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Unattended Ground Sensing and In-Situ Processing of Geophysical Data

William O’Rourke, Tyler Morrow, Anirudh Patel, Matthew DeKoning, Brian Evans

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ORAL
PRESENTATION

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Sandia National Labs

INTRODUCTION

- 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.

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GOALS

- 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 follow 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

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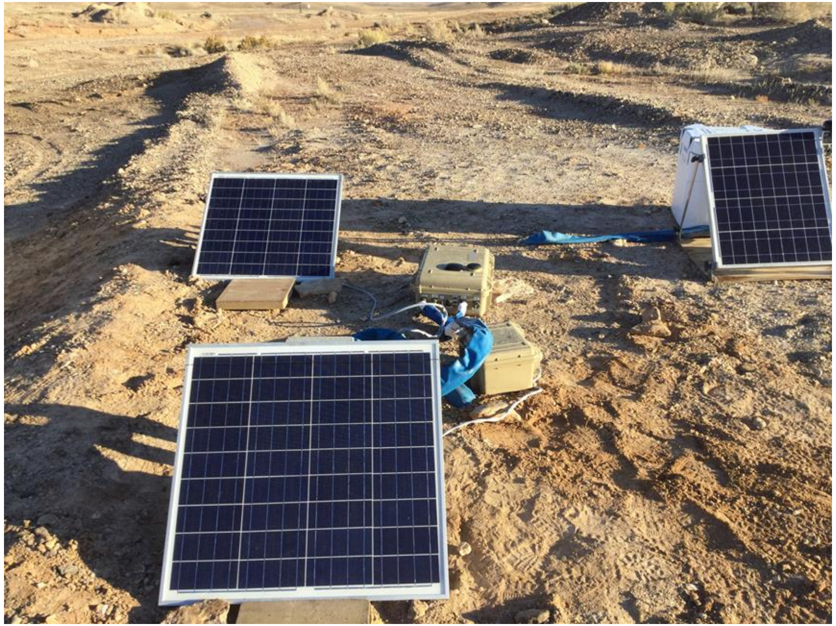
HARDWARE

- 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



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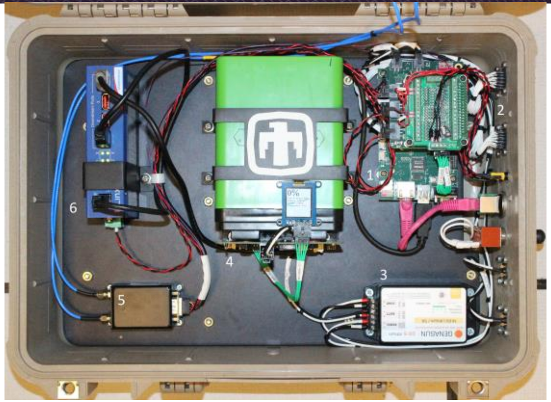
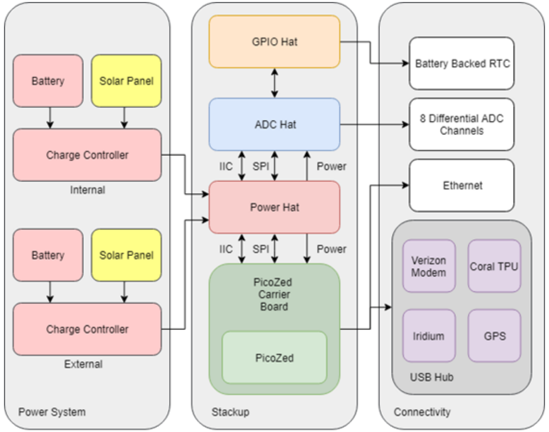
SYSTEM

- 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





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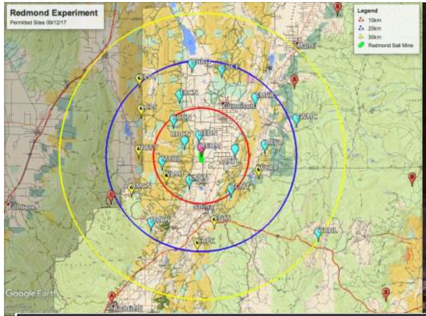
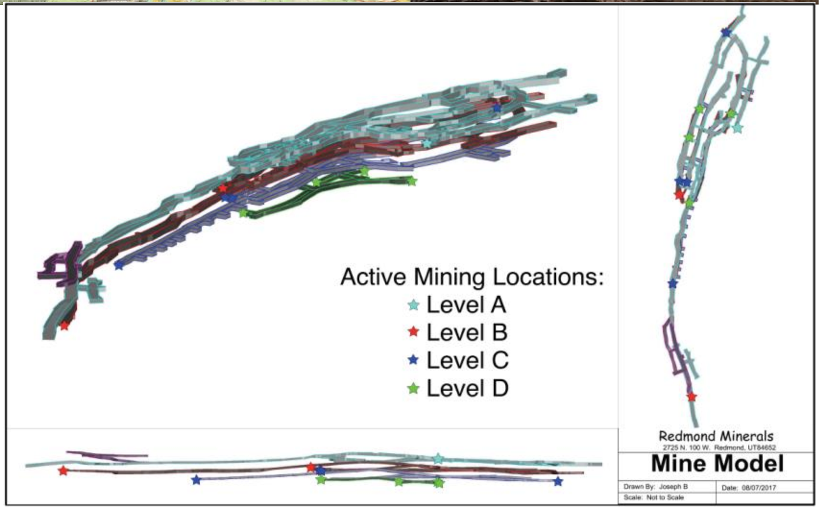
REDMOND MINE

- 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





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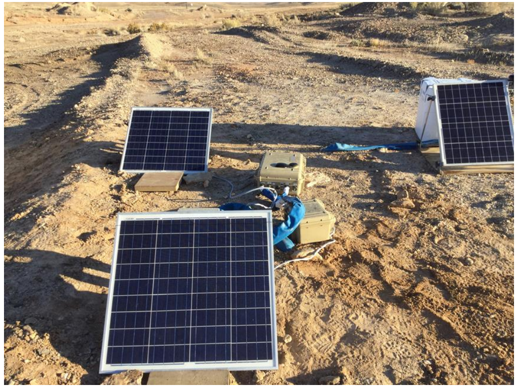
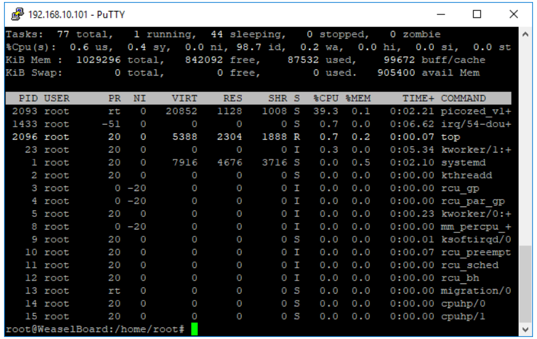
DEPLOYMENT

- 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





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%Cpu(s):  0.6 us,  0.4 sy,  0.0 ni, 98.7 id,  0.2 wa,  0.0 hi,  0.0 si,  0.0 st
KiB Mem :  1029296 total,   842092 free,    87532 used,    99672 buff/cache
KiB Swap:        0 total,        0 free,        0 used.   905400 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
 2093 root      rt   0   20852   1128   1008 S  39.3  0.1   0:02.21 picozed_v1+
 1433 root     -51   0       0      0      0 S   0.7  0.0   0:06.62 irq/54-dou+
 2096 root      20   0    5388   2304   1888 R   0.7  0.2   0:00.07 top
   23 root      20   0       0      0      0 I   0.3  0.0   0:05.34 kworker/1:+
    1 root      20   0    7916   4676   3716 S   0.0  0.5   0:02.10 systemd
    2 root      20   0       0      0      0 S   0.0  0.0   0:00.00 kthreadd
    3 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 rcu_gp
    4 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 rcu_par_gp
    5 root      20   0       0      0      0 I   0.0  0.0   0:00.23 kworker/0:+
    8 root       0 -20       0      0      0 I   0.0  0.0   0:00.00 mm_percpu_+
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   11 root      20   0       0      0      0 I   0.0  0.0   0:00.00 rcu_sched
   12 root      20   0       0      0      0 I   0.0  0.0   0:00.00 rcu_bh
   13 root      rt   0       0      0      0 S   0.0  0.0   0:00.00 migration/0
   14 root      20   0       0      0      0 S   0.0  0.0   0:00.00 cpuhp/0
   15 root      20   0       0      0      0 S   0.0  0.0   0:00.00 cpuhp/1
root@WeaselBoard:/home/root#
```

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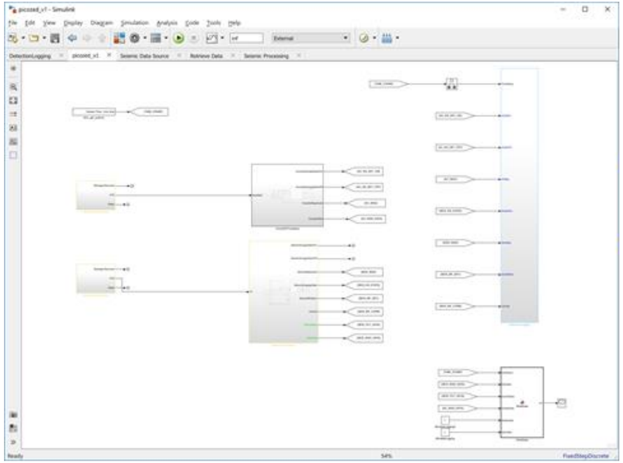
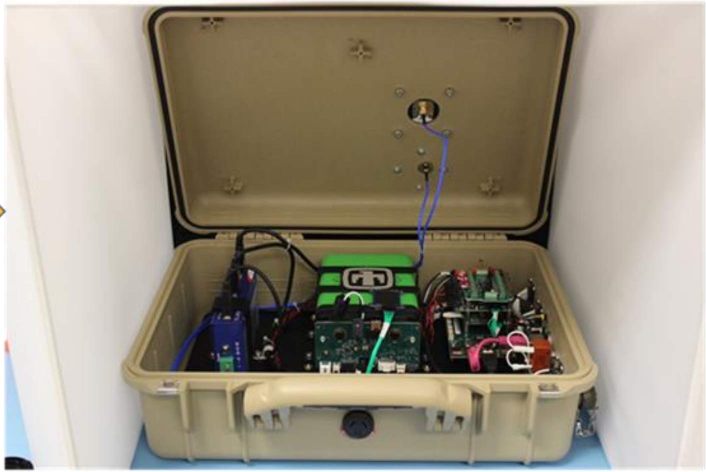
DETECTION

- 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.



C++ Code Generation



MatLab Simulink model and code used to generate C++ Code to run on sensor platform

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ML APPROACH

- 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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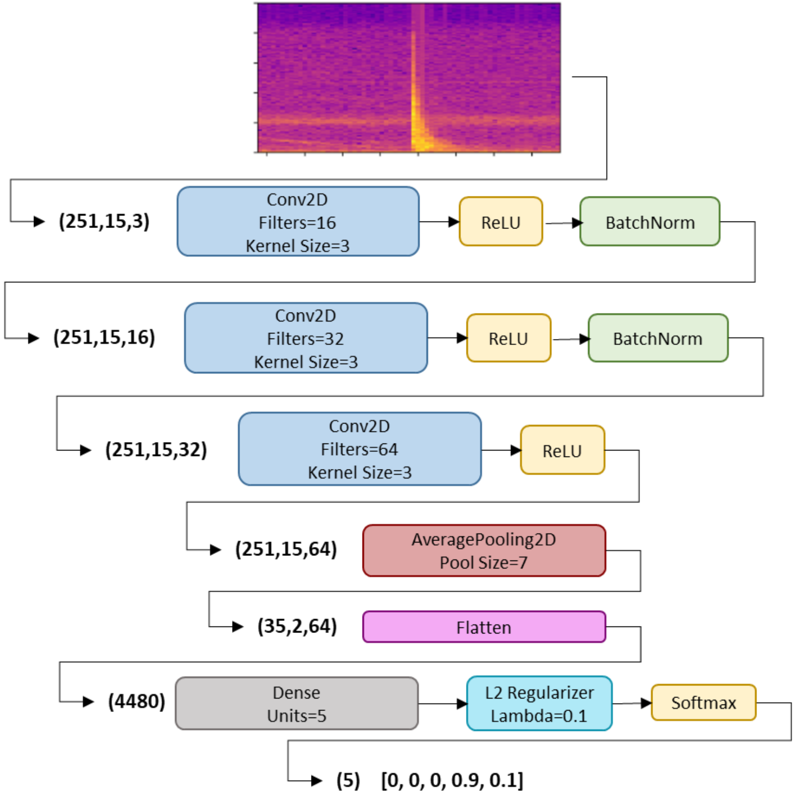
ML ALGORITHM


(251,15,3) → Conv2D Filters=16 Kernel Size=3 → ReLU → BatchNorm

(251,15,16) → Conv2D Filters=32 Kernel Size=3 → ReLU → BatchNorm

(251,15,32) → Conv2D Filters=64 Kernel Size=3 → ReLU

(251,15,64) → AveragePooling2D Pool Size=7

(35,2,64) → Flatten

(4480) → Dense Units=5 → L2 Regularizer Lambda=0.1 → Softmax

(5) [0, 0, 0, 0.9, 0.1]

- 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

	Loss	Accuracy
Train	0.22	0.95
Validation	0.87	0.76

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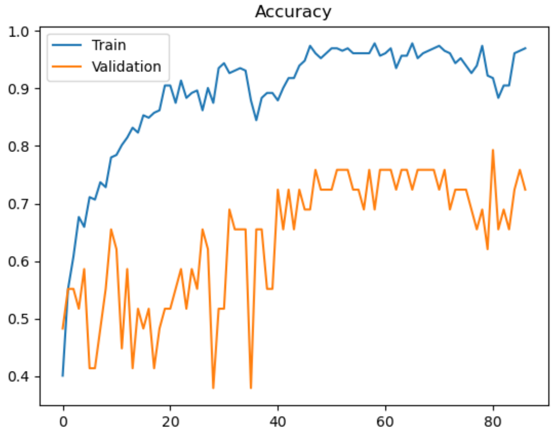
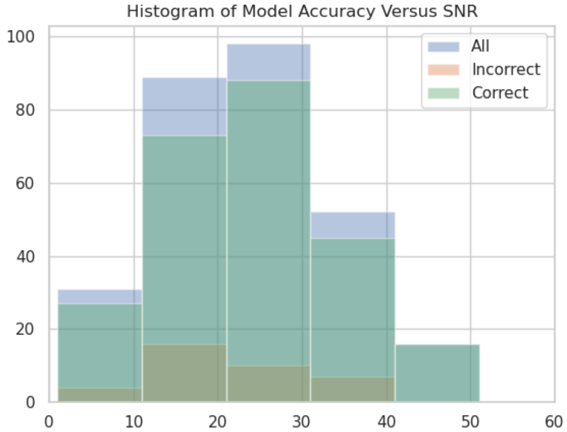
ML RESULTS





- 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

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CONCLUSIONS

- 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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FUTURE WORK

- 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

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