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THE UNIVERSITY OF RHODE ISLAND

THINK BIG WE DO™

Digital Component Replication and Predictive Maintenance

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GENERAL DYNAMICS
Electric Boat

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Project Motivation

In many cases, machine's long-term performance is not well understood, and that performance can change based on the machines history. In order to have a clearer understanding of a specific machines performance, a "Digital Twin" of the machine can be created to using sensors to record the systems state and keep its history record. The Digital Twin is a new Internet-of-Things (IoT) concept that has potential to drastically change the operation of systems and components. Using this technology, operators will be able to make vital predictions of the machine's long-term performance. Machine Learning and Artificial Intelligence can be integrated into a Digital Twin to allow it to make these predictions autonomously even send feedback to the system to optimize its performance. If designed for naval applications, the Digital Twin would be able to optimize performance reduce maintenance costs which are a significant part of the Navy's operating budget.

Key Accomplishments

- **Software Selection:** Researched and performed a cost-benefit analysis on various programming languages and software. The software was selected based on its compatibility with the microcontroller and ability to interface with GUIs, embedded systems, and machine learning libraries.
- **Component Selection:** We researched and selected a pump to use as the foundation for all of our data collection and work. We also selected a sensor suite and microcontroller that would feed data to our software for analysis. The pump had to be able to support a suite of sensors, and these sensors had to be minimally invasive.
- **Software Architecture:** Designed a fog computing model (included in **Fig. 2**) to provide optimal performance of the application and allow for real time monitoring and interactions with the system. This was realized using serial communication, between the embedded system and back-end system, and embedded SQL for interactions with the database.
- **Construction of Hardware:** The pump needed a water flow loop that would allow it to infinitely transfer water for data collection (**Fig. 4**). The sensors had to be mounted to the pump and connected to the microcontroller, then configured to deliver data accurately. A cart to hold the system was also assembled, and safety measures were added to prevent the water from damaging the electronics (**Fig. 3**).
- **Damaging of Diaphragms:** In order to train the software with artificially aged performance history, we damaged the pump's nitrile diaphragms at different stages. The best way that we found to damage these was to soak them in acetone for up to 2.5 hours. The acetone degraded the nitrile and caused the diaphragms to behave differently when installed. We attempted other methods of degradation, but acetone proved to be the most reliable and consistent.
- **Machine Learning Implementation:** Implemented a bagged regression tree algorithm that is trained on data acquired from the pump at different stages of operation and ensured it was able to make predictions within an error range (**Fig. 1**). The damaged diaphragms were installed into the pump and data was collected to show what a degrading pump looks like to the software. One by one, the diaphragms were installed and tested until a good curve of data was collected and the application was able to identify that it was nearing the end of its life expectancy.
- **Life Expectancy Predictions:** The application can analyze data from the water pump and make consistent, accurate predictions of the pumps life expectancy, which was validated with extensive simulated data showing different scenarios and live testing using diaphragms degraded to different stages of wear-and-tear.
- **Graphical User Interface:** In addition to meeting the anticipated best outcome's requirements, the GUI (as shown in **Fig. 1**) allows the user to have some control over the display, with the ability to reset sensor averages, change how the data is visualized, and interact with the database even when the system is offline.
- **Data Logging:** A time-series database was created in order to store data for future use with machine learning algorithms as well as allow the user to view the pump's performance history to assess anomalies. The user is able to control how much data is seen.
- **User Notifications:** The application gives clear graphical changes (**Fig. 1**) when the pump is operating abnormally or when its life expectancy reaches certain points, allowing the operator to easily determine when the pump needs maintenance or inspection.
- **Safety and Security:** The systems implementation included taking appropriate measures of safety when adding sensors and other electrical equipment and potential cyber and cyber-physical security measures were well documented, but not implemented on the project.

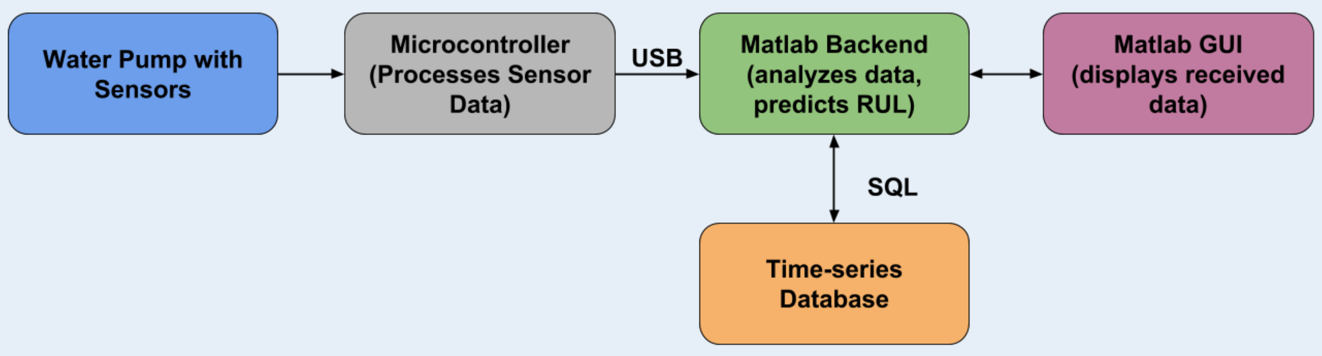

Fig. 2: Digital Twin System Architecture

Anticipated Best Outcome

The Anticipated Best Outcome for the project was to create a Digital Twin prototype that is able to monitor the current state of the pump and predict its remaining useful life. It should be able to identify changes in the pump's performance, remaining life, identify abnormal readings and present all this information to the user in real time. The best outcome of the project is to create a Digital Twin prototype that can accurately and reliably analyze performance and predict the remaining useful life.

Project Outcome

The Anticipated Best Outcome was achieved; with minimal investment, the system was successfully able to give real-time predictions of the systems life expectancy and monitor for abnormalities.

Figures

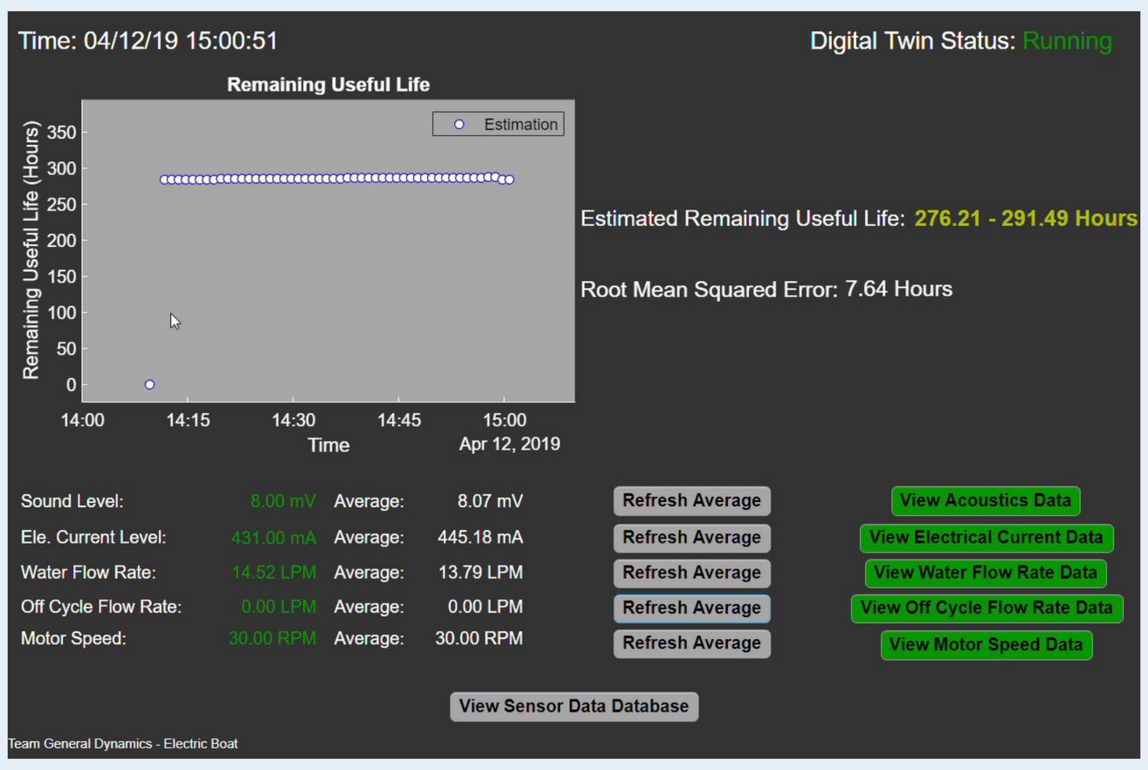

Fig. 1: Digital Twin Graphical User Interface (GUI)

Fig. 3: View of pump, flow rate sensor, and microcontroller inside box.

Fig. 4: Cart with water tank on bottom and pump with electronics on top.

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