Unattended Ground Sensing and In-Situ Processing of Geophysical Data

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• In some cases, it may not be feasible and/or desired to install a permanent geophysical monitoring station.

• Unattended Ground Sensors (UGS) can help fill the gap in these instances.

• UGS deployments present challenges that permanent monitoring sites do not have.
  – Typically, no access to internet or other means to send data
  – Typically, no access to electrical power

• Sandia has a long history of developing custom UGS systems for other applications.
The goal of our work was to develop a real-time sensing system with data collection for on-board processing of seismic/acoustic data. At a minimum, the system must provide the following capabilities:

- Operate autonomously once deployed without the need for servicing
- Operate continuously on battery and solar power only
- Provide a communication path that allows for command and control along with data-exfil capability
- Provide a processing capability to discriminate between events of interest and clutter/noise in the local area
- Small Size Weight and Power (SWaP) constraints to allow for transport by foot to deployment locations

This system will not serve as a final solution but rather a test system that allows for a concept to field capability.

- Algorithms can be rapidly deployed onto the hardware and tested in the field
• Sandia has developed a sensor platform that allows for rapid integration of sensors and software for rapid prototyping.
  – A fieldable hardware and software platform for rapidly deploying novel algorithms to detect, discriminate, and classify a wide range of targets in a testbed
  – Hardware is largely commercial with custom Sandia designs as needed
  – Variety of sensor types including acoustic, seismic and infrasound
  – Comms: Cellular, Iridium, Wi-Fi, other
• Integrated Sensor Platform (ISP)
  – Designed for rapid prototyping of algorithms from a variety of sensors

• Currently uses a Pico-Zed Processor
  – Early version of this system utilized the Raspberry Pi
  – FPGA with Arm 9 SOC

• Coral TensorFlow Processing Unit (TPU)
  – Processor optimized to run TensorFlow machine learning models

• Linux OS (Debian)
  – Allows for easy deployment of MatLab algorithms via Simulink, Python, etc.
  – 8 Synchronized Differential ADC channels allow multiple sensors
  – Tested up to 16ksps per channel
  – Iridium SBD communication enables remote alerts and data transfer
  – Verizon cellular modem

• Power system and solar design
  – Indefinite operation in most environments
• Sandia has had an active experiment in southern Utah since 2017

• The experiment has focused on seismic monitoring of activities at the Redmond Salt Mine
  – Blast logs from 7 months received from mine engineer
    ▪ 300+ blasts with time, mine level and drift ground truth data
    ▪ Blasts are on the order of 1000 pounds TNT
DEPLOYMENT

Currently deployed ISP at Redmond Salt Mine

- Running since July 15th, 2020
- Communications:
  - Via Cellular we can update code and pull data
  - Via Iridium SatCom we can receive State-of-Health messages from the ISP via email
- Processing:
  - Currently running STA/LTA detector and saving off data
  - STA/LTA detections will then be processed by a 2D-CNN Classifier (current work)
- Trillium Compact Seismometer
- Running a “shadow” system locally at Sandia for testing of code prior to deployment on fielded system
• Algorithms can be developed in MatLab Simulink then C++ code can be auto-generated for execution on the ISP.

• The ISP is running Debian Linux OS so it also supports Python.
Goal: Develop a ML algorithm to run on the ISP as an exemplar for proof-of-concept

- Use ground truth catalog data to develop a classifier of events by mine location (level, drift, etc.)
- Probability of detection (Pd) goal 70%
- Develop algorithm on a workstation then move to the ISP
  - Using Python and Tensor Flow 2.0
- Initially focus on implementation of inference model then eventually look into training on the ISP
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2-D Convolutional Neural Network
- Adam Optimizer
  - $\beta_1 = 0.9$
  - $\beta_2 = 0.999$
  - $LR = 0.001$
- Categorical Cross-Entropy Loss
- Minibatch size of 32
- 500 Epochs with Early Stopping

<table>
<thead>
<tr>
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<th>Loss</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td>Train</td>
<td>0.22</td>
<td>0.95</td>
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<tr>
<td>Validation</td>
<td>0.87</td>
<td>0.76</td>
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</tbody>
</table>
• Train Accuracy: 95.3%; Validation Accuracy: 75.9%

• High amount of overfitting motivates further regularization
  • As we are focused on inference, we have accepted the overfitting for now.

• As expected, signals with lower SNR are more difficult to classify
• We have developed a custom UGS capable of remote and autonomous operation.

• We have demonstrated a semi-complex ML model running on the system.

• As expected, we saw a reduction in performance when we quantized the model to run on the Coral TPU. The result was our validation accuracy dropped to 52%.
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• Short-term
  – Event association across multiple spatially separated (5-10s of km) units
  – Explore ways to overcome the drop in performance due to quantization on the Coral TPU

• Long-term
  – Identify one or more candidate algorithms with real-world use for implementation on the ISP
    ▪ i.e., earthquake vs. explosion
  – Attempt to train the models on the ISP