Missouri University of Science and Technology

PROGRESS UPDATE ON CDC-NIOSH U60 PROGRAM

Research, Technological Innovations in Automation, Robotics, and Other Intelligent (ARI) Mining Systems for Transformative Improvements in Workplace Safety, Health, and Efficiencies

Samuel Frimpong, PhD, PEng
Professor of Mining and Explosives Engineering

October 10, 2024

OUTLINE

- Motivation and Objectives
- Research Leadership and Personnel
- Partnership with Industry and CDC-NIOSH
- Research Focus Areas
- Research Progress Updates
- Summary and Conclusions

Research Motivation and Background

- U.S. Mining Industry has advanced Technological Innovations to improve Safety, and Health
- No. of Fatalities decreased by 65% from 206 (1984) to 71 (2010)
- Fatality Rate decreased by 56% from 58.43 (1984) to 25.74 (2010)
- BUT the 2021 Rate of 16.15 was 4X Average Rate for US industries
- The NEED for Research, Technological Innovations and their Effective Deployment and Management within the Next Two Decades

Primary Research Objective

Contribute Towards Eliminating Mining Fatalities within the Next Two Decades by Efficiently Managing ARI Systems, and Controlling their Risks and Hazards, within Human-Centered Environments

Specific Objectives

- Accurate Predictions, and Process Management to assure ARI Systems
- Secure, Protect, and Prevent Adversarial Attacks against ARI Systems
- Efficient Management in the New Paradigm
- Transfer Bulk Data to provide 360^{O} Vision and Prevent Collisions
- Safe Operations in Dangerous Mining Environments
- Intelligent Evacuation in Post-Disaster Emergencies

Research Leadership (S&T & UKY)

No.	Research Faculty	Role	Discipline	Focus Areas
1	Dr. Samuel Frimpong	PI	Mining & Explosives Engineering	IDA/CSNS/IMRPDS
2	Dr. Kwame Awuah-Offei	Co-PI	Mining & Explosives Engineering	HF/IMRPDS
3	Dr. Sanjay Madria	Co-PI	Computer Science	IDA/CSNS/IMRPDS
4	Dr. Venkat Allada	Co-PI	Eng Management & Systems Eng	HF/IMRPDS
5	Dr. Yun Seong Song	Co-PI	Mechanical & Aerospace Engineering	IRAM/IMRPDS
6	Dr. Maciej Zawodniok	Co-PI	Electrical & Computer Engineering	ICS/IMRPDS
7	Dr. Devin Burns	Co-PI	Psychological Science	HF/IMRPDS
8	Dr. Muhammad A Raza	Res. Mgr.	Mining & Explosives Engineering	IMRPDS
9	Dr. Pedram Roghanchi	Co-PI	Mining Engineering/Univ of Kentucky	IDA

Post-Doctoral/Doctoral Researchers

No.	Name	Status	Discipline	Focus Area
1	Dr. Khawar Naheem	PDF	MIN ENG	AI/ML, Cybersecurity
2	Dr. Mohamed A Elmahallawy	PDF	COMP SCI	AI/ML, Cybersecurity
3	Dr. Saima Ghazal	PDF	PSYCH SCI	Human Factors
4	Mabel Obosu	PhD	MIN ENG	AI/ML in Automation Safety
5	Rosebella Osei	PhD	ENG MGMT	Change Management
6	Michael Tweneboah	PhD	MIN ENG	Human Factors
7	Md. Sazedur Rahman	PhD	COMP SCI	Big Data Analytics
8	Mizanur Rahman Jewel	PhD	COMP SCI	AI/ML Predictive Modeling
9	Khosro Ghorbani Zadeh	PhD	MECH ENG	Robotic Assistance in Mining
10	Ellen Essien	PhD	MIN ENG	AI/ML in Mine Safety
11	Sai Prabhath Koneru	PhD	COMP ENG	Wireless Communication
12	Esther Gyabaah	PhD	MIN ENG	Thermal Robotics
13	Philip Samil	PhD	MIN ENG	AI/ML and Data Analytics

Industry Research Advisory Board (IRAB)

- John Drexler, Chief Operating Officer, ARCH Resources
- Tom Barnes, Sr. Manager, Global Service Excellence, Komatsu America Corp
- Jim Humphrey, Sr. Marketing Specialist – Autonomy (Rtd.), Caterpillar Global Mining
- Justin Higginbotham, General Manager, Operations & Projects, Fred Weber Inc.
- Tracy Hayford, Director of Technology, MATRIX Design Group, LLC
- David L. Weaver, Regional Manager, South-Central Division, MSHA
- Bryan Galli, Group Chief Executive (Rtd.), Peabody Energy Corporation
- Lane Hendricks, Safety Manager, Prairie State Generating Company
- Tom Michaud, Chief Technical Officer, Strata Worldwide
- Luke Mahony, Global Head of Eng, Technology & Innovation, Vale Base Metals

Partnership with CDC-NIOSH

- Dr. Denise A. Baker, Behavioral Scientist & Associate Research Fellow, CDC-NIOSH Pittsburgh Mining Research Division
- Robert (Bob) Bissonette, PE, A&T Team Lead, CDC-NIOSH Spokane Mining Research Division
- Todd Ruff, MS, PE, Senior Scientist, CDC-NIOSH Spokane Mining Research Division

Six Research Focus Areas

- IDA – Intelligent Data Analytics
- CSNS – Cyber & System Network Security
- HF-CM – Human Factors and Change Management
- ICS – Intelligent Communication Systems
- IRAM – Intelligent Robot Assistance in Mining
- IMRPDS – Intelligent Mine Rescue and Post-Disaster Surveillance

Cybersecurity Research Motivation

- Mine ARI Systems require Safe, Secure, & Reliable Transfer and Processing of Large Data over Multiple Complex Networks
- Data Losses Causes: Human Errors, Malware, Dard Drive Malfunction, Software Corruption, and Sudden Power Outages
- Cost of Data Losses or Sensitive Data Leakages is Very High
- Disaster Recovery Preparedness Council: 2.1% of Surveyed Industry Reported Large Data Loss Costs
- 94% of Companies with Data Losses were Unable to Recover the Data and 51% ceased Operations

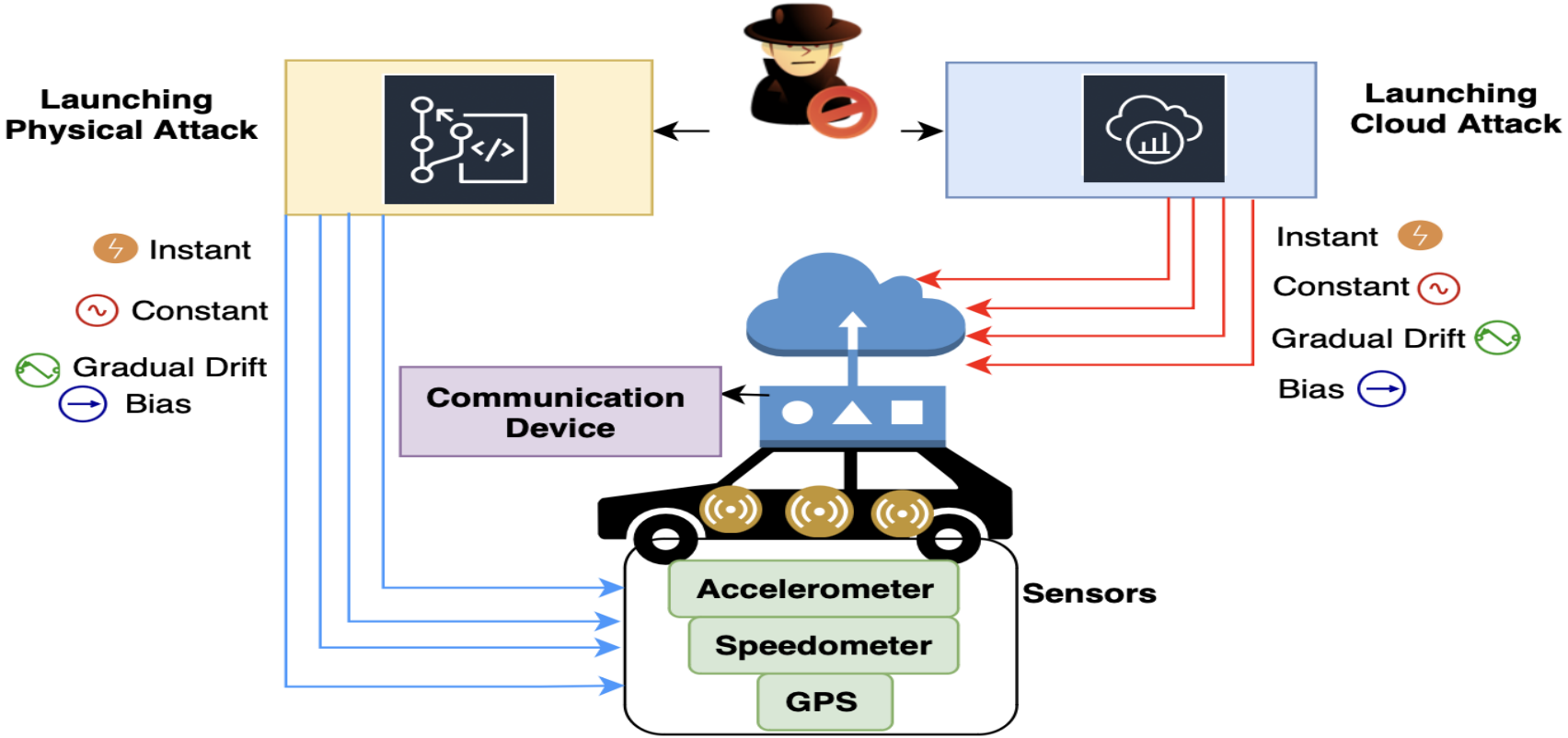
Research Focus Areas

- Network and Data Security
- Data for Secure Message Delivery
- Multi-Sensor Fusion for Detection and Mitigation
- Advanced Virus and Data Encryption
- Network Authentication Process
- Random Threats Evaluation and Simulation

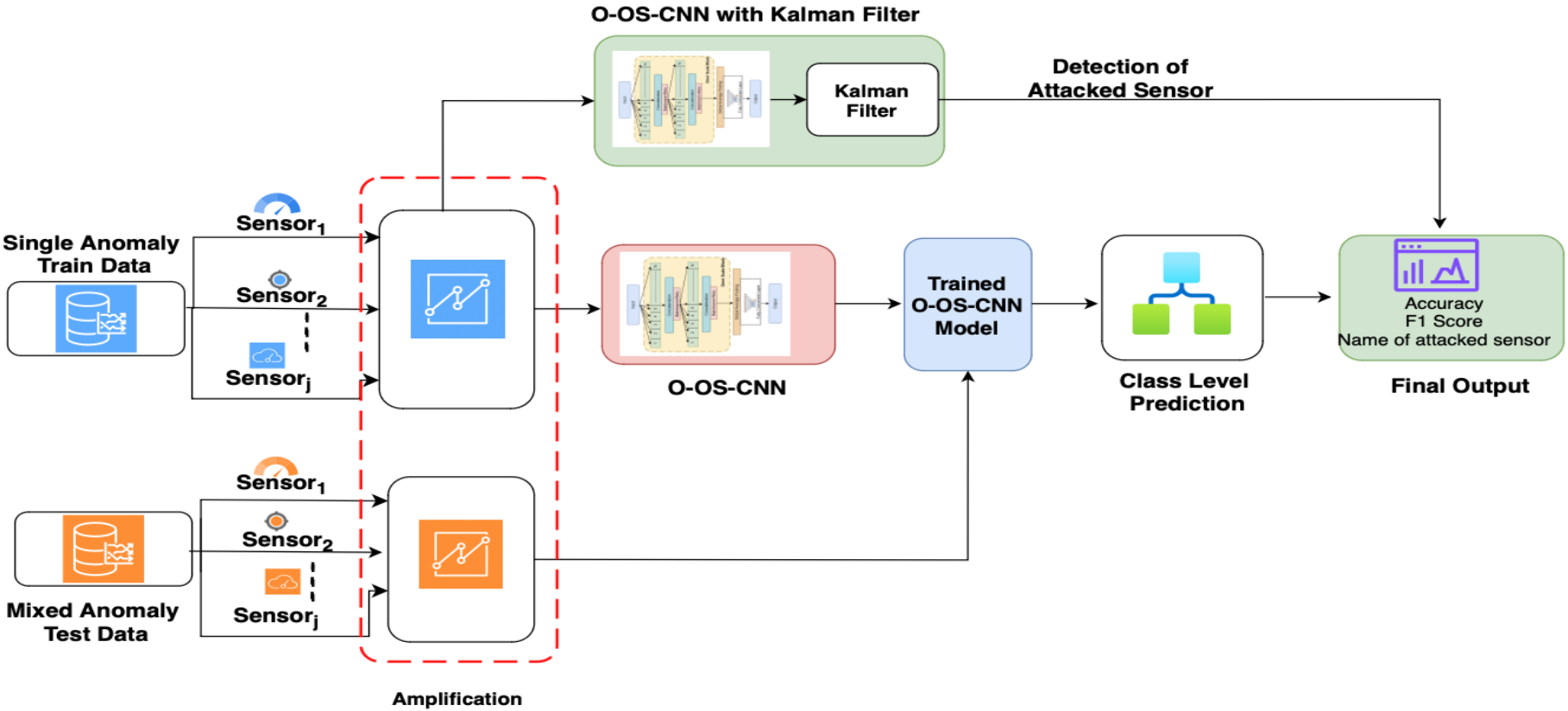
A Novel CAV-AD Cybersecurity Model

- Connected and Automated Vehicles (CAVs) are used in Public Transport Systems, Electricity Grid, and Manufacturing Systems
- CAVs uses Sensors and are susceptible to Critical Threats that compromise CAV Network Security
- We developed a Modified Anomaly Detection (AD) for CAVs, CAV-AD, for addressing CAVs Susceptibility to Critical Threats for Mining Assets
- CAV-AD comprises: (i) Convoluted Neural Network (CNN) Model called Optimized Omni-Scale CNN (O-OS-CNN), and (ii) Amplification Block to enhance Sensitivity for Detecting Anomalies

Mining Infrastructure Threat Model

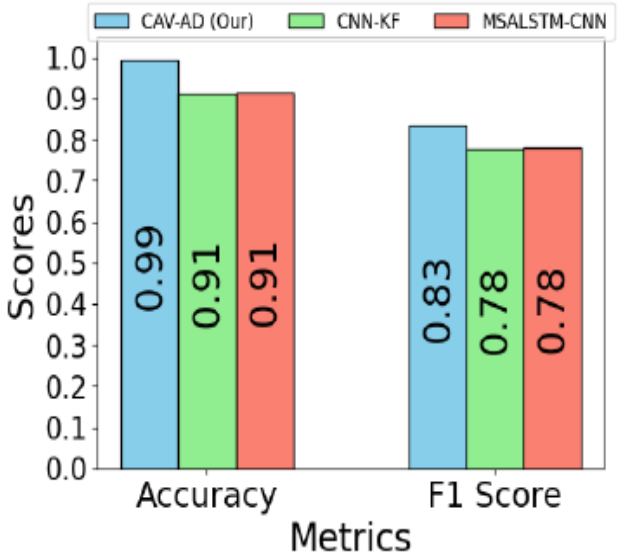


CAD-AD Framework with O-OS-CNN

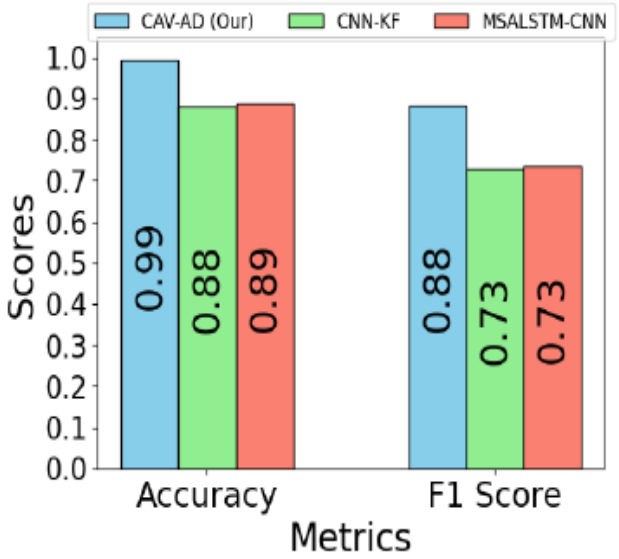


Accuracy & F1 Score: CAV-AD, CNN-KF, MSALSTM-CNN

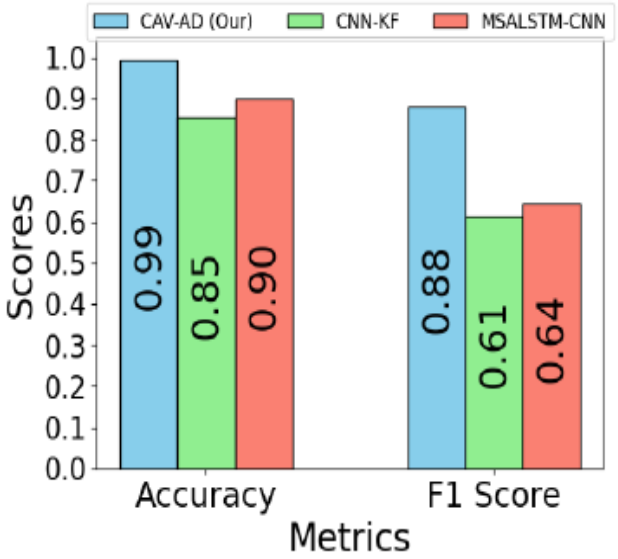
Random Anomaly Detection



(a) Sensor#1.



(b) Sensor#2.



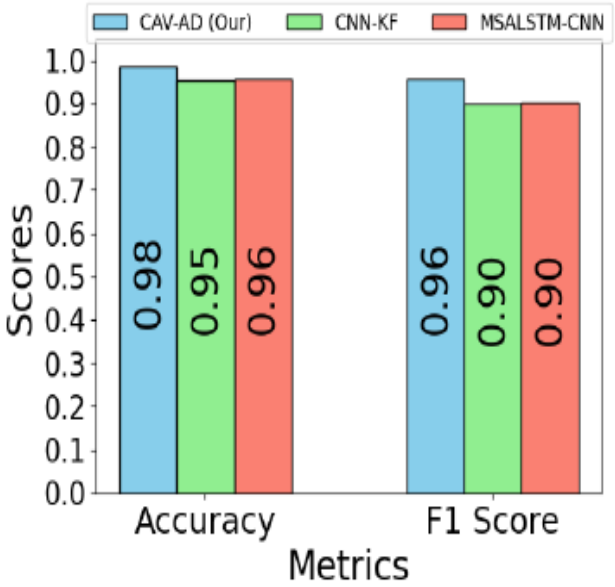
(c) Sensor#3.

CNN-KF and MSALSTM-CNN are SOTA (State-of-the-Art) Methods

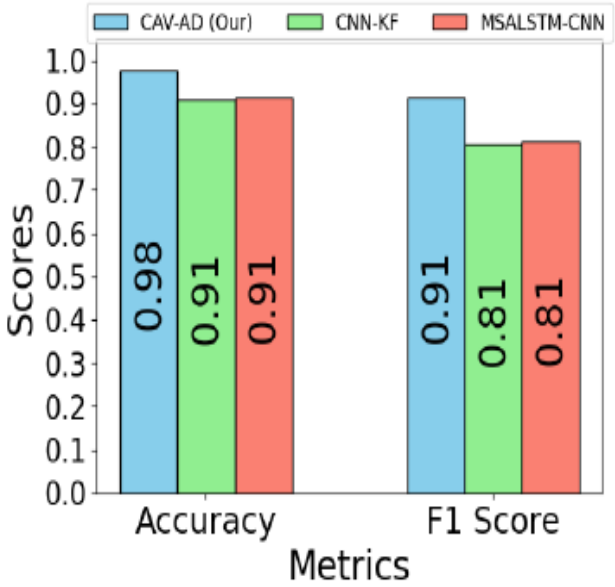
MISSOURI S&T

Accuracy & F1 Score: CAV-AD, CNN-KF, MSALSTM-CNN

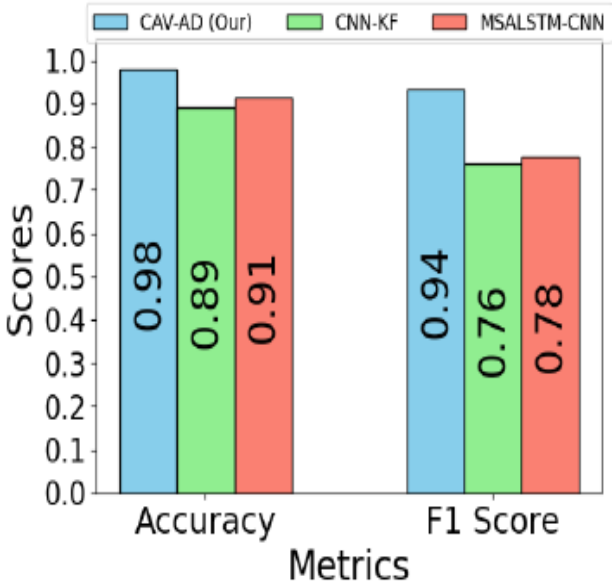
Constant Anomaly Detection



(a) Sensor#1.



(b) Sensor#2.



(c) Sensor#3.

CNN-KF and MSALSTM-CNN are SOTA (State-of-the-Art) Methods

MISSOURI S&T

Novel CAV-AD Cybersecurity Model

- CAV-AD integrates the proposed O-OS-CNN with a Kalman Filter to instantly identify malicious threats
- The results show that CAV-AD outperforms state-of-the-art methods, achieving an average accuracy of 98% and an average F1 (a measure of the harmonic mean of precision and recall) score of 89%
- Research is under way to develop a robust CAV-AD that achieves 100% average accuracy, since any inability to capture any malicious threat could be a disaster for any operation

Human Factors Research

Initial Learned Trust for AI or Human System

- Hazard Detection; Confidence Level and Level of Interaction with System
  1. Design Interface (Dynamic Learned trust)
     - Perceived security; Benevolence (Sense of Care); Credibility; Personalization; Transparency and Communication; Familiarity and Predictability; and Ease of Navigation
  2. Trustee (Miner) (Dispositional Trust):
     - Gender; Culture; Age; Traits; Previous Hazards Exposure; and Activity
  3. Nature of Message, Alert, or Signal

Human Factors Research

- IRB Approval and Conducted Online Survey
- Received ≈200 Participants' Responses
- Data Analysis Underway

Analyze Data to determine Effect/Influence System Type (Human or AI) and Detail System Information (Low or High Level) have on Miner's Sense of Safety, Willingness to trust and delegate Operations to System

Analyze to understand how Miners Demographics (Age, Sex, Marital Status, etc.) influence their Safety, Trust and Delegation Decisions

Intelligent Communication System (ICS)

Site Awareness Technologies:

- Assist in Monitoring and Controlling Operations in Real-Time
- Enable Operators to identify Potential Hazards and take Actions to preclude Accidents and Fatalities
- Use Sensors, Wi-Fi and Wireless Sensor Networks, and Real-Time Location Tracking Systems within RF Spectrum
- High Levels of Moisture, Dust, Rocks, Tunnel Effect, and other Obstacles can attenuate, reflect, or interfere with RF Signal Propagation

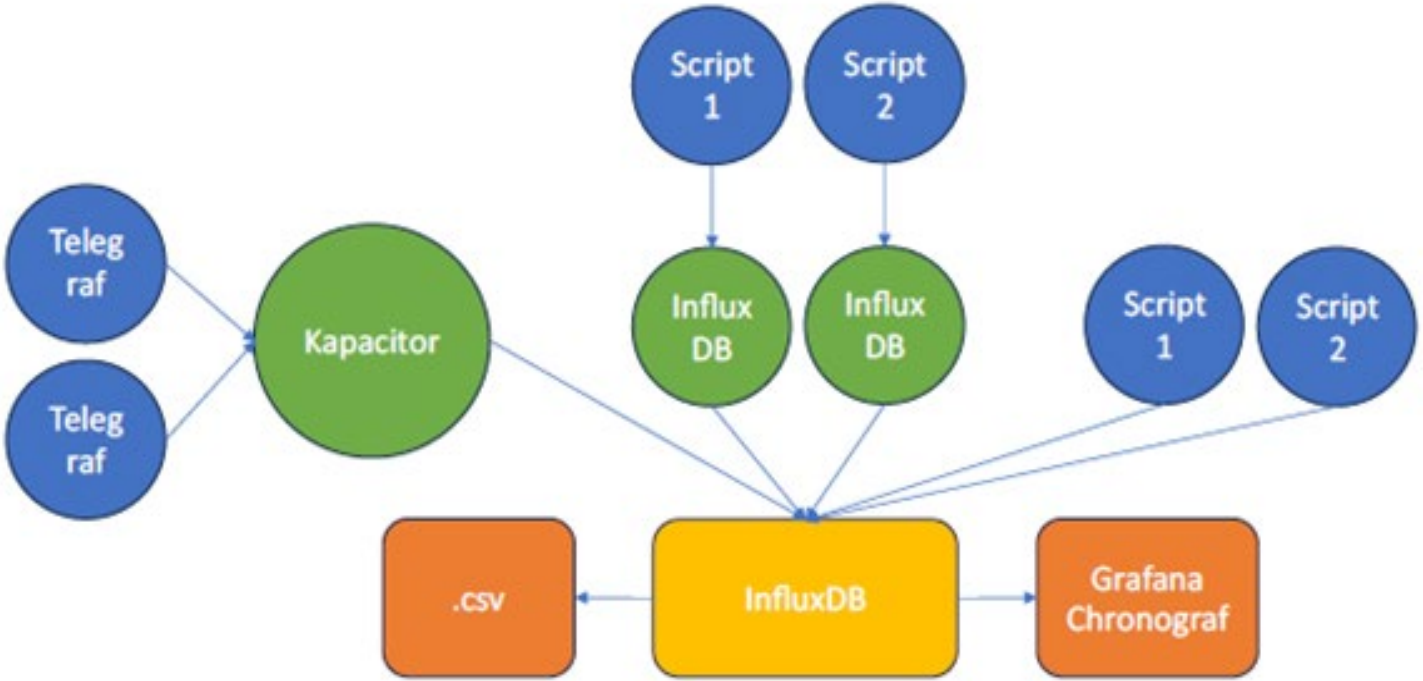
Study focuses on developing a New Network System to provide Robust Broadband Connectivity in Mining

Intelligent Communication System (ICS)

Summary of Research Progress: **Developed Mesh Network Monitoring Tools to automate data collection with network status and its performance metrics throughout the network and with Network Status Visualization**

Summary of Notable Accomplishments: **Developed Wireless Mesh Network Monitoring Tools for Rapid Deployment and Experimentation with Mesh Network for Data Collection, Analysis and Optimization**

ICS: VLC/RF Network System

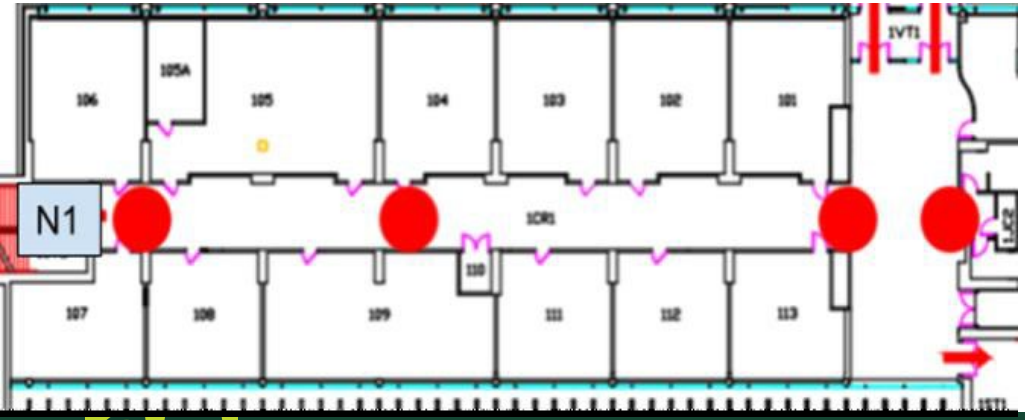


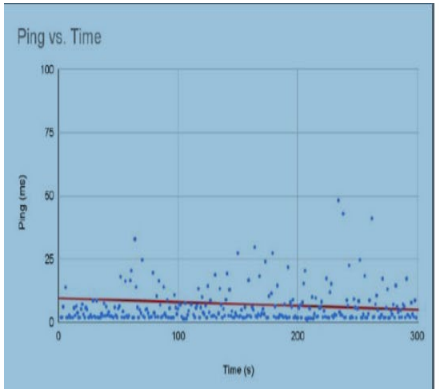
Raspberry Pi compute Module 4 to implement Data Processing, Networking Protocol Library, and Digital Signal Processing

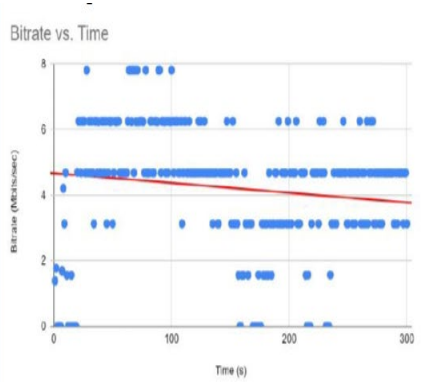
ICS: High-Capacity Wi-Fi Based Mesh Network

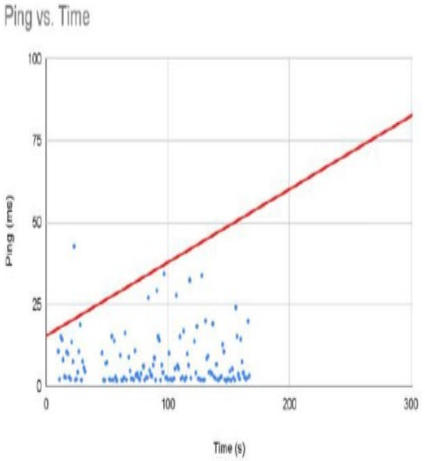
High capacity for data transfer and a mesh network monitoring to identify areas with low coverage for high-capacity systems

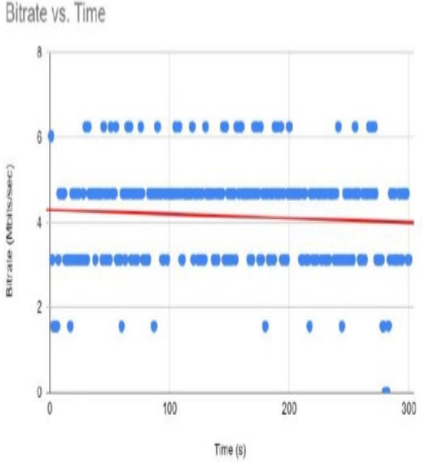
- Ad-hoc On-Demand Vector (AODV).
- Baseline Performance Testing
- Nodes placed along corridors in a to simulate mine shaft placement











Intelligent Robotic Assistance in Mining (IRAM)

Develop IRAM for Safe Operations in Deep Mines, High-Temperature Areas, Isolated Areas with Toxic and Explosive Gasses, or Tight Spaces

IRAM Provides: A research Testbed and Evaluation Platform to improve Workplace Safety and Health Conditions

Intelligent Robotic Assistance in Mining (IRAM)

Case Studies: Two primary objectives:

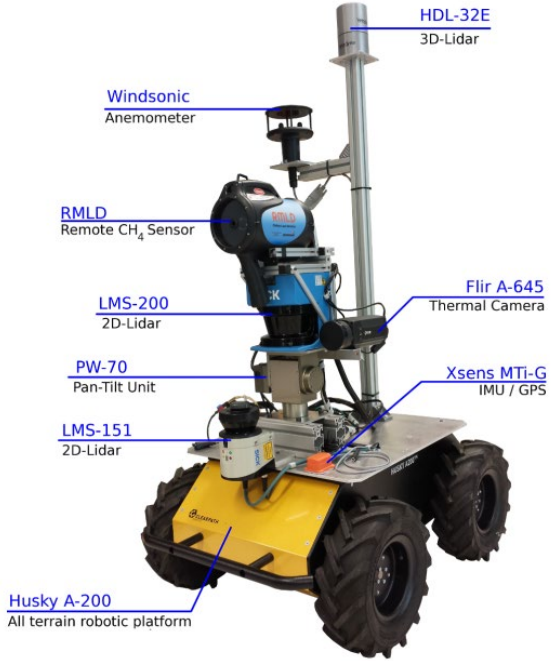
(A) - Inherent safety

(B) - Technological expandability

- Alexander

- Julius

Robot Assisted Gas Tomography



Immediate Strategies for Research Advances

- Complete the Hiring of Researchers by 1ST Qtr. of 2025
- Meetings with PMRD/SMRP within 1ST Qtr. of 2025
- Visits with Caterpillar/Komatsu ASAP
- IRAB Meeting in 1ST Qtr. of 2025
- First Site Visit at Missouri S&T in Summer 2025
- Full Throttle Research Advances

Thanks for Your Attention!!

We MUST endeavor to eliminate mining fatalities within the NEXT TWO DECADES by efficiently managing ARI Systems, and controlling their risks and hazards, within human-centered environments.

We MUST harness the POWER of our CRITICAL PARTNERSHIPS with CDC-NIOSH, Industry, Academia, and other Public and Private Enterprises in making this happen.