Editorial

Special Issue: Smart Manufacturing PHM

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The age of Smart Manufacturing has arrived where more and more organizations are embracing it to innovate and maintain their competitiveness. Smart Manufacturing blends information technology (IT) with operations technology (OT) to enable greater productivity, efficiency, quality, and customization within factory operations. More specifically, emerging and existing factory-floor level technologies (including robotics, machine tools, additive processes, automation, and sensors) are being fused with networking (both wired and wireless) and analysis technologies to generate more timely, accurate, and appropriate communication. This communication directly enables more intelligent sensing, monitoring, and control of the overall manufacturing system, including its constituent processes and sub-systems. Organizations that are adopting a smart manufacturing approach have become more flexible and adaptive to address changing customer demands, integrate new technologies, mitigate supply chain disruptions, and better utilize their human workforce. Prognostics and Health Management (PHM), in the context of Smart Manufacturing, focuses on the technologies and capabilities that enable health monitoring, diagnostics, and prognostics to promote greater intelligence in maintenance and control activities.

This Special Issue on Smart Manufacturing PHM contains six outstanding technical papers and one communication that collectively present a diverse range of research and practical application topics within the field of Smart Manufacturing PHM. Although Smart Manufacturing is relatively new, manufacturing has been in existence for centuries and stemmed from revolutionary innovations. The first industrial revolution is considered to have occurred in the late 1700's with the development of mechanical production equipment, water power, and steam power. The second industrial revolution transpired in the late 1800's/early 1900's with the invention of the assembly line, mass production, and electricity. The third industrial revolution occurred in the late 1960's/early 1970's with the development of information technology and automation. The fourth industrial revolution, sometimes known as Industry 4.0, can be considered synonymous with Smart Manufacturing. With that being said, the manufacturing community is leveraging new technologies and principles to improve their existing operations. Given that Smart Manufacturing did not start from scratch, the first paper in this issue, written by Jin, Weiss, Siegel, & Lee, highlights the current status and expected future growth of emerging maintenance technologies and strategies within the United States manufacturing community. This article discusses site visits and discussions with several dozen manufacturers to better understand their current capabilities, challenges, and needs with respect to increasing their PHM technologies at the factory-floor level. This effort is highlighted by the findings from six specific site visits that provide in-depth perspectives from large and small to medium-sized manufacturers as well as the perspective of a manufacturing technology provider.

Prior to applying health monitoring, diagnostic, and prognostic techniques to a manufacturing environment, it is critical to appropriately scope the problem (i.e., *What are you trying to solve?*), followed by focusing on exactly where maintenance should be performed. Two manuscripts address some of these areas. Hester, Collins, Ezell, & Horst examine problem structuring methods (PSMs) as a means to develop the problem understanding and focus to accelerate the development and application of prognostics for manufacturing. PSMs would not replace traditional prognostic methods; PSMs would enhance the scoping and definition of the problem to ultimately make it easier in applying traditional methods. The second manuscript, written by Rodrigues, provides a method to define the optimal maintenance scope of a production system that is running multiple sub-systems in series. The method determines the appropriate maintenance focus by minimizing cost per unit cycle until the next maintenance activity. Rodrigues presents a numerical example that highlights that the task of defining the maintenance scope of a system can be done more efficiently with his proposed method.

In addition to scoping the problem appropriately, it is critical to model and structure the system such that physical and functional boundaries are clearly identified, making it easier to design and deploy PHM. Choo, Adams, Weiss, Marvel, & Beling, introduce the Adaptive Multi-scale Prognostics and Health Management (AM-PHM) methodology as a means of defining a hierarchy across the overall manufacturing system. The AM-PHM methodology includes decompositions at levels below the system level, and aims to structure and organize prognostic and diagnostic intelligence that is gathered throughout the hierarchy. The methodology's ultimate goal is to enable maintenance decisions to be made in an economical way that increase operational efficiency.

Successful PHM implementations include a means of capturing available data about the health or state of a machine or process and applying analysis tools to generate performance metrics. Because of the necessity and evolution of analysis tools, the field of data analytics is providing value to the PHM community by promoting greater innovation in how large, uncertain, and/or disparate data sets are analyzed to produce meaningful metrics. O'Donovan, Bruton, & O'Sullivan present a case study that discusses an industrial analytics methodology that documents and organizes an industrial analytics ecosystem. Their paper also presents a reference architecture that facilitates an industrial analytics lifecycle. The case study focuses on an industrial analytics platform that identifies operational issues in a large-scale air-handling unit.

Thus far, all of the papers mentioned highlight techniques or approaches applicable to a broad range of domains with Smart Manufacturing. The last technical paper presents emerging research focused on PHM for industrial robotics in manufacturing environments. Qiao & Weiss present their research and initial efforts in developing the necessary measurement science (e.g., performance metrics, test methods, reference data sets) to verify and validate the performance of industrial robotic arms.

This special issue concludes with a communication from Momeni, Jin, & Ni. They propose a new approach for degradation modeling for prognostics which would be applicable to complex engineering systems. Likewise, the authors intend this approach to be valuable to structures created from emerging manufacturing processes such as additive manufacturing.

We, the editors, are confident that this special issue on Smart Manufacturing PHM will advance the state of research and development in this field through the dissemination of these research papers. We would like to express our sincere appreciation to the authors for their efforts in preparing and submitting these outstanding manuscripts. Likewise, we would like to thank the reviewers for their time and thoughtful feedback as they examined each of the submitted papers.

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