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Risk Mitigation Effects on Dynamic Positioning Control System in the Arctic

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ABS

Abstract

Offshore marine and oil and gas operations in the Arctic face unique challenges for the design of the dynamic positioning (DP) system intended to perform normal stationkeeping operations under harsh environmental conditions. Maintaining, maneuvering and positioning a complex vessel in ice-covered waters is very different than those in open waters. When working with sea ice, the Arctic DP system development personnel should pay attention to the ice strengthening design of the ship. It should include ice management and effective strategies for the DP control system to compensate ice loads. These added challenges pose additional risks to the control system. The combination of software development practices, risk management processes, software updates and operating parameters influence the operation and efficiency of the DP system, and therefore the asset. These combined risks are traditionally identified on offshore assets operating in open seas through the hardware failure mode and effect analysis (FMEA), and are managed using risk mitigation procedures. These are verified during the FMEA proving trials. However, software controls the DP system with added functions to such an extent that a software-focused FMECA is needed to determine if programmed actions are appropriate for a particular vessel.

Current dynamic position control systems do not integrate the influence of these new risk areas such as prediction of ice on vessel movements and constantly changing course to avoid hazardous ice conditions. This creates additional complications in applying thruster compensation on the vessel because of the constant changing of course necessary in avoiding the breaking of the ice. Although substantial knowledge in DP is available through the offshore and the shipping industry in this area, this should be applied to develop verification of DP software that will sustain in Arctic conditions.

Risk mitigation, traditionally occurring through a hardware-focused FMEA, should be followed by a software-focused FMECA. The software-focused FMECA should be based on related hardware-focused FMEA outcomes, and should investigate failure management of both the controlled equipment and the software itself. When coupled with the hardware FMEA, software FMECA will more fully inform the owner of the reaction to degraded equipment conditions. The software FMECA is designed to identify and resolve core issues that is often masked by workaround solutions. The key to delivering a robust DP system that can handle challenging environments like the Arctic is to combine this software-focused risk analysis with a comprehensive DP simulator that verifies all the functions.

Introduction

The marine and offshore industry has been conducting research above the Arctic circle for decades. Due to the increasing scarcity of easily accessible resources, there is a growing interest in the hydrocarbon exploration and exploitation in the frigid waters of the Arctic. Harsh environments where the temperature can drop to -30^{o} C to -55^{o} C, pose several challenges for DP operations especially in assessment and management of risk. The ice management system on board has to work strenuously with the DP control system to provide optimal maneuvering for collision avoidance. The workload required by the thrusters will have to perform at a much quicker pace than they do in open water during normal operations. With the already existing DP shortfalls, these factors add a significant risk to the Arctic DP operations. Due to the increasing requirements of fail-safe systems, there is a need for rigorous testing of the systems to handle unexpected behaviors.

Operations in the Arctic are a new frontier and pose its own challenges in a sensitive marine environment. Since the entire operation is now different, a system should be in place to handle disasters. There is a need to have emergency evacuation systems, procedures for oil recovery, spill containment, and other vessel requirements to name a few. With all of these challenges, it is important to avoid having software issues occurring during these operations. In order to meet the challenges that the Arctic region presents, the software needs to be more robust compared to that used in regular open waters. Since the Arctic environment is one of the unexplored, unknown frontiers, most of the industry that operates in these or similar conditions have been focusing on dynamic positioning. Many Arctic operations are time sensitive. The time it takes for a certain phase of the certain drilling sequence operation (that could take three days or more to complete) will have to be planned days ahead keeping ice management under consideration. In these type of situations, a healthy control system is required so the operators can concentrate on the planning and managing of the operation rather than worry about the control systems. This paper aims to integrate the existing DP technology and ice management with the latest software risk assessment techniques in order to address the challenges of the Arctic environment.

Existing Rules, Regulations, and Related Works

The vessels that operate in the Arctic or low temperatures have to be designed to endure the harsh environmental condition. The severe weather condition affects not only the hull structure but also the equipment on board. Many organizations such as the International Maritime Organization (IMO), classification societies, and national authorities are developing regulations to enhance the safety and environmental requirements for operations in the Arctic. IMO has adopted the International Code for Ships Operating in Polar Waters (Polar Code) and related amendments to make it mandatory under both the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL) in November 2014. The Polar Code will take effect on 1 January 2017 (Ref 1). Since 2008, the International Association of Classification Societies, IACS, issued a common set of Polar Classes (PC) (Ref 2). ABS published a guide for vessels operating in low temperature environments (Ref 3) in 2006. DNV-GL proposed a guide for winterization of ships (Ref 4) in 2013. ISO specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures, related to the activities of the petroleum and natural gas industries in the Arctic and cold regions (Ref 5).

Dynamic positioning is one of the important systems that can be affected by the low temperatures. It is generally difficult to predict the movement and the additional ice loads in the Arctic and therefore the forces on the ship. The ice floes can produce difficult conditions to keep the position because of the quickly changing ice forces. Alain Wassink (Ref 6) published a research and development program for dynamic positioning system that will be applied to Arctic condition. Some of DP model tests are done in ice conditions (Ref 7, Ref 8). Stena IceMAX is the first ice-class drillship with a DP system (Ref 9), but at present it is operating in the Gulf of Mexico.

The Arctic conditions necessitate additional sensors and related equipment to evaluate the additional loads of the ice floes as well as the normal wind and currents. The added ice conditions lead to additional software functionality and calculations with the DP system in order to manage the additional forces.

Software Focused Risk Mitigation

In the world of dynamic positioning, a Failure Mode and Effects Analysis (FMEA) has been implemented since the 1970s – early 1980s (Ref 14). This process of risk analysis is a well-known, well-established method that has been used for decades. However, as the complexity of the control systems increase, this type of risk analysis method alone may not be sufficient. As software became more pervasive, a single hardware based FMEA is not sufficient for the system. Therefore, a software-focused risk analysis method is needed in addition to the existing hardware focused risk analysis.

Software failure modes in general are either data related or event related during everyday operations. However, current testing methods focus on normal operating modes and range testing with several failures tested. Given the nature of the Arctic environment, it is anything but normal condition. The climate, ice formation, and ice movement are unique to the Arctic environment, necessitating the need for new models to be developed in order to predict the outcome and how the control system handles the variables.

Additionally, the vessel and all the systems on board are exposed to extreme weather conditions, of which increases the risk of system failure, collision with icebergs, stress or overload on the engines and thrusters. These scenarios need to be simulated and analyzed thoroughly in a safe environment.

A software focused risk analysis is more effective than traditional design and code reviews because the analysis focuses on failure modes rather than the individual modules. The typical reviews may reveal issues within the system. However, it does not reveal the global effects that the system can have during a failure.

The typical risk analysis only focuses on failures during normal operations of the system. However, it is important to take into consideration the failures during degraded or failed modes of operation (two-level deep). It is better to anticipate degradation and failed modes of operations in harsh environments such as the Arctic in order to improve the control system design. Additional functionality due to ice conditions needs to be added to the existing DP risk assessment so the functionalities can be properly analyzed and tested.

Ice Management

In addition to the existing challenges in DP, there are several challenges that we face in the Arctic environment. These range from frigid temperatures, dynamic sea ice conditions, ice ridges, to atmospheric occurrences such as limited daylight, precipitation, iceberg movement, etc. Ice detection technology has been used in the industry since the dawn of Arctic exploration. These include aerial photography, marine radar, satellite imaging, infrared cameras, weather balloons, sea ice charts, etc. (Ref 20). In addition to these, we now have a global positioning system (GPS), air drones, autonomous underwater vehicles (AUVs), data maps, ice concentration images, and improved forecasting methods from the gathered data (Ref 17). Even with all the data that is available to us, missing or overlooking a single piece of information can challenge the operations.

Once the ice detection is performed, ice observation and monitoring is an equally important task. There are several factors involved in the process such as flow and size distribution, speed detection, forecasting, risk assessment, ice geometry, ice density, ice age (first year or multi-year), ice strength, ice salinity, ice stiffness, process and training, and iceberg towing to name a few (Ref 19). These methods can also be used to track and monitor ice and maneuver accordingly to avoid any ice incidents.

According to Eik (2010), ice management is the sum of all these activities performed where the ultimate goal is to reduce or avoid actions from any kind of ice features (Ref 21). This becomes an integral part of the DP control system where ice management is one of the inputs to the control system (Ref 18). Incorporating the ice management data into the risk assessment and to the test cases is essential for DP operations in the Arctic.

Even with all the detection, monitoring and management, sea ice movement can still be unpredictable at times. A quick, responsive control system is needed to handle the sudden changes. One strategy to achieve a more rapid response is to combine the conventionally used feedback controller with the more predictive feedforward controller within the same DP system. This allows for any disturbances (unpredicted ice behavior) to be part of the input for the system and helps the control system make better decisions. Considering these ice conditions into the DP model, a new algorithm and a redesign of the current DP software is required (Ref 13).

Feedback versus Feedforward Control Systems

A simple control = Sense + Compute + Actuate.

In a feedback control system, the system reacts to a deviation from a commanded position to stabilize the floating asset back to the original position after a deviation is detected. Sometimes this can be too late in a harsh environment such as the Arctic. With the feedforward control loop, it anticipates and reacts before a disturbance occurs without having to wait for a nonconformity. The system responds to a change in the commanded position or a measurable disturbance in a predefined way. For any control loop that is subject to sizable, measurable disturbances, it can benefit greatly from adding a feedforward control system. There are fundamental limitations to the effects of disturbance such as measured noise (from sensors), actuator saturation (thruster control), and process dynamics (Ref 16). The DP control system needs to be designed to take these limitations into consideration.

The disturbances are measurable by means of real-time sensors and several tools that utilize the data. We need to program the system how to behave in any given situation. The disturbances can also be induced based on predictive behavior of the sea ice movement from gathered data. With an adaptive feedforward control system, we can estimate the parameters which can then be input for the overall DP control system.

The most common feedforward control signal comes from the wind and wave. In order to improve the performance of the system during tracking operations, a reference feedforward is computed. Figure 1 below depicts a simple feedback and feedforward combination control system to improve the output for the thruster control.

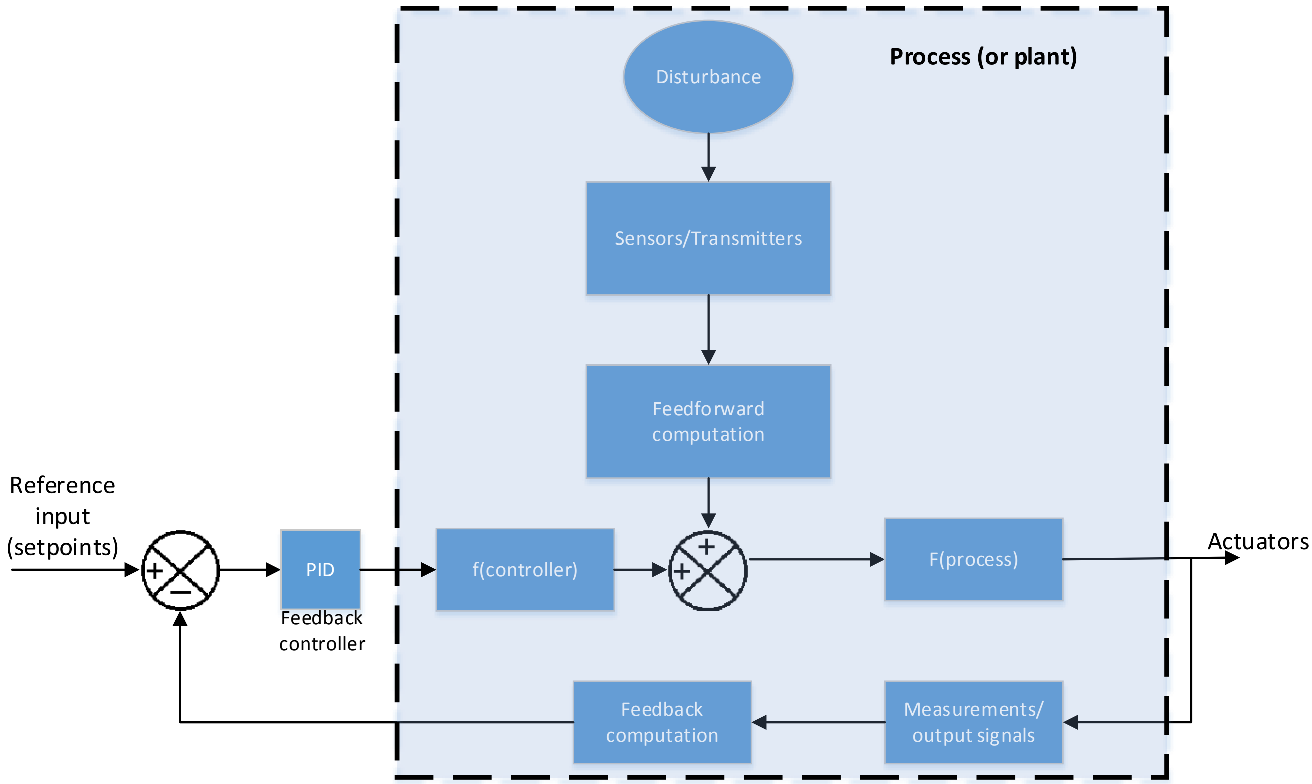

Figure 1: A block diagram of feedback and feedforward control system

Feedback control can act only on the result of a disturbance, which means feedback control cannot do anything until the process variable (desired position) has been affected by the disturbance. However, with model predictive feedforward control, the disturbances can be predicted before they occur based on data collected and monitored. Many PID controllers have the capability of adding an external input coming from a feedforward controller. Or this signal can be easily combined with the output of the feedback controller.

Combining feedback and feedforward control loops can have a significant performance improvement when there is disturbance that can be measured before it affects the process output. While the feedforward control loop provides a rapid response to a change in the system, the error-driven feedback control loop fills in the rest of the response accurately. The combined control system can only enhance a simple feedback control system to improve the overall integrity.

Just as any other control system, it is important to have redundancies built in within this combined control systems. These require a tremendous amount of calculations, therefore a proper testing methodology and a testing environment is desired.

Testing methodology and effects

With added risk factors and additional functionality, a proper testing method is needed. There are several testing methods in existence (Ref 22) that are used currently to test the DP control system. These are based on risk analysis performed on the control system before the testing. However, with added complexity to the control system, we need a robust testing methodology where it is possible to test every risk factor that has been discovered during the analysis. Additional test cases with two-level deep failure scenarios can make the control system robust and reliable.

An effective testing relies on good background data for analysis and test cases which can lead the control system for proper decision making. These data can come from several sources (GPS, AUVs, ice data charts, etc.) and at several time frames (real time, operational time, planning, etc.). It is important to combine these into the testing model to analyze the control system software. The ice management data can be simulated separately and can be part of the input data for the DP control system. Traceable test cases relating to the ice data need to be developed as part of the testing strategy. This is a cost effective method to investigate the DP system behavior at boundaries of the control system without actually damaging any equipment. The testing methods and the simulation can also be utilized for upgrading or updating, bug fixing and training purposes of the DP system.

A typical DP testing may include function testing, failure mode testing, performance testing and integration testing. However, they are tested for just one level deep failure. It is important to go further to cascading or multiple failures to understand the interaction of the DP system with other control systems and how the system will react to compounded failures. Figure 2 gives a simulation model of the DP control system including the ice management inputs. To ensure safe offshore operations in the Arctic, rigorous testing is fundamental. Therefore, it is vital to enhance the testing methods with new test scenarios specific to the Arctic environment. The testing may need several levels of failures to program the control system to make the right decision at the right time.

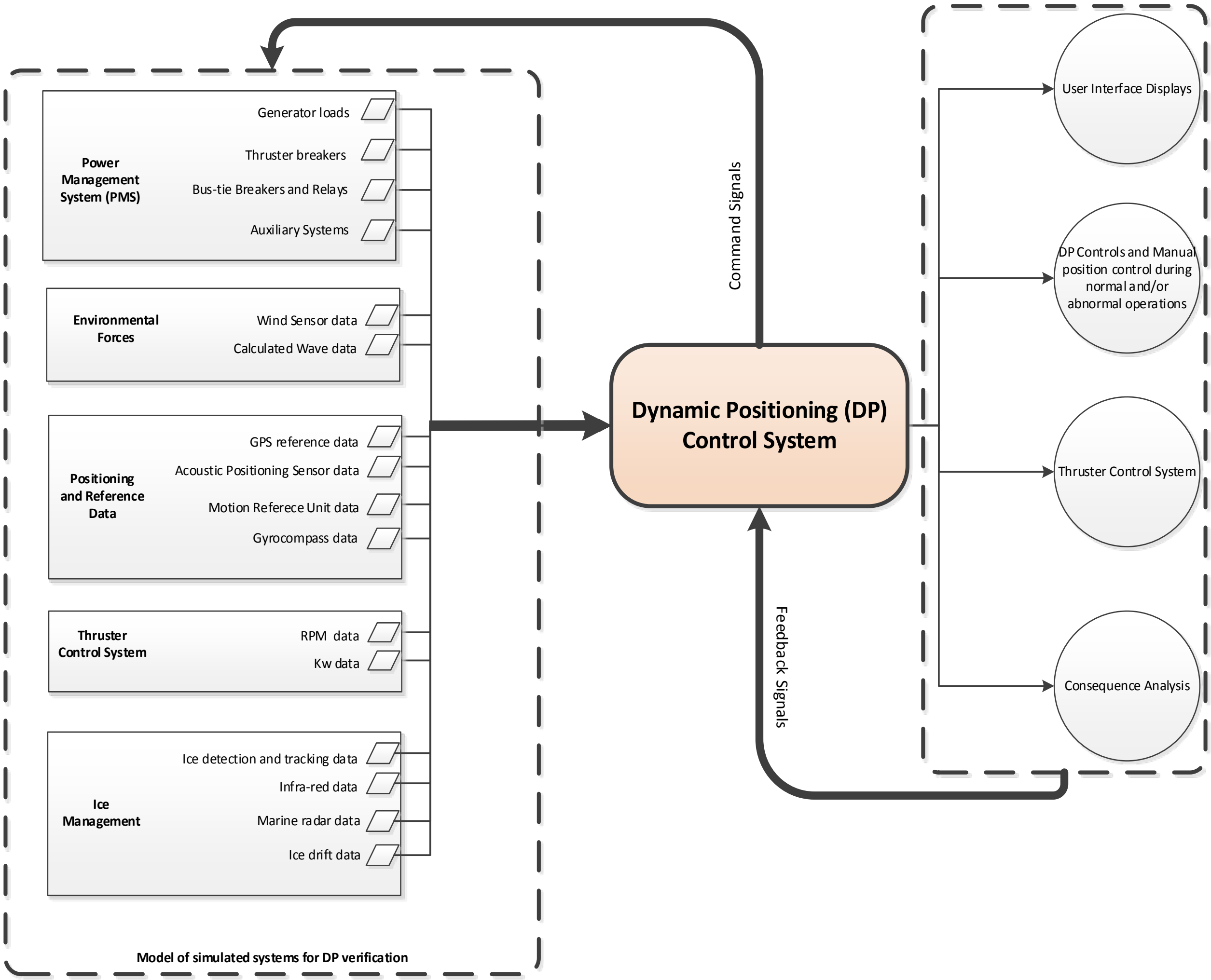

Figure 2: DP Control system model with ice management inputs

Conclusion

There is a demand for a DP system to work persistently with additional requirements to operate in Arctic regions. Due to the harsh environment, the control system needs to be integrated with the onboard ice management systems. These systems should be capable of rapid and repeated variation of thruster power and direction to avoid collision with icebergs, ice ridges, rafted ice and pressured ice conditions. This DP operation takes tremendous amounts of input to perform the necessary calculations and to provide the desired action to maneuver the asset safely. While DP has been utilized in this industry since the 1960s, the complexity of the software that encompasses the control system has been ever increasing. Modern day offshore assets in open water already rely heavily on software and automation. The Arctic region poses an extra challenge where risk assessment and ice management play a key role.

The influence of the harsh environment, extreme temperature, ice movements on the DP control system still poses a challenge. Combining the existing knowledge on Arctic ice management and performing a software focused FMECA on the new functionalities, and by properly testing them, we can pave the way to exploring the Arctic and mitigating the risks involved. With thorough testing done on additional functionality, risk can be mitigated allowing the DP system to be reliable on ice. As a result, the operators and ice management can make more informed decisions, reduce downtime and cost due to the dangers of ice under extreme conditions, and maximize the effectiveness of every operating season in icy waters

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