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Use Case Development to Advance Monitoring, Diagnostics, and Prognostics in Manufacturing Operations

Brian A. Weiss, Moneer Helu, Gregory Vogl, Guixiu Qiao

National Institute of Standards and Technology, Gaithersburg, MD 20899
USA (Tel: 301-975-4373; e-mail: brian.weiss@nist.gov, moneer.helu@nist.gov, gregory.vogl@nist.gov, guixiu.qiao@nist.gov).

Abstract: Manufacturing operations suffer from degradation as equipment and processes are continually used to generate products. The development and integration of monitoring, diagnostic, and prognostic (collectively known as PHM) technologies can enhance maintenance and control strategies within manufacturing operations to improve asset availability, product quality, and overall productivity. As these technologies continue to evolve, it is critical for PHM technologies to be assessed to ensure the manufacturing community is aware of the true capabilities and potential of PHM technologies. The National Institute of Standards and Technology (NIST) has developed a use case that is representative of common manufacturing operations to support the assessment of PHM technologies. This use case will produce test scenarios, reference data sets and protocols, and verification and validation tools. The use case is described including its three constituent research areas: *Manufacturing Process and Equipment Monitoring, Machine Tool Linear Axes Diagnostics and Prognostics,* and *Health and Control Management of Robot Systems.*

Keywords: diagnostics, manufacturing processes, manufacturing systems, condition monitoring, prognostics, use cases

1. INTRODUCTION

Advanced technology continues to emerge and evolve leading to increasing capabilities within manufacturing operations. Smart Manufacturing or Industrie 4.0 are focused on integrating and connecting hardware, software, and data to increase operational efficiency, asset availability, and quality while decreasing unscheduled downtime and scrap (Kagermann et al., 2013) (McKinsey, 2012) (PCAST, 2012). This translates into manufacturing operations becoming more efficient to keep up with changing consumer demand and increasing competition.

Asset availability is critical for manufacturers to output products to meet consumer demand. Unexpected downtime and lost production are 'pain points' for manufacturers, especially in that they usually translate to financial losses. To minimize these pain points, the manufacturing stakeholder community (including manufacturers, technology developers, integrators, and academic researchers) are advancing monitoring, diagnostic, and prognostic (commonly known as prognostics and health management - PHM) technologies to improve maintenance and control strategies.

The United States (U.S.) Federal Government has a research focus in advancing the means of assessing, verifying, and validating PHM technologies operating within manufacturing environments (National Institute of Standards and Technology, 2016). This effort resides at the National Institute of Standards and Technology (NIST) and includes a focus on machine tool and robotic manufacturing operations. NIST researchers are actively developing use cases, performance metrics, test protocols and reference data sets to enable the verification and validation (V&V) of PHM technologies.

2. BACKGROUND

The need for PHM is motivated by the fact that as soon as you turn on a piece of equipment or initiate a process (requiring the interaction of one or more physical entities), the system begins to degrade, ultimately causing 'wear & tear.' If unchecked, this degradation will lead to faults or failures impacting the overall quality and/or productivity of the process. The field of PHM has emerged from the study, design, and implementation of monitoring, diagnostic, and/or prognostic technologies to minimize the occurrence of failures. PHM aims to increase our knowledge of a process so that one can make better maintenance and control decisions.

2.1 Manufacturing Health and Control Management

Four maintenance strategies have been documented and applied in varying extents across the manufacturing environment. The strategies are known as reactive, preventative, predictive, and proactive maintenance (Jin et al., 2016). Reactive maintenance is the simplest form of maintenance; no maintenance is performed on the machine until a failure occurs. Although this maintenance strategy is the easiest to implement (i.e., do nothing until something breaks), it is often the most expensive strategy when considering maintenance costs, lost asset availability, lost production, and potential collateral damage. Preventative

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maintenance is when maintenance is performed on specific unit intervals (e.g., x cycles, y hours) and is widely performed in the manufacturing industry (Ahmad and Kamaruddin, 2012) (Coats et al., 2011). Predictive maintenance, sometimes known as condition-based maintenance, uses health and/or performance data captured from the equipment or process to indicate when maintenance should be performed (Byington et al., 2002) (Tian et al., 2012). There are instances of manufacturers using predictive maintenance strategies within their operations, yet this is typically incorporated in areas where data collection, and subsequent analysis, is feasible and there is a known value proposition to such a strategy. Proactive maintenance, sometimes known as intelligent maintenance, is an emerging strategy that relies upon data collection from the manufacturing process to improve and sustain the process, in addition to minimizing the occurrence of failures (Barajas and Srinivasa, 2008) (Lee et al., 2011) (Lee et al., 2006). Proactive maintenance is unique from other maintenance strategies in that it is marked by varying levels of equipment or process intelligence in terms of maintenance and control activities. Equipment or processes have some capability(ies) in performing certain maintenance activities until an appropriate human intervention can be achieved or until specific production objectives are met. Proactive maintenance is the most advanced of the maintenance strategies and is minimally employed given its state of development. Aside from implementing reactive maintenance, the implementation of preventative, predictive, and/or proactive maintenance will lead to improved health and control management of a piece of equipment or an overall process.

Apart from reactive maintenance, these maintenance strategies are each supported by monitoring, diagnostics, and prognostics (to a certain extent). Monitoring is the act of identifying, observing, or understanding the current health state of equipment or a process. Diagnostics is the determination of what is going to fail and, depending upon the system, where the failure will occur. Prognostics is the determination of the future state of the equipment or process. Prognostics is also responsible for predicting the remaining useful life (RUL) of equipment or a process (Ly et al., 2009).

The advancement of monitoring, diagnostic, and prognostic technologies has increased the development and implementation of preventative, predictive, and proactive maintenance strategies. A wide range of techniques, algorithms, and practices have been developed with varying success (Vogl et al., 2016b). Not only has PHM enhanced maintenance strategies, but it has also promoted more intelligent control of processes. Some monitoring, diagnostic, and prognostic techniques feed adaptive control strategies allowing processes to automatically adjust their performance (or output) given their current state of health (Ehrmann and Herder, 2013, Liu, 2001) (Shin and Lee, 1999). These control strategies are limited and have room for expansion.

2.2 Manufacturing Case Studies

According to the manufacturing and PHM communities, there is still much work to be done to improve monitoring, diagnostic, and prognostic practices to enhance maintenance and control strategies. NIST personnel conducted manufacturing case studies to understand the current successes and challenges to developing and implementing PHM within manufacturing operations. This information was gathered by having representatives of the manufacturing community come to NIST or by NIST personnel directly reaching out to manufacturers via phone calls or site visits.

A workshop was held at NIST that brought together small, medium, and large-sized manufacturers along with technology developers, technology integrators, academia, government, and standards development organizations to examine the challenges and barriers to advancing the state of PHM within manufacturing operations. This workshop resulted in the generation of a substantial roadmapping document that highlighted over a dozen research topics that should be undertaken to enhance the state of PHM (National Institute of Standards and Technology, 2015). The workshop presented some trends across multiple manufacturers as far as areas for improvement. Some of the common themes included the manufacturing community's desire to 1) better understand and integrate advanced sensing capabilities into equipment and processes to increase PHM, 2) identify a suite of common PHM performance metrics that would present a holistic understanding of equipment or process health, and 3) generate/access larger volumes of structured and contextualized failure data for prognostics and diagnostics to promote further maintenance strategy development (Weiss et al., 2015).

NIST personnel, and their collaborators from the University of Cincinnati and the University of Michigan – Ann Arbor, spoke/met with over 30 manufacturers representing small to medium-sized enterprises (SMEs) and large companies (Helu and Weiss, 2016) (Jin et al., 2016). Many trends, including similarities and differences, were documented between SMEs and large companies. One similarity that stands out is that no single organization used the same maintenance strategy across all of its equipment and processes. For example, some companies employed a mix of reactive and preventative maintenance strategies, while other companies employed a mix of preventative and predictive maintenance with minimal reactive maintenance. One of the biggest differences between SMEs and large companies is that an overwhelming majority of the large companies are more advanced in their maintenance strategies as compared to the SMEs. This can be attributed to the greater resources available to the large companies including more financial capital and available personnel. These manufacturing case studies also revealed some common scenarios in which implementing or increasing PHM would be beneficial to a process' asset availability, output quality, and overall productivity.

3. USE CASE DEVELOPMENT

It is imperative to generate appropriate use cases to produce test scenarios, reference datasets and protocols, and V&V tools that allow technology developers and integrators to address the manufacturing community's needs and promote the evaluation of various technology options. Six areas for