Artificial Neural Network for MSW Characterization

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FY 20 Topic 2: Waste to Energy Strategies for the Bioeconomy
Feedstock Technologies Session

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Terms

Term	Meaning	Note
MSW	Municipal Solid Waste	Often extends to other residue-bound wastesheds such as recycling residuals.
RGB	Red-Green-Blue	General purpose vision cameras
NIR	Near Infrared Range	NIR generally refers to light within the range of 12,500 to 4,000 cm-1
MIR	Mid Infrared Range	MIR refers to light within a wavelength range of about 1,300 nm to 3,000 nm.
SWIR	Short-wave Infrared	SWIR refers to non-visible light falling between 1400 & 3000 nm in wavelength
XRF	X-ray fluorescence	Emission of characteristic X-rays from a material excited high-energy X-rays or gamma rays
UV	Ultraviolet	A form of electromagnetic radiation with wavelength from 10 nm to 400 nm, longer than X-rays.
AI	Artificial Intelligence	For this presentation: General purpose computer vision techniques.
(A)NN	Artificial Neural Net	Synonymous with the above.
INL	Idaho National Lab	Federal R&D Center in Idaho.

Project Team

INL

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Project Overview

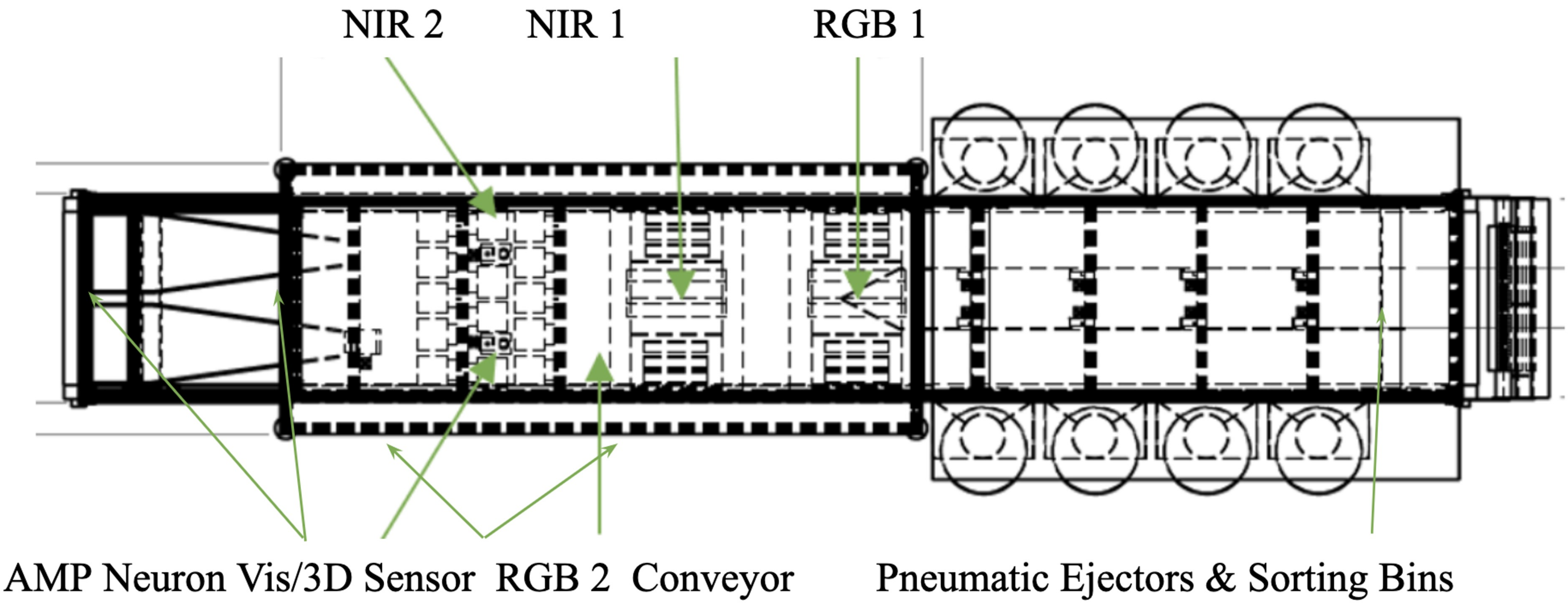
- Goal of developing a robust, cost-efficient sensor for high-confidence detection and control of feedstock contaminants in MSW at <$30/ton.
- Any item that can affect fuel-conversion yield are considered contamination.
- AMP will baseline an RGB-only AI on MSW, and then work with INL to develop an AI that fuses 6 different modalities (XRF, NIR, MIR, SWIR, UV, Depth, RGB).
- We will then ablate those sensors, their sampling rates, and frequency ranges, while studying performance across a range of MSW categories.
- We will ultimately present an efficient sensor package and corresponding AI performance baseline for commercialized detection of all MSW contaminants.

1 – Approach

1. Baseline RGB-only AI performance on key MSW categories across organics, metals, and different plastics.
2. Complete assembly of INL’s novel sensor array, including homography and data egress across NIR, MIR, SWIR, Depth, RGB, ~~XRF~~ (delayed beyond project timelines), ~~UV~~ (descoped).
3. Train a Neural Net using all sensors, with a variety of fusion techniques, on 12 distinct categories of waste. Iterate on this training with 2 rounds of sample collection and training data.
4. Ablate these sensors across sampling rates and frequencies, and pair with a cost-benefit analysis to demonstrate best performance relative to cost on primary categories. Establish basis for feasibility of additional novel levels of chemical control.
5. Go/No-Go’s after Budget Period 1 for successful baselining, and after Budget Period 2 for evaluating performance of AI after multi-modal fusion and one round of iteration. Key for establishing technological feasibility, and understanding cost:performance tradeoffs related to financing an iterative AI development effort for MSW
6. Final TEA/LCA and sensor ablation study to maximize cost-to-performance ratio within budget.

1 – Approach

Sensor Array at BFNUF



 www.amprobotics.com

1 - Approach

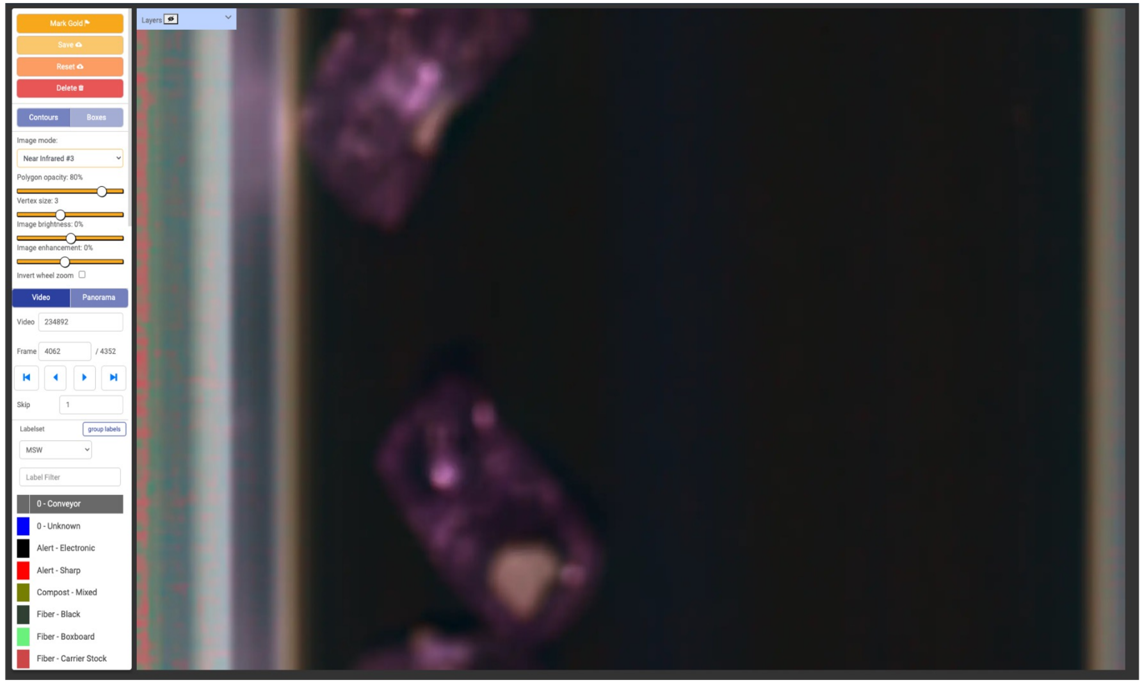
Sensor Array at BFNUF

AMP System and MIR, NIR, SWIR Sensors.

Material being scanned under Sensor Array

1 – Approach

Annotation & Data



Toolkit™, AMP's internal data platform for multi-modal data annotation

NIR data visualized in RGB using Principal Component Analysis

Key Risks & Challenges

Factors affecting accurate MSW characterization at scale

Item Variability

Items will often be partially or fully occluded, and lack proper singulation. In MSW particularly, it is common to see excessive contamination, which can affect NIR penetration or item appearance.

AI Performance

AI has significant diminishing marginal returns "in the long tail", i.e. at the upper end of the performance spectrum. Combine this with intrinsic variability across the categorization challenge, and there is risk that mAP is not sufficient for high-yield performance.

System Integrity

MRFs and particularly MSW processing facilities are extremely hostile environments for technology. NIR has a high maintenance burden, and GPUs require good airflow to maintain low operating temperatures. Environmental factors can severely affect performance and managing them effectively will be crucial for a high-TRL deployment of this technology.

2 - Progress & Outcomes

- The project has seen significant delays due to third party sensor array procurement and commissioning at BFNUF. It is 9 months behind schedule, with 75% of the work outstanding.
- AMP has baselined our RGB-only AI, developed an architecture for fusing sensor modalities, and fused with NIR spectra to achieve state-of-the-art performance.
- We have also developed multi-modal annotation capabilities and shipped our MSW samples to INL for characterization. Lastly, we are finalizing our preliminary TEA/LCA and validating system actuals.
- To maintain forward progress, we have had to forego UV and XRF fusion, using remaining 5 modalities to drive characterization.
- We are now in the process of scanning all the material, by type, under the sensor array to collect data for our first AI training, which we expect to complete near the end of April.

3 - Impact

Successful cost-minimized performance of a general purpose AI sensor for MSW characterization would enable successful high-TRL MSW feedstock control. This is a critical first step in enabling feedstock conditioning for removal of PVC, metals, inerts, and other chemical imbalances that might drive down yield and performance of fuel conversion pathways such as gasification. No such capability exists, and it would enable sortation solutions such as the robots among AMP's product portfolio to deliver the consistent, high-yield feedstocks necessary for commercialization of MSW-to-fuel pathways.

AMP Cortex™

Robotic Sorting System

- 80-120 picks / min vs manual sortation of 40 picks / min
- 99% accurate in precision object recognition
- Can sort up to 8 separate commodities
- 12 to 24-month payback

AMP Vortex™

Robotic Sorting System

- Film and Light Density Separation
- 120 picks / min

Summary

- We are making cost efficient sensors for detecting all necessary conditions to use MSW as a fuel source.
- We are also establishing a research pathway for more robust MSW chemical detection and control in industrial environments.
- Our work will enable higher-TRL projects such as AMP's FY21 BETO award, which focus on incorporating these techniques with sortation technology to prepare feedstocks. These awards will lead to products sold in-market.
- MSW Feedstock consistency and availability remain the largest bottleneck to large-scale commercialization of Gasification and other high-TRL sustainable fuel pathways.

Quad Chart Overview

Timeline
- March 2021
- December 2023

	FY22 Costed	Total Award
DOE Funding	$767,105	$1,886,922
Project Cost Share	$302,759	$614,305

TRL at Project Start: 3
TRL at Project End: 5

Project Goal
The goal of this project is to develop a cost-competitive multi-modal sensor sufficient for full MSW feedstock characterization, en route to feedstock control. In doing so, we will profile performance sensitivities across a range of characteristic MSW materials and sensor modalities.

End of Project Milestone
At the end of the project we will aim to demonstrate the most efficient sensor combination, sampling rate, and range for AI-enabled classification of MSW.

Funding Mechanism
BETO FY20 Topic 2: Waste to Energy Strategies for the Bioeconomy

Project Partners
- Idaho National Laboratory
- Cascadia Consulting Group
- University of Arizona

Additional Slides

Commercialization

- EE0009264 will directly inform cost-effective sensor requirements for novel feedstock preparation for gasification and other fuel production pathways, for future AMP facility & product development.