令和元年(第19回)海上技術安全研究所研究発表会

船舶推進プラントとして主機デジタルツインの開発

○ ボンダレンコ　オレクシー
環境・動力系

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環境・動力系

北川　泰士
流体性能評価系

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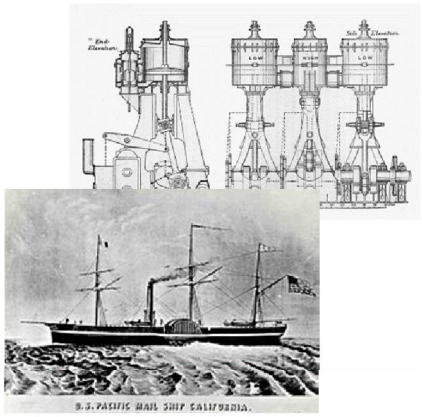
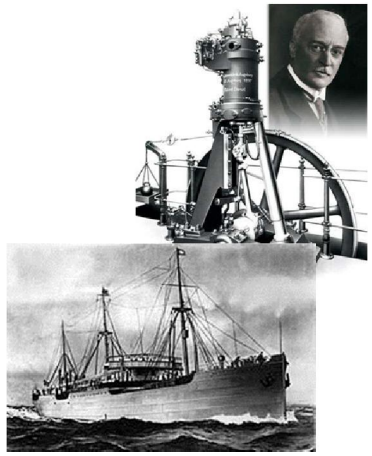
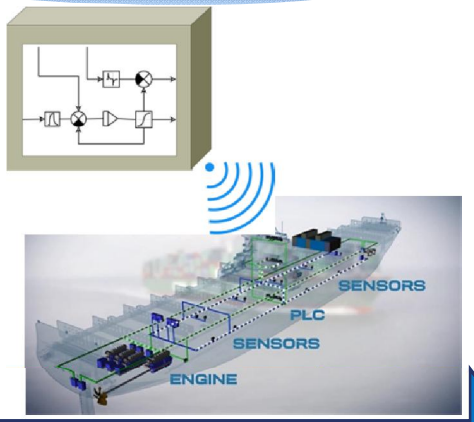
Introduction: 4th Industrial Revolution







~1800 ~1900 ~1980 ~20..

1st Industrial Revolution

Mechanization, Steam Power

2nd Industrial Revolution

Electricity, Diesel Engine

3rd Industrial Revolution

Automation, Computers & Electronics

4th Industrial Revolution

Cyber-physical systems, Artificial Intelligence

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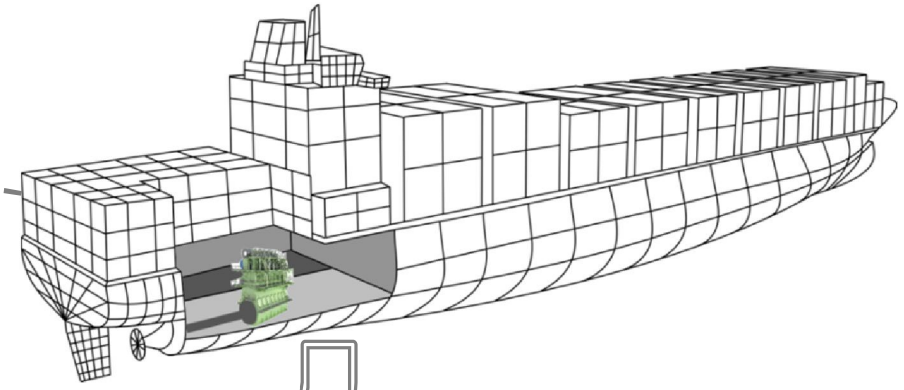
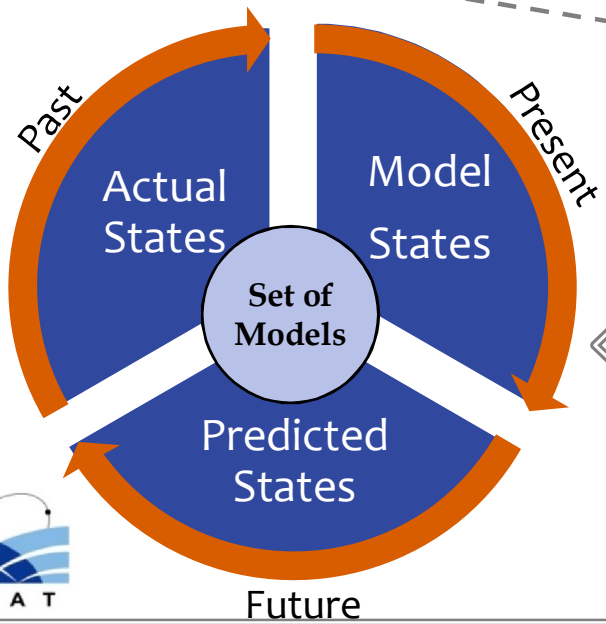
Introduction: Digital Twin Concept

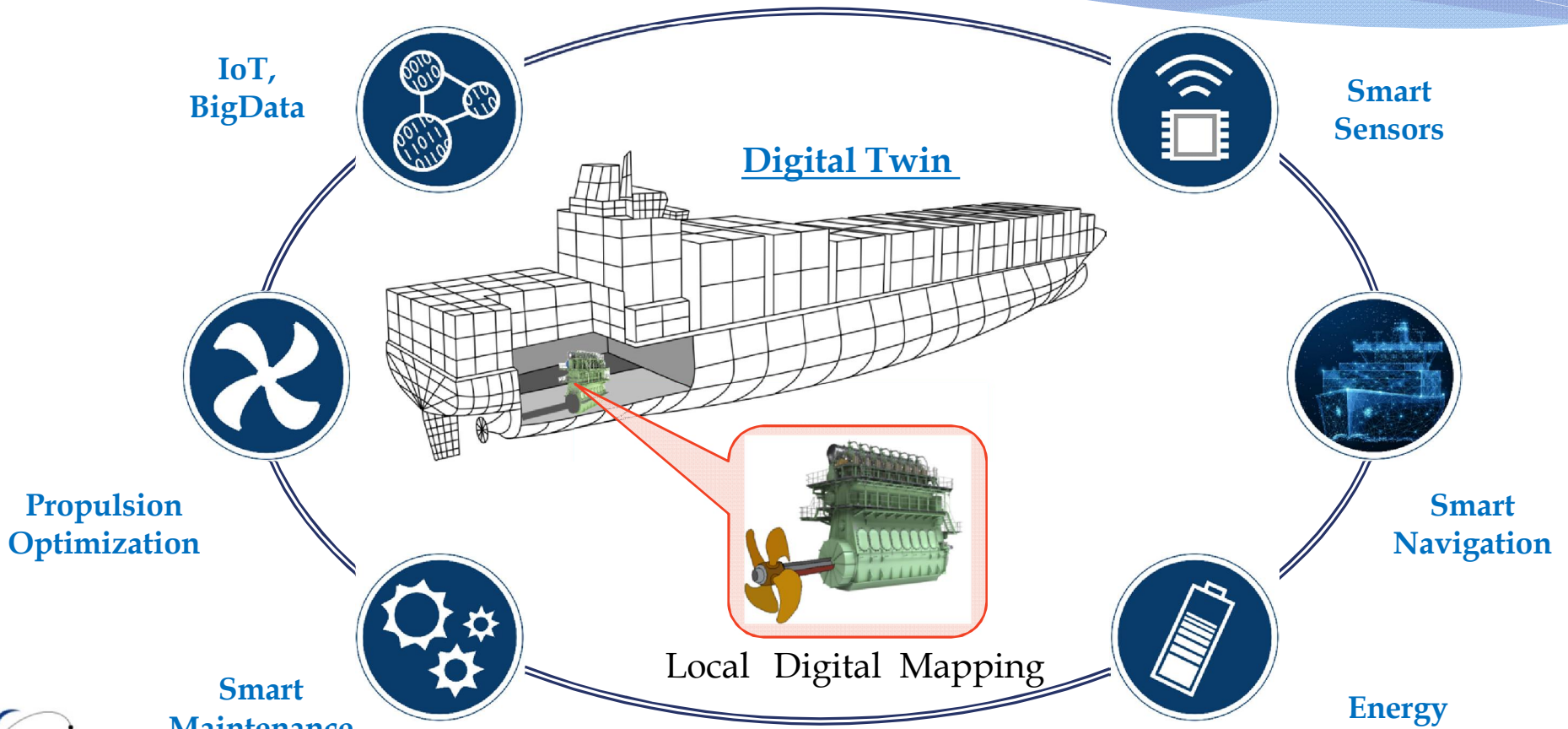
Global Digital Mapping



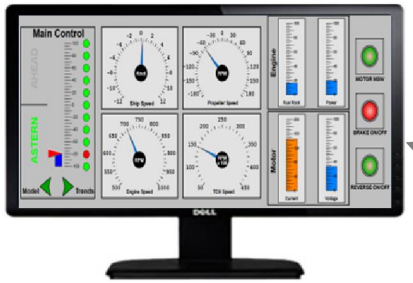


Digital Twin is the combination of real-time data and a mapping of system behavior which continuously coexists with its physical counterpart

Introduction: Digital Twin Ecosystem



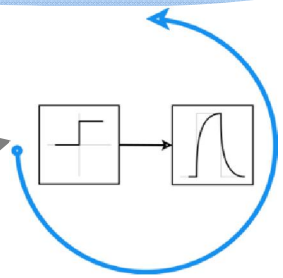
Introduction: Digital Twin Focus

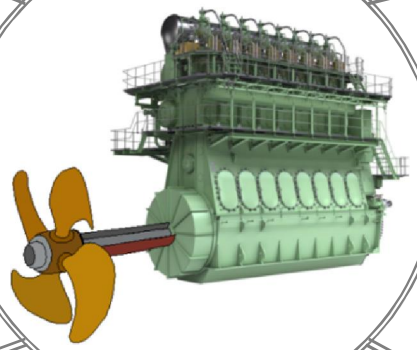


*Details are presented on PS-6 at the Poster Session

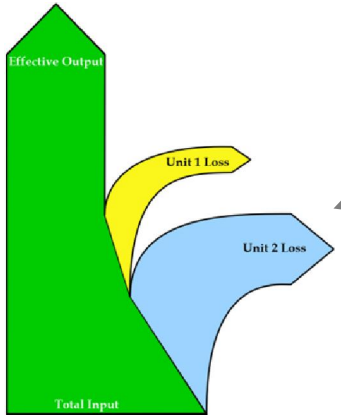
In-Depth Monitoring

Transient Response



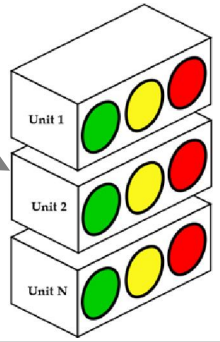


Aging Prediction



Efficiency Optimization

Anomaly Detection



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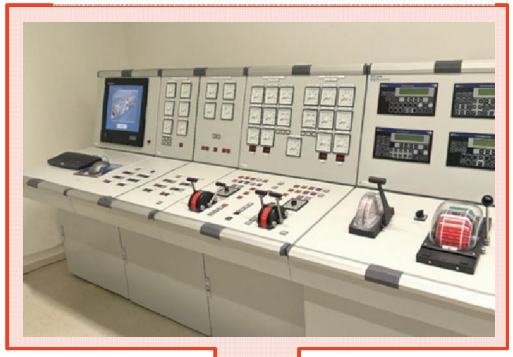
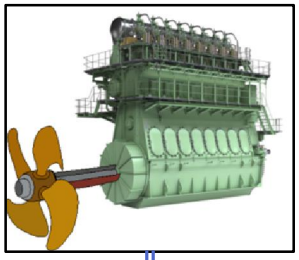
Anomaly Detection

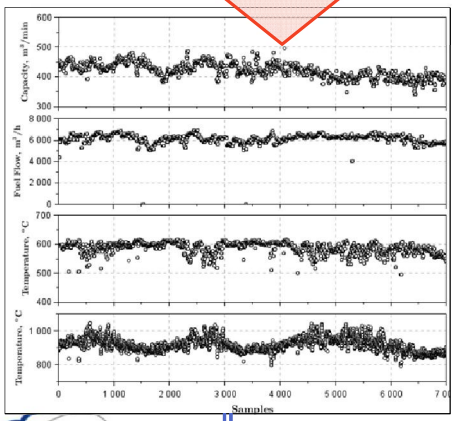
Digital Twin

Real Space - Engine Monitoring



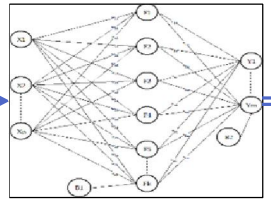
Cyber Space - Engine Model





{ Reference State }

(Aging Trend)



{ Actual State }

Intelligent Monitoring

{ Diagnostic Parameters }

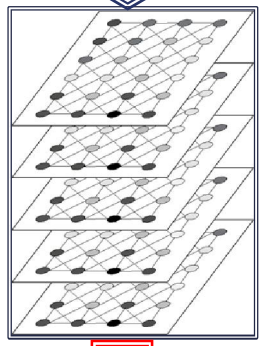
$$\{x'_{b2}, x'_{d3}, x'_{g5}, \cdots\}$$
$$\{x_{b2}, x_{d3}, x_{g5}, \cdots\}$$

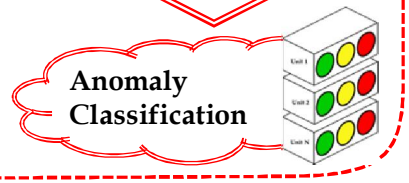
Features Map

$$\begin{array}{c} \\ f_{1,1} \\ f_{1,2} \\ f_{1,3} \\ f_{1,4} \end{array} \begin{array}{c} \begin{array}{cccc} f_{1,1} & f_{1,2} & f_{1,3} & f_{1,4} \end{array} \\ \begin{bmatrix} 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \end{bmatrix} \end{array}$$

Classification

AI, Machine Learning





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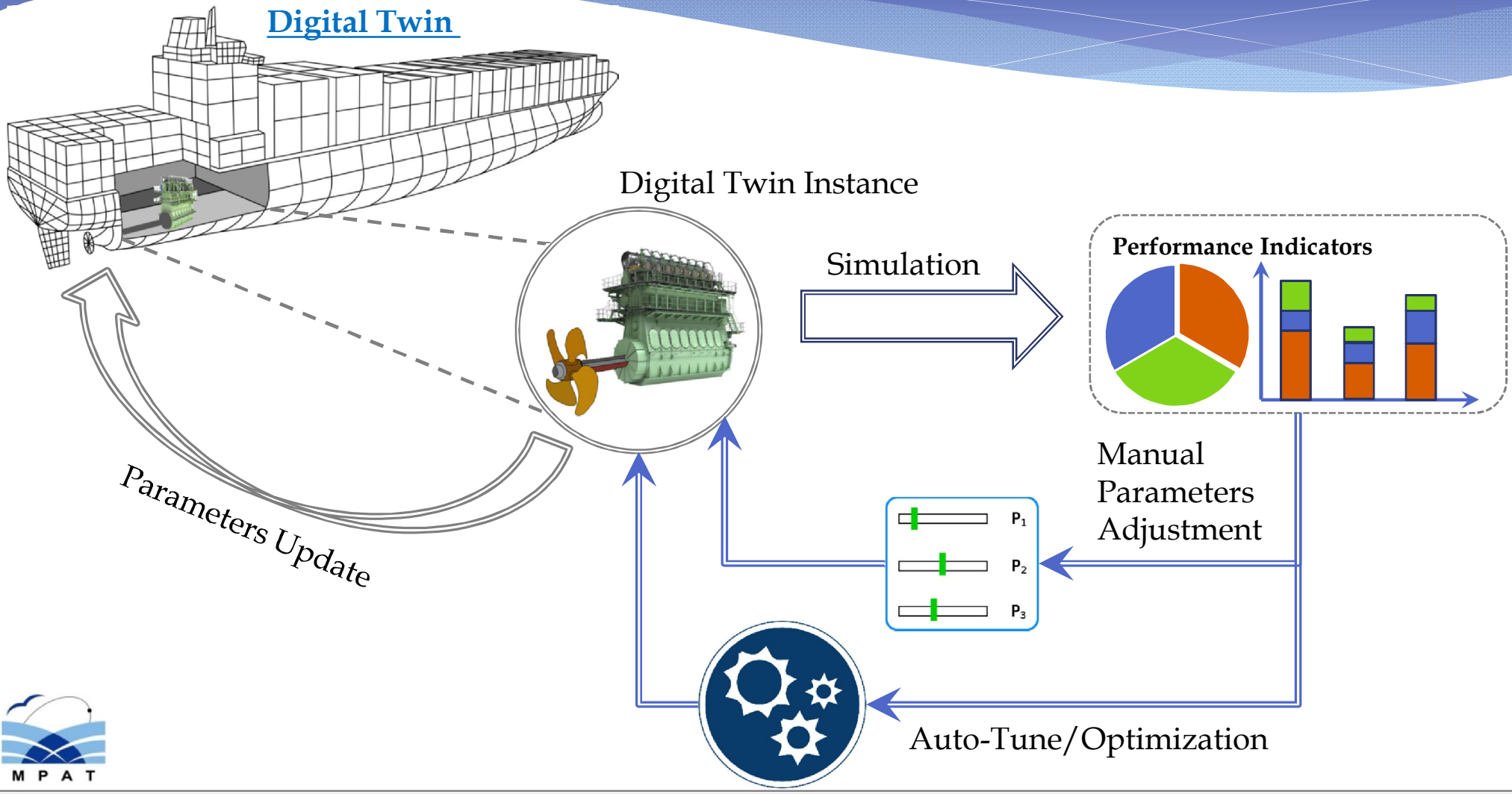
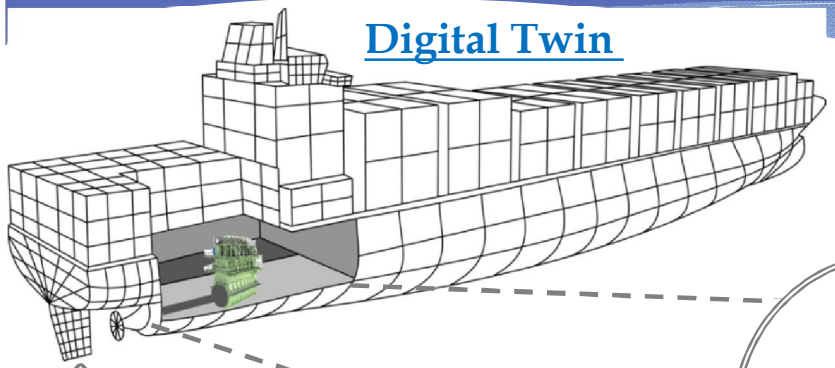
Optimization: Operation Efficiency

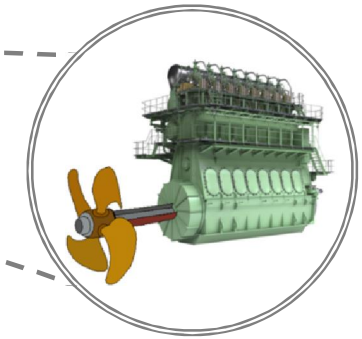


Optimization: Cyber-Physical System

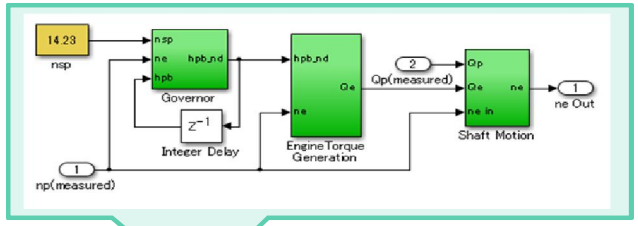
Digital Twin



Digital Twin Instance



Engine Model



Propulsion System Responses

Design / Operation Update and Optimization

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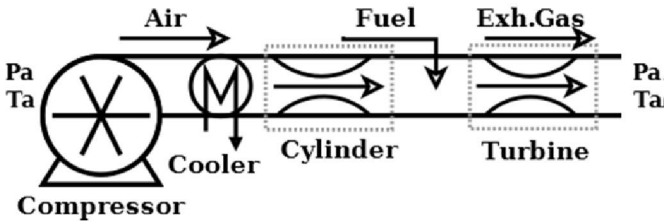
Engine Modelling for Digital Twin

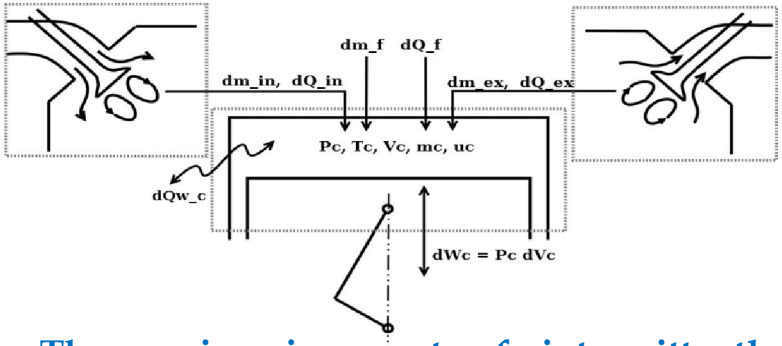
❑ Cycle-Mean Value (CMV) Engine Model



- The engine is a series connection of throttles
- Continuous flow of air and exh. gases through the throttles
- Combustion is considered as a cycle-averaged enthalpy increment

Fast Execution and
Limited Information

❑ Filling-Emptying (Phenomenological) Engine Model



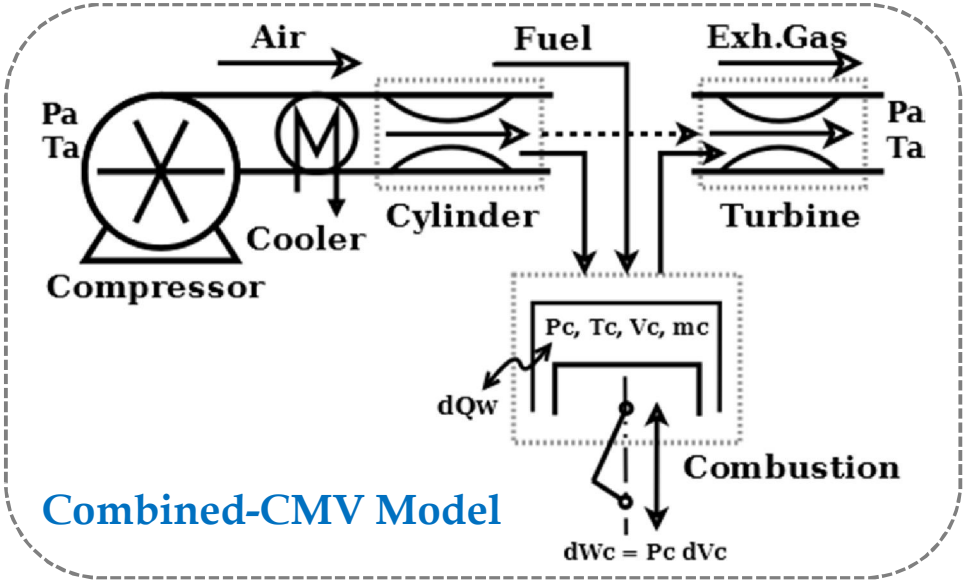
- The engine is a set of intermittently connected control volumes.
- The energy and mass conservation laws are resolved at every degree of the crank-angle
- Combustion is represented by the phenomenological model of a heat release rate (Wiebe function)

Slow Execution and
In-depth Information

Engine Modelling for Digital Twin

Fast Execution of CMV Model

In-depth Detailing of Combustion Model

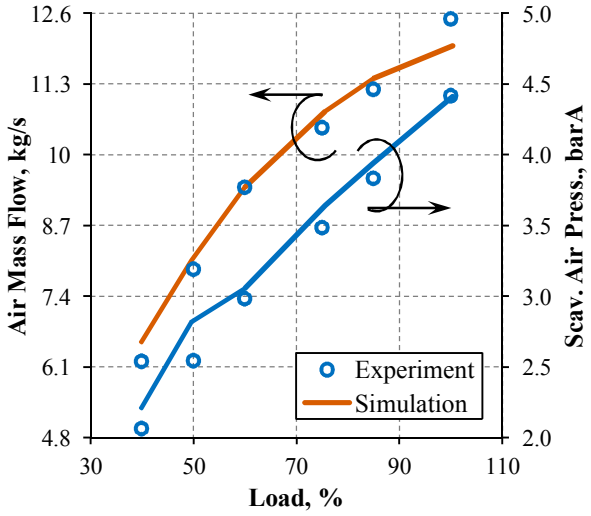


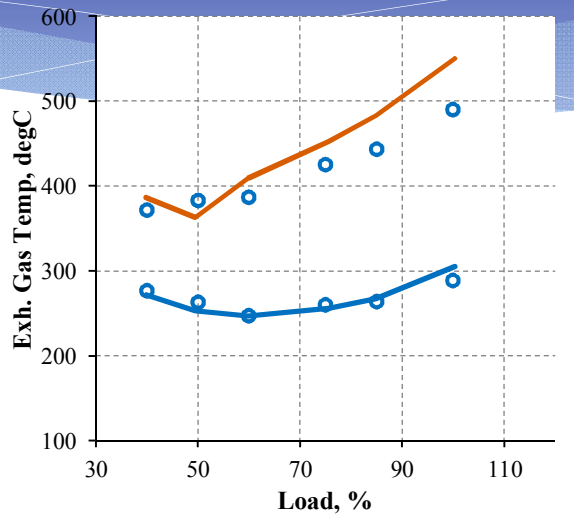
- Continuous flow of air and exh. gases through the throttles

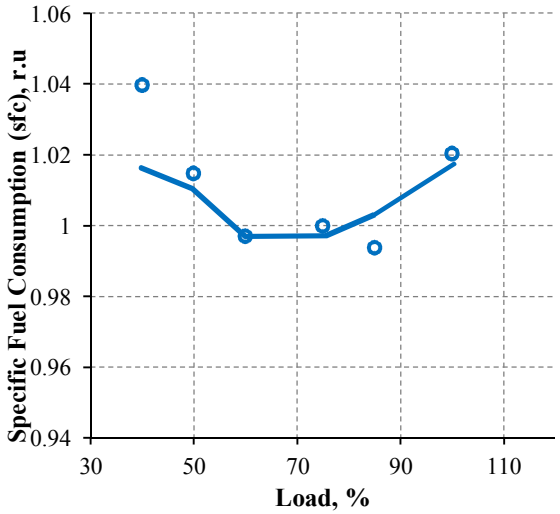
- Precise calculation of combustion for closed part of the cycle (from EVC to EVO)

Combined-CMV Model is a Good Candidate for the Digital Twin

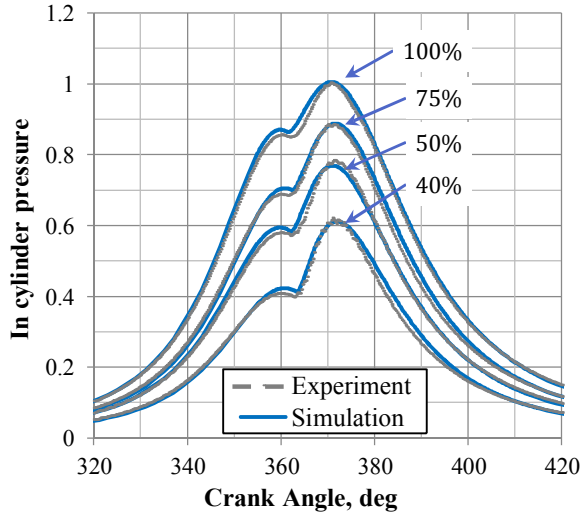
Digital Twin Model Performance





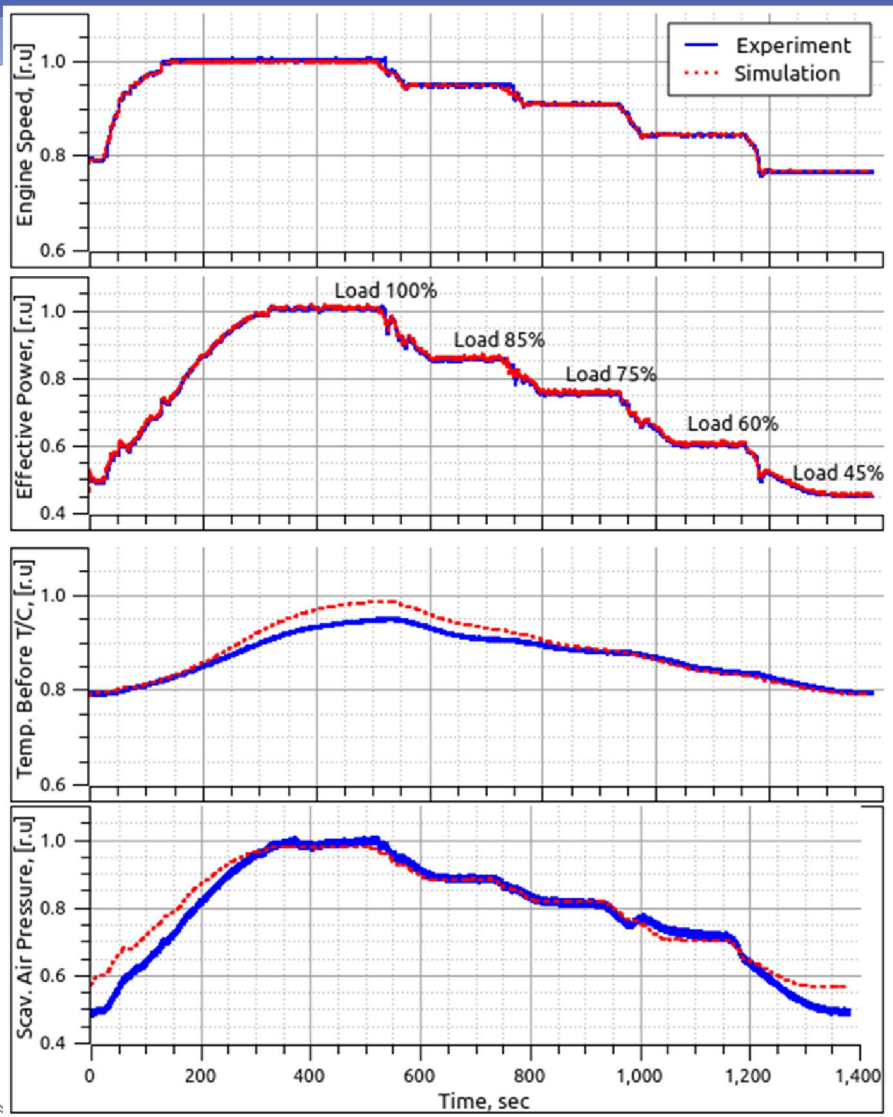


Steady-state performance of the prototype engine is mapped fairly-well.



Digital Twin Model Performance

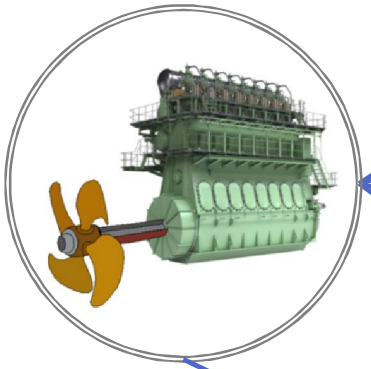
Transient performance of the prototype engine is mapped reasonably well, however there is still a room for improvement.



Engine Modelling for Digital Twin

System Analysis

Engine Decomposition



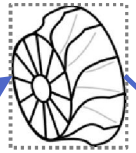
Compressor

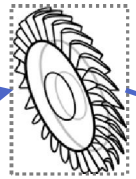
Turbine

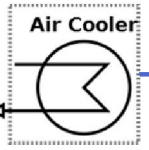
Air Cooler

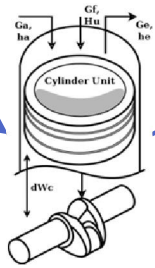
Cylinder Unit

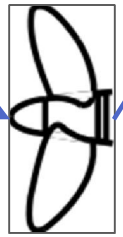
Propeller



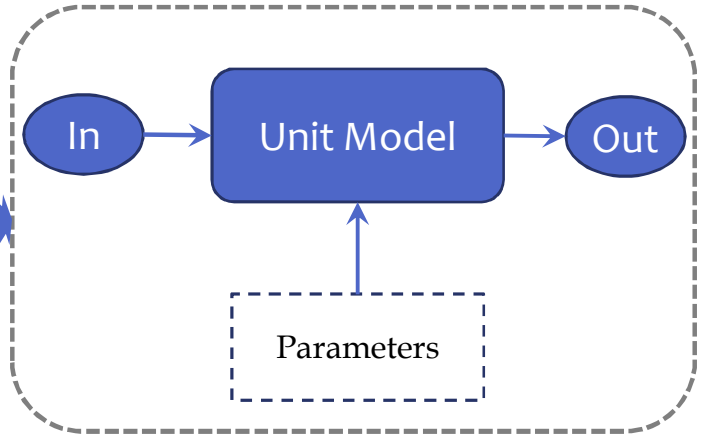








Unit Model



- Every unit model is composed of a set of algebraic equations and a set of constant parameters. The last has to be adapted to a particular engine and condition.

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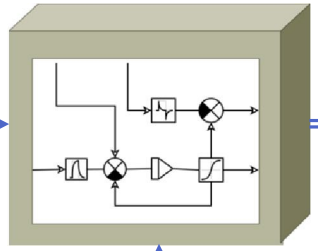
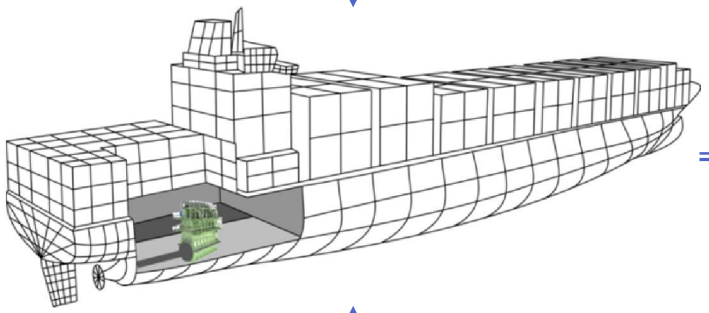
Concept of the Tracking Filter

The tracking filter is used to match continuously the digital twin model with measured sensor data from the real propulsion plant.

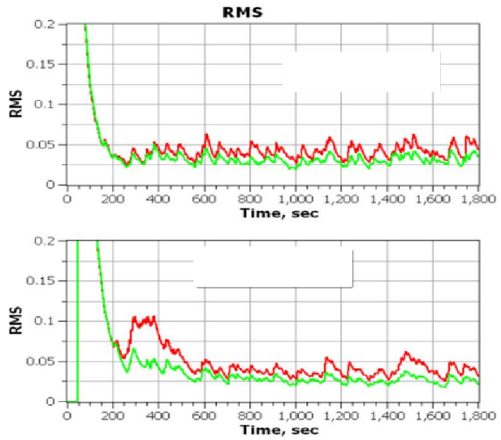
Tracking Filter



Monitored Data
from Real Space



Predicted Data
from Cyber Space

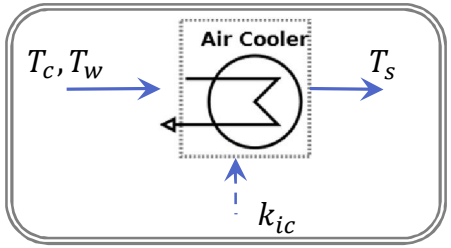


{ Parameters Update }

Example of the Tracking Filter

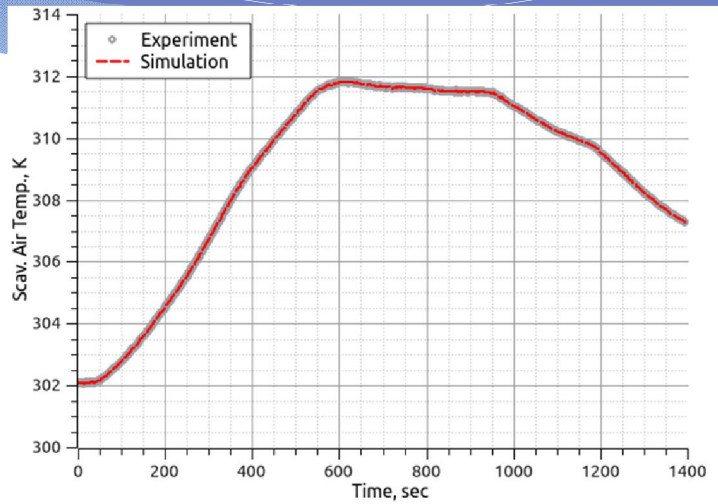
- **Air Cooler Unit Model:**

$$T_s = T_w + k_{ic}(T_c - T_w)$$



$$\boldsymbol{k_{ic} = f(G)} - \text{Function of mass flow}$$

$$k_{ic} = k_1 + k_2\,\tilde{n}_{tc}^2, \qquad \therefore \tilde{n}_{tc} \equiv \tilde{G}_c$$



- **The Kalman Filter for Coefficients adaptation:**

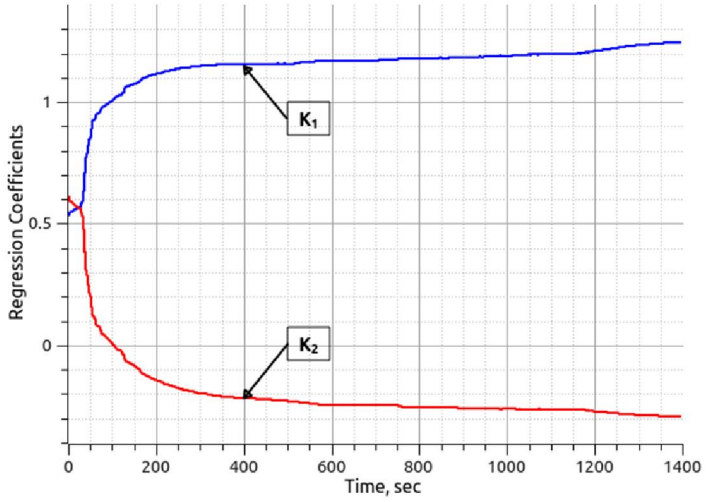
$$\frac{d\hat{x}_i}{dt} = 0, \qquad \therefore \hat{x}(t_0) = x_0$$

$$\hat{x}_i = \hat{x}_{i-1} + H\left(T_s^m - T_s^p\right), \qquad \therefore \hat{x} = [k_1, k_2]^T$$

H – is the Kalman Filter Gain

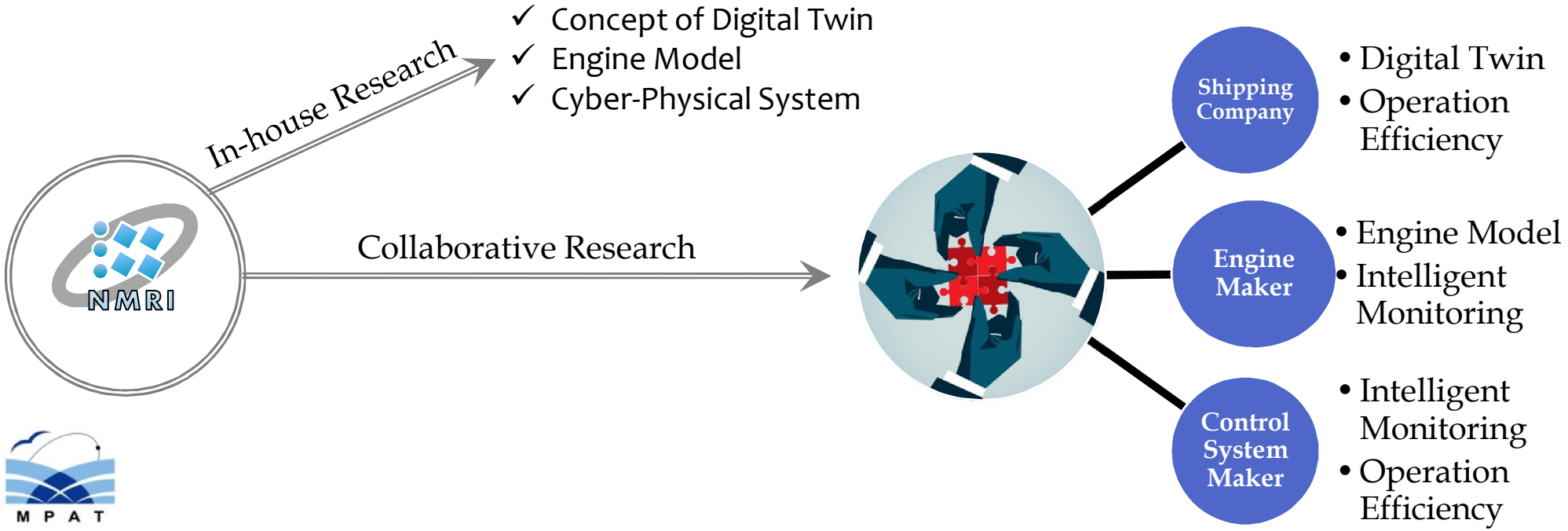
T_s^m – measured temperature

T_s^p – predicted temperature



Conclusions

The Digital Twin is the emerging technology in demand for the 4th Industrial Revolution. The concept of Digital Twin provides in-depth information for better decision making and also bring broad possibilities to the ship operation enhancement.



Thank You for Your Kind Attention

ご静聴ありがとうございました