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A Robotics Enabled Eddy Current Testing System for Autonomous Inspection of Heat Exchanger Tubes

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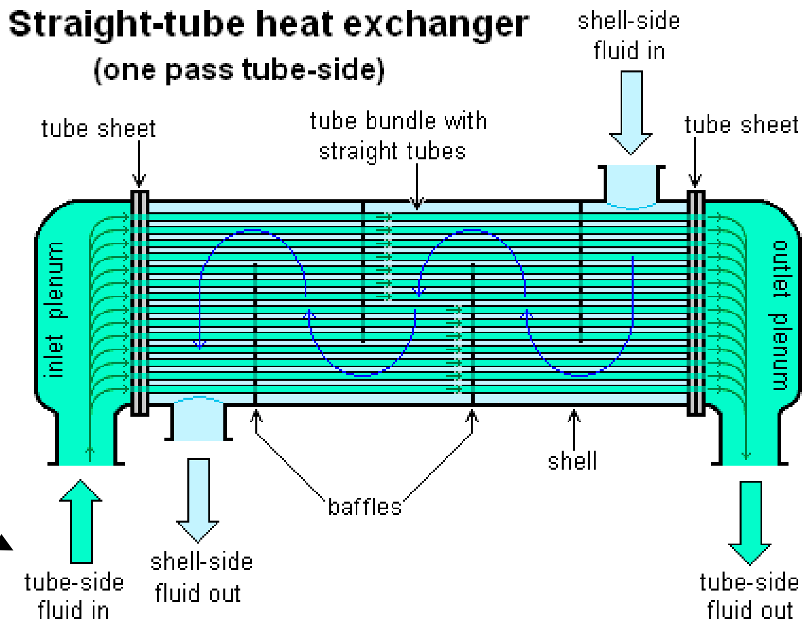
Heat Exchanger Tubes in Power Plants

Heat exchangers in power plant

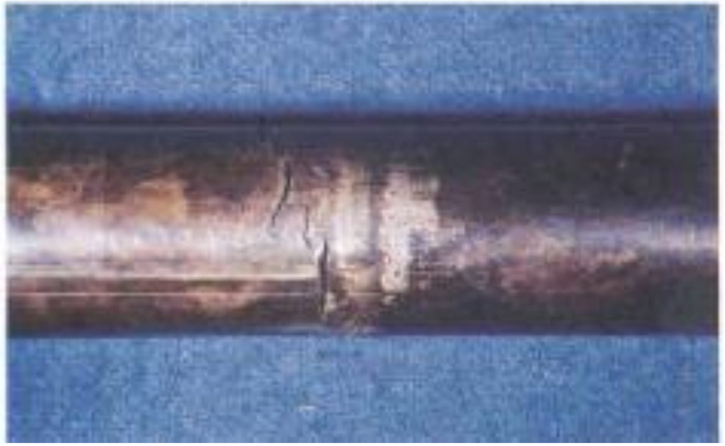
https://fr.dreamstime.com/photo-stock-%C3%A9changeur-de-chaleur-%C3%A0-l-usine-de-raffinerie-image56323288

Shell & tubes heat exchangers



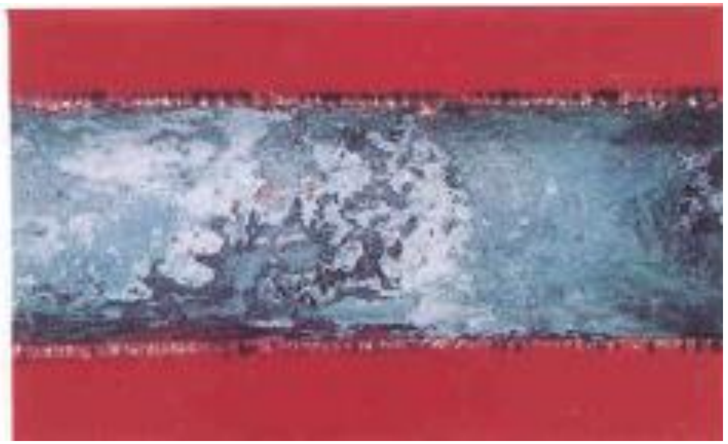
https://en.wikipedia.org/wiki/Shell_and_tube_heat_exchanger

Failures of Heat Exchanger Tubes

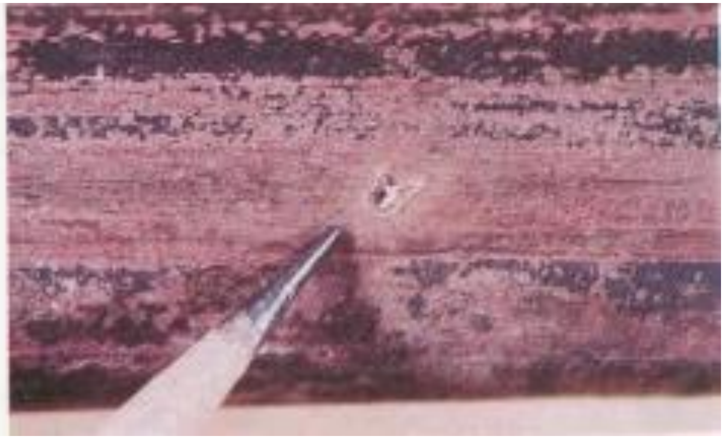


Stress corrosion

Stress cracking

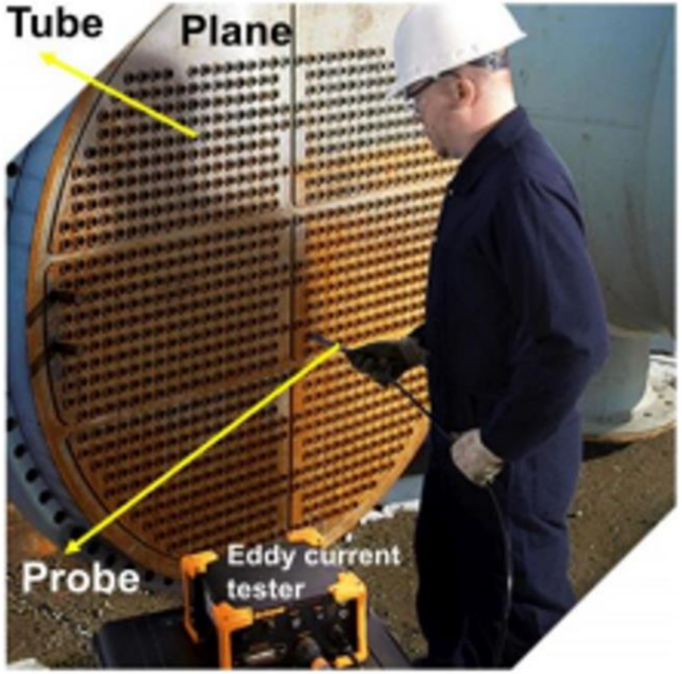


General corrosion inside copper tube because of CO_2



Oxygen pitting attack on copper tube

Current State-of-Art and Problems



The human inspection of heat exchanger tubes

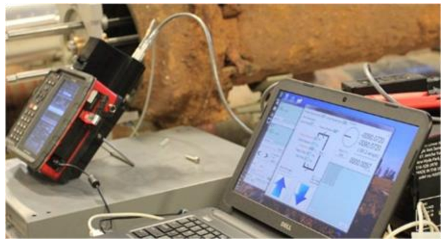
- Labor intensive: routine insertion and extraction of a probe
- Well-trained technicians to operate
- Inconsistent data collection
- Decision making essentially relies on the technician's experience: historic data may not be properly documented and utilized.

A robotic platform that can recognize tube location, perform actuation, and do the testing in a autonomous manner has not been demonstrated for solving the aforementioned problems.

Challenges of Developing Robotic Platform for Autonomous Inspection

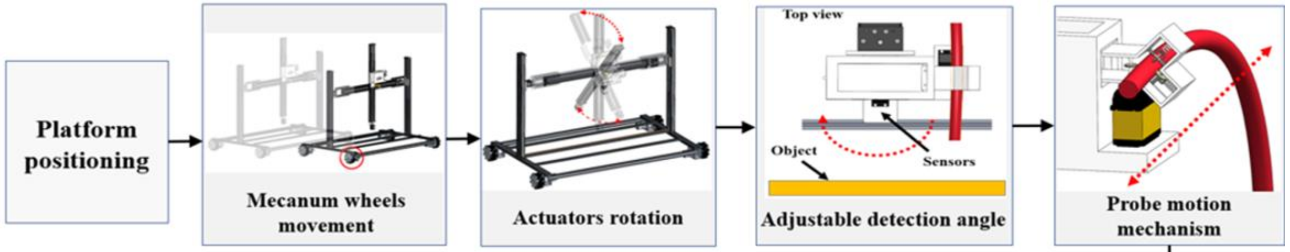
Requirement → The robot that can recognize the tube position → Solution → **Machine Vision**

Requirement → Precise control over motion of the ECT probe according to the inlets position of the tubes → Solution → **Accurate Actuation and Agile control Algorithm**

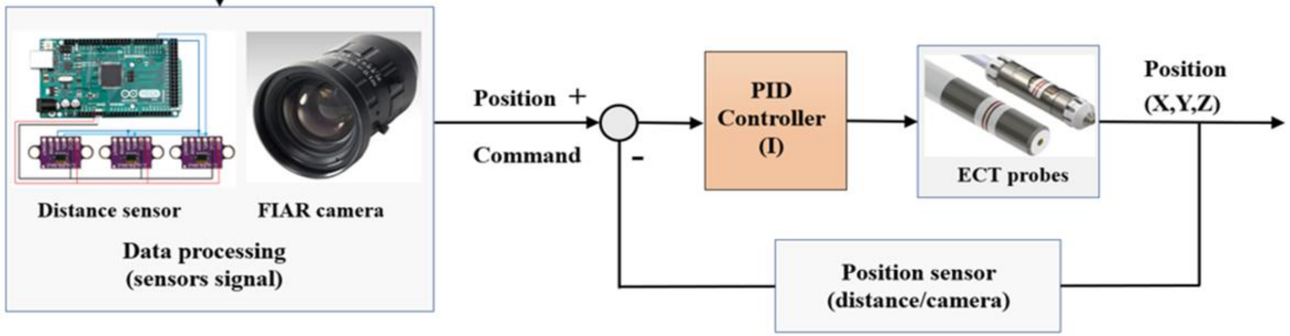


Requirement → Autonomous inspection and analysis capability for decision making → Solution → **Machine Learning Algorithm**

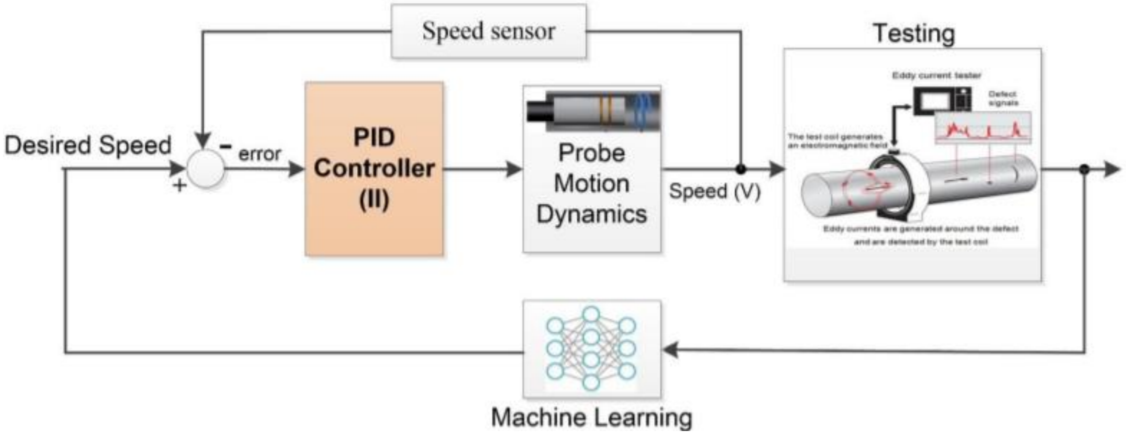
Conceptual Design of the Robotic Platform



(a) Platform Positioning

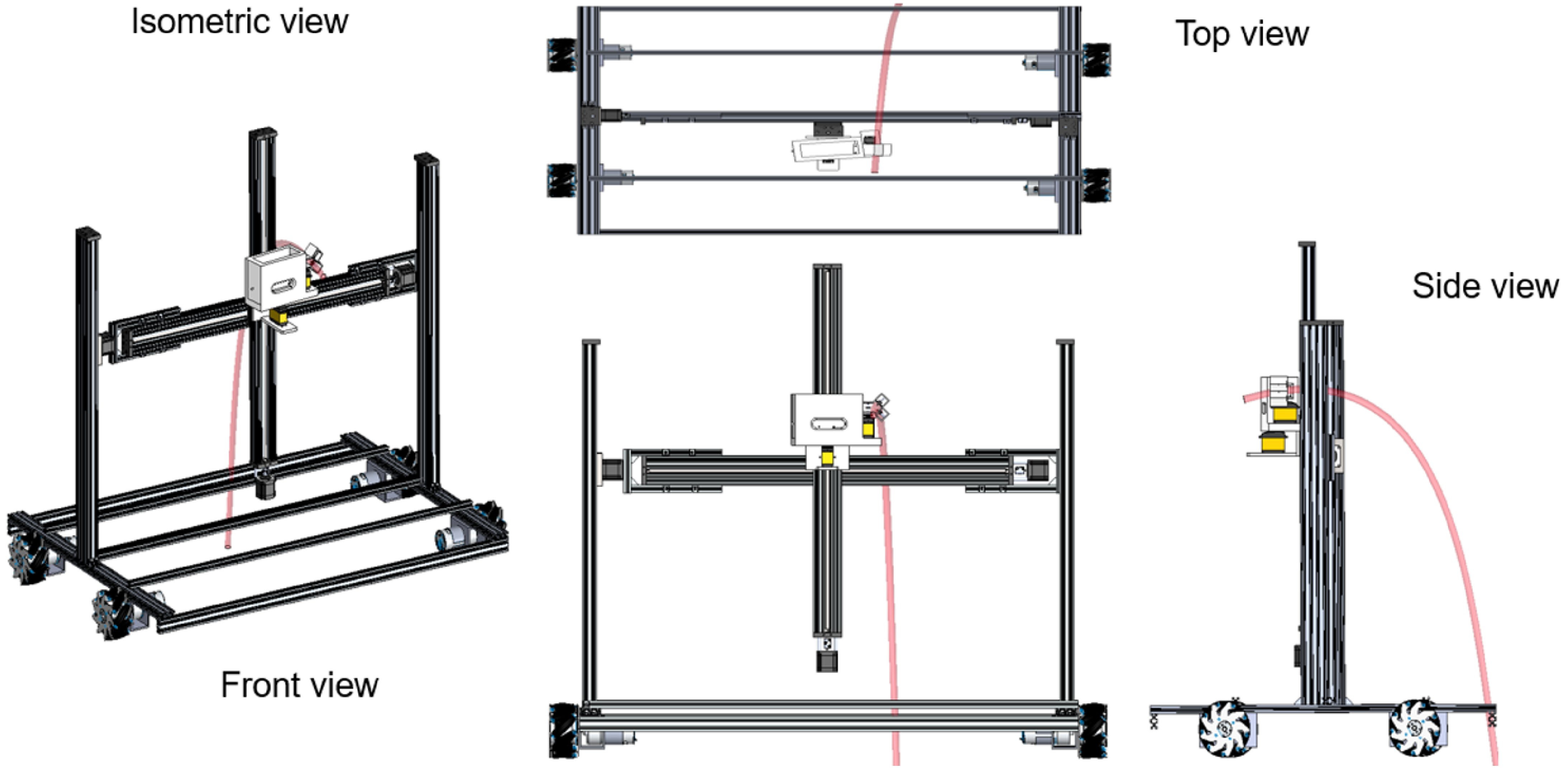


(b) Platform Actuation

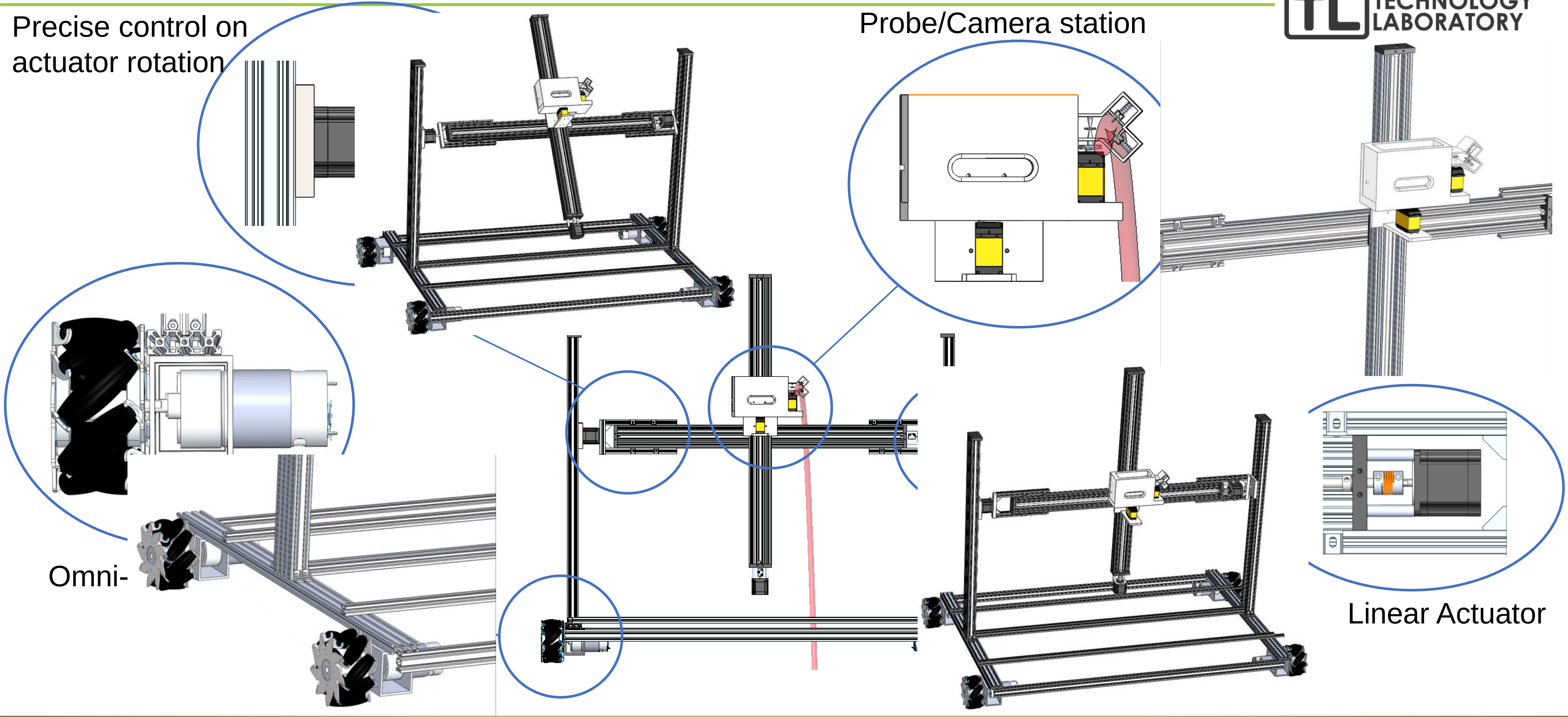


(c) Control of the Probe and Decision Making by Machine Learning

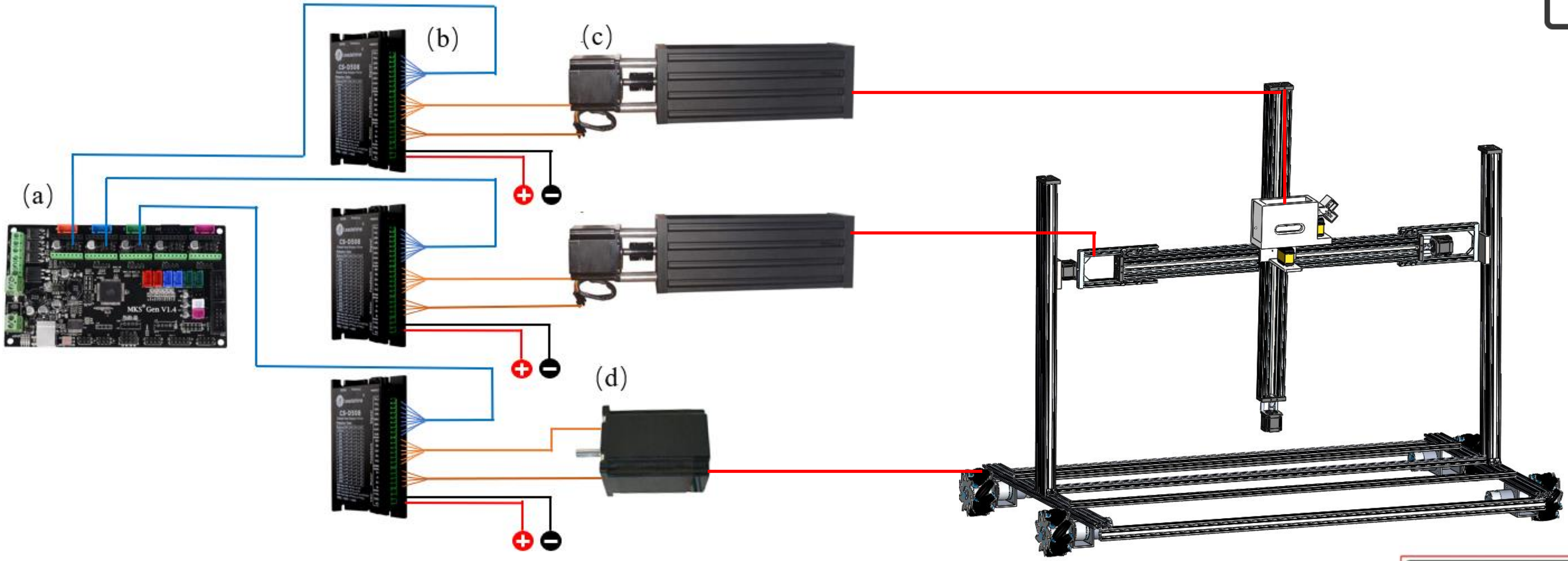
Structural Design of a Robotic Platform



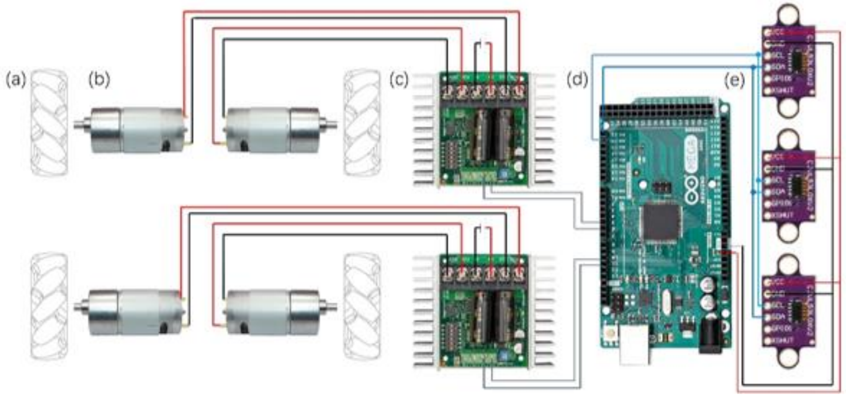
Actuation Systems



Control for Actuation System

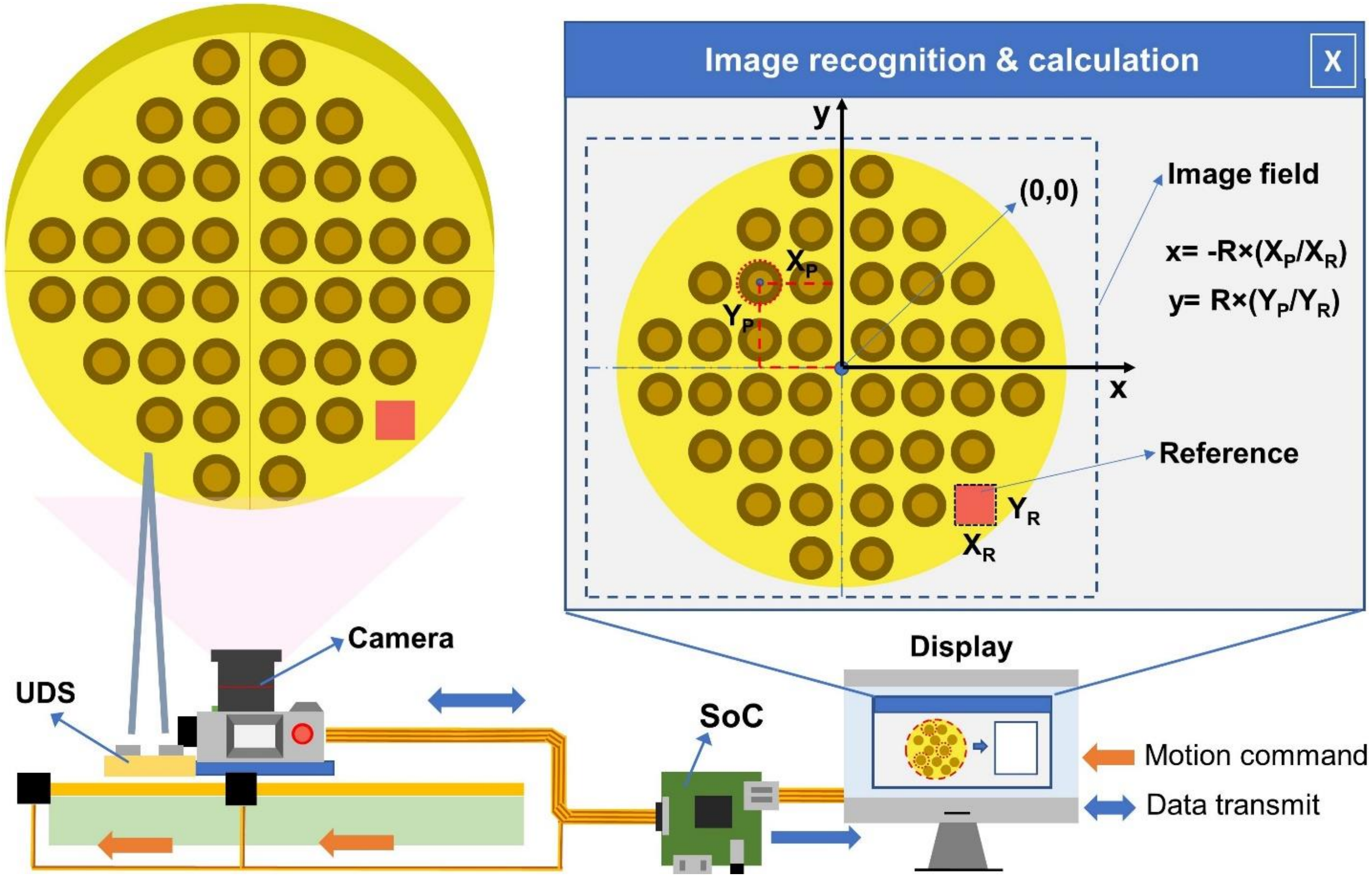


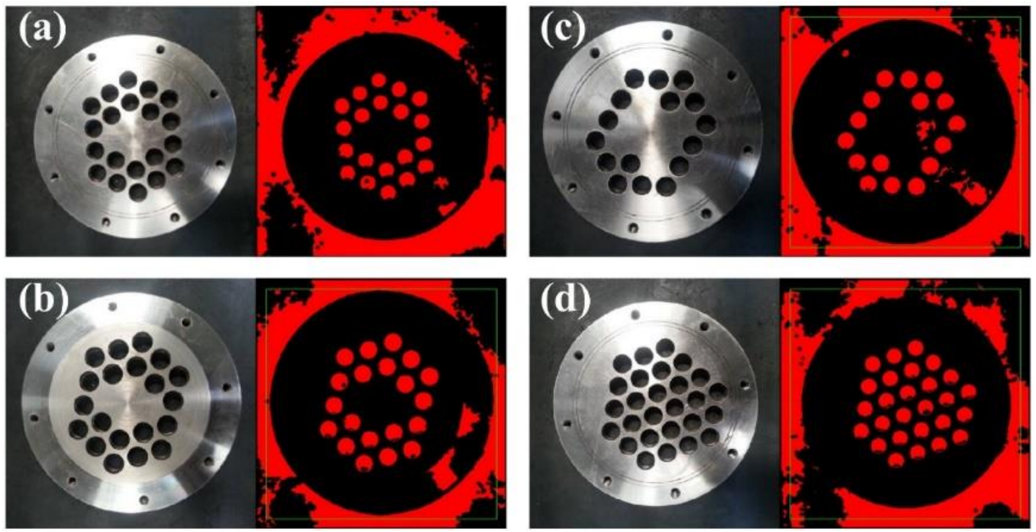
(a)MKS Gen V1.4 Motherboard (b) Closed loop Stepper drive
(c) C-Beam® Linear Actuator (d) Nema 23 stepper motor



Circuit schematic diagram for
Mecanum wheels and distance sensor

Machine Vision for Identification of Tube Inlet Positions

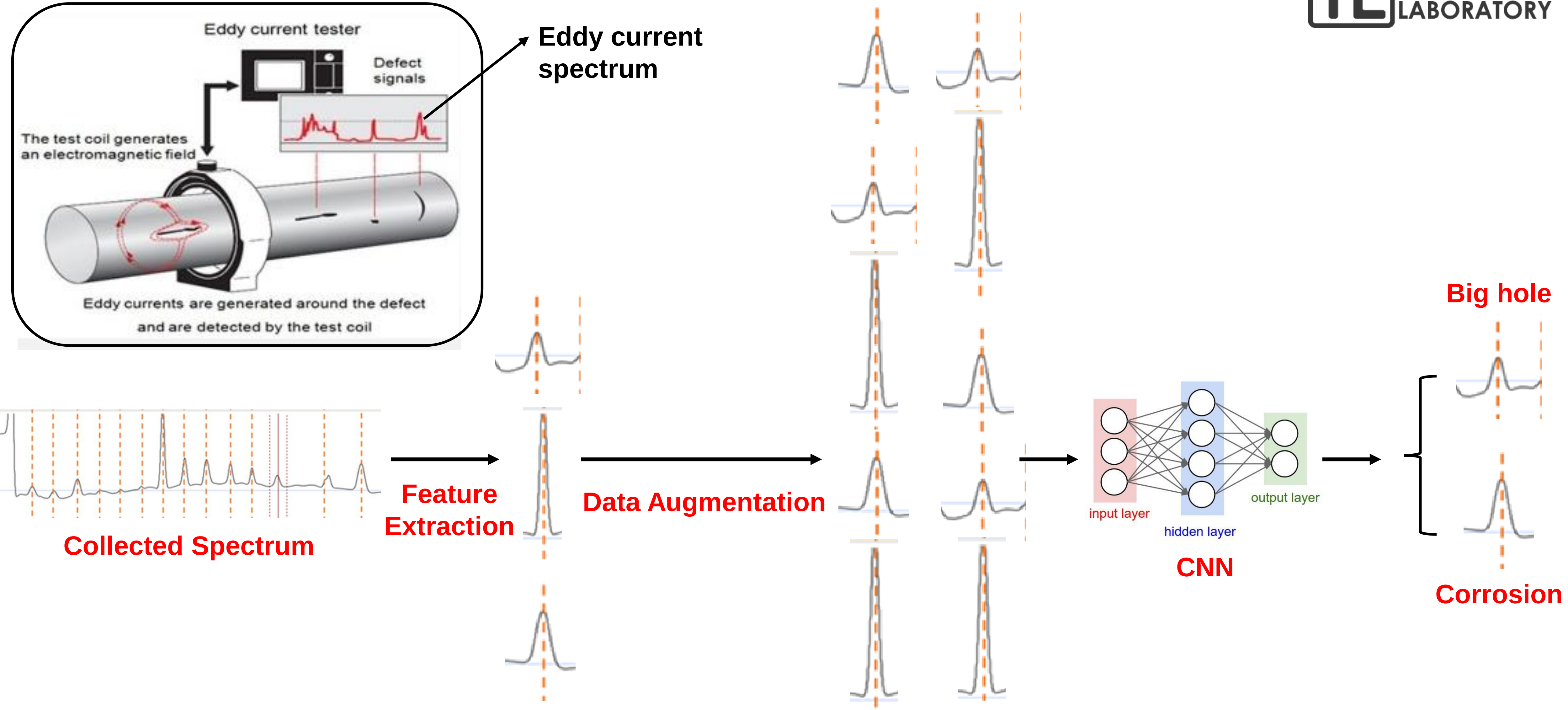




	Quantity	Detection quantity	Average radius (a.u.)	Accuracy (%)
Case a	20	20	13.023	100
Case b	20	20	15.018	100
Case c	16	16	14.528	100
Case d	27	27	13.100	100

Demonstration

Deep Learning for Spectra Data Classification



Other Outcomes

Journal Publications Partially Funded by the Grant:

1. H. Wang, Y. Xie, D. Li, M. Xin, and **J. Lin***. Rapid Identification of X-ray Diffraction Patterns Based on Very Limited Data by Interpretable Convolutional Neural Networks. ***Journal of Chemical Information and Modeling***, 60, 4, 2004-2011 (2020).
2. Y. Xie, C. Zhang, X. Hu, C. Zhang, S. P. Kelley, J. L. Atwood*, and **J. Lin***. Machine Learning Assisted Synthesis of Metal-organic Nanocapsules. ***Journal of the American Chemical Society***, 142 (3), 1475-1481 (2020).
3. Y. Dong, D. Li, C. Zhang, C. Wu, M. Xin, J. Cheng, and **J. Lin***. Inverse design of two-dimensional graphene/h-BN hybrids by a regressional and conditional GAN. ***Carbon***, Accepted (2020).

Education and Training

- So far one domestic Ph.D. student, one M.S. student, and four undergraduate students are involved in this project.
- Knowledge obtained from the project is integrated to course of “Manufacturing” that the PI is teaching.

Collaboration with Industrial Partners

- Establish relationship with Eddify which is a Eddy current tester manufacturing company. They showed interest in collaboration on autonomous detection enabled by deep learning algorithms.
- Survey the need from local power plant.
- Participate in the field maintenance of the exchange heat tubes.

Technical Challenges and Next Steps

NATIONAL ENERGY TECHNOLOGY LABORATORY

Technical Challenges

- Machine vision works well with lab setup. As the environment in real power plant is complex and the tube conditions vary, there may be gap in testing results.
- Accumulative positioning error exists as the number of the tubes increases.
- Lack of eddy current spectra data for deep learning algorithm development.

Next Steps

- Improve the machine vision capability by using simulated setup that is close to real situation when training the model.
- Use a close-loop control algorithm to offset the accumulative positioning error.
- Employ our recently developed data augmentation technique to overcome the issue of limited data.
- Integrate all sensing and actuation systems to one control unit.
- Perform the system testing.

Conclusion

Benefits

- Autonomous robots for testing the exchange heat tube can fill the market gap that calls for increasing automation for power plant maintenance.
- Autonomous decision making enabled by deep learning the eddy current testing data will provide new opportunity for the eddy current testing market.

Technology-to-Market Path

- The developed control algorithm and software can be integrated into existing eddy current tester manufacturers.
- The developed robotic platform can achieve autonomous testing and automate the power plant maintenance, laying foundation for future research in developing field robots.
- Challenges of improving machine vision capability and reducing the position error for accurate path planning will be overcome to achieve the proposed goal.
- Working closely with industry collaborators for understanding the market need and technology transfer will be needed.

Funding: DE-FE0031645

2019: Group members attended training on demonstration of exchange heat tube maintenance in the MU power plant.

Thanks

for your attention!

Questions?