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Changes for the Better

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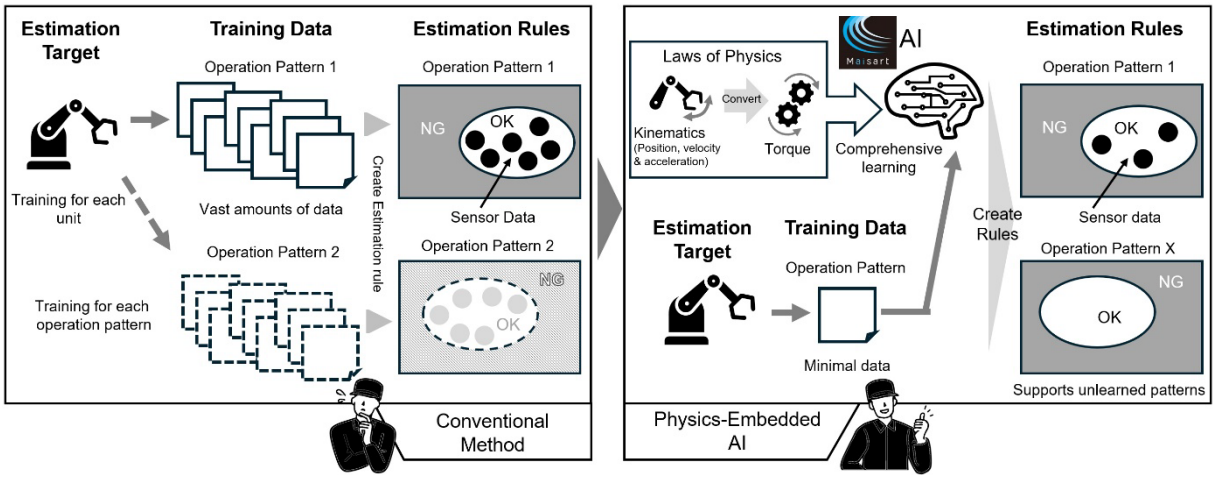
Mitsubishi Electric Develops Physics-Embedded AI for Accurate Estimation of Equipment Degradation from Small Amounts of Training Data

Reduces maintenance costs while supporting productivity and quality at manufacturing sites



Advantages of physics-embedded AI vs. conventional degradation estimation

TOKYO, December 10, 2025 – Mitsubishi Electric Corporation (TOKYO: 6503) announced today that it has developed a physics-embedded AI[1] that can accurately estimate equipment degradation using minimal training data. The technology is an outcome of the company's Neuro-Physical AI[2] initiative within its Maisart®[3] AI program, which emphasizes reliability and safety in the physical world. Leveraging Mitsubishi Electric's extensive equipment-development expertise, the new technology supports the optimization of manufacturing-site assets to maintain productivity and quality as well as reduce maintenance costs.

Japan's manufacturing sector is deploying increasingly sophisticated production equipment at a time when the nation's aging and shrinking population is reducing the number of experienced maintenance technicians. Meanwhile, there is a growing demand for preventive-maintenance solutions that can predict equipment degradation for timely responses, since continued use of degraded equipment can result in equipment failure

[1] An approach that bases AI systems on a physical model—an analytical mechanism that reproduces a machine's behavior and characteristics using physical laws and equations—and embeds that knowledge and theory into AI to achieve more accurate and physically consistent prediction and control.

[2] Mitsubishi Electric's proprietary physical AI integrates decades of business expertise, on-site know-how and insights with physical laws, making equipment and entire systems smarter, safer and more reliable.

[3] "Mitsubishi Electric's AI creates the State-of-the-ART in technology":
Mitsubishi Electric's AI technology brand aimed at making every device smarter.

Maisart

or defective products. Conventional preventive maintenance typically mimics equipment behavior using mathematical models or simulations to estimate degradation. But this approach requires domain experts with knowledge of physical systems to design degradation-detection mechanisms from scratch, which can require significant time and effort. To address this issue, there is a movement to estimate degradation by training AI with operational data. However, these efforts typically require vast amounts of data to comprehensively cover diverse operating patterns, unit-to-unit variability and installation environments, as well as retraining whenever conditions change, hindering the practical deployment of AI to estimate equipment degradation.

In response, Mitsubishi Electric's Information Technology R&D Center in Kamakura, Kanagawa Prefecture, Japan and Mitsubishi Electric Research Laboratories, Inc. in Cambridge, Massachusetts, USA have developed an AI that is pre-trained using the theoretical equations of a device's physical model, enabling the AI to learn the device's expected behavior and characteristics in advance. Then, by providing a small amount of measured data reflecting unit-to-unit variability and environmental conditions, the AI can accurately estimate degradation. When embedding a physical model into AI, previous approaches fixed the weighting[4] between the model and measured data, making optimization for different devices or environments difficult. However, the new technology enables the AI to dynamically adjust these parameters, resulting in higher estimation accuracy and improved usability.

Consequently, this new technology can prevent major equipment failures and reduce the need for part replacements at manufacturing facilities, thereby helping to lower maintenance costs while maintaining productivity and product quality.

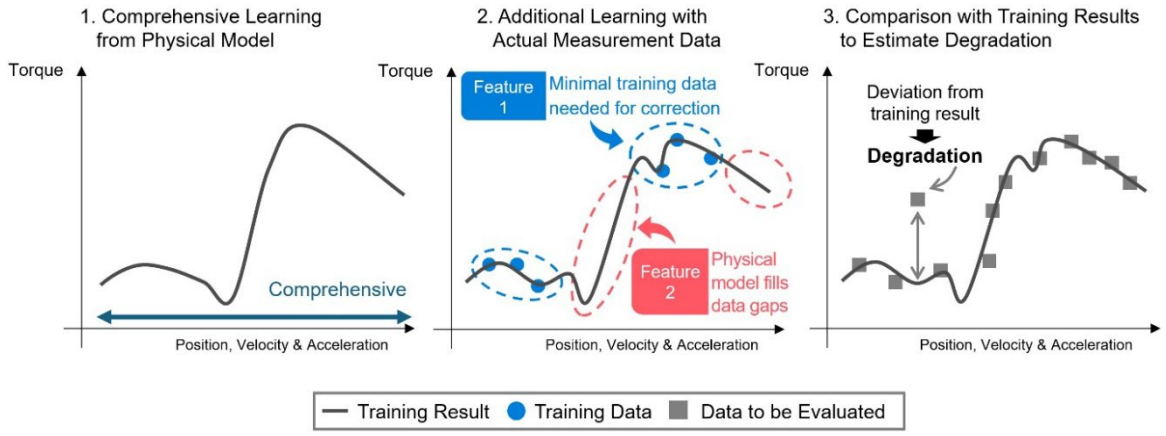
Product Features

1) ***Embedded physical model enables AI to predict equipment degradation using small training datasets***
   - Mitsubishi Electric's new technology uses the theoretical equations of a physical model reflecting a device's design specifications (inverse-dynamics equation[5]) to pre-train the AI on the device's behavior and characteristics. By performing additional training only on measured data that capture unit-to-unit differences and environmental conditions not reflected in the design specifications, the AI is able to estimate unit-to-unit variability.
   - The additional training solely corrects the physical model, so only a small number of measured samples are required, improving the efficiency of AI-based degradation estimation.
   - In validation testing performed with Mitsubishi Electric industrial robots,[6] the method reduced training data by approximately 90% while maintaining estimation error comparable to that of conventional methods.[7]

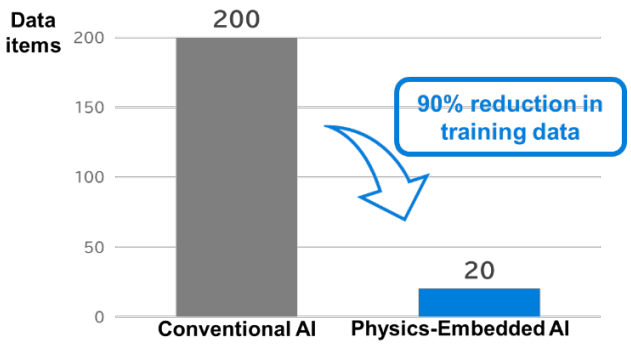
2) ***Physical model handles operating patterns and environmental conditions not encountered during training, improving degradation-estimation accuracy***
   - Even when variations not present in the training data occur, the physical model can be used to estimate the device's characteristics under those variations, which improves degradation-estimation accuracy.

[4] Weighting between physical model and measured data: A numerical weight representing how much importance to place on each information source when combining a physical model with measured data.
[5] An equation used with a dynamics model to compute the joint torques or external forces required to achieve a desired motion (joint position, velocity or acceleration); commonly used in biomechanics and mechanical engineering.
[6] In validation, an inverse-dynamics model was used to estimate joint torques from joint angles, velocities, and accelerations.
[7] Baseline method: A Gaussian process regression-based method commonly used in machine learning to model nonlinear phenomena.

- In validation testing with Mitsubishi Electric industrial robots, evaluations using ROC curves[8] resulted in an area under the curve (AUC) of 0.68–0.89 with the conventional method,[7] but Mitsubishi Electric's new technology achieved an AUC of 0.98–1.00, correctly classifying nearly all cases and demonstrating superior estimation accuracy.



Features of degradation estimation using physics-embedded AI



Effect of training data reduction in industrial robot validation

Future Development

Mitsubishi Electric will continue demonstration testing using actual industrial equipment and robots, aiming at applying the technology commercially in or after the fiscal year beginning in April 2027.

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About Mitsubishi Electric Corporation

With more than 100 years of experience in providing reliable, high-quality products, Mitsubishi Electric Corporation (TOKYO: 6503) is a recognized world leader in the manufacture, marketing and sales of electrical and electronic equipment used in information processing and communications, space development and satellite communications, consumer electronics, industrial technology, energy, transportation and building equipment. Mitsubishi Electric enriches society with technology in the spirit of its "Changes for the Better." The company recorded a revenue of 5,521.7 billion yen (U.S.$ 36.8 billion*) in the fiscal year ended March 31, 2025. For more information, please visit www.MitsubishiElectric.com

*U.S. dollar amounts are translated from yen at the rate of ¥150=U.S.$1, the approximate rate on the Tokyo Foreign Exchange Market on March 31, 2025

[8] A graph used to evaluate binary classifiers; its area under the curve (AUC) reflects classification performance, with larger areas indicating better discrimination.