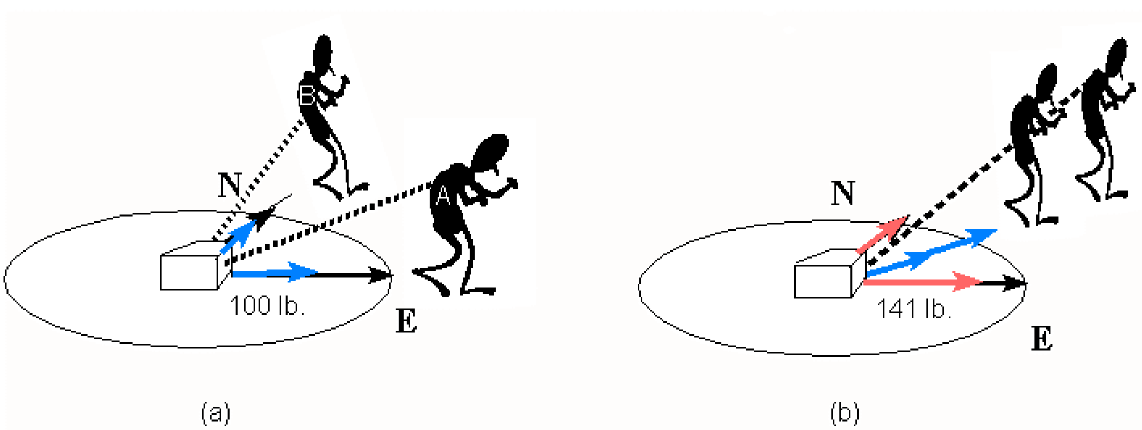

Figure 3. Coordinated Control Analogy

A simple example can be used to illustrate this point: Imagine that two men, each with their own rope, are pulling a weight over the ground (figure 3). Man A's task is to maximize his displacement in the Easterly direction, While Man B must maximize his Northerly displacement. They each can pull with a force of 100 lbs. The obvious (uncoordinated approach) is for each man to pull as hard as he can in his respective optimal direction; i.e. East for Man A and North for Man B, illustrated in Figure 3(a). This is the best solution if they don't know about each other and take an uncoordinated approach. However, if they were to coordinate their efforts, by both heading NE (they each alter course by 45 degrees), they can achieve a better result than they did separately. This can work in two different ways: the first way illustrated in figure 3(b), shows them continuing to pull with a force of 100lbs along the new heading. They each contribute 70.7 lbs. to each other's direction, so the total force in each man's direction is now 141lbs. Alternatively, they could reduce their individual efforts by reducing their pull forces to 70.7lbs each, and still achieve the same result as in the uncoordinated approach

In an analogous way, coordination of controllers on board a single vessel and across multiple vessels, (in close proximity to each other) may produce an improved overall performance.

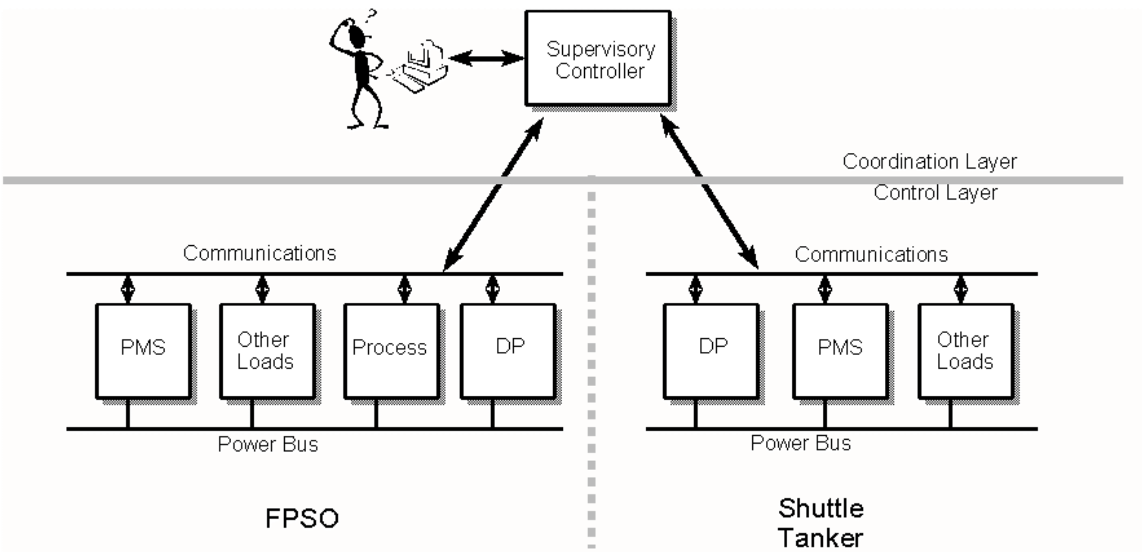

Figure 4. Coordinated Control for Two Vessel System

In Figure 4, a supervisory controller has been placed in such a way that it can collect status information from all controllers throughout both vessels (the Coordination Layer). Since the communications link is bi-directional, it can also send commands to the controllers, which reside in the control layer. The supervisory controller does not do the job of the DP or other underlying controllers; it decides on the set-point commands for these systems, while the actual controllers carry out the closed-loop job of ensuring that the commands are carried out. Some advantages to this approach:

- **Improved Performance**: A coordinated optimal approach as opposed to a distributed optimal approach.
- **No Additional Risk**: should the supervisory controller fail, the other control systems are still in place doing their jobs as before.
- **Reduced Operator Loading**: the supervisory controller offloads much of the monitoring, delivering a reduced set of information to the operator.
- **Improved Safety**: in times of high-stress (system failure in the control layer), the operator can be presented with a suggested course of action, which can be carried out automatically for him by the supervisory controller.

Design Verification

In the previous section, we spoke about the need for a coordinated approach to overall control. If such a controller were to be designed, coordinating the behavior of each controller in a system of two vessels for instance, how do we verify that the controller does what we say it will do? In other words, is the whole system safe for all possible conditions? This is essentially what the Failure Modes and Effects Analysis (FMEA) and Fault Tree (FT) analysis attempt to answer. Fault Tree establishes the logical (Boolean) relationship between interconnected systems and determines the sequence of events that may lead to a system failure. While this is a powerful tool to the designer, we are aiming to extend the usefulness of such methods by including not only the logical (discrete) control structure, but also the continuous variables of the system. Discrete elements include alarms, system failures, and status levels; for example, generator faults, thruster faults, emergency shutdown (ESD) alarms, and process alarms. The continuous variables include the environmental forces and thruster forces applied to the vessels and the positions and heading angles of the vessels.

Hybrid System Analysis

The difficulty with verifying a design that includes both discrete and continuous variables is that the well-established methods are able to analyze either the continuous systems or the discrete systems, but not both at the same time. A new concept, which has developed from aspects of computer science and control engineering, allows in a somewhat limited fashion, both continuous and discrete systems to be modeled and verified. Hybrid systems theory (HST) is very new and is starting to be applied in areas including air traffic control, smart highway systems (automobile traffic control), and automobile engine control systems. Automatic verification software has been developed that is capable of analyzing small-scale hybrid systems. Therefore at this time, only small parts of our overall control scheme can be modeled and verified.

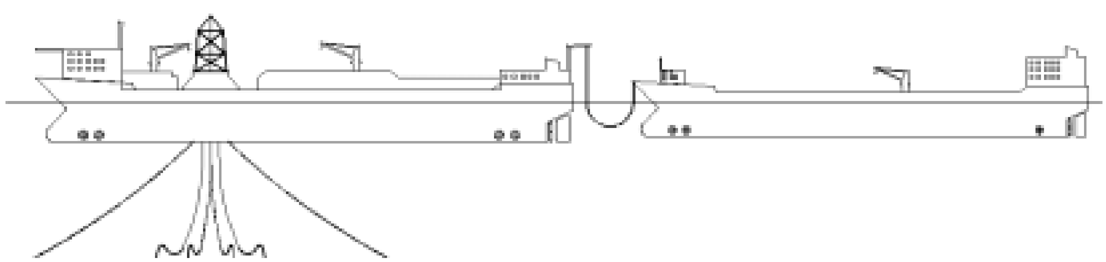

Figure 5. FPSO Offloading to a Shuttle Tanker

We have performed some preliminary evaluation of HST as a design verification tool. A controller was designed to coordinate the ESD alarms and functions with the DP and Power systems for a two-vessel FPSO/shuttle Tanker system. Using the hybrid system automatic verification software we were able to verify correct (safe) operation of this system for total power system failure. This application is covered in more detail in report and conference papers in the References section. For more information on HST in general, it is recommended that the interested reader consult some of the references for more in-depth information regarding Hybrid System Theory and its applications.

Model Testing & Controls Development

The effectiveness of the coordinated control scheme is to be tested early next year using physical models of both vessels in IMD's Offshore Model Basin (see Figure 6). At model scale, the results of the coordinated controller would be compared to that of two autonomous vessels. To make the model testing a more streamlined process, IMD has developed an advanced model DP system that is capable of accurately emulating a full-scale DP system. The DP Operator Interface Software runs on a Microsoft Windows-NT™ platform, using a standard windows-style interface that gives the operator a familiar interface to work with. The system also incorporates a tunable Kalman filter for removal of wave-induced control effects, while eliminating unwanted control signal phase shift. Using a non-contact Qualisys™ system to measure surge, sway and yaw motions of the vessel, the system computes a closed-loop control solution at 50Hz, affording smooth, real-time model response. We have also developed miniature azimuthing thrusters that are instrumented to measure propeller thrust.

Figure 6. Tandem Moored Tanker Model Test in Offshore Basin

We are further developing the tools to streamline the testing of control algorithms and configurations, based on the Mathworks SIMULINK™ environment. Test and design of controller algorithms can be done numerically in the SIMULINK™ environment using numerical models of the vessels and the environment. Once we are satisfied with a design, the controller algorithms (in SIMULINK™) are automatically translated to C/C++ code, compiled and downloaded over a network directly to the target hardware for execution in a real-time QNX environment.

As a final step in this program, the model test results for the traditional controller strategy would be compared to data collected on full-scale vessels in order to assess the effectiveness of modeling for testing of DP control schemes. Assuming that the comparison is favorable, it would be reasonable to assume that the coordinated controller would also offer improvements at full scale.

Summary & Future Work

A strategy for coordinating the control systems within a vessel and across more then one vessel was outlined. The potential advantages of a coordinated control approach through a supervisory controller have been identified. A procedure for verifying controller (and system) behavior was described using new techniques known as hybrid system theory (HST). At this time IMD has been performing research in this area for a little over one year, so results are. A simple coordinating controller scheme was designed and tested numerically to prove that automatic verification using HST could be applied to the problem.

It would be desirable to have input from DP equipment manufacturers and the industry end-users as this work progresses. A model test is slated for early next year to test the coordinated controller, comparing it at model scale to the uncoordinated approach. Results of the model testing would be compared to full-scale vessel results, in order to assess the validity of model testing for control system verification.

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