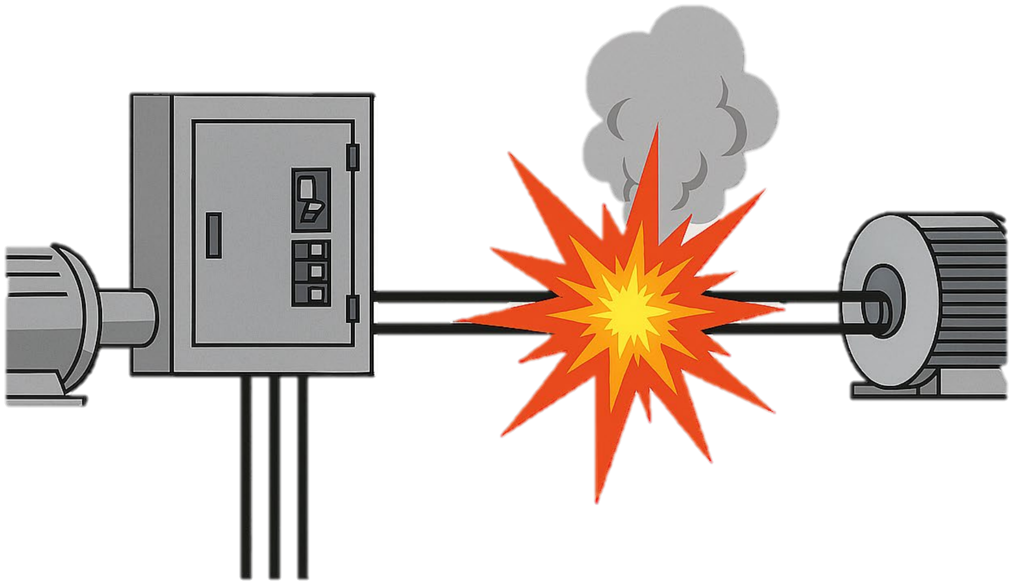


Multiphysics-Driven Arc-Fault Detection for Shipboard Electrical Systems via Sensor Fusion and Machine Learning
(Task Order 2026-361)

Project PI
Philip Pong
philip.pong@njit.edu
Associate Professor
Department of Electrical & Computer Engineering
New Jersey Institute of Technology

Presented by
Tanima Bal
tb445@njit.edu
Ph.D. Student
Department of Electrical & Computer Engineering
New Jersey Institute of Technology

Team Members

NAME	POSITION	AFFILIATION	EMAIL
Philip Pong	Associate Professor	New Jersey Institute of Technology	philip.pong@njit.edu
Tanima Bal	PhD Student	New Jersey Institute of Technology	tb445@njit.edu
Jason Farmer	Project Lead	Ingalls	jason.farmer@hii-ingalls.com
Brandon Whaley	Engineer	NSWC Philadelphia	brandon.f.whaley.civ@us.navy.mil
Jacob Matthews	Engineer	NSWC Philadelphia	jacob.e.matthews3.civ@us.navy.mil
Kyle Robinson-Jordan	Engineer Officer	Naval Sea Systems Command	kyle.m.robinson-jordan.civ@us.navy.mil
Christopher Nemarich	Engineering Manager	Naval Sea Systems Command	christopher.p.nemarich.civ@us.navy.mil
Rickey DeLoge	Electrical Engineering Supervisor	General Dynamics Bath Iron Works (GDBIW)	rickey.deloge@gdbiw.com
William Bessette	Electrical Engineering, Design Services	General Dynamics Bath Iron Works (GDBIW)	William.Bessette@gdbiw.com
Odirlei Moser	Product Marketing Specialist	ABB	odirlei.moser@us.abb.com
Walt Skalniak	Territory Manager	Ashby	wskalniak@ashbyco.com
Lydia Szydlo	NSRP Panel Coordinator, Sr. Program Administrator	NSRP / Advanced Technology International	lydia.szydlo@ati.org
Ryan Schneider	Program Manager	NSRP / Advanced Technology International	ryan.schneider@ATI.ORG

Multidisciplinary collaboration across academia, the U.S. Navy, shipbuilding, industry, and program management

Tanima Bal

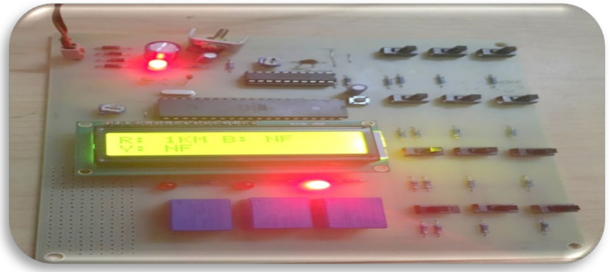
PhD Student • Electrical Engineering

BACKGROUND & EXPERIENCE

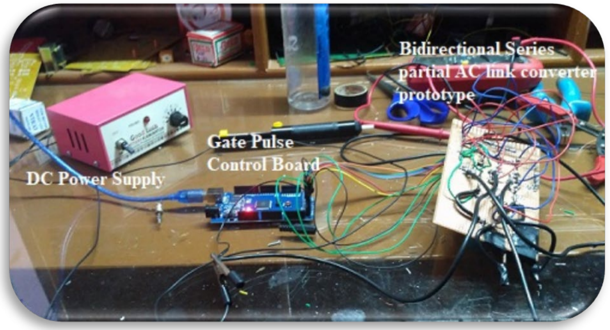
- Ph.D. student in Electrical Engineering — NJIT
- M.Tech. in Power Electronics & Drives — NIT India
- Developed an underground fault detection and localization prototype
- Designed control strategies for microgrid bidirectional converters.
- Applied real-time, data-driven optimization for net-zero energy buildings.
- Focused on improving system reliability via controller configurations.

CURRENT RESEARCH FOCUS

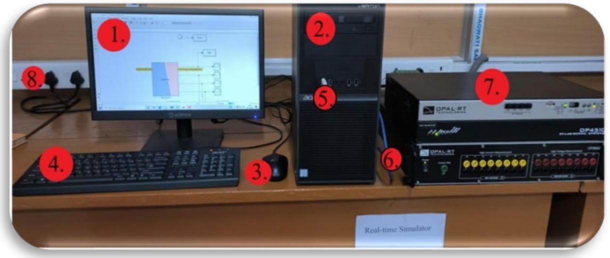
- Smart sensors for power-system monitoring
- Finite-element and real-time fault modeling
- Machine-learning methods for system resilience



Prototype of the underground fault detector



Micro-grid Bidirectional converter



Real-time NZEB controller validation

Presentation outline

- **Overview and Project Objectives**
- **Proposed Solution**
- **Multiphysics Simulation**
- **Experimental Setup**
- **Real-Time Arc Current Monitoring**
- **Experimental Results**
- **Machine-Learning Detection Framework**
- **Challenges Encountered**
- **Key Accomplishments & Future Work**
- **Project Timeline and Finance**

Overview and Project Objectives

Project Overview

- Protect personnel, critical equipment, and mission continuity from shipboard arc-fault hazards
- Modernize arc-fault protection by addressing false alarms
- Obsolescence
- Compatibility limitations

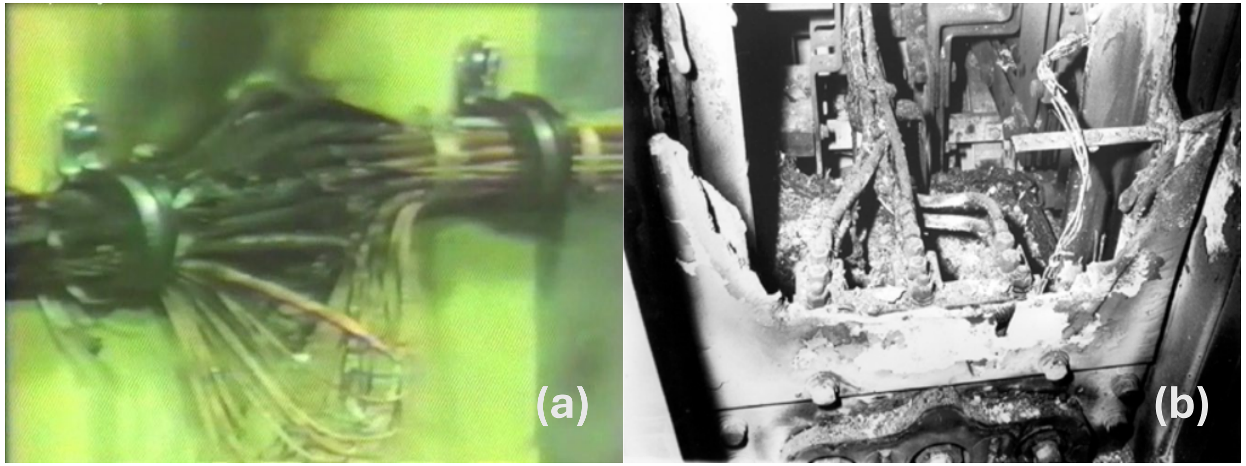


Figure: **(a)** Projectile damage to wire harness [1]; **(b)** Arc damage in switchboard [2]

Project Objectives

- To reduce False Alarm Rate to less than 1%
- To enhance Detection Speed to less than 2.5 milliseconds
- To adapt to harsh and variable conditions of Shipboard Environments
- To comply with stringent naval safety standards and regulations.

Rule-Based Approach with Fixed Threshold

Rule a.1

For any single $i \in \{1,3\}$ and for $\forall X_i \subseteq X$

IF $PI\left(\rho_{X_i}(k)\right) > PI^{max}\left(\rho_{X_i}(k)\right)$ for $1 \leq k \leq nk_i$

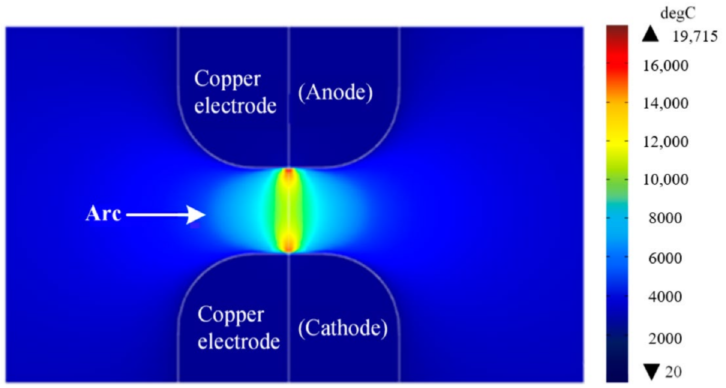
THEN Schedule appropriate control for $X_i(\rho)$

Parameter ρ_{X_i} associated with state X_i is the dominant violator contributing to the arc fault.

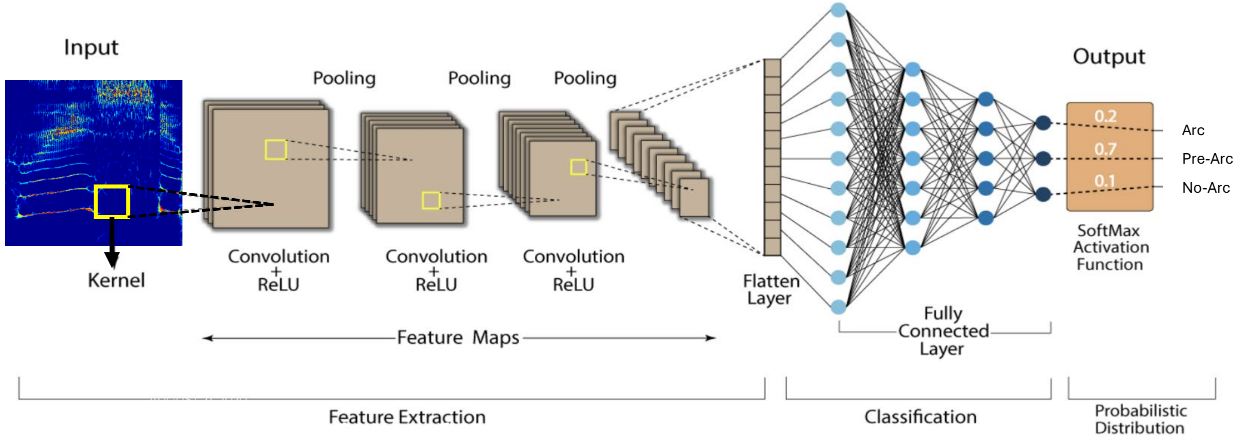
[1] Arc flash assessment on naval vessels: https://lectromec.com/arc-flash-assessment-on-naval-vessels/
[2] Evolution of Arc Fault Protection Technology at APL: https://www.jhuapl.edu/techdigest/content/techdigest/pdf/V25-N02/25-02-Land.pdf

Proposed Solution

- Accuracy: Multiphysics approach by sensor fusion: light, current, and acoustic sensors.
- Speed, Compatibility and Environmental Hardening : Adopt ABB REX615 protective relay for high-speed reliable fault detection with up-to-code communication.
- Reliability: taking machine learning and statistical approaches.
- Compliance: Lab and On-Site Testings with Shipyard and Navy partners.



Convolution Neural Network (CNN)




Acoustic sensor


Current sensor


Optical sensor


IR Camera

Multiphysics Simulation

Considerations: Axisymmetric geometry • LTE air plasma • Temperature-dependent properties • Joule heating • Radiation losses • Refined arc-region mesh

- Joule heating initiates and sustains the high-temperature arc channel.
- Temperature-dependent air-plasma properties are incorporated.

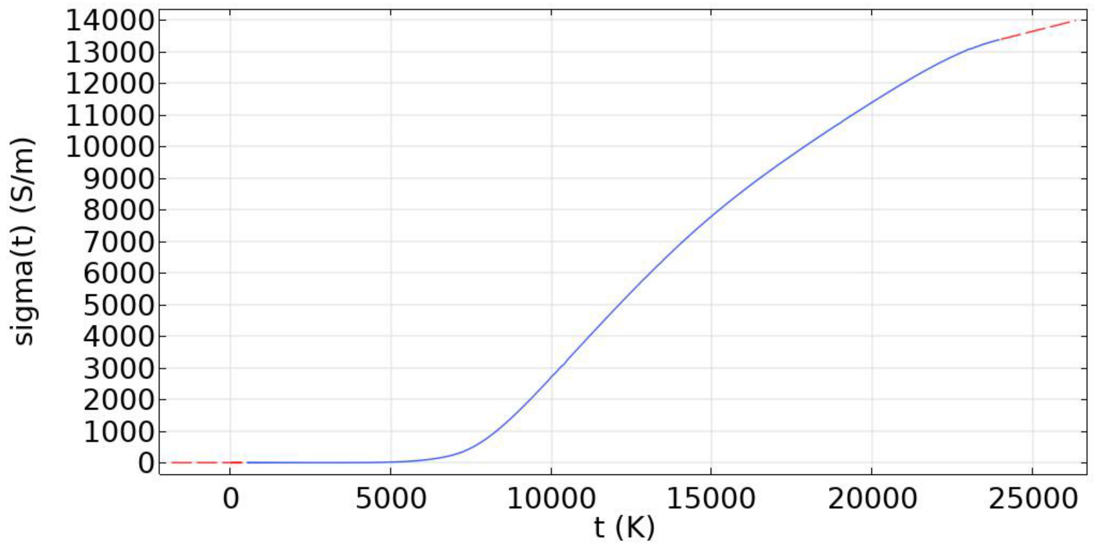


Figure: Electrical conductivity of air plasma as a function of temperature

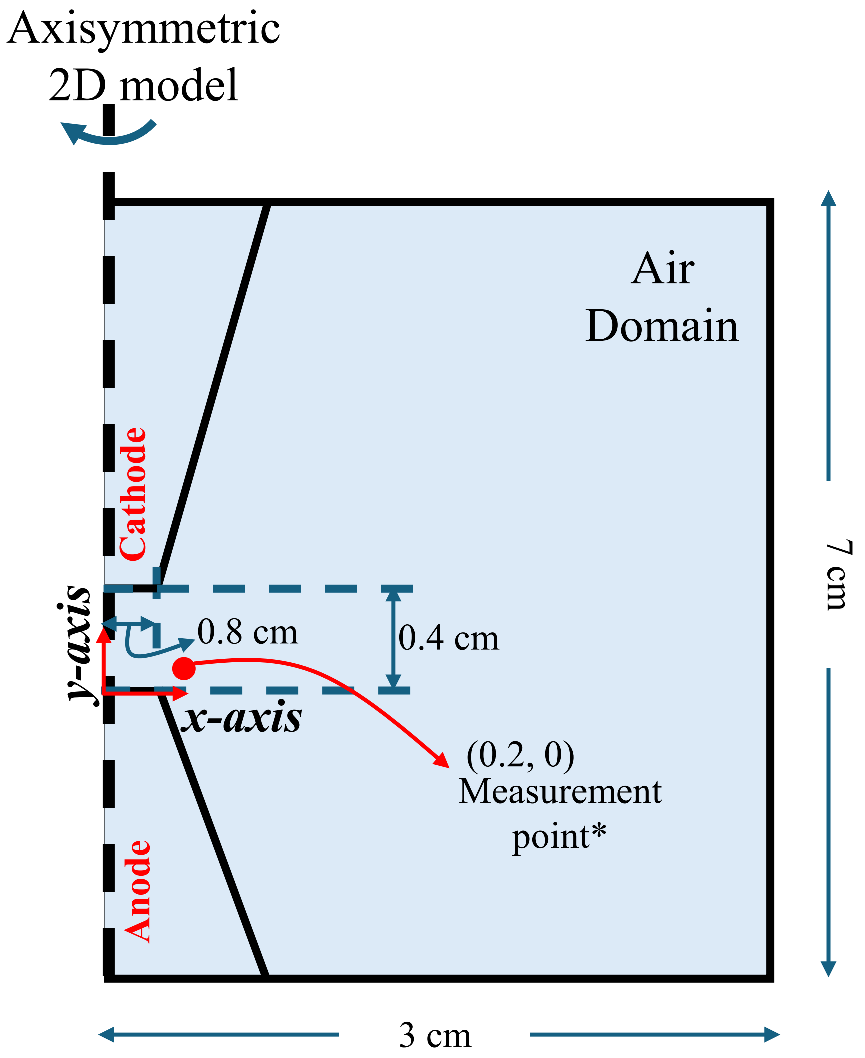


Figure: Multiphysics simulation model

*Z. Chen, X. Zou, H. Li, H. Luo and X. Wang, "Numerical Simulation of Acoustic Wave Generated by the AC Arc," in IEEE Transactions on Plasma Science, vol. 47, no. 8, pp. 4136-4141, Aug. 2019, doi: 10.1109/TPS.2019.2924370.

Multiphysics Simulation

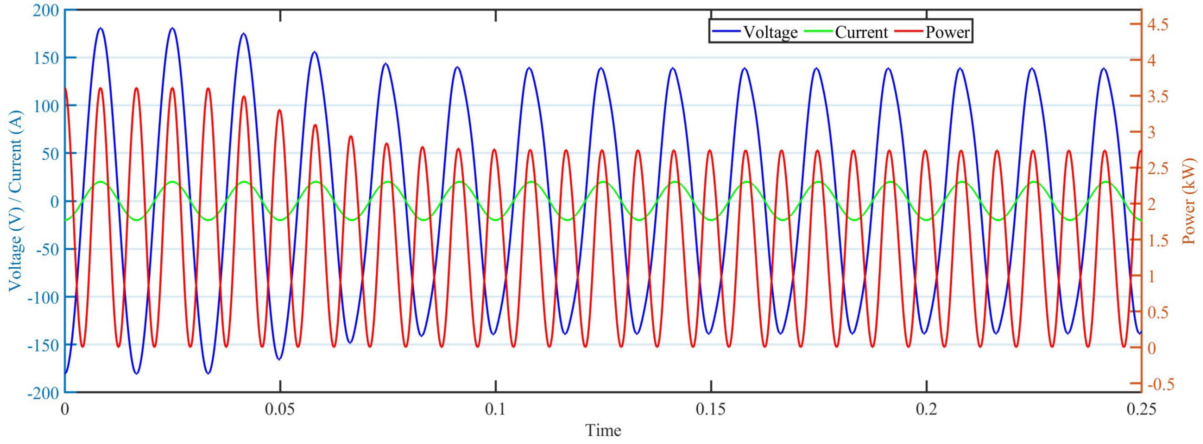


Figure: Supply Current, Voltage and Power

- The maximum temperature reaches 6330 K for 0.03 sec of simulation time.
- Arc voltage varies and it decreases 20V for a continuous 20A AC current supply at 60 Hz.

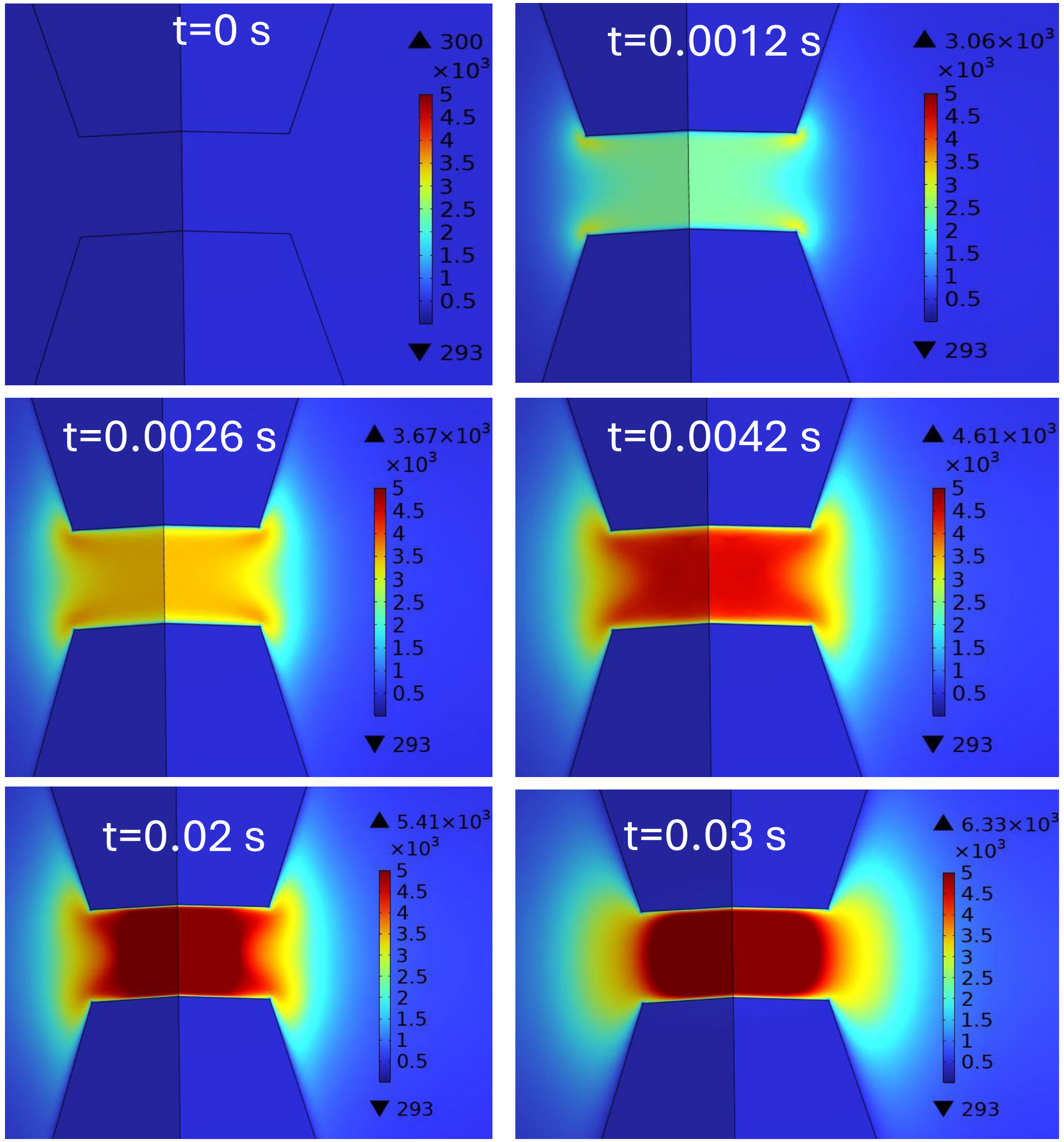


Figure: Axisymmetric temperature (K) distributions at different time instants.

Multiphysics Simulation

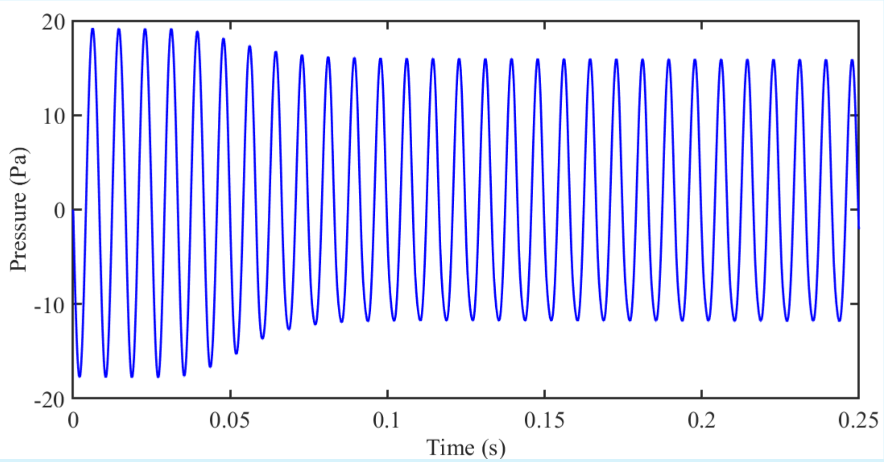


Figure: Arc acoustic sound pressure with time

- Rapid plasma expansion generates initial high-pressure oscillations.
- Periodic heating and plasma expansion produce sustained pressure variations.
- The pressure signature supports acoustic arc detection.

- High arc temperature creates strongly radiating plasma.
- Radiation intensity increases as the plasma temperature rises.
- Irradiance decreases with distance as the radiation spreads.
- These trends help optimize sensor placement for rapid detection.

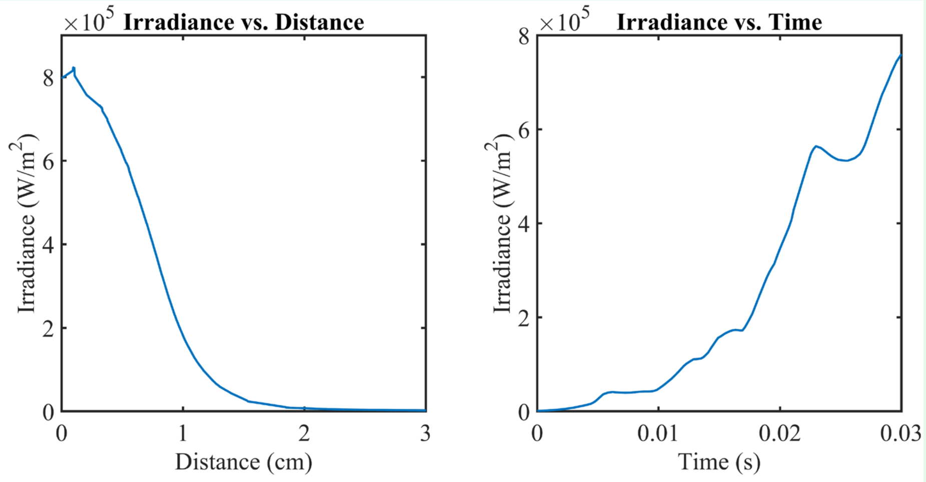
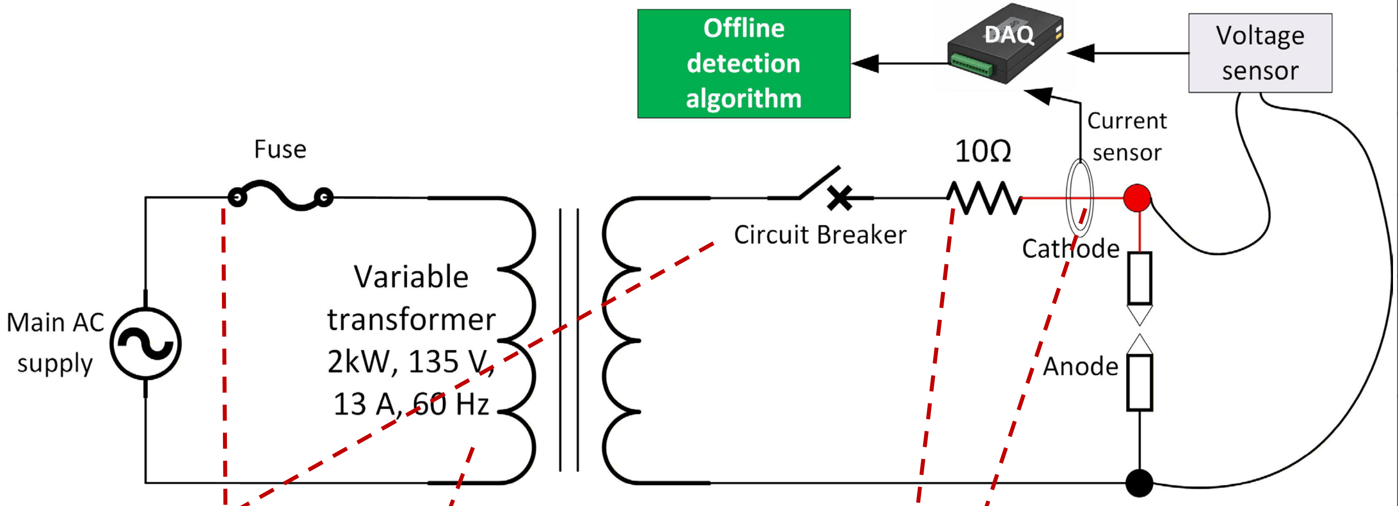
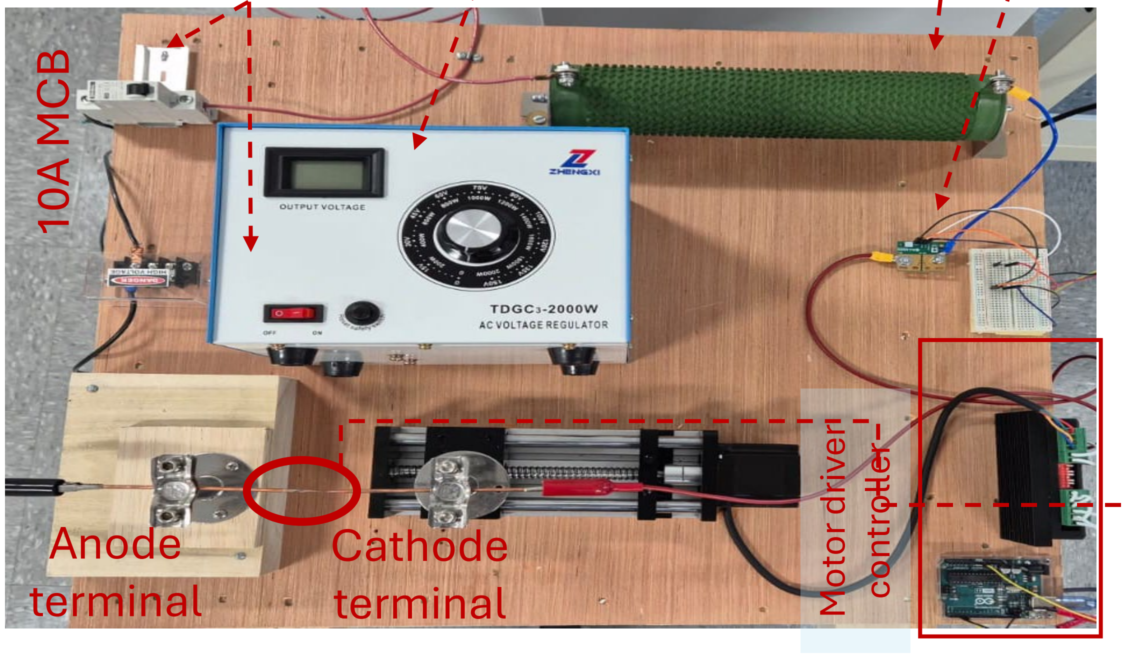


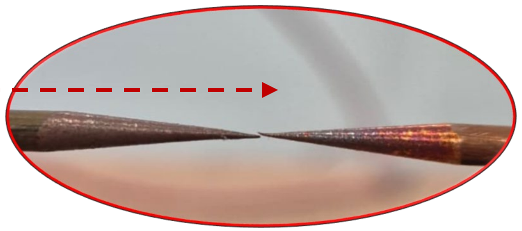
Figure: Arc irradiance variations w.r.t distance and time

Low-Voltage Experimental Set-up





Zoomed view of conductor gap



Product	Specifications
Main supply	120 V, 60 Hz
TDGC2 Variable Autotransformer	2 kW, 1000 VA. (0–135 V AC, 13 A)
MCB	10 A, Single-Pole, type B AC/DC
Wirewound Chassis Mount Resistor	10 Ohms, 1000W, tolerance ±5%
TMR sensor CT433 (Pololu)	±70 A (bidirectional), 3.0 V to 3.6 V, 14.3 mV/A, 1 MHz
Ni mioDAQ USB-6451	20-bit, 1 MS/s/ch, 16 analog input channels, 2 analog output channels, and 16 digital I/O lines
Arduino Uno	ATmega328P Microcontroller, 16MHz, 14 Digital I/O Pins, 6 Analog Inputs, 32KB Flash, MediaTek MT8125
Ball Screw Linear Guide Stage	2-phase NEMA 23, a ball screw mechanism, (100 mm Stroke)
DM542 Stepper motor driver	23 Nema, 24V, 3A, Torque: 0.9 N.m, Lead: 0.16‘’. Ball Screw Guide Sliding Table: Model: 100mm/4''; Accuracy: 0.03mm/0.0012''; Speed: 1.5''-4'' per second
Copper conductor (SZLIZHUO)	99.98% Bare Solid Copper Rod, 0.20" Dia x 12" Length

Real-Time Arc Current Monitoring

- Developed a LabVIEW-based control and data-acquisition system.
- An AC arc is generated by separating the electrodes.
- The linear actuator adjusts the electrode gap in increments of 0.05 mm.

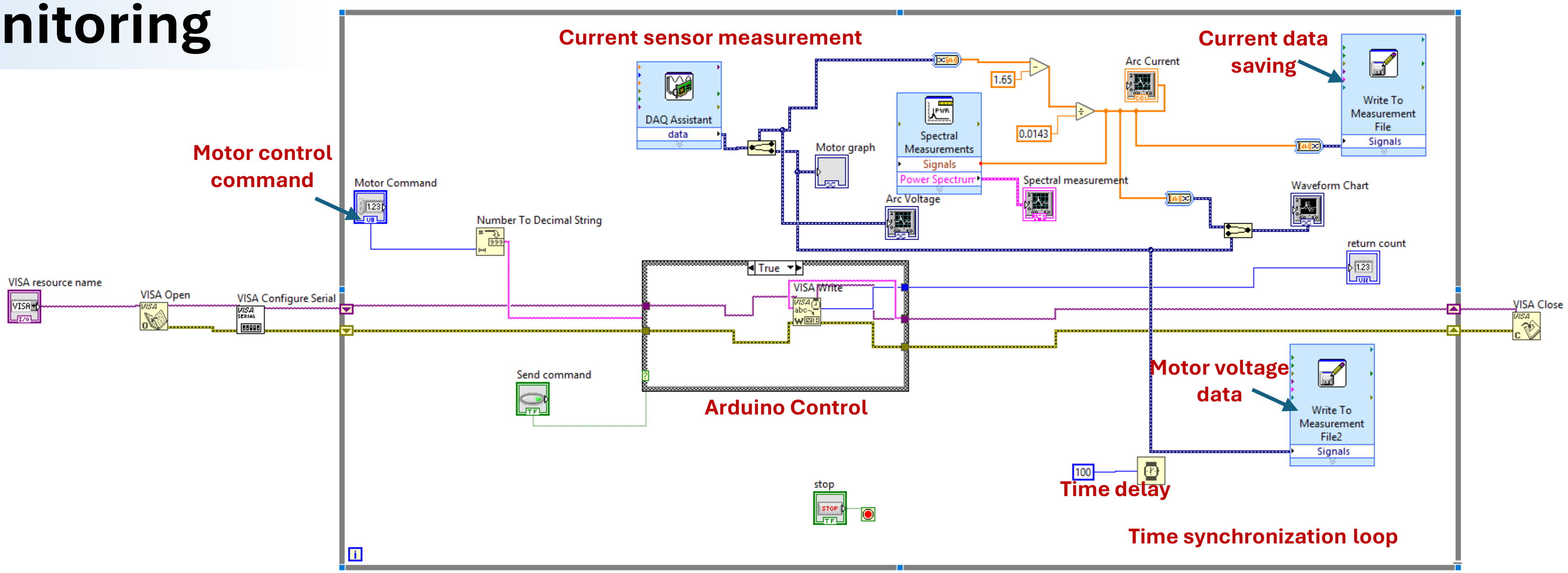


Figure: LabView control model for real-time arc monitoring

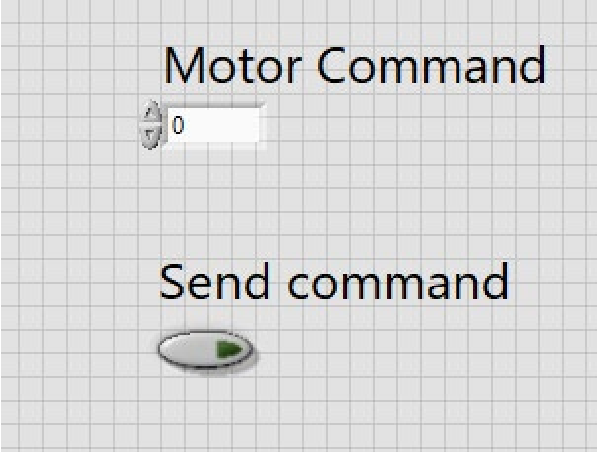


Figure: Switches for electrode gap control

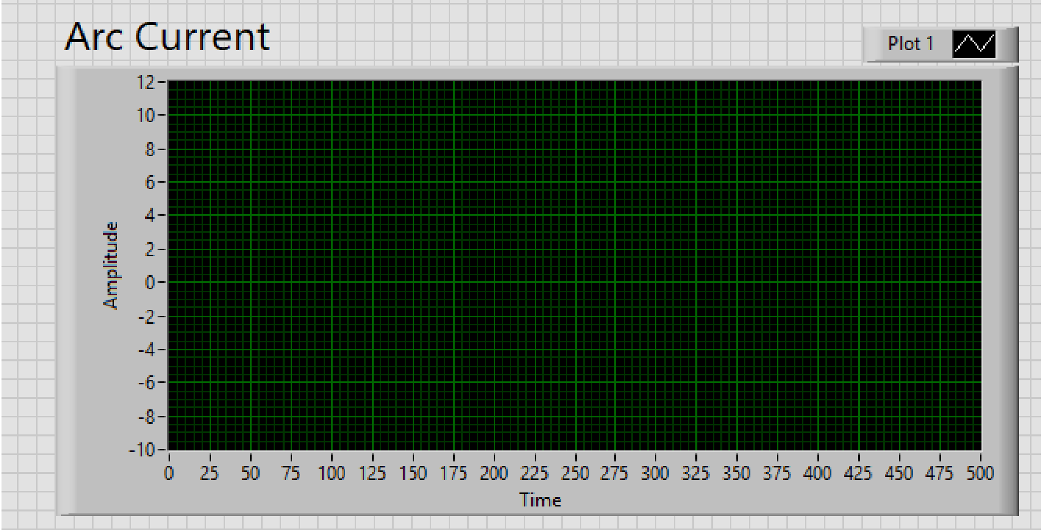
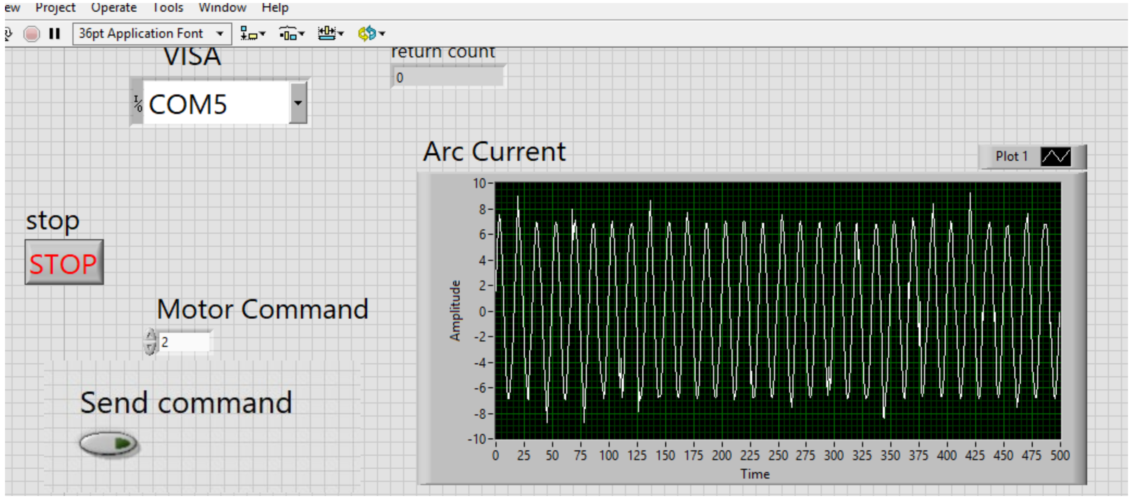


Figure: Arc current monitoring window at real-time

Real-Time Arc Current Monitoring

(a)



(b)

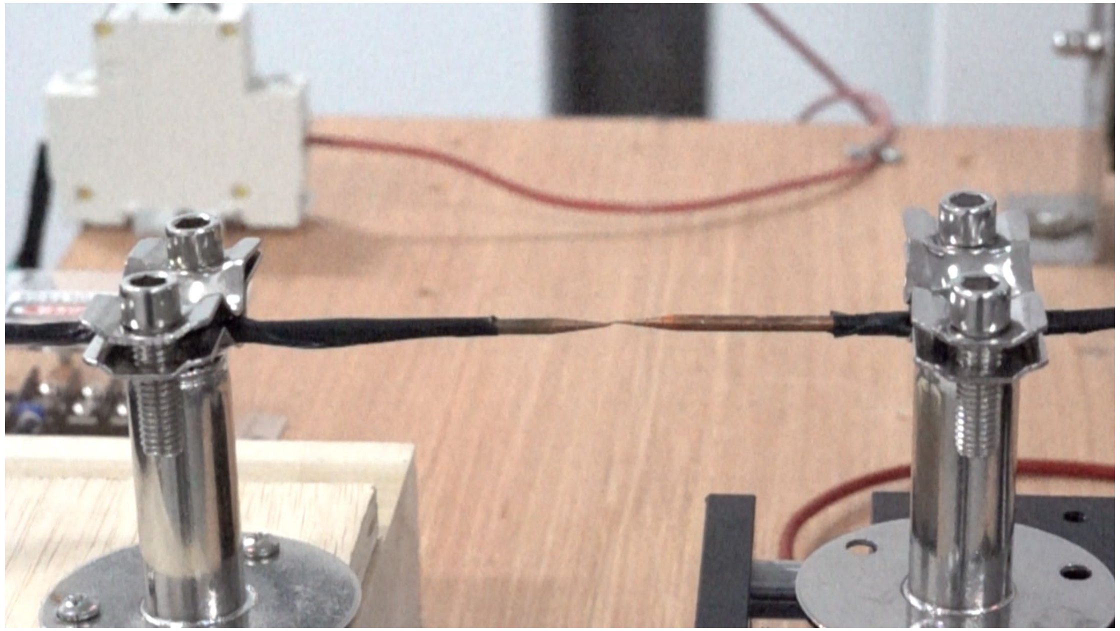


Figure: (a) Screenshot of real-time arc current monitoring; **(b)** Arc captured in a controlled environment

Tiny gap of 0.05 cm between the electrodes after the experiment

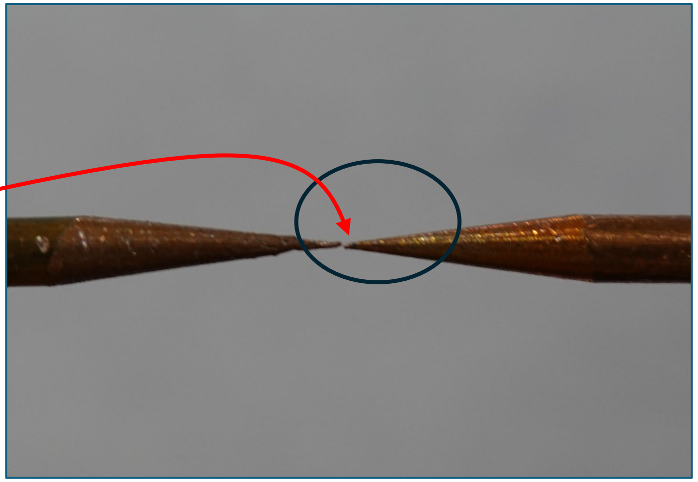
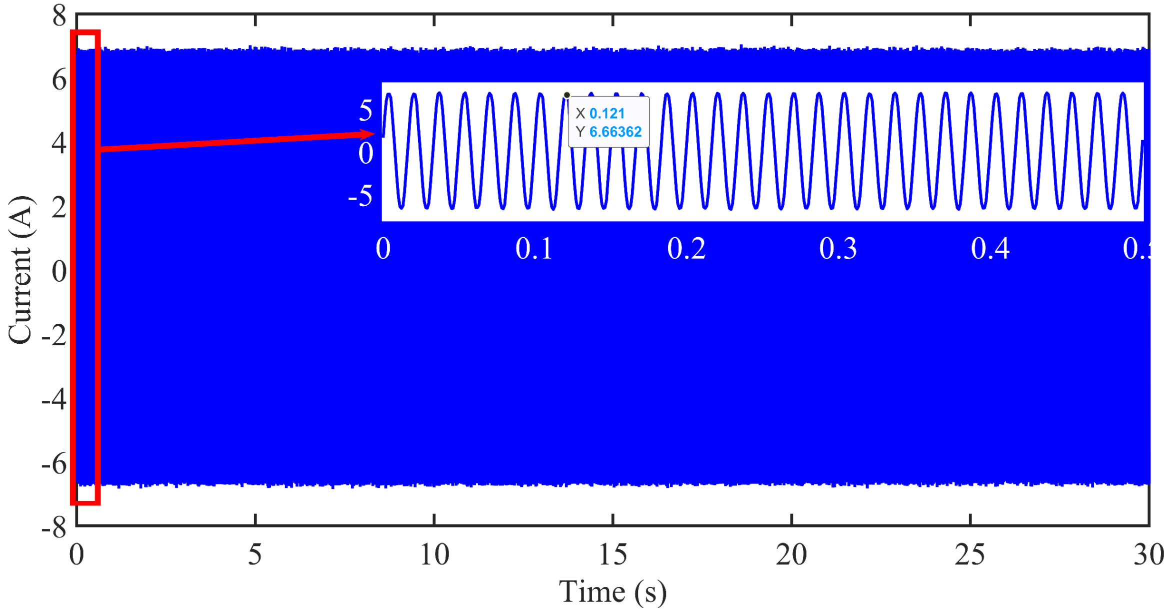


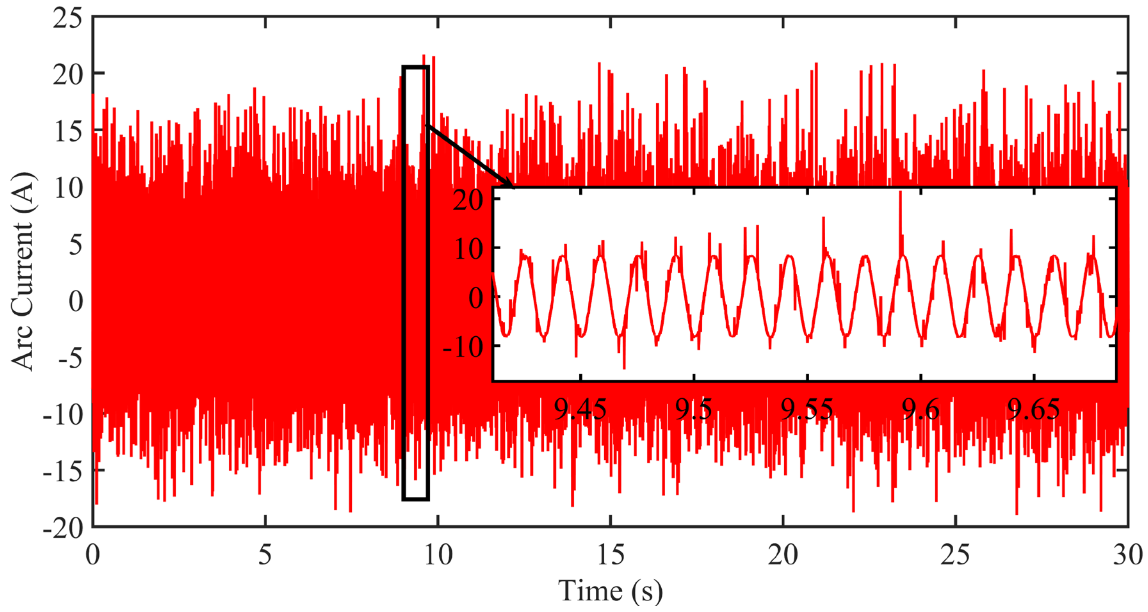
Figure: Electrode position

Experimental Results

Without Arc



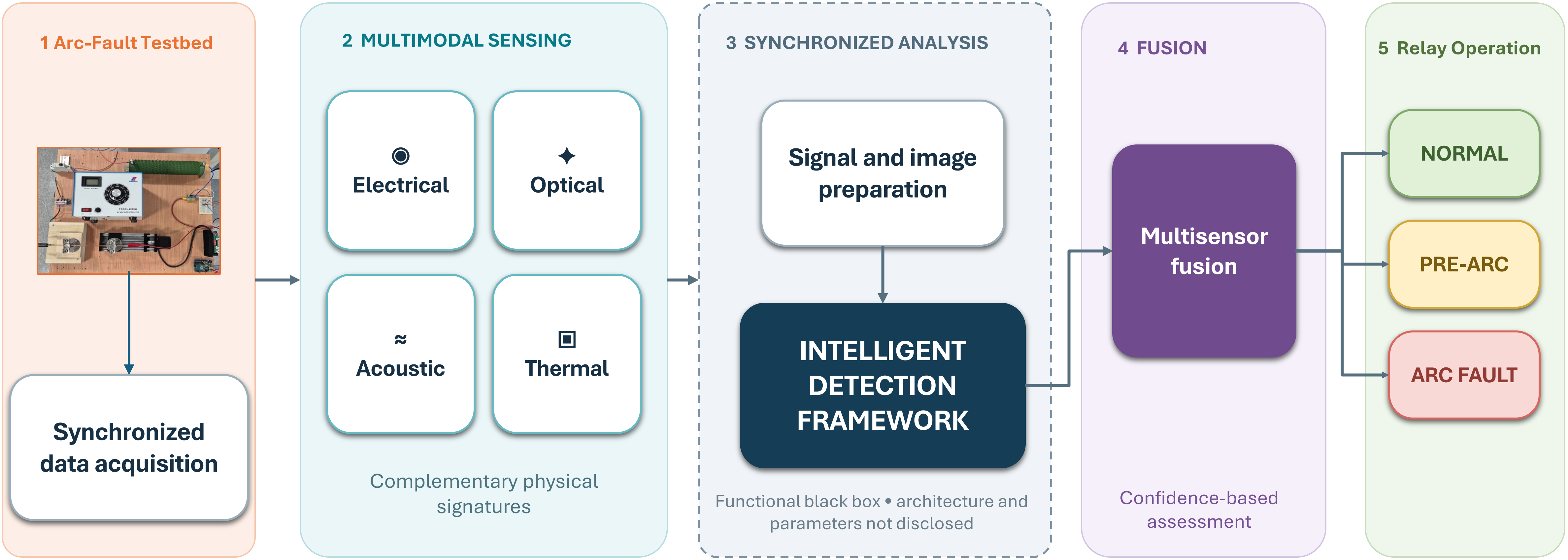
With Arc



Statistical Analysis

Signal	Mean (A)	Median (A)	Std. Dev. (A)	RMS (A)	Min. (A)	Max. (A)	Peak-to-Peak (A)	Crest Factor	Skewness	Kurtosis
Without Arc	0.0924	0.0934	4.9590	4.9599	−7.1050	7.3264	14.4314	1.4772	0.0004	1.5044
With Arc	0.1092	0.1048	6.9285	6.9294	−20.5616	22.8869	43.4485	3.3029	0.0023	1.5531

Machine-Learning Detection Framework



Overview of the Proposed Multisensor Arc-Fault Detection Approach

Challenges Encountered

TESTBED & MEASUREMENT

1 **Repeatable arc initiation**
Automated 0.05-mm gap control

2 **Electrode-gap stability**
Ball-screw positioning and gap checks

3 **Noisy arc transients**
Refined DAQ and channel settings

REAL-TIME CONTROL & SYNCHRONIZATION

4 **Continuous data acquisition**
Separated DAQ and motor-control tasks

5 **Motor–DAQ synchronization**
Added coordinated timing and event markers

6 **Repeated motor commands**
Implemented one-shot serial control

KEY ACCOMPLISHMENTS

1. Developed the multiphysics arc model
2. Built the real-time low-voltage arc testbed
3. Integrated LabVIEW, DAQ, current sensor, and linear actuator
4. Collected preliminary normal and arc-current data
5. Designed the proposed suitable machine learning detection algorithm framework

FUTURE WORK

1. Integrate voltage, acoustic, optical, and thermal sensing

Voltage sensor

Sound Pressure sensor

IR Camera

2. Implementation of detection algorithm
3. Validate the model and develop multisensor detection
4. Integration of REX615 with sensor fusion detection

Progression: validated measurements → multisensor dataset → real-time fault assessment

Project Timeline and Finance

We are here

Month	1	2	3	4	5	6	7	8	9	10	11	12
1. Multiphysics Simulation	■	■	■									
2. Experimenting			■		■	■						
3. Prototyping and Algorithm					■	■	■	■				
4. Compliance and Adaptation for Shipboard							■	■	■			
5. Demonstration									■	■	■	
6. Reporting and Documentation										■	■	■

- **Program Funds: $199,700**
- **Project Duration: 27 March 2026 – 27 March 2027**

Thank You

- **Questions?**

- For further inquiries, please contact:
Tanima Bal
tb445@njit.edu