Intelligent Maintenance Systems (IMS)

A CISE-funded Center

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Platform for Prognostics and Health Management (PHM) System Development

In the field of industrial equipment health monitoring and maintenance logistics optimization, new predictive health equipment algorithms and methodologies are emerging from academia and industry. In today's industry and academia, much work focuses on either a physical health monitoring approach or a pattern recognition health monitoring approach. Both have advantages and limitations.

Application of Watchdog Agent® in monitoring ballscrews for precision machining.

With data driven technologies, predictions of maintenance needs are made from comparing actual sensory data collected from assets to historical reference patterns. With model based technologies, sensory data are compared with a physical model of the equipment to determine deviations from expected performance.

When the two approaches are combined, both accuracy of equipment degradation measures and accuracy of predictions are greatly improved. Building on the 2012 nominated works, as listed at "Assessing Equipment Performance with the Watchdog Agent®" on page 179. The University of Cincinnati has completed an important phase of model-based prognostics. Both the physical model-based and data driven prognostic approaches work together to tune each other as new sensory data arrives from monitored equipment.

The Coupled Model for prognostics and health management investigates physi-

cal model development for common mechanical components in order not only update the physical models over time but also to fuse the health monitoring result from both aspects. Effectively, the Coupled Platform combines the model-based approach with a data driven approach to bring forth the best of both methods into a single application.

National Instruments offers several products for equipment health monitoring applications. These products are influenced by the University of Cincinnati's work in the area of PHM. They benefit National Instruments' customers in that they optimize logistics of maintenance, increase revenue, and improve the reliability of operations. With the incorporation of the Intelligent Maintenance Systems (IMS) work in the areas of PHM, National Instruments' health monitoring now includes a new dimension beyond basic sensory measurements.

> **Economic Impacts**: With this breakthrough National Instruments is becoming more competitive in the equipment monitoring market. National Instruments can rely on the validation of algorithms and techniques developed by IMS to avoid more costly efforts and the need to have prognostics experts on staff to perform this work. For National Instruments to develop this Intellectual Property, they would need to employ 3 to 5 researchers full time. Beyond the monetary savings with respect to R&D cost avoidance, there is significant potential for increasing data acquisition hardware sales that are related to asset monitoring. In addition to the increased hardware sales that National Instruments will receive from these installations, end-customers should also reap the benefits of having better productivity, less unplanned downtime and outages, and more reliable power production. There will be even more widespread impacts to the economy and society by having more reliable power generation, which is one of the potential benefits from these predictive monitoring systems.

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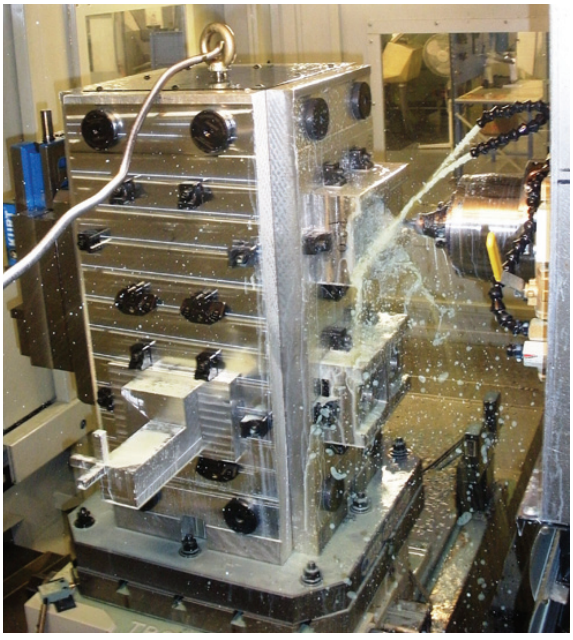
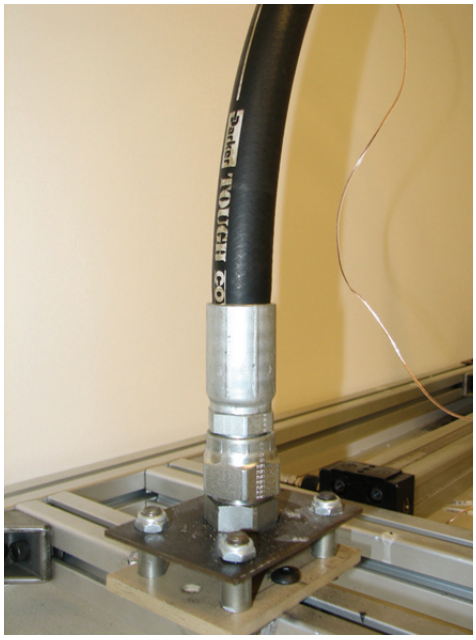
Prediction and Prevention of Hydraulic Hose Failure

The University of Cincinnati researchers from the NSF I/UCRC for Intelligent Maintenance Systems (IMS) and the NSF ERC for Revolutionizing Metallic Biomaterials (RMB) collaborated in the research and development of a smart sensor that can be utilized for flexible tube fittings (such as a hose), as well as the advanced analytics-based monitoring solution, in order to predict and prevent expensive and catastrophic hydraulic hose system failures.





IMS researchers have developed a smart sensor that has an embedded prognostics algorithms can easily attach to hydraulic hoses. The sensor monitors the degradation of hoses and automatically sends alerts when potential failures are predicted to occur.

There have been a limited number of studies involving hose prognostics, owing to the lack of an appropriate and effective sensor, both in the research and industrial communities, that can be used with hydraulic hose systems. The previous state-or-the-art inspection method was very time-consuming and costly. It was associated with the risk of catastrophic accidents most especially in high-pressure applications. As a result, there was a dire need for an intelligent hydraulic hose sensing and analysis method.

Parker Hannifin helped support the research and development of the novel sensing method and hydraulic hose health monitoring analysis methods. Parker Hannifin is one of the largest manufacturers of motion and control technologies and systems, including hydraulic systems and hoses.

The hydraulic hose health monitoring technology can be adapted for a variety of customer segments, including oil, gas, and mining applications. For customers in the oil and gas industry, having a hydraulic hose with this health monitoring capability could prevent many hose failures that could cause serious economic or environmental impacts.

> **Economic Impact:** Because the previous hydraulic hose inspection state-of-the-art method was inconvenient, time-consuming, and costly, having an intelligent sensing and analysis method can provide significant time and cost savings. This breakthrough technology has many critically important industrial applications. Significant reductions of environmental and human safety consequences related to hose failure are now possible. Across-the-board, end-users of systems that rely on hydraulic hoses will be able to realize dramatic improvements in productivity and in safer working environments. With the new technology the sensor sleeve is designed to change electrical impedance (resistance) due to fluid pressure initiating a hole through the sensor itself. The sensor sleeve will detect the earliest fluid leak when the hole penetrates the sensor and brings the two elastic electrodes in contact with each other and/or the fluid. This creates a signal path between the first electrode layer and the second electrode layer. It also changes the impedance as measured across the electrode layers. Smarter, stronger, and safer hydraulic hose systems will provide significant economic benefits to customers across many applications. Due to its predictable potential economic potential, the inventors and sponsors of this technology applied for a patent. The patent focuses on a sensor sleeve for use in detecting a failure in an article (e.g., a hydraulic hose). Patent number EP2569620 A1 was granted on March 20, 2013.

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Assessing Equipment Performance with the Watchdog Agent®

The goal of every machine user is to reap the maximum return on investment for their assets. This can be achieved with optimal equipment utilization that is characterized by high usage reliability and safer working environments for system operators.

Since 2001, and continuing through 2014 the Center for Intelligent Maintenance Systems has been pioneering research on the Watchdog Agent®, a suite of predictive analytic tools, that can be deployed to industrial equipment. Unplanned machine or process breakdowns and non-sustainable production throughputs can severely limit equipment effectiveness. Systematic methods utilizing advanced analytic tools, such as those found in the Watchdog Agent®, are needed in order to predict equipment performance over time so that failure events can be detected at their onset and avoid them altogether.

The Watchdog Agent® is a toolbox of advanced analytic tools that can be reconfigured and customized for any products or systems for which it would be beneficial to predict when and how they fail. It can be applied from a system-level (an entire equipment) down to component level (such as a valve). The Watchdog Agent®-based monitoring solutions assess and predict the performance of processes or equipment based on inputs from sensors mounted on them. System health indicators are extracted from the signals recorded from the aforementioned sensors and they are intelligently fused to generate health information, also known as confidence value (CV).

By referencing historical machine behavior degradation patterns, performance on future usage can be inferred to estimate when the next maintenance event should occur. The Watchdog Agent® toolbox covers a broad range of analysis tools so that it can be applied for a wide variety of applications including, but not limited to, wind turbines, industrial robots, machine tools, EV batteries, locomotives, and mining and construction trucks. The IMS consortium has provided necessary test-beds and domain expertise to validate the tools. Among the participants are: Siemens, Nissan, Harley-Davidson, Caterpillar, Toyota, Metron Hong Kong Limited, Bosch, BorgWarner, Tongtai, Komatsu, Daimler Chrysler, Kone, Woodward, TechSolve, P&G, Precision Machinery and Research Development, Parker Hannifin, Omron, National Instruments, Industrial Technology Research Institute, Institute for Information Industry, Hiwin, Goodyear, General Motors, Boeing, Flanders Mechatronics Technology Center, etc.

Economic Impact: The Watchdog Agent® toolbox is now available as a commercial technology through the National Instrument's LabVIEW platform. This commercialization allows users to rapidly design and develop predictive monitoring solutions for their critical assets. Industry practi-

tioners have benefitted from the Watchdog Agent® technology by having more in depth understandings of their equipment's reliability and process stability. Since its inception, the IMS Center has grown and validated the Watchdog Agent®, conducted research on innovative approaches and techniques in order to apply these new analytic tools more appropriately. The early adopters were machine end-users, but after seeing the benefits and providing reliable and therefore convincing early successes, more and more machine original equipment manufacturers are now incorporating these advanced predictive solutions into their products as built-in capabilities. In an independent study sponsored by the National Science Foundation, it was determined that the IMS Center has generated over $855 million of economic impact to its members for a year in the form of severe and catastrophic failure avoidance, productivity improvements, higher efficiency, and lower scrap rates, among others. These benefits are documented via an objective evaluation of machine performance using advanced analytics so that future failure events can be predicted and avoided.

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