

RESEARCH

Inside IISE Journals

This month, we feature two articles from the September issue of *IISE Transactions*, the first volume of the AI/Machine Learning for Manufacturing special issues. The first article asks in the context of additive manufacturing quality control, “Can the log files and camera images, which were already collected, be used for detecting and preventing defects as the manufacturing process progresses?” While doing feature selection, the authors found that one had to deal with the data imbalance challenge, as there are far fewer defects data than normal conditions data. They viewed feature selection through the lens of “simulation optimization” and devised several resampling methods for tackling the data imbalance issue. The second article is also about process monitoring in additive manufacturing, but it focuses on sensor fusion – namely how does one integrate various kinds of signals in the manufacturing process for better monitoring and effective quality control? The authors combined deep neural networks with mixed-effects models for capturing intricate relationships among the in-situ sensing signals. The change of these intricate relationships is usually a solid hint for the occurrence of anomalies. The authors applied their method to the process control of a metal additive manufacturing process and demonstrated that the new sensor fusion method could shorten the detection delay by half or more.

Having trouble spotting defects in your automated process because of overwhelming logfiles? Try using simulation optimization

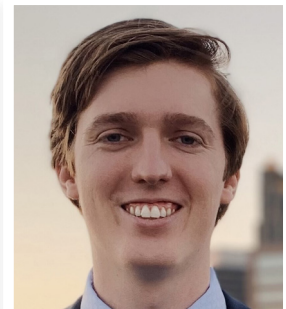
Modern technology allows us to monitor complex processes in real time, hoping to catch and avoid issues before they become problems. One such advancement is in additive manufacturing, specifically with electron beam machines (EBMs). These next-generation tools create intricate designs with minimal waste by appropriately melting the metal powder to form solid objects.

To ensure the build is consistent, process variables such as temperature, the electron beam’s path and many others must be monitored. Typically, after a build is complete, the industry standard for quality control is to use CT scanning. However, this method is both time-consuming and expensive. The question arises: Can we use the vast amounts of data collected – enormous log files and camera images – to detect and prevent defects as the build progresses rather than after it’s finished?

Machine learning can analyze this data, potentially even in real time. One traditional machine learning approach is “feature selection,” which seeks the most relevant variables to predict and interpret defects. However, machine learning methods especially struggle



Ola Harrysson



Ethan Houser



Yongseok Jeon



Sara Shashaani

when defects are rare, a situation known as “data imbalance.” Imbalance can lead to incorrect conclusions because classifiers might focus on noise rather than meaningful trends.

Researchers Ethan Houser, Yongseok Jeon, Sara Shashaani and Ola Harrysson from North Carolina State University tackled this challenge. In their study, "Predicting Additive Manufacturing Defects with Robust Feature Selection for Imbalanced Data," they treated the data from log files just as one possible version of many. By considering the generated prediction errors from selected features as random outputs linked with training and test data as the random inputs, and replicating to estimate expected performance, they view feature selection through the lens of "simulation Optimization." They proposed several ways to implement this idea by careful resampling, inspired by simulation methods, while integrating well-known machine learning tools such as LASSO and under sampling schemes.

Their approach proved effective, as the selected variables better captured trends while other common techniques failed. The innovation in this work offers a new way to tolerate noise in the data and attain better guidance toward improved efficiency and reduced costs, providing clear insights into how to correct or avoid defects during production across various industries. CONTACT: Sara Shashaani; sshasha2@ncsu.edu; Edward P. Fitts Department of Industrial and Systems Engineering, 915 Partners Way, Room 4175, Raleigh, NC 27606

Online monitoring of metal additive manufacturing process

In the rapidly evolving field of additive manufacturing (AM), achieving flawless production quality remains a critical challenge. Traditional methods often fall short in detecting anomalies during the process, leading to significant material waste and cost overruns. Despite enormous progress in embedding various sensors into the AM system, effectively fusing these sensor data for real-time anomaly detection is challenging due to the complex relationship among sensing signals, process conditions and environment.

Such in-situ AM process monitoring problem is investigated in the paper "A Deep Mixed-effects Modeling Approach for Real-time Monitoring of Metal



Zheren Song



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Additive Manufacturing Process." In this paper, Jianguo Wu and his doctoral students Ruiyu Xu, Song Huang and Zheren Song from Peking University, and Yuanyuan Gao from Nanjing University of Aeronautics and Astronautics,



Ruiyu Xu

proposed a deep mixed-effects modeling approach, which combines deep neural networks (DNNs) with mixed-effects models to capture intricate relationship among in-situ sensing signals.

This combination is effective in handling the dynamic and complex nature of metal AM processes, particularly in monitoring melt pool temperature, a crucial indicator of process stability and product quality. Based on this model, they designed efficient control charts to monitor the reconstruction errors for real-time anomaly detection. Once anomalies occur during the manufacturing process, the changes of the intricate relationships among sensing signals can be promptly detected by the proposed model, allowing for timely alerts and immediate corrective actions.

This research significantly advances the field by enhancing AM process quality assurance through real-time anomaly detection and supporting the development of closed-loop control systems. Such advancements facilitate immediate process adjustments during manufacturing, avoiding traditional post-process that are not only costly but also time-consuming. The effectiveness of the model is demonstrated by extensive simulations and real-world application studies, showing its great potential for in-situ quality control of metal additive manufacturing processes.

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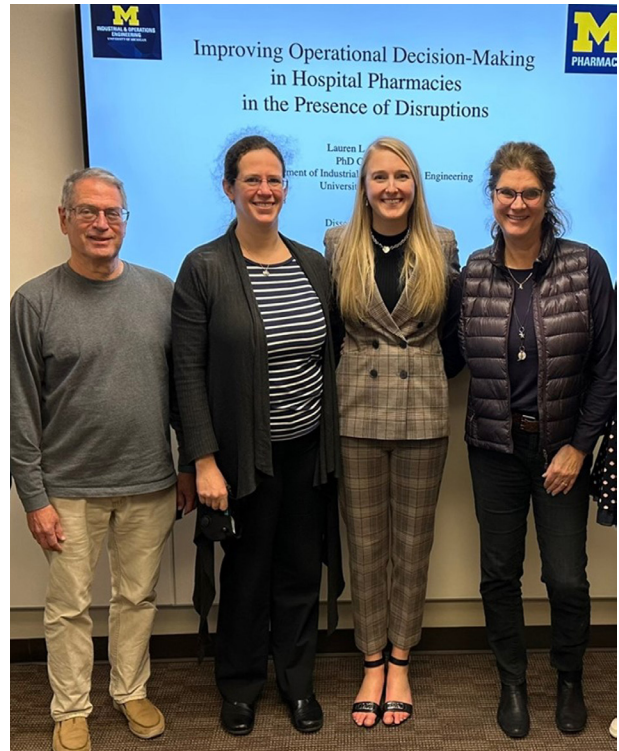
This month we highlight two articles from the month/year issue of *IISE Transactions on Healthcare Systems Engineering* (Volume 14, No. 2). The first article features University of Michigan researchers examining whether hospital network pharmacies could benefit from the practice of sharing drug inventories with another pharmacy, which is usually prohibited by regulations. They developed a modeling framework to solve integrated inventory policies and found that perishable inventory systems with supply chain disruptions may indeed benefit from sharing medicines. In the second article, researchers considered the challenge of detecting early-stage diseased tissue in the heart, as using traditional imaging techniques like CT or MRI is unreliable and directly accessing heart signals is invasive and risky. They developed a framework to identify and localize myocardial infarctions in a 3D body-heart system. The results showed a high accuracy in both defect region and system property estimation using body sensor measurements without invasively accessing the heart signals.

Drug sharing across hospital network pharmacies: Is it beneficial or not?

Managers at hospital network pharmacies (the central pharmacies that provide drugs for all hospitals in the healthcare network) make decisions for thousands of different drugs with supply chain disruptions. These managers make decisions to ensure that patients have access to the care that they need (i.e., avoid drug shortages) and that drugs are not discarded due to expiration (i.e., avoid drug waste).

To counteract instances in which a drug may be under- or overstocked, these managers may consider sharing inventory, or equivalently, operate as an integrated inventory system with another network pharmacy. However, strict regulations in current practice generally prohibit pharmacies from sharing drugs outside of their network or make it very difficult for them to stay compliant when sharing drugs outside of their network. Are these strict regulations helping or hindering the inventory system?

Lauren Czerniak, former doctoral student at the University of Michigan and current senior planning analyst at Grainger; Mariel Lavieri, associate professor at the University of Michigan; and Mark Daskin, Professor Emeritus at the University of Michigan, teamed up with



University of Michigan research team members, from left, Mark Daskin, Mariel Lavieri, Lauren Czerniak and Burgunda Sweet. Team members Jennifer Leja, Matthew Tupps and Karl Renius are not pictured.

pharmacy experts Burgunda Sweet, PharmD, assistant dean for curriculum and assessment and clinical professor at the University of Michigan; Jennifer Leja, PharmD, central pharmacy manager at Michigan Medicine and adjunct clinical faculty at the University of Michigan; Matthew Tupps, PharmD, former central pharmacy manager at Michigan Medicine and current manager of medical affairs at BD; and Karl Renius, PharmD, analytics central pharmacy manager at Michigan Medicine. They hypothesized that these strict regulations may be hindering the performance of the inventory system.

In their article, these researchers answered, "When Is It Worth It for Two Hospital Network Pharmacies to Operate as an Integrated Inventory System in the Presence of Supply Chain Disruptions?" The authors developed a modeling framework to solve for integrated inventory policies and found that perishable inventory systems with supply chain disruptions may benefit from sharing inventory. The possible benefit depends on the cost of shipping a drug between hospital network pharmacies as well as the expected duration of and time between supply chain disruptions at each site. This possible benefit of sharing inventory contradicts the strict regulations in current practice that generally prohibit hospital network pharmacies from sharing drugs or make it very difficult for them to stay compliant when sharing drugs outside of their network.

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Defect localization in 3D complex systems: How can body sensor signals be leveraged for myocardial infarction characterization?

Advancements in modern sensing techniques have enormously enhanced the data-driven modeling of complex systems. Numerous industrial applications have emerged from the data-rich environment, with defect detection being one of the most crucial for ensuring system reliability.

However, many traditional data-driven methods fall short of providing detailed characterizations of defect states, limiting their effectiveness in facilitating precision treatment plans. Moreover, certain defects, such as early-stage diseased tissue in the human heart, cannot be detected using traditional imaging techniques like CT or MRI due to the lack of obvious shape deformation, and directly accessing the heart signals is invasive and with high risk. Such limitations motivated our research to develop a robust algorithm that automates system characterization from noninvasive sensor observations.

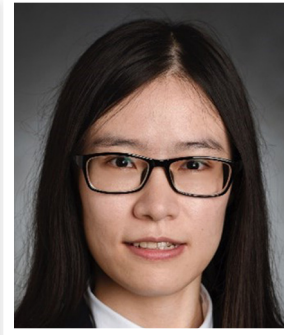
Jianxin Xie, assistant professor with the School of Data Science at the University of Virginia, and a former Ph.D. student at the University of Tennessee, and Bing Yao, Dan Doulet Early Career assistant professor with the Department of Industrial and Systems Engineering at Tennessee, present their findings in the article, "Hierarchical Active Learning for Defect Localization in 3D Systems."

They developed a hierarchical gaussian process-based active learning (HGPAAL) framework to adaptively search for possible defect locations in 3D systems with complex structured geometries. This innovative framework integrates physics-based simulation modeling and advanced data-driven methods to estimate spatial-varying system properties, enabling defect localization in complex 3D systems, such as the human heart, from noninvasive sensing observations.

The HGPAAL framework was applied to identify and localize myocardial infarctions in a 3D body-heart system. The results were promising, demonstrating a high accuracy in both defect region and system property estimation using body sensor measurements without invasively accessing the heart signals. This is not only important to reduce measurement costs and risk but also essential for precise and personalized treatment planning. This new paradigm for defect localization in complex 3D systems presents strong potential for practical applications in precision engineering system design and healthcare treatment planning.



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Bing Yao

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ABOUT THE JOURNALS

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IISE Transactions on Healthcare Systems Engineering (link.iise.org/iisetransactions_healthcare) is a quarterly, refereed journal that publishes papers about the application of industrial engineering tools and techniques to healthcare systems.

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