CPS: Medium: Artificial-intelligence-enabled Atomic Force Microscopy (AI-AFM)

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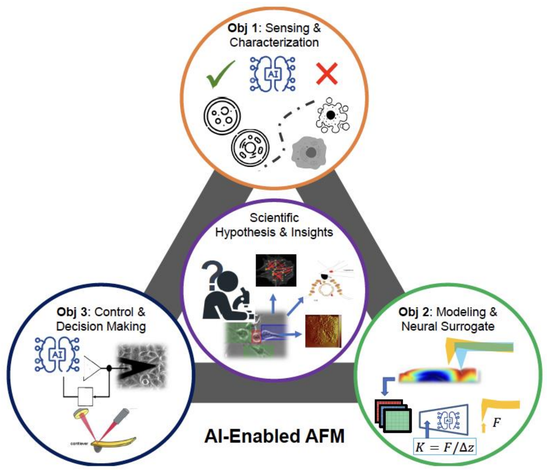
Introduction

The AI-AFM project aims to build a transformative new CPS framework that leverages the recent advances in artificial intelligence (AI) and machine learning (ML) towards high-throughput, scalable, and ultra-precise next-generation AI-enabled atomic force microscopy (AFM) with AI-based sensing, modeling, and control.

Objectives

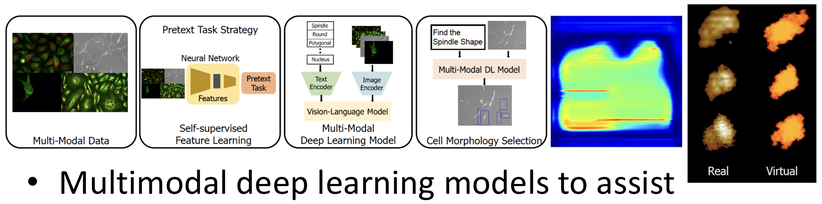
- Generative AI models for accelerated and enhanced AFM experimentation with automated sample selection, characterization, and data enhancement
- Digital twin of the AFM for probe-sample interaction mechanics and AFM automation dynamics modelling utilizing sensor data to capture the unmodeled dynamics
- ML-based real-time control of the AFM operation with data-based learning and decision making
- Validate & evaluate using three cellular biomechanical studies



Scientific Impact

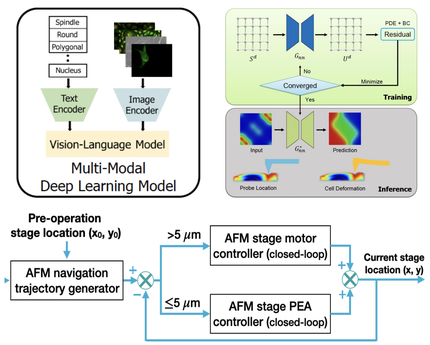
- LLMs for material topography imaging and AFM data characterization with natural language descriptors and multimodal data fusion
- Fast digital twin surrogate to model and predict probe/sample health to enable fault detection in nano/micro 3D manufacturing
- ML-based adaptive feedback+feedforward predictive control toolkit to enable precision control of nano/micro positioning systems

Technical Approach

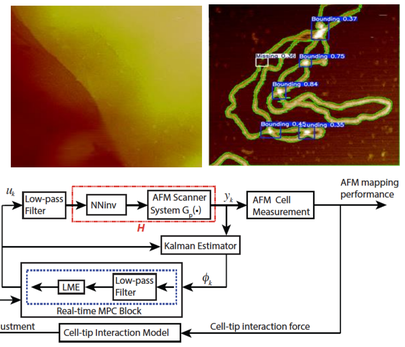


- Multimodal deep learning models to assist experimentalists
- Physics-aware AFM digital twin
- Computation efficient control framework

Solution – Year 1



- Automated cell sample selection and mechanical characterization using multimodal vision
- AFM image enhancement using generative models
- Physics-aware deep learning surrogate for modeling AFM tip-cell interaction
- Dual-actuation AFM navigation control
- ML-based predictive scanning control



Broader Impact

- CPS innovations transferable for diverse applications
- Knowledge dissemination – CPS, controls, and biomechanics communities and public
- Technology commercialization

Education & Outreach

- Integration with graduate & undergraduate curriculum
- Collaboration with ISU REU sites and undergraduate research programs
- K-12 outreach: summer internships and open-lab tours

Impact Quantification (Goals)

- Increase AFM nanomechanical mapping speed by one order of magnitude
- Reduced expert effort and time for experiment
- Broaden participation in computer and engineering