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Design

Coordination of FPSO and Tanker Offloading Operations

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Introduction

- The effects of control and **automation technology** on the **marine transportation industry** have been great.
- **Invention** of the **first autopilot** by Sperry early in the last century
- Introduction of new **control technology** has lead to heavily automated vessels.
- This paper looks at the application of intelligent or knowledge-based control (IC or KBC) technology to the control of **marine vessels.**
- How can marine vessel operations benefit from the application of IC?
- Example of an FPSO and an **offloading tanker operation.**

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Intelligent Control

- **Control system research is shifting** away from **classical continuous control**
- In large-scale systems ideally, **traditional control techniques** take care of the low-level continuous control tasks
- Proliferation of embedded systems and cheap digital hardware, control becomes cheaper and easier to deploy in **large-scale systems.**
- **Intelligent control technologies** is a way of managing and controlling large systems.
- Intelligent control coordinates the logical (also known as discrete-event) aspects of the many controlled subsystems

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Intelligent Control

- Traditionally, **control systems** are thought of in terms of controlling single or multiple variables in a continuous way through various **control algorithms;** i.e. **PID,** LQ, etc.
- The **designer** or implementer has to consider the stability and efficiency (optimality) of the system as he deploys it.
- The weakness of **traditional control techniques** is primarily in fault tolerance, reconfigurability and recovery, areas where **intelligent control** is particularly strong.

Human Factors

- **Human operators** are currently being relied upon to serve as the coordination (or intelligent) layer in large, complex systems.
- **Designing controllers** for large-scale systems is becoming more difficult.
- Human error can be inserted into a control system at the design, training, maintenance and operation phases of a project.

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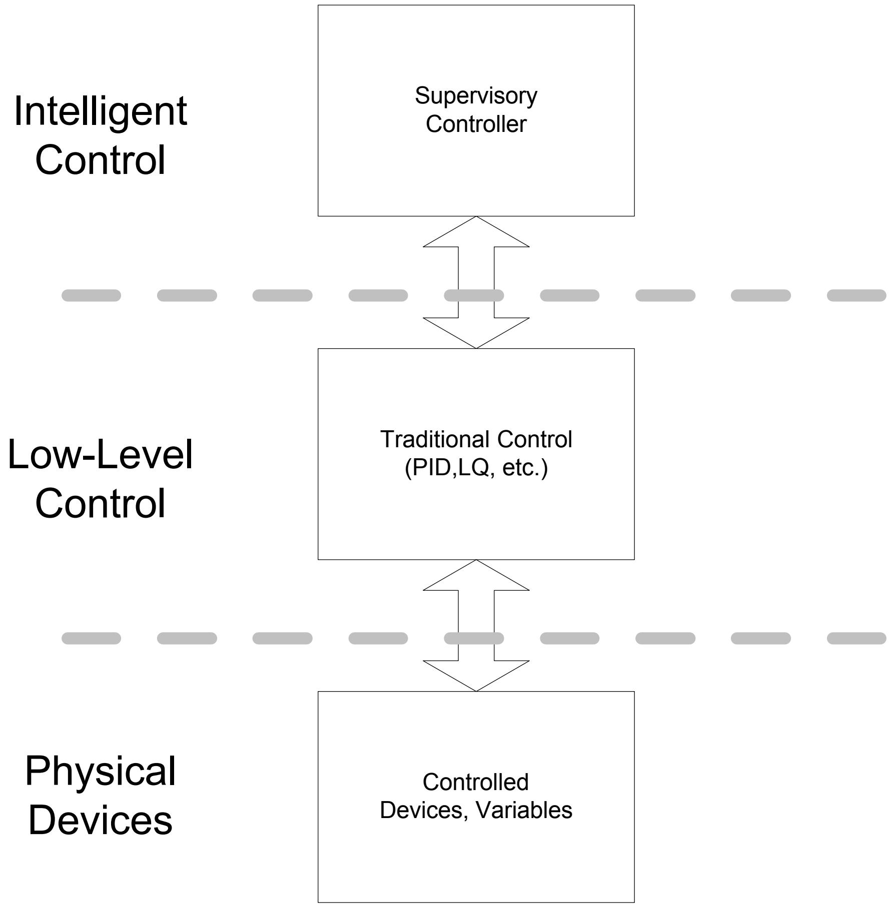
Intelligent Control



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System Complexity

• M**ultiple** subsystems interact to form more complex large systems: *interactive complexity*

• The system complexity increases dramatically if we include additional subsystems, each having **interconnected states** and actions.

• Some of the combinations of these subsystem states may lead to **undesirable consequences** and we would like to design a controller that can prevent the system from reaching this state.

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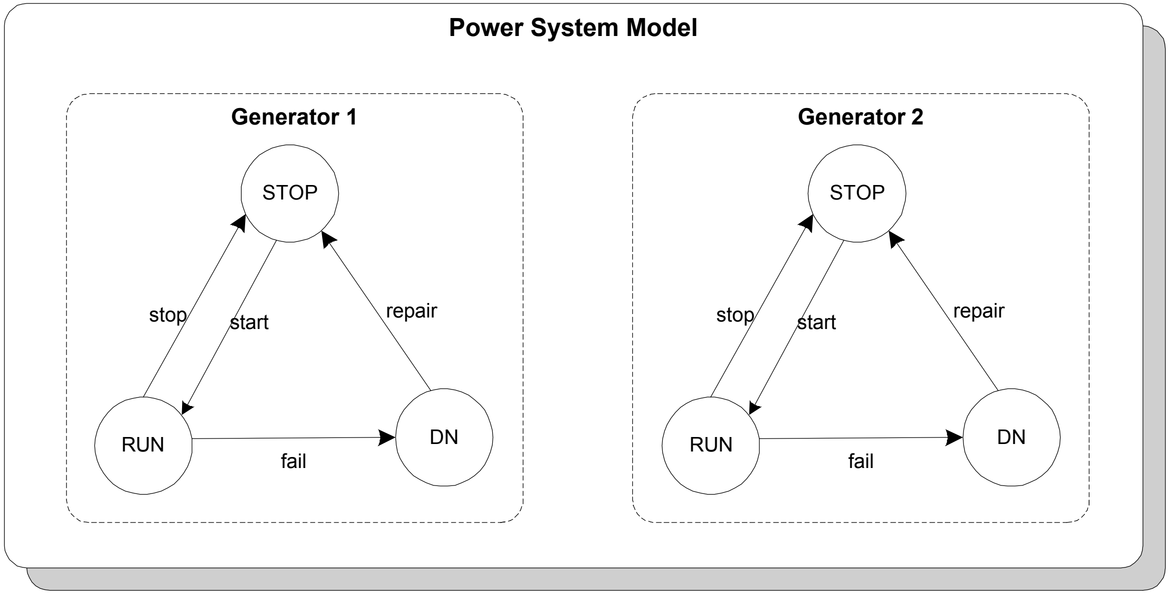
Example



A discrete model of a pair of **generators** is represented by two graphs (finite state machines).

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Example (cont.)

System State #	Generator 1 State	Generator 2 state
1.	STOP	STOP
2.	STOP	RUN
3.	STOP	DN
4.	RUN	STOP
5.	RUN	RUN
6.	RUN	DN
7.	DN	STOP
8.	DN	RUN
9.	DN	DN

All possible systems states for 2 generator system

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Example (cont.)

- The states are connected by events that may be controlled (start, stop and repair) by the **controller** and one event (fail) that can't be controlled since it occurs spontaneously.
- The system complexity increases dramatically if we include additional **subsystems,** each having **interconnected states** and actions.
- In general, the **complexity** increases by the Nth power (where N is the number of interconnected subsystems) if there are no shared common events between systems.
- Some of the combinations of these subsystem states may lead to **undesirable consequences** and we would like to **design** a controller that can prevent the system from reaching this state.

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Controller Design

- Design a controller for the simple two generator system. Goal: (DN,DN) must be avoided
- Since **failure** of a **generator** is a spontaneous (uncontrollable) event, the controller cannot prevent it, and if both generators are running at the same time, it is possible that they could both fail.
- An inane solution: we are prevented from using a working generator while another is being repaired!
- This is the literally “correct” solution, given the **design requirement.**

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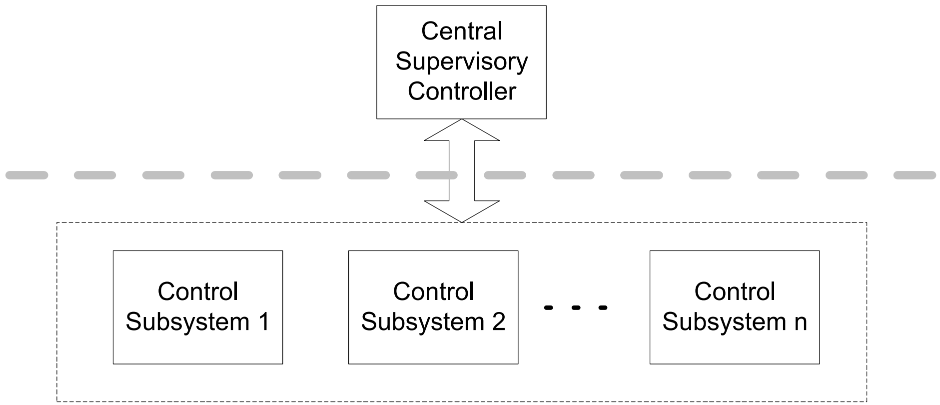
Controller Design

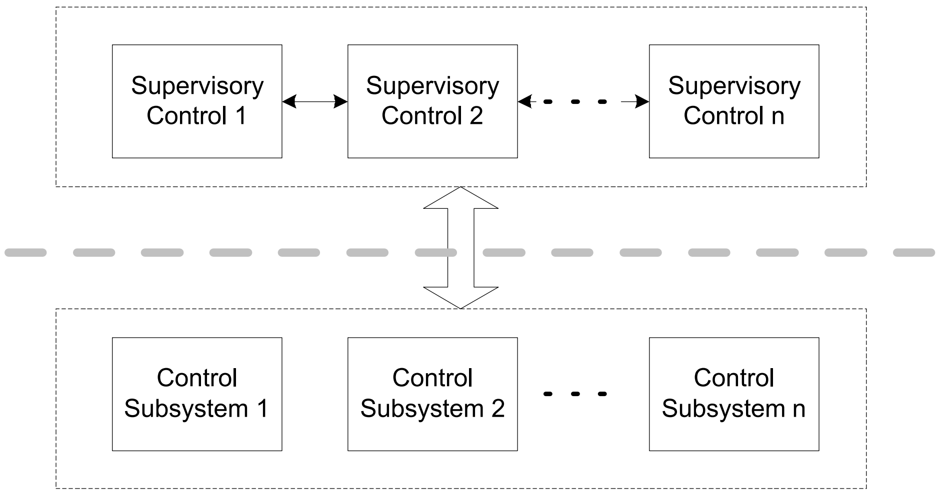
- It is this **automated controller synthesis** that is most useful to the controls designer.
- A computer can exhaustively search all possible system states, in order to identify and **avoid illegal** or unsafe conditions or sequences.
- For example, we may wish to prevent generator 1 from executing a **start/stop sequence** more than three times; i.e. we would disallow the sequence of events {start, stop, start, stop, start, stop).

Centralized vs. Decentralized Implementation

Centralized Supervisory Control



Decentralized Supervisory Control



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Controller Design (cont.)

- We **considered modeling** and **controlling** only the **logical behavior** of the system.
- Add **timing information** to the simple two generator problem
- Time required to start the **generators** could be taken into account and specification for **safety** could be more specific; i.e. “the two generators must not run together for more than 10 minutes”.

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Marine Application

- There are many marine operations that may require **multiple vessels** to work closely together, including pipe-laying, drilling and **offshore production.**
- **Reliability** of the DP system is no longer just limited to the traditional component failures such as wind sensors, thrusters, or DP computers.
- Systems "communicate" through a **common power demand** on the power buss
- In the case of an FPSO gas injection, flaring and other oil-related production processes may affect the station-keeping.

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Terra Nova FPSO

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Multi-Vessel Control

- **Automation techniques** that have been used for logical scheduling of processes and work in factories can be applied to **vessel control.**
- A multi-vessel system is more complex, due to additional control systems.
- Moves DP operators command of vessels in a multi-vessel system can be compared to the **instructions issued** to a **factory robot**

Multi-Vessel (cont.)

- For example, an offloading tanker and FPSO can be instructed by the **coordinating controller** to make a weathervaning maneuver together.
- The point of an intelligent control system is to either replace the operators' manual instructions by automatically moving the vessel, or to at least assist the operator to perform the **maneuver**

Model Testing

- Less expensive to implement and operate and the risk of **harming real vessels** or personnel are low.
- Identify the most challenging conditions for a **vessel control system,** in a safe and controlled environment; i.e. a wave basin.
- **Model tests** were conducted in August 2001, using a full model of an **FPSO** and **offloading tanker**
- **Weathervaning, Station Keeping, and Tanker Approaches**

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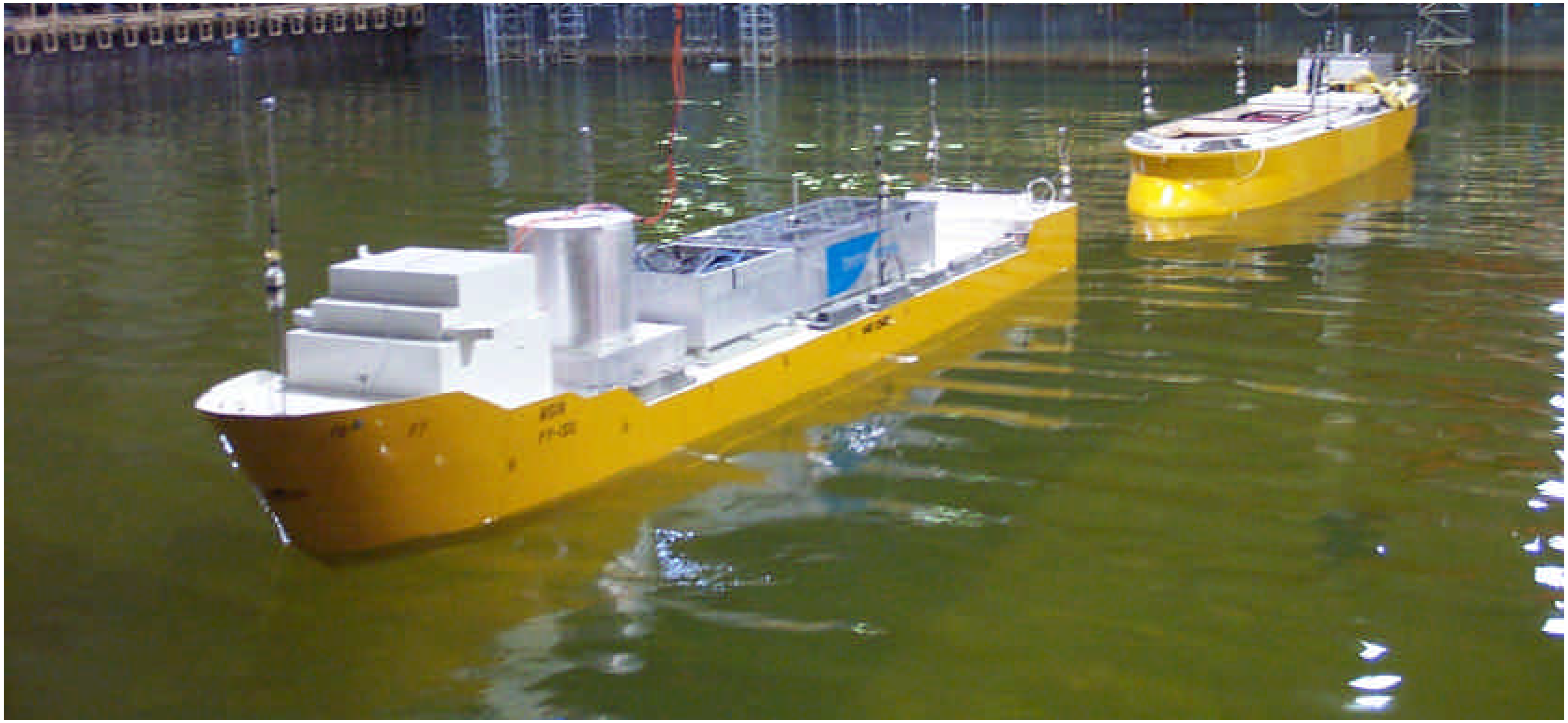
Model Testing



Model test at the Offshore Engineering Basin (OEB) located at the Institute for Marine Dynamics in St. John's, Newfoundland, Canada (August, 2001)

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Conclusions

- **Intelligent Control methods** are being developed to deal with the **increasing complexity** and decentralization of various industrial processes.
- Due to the magnitude of today's **controlled systems,** it is becoming increasingly difficult for **traditional design** checks such as design reviews, simulations and testing to find flaws in a system.
- One method for constructing an intelligent controller that is "correct by design" is to incorporate a model of the **logical behavior** of the system to be supervised, along with the designer's specifications for safety and correct operation.
- Automated design methods currently exist to implement an intelligent controller to **supervise** and **coordinate** safety-critical applications such as DP positioned vessels.
- The development of new software tools and training for control system designers will be necessary before there is wide-scale acceptance of this technology by **industry.**

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