INL/CON-23-71125-Revision-0

Use of Sensors and Machine Learning for Signal Discovery in a Solvent Extraction Process

March 2023

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

Changing the World's Energy Future

Idaho National Laboratory

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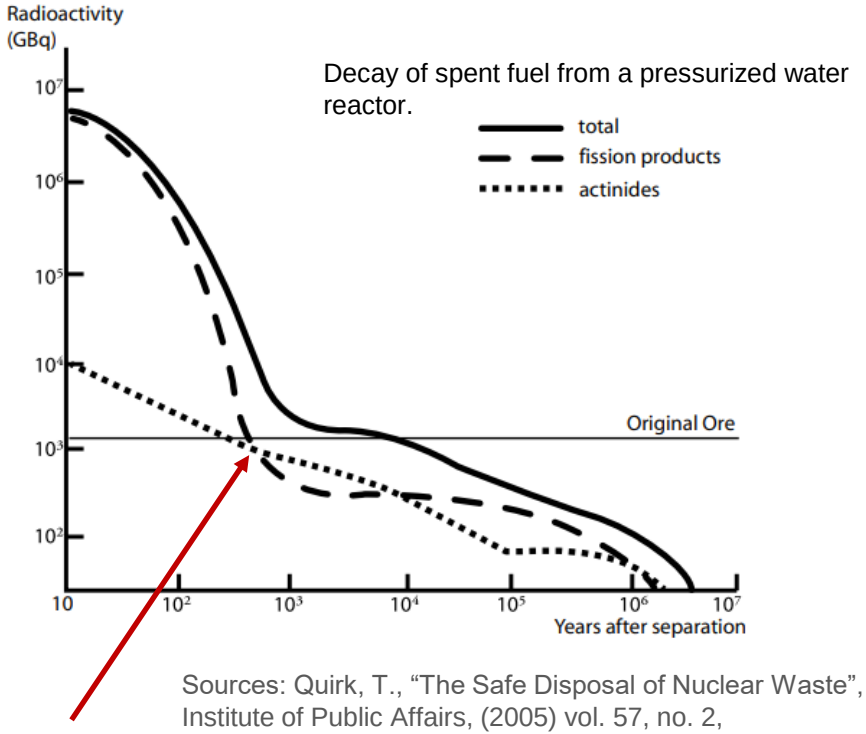
Solvent Extraction

Nuclear industry

- Recovery of uranium and plutonium from high-level waste.
- On going research into separation of minor actinides from remaining fission products.
- Reduces the radiotoxicity of the waste and the waste volume.



Decay of spent fuel from a pressurized water reactor.

Sources: Quirk, T., “The Safe Disposal of Nuclear Waste”, Institute of Public Affairs, (2005) vol. 57, no. 2,
OECD, “Radioactive Waste Management in Perspective”, ISBN : 92-64-14692-X.

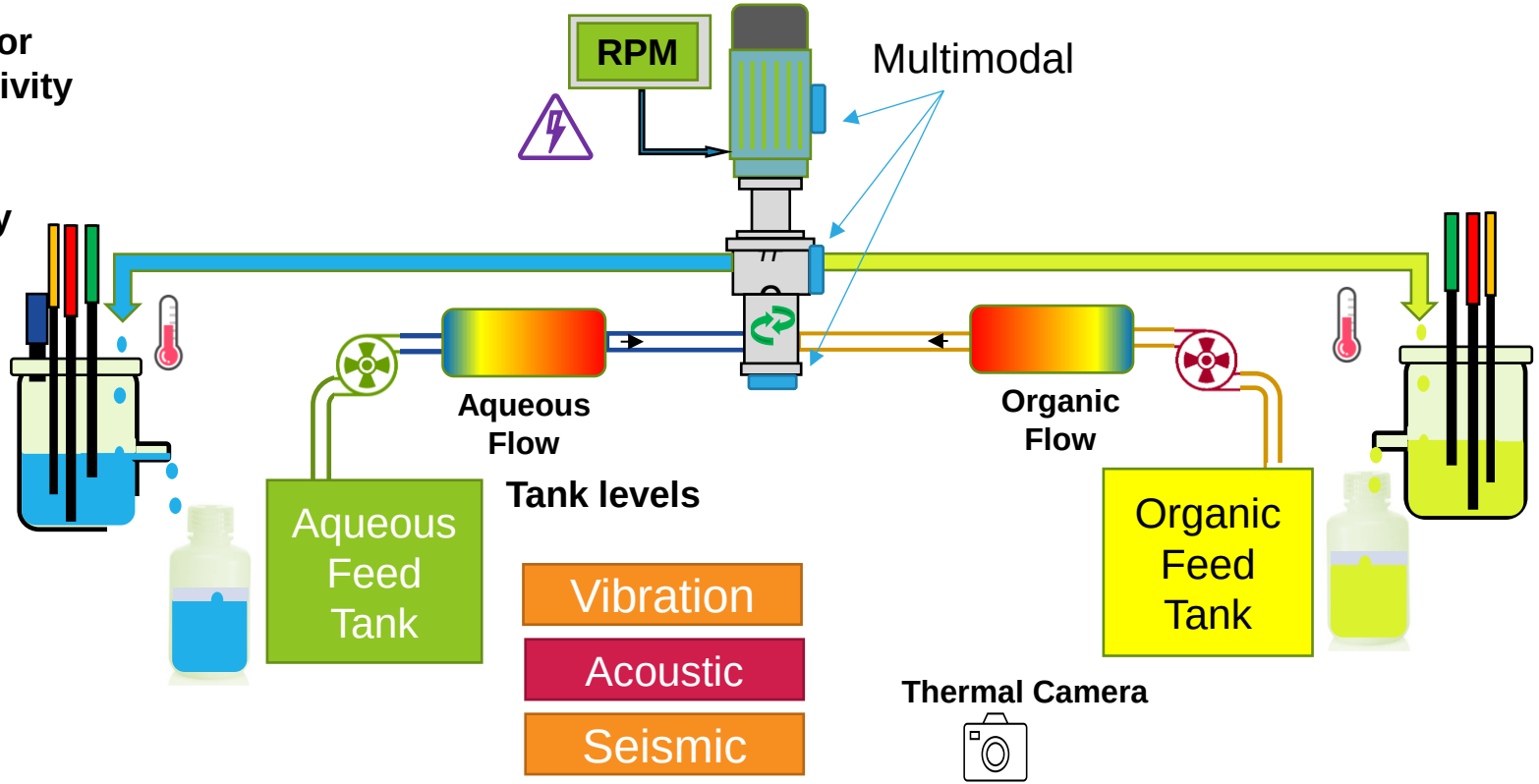
Radioactivity reduces 2 orders of magnitude when fission products are separated from the actinides.

INL's Beartooth Testbed

- INL is initiating knowledge and training into the nuclear fuel cycle.
  - Constructing the Beartooth testbed.
    - Infrastructure:
      - glove box lines
      - dissolution equipment
      - centrifugal contactors
    - Test novel separations methods
    - Train early-career researchers
    - Beartooth uniquely designed to include equipment for monitoring and the implementation of machine learning models.

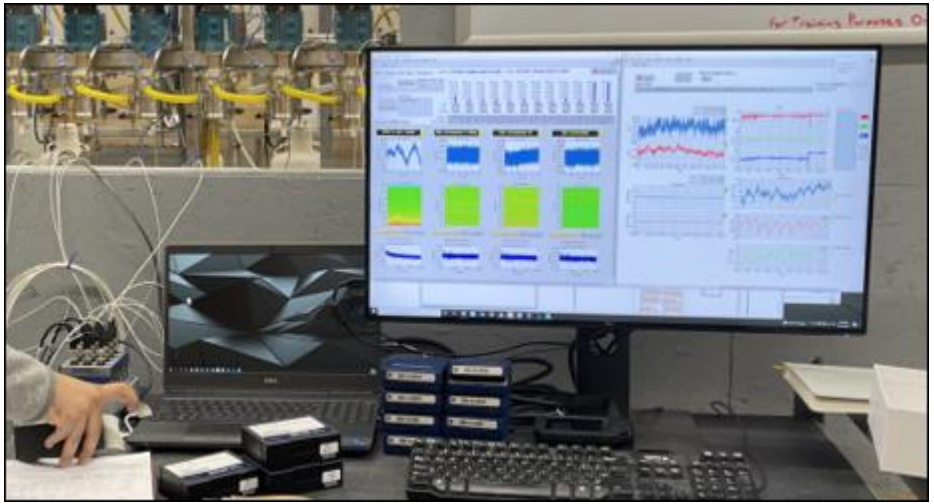
LDRD Goal 1 - Sensor Integration

RGB color
Conductivity
pH
Density
Viscosity



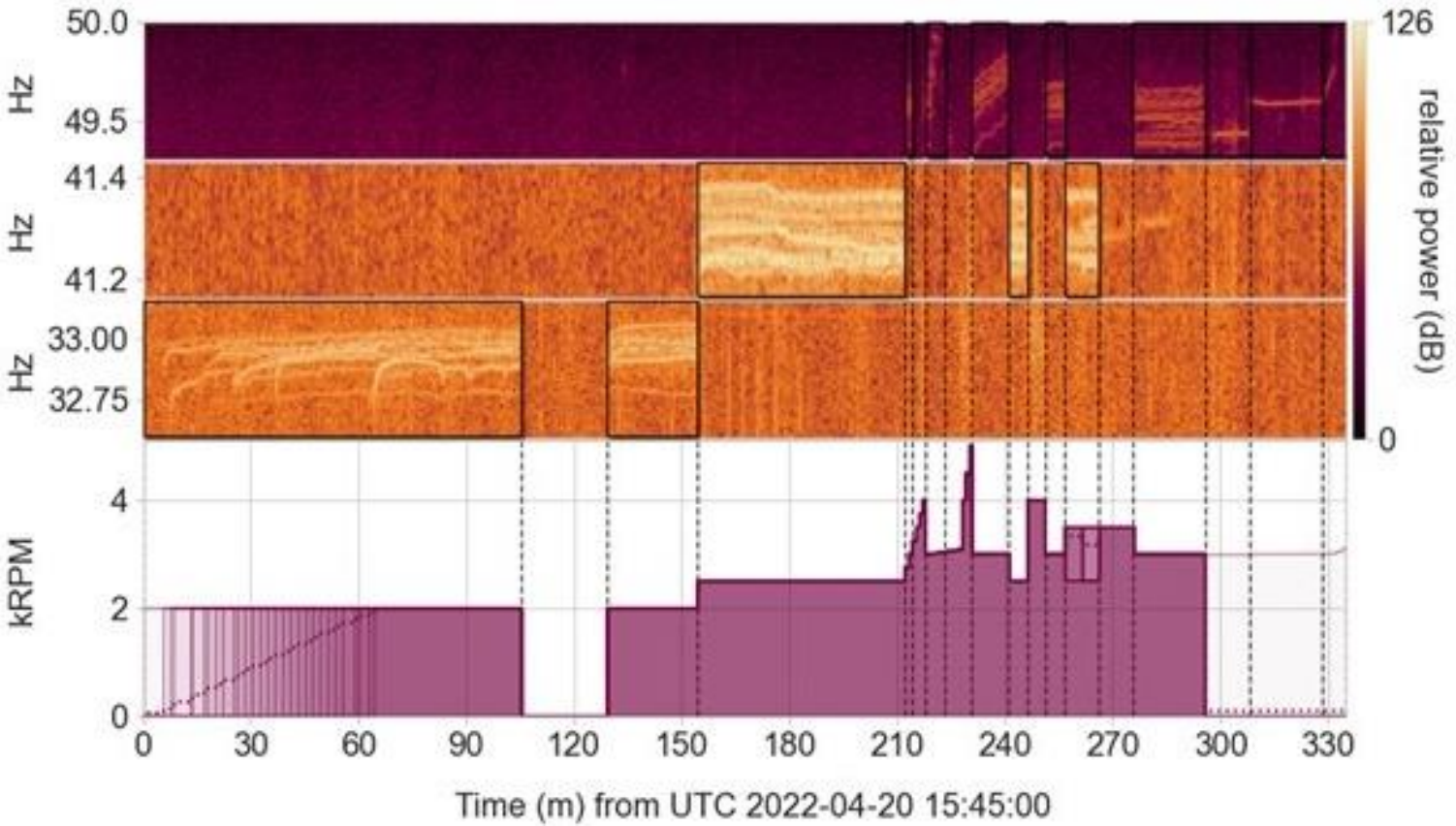
LDRD Goal 2 - Data Science

- Data analytics:
  - discover relevant features that lead to identifying process events.
- Machine learning:
  - predict equipment faults/failures, notify of abnormal conditions such as leaks or material diversion.



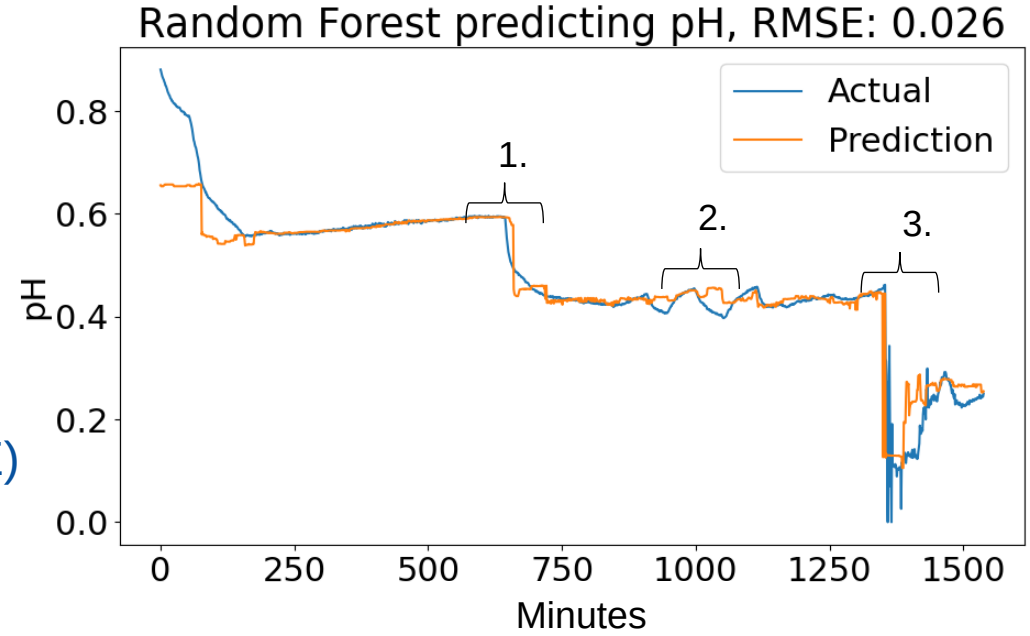
Increase scientific understanding of the process.

Acoustic signals



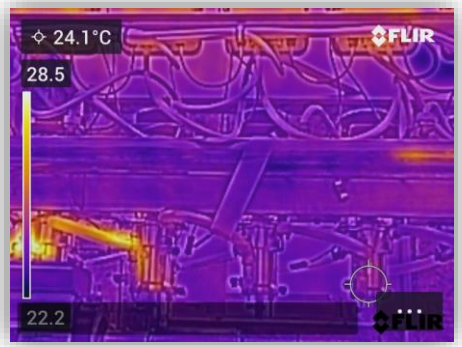
Predicting pH using Machine Learning

- Used Random Forest to predict the pH.
- Kfold 20 used for cross validation.
- Local Interpretable Model-Agnostics Explanations (LIME)
  - Color, temperature, conductivity



1. Establishing organic flow.
2. Changing contactor motor RPM.
3. Changing organic flowrate.

Infrared Camera Shows Solution Transfer



Contactor 30 to 29

Solution enters contactor 27

Flow is constant

- Contactors turned on one-by-one starting with aqueous solution.
- Results: Able to detect solution flowing from contactor to contactor.

Solution location desired by process operator.

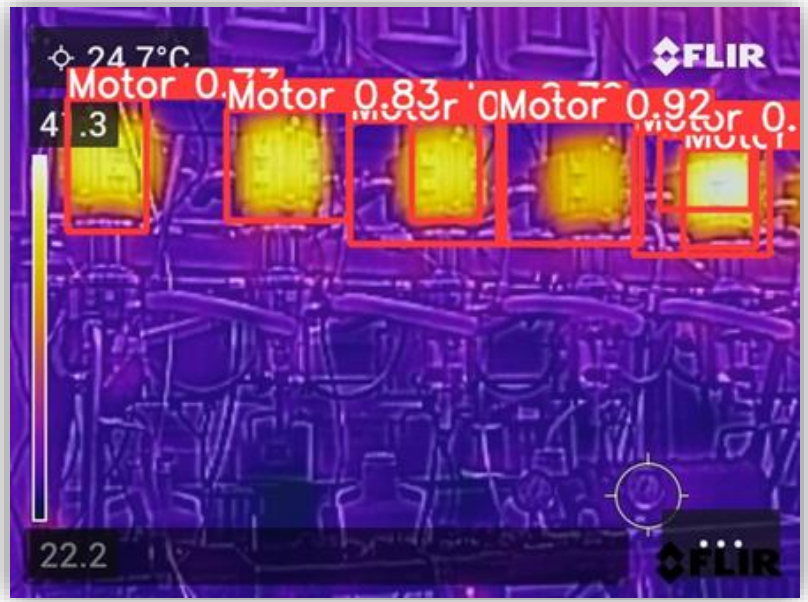
Infrared Camera Captured Unexpected Event

- Camera location: In front of contactors.
- Contactor 5 motor temperature increased, overheated, failed.
- Flooding occurred.

Temperature changes were measured in the sensors before staff realized a failure.

Contactor temperature high

Infrared Camera and Machine Learning

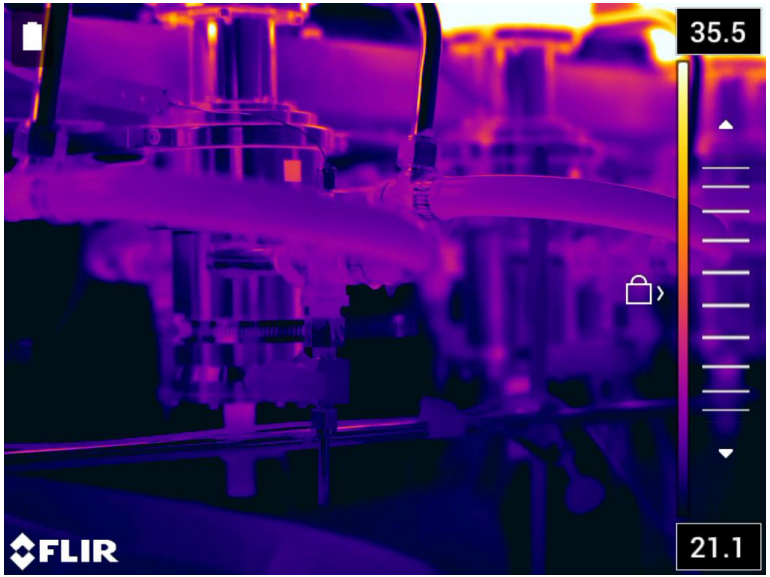


YOLO = You Only Look Once

- Used for object detection.
- Trained to pick out the motors in this image.
- ML method used to place the red boxes around the motors.
- Number are the confidence that the objects are contactors.

YOLO can identify where the motors are in the image, so we can determine temperatures and help to predict motor failures.

Using ML for Leak Detection



Hard to identify with single image

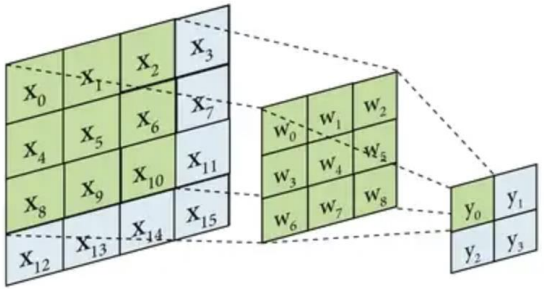
- Image capture frame rate
- Slowness of the leak

Easier to determine with video

- Activity Recognition through multiple images.

Differences in Processing Images and Video

Images



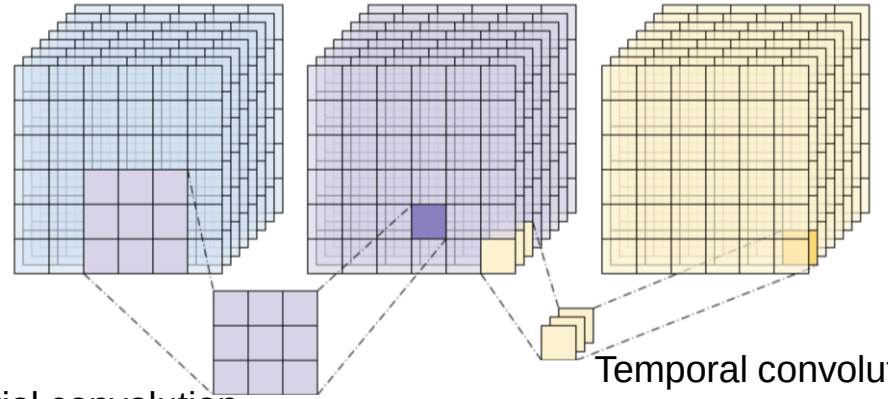
https://medium.com/analytics-vidhya/2d-convolution-using-python-numpy-43442ff5f381

2D Convolutional Neural Networks (CNN) used to extract information.

- The input are pixels from a single static image.

Video

(2 + 1)D convolution



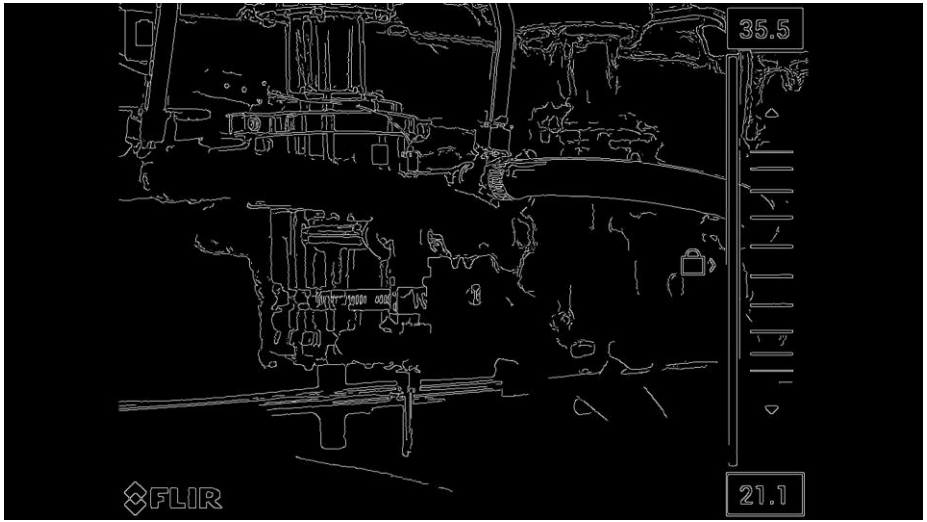
Spatial convolution
Kernel: 1 X 3 X 3

Temporal convolution
Kernel: 3 X 1 X 1

https://www.tensorflow.org/tutorials/video/video_classification

(2+1)D convolution refers to the same 2D CNN used in singular image analysis with the addition of 1D for the temporal convolution.

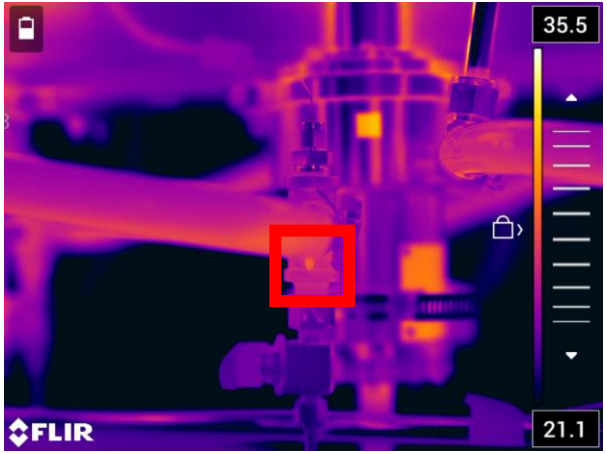
Edge Detection may Aid in Activity Recognition

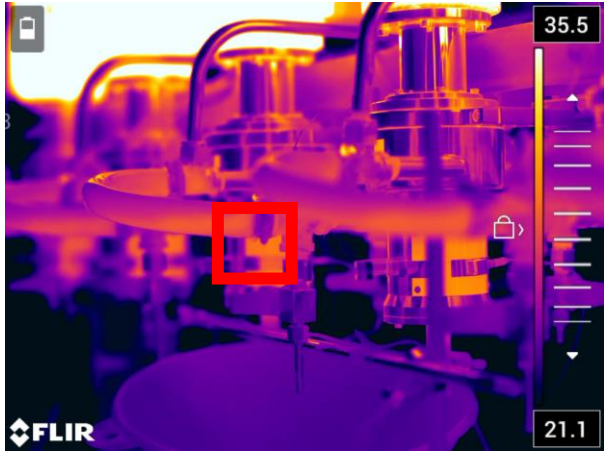


Edge detection modifies the input image or video so that object edges are highlighted.

- May aid in identifying a leak.
- Noise may challenge the identification.

Multiple Angles Help Model Learn the Activity





- Three different angles
- Different leak locations.
- Two different leak sizes

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