INL/CON-22-67921-Revision-0

Use of Machine Learning for Signature Development in a Multi-Sensor Environment for Safeguard Applications of Solvent Extraction Processes

July 2022

Cody McBroom Walker, Edna S Cardenas, Luis A Ocampo Giraldo, Mitchell Greenhalgh, Jay D Hix, Katherine Neis Wilsdon, James T Johnson

Changing the World's Energy Future

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/CON-22-67921-Revision-0

Use of Machine Learning for Signature Development in a Multi-Sensor Environment for Safeguard Applications of Solvent Extraction Processes

Cody McBroom Walker, Edna S Cardenas, Luis A Ocampo Giraldo, Mitchell Greenhalgh, Jay D Hix, Katherine Neis Wilsdon, James T Johnson

July 2022

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

July 25-28, 2022

Cody Walker
Research Scientist

Use of Machine Learning for Signature Development in a Multi-Sensor Environment for Safeguard Applications of Solvent Extraction Processes

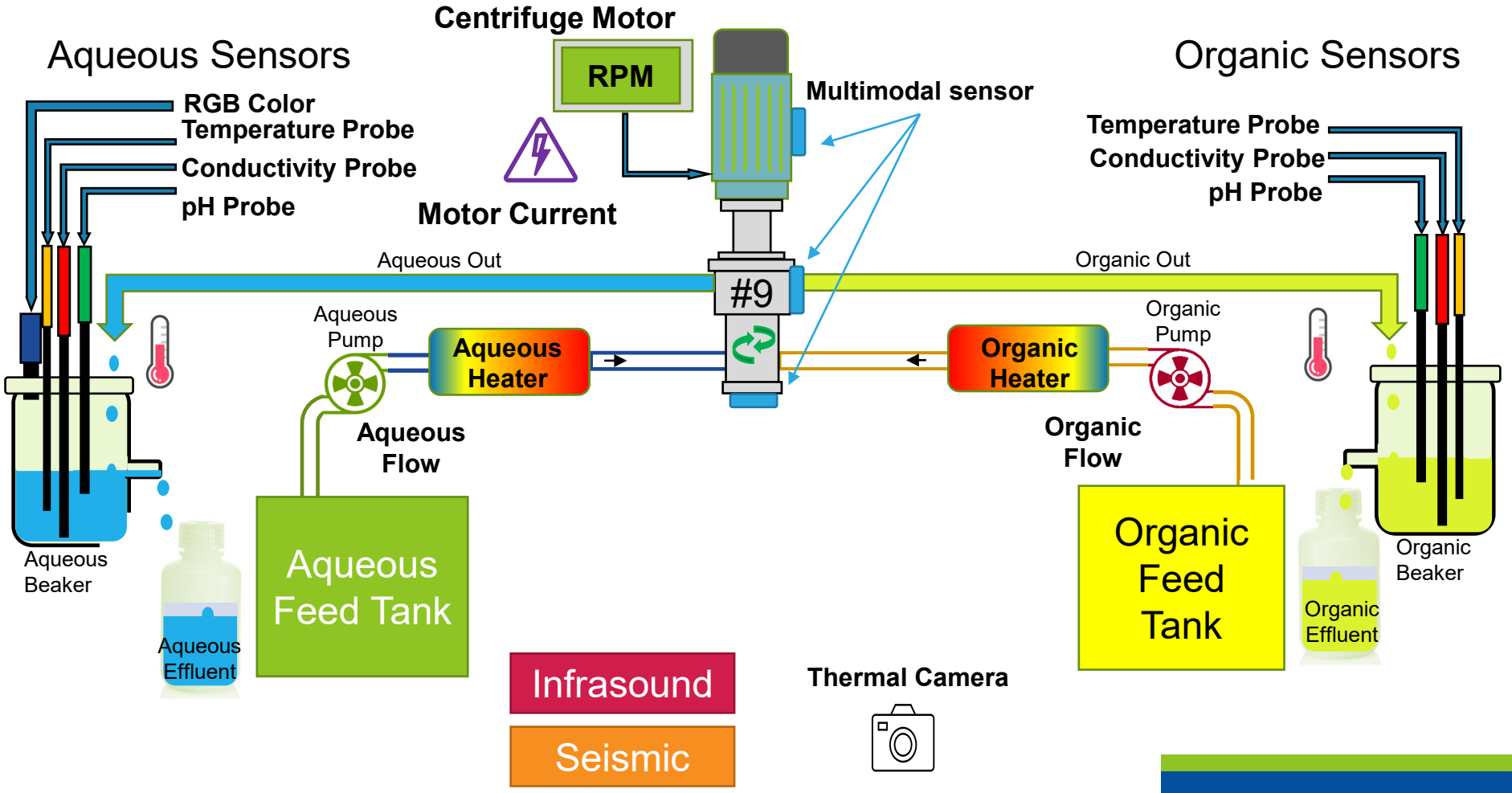
INL is managed by Battelle Energy Alliance
for the US Department of Energy

Idaho National Laboratory

Goals and impacts

Goal 1	Integrate a variety of atypical sensors into a system of centrifugal contactors for signal discovery.
Goal 2	Use data science and signal analysis techniques to extract features that identify process stages and equipment usage in various stages of operation.
Local Impact	Equip system operators with process awareness so they can be informed of: • Process conditions • Normal/abnormal operations • Ways to improve process operations • Equipment failures and predictions of failure.
Broad Impact	If features provide evidence of diversion, this research could potentially enhance the safeguarding of special nuclear materials.

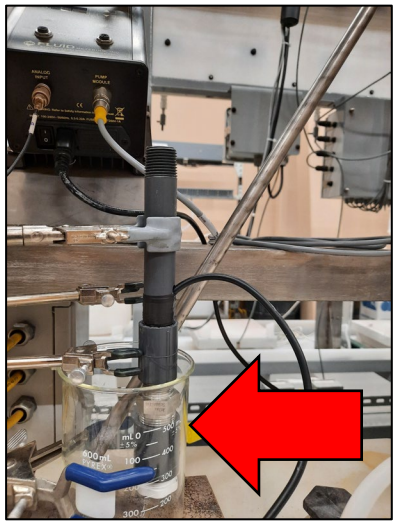
Many types of sensors for monitoring a chemical separation process

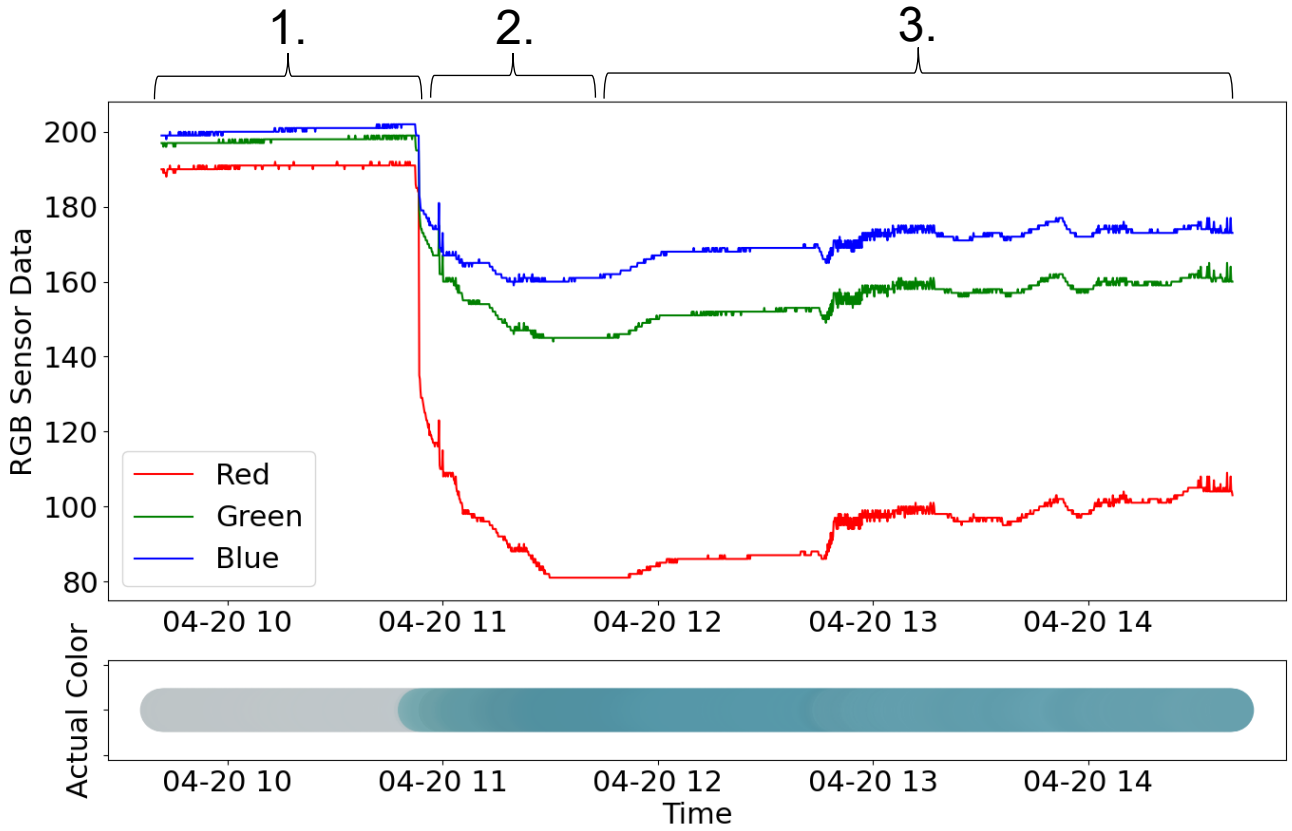


Atypical sensors can generate new insights

- Colorimetric sensors monitor the organic concentration throughout the process.

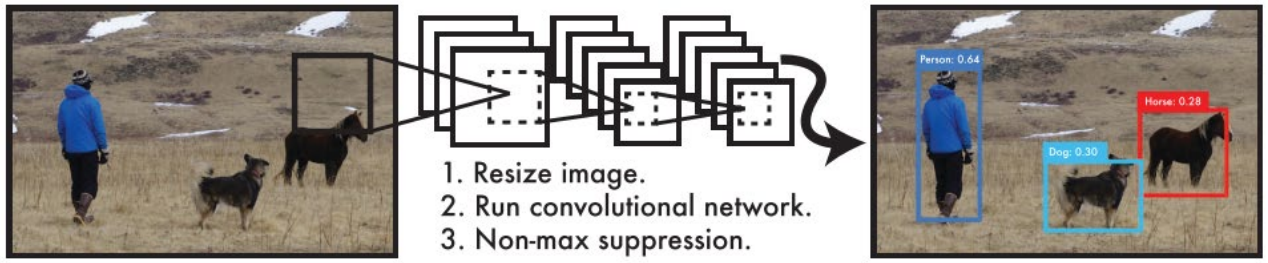
1. No organic present (color of container)
2. Organic slowly introduced in the solution
3. Concentration of organic increasing

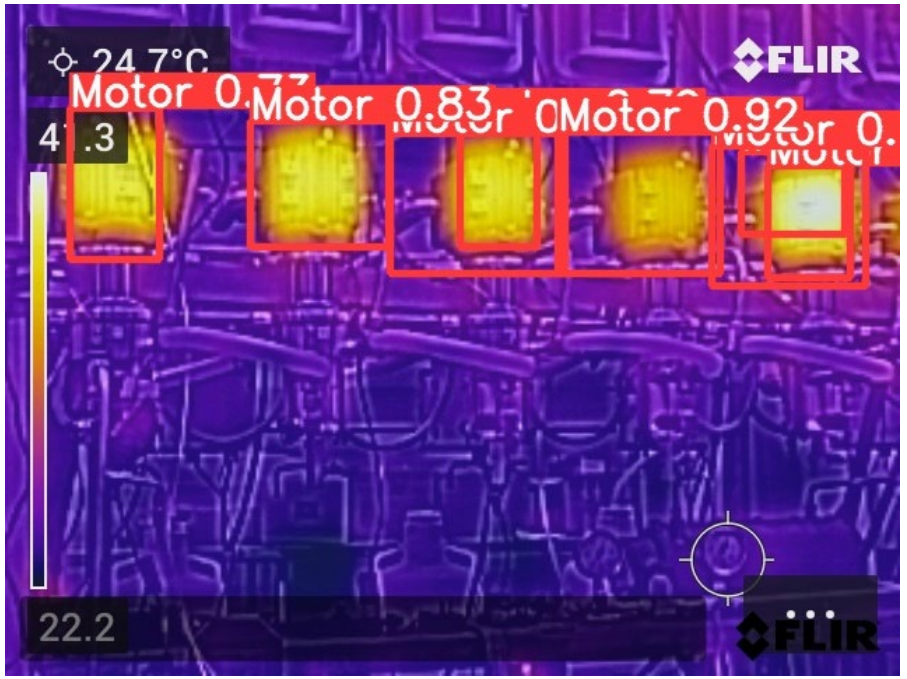




Yolov5 is being used with an infrared camera to gauge the temperature of motors and contactors

- Images from an infrared camera are processed to locate thermally active equipment (e.g., motors).
- The approximate temperature is measured based on the color of the object.
- This temperature is then used as a process variable to determine whether the component is “healthy” or “faulted.”
- Instead of using one thermocouple per component, the infrared camera covers multiple units.

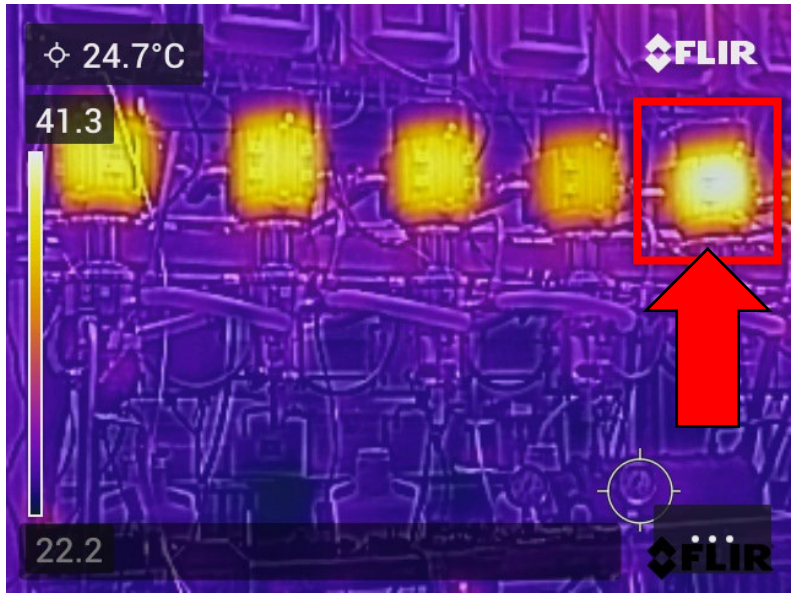


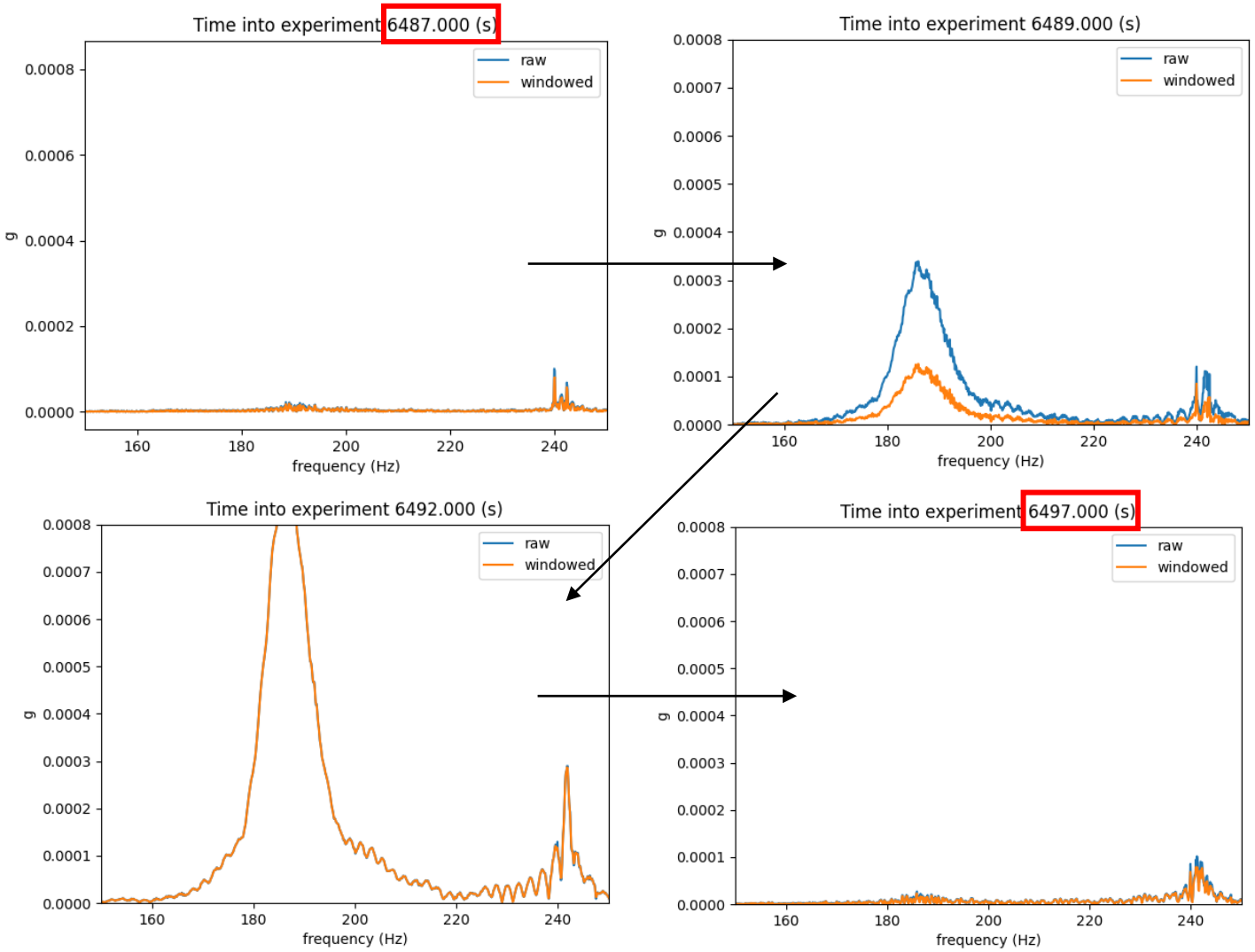


He, K., Zhang, X., Ren, S., & Sun, J. (2016). Deep Residual Learning for Image Recognition. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 8.

Contactor fault identified in the data

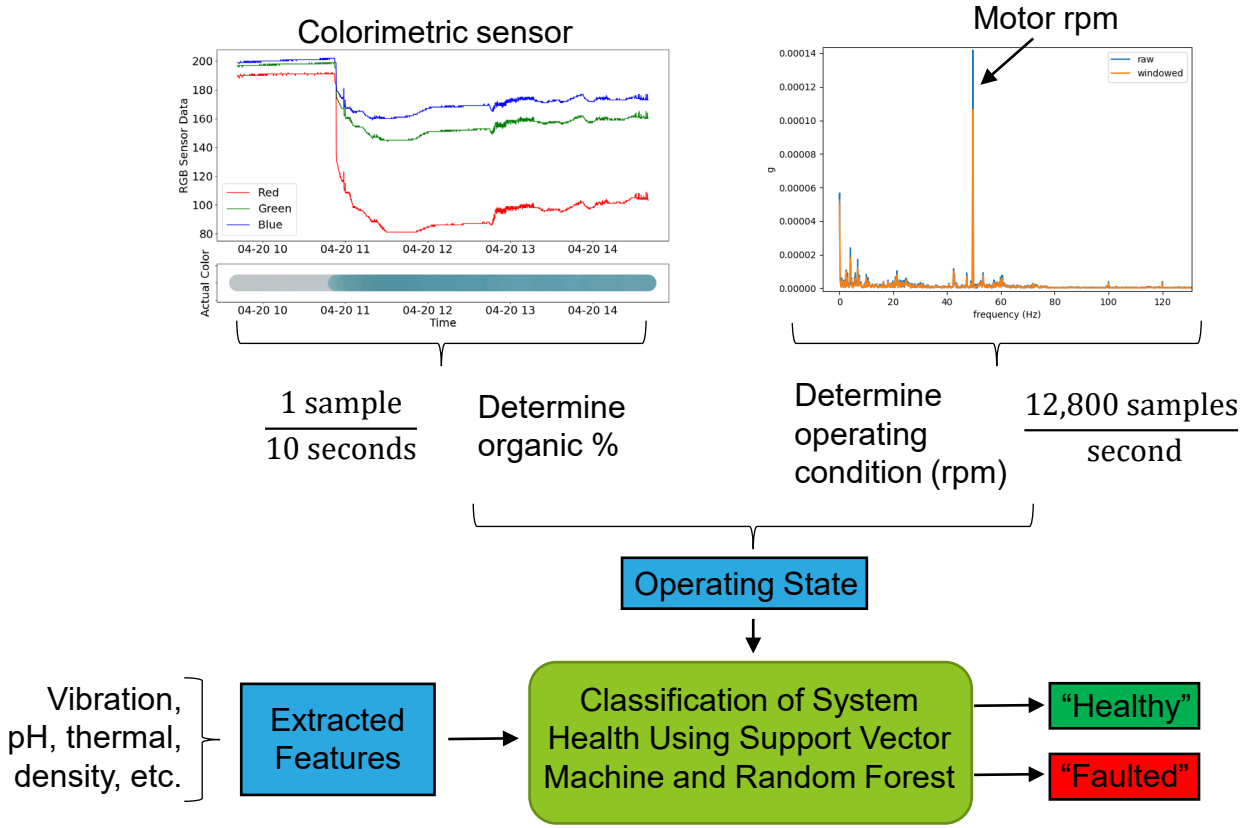
- An event caused a contactor to flood.
- The entire event occurred within 10 seconds (initiation to shutoff).
- It was captured by the vibrations and infrared cameras.





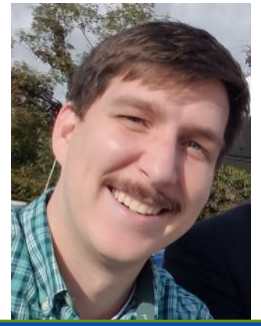
Data wrangling and feature extraction enable easy analysis of large, complex datasets

- Measurement sources include vibration, acoustic, current, conductive, flow, colorimetric, pH, viscosity, density, humidity, and thermal data.
- These measurements vary in magnitude, frequency, and location.
- Feature importance is determined by using SHAP values.
- Information is being used to detect operational changes that are either intentional (e.g., changing operational set points) or malicious (e.g., flow diversion) in nature.



MUSSDBear Team

Luis Ocampo Giraldo
Safeguards, data collections, data communications, signal analysis



Cody Walker
Machine learning, statistics, signal analysis, feature extraction

Mitchell Greenhalgh
Extraction process expert, sensor installation, process operations

Jay Hix
Sensor installation, sensor communications & networking, data collections, LabView expert

Katherine Wilsdon
Deep Lynx integration and programming, GUI programming

James Johnson
Sensor installation, sensor communications & networking, data collections, LabView expert

Edna Cárdenas
Data collections, signal analysis, feature extraction, experiment planning & organization

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.