tinyML Summit
Enabling Ultra-low Power Machine Learning at the Edge

Products and applications enabled by tinyML

March 28 – 29, 2023

www.tinyML.org
Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) and metal active gas (MAG) is a welding process in which an electric arc forms between a consumable MIG wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to fuse (melt and join). Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from atmospheric contamination.
#4 = Contact Tip
GMAW Defects which are difficult to detect with conventional means

Porosity, caused by:

• Too much/little flux Gas
• Oil on parts
• Excessive “stick out” or distance between the contact tip and the part
• Etc.
GMAW Defects which are difficult to detect with conventional means

Burn Through, cause by:

- Wire Feed Restriction, Tangled Wire Barrel
- Loose Drive Rolls
- Wire Conduit Detachment
- Etc.
Goals

- Reduce 100% Human Visual Inspection to anomaly based only.
- Improve Quality.
- Improve Throughput.
Reason for current 100% inspection

• Once parts are loaded at the beginning of the line, they are not inspected again until end of line. This is why 100% inspection is performed at the baseline cell.
GMAW

Defects which are difficult to detect with conventional means

• Conventional means of anomaly detection have several limitations:
  • Require additional hardware.
  • Low sampling rate.
  • False negatives/ false positives.
  • No data logging.
• These defects can be audibly heard by a person. Can we give the robot that capability?
Project: Acoustic Detection using tinyML
Why tinyML?

• Realtime Requirements: Fast Model Update Time Required for Anomaly Reaction.

• Availability: The emergent field of tinyML now facilitates this project which we have been trying to accomplish since 2021.

• On inexpensive, available, easy-to-mount hardware
Challenge #1: How to interface with model?
Solution: NodeRed Event Engine
MQTT direct to Siemens PLC
Challenge #2: How to store data?

- Influx DB latest version with FLUX query language. Time series optimized database with vastly superior performance compared to established SQL databases.
Challenge #3: How to view Data? Solution: Grafana

**Variant Type**
- Green Line is Arc Established
- Yellow Line is Confidence Level Good
- Orange Line is RMS Value Confidence Good /Weld

**Per Weld Details**
- RMS by Weld
- RMS Min. Setpoint by Weld
Viewing welds over time

RMS by Variant Robot, Weld, Fixture

RMS Min. Setpoint Require Inspection
Challenge #4: Model Training and Workflow Efficiency

- Initial classification model had three classes. Training data was from multiple sources and recorded on different hardware. Due to low success rate we re-strategized to a single classification model (Good Welding) and recorded all training data on the same hardware that the model runs on/with.
- Started a Design of Experiment to discover model parameters and improve training workflow.
- Automated the recording of training data using Nodered.
- Developed “Loopback Testing” methods for model testing offline against recorded anomalies.
- Reduced the number of epochs during training to reduce training time.
Imagimob
Design
Environment:
Track labeling
### Imagimob Design Environment: Pre-processor Settings

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Create Track from Preprocessor...            Build Preprocessor...

Project successfully validated.
Challenge #5: PLC Integration?

- Developed PLC Function block to facilitate machine integration with model.
- RMS value of the confidence level was added for a better benchmark of weld quality.
Challenge #6:
PLC Integration?

- In addition to time windows on the confidence level, the RMS value of the confidence level was added for a better benchmark of weld quality.
Actual Arc Fault detected
Validation Testing
60% Gas Reduction
Validation Testing

100% Gas Reduction
Validation Testing
60-100% Gas Reduction
Validation Testing Seam Off Location
Validation Testing
Seam Off Location
Validation Testing
Incorrect weld wire. 0.040 vs 0.045
Key Lessons

• Ensure that optimal process state considers all process variables. In our case I had not considered contact tip life, upstream fixture source, or variant.

• Simplify D.O.E. as much as possible for greater chance of success. (I.E. single classification if using a classification model). Record training data with same hardware as the model will run on.

• Gain / Dynamic range is critical for training data, offline “loopback” testing and model run parameters.

• Classification labeling is critical for model performance. I.E. windowing of wave form.

• Speed of training iterations and testing is vital.

• Raspberry Pi4 is more than sufficient for application. TinyML Model uses 1% of one core. Currently all four cores are running under 15% in current configuration (Two Models Running).

• College intern contributions made this project possible. Encourage all to employ interns wherever possible.
Insights

- TinyML hardware needs industrial ethernet interface capability. Profinet, Ethercat, Ethernet IP. CAN is too slow and is outdated.
- Industrial space is ripe for hardware disruption. Current state is long delivery times, high cost, cloud centric approach. No low cost, industrial sensor tiles available.
- Acoustic anomaly detection has many use cases in industrial manufacturing.
- Proof of concept projects are difficult to get funding for. Imagimob enabled our project to occur with their pricing model and initial project support.
- Large language models can be very helpful in ML projects. C code samples, hardware (microphone) settings, pre-processor settings, SCL PLC code, and many others. We are using LLMs to increase efficiency nearly everyday now.
Next Steps

• Add anomaly detection to all robots of the test cells.
• Improve spectral analysis of waveforms
• Program machine to send to inspection only parts which fall below the minimum threshold for RMS setpoint.
• Find more suitable hardware
• Test other use cases in the manufacturing environment.
• Add “Stop Process” RMS threshold.
• Improve robot dress package for acoustic equipment.
• Improve sampling rate below the current 400 ms.
Challenges

Severe environment
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