RESEARCH

Inside IISE Journals

This month we highlight two articles to be published in the December issue of *IISE Transactions* (Volume 56, No. 12). The first article looks into how to find a robust optimal solution. The key word is robust. Many theoretically best solutions may turn out to be far less desirable when such solutions are sensitive to the uncertainties associated with the models or noises coming from the data. The authors analyzed the concept of adversarial robustness, an idea arising in machine learning, which is to evaluate the vulnerabilities of a data science or machine learning model under various types of adversarial attacks. They applied adversarial robustness to Bayesian optimization to ensure that the worst cases could be avoided. Not only more robust, the new algorithm also outperforms traditional Bayesian optimization methods by 15% in several testing cases analyzed. The second paper studies a manufacturing problem about the finishing quality of 3D-printed parts. Unlike traditional manufacturing processes like precision machining, additive manufacturing does not yet have the capability of producing a final product with sufficient surface smoothness. Polishing is inevitable to make some or all of the parts' surfaces functioning. "Polishing or perish," the authors tell us. They treated a part's surface as a geological landscape and modeled it using a graph model. It showed that an intelligent polishing process advised by this graph model can make the final surface finishes consistent and reliable, while the polishing time is shortened and its cost lowered.

Robust optimization – don't put all your eggs in one basket

Often in life, one does not care about the single decision that gives the theoretical optimal output, but rather one prefers the decision that guarantees "good enough" results while avoiding potential for disastrous outcomes.

For example, such is the case when investing where we often hear the advice "don't put all your eggs in one basket." While investing in a single asset may yield the highest returns, it also carries tremendous risk. If the company goes bankrupt or the real estate gets hit by a natural disaster, your life savings can disappear overnight. On the other hand, being robust to negative outcomes by spreading your investments out may have lower expected returns but may still represent an excellent investment by avoiding catastrophes.

In their article, "Robust Expected Improvement for Bayesian Optimization," Ryan Christianson, Ph.D., from NORC at the University of Chicago and Professor Bobby Gramacy from Virginia Tech apply the principle of robustness to Bayesian optimization algorithms to ensure good performance for imprecise inputs. Traditionally, the goal of Bayesian optimization is to find the single maximum value that optimizes a function, ignoring robustness. The authors apply the idea of adversarial robustness to Bayesian optimization, ensuring disastrous outcomes are avoided.

Ryan Christianson

Bobby Gramacy

This robustness is highlighted on several toy example problems and a real-world example using a virtual robot pusher simulator. Robot pushers are used in automating manufacturing endeavors, to move products from one task to the next. Here, it is not important that the robot pushes to the exact target location but more so that it always gets the item to the general area such that the next task in the assembly line can still occur. If a full miss happens, the line may be shut down completely, losing out on valuable manufacturing time.

The authors' new algorithm, robust expected improvement, performs over 15% better than traditional BO methods when specifying robot parameters to push the virtual box to the target.

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Polish right or perish: A graph-based approach to intelligent finishing of 3D-printed parts

The rapid advancement of 3D printing technology has revolutionized manufacturing by enabling the creation of complex and customized components. However, achieving the desired surface finish remains a significant challenge due to the inherent roughness caused by the layering effect of the additive manufacturing (AM) process. The presence of defects and irregularities on the surface can compromise the part's structural integrity, functionality and aesthetic quality, often necessitating additional finishing processes to meet stringent performance standards.

Current polishing methods are predominantly manual and iterative, requiring frequent surface measurements. This not only increases the time and cost of production but also makes the process difficult to automate, leading to inconsistencies in the quality of the final product.

To address these challenges and automate the polishing process, doctoral students Adithyaa Karthikeyan and Soham Das, along with professors Ceyhun Eksin, Ph.D., and Satish Bukkapatnam, Ph.D., present a model to capture surface morphology evolution due to material removal and redistribution during polishing in their article, "Statistical and Dynamic Model of Surface Morphology Evolution during Polishing in Additive Manufacturing."

The surface is conceptualized as a landscape of hills and valleys, with the applied force initially concentrated on the tallest hills. As frictional heat is generated during polishing, these hills experience localized softening, facilitating material flow toward the valleys. The model uses differential equations to track changes in temperature, height and radii of the surface's hills and valleys.

A key innovation of their approach is representing surface as a graph, with its evolution during polishing quantified by the network's connectivity. The network connectivity quantifies surface smoothness allowing the marking of a clear endpoint for the polishing process. By providing a framework for model parameter estimation and validating the model with empirical data, the authors ensure its applicability across various 3D-printed materials and polishing techniques.

This approach promises to enable more consistent and reliable surface finishes, ultimately improving the quality and performance of 3D-printed parts across various industries. The impact of the research offers the potential to reduce the time and cost associated with polishing 3D-printed components, making the production process more efficient and accessible.

Research authors, from left, Adithyaa Karthikeyan, Ceyhun Eksin, Satish Bukkapatnam and Soham Das stand beside the polishing machine used for 3D-printed parts.

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This month we highlight two articles from *IISE Transactions on Healthcare Systems Engineering* (Volume 14, No. 3). The first article explores the potential use of drone technology to deliver pediatric vaccines to remote and underserved areas in low-income and middle-income countries. Modeling and data based on the nation of Niger shows promising results in demonstrating how vaccines transported by drones can enhance availability and reach where conventional logistics are challenging. The authors also note the importance of budget constraints, cold storage capacities and community accessibility in designing such distribution networks. The second article addresses the problem of long wait times, overcrowding and ambulance retention and diversion in emergency medical services. Researchers developed a discrete-event simulation model to improve patient distribution using real-world data. Their model simulates ambulance transport times considering factors such as traffic and emergency department crowding. The findings show how incorporating real-time data on crowding and traffic conditions can reduce patient waiting times, improve outcomes and enhance efficiency.

Reaching the unreachable: Drone networks transform vaccine supply chains

The motivation behind our work stems from the critical global challenge of ensuring the availability of life-

Sandra D. Eksioglu

Maximilian Kolter

Sarah Nurre Pinkley

Ruben Proano

saving pediatric vaccines in remote and underserved areas. Despite significant advances in public health, low-income and low-middle-income countries continue to struggle with the timely delivery of vaccines to children, particularly in regions with inadequate road networks and long transportation distances. Road transportation of vaccines often falls short in these environments, leading to stockouts, vaccine wastage and ultimately, lower vaccination rates. Recognizing the potential of emerging technologies, the use of drones to bridge this gap was explored.

In "Designing Drone Delivery Networks for Vaccine Supply Chain: A Case Study of Niger,", Sandra D. Eksioglu, Ph.D., and Sarah Nurre Pinkley, Ph.D., of University of Arkansas, Ruben Proano, Ph.D., of Rochester Institute of Technology, and Maximilian Kolter, a Ph.D. student at Technical University of Munich, propose a mathematical model to determine the location of drone hubs to facilitate vaccine delivery and improve access to vaccination.

The paper uses the model and real-world data from Niger, a country with rough terrain and vast rural expanses, to evaluate the impact of drone deliveries on outreach sessions in remote communities. The results are promising, demonstrating that drone-supported vaccine deliveries can significantly enhance vaccine availability and reach, particularly in areas where conventional logistics are not feasible. The findings also underline the importance of considering budget constraints, cold storage capacities and community accessibility when designing vaccine distribution networks in resource-limited settings.

As the findings of this work gain visibility, the authors hope to inspire further exploration and implementation of innovative solutions like drone technology in critical healthcare delivery systems worldwide.

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Digital twins in emergency medical services: Using simulation modeling for quicker care

With the growing demand for emergency medical services (EMS) and a shrinking number of emergency departments (EDs), there is an urgent need to improve patient distribution to prevent overcrowding, long waiting times and ambulance retention and diversion. To address this issue, Alvaro Caicedo-Rolón, Ph.D., Leonardo Rivera Cadavid, Ph.D., and David Claudio, Ph.D., developed a discrete-event simulation model using colored Petri nets, a sophisticated tool to compare two hospital selection policies: one that directs patients to the nearest hospital and another that also considers ED congestion.

The research team incorporated real-world data into their model to ensure its relevance and accuracy. They integrated historical data from Massachusetts Region 3, a diverse area with significant traffic and healthcare demand variations. To further enhance the model's accuracy, they developed a Python-based code using Google Maps API and Direction function, which accounts for real-time vehicular traffic. This allows the model to simulate ambulance transport times more realistically, providing a nuanced understanding of how different factors, like traffic and ED crowding, impact patient outcomes.

The model itself is a sophisticated integration of various components of the emergency medical system, including dispatch centers, EMS and EDs. Using statistical data on traffic congestion and ED crowding, the model can dynamically decide which hospital to send a patient to, balancing both proximity and the current state of EDs. The results of the simulations are compelling; the proposed policy, which considers both travel time and ED waiting times, consistently outperformed the traditional proximity-only approach.

The findings demonstrate that incorporating real-time data on ED crowding and traffic conditions into hospital selection processes can significantly reduce patient waiting times, leading to better allocation of ambulance patients across hospitals. This approach not only improves individual patient outcomes but also enhances the overall efficiency of the EMS.

Moreover, the research provides a strong argument

Researchers Alvaro Caicedo-Rolón and David Claudio visit a Massachusetts Region 3 Emergency Department.

for using digital twins in healthcare. By effectively modeling the complexities of the EMS system, this study lays the groundwork for future advancements in digital twin technology. These digital twins could one day revolutionize how we manage emergency responses, offering life-saving potential by enabling more informed and timely decision-making.

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