ENGEN582-24X Honours Research and Development Project Proposal

Integrating streamed sensor data into a distributed model of a complex system

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1 Proposal Summary

Process Engineering is a discipline of Engineering that focuses on designing, controlling, and operating systems that convert raw materials into useful products. A key challenge in this field is ensuring that factories and systems can maintain optimal operating conditions, even with varying external conditions such as weather, electricity price, and feedstock quality. One method of doing this is to incorporate real-time data from on-site sensors, to report abnormal conditions. However, while this can report inconsistencies, this cannot predict the result of the conditions on downstream processes. This is a gap in current research.

It is proposed that by implementing a mathematical model of the process engineering system and integrating live sensor data, predictions of downstream processes can inform decisions on adjusting to varying external conditions. This will ensure that factories can maintain optimal operating conditions.

This will be done by developing APIs to integrate live data into the Ahuora Adaptive Digital Twin Platform and working on implementing dynamic model analysis. Project Ahuora will provide resources required for a test case with a heat pump system.

This project has aspects of Sustainability and Vision Mātauranga through contributing to the aims of Project Ahuora, which focuses on decarbonisation through efficient energy usage.

2 Background

The manufacturing economy takes up 12% of New Zealand's GDP. Manufacturing has intense overseas competition, because New Zealand's small domestic market makes it hard to produce things at scale. At the same time, there is a growing consumer and political push to become carbon neutral, by reducing energy usage or switching to sustainable alternative. As fossil fuel and energy prices rise, efficient energy usage is increasingly becoming an economic advantage as well.

Downtime also has a significant effect on manufacturing sustainability and efficiency. When a factory line needs to be stopped, process heat is wasted. Restarting a factory can involve a significant increase in energy usage.

Digitisation and automation are increasingly being relied on in order to make factories efficient enough to compete. Digitisation can help to decrease the cost of running a factory by replacing manual tasks, detecting abnormal conditions to prevent downtimes, and helping to optimise processes. This is becoming more prevalent with the rise of "Industry 4.0" and the Internet of Things. Factories are able to gather more data on operations than ever before. However, the technology to make use of the gathered data is still developing.

Project Ahuora, a research team based in Waikato, Auckland, and Massey Universities, is working on methods to make better use of this technology. Their aim is to "develop a novel energy-technology platform based on adaptive digital twin technology" [1]. Digital Twin technology involves creating a digital model of a physical system. This allows for virtual simulation and testing, which is often not possible in physical sites. *Adaptive* Digital Twin technology means the model can also adapt to changing real world environments, which is made possible by integrating live data from IoT sensors back into the digital model. This enables for new types of analysis. For example, when abnormal conditions are detected in a factory, the digital twin can be used to simulate different mitigation strategies, and the impacts on downstream processes.

In order for these new analysis methods to be used, the IoT data needs to be connected and represented on the Digital Twin. Project Ahuora is developing software that can create mathematical models of a system, and therefore the IoT data needs to be represented as mathematical constraints on the model. This project will solve this issue.

3 Overall Aim of the Project

How can live data be integrated into digital twins in order to improve model and factory performance?

The aim of the project is to research novel methods to integrate live sensor data into a complex mathematical model. This comes with a number of specific objectives, which are modeled on similar research in related fields[3]. These include:

- Finding appropriate methods to gather relevant data;
- Creating a static and dynamic knowledge base and relevant querying methods;
- Researching and developing methods to relate raw data to properties of a mathematical model;
- Designing user interfaces that allow for access, setup, and use of sensor data in mathematical modelling.

This research will be done by developing an extension to the Ahuora Adaptive Digital Twin Platform.

4 Research and Development

The extension to the Ahuora Adaptive Digital Twin Platform will be the main deliverable of this project. The initial stage of the project will involve studying existing literature, and some novel research, in order to find appropriate methods to integrate live data into the mathematical model. This will be implemented into the Ahuora Digital Twin Platform, using industry standard practices to create maintainable code and a user-friendly interface. The result of this development will be used as a case study to prove the efficacy of the system.

4.1 Literature Review and Prototyping

The literature review will provide an overview of existing research, in order to determine what has already been done in the field, or in related fields. This will be used to plan a strategy to design and prototype the IoT systems, and the integration with Ahuora's mathematical model. The prototyping will be conducted in conjunction with the literature review, which will enable the literature review to be focused on the largest barriers to implementation.

4.2 Development

After being informed by the literature review and initial prototyping, development on the integration with the Ahuora Digital Twin will commence. This is expected to take the majority of the project's time. The Ahuora Digital Twin platform has to be modified in order to support different custom "extensions" such as live data processing. Then a platform to ingest data from IoT sensors needs to be created. The data will then need to be converted into "constraints" on the mathematical model, using machine learning techniques or other means, as influenced by the literature review. Finally, a user interface needs to be created in order to enable easy implementation of IoT in a variety of process systems.

Once the development is nearing completion, it can then be tested in a real-world case study. For example, a heat pump can be modelled in the Ahuora Platform, and then live temperature data can be imported in order to predict efficiency, energy usage, report abnormal conditions, etc. Some hypotheses that may be investigated include:

- *Integrating live sensor data into mathematical models will improve predictions of abnormal conditions in a system*
- *Using a mathematical model and live temperature data, other thermodynamic properties of a process can be accurately estimated.*

The exact details of this testing and research phase will be decided based on learnings from the literature review and initial prototyping.

4.3 Additional Information

A Gantt chart with an expected timeline can be found in Appendix A.

5 Resources

During the initial phases of the project, the main resources required are expertise in Chemical Engineering and Software Development. This is available through others involved in the Ahuora project and the Computing and Mathematical Sciences department at Waikato University. Additionally, development resources and space has been allocated as part of Project Ahuora. Access to simple IoT devices, such as temperature and humidity sensors, for initial prototyping has been provided by Project Ahuora. Finally, Ahuora has provided access to the source code of the Digital Twin platform to develop on.

During the later stages, more practical testing will be required. Access to a physical process will be needed to enable research to be conducted on the efficacy of predictions. The details of this have not yet been determined, however this may be done in conjunction with other Honours students who are working on heat pump testing, as creating a digital twin of a heat pump will provide a good controlled real-world test case. Space and time on-site will be required to conduct this testing.

6 Sustainability and Vision Mātauranga

The industrial sector of New Zealand uses around 170 PJ of energy every year [4]. This is around 30% of the total energy usage. Being able to optimise processes, such as by reducing waste heat or downtime, is able to make a significant impact in the total energy usage of the country. Less energy usage means there will be less reliance on carbon-based fuels, and will speed up the process of electrification. Energy production and consumption also has a significant impact on the land and ecology of New Zealand.

As this is project based around decreasing energy usage, it is related with the “Te Taiao” theme of Vision Mātauranga. The environment is an important part of New Zealand’s identity and history, particularly for Māori. Sustainable resource management is specifically mentioned as a point of focus in New Zealand’s Vision Mātauranga policy [2], which includes sustainable energy usage.

References

[1] 2024. Ahuora - Center for Smart Energy Systems, University of Waikato. https://ahuora.waikato.ac.nz/.

[2] 2024. Vision Matauranga: Unlocking the Innovation Potential of Māori Knowledge, Resources and People, Ministry for Business, Innovation, and Employment. https://www.mbie.govt.nz/assets/vision-matauranga-booklet.pdf.

[3] Dagimawi D. Eneyew, Miriam A. M. Capretz, and Girma T. Bitsuamlak. Toward smart-building digital twins: Bim and iot data integration. *IEEE Access*, 10:130487–130506, 2022.

[4] 2024. Ministry for Business, Innovation, and Employment. https://www.mbie.govt.nz/.

Appendices

A Gantt Ghart

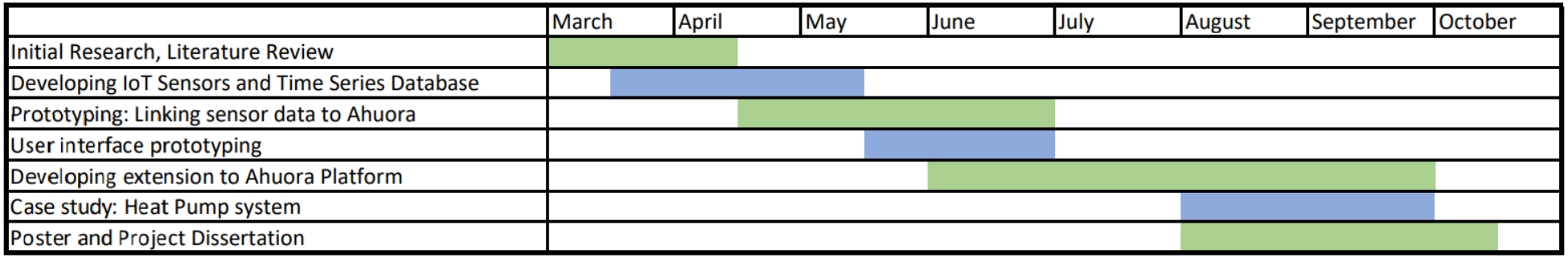

Figure 1: Gantt Chart with estimated project progress.

This Gantt Chart provides an estimated project timeline, and provides a standard to measure progress against. Many things can be worked on concurrently, as they will be related tasks. A significant amount of time will be spent prototyping, but the longest task will be developing the extension to the Ahuora Platform, because of the level of detail required.