MOWER 14 -10 UMES

PROGRESS REPORT

MARYLAND HIGHER EDUCATION COMMISSION (MHEC)

JUNE 15, 2015

MOWER 14-10: University of Maryland Eastern Shore

First Annual Progress Report

Submitted to

Maryland Higher Education Commission (MHEC)

June 15, 2015

1. Project Title

Maintenance Management Strategy to Produce Cost Effective Offshore Wind Power

2. Project Abstract

The current state of offshore wind energy presents economic challenges that call for concerted efforts to seek solutions and chart out future paths of technology and research that will reduce the overall cost of production of offshore wind power. Among the several things needed in order to bring down the cost and make offshore wind power more viable are: Economic modeling and optimization of costs of the overall wind farm system, including installation, operations, and maintenance and Service methodologies, remote monitoring, and diagnostics. Key parts to this are the collection of pertinent data on all components and related systems of the offshore wind farm and developing a robust health monitoring system for the operation of the turbines that will seek to reduce the cost of operations and maintenance. The research question this proposal addresses is: To what extent will an integrated health monitoring system reduce the cost of offshore wind operation and maintenance? Consequentially the sub-topical areas that will be further investigated will include: (a) To gain a better understanding of a health monitoring system algorithm for data collection and system health diagnostics resulting in devaluing quick response protocol and issues resolution methodology. (b) Identifying gaps in present day data gathering to enhance the best practice in health monitoring that will enhance the proposed health monitoring system in cost reduction (i.e. known profile, position and characteristics of the structural issues that have been resolved) to provide next generation repair and maintenance warehouse of information. And (c) Is it also possible to use the database and the health monitoring system software to correlate the results of the Environmental Impact Studies done by OSW Developers and capture additional relevant environmental issues if any that may be of concern as a result of the installation of the wind farms? This research proposal will be executed by a Principal Investigator and four (4) Co-PIs from the Departments of Technology, Engineering and Aviation sciences and Mathematics and Computer Science.

3. Project Team Members

Dr. Joseph O. Arumala – PI
Dr. Ibibia K. Dabipi – Co PI
Dr. Mohammed K. Fotouhi - Co PI
Dr. Gurdeep S. Hura - Co PI
Dr. Aaron Rababaah - Co PI

Student Members

Avinash Dudi (Graduate)
Brian Miller (Undergraduate)

4. Introduction

In a letter dated July 30, 2014, the UMES MOWER Team was informed of the review and acceptance of its supplemental application materials for the Maryland Offshore Wind Energy Research Grant Challenge (MOWER). Therefore on June 8, Team held a pre-award meeting to review the grant proposal and chart out a plan of action to execute the first year activities of the proposal. On Friday, September 12, 2014, the Team held its first meeting with Mr. Ross Tyler, Maryland Offshore Development Fund/Maryland Energy Administration, the Grant Technical Administrator. In the meeting, Mr. Tyler gave a brief history behind the Maryland's path to installing an offshore wind energy farm. He also provided information on the need to have, a policy, involve the business community, seek finance and involve an active and engaged academic community. In the discussion, Mr. Tyler wanted the Team to use literature research, meetings, and specific conferences in Operations and Maintenance to investigate the types of work that are presently underway in this critical area. The research will be conducted with an aim to understanding how any data collected may have an impact on the commercial dynamics within the Operations and Maintenance phases including potential barriers against establishing O & M independent service providers (ISPs). The purpose and possible outcome of this first phase of the project will be to:

- Tease out gaps in which data is being collected
- Seek to identify how the MOWER II project experts could focus its efforts in filling some of the identified gaps, and
- To identify how the project's team efforts could have a practical application to Maryland's Offshore Wind Farm as well as beyond

The summary of the proceedings of the September 12, 2014 meeting as submitted by Ross Tyler is shown in Appendix I.

5. Meetings

Apart from the Pre-award meeting, the Team met monthly to review progress and consolidate the efforts and activities of all members. On Friday, May 15, 2015, we had our second meeting with Mr. Tyler in which we presented an overview of the work the Team had done. We also covered efforts we were making to collaborate with the Center for Advanced Life Cycle Engineering (CALCE), University of Maryland College Park and partnering with the IBM Intelligent Operations Center (IBM IOC) and pending meetings with these groups. Among the things we discussed were our exploring collaboration and partnership opportunities with the Center for Advanced Life Cycle Engineering, University of Maryland College Park and IBM Intelligent Operations Center. We had a meeting scheduled with the CALCE group on Wednesday, May 20, 2015. We indicated that we would have liked to have some concrete information to report on these contacts in our First Year Progress Report. Consequently, we requested and was granted a 4-week delay in sending in our Progress Report so that we can pursue these prospects to some logical conclusion. This therefore puts the submission date of the Mower 14-10 First Year Progress Report on June 18, 2015.

6. Literature Review

The Team was engaged in extensive literature review of research work on Offshore Wind Farms including operations and maintenance activities. We reviewed works on turbine manufacture, turbine performance characteristics, supervisory control and data acquisition (SCADA) systems, structural health monitoring, life cycle management and sensors. SCADA is a system operating with coded signals over communication channels so as to provide control of remote equipment (using typically one communication channel per remote station). The summary of some of the papers reviewed are shown below.

K. Smarsly et al. [1] presented a Multi-agent diagnostic system for sensor and DAU malfunction Regression analysis, machine learning and data mining techniques. FFT was applied on signals and Peakfinder algorithm is applied to find the natural frequency of the structure. The data is collected via a sensor network on the structure and blades of real WTU. Sensors modalities included: 3D accelerometers, piezoelectric seismic sensor, inductive displacement transducers and temperature sensors. DAUs locally collect and relay it (using DSL) to an onsite server which in turns backs it up then communicates it to an offsite server for processing. A case study on a real

WTU for two years. Compared manufacturers claimed power efficiency to actual measured efficiency and to the optimal theoretical (called Betz limit = 0.593). They proposed a polynomial regression model of the power curves. The proposed system was said to be very useful in the overall LCM.

Ashley Crowther et al. [02] studied Load measurement and fatigue using blade strain sensors real time sensing/processing focusing on gears and bearings, continuous updated life prediction and probability of failure oil, grease and filter analysis (lubrication monitoring). SCADA data statistical analysis is used (temp, power, pitch motor currents, etc), vibration signals analysis (simulation is used to estimate the resonance freq. of gears). Sample data for one week are visualized, processed and presented. Simulated data also was used to demonstrate significance of pitch-error in gear fatigue. Captured several major failure modes. Gave good measure of harshness of operation for other failure modes. They demonstrated a case were the system was able to flag a spalling in bearings and do preventive maintenance before the problem escalates. Customized signal processing can bring a lot of benefit and traditional signal processing method work well for many failures.

K. Smarsly et al. [03] used DAUs and database backup (RAID) in remote access to on-site server. They used sensors including tower temp, wind speed, acceleration, and displacement. The study addressed the need for SHM reliability as well by having software agent-based monitoring on the different units of SHM to detect the possible software malfunctions. Case studies and scenarios for SHM reliability were presented. Examples of collected sensory data retrieved remotely were presented. They recommended that SHM reliability need to be addressed.

Douglas Adams et al. [04] studied SHM and focused on individual wind turbines at the component level. They argued that if the loading and health of individual wind turbines could be quantified, the maintenance, operation and control of each turbine could be tailored to maximize uptime by increasing the mean time between inspections and other factors that influence uptime. Proposed a four-step method: operational evaluation to understand how loading environment affects the WTU responses, data acquisition and filtering, feature extraction, statistical model for discrimination.

Berthold Hahn et al. [06], presented a paper that discussed many available condition monitoring system and comparison between sensors used in those systems. The authors also compared different analysis techniques used by these companies to analyze the collected data. They concluded that vibration monitoring is currently favored in commercially available systems using standard time and frequency domain techniques for analysis.

Fausto Pedro et al [07] discussed many available sensors in the market along with the techniques involved in collecting data and analyzing it. They presented different analyzing techniques like statistical methods, time synchronous analysis, FFT, Cepstrum Analysis, Time domain and wavelet transforms etc. are said to be helpful in signal analysis. An inventory of the available CM techniques along with signal processing algorithms has been provided and selection of a set of techniques which is feasible and better suited for WTs has been made possible.

James Carroll et al. [08] compared five sets of drive trains and gearboxes available in market and tested them under controlled conditions to see their performance. The tests are conducted on these systems with off shore and on shore wind data and failure rates. Results are tabulated according the installation site and concluded that Direct Drive Permanent Magnet Synchronous Generator with a Fully Rated Converter shows the best availability at 93.35%.

Kerri Hart et al. [09], presented a direct-drive option that can deliver the lowest Cost of Energy. They argued that permanent magnet generators have a limited track record in the wind industry (particularly offshore) and so the scenario of a generator replacement – once during the turbine's lifetime – is not unreasonable

For more details on the literature survey see Appendix II

7. Project Advisory Committee

We originally planned to form a Project Advisory Committee to comprise of two MHEC, three Industry and two UMES Officials with a total of seven members. However due to logistics, we are now planning a six member committee comprising, of one MHEC, one Industry, two UMES officials and the Project PI. The two UMES officials will be Dr. Ayodele J. Alade, Dean of School of Business and Technology and Dr. G. Dale Wesson, Professor and Vice President for Research and Economic Development & Director of the Maryland Hawk Research Foundation. We will request Mr. Ross Tyler to be the MHEC Representative. We are in contact with Liz Burdock, Managing Director of the Business Coalition for Maryland Offshore Wind, to provide us a local list of Coalition members to contact in order to select a potential industry member of the Advisory Committee.

8. Professional Meetings

8.1 International Offshore Wind Partnering Forum, Baltimore, November 12- 14, 2014

Representatives from 250 of the world's most experienced offshore wind companies attended the Business Network for Maryland Offshore Wind's International Offshore Partnering Forum in Baltimore from November 12-14, 2014. This 3-day gathering of European and American business executives, government officials, technical experts and academics consisted of over 18 separate workshops and 88 speakers. Participants came from the U.S., Germany, Denmark, United Kingdom, and Norway including Dong Energy, Siemens, Vestas, Alstom, Bladt Industries, Blue Water Shipping and A2Sea. An International and U.S. Business Partnering Session was held to assist local businesses to connect with experienced international firms. Forum participants heard from US Wind, Inc., the newly selected Maryland Wind Energy Area Developer. U.S. Wind, Inc. expects to have the turbines constructed by 2019. US Wind Inc. is investigating the variety of American companies available for subcontracting opportunities as they begin the process of finding local content to meet the MD Offshore Renewable Energy Credits (OREC) requirements. On November 12, 2014, the first day of the Forum, a Session titled MOWER I & II Maryland's Academic Institutions Advancing Offshore Wind was held. During this session, Research Groups from University of Maryland College Park, University of Maryland Eastern Shore, Morgan State University, Salisbury University and University of Maryland Baltimore County made presentations on their MOWER Grants. Our presentation was titled "Maintenance Management Strategy to Produce Offshore Wind Power". All Team members were at hand for the session. We had networking opportunities with many of the attendees.

8.2 6th Annual Offshore Wind Power USA Leaders Congress, Boston, 24-25 February 2015

Two Team members, Dr. Arumala and Dr. Rababaah attended the Congress. The Congress was very informative and we met offshore experts from Europe and North America. A report on the Congress is in Appendix III.

8.3 UMES Renewable Energy Seminar Series

Some members of the Team attended a 5 seminar series (each seminar is different) on renewable energy, presented by the University of MD Eastern Shore, with sponsorship from the U.S. Department of Energy and support from Princeton Energy Resources, International. The intended audience was anyone with interest in renewable energy including graduate and undergraduate students and researchers and anyone planning a career in renewable energy. The seminars were also intended to inform rural communities, landowners, agricultural facility operators, and homeowners about the benefits of local renewable energy generation, from rooftop solar to megawatt-scale wind turbines. The schedule was as follows:
4/14/2015 - Introduction to Renewables - Wind and Solar
4/16/2015 - Data Collection, Analysis, Resource Assessment
4/21/2015 - Project Planning, Site Selection, Impact Assessment
4/23/2015 - Grid Connection/Integration, Micro-Grids, Off-Grids
4/28/2015 - Applications, Policies, Subsidies, Economics

Team Members are also planning to attend a follow-up UMES/DOE sponsored seminar/webinar which will go into more detail on how wind resource assessment is done and how wind farms are designed to optimize performance. The seminar will be held from 1.00 p.m. to 3.00 p.m. on June 18, 2015 and will include a case study using WindPro, a leading software tool for wind developers.

Our interest and attendance in these Seminars is to position the Team members to be leaders in Renewable Energy and possibly design a course or courses in Renewable Energy

9. Collaborations and Partnerships

9.1 IBM Intelligent Operations Center

We are having talks with Jimmy Keegan and his Team at IBM Intelligent Operations Center (IBM IOC) to look at ways we can collaborate and use IBM IOC enhanced computing capacity to process BIG DATA to analyze and manage expected large volumes of sensor data from offshore wind farm components. The approach will be to collect data from systems that manage video cameras and sensors positioned throughout the Offshore Wind Farm. A solution will be designed to integrate data from multiple systems and enable access to information via a web-based portal. By integrating information, the solution is expected to help Offshore Wind Farms efficiently plan for operations and maintenance services, remotely fix problems on components and predict preemptive measures to be taken to prevent major disruption to Wind Farm productivity. Technicians and Officials in the operations room will gain a clearer and more accurate picture of O & M problems and challenges with near-real-time information presented in a single, unified view. Consequently, the Offshore Wind Farm can coordinate service and repair efforts more rapidly and efficiently to help prevent catastrophic disruption to Farm operations. Correspondences of interactions are shown in Appendix IV

9.2 Center for Advanced Life Cycle Engineering (CALCE), University of Maryland, College Park.

We first met Dr. Peter Sanborn of CALCE during the International Offshore Wind Partnering Forum in Baltimore on November 12, 2014. At that time we indicated mutual interest to meet and explore ways and areas of collaboration. We eventually met at CALCE on May 20, 2015. In attendance were the five-man MOWER 14-10 Project Team, Dr. Michael Azarian, and Dr. John Wolfe, and other CALCE Staff and Graduate Students. During the meeting, Dr. Sanborn gave an overview of CALCE and CALCE PHM (Prognostics Health Monitoring) and we were given a tour of CALCE Laboratories. Dr. Arumala and Dr. Rababaah gave an over of the MOWER 14-10 Project and progress made. The outcomes of the meeting were:

- We learnt more about the activities of each group
- There is the possibility of collaborating with CALCE to combine Structural Health Monitoring with Life Cycle Management to provide a more robust diagnostic tool for making offshore wind farms more cost effective.
- Collaborate in preparing and submitting grant proposals of mutual interest to different funding agencies.

The Agenda for this meeting and corresponding leading to the meeting are in Appendix IV

10 Webpage

A webpage has been designed for the project and is continuously being updated with relevant information. The URL for the Webpage is http://www.umes.edu/MOWER

11 Data and Sensors

In our meeting with Ross Tyler on Aril 15, 2015 we presented the challenges in obtaining data relevant to the operation and maintenance of an offshore wind farm. Our finding is that all component data are considered proprietary and therefore not available for public access. We therefore proposed that in order for Maryland to have access to such data from the offshore wind farm operators and component manufacturers it must start negotiating that access early in its deliberations with the entities involved. The data is needed to train the health monitoring system being developed. During the meeting, the Team stated that it was not looking to install sensors on the wind farm components because it will be more cost-effective to use data from the sensors installed by the component manufacturers. This means that the Team and other Maryland interested parties will have access to the data. The Team pointed out that Maryland should negotiate access to sensor data as part of the deal with designated manufacturers, installers and operator.

For our work, we believe that the data will allow us to have access to real sensor data which we can use to train the system being designed and to provide gap data during the warranty period. The monitoring model can then be used to maintain the wind farm during post warranty period.

As part of our Literature review, we also looked at the types of sensors used in wind farm components and the kind of data collected.

12 Intelligent Health Monitoring Software System Development.

Plan of Action:

The research investigation in MOWER 14-10 is mainly focused on developing and implementing a comprehensive Intelligent Health Monitoring Software System (IHMSS) that will be used as a training and information gathering tool. The aim of developing the IHMSS is to reduce the cost of maintenance and operation of Maryland offshore wind power generation. This development was designed to be carried out in multi phases:

- Phase 1 System Modeling
- Phase 2 System Training
- Phase 3 System Simulation
- Phase 4 Small-Scale Real World System Deployment
- Phase 5 Large-Scale Real World System Deployment

We have completed Phases 1 & 2 and are currently working on Phase 3 System Simulation. A brief description of these three phases are shown below:

Phase 1 **System Modeling**

Based on the proposed model (Figure 1), we will develop the software that accept inputs/ implement different real world system components including: sensors, data sink, server, clients, etc. Then these components will be integrated so that they will function as the intended system.

Phase 2 **System Training**

The training and the intelligence of machine learning component of the system will be accomplished through building signal samples that are statistically significant, establish training sample set and testing sample space to train the system and evaluate its preliminary reliability in detecting and classifying structural anomalies.

Phase 3 **System Simulation**

Virtual scenarios of normal and abnormal/anomalous structural states will be simulated and fed into the system to investigate the system capability of recognizing and reporting properly the registered events. The success and satisfactory result of this stage will give us a confidence to move forward with small-scale real world system deployment.

In the Figure 1 below, we have highlighted (green-shaded area and dash line) our current stage of the model development which include the following components:

- **Signal normalization**: it is an important step where all signal vectors need to be amplitude normalized by transforming them linearly to the scale of [0, 1] so in the training phase the classifier can be trained with a consistent data set.
- **Signal segmentation**: signals are recorded in real time and can be very lengthy which is inappropriate for signal processing techniques therefore, a systematic time-window is used to crop the signals into uniform size to be processed into feature vectors in the next stage.
- **Feature extraction**: the segmented signals are processed by two techniques: FFT and DCT to characterize their features and represent them in a vector form.

- **Vector space formation**: the input set of vector are organized into two vector spaces: training set which usually 75% of the original set and testing set which is typically 25% of the original set. Both sets are used to train/test an intelligent agent (Neural network, fuzzy logic, etc.).

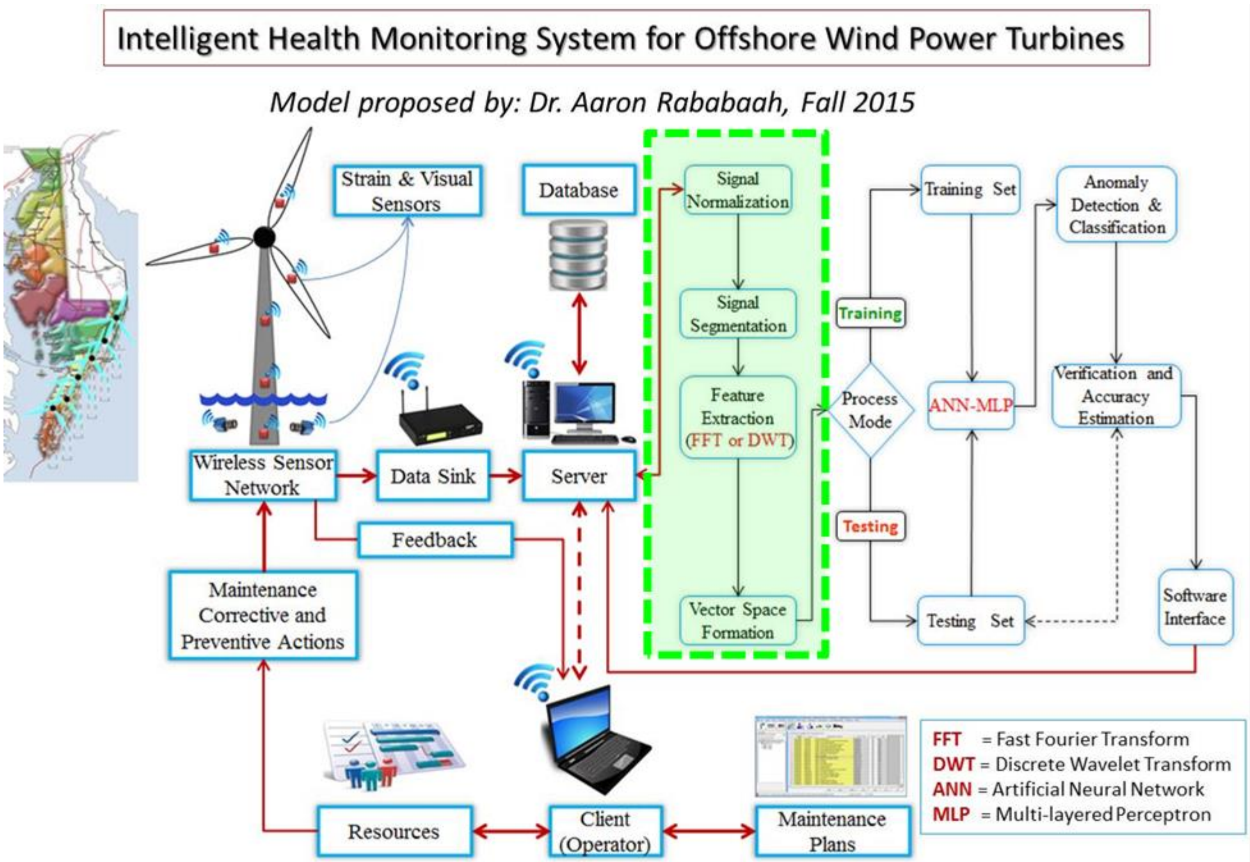

Figure 1 Intelligent Health Monitoring Software System (IHMSS) Development

13. NREL Turbine Test Data

We obtained Turbine Gear Box test data for "Healthy" and "Damaged" gear boxes from National Renewable Energy Laboratories (NREL). We are currently using this data to train our model to differentiate between sensor signals from healthy and damaged gear boxes.

With demand for energy raising every day and climate change in mind a reliable renewable energy resource is what in need of hour. Wind energy provides that alternative with only small share of its huge potential utilized on both off and on-shore there is a lot of untapped potential which can be harnessed. With no noise pollution, eco-friendly and much more consistent frequency of strong winds offshore wind farms trounced onshore wind farms. Even with these advantages offshore is not immune to all the operation and maintenance overburdens. Considering turbine gearbox failures are leading reasons for higher maintenance costs in offshore wind farms we consider this stage very vital in developing the proposed health monitory system.

We are analyzing signal data using different characterization techniques (DFT, DCT) and comparing them to find the better performing method in failure events classification. The identified signal patterns are then fed to a classifier for classifying (decision making) as normal or faulty. Our goal is to find characterization and classification techniques which are effective and efficient in identifying and predicting anomalies in system through signal processing techniques. Our preliminary investigation included applying FFT and DCT on the raw signal data after signal segmentation to generate a space vector of both characterization techniques. The two space vectors are then tested with two vector similarity measures of Pearson correlation coefficient and Euclidean distance. The results of these experiments revealed that the Euclidean distance measure was superior to the correlation-based method in separating the healthy from damaged signal vectors with an average ration of 10% to 50% respectively. Some preliminary results are shown in Appendix V

14. Conclusion

Proposed Intelligent Health Monitoring System for Offshore Wind Power Turbines (IHMS-WPT)

The concept of the proposed IHMS-WPT system is based on the model illustrated in Figure 1 below. The model consists of five main components including: the sensor network attached (or embedded in) to the structure of the wind turbine, the server that manages the data collection and database maintenance, the intelligent anomaly detection and classification software, the client (operator) that interacts with the server, resources and maintenance plans to issue needed corrective and preventive actions, and the resources available to the entire system to be used upon request by the client. These components are discussed as follows:

Wireless Sensor Network

A network of sensors is deployed on the structure of the turbine to monitor the current structural health of the wind turbine. The modalities of the sensors include vibration, stress, strain and visual. The sensors collects data periodically and wirelessly transmit it to a data sink which temporarily buffers all data collected from all sensors and wirelessly transmit them to the server which in turns, permanently archives streams of collected sensor readings in a database to be used in the analysis phase of the intelligent software system.

The Server

The server is a computer node that coordinates and maintains the sensors readings in a database. This database can be remotely queried by the client operator. The database is used by the intelligent software system for data analysis and inferences needed for further decision making and actions based on the anomaly detections.

The Client Operator

The client is a computer node that provides an operator to access the server and database remotely in teal time and query the current and archived status of the sensor readings. Further, the client can manage the operation of the intelligent system and collect results and issue reports to schedule maintenance plans for the wind turbine structure. The client operator has access to the available resources of the system to task them to do the recommended maintenance plans.

The Intelligent Software System

The software system integrates two techniques to achieve reliable anomaly pattern detection and classification. These techniques are Digital Signal Processing (DSP) and Artificial Neural Networks (ANN). For the DSP, the Fast Fourier Transform (FFT) and the Discrete Wavelet Transform are used to denoise and characterize the sensor signals. For the ANN, the Multi-Layered Perceptron (MLP) is used as classification network for the characterized signals of the sensors.

The online monitoring system using sensors will reduce the cost and improve life / health and safety of operation and maintenance by considering following factors:

- Reducing the frequent of offshore trip and transport / transferring equipment to the site
- Save time
- Reducing the frequency of exposure of maintenance crew to potential hazardous activities
- Remove and minimize critical decision making away from Maintenance Crew facing the emergencies site and transfer it to The high level trained and expert people for situations
- Provide several Central Monitoring locations , that they can share their inputs , expertise, scheduling and managing the emergencies
- Improve the mythology of operation and maintenance and reduce the interference and redundancies

Cost reduction in operation and maintenance should not be detrimental to safety of operation and the health of systems.

CONCLUSION

LITERATURE REVIEW

CONCEPTUAL MODEL

NREL DATA SET AND ANALYSIS USING SIGNAL PROCESSING TECHNIQUES

NREL MEETING

MAKE CONTACTS FOR NEW SOURCES OF DATA

FIND OUT NREL'S NEW PROJECTS

DOCUMENT DERTAILS MD GROUP MEETINGS

OUTCOMES OF MEETING

APPENDICES

APPENDIX 1

Summary of October 12, 2014 meeting with Ross Tyler

From: Ross Tyler -MEA- [mailto:ross.tyler@maryland.gov]
Sent: Tuesday, September 16, 2014 11:29 AM
To: Arumala, Joseph O
Cc: Dabipi, Ibibia K; Fotouhi, Kenny M; Hura, Gurdeep S; Rababaah, Aaron R; Vann, Melinda
Subject: Re: MOWER 14-10

MOWER 14-10

Gentlemen

It was good to meet you on Friday and to share some of the history behind Maryland's path to installing offshore wind and to creating a new and important industry within the state. I hope the backdrop I provided with the need to have: i) policy, ii) the business community, iii) finance and iv) an active and engaged academic community, helps underscore the importance of the work you are about to conduct.

Within our kick-off meeting, my understanding is that we agreed the first step for the project will be to use the next 6 to 9 months to investigate the data and sensors used in the creation of the offshore wind facility, specifically within and possibly prior to the warranty period. Typically, for the primary components, the initial warranty period is 5 years.

We also discussed the growing importance of the operational and maintenance (O&M) phase of the offshore wind facility which typically is expected to cover a minimum of 20 years. The latest thinking in Europe is that the data collected for the early history of the components in the warranty period, including the time they are manufactured, stored and transported prior to installation (pre-warranty period), could have a significant impact on their performance and without such history, there is a real or perceived higher risk associated with taking on the O & M functions in the post-warranty period.

The MOWER 14-10 team will look to use literature research, meetings, specific conferences such as the O&M conference in Hamburg and / or the EWEA 2015 conference in Copenhagen to investigate the types of work that is presently underway in this critical phase. The research will be conducted with specific aim of understanding how any data collected may have an impact the commercial dynamics within the O & M phase, including potential barriers against establishing O & M independent service providers (ISPs).

The purpose and possible outcome of this first phase of the project will be to: i) tease out gaps in where data is being collected, ii) seek to identify how the MOWER II project experts could focus its efforts in filling some of the identified gaps and iii) to identify how the project's team efforts could have a practical application to MD's OSW farm as well as other's beyond.

Please remember that I am here to help support your work. Call for help, assistance or a just a chat at any time.

Please let me know if this meeting summary is not reflected accurately or if I have omitted anything.

Many thanks for your interest in MD's offshore wind. I look forward to continuing to working together.

Ross

Please note my new e-mail address is Ross.Tyler**@maryland.gov**.

Follow us on Twitter!

Ross Tyler / Maryland Offshore Development Fund
D: 443 694 3077/ Ross.Tyler@maryland.gov

Maryland Energy Administration
O: (410) 260-7655 / F: (410) 974-2250
60 West Street, Suite 300, Annapolis, MD 21401

On Sun, Aug 24, 2014 at 9:46 PM, Arumala, Joseph O <joarumala@umes.edu> wrote:

Dear All,

In respect of the our project a meeting is being set up to meet with Mr. Ross Tyler of Maryland Offshore Development Fund/Maryland Energy Administration as follows:

Date: September 12, 2014

Time: 8:00 a.m.

Venue: Arts & Technologies Conference Room

Let us be prepared to give an update on your assignments for this period of the grant.

Thanks

Joseph O. Arumala

APPENDIX II

Literature Review Summary

MOWER 2014

Literature Review

Acronym Glossary

SHM: Structural Health Monitoring
LCM: Life-Cycle Management
WTU: Wind Turbine Unit
DAU: Data Acquisition Unit
DSL: Dedicated Subscriber Line
FFT: Fast Fourier Transform
FEM: Finite Element Modeling
WE: Wend Energy
WWEA: World Wind Energy Association

#	Yr	Need & Motivations	Technical Approach	Testing	Conclusions
01	2012	▪ Schedule maintenance work at minimum associated life-cycle costs ▪ Capture the structural behavior of wind turbines and to reduce uncertainty ▪ Continuous updating structural loads for accurate life-cycle management ▪ 83 countries uses WEG, Europe saves €6 Billion/year = 106 Million tons of CO_2 = 25% cars in Europe. ▪ Unmanned remote facilities being exposed to large numbers of load cycles that cause high mechanical stress on the structures.	▪ Multi-agent diagnostic system for sensor and DAU malfunction ▪ Regression analysis, machine learning and data mining techniques ▪ **FFT** is applied on signals ▪ **Peakfinder** algorithm is applied to find the natural frequency of the structure ▪	▪ Data is collected via a sensor network on the structure and blades of real WTU ▪ Sensors modalities: 3D accelerometers, piezoelectric seismic sensor, inductive displacement transducers and temperature sensors. ▪ DAUs locally collect and relay it (using DSL) to an onsite server which in turns backs it up then communicates it to an offsite server for processing. ▪ Case study on a real WTU for two years	▪ The system computes natural frequency very closely to well established techniques such as FEM. ▪ Compare manufacturers claimed power efficiency to actual measured efficiency and to the optimal theoretical (called Betz limit = 0.593) ▪ Proposed a polynomial regression model of the power curves. ▪ The proposed system was said to be very useful in the overall LCM.

		▪ Damage can reliably be identified before it reaches critical levels ▪ Reactive maintenance is about 500% more costly Preventive maintenance ▪ Research in SHM & LCM is still in its infancy			
02	2012	▪ **ROMAX** technology ▪ Number of integrated technologies are presented in this paper ▪ Good and detailed common WTU problems and failures	▪ Load measurement and fatigue using blade strain sensors ▪ Real time sensing/processing focusing on **gears** and **bearings** ▪ Continuous updated life prediction and probability of failure ▪ Oil, grease and filter analysis (lubrication monitoring) ▪ **SCADA** data statistical analysis is used (temp, power, pitch motor currents, etc ▪ Vibration signals analysis (simulation is used to estimate the resonance freq. of gears)	▪ Sample data for one week are visualized, processed and presented ▪ Simulated data also was used to demonstrated significance of **pitch-error** in gear fatigue	▪ Captures several major failure modes ▪ Gives good measure of harshness of operation for other failure modes ▪ Tune with combined statistical approach as farm ages ▪ Demonstrated a case were the system was able to flag a spalling in bearings and do preventive maintenance before the problem escalates. ▪ Customized signal processing can bring a lot of benefit ▪ Traditional signal processing method work well for many failures
03	2012	▪ WE is the fastest growing renewable energy resources ▪ key considerations: availability, reliability, and profitability ▪ Systematically monitoring for potential damages and deteriorations	▪ DAUs and database backup (RAID) ▪ Remote access to on-site server ▪ Sensors: tower temp, wind speed, acceleration, displacement, ▪ Addressed the need for SHM reliability as well by having software agent-based monitoring on the different units of SHM to detect the possible software malfunctions.	▪ Case studies and scenarios for SHM reliability were presented ▪ Examples of collected sensory data retrieved remotely were prsented	▪ SHM reliability need to be addressed ▪
04		▪ SHM focuses on individual wind turbines at the component level ▪ If the loading and health of individual wind turbines could be quantified, the maintenance, operation and control of each turbine could be tailored to	▪ Four steps method: operational evaluation to understand how loading env. Affects the WTU responses, data acquisition and filtering, feature extraction, statistical model for discrimination.	▪ Simulated data and real data collection	▪ The section (3.1) operational evaluation need a careful review and understanding

		maximize uptime by increasing the mean time between inspections and other factors that influence uptime.			
05	2007	▪ One of the most **important** papers in the area. 15 years of experience in WE presents a comprehensive analysis of types of failures in wind turbines	▪	▪	▪
06	May 2014	▪ One of the most recent survey papers on commercially available condition monitoring systems.	▪ Paper discussed man y available condition monitoring system an d comparison between sensors used in those systems. Authors also compared different analysis techniques used by these companies to analyze the collected data.	▪	Authors concluded that Vibration monitoring is currently favoured in commercially available systems using standard time and frequency domain techniques for analysis.
07	2012	▪ This paper is a collection of comprehensive conditioning monitoring techniques available in market along with sensors and type of sensors ban used or already in use. Also gives a much needed insight into different analyzing techniques for data collected.	▪ Paper discussed many available sensors in the market along with the techniques involved in collecting data and analyzing it.	▪ Different analyzing techniques like statistical methods, time synchronous analysis, FFT, Cepstrum Analysis, Time domain and wavelet transforms etc. are said to be helpful in signal analysis.	An inventory of the available CM techniques along with signal processing algorithms has been provided and selection of a set of techniques which is feasible and better suited for WTs has been made possible.
08	2014	This paper is providing the creation and adaptation of new and current availability models, this paper provides an availability overview for a number of different offshore drivetrain configurations.	▪ Authors compared five sets of drive trains and gearboxes available in market and tested them under controlled conditions to see their performance.	▪ Tests are conducted on these systems with off shore and on shore wind data and failure rates.	▪ Results are tabulated according the installation site and concluded that Direct Drive Permanent Magnet Synchronous Generator with a Fully Rated Converter shows the best availability at 93.35%.
09	2011	▪ This study provides a comparison between four different drivetrain configurations using permanent magnet generators. ▪ The paper investigates geared and direct drive train models for wind turbines.	▪ A direct-drive option can deliver the lowest Cost of Energy. ▪ Permanent magnet generators have a limited track record in the wind industry (particularly offshore) and so the scenario of a generator replacement – once during the	▪ Testing is based on equations generated by using *Fingersh et al.* and results are generated in MATLAB.	▪ The higher speed generator drivetrains faired much worse under the baseline and other scenarios.

		▪ Cost difference between these models are compared .	turbine's lifetime – is not unreasonable		
10	2012	This paper presents the analysis of wind and wave data collected at an offshore wind farm in the North Sea and discusses how we might extract weather window and waiting time information to support availability growth modelling.	▪	▪ Models for different scenarios are constructed and tested for different seasons to calculate waiting time to service three different levels of failures.	▪ Data results shows that during winter waiting time much more than during summer season.
11	2013	In this paper authors are proposing and testing a method for detecting faults in wind turbines using the existing SCADA system.	▪ Data is analysed using partial least sum and cumulative sum algorithms.	Using PLS models for modelling the relationship between different measurements faults in turbines are detected. CUSUM algorithms are used for evaluating the residuals from the turbines.	▪ Identification of the faults where approximately one month ahead of the services. ▪ This model can be extended to other types of data and detection of failures in different structure/parts of turbine.
12	2012	A pattern recognition algorithm used to is used to model baseline behaviour and measure deviation of current behaviour, where a Self-organizing Map(SOM) and minimum quantization error (MQE) method is selected to achieve degradation assessment.	▪ Spectral Kurtsosis filtering for reducing noise and wavelet energy analysis are used for pattern recognition in	▪ RMS, kurtosis and crest factor are time domain features which are used for testing.	▪ Regarding wavelet transform for feature extraction, the selection of mother wavelet function is crucial for obtaining the optimal decomposition results.

REFERENCES

[01] K. Smarsly, K. H. Law and D. Hartmann, "*Towards Life-Cycle Management Of Wind Turbines Based On Structural Health Monitoring*.", Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, USA, 2012.

[02] Ashley Crowther, "*Using Prognostics and Diagnostics for Wind Farm Health Monitoring*", US Wind Technical Center, Boulder, CO, 2012.

[03] K. Smarsly, K. H. Law and D. Hartmann, "*Structural health monitoring of wind turbines observed by autonomous software components – 2nd level monitoring*", Stanford University, CA, USA, 2012.

[04] Douglas Adams, Jonathan White, Mark Rumsey and Charles Farrar, "*Structural health monitoring of wind turbines: method and application to a HAWT*", Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/we.437, 2011.

[05] Berthold Hahn, Michael Durstewitz, Kurt Rohrig, *"Reliability of Wind Turbines, Experiences of 15 years with 1,500 WTs"*, Institut für Solare Energie versorgungs technik (ISET), Verein an der Universität Kassel e.V., 34119 Kassel, Germany, 2007.

[06] Crabtree, C.J. and Zappala, D. and Tavner, P.J ,"*Survey of commercially available condition monitoring systems for wind turbines*", Technical Report. Durham University School of Engineering and Computing Sciences and the SUPERGEN Wind Energy Technologies Consortium.

[07] Fausto Pedro García Márquez a,, Andrew Mark Tobias b, Jesús María Pinar Pérez a, Mayorkinos Papaelias,"*Condition monitoring of wind turbines: Techniques and methods*" Ingenium Research Group, Universidad Castilla-La Mancha, 13071 Ciudad Real, Spain and University of Birmingham, Birmingham B15 2TT, United Kingdom.

[08] James Carroll, Alasdair McDonald, Julian Feuchtwang, David McMillan, "*Drive train availability in offshore wind turbines* ",University of Strathclyde, Glasgow.

[09] Kerri Hart , Alasdair McDonald, Henk Polinder, Edward Corr James Carroll, "*Improved cost of energy comparison of permanent magnet generators for large offshore wind turbines ",* University of Strathclyde, Glasgow.

[10] J. Dowell, A. Zitrou, L. Walls, T. Bedford, D. Infield, "*Analysis of Wind and Wave Data to Assess Maintenance Access to Offshore Wind Farms"* ,University of Strathclyde, Glasgow.

[11] Anders Bech Borchersen, Jesper Abildgaard, Larseny Jakob Stoustrupz ,"*Predicting Faults in Wind Turbines using SCADA Data* ",Vattenfall R&D, 7000 Fredericia, Denmark and Department of Electronic Systems, Section of Automation and Control,Aalborg University, 9220 Aalborg, Denmark

[12] Wenyu Zhao, David Siegel, Jay Lee and Liying Su, "*An Integrated Framework of Drivetrain Degradation Assessment and Fault Localization for Offshore Wind Turbines"* University of Cincinnati, Ohio, U.S.A- 45221-0072.

APPENDIX III

The Offshore Wind Power Leaders Congress Report

The Offshore Wind Power Leaders Congress showcased the expertise of leading offshore pioneers representing a strong cross-section of the who's-who in the North American and European wind industry. The **Agenda** featured an exclusive Q&A session with the Bureau of Ocean Energy Management (BOEM), new Director, **Abigail Ross Hopper, appointed by Interior Secretary Sally Jewell.** She comes to BOEM from the Maryland Energy Administration with a broad background in energy management. The sessions included:

1. The New York State Clean Energy Policy – Tool for getting Renewable on the Grid.
2. Policy Roadmap Panel Discussion: Exploring Plausible Avenues for Reducing Uncertainty by Creating State-Level Mechanisms to Drive Industry Investment.
3. State Debate: Getting Buy-In and Developing a Comprehensive Infrastructure Plan to Ensure Investment Infrastructure and reduce the Effects of Political Resistance.
4. Technical Lessons from 20 Years of EU Experience Transferable to the US to save time and money without recreating the Wheel!
5. What will Attract EU Developers to the US Market and how will they participate.
6. Achieving Economies of Scale for the US Market – What will it look like and how do we get there?
7. Pieces of the Puzzle: Creating Local Jobs and Developing a Skilled Workforce to Drive Public Support and ultimately drive down long-term Supply Chain Costs.
8. Managing Risk in the Project Development Cycle and the Associated Dollars, Minimize Liability and Manage Uncertainty.
9. Developing Cost-Effective Foundations for Offshore Wind to Drive Down Overall Cost.

Contacts

1. Jens Eckhoff, President, German Offshore Foundation & Wind Energy Agency
2. Dr. Willett Kempton, Professor, University of Delaware's School of Marine Science and Policy
3. Jeff Grybowski, CEO Deepwater Wind
4. Habib Dagher, Director, Advanced Structures and Composites Center, University of Maine

Agencies

1. BOEM – Bureau of Ocean Energy Management
2. DOE – Department of Energy - 5 Offshore Demonstration Projects: Show case Technology, Provide Regulatory Pathway, and Assist Investors. Workforce Training Program – Welding, Lathe Technicians, Logistics
3. NYSERDA – New York State Energy Research and Development Authority. Report on Offshore Wind Power for New York Provides Roadmap for Reducing Costs. Reaching Potential of Utility-Scale Clean Energy.

Some Important Facts

- Reduction of O & M and financing costs offer the largest single potential savings (Reduction up to 20%)
- Cost reduction comes through volume. Volume needs confidence, confidence needs constant policies (Andrew Garrand, Windkracht 14)

- Total Wind Farm Project Life: 27 – 37 Years.
- AWEA Offshore WINDPOWER 2015 Conference & Exhibition, September 29 - 30, 2015, Baltimore, MD
- America's first planned utility scale offshore wind farm. 130 turbines was to be located on Horseshoe Shoal, Nantucket Sound off the coast of Cape Cod, Cape Cod, MA, was joined July 2009.

APPENDIX IV

Correspondences with CALCE & IBM IOC

CALCE

From: Arumala, Joseph O
Sent: Wednesday, May 20, 2015 12:32 AM
To: 'Peter Sandborn'
Subject: RE: Can you present your MOWER work when you visit us on May 20?

Thanks

From: sandbornroad@gmail.com [mailto:sandbornroad@gmail.com] **On Behalf Of** Peter Sandborn
Sent: Tuesday, May 19, 2015 10:07 AM
To: Arumala, Joseph O
Subject: Re: Can you present your MOWER work when you visit us on May 20?

Joseph,

No problem. I will increase the lunch reservation to account for me people.

Peter

On Tue, May 19, 2015 at 10:01 AM, Arumala, Joseph O <joarumala@umes.edu> wrote:

Peter,

Thanks for the Agenda. It appears we did not communicate with you well, Our Team of five plan to be in the meeting tomorrow. I hope this does not cause any difficulties.

Thanks

Joseph

From: sandbornroad@gmail.com [mailto:sandbornroad@gmail.com] **On Behalf Of** Peter Sandborn
Sent: Tuesday, May 19, 2015 7:01 AM
To: Arumala, Joseph O
Cc: Michael Azarian; Dabipi, Ibibia K
Subject: Re: Can you present your MOWER work when you visit us on May 20?

Joseph,

Thank you for the title and abstract. The agenda for your visit is below. The meeting location is 2111 Potomac Building

10 am Arrive

10 am CALCE and CALCE PHM overview

11 am UMES Presentation

Noon Lunch - Adele's (Arumala, Ibibia, Azarian, Sandborn, Baeder)

1 pm CALCE Lab tour

1:45 pm Wrap up

2 pm Depart

Ross Tyler indicated that he may stop by at the end of the agenda.

Peter

On Mon, May 18, 2015 at 5:04 PM, Arumala, Joseph O <joarumala@umes.edu> wrote:

Peter,

Please find attached the title and abstract for the presentation. We are looking forward to the meeting on Wednesday.

Thanks

Joseph

From: sandbornroad@gmail.com [mailto:sandbornroad@gmail.com] **On Behalf Of** Peter Sandborn
Sent: Monday, May 18, 2015 10:15 AM
To: Dabipi, Ibibia K; Arumala, Joseph O
Cc: Michael Azarian
Subject: Fwd: Can you present your MOWER work when you visit us on May 20?

Ibibia, Joseph,

I know you are probably busy with final exams, but could I get a title (and maybe a 1-paragraph abstract) from you for your visit on Wednesday. We have set aside an hour for you to present what you are doing for your MOWER grant.

Peter

---------- Forwarded message ----------
From: **Peter Sandborn** <sandborn@umd.edu>
Date: Mon, May 11, 2015 at 1:18 PM
Subject: Can you present your MOWER work when you visit us on May 20?
To: "Dabipi, Ibibia K" <ikdabipi@umes.edu>
Cc: Michael Azarian <mazarian@calce.umd.edu>

Ibibia,

We want to plan a seminar (~1 hour) for you to present what you are doing under your MOWER II contract with the State of Maryland when you visit us on May 20. Can you send me a title and abstract that I can circulate to our group.

Peter

Peter Sandborn
Director - Maryland Technology Enterprise Institute (Mtech)
Professor - Department of Mechanical Engineering
University of Maryland
(301) 405-3167
sandborn@umd.edu

IBM IOC

From: Paul Wojciak [mailto:wojciak@us.ibm.com]
Sent: Friday, May 29, 2015 9:15 AM
To: Arumala, Joseph O
Cc: Osman, Abuobida E; Alade, Ayodele J; Dabipi, Ibibia K; James P Keegan
Subject: RE: Intelligent Operations Center Follow up

Hello Dr. Arumala,

So good to hear from you. Another year of success at UMES eh?

Jimmy and I exchanged some info and he'll be contacting you to arrange next steps. He's got to pull some things together with his team first.

When we spoke briefly in April, I believe you said that we should aim to have the proposal together by the end of the summer. If that time line remains or if there are adjustments necessary, please let us know.

Regards,
woj

Paul A. Wojciak

STSM - CAMSS System Test Architect
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IBM Systems

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E-mail: wojciak@us.ibm.com
Chat: paul.wojciak
Find me on:

2455 South Rd
Poughkeepsie, NY 12601-5400
United States

From: "Arumala, Joseph O" <joarumala@umes.edu>
To: James P Keegan/Baltimore/IBM@IBMUS
Cc: Paul Wojciak/Poughkeepsie/IBM@IBMUS, "Alade, Ayodele J" <ajalade@umes.edu>, "Dabipi, Ibibia K" <ikdabipi@umes.edu>, "Osman, Abuobida E" <aeosman@umes.edu>
Date: 05/18/2015 05:26 PM
Subject: RE: Intelligent Operations Center Follow up

Hi Jimmy,

Thanks for our interactions on the wind farm. It is not for lack of interest that I have not gotten back to you till now, but the current semester was kind of hectic for us. Now that it is over, we want to actively explore and pursue the partnership with your group. Our Team is ready and I want to find out when next we can continue the conversation. We are looking forward to hearing from you soon.

Joiseph
Dr. Joseph O. Arumala, P.E., F. ASCE
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Construction Management Technology Program
Department of Technology
11931 Art Shell Plaza
Room 1117 Art and Technology Center
University of Maryland Eastern Shore
Princess Anne, Maryland 21853
Tel: (410) 651-6472, Fax (410) 651-7959
Princess Anne, MD 21853-1299
E-mail: joarumala@umes.edu

From: James P Keegan [mailto:jpkeegan@us.ibm.com]
Sent: Tuesday, March 10, 2015 4:54 PM
To: Arumala, Joseph O
Subject: Intelligent Operations Center Follow up

Dr. Arumala,

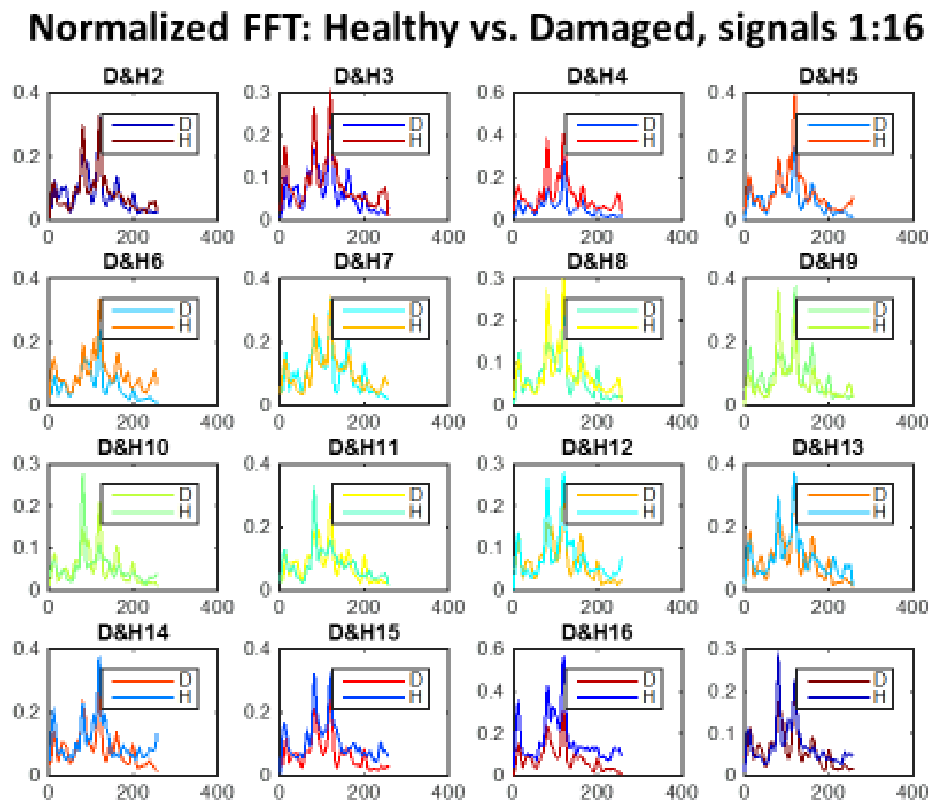
I have spoken extensively with my team regarding IOC for the wind farm management as we discussed last month. We feel like it is a great use of the technology. It can be used to manage any form of data you want it to. I have attached the white paper for the solution, and I would love to set up another meeting to go through it in a bit more detail. Please let me know when is a good time for you to have another conversation, and I will bring together some of the members of my team to discuss it with you. Thank you for your time and interest.

Jimmy Keegan
Brand Specialist - i2 & IOC

Phone: 240-848-1448
E-mail: jpkeegan@us.ibm.com

APPENDIX V

Results of Using Monitoring Model on NREL Gearbox Test Data


Normalized FFT: Healthy vs. Damaged, signals 1:16
D&H2
D&H3
D&H4
D&H5
D&H6
D&H7
D&H8
D&H9
D&H10
D&H11
D&H12
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D&H14
D&H15
D&H16
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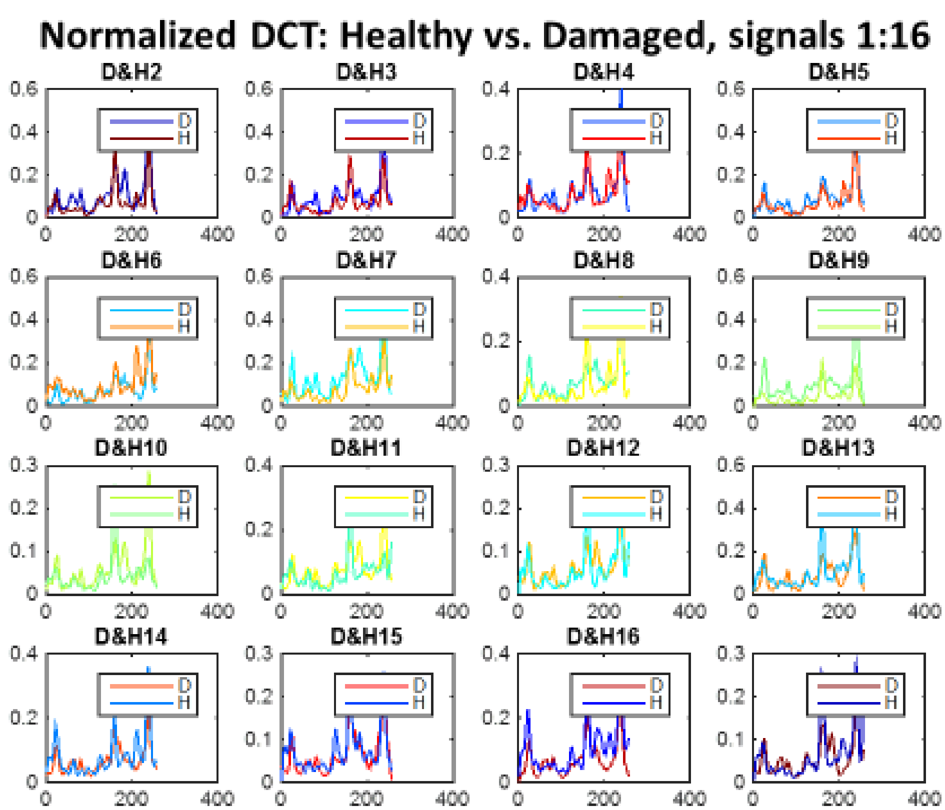
H


Normalized DCT: Healthy vs. Damaged, signals 1:16
D&H2
D&H3
D&H4
D&H5
D&H6
D&H7
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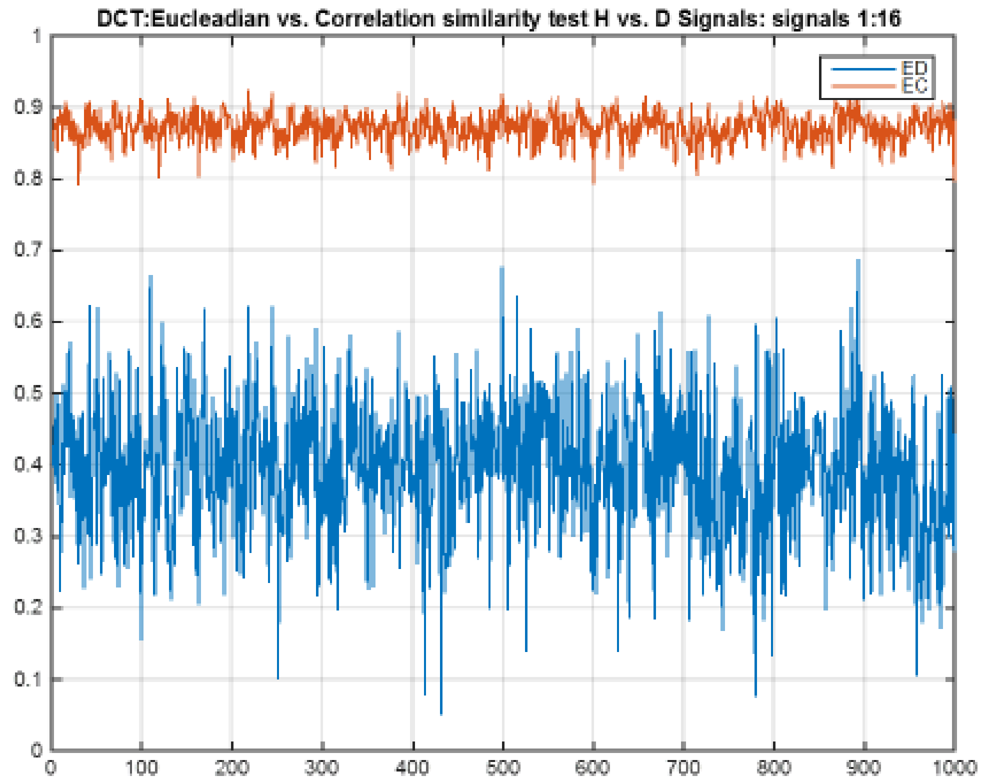
D&H16
D
H


DCT:Eucleadian vs. Correlation similarity test H vs. D Signals: signals 1:16
ED
EC
0
0.1
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0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
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100
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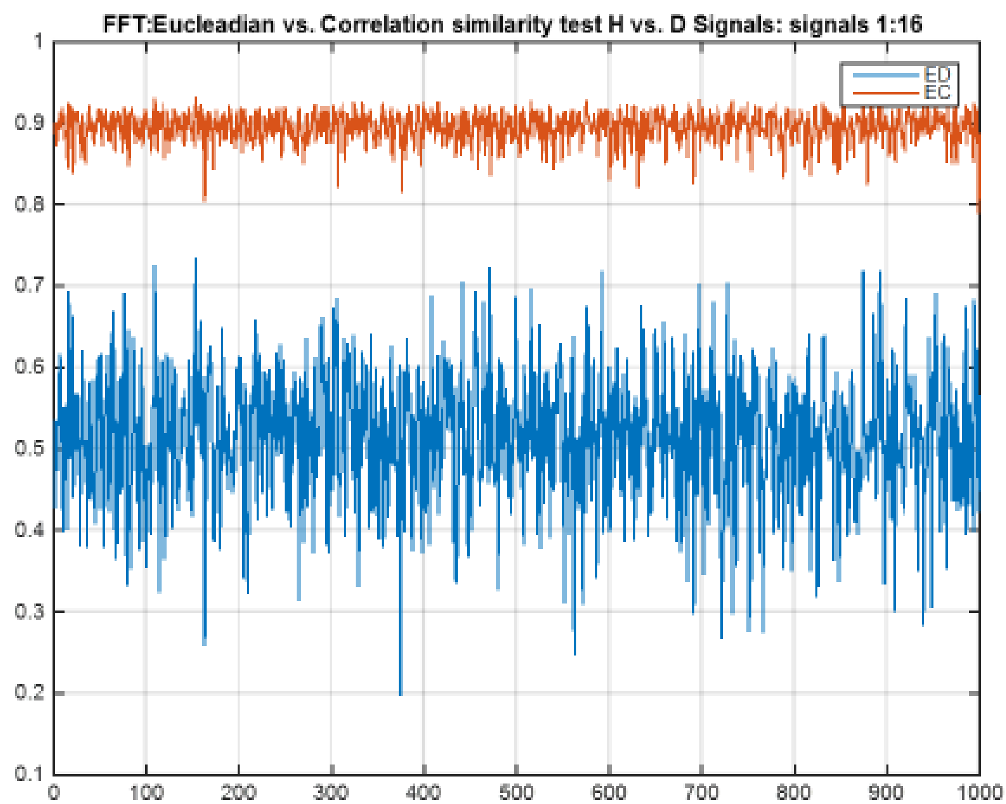
300
400
500
600
700
800
900
1000


FFT:Eucleadian vs. Correlation similarity test H vs. D Signals: signals 1:16
ED
EC
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
700
800
900
1000