Control Systems in Marine Application

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Abstract. Marine operations have always been complex and risky, particularly when carried out at sea. Adverse weather conditions can compromise safety and operational efficiency. In the past, marine control systems, designed and installed for various missions at sea, were often unreliable, bulky, and less responsive due to the limitations of available technology. However, advances in control systems for marine operations have significantly improved in recent years, thanks to innovation and technology, resulting in safer and more cost-effective operations. These advancements were achieved through extensive research and collaborative development aimed at improving global operational standards. Key improvements have been made in the design, materials, and IT technology, leading to more effective control systems in marine operations. This paper explores the potential of existing marine control systems and their role in enhancing safety, security, and environmentally friendly practices in global business operations.

Keywords: marine operation, marine control, marine safety, marine environment, reliability

1 Introduction

Control system engineering is a branch of engineering that applies control theory to design and manage systems with specific desired behaviors. It involves using mathematical models, empirical evidence, and a wide range of scientific, economic, social, and practical knowledge to invent, innovate, design, build, maintain, research, and improve structures, machines, tools, systems, components, materials, and processes. The goal is to create systems that can automatically adjust their behavior to meet predefined objectives, ensuring efficiency, stability, and reliability in a variety of applications, including manufacturing, transportation, robotics, and marine operations.

Empirical evidence, data, or knowledge, also known as sense experience, is a collective term for the knowledge or source of knowledge acquired using the senses, particularly by observation and experimentation. Empirical evidence is information that justifies a belief in the truth or falsity of a claim. In the empiricist view, one can claim to know only when one has a true belief based on empirical evidence.

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2 Theory on Control

Control theory is an interdisciplinary field that combines engineering and mathematics to study the behavior of dynamic systems with inputs and how feedback affects their behavior. The primary goal of control theory is to regulate a system—often referred to as the "plant"—so that its output closely follows a desired control signal, known as the "reference." This reference can be either a fixed or a changing value. Through feedback, control systems adjust the system's behavior to achieve the desired output, ensuring stability, accuracy, and performance. This theory is widely applied in fields like automation, robotics, aerospace, and marine operations, among others.

Control theory is a branch of applied mathematics dealing with the use of feedback to influence the behavior of a system to achieve a desired goal. One can distinguish two classes of systems for which control theory plays an indispensable role, namely man-made systems and biological systems.

A controller is designed, which monitors the output and compares it with the reference value. The difference between actual and desired output, called the error signal, is applied as feedback to the input of the system to bring the actual output closer to the reference. Some topics studied in control theory are stability (whether the output will converge to the reference value), controllability, and observability.

Extensive use is usually made of a diagrammatic style known as the block diagram. The transfer function, also known as the system function or network function, is a mathematical representation of the relation between the input and output based on the differential equation describing the system.

2.1 Background

Past incidents led to disasters related to control system problems;

1. When the control system fails
2. Before the era of modern control

Amongst the improvements that have been taken in the control system and impacts;

1. Early ship control
2. Modern ship control
3. Modern offshore system control
4. Schematic diagram in modern offshore system control

Prospect for further research for further improvement

1. Dynamic positioning (DP)
2. Remotely operated vehicle (ROV)
3. Sea glider
4. Active heave compensator

5. Gyro stabilizer
6. Auto piloting navigation system

Before the introduction of modern control systems in marine operations, especially those involving ship operations at sea, the risks were significant and led to many failed operations. Figure 1 illustrates how harsh weather and challenging sea conditions can affect ship operations. During these conditions, maintaining the correct speed, stability, and direction for navigation to the intended destination becomes critical. Without advanced control systems, ships were more vulnerable to operational failures, and the ability to navigate safely and efficiently was compromised. Modern control systems, however, have significantly improved the safety and reliability of marine operations, allowing ships to respond to changing conditions with greater precision and effectiveness.

Similarly, when the control system fails to function effectively, a disaster will almost surely tend to take place. Figure 2 shows the impact on the sea and environment when the ship failed to steer safely, which resulted in a ship grounding that spilled off the crude oil carried on the tanker ship, namely Exxon Valdez, in 1989.

Fig. 1. Bad weather and sea condition during ship operation

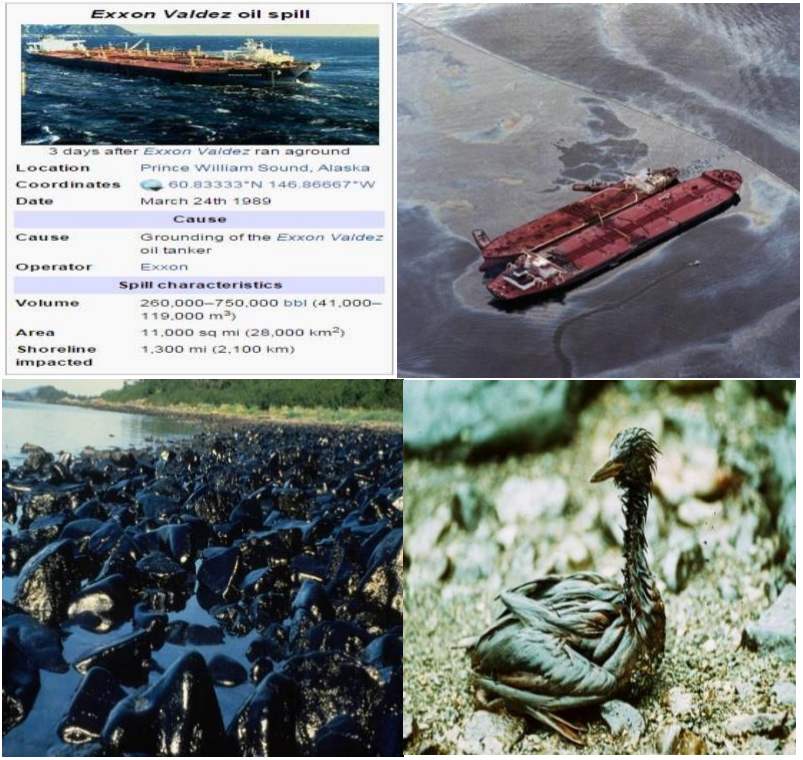

Fig. 2. When the control system failed and malfunction

3 Early Ship Control System

There are quite several disadvantages to the early control system. Some of the reasons for these are as follows;

1. Lack of reliability – Need to monitor manually as exact control action is only applicable at one operating condition (led to comments that it was a moderator, not a controller).
2. Bulky size – The hardware for example computers was bulky and it required a very big area to place all the computer and instrumentation devices.
3. Slow response – Due to heuristic tuning methods of PID controllers. Sometimes, the tuning parameters need to be manually tuned as some of the parameters change in the system plant.

3.1 Modern Ship Control

In a modern control system for a ship, for example, many of the systems are fully integrated and automated resulting in a better and more effective control for the intended operation to achieve safe and environmental operation. This can be illustrated in Figure 3 below.

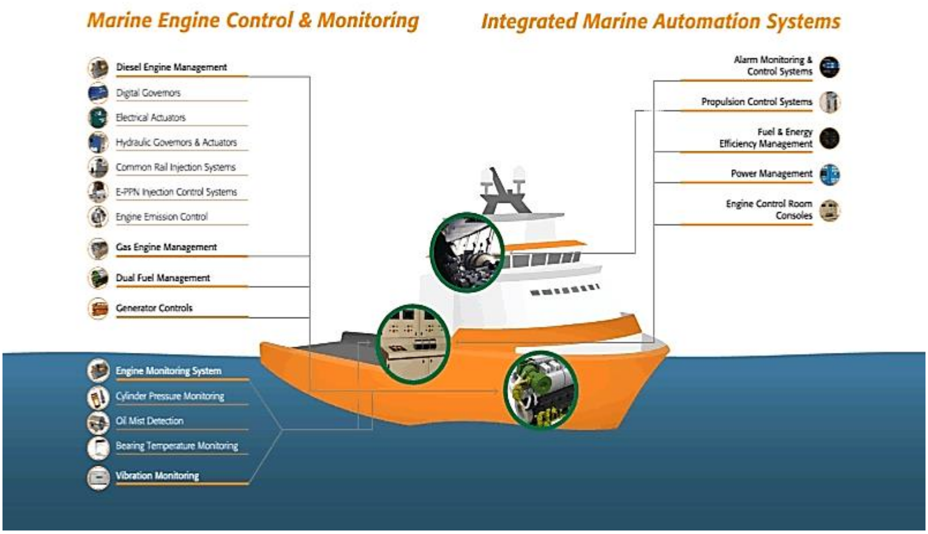

Fig. 3. Modern ship control system

4 Advantages of Modern Ship Control System

1. Real-time monitoring and analyzing:

   Recent technology of control systems allows users to monitor and analyze in real-time with single or multiple input-to-output systems.

2. Increase reliability:

   With modern sensors and actuators, an accurate reading will be more reliable as compared to previous methods.

3. Optimization:

   Optimization of the control system will allow a reduction in fuel consumption which will reduce the operating cost of ship voyage.

4.1 Existing and future marine control systems for various operations

1. Dynamic Positioning (DP) is a computer-controlled system that automatically maintains a vessel’s position and heading. A dynamic positioning system is a computer-controlled system used to automatically maintain a vessel's heading and position without the use of mooring lines and/or anchors.

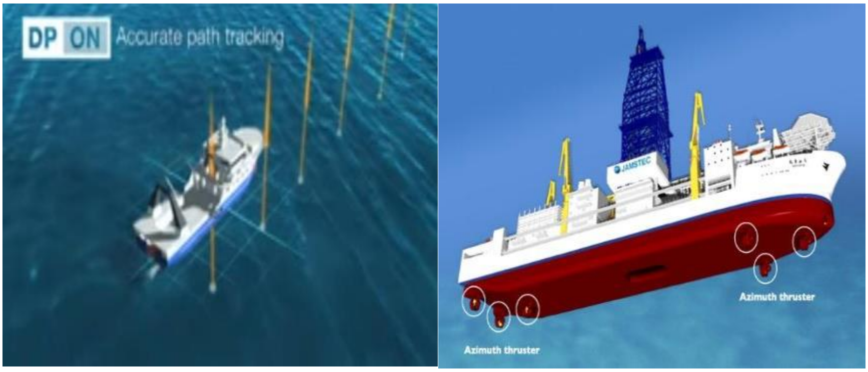

Fig. 4. Dynamic Positioning. https://www.youtube.com/watch?v=SP1KRiUrDTg

2. Remotely Operated Vehicle (ROV). ROV is a tethered underwater mobile device developed for submersible operations in the oil and gas industry and subsea surveillance. A remotely operated vehicle (ROV) is an unoccupied underwater robot that is connected to a ship by a series of cables. These cables transmit command and control signals between the operator and the ROV, allowing remote navigation of the vehicle.

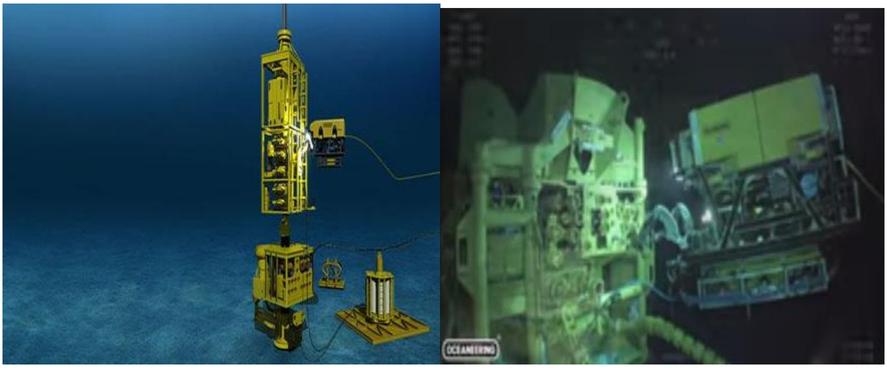

Fig. 5. Remotely Operated vehicle (ROV). https://www.youtube.com/watch?v=CoOwT0X5dpo

3. Sea/Ocean Glider

   A sea glider is an autonomous underwater vehicle (AUV) designed for continuous, long-term data collection in oceanographic applications. The Seaglider is specifically built for deep-diving missions, capable of operating for months at a time and covering thousands of miles. Its primary function is to gather critical data from the ocean's depths without the need for human intervention. In military contexts, the Seaglider is often referred to as an Unmanned Underwater Vehicle (UUV), emphasizing its autonomy and ability to carry out long-duration missions without direct control. These vehicles are highly effective for tasks such as environmental monitoring, resource exploration, and surveillance.

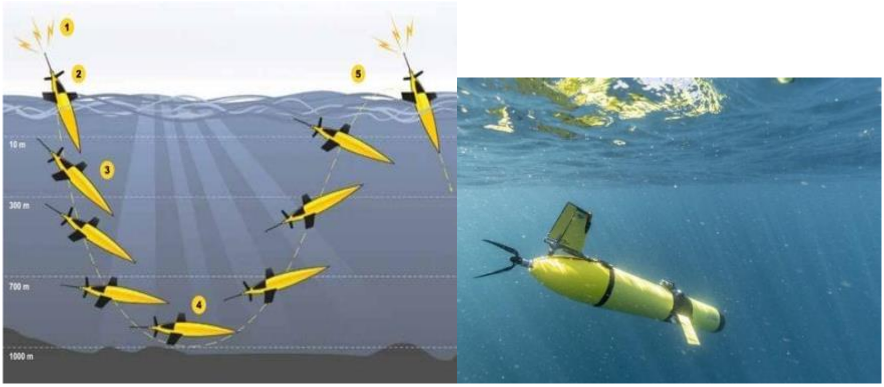

Fig. 6. Sea/Ocean Glider. https://www.youtube.com/watch?v=J3ViBke2ZQg

4. Active Heave Compensator

Active heave compensation (AHC) is a technique used in offshore operations to mitigate the effects of wave-induced motion on lifting equipment. It utilizes a control system that applies power to the lifting gear, allowing it to maintain the stability of the load along the vertical axis. This system compensates for any movement of the platform, such as a drilling rig or crane vessel, ensuring that the load remains steady despite changes in the platform's position due to wave motion. AHC systems enhance the accuracy of load placement, improve safety, and increase operational efficiency in offshore lifting and installation tasks.

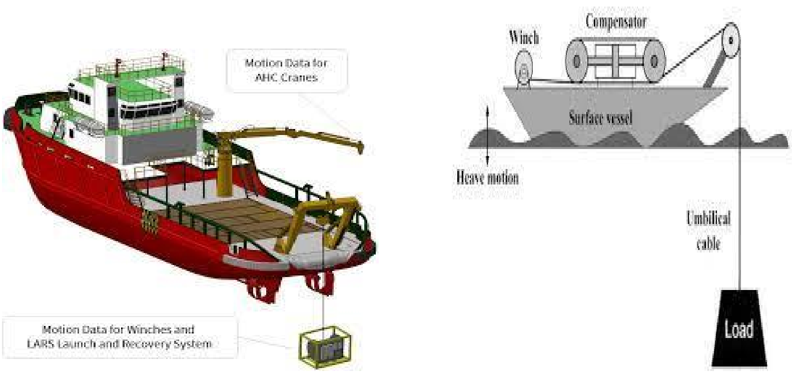

Fig. 7. Heave compensator

5. Gyro stabilizers use rotating flywheels to generate moments that change the amplitude of the oscillating motion of the ship. A gyroscopic stabilizer is a control

system that reduces the tilting movement of a ship or aircraft. It senses orientation using a small gyroscope and counteracts rotation by adjusting control surfaces or by applying force to a large gyroscope.

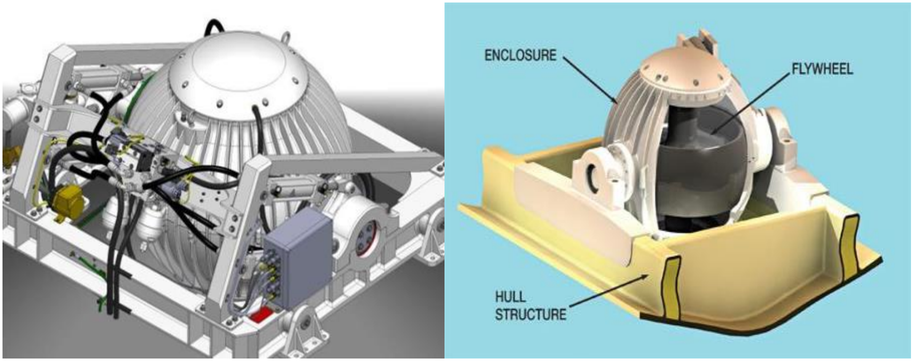

Fig. 8. Gyro Stabilizer. https://www.youtube.com/watch?v=W9uNrR2Dx-

6. The automatic identification system, or AIS, transmits a ship's position so that other ships are aware of its position. The International Maritime Organization and other management bodies require large ships, including many commercial fishing vessels, to broadcast their position with AIS to avoid collisions.

Fig. 9. AIS System

A research project has been carried out in UTM for an AIS project to detect ship movement along the Strait of Malacca and Singapore's water.

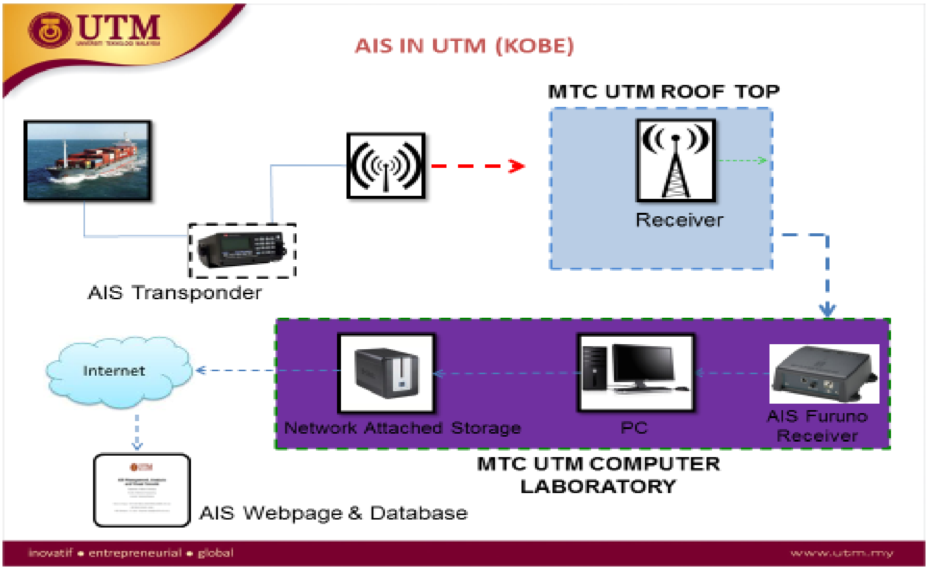

Fig. 10. AIS project in UTM

5 Conclusion

1. Control Engineering is one of the important aspects that need to be considered in ship and offshore industries.
2. Without a modern control system, the system could not be optimized and will lead to extra costs for operation and maintenance.
3. Implementation of recent technology of modern control strategy is vital in ensuring reliability, safety, and smoothness of ship and offshore systems.
4. Subsequently, will reduce the maintenance and operation cost even initial cost would be higher.

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