Bio-Inspired Acoustic-Based Inspection and Sensing

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Arizona State University

NM STATE

NATIONAL ENERGY TECHNOLOGY LABORATORY

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US Department of Energy
2023 FECM/NETL SPRING R&D PROJECT REVIEW MEETING

Outline

1. Lizard-inspired Tube Inspector (LTI) robot

- Sensing
- Robotics

2. Broader Impacts

<u>Direct</u>

- Publications
- Tech transfer
- Workforce development

<u>Indirect</u>

- Professional development
- NSF CAREER (Bio-inspired Acoustic Sensing)
- QCAM Consortium

A Lizard-inspired Tube Inspector (LTI) Robot (FE0031649)

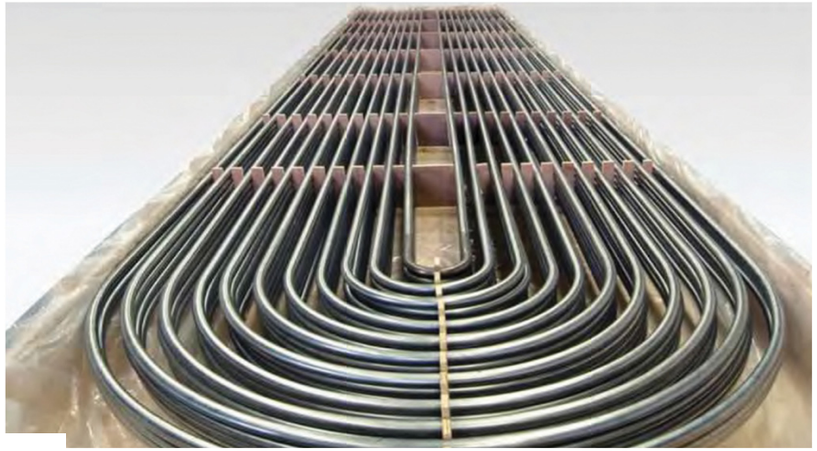
Problem statement

Heat exchanger

Heat recovery steam generator (HRSG)

Thinning

Pitting corrosion

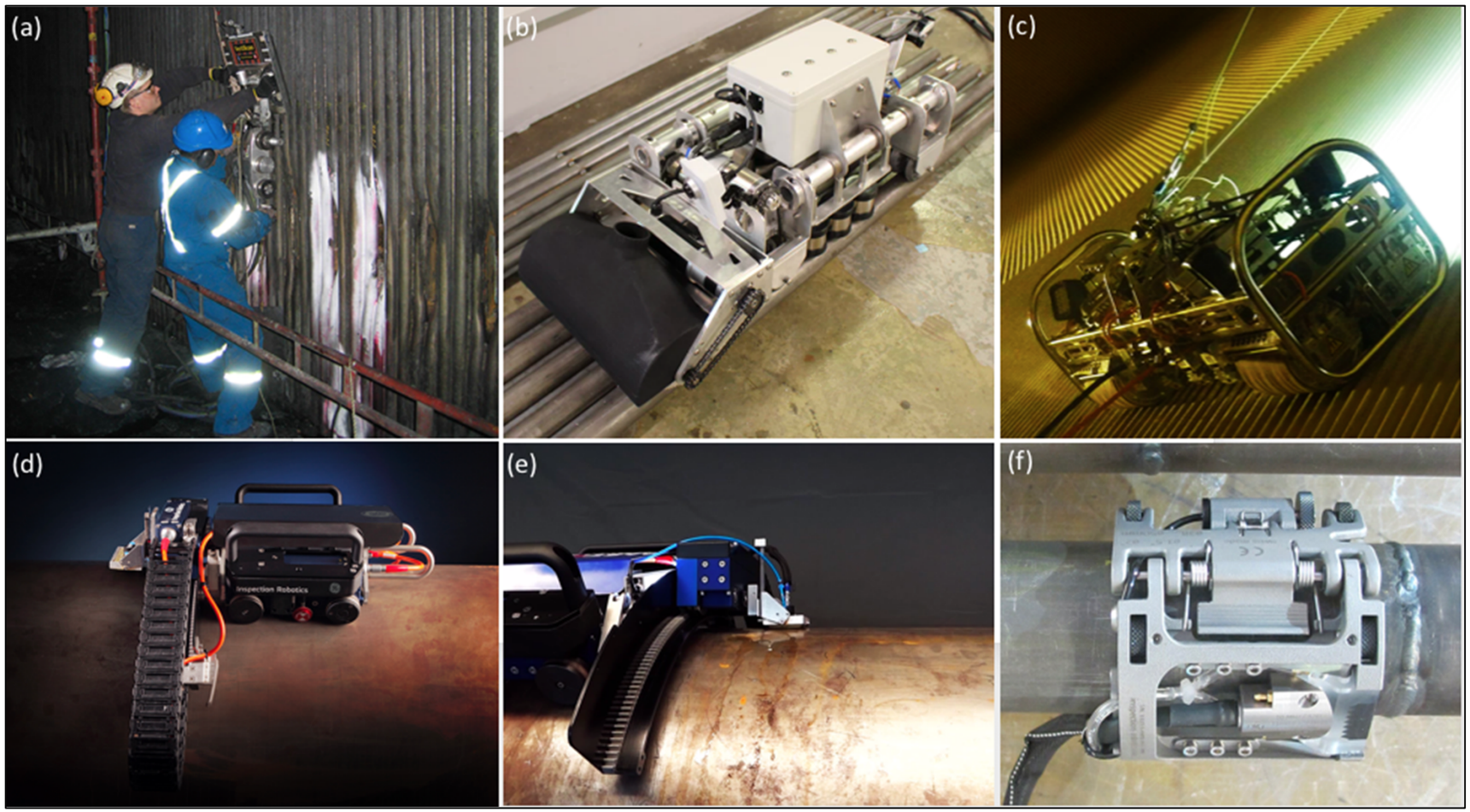


Boiler

Deposit corrosion

Stress corrosion cracking

Problem statement

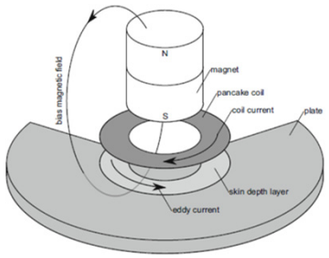


Tube inspection robots. (a) Vertiscan system, (b) ICM climbing robot, (c) boiler wall cleaning and inspection robot, (d) inspection robotics system, (e) FAST UT system, and (f) PALM scanner.

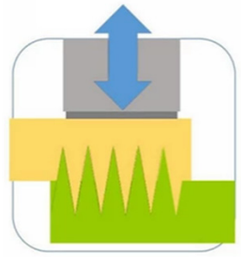
A Lizard-inspired Tube Inspector (LTI) Robot

Sensing system

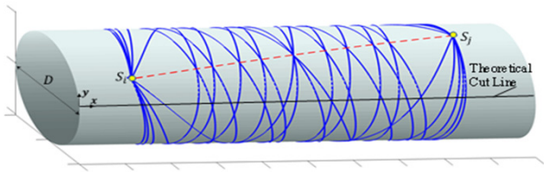
Objective 1
Couplant-free ultrasound generation



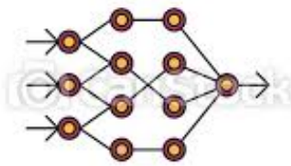
EMAT



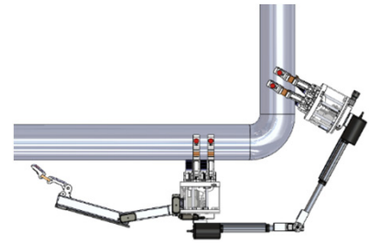
Friction-based ultrasound

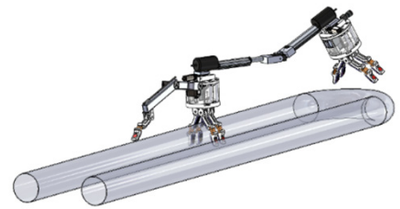


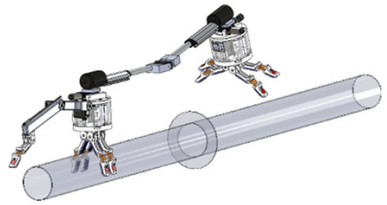
Deep learning-based detection



Objective 2
Friction-based mobility

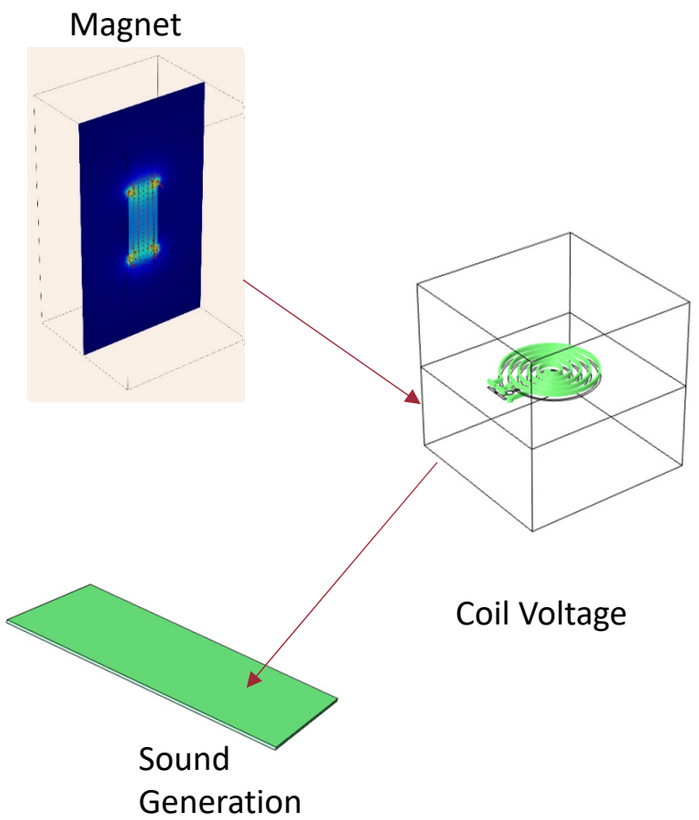




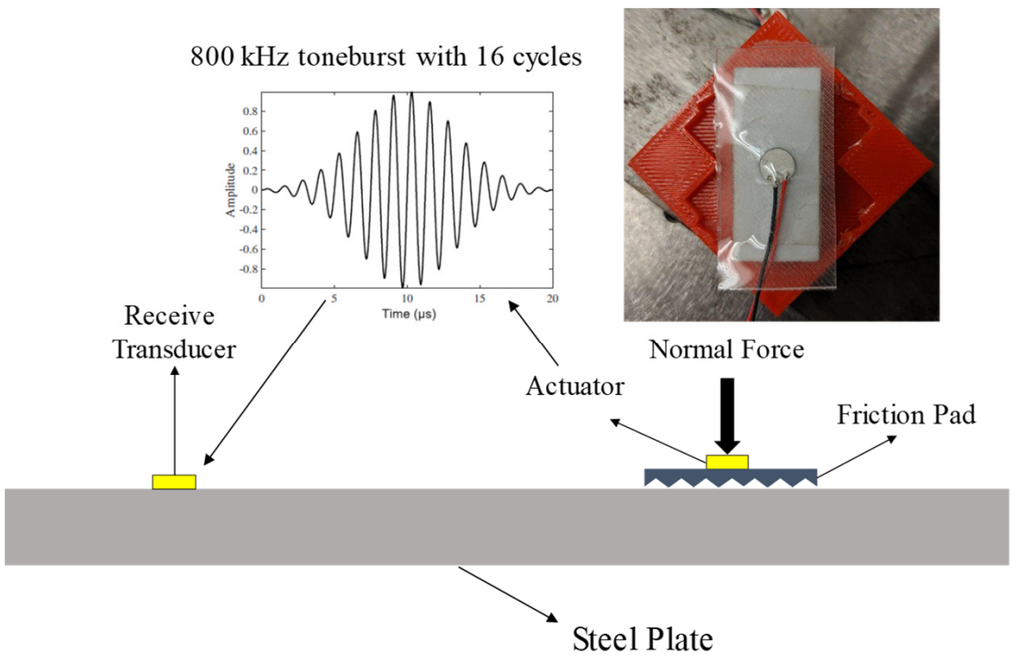


Couplant-free ultrasound transmission

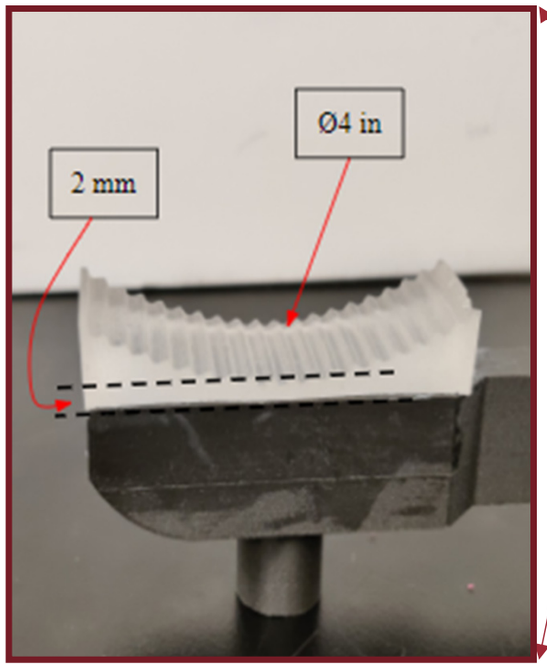
Electromagnetic acoustic transducer (EMAT)

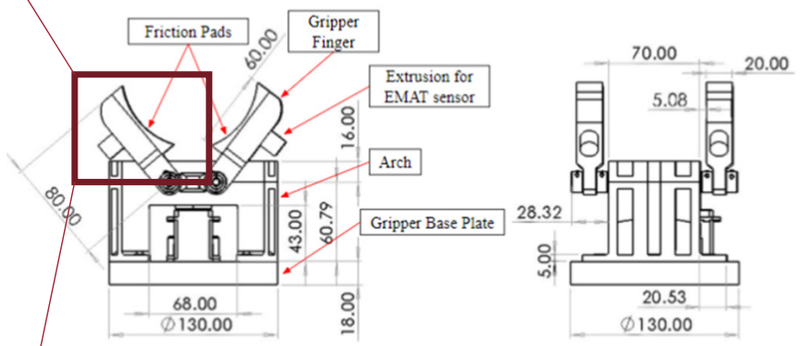


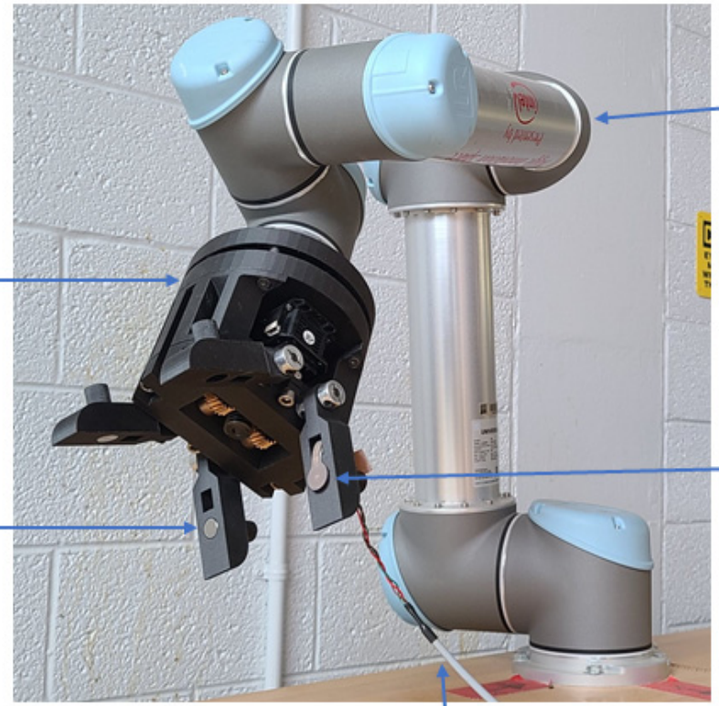
Friction-based dry couplant transducer

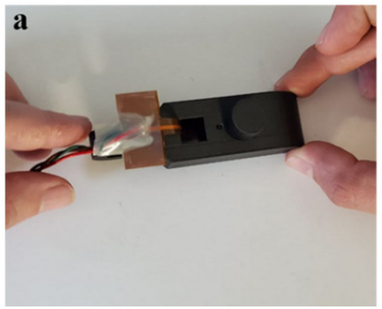


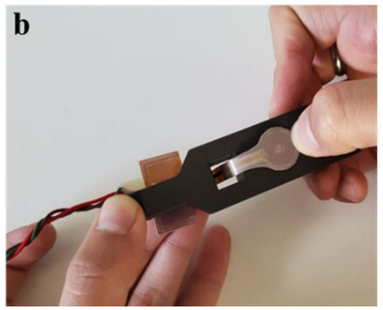
Integrating EMATs into modular gripper

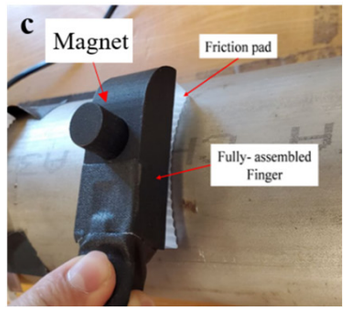




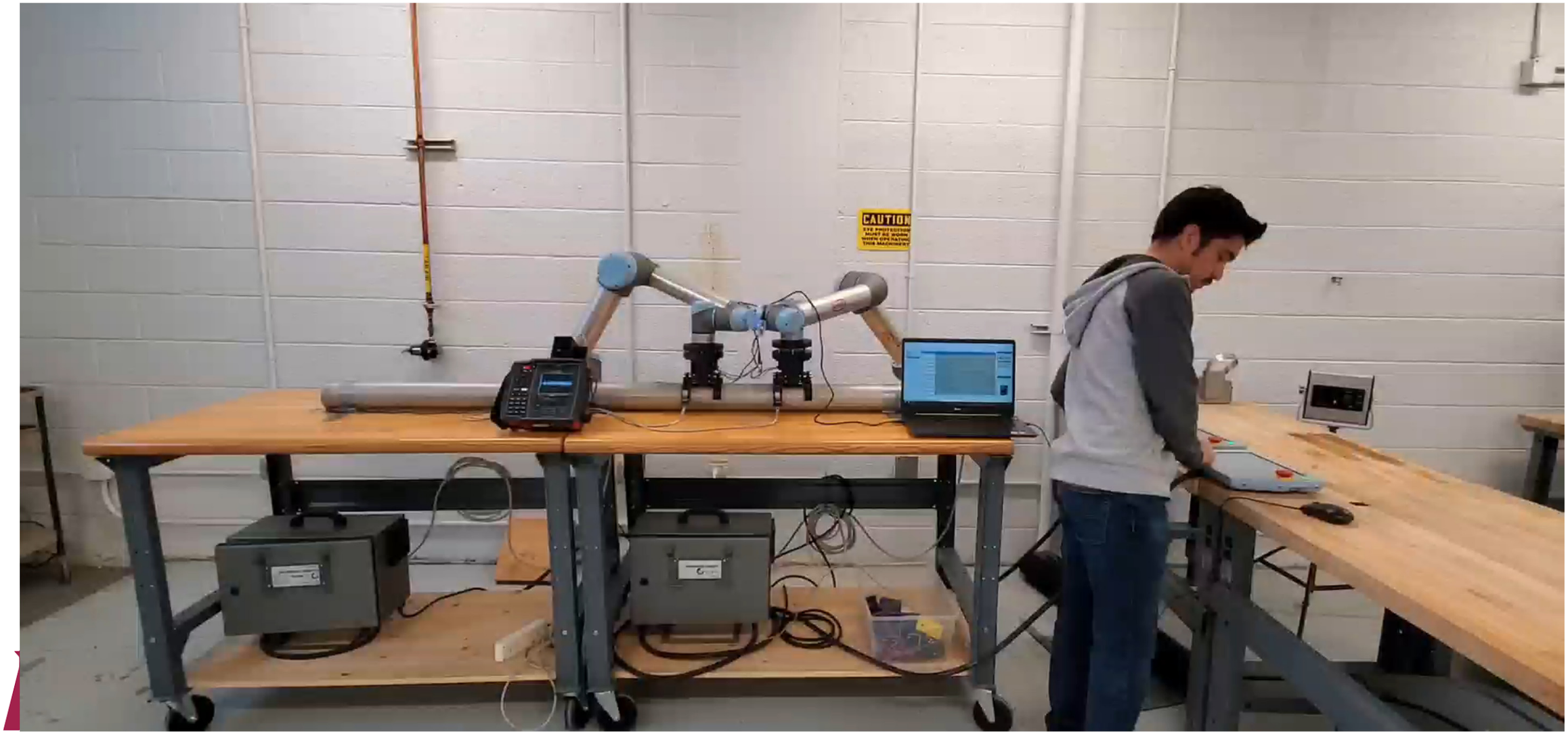




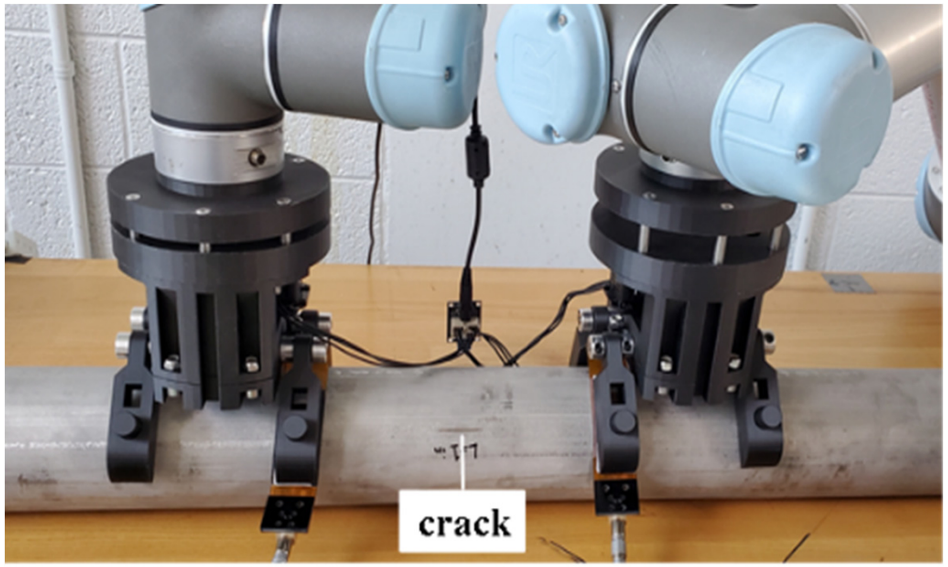


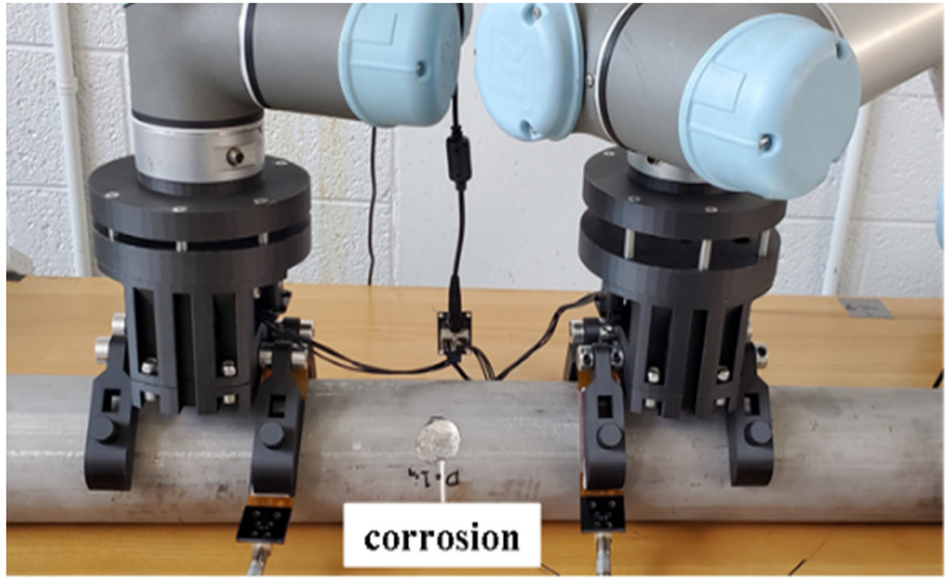


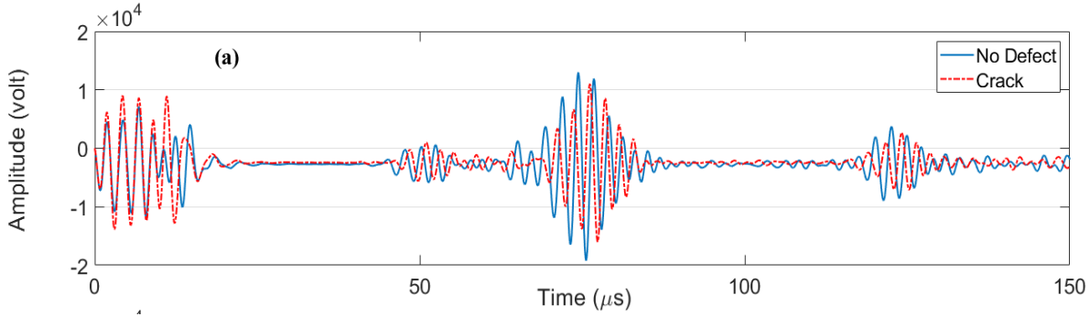
Integrating EMATs into modular gripper

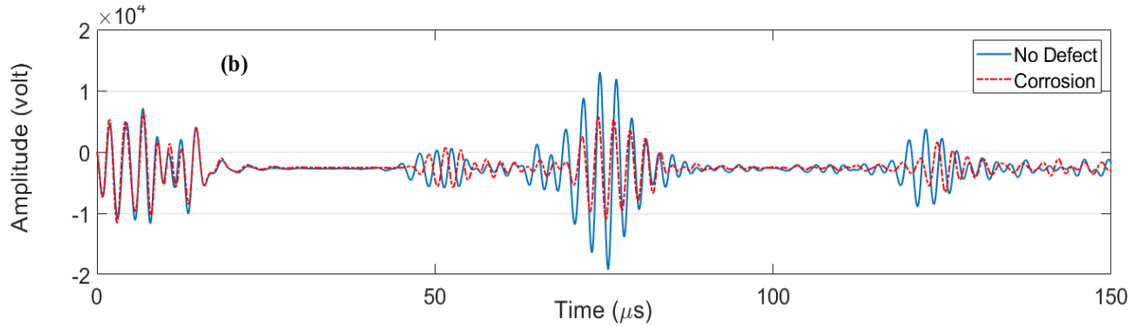


Crack and corrosion detection



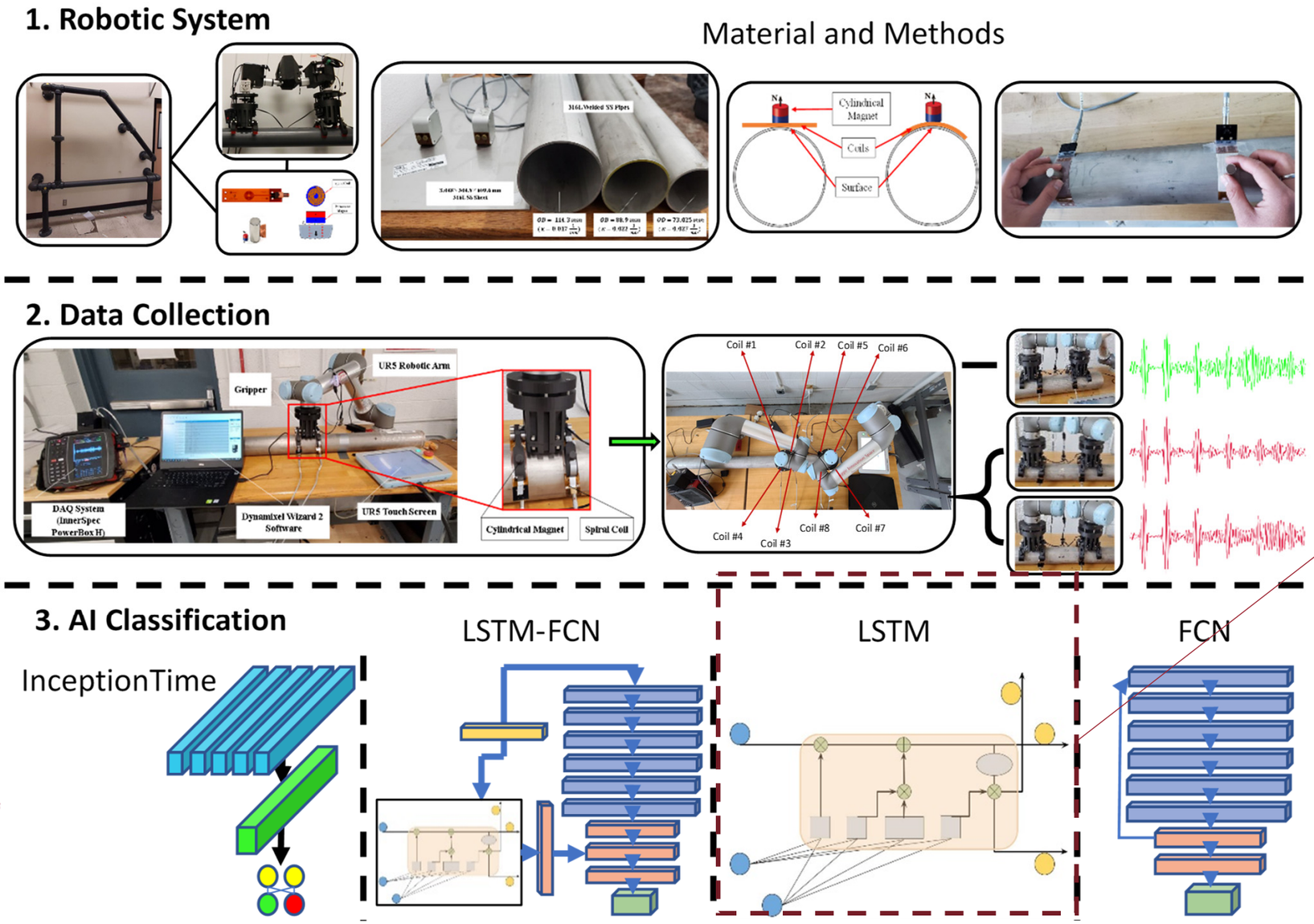






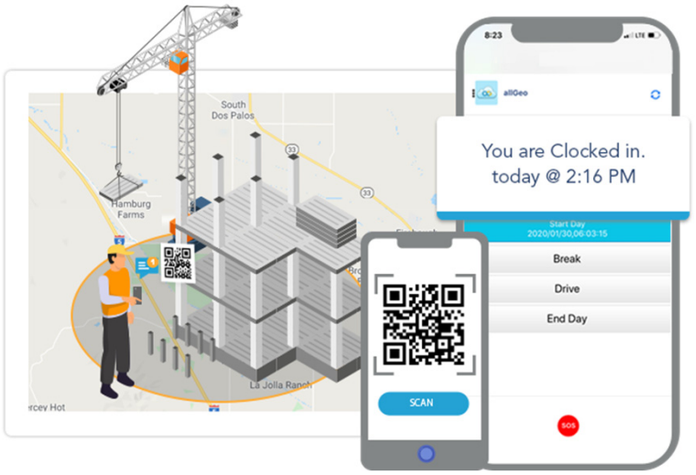
H. Nemati, F. Alvidrez, A. Das, N. Masurkar, M. Rudraboina, H. Marvi, and **E. Dehghan-Niri**, "Integrating electromagnetic acoustic transducers in a modular robotic gripper for inspecting tubular components", Materials Evaluation, July, 2021, pp. 715-727.

AI enabled defect detection



Long-short term memory (LSTM) Over **80%** detection accuracy

Navigation and visual inspection



https://www.allgeo.com/qr-codes-mobile-inspection-app

Position 1

(x_1, y_1, z_1)

Position 2

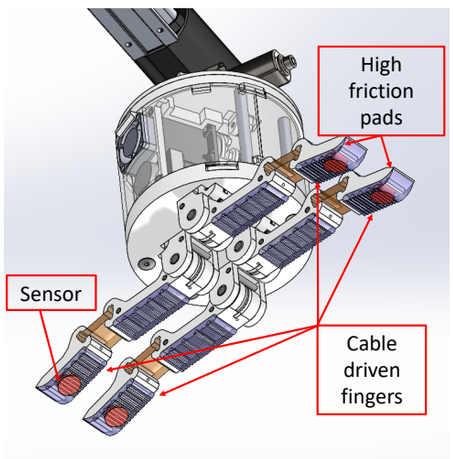
(x_2, y_2, z_2)

Position n

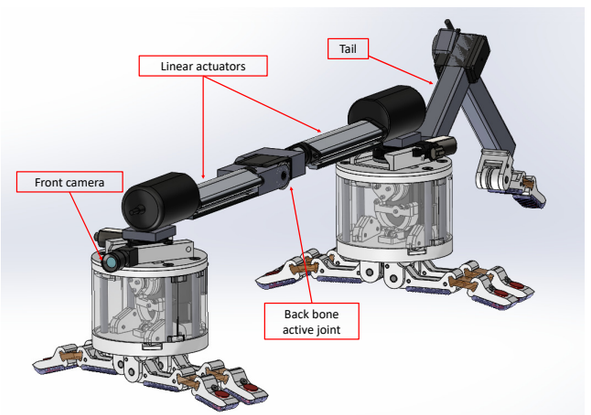
(x_3, y_3, z_3)

LTI robot

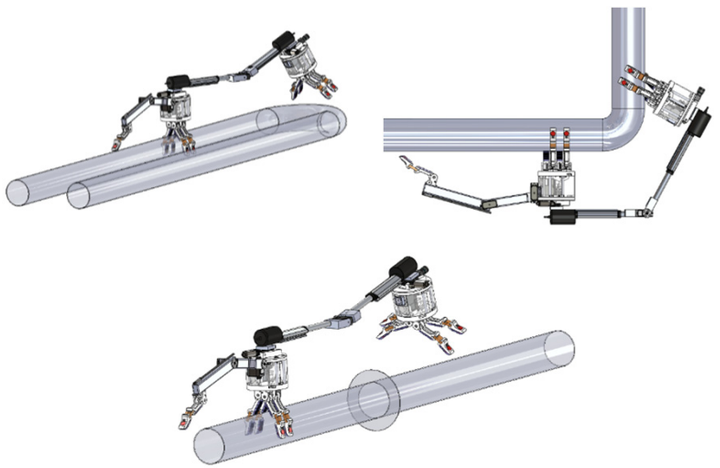
Multifunctional Gripper



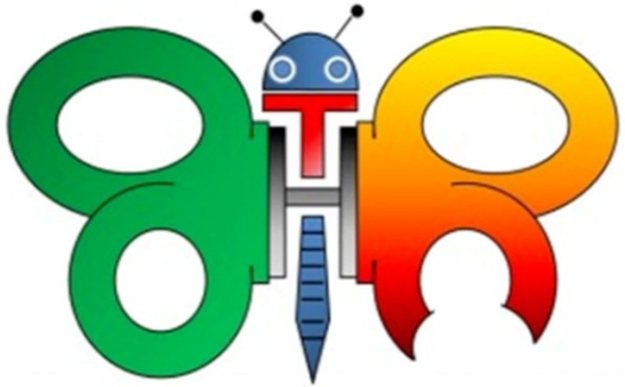
Main Body



Experimentation



Lizard Inspired Tube Inspection Robot



BIRTH Lab

Bio-Inspired Robotics,
Technology and Healthcare Lab

Arizona State University

NM STATE

NATIONAL ENERGY TECHNOLOGY LABORATORY

Direct impact

Publications

Journals

1. H. Nematia, F. Alvidrez, A. Das, N. Masurkar, M
robotic gripper for inspecting tubular componen
2. M. Ghyabi, H. Nemati and E. Dehghan-Niri, "A
like structures," Structural Health Monitoring: and
3. S. Zamen, E. Dehghan-Niri, M. Ilami, V. Anand
like structures", Ultrasonics, Vol. 120, March 2022,
4. Das, M. Rudraboina, N. Masurkar, F. Alvidrez
Robotics and Applications, under review.
5. S. Hespeler, N. Masurkar, H. Marvi, and E. D
underreview
6. N. Masurkar, V. Anand Senthilkumar, E. Dehgh

Thesis

1. F. Alvidrez, "*INTEGRATING ELECTROMAGNETIC A*
2. N. Masurkar, "*Design and Control of a Lizard-ins*

Conferences

1. Ghyabi and E. Dehghan-Niri, "*Structural he*
Hyatt Regency Orange County Garden Gro
2. Ghyabi and E. Dehghan-Niri, "Comparison o
Structures", SPIE Smart Structures + Nondestru
3. S. Zamen, M. Ilami, V. Senthilkumar, H. Marv
Conference, Virtual, Nov. 2020.
4. H. Nemati, M. Ilami, J. Bhadra, H. Marvi, a

ating electromagnetic acoustic transducers in a modular

overage in real-time structural health monitoring of plate-

ction based dry-couplant ultrasonic Lamb waves in plate-

be Inspection Robot", International Journal of Intelligent

g of pipelines using deep learning data-driven models",

form for pipeline inspection", in preparation

PER FOR INSPECTING TUBULAR COMPONENTS", NMSU, 2021.

rtial crack detection", ASNT 28th Research Symposium,

angements for Structural Health Monitoring of Plate-Like

ction Effects on Lamb Waves Generation", ASNT Annual

on the performance of an integrated robotic gripper

ME is mailed out to approximately **16,000 ASNT members each month**. Approximately half are US based and the rest are worldwide. Each paper is assigned a DOI number and added to the ASNT Library to be accessed by future researchers. Our last Technical Focus Issue was **open-access** and was accessed by approximately **12,000 readers**.

Tech transfer/comercialization

Patents

H. Marvi, E. Dehghan-Niri, and M. Ilami, "*Systems and metho for a Lizard-Inspired Tube Inspector (LTI) robot*", US patent pending, US 11,504,854, 2022.

(12) **United States Patent**
Marvi et al.

(10) **Patent No.: US 11,504,854 B2**
(45) **Date of Patent: Nov. 22, 2022**

(54) **SYSTEMS AND METHODS FOR ROBOTIC SENSING, REPAIR AND INSPECTION**

(71) Applicants: **Hamidreza Marvi**, Tempe, AZ (US); **Ehsan Dehghan-Niri**, Las Cruces, NM (US); **Mahdi Ilami**, Tempe, AZ (US)

(72) Inventors: **Hamidreza Marvi**, Tempe, AZ (US); **Ehsan Dehghan-Niri**, Las Cruces, NM (US); **Mahdi Ilami**, Tempe, AZ (US)

(73) Assignees: **Arizona Board of Regents on Behalf of Arizona State University**, Tempe, AZ (US); **Arrowead Center**, Las Cruces, NM (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 146 days.

(21) Appl. No.: **16/844,519**

(22) Filed: **Apr. 9, 2020**

(65) **Prior Publication Data**

US 2020/0324415 A1 Oct. 15, 2020

Related U.S. Application Data

(60) Provisional application No. 62/831,268, filed on Apr. 9, 2019.

(51) **Int. Cl.**
B25J 9/16 (2006.01)

(52) **U.S. Cl.**
CPC ***B25J 9/1694*** (2013.01); ***B25J 9/1664*** (2013.01)

(58) **Field of Classification Search**
CPC B25J 9/1694; B25J 9/1664; B25J 9/065; B25J 15/0009; B25J 15/0038; B25J 15/0213; B25J 19/026; B25J 15/0033; B25J 15/0206; B25J 13/087; G01N 2291/0234; G01N 2291/0258; G01N 2291/0427; G01N 2291/2634; G01N 29/069; G01N 29/225; G01N 29/228; G01N 29/2412; G01N 29/24; G01N 2015/142; G01N 2021/1708; G01N 29/04; G01N 29/041; G01N 29/046; G01N 29/06; G01N 29/0663; G01N 29/11; G01N 29/2437; G01N 29/2462; G01N 29/34; G01N 29/343; G01N 29/348; G01N 29/36; G01N 29/44; G01N 29/4445; G01N 29/4454; G01N 21/9505; G01N 2203/006;
(Continued)

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U.S. PATENT DOCUMENTS

9,193,402 B2 * 11/2015 Chin B25J 5/00
9,879,981 B1 1/2018 Dehghan Niri et al.
(Continued)

FOREIGN PATENT DOCUMENTS

WO 2020191399 A1 9/2020
WO 2021041471 A1 3/2021

OTHER PUBLICATIONS

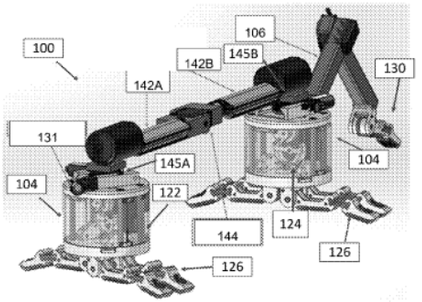
Salamone, "A multi-helical ultrasonic imaging approach for the structural health monitoring of cylindrical structures", Jan. 2015, Structural Health Monitoring vol. 14, pp. 73-85 (Year: 2015).*
(Continued)

Primary Examiner — Abby Y Lin
Assistant Examiner — Esvinder Singh
(74) *Attorney, Agent, or Firm* — Polsinelli PC

(57) **ABSTRACT**

Various embodiments of a bio-inspired robot operable for detecting crack and corrosion defects in tubular structures are disclosed herein.

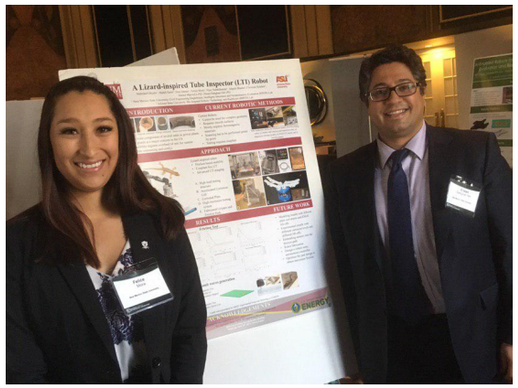
20 Claims, 9 Drawing Sheets
(9 of 9 Drawing Sheet(s) Filed in Color)

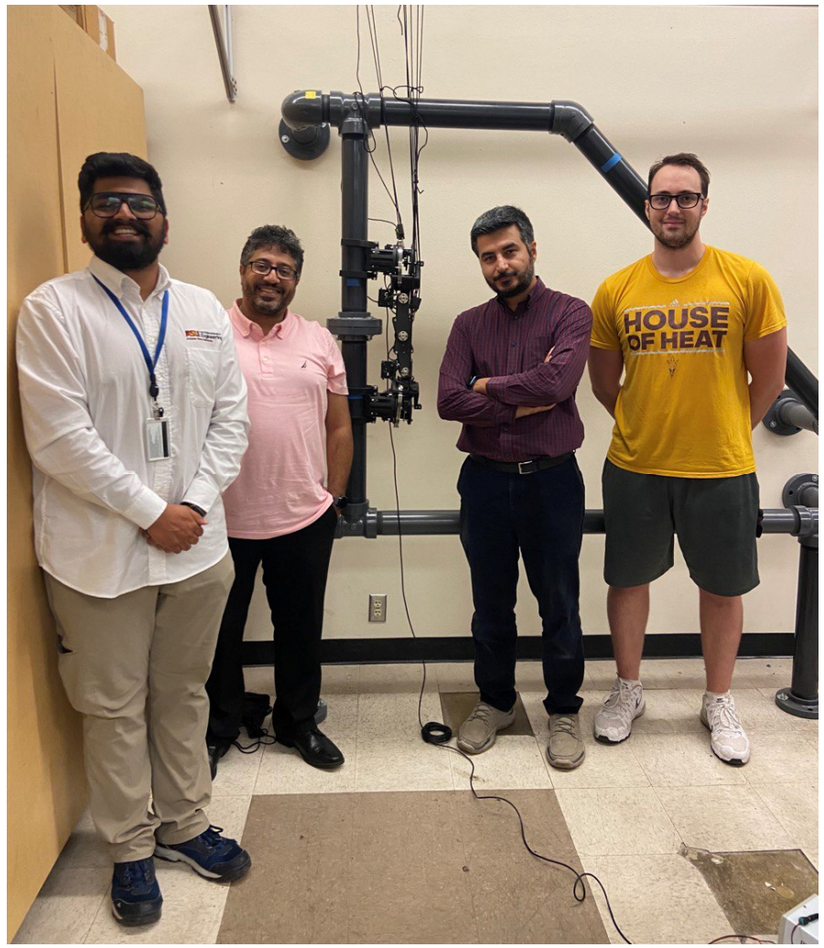


ASU SkySong

Several inspection service companies have contacted the inventors to pursue licensing

Future workforce



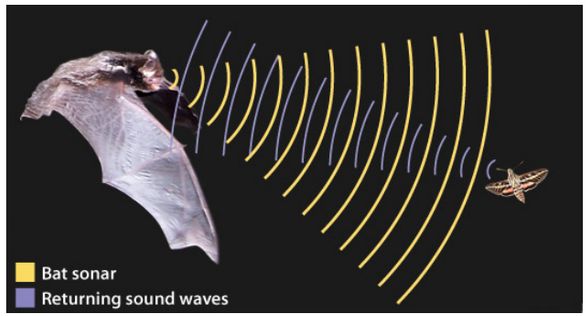


5 undergraduate students, 4 master students, 3 Ph.D. students, and 1 postdoctoral scholar

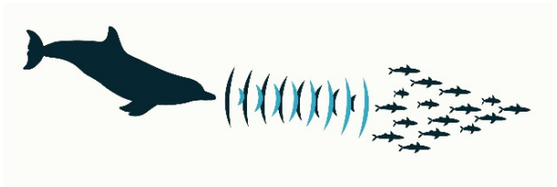
Indirect impact

Early career professional development

Bat (in air)



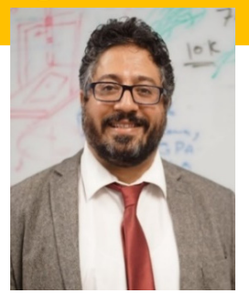
Dolphin (in water)

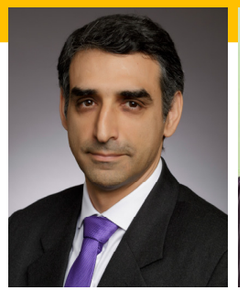


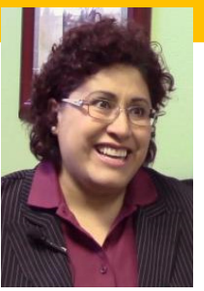
Aye Aye (in solids)

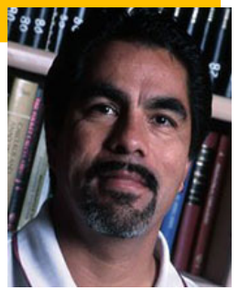
2021 NSF CAREER "Understanding the exceptional near-field auditory system of the aye-aye, one of the most unusual primates in the world"

Early career professional development









ASU

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DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

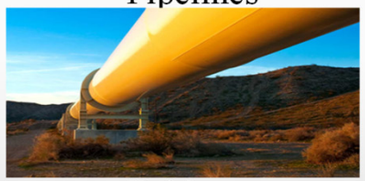
NNSA
National Nuclear Security Administration

Graduate Studies → Industrial Experience → Early Career (Ongoing) → Next 5 years → Long-term Vision

Ultrasound Lamb waves for NDE and SHM of Infrastructures

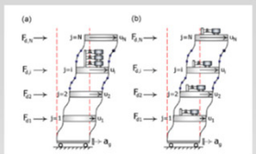
Built-in Sensor Network Aircrafts

Pipelines



Bridges

Structural Control



17 Journal Publications

NDE of Advanced Manufacturing in GE

Wind Energy

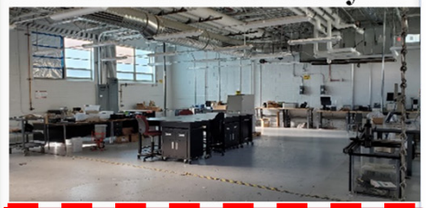
Power Systems

Additive Manufacturing

11 Patents

Smart Structures and Manufacturing

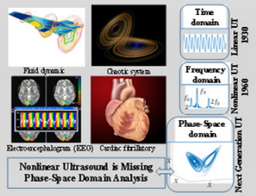
ISNDE Laboratory



Robotic Inspection

Aye-Aye

Nonlinear Ultrasound

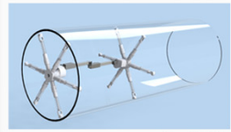


Establishing ISNDE
10 Journal Publications
3 Patents

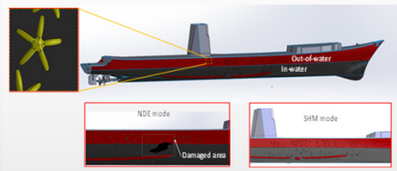
Bio-inspired Sensing

Woodpecker Striped Possum

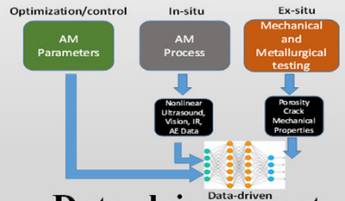
Robotic Inspection



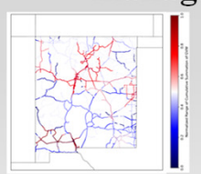
ACSN

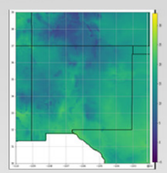


AM Quality Control



Data-driven asset management



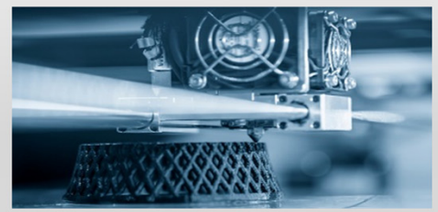


ISNDE Center

Integrated Robotic and Sensing

Infrastructures Monitoring

Additive Manufacturing QC



NDE in Food and Agricultural Industries

Acoustic Meta-Materials

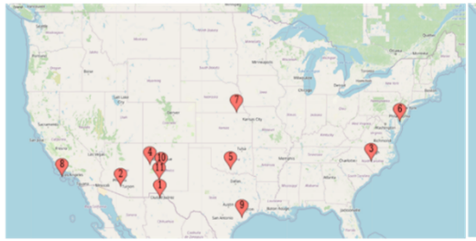
Workforce Development

Lessons learned and final remark

- Continue supporting and trusting junior faculty members (professional development)
- Being part of the team
- Reassessing your vision
- Pathway to higher TRL and commercialization

In many cases, the indirect impact of a project is much greater than its direct impact during the project's implementation phase. It's important for leaders and stakeholders to recognize and account for these indirect impacts when assessing the overall success of the project and its contribution to broader goals and objectives of a program.

ISNDE Academic Partners/collaborators



1. New Mexico State University
2. Arizona State University
3. Duke University
4. Navajo Technical University
5. University of Oklahoma
6. Drexel University
7. University of Nebraska at Lincoln
8. UC Santa Barbara
9. Prairie View A&M University
10. University of New Mexico
11. New Mexico Tech University
12. Virginia Tech

ISNDE Industrial Partners/collaborators

1. General Electric (GE Power)
2. Relativity Space Company
3. Boeing
4. American Aerospace Technical Academy
5. Transportation Technology Center Inc.
6. FormAlloy Inc.
7. Los Alamos National Laboratory
8. Sandia National Laboratories
9. Kansas City National Security Campu
10. Oak Ridge National Laboratory

Research

https://www.youtube.com/watch?v=dzYPnoiWL0Q&t=11s

QCAM consortium

https://www.youtube.com/watch?v=pn6KwJuW9wU&t=18s

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