Research Statement

Md Abu Sayed

1. Research Vision and Motivation

My research develops machine learning systems that interpret complex patterns, anticipate future states, and support decision-making in safety-critical environments. I unify deep temporal learning with cross-domain intelligence across autonomous agents, simulation-based modeling, human–robot collaboration, and medical and visual AI.

I first began research in biomedical image analysis, where robust feature extraction under noise and limited labels is essential for reliable diagnosis. Later, during my Ph.D., while working with Prof. Monica Nicolescu on robotic/agent vision, I recognized that perception alone is insufficient for autonomy: intelligent agents must infer and anticipate intent early enough to act safely. This insight drives my Ph.D. research on predictive autonomy. Throughout my work, I seek to answer the following one overarching question:

> *How can AI systems anticipate patterns early under partial or noisy data, and provide interpretable and actionable predictions that improve safety and autonomy in real world settings?*

2. Related Research

My initial research focused on developing robust, multimodal biomedical image analysis techniques to reliably extract structural information despite noise and data limitations. Key contributions include a semi-supervised vessel segmentation method for retinal images, combining multi-scale detection and ensemble learning (IET Image Processing, AIME 2019), and a multi-view Graph Convolutional Network for mammography that fused bilateral/ipsilateral cues for architectural distortion analysis. These projects established my expertise in image segmentation, multimodal fusion, spatial–temporal pattern learning, and modeling under data scarcity, which I built for my Ph.D. research in simulation-driven autonomy and interpretable deep temporal sequence modeling.

3. Current Research: Maritime Autonomy, Intent Prediction and Generative Modeling

My doctoral research (funded by the Office of Naval Research) focuses on predictive maritime autonomy, enabling vessels to detect threats early, interpret behaviors, and take proactive action. Maritime data are often sparse, sensitive, and noisy; behaviors arise from complex multi-vessel interactions; and operators require transparent justifications for automated recommendations. To address these challenges, I built an integrated pipeline that combines high-fidelity simulation (*NavySim*), threat visualization (*ThreatMap*), temporal intent models (HMMs, LSTMs, Transformers), and generative models for missing-data reconstruction and future-trajectory prediction, all tailored to maritime intent understanding.

3.1 NavySim: A Multi-Vessel Simulation and Analysis Engine

To study intent at scale, I was the lead designer, along with colleagues in my research group, for *NavySim*, a Unity-based multi-vessel simulator that supports realistic ship dynamics, sensing and defensive systems, and live heatmap rendering via custom shaders (COG 2024, IEEE Transaction on Games). *NavySim* connects to Python machine-learning models through a TCP pipeline and integrates *ThreatMap*, an intent recognition model, and scenario generation capabilities. It provides a controllable platform for benchmarking early intent prediction algorithms and supports future deployment to on-water vessels.

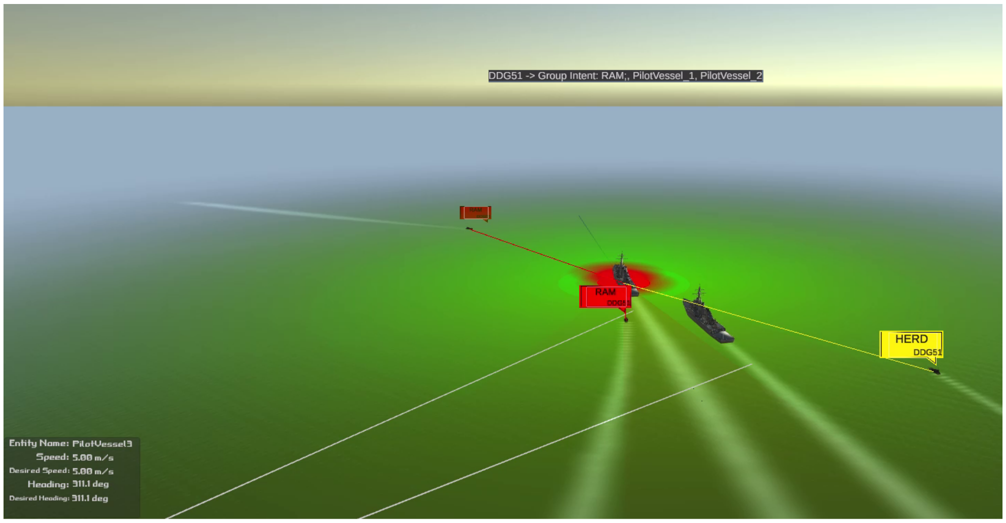

Figure 1: *ThreatMap* showing high-danger hotspots around a DDG51 vessel caused by three approaching pilot vessels. Two exhibit RAM behavior and one shows HERD, with group behavior and intents, predicted by the intent recognition model, indicated in the top panel.

3.2 ThreatMap: Predictive Coverage, Vulnerability, and Threat Visualization

To support operator trust and provide spatial context behind mathematical model-based predictions, I created *ThreatMap*, an interpretable real-time visualization of maritime risk (HMS 2024). *ThreatMap* fuses (1) sensor and weapon coverage, (2) vulnerability fields created by blind zones and pose, and (3) CPA-based threat estimates computed from kinematic features. Integrated into *NavySim*, the resulting heatmap offers a clear green-to-red representation of safe vs. dangerous regions around a vessel, giving decision-makers an intuitive understanding of evolving threats and the factors driving model outputs.

3.3 Temporal ML/DL Models for Early Intent Recognition

Autonomous maritime systems must recognize vessel intent early, despite sparse and noisy observations, to maintain situational awareness and enable timely, safety-critical decisions. Building on early HMM-based modeling, I developed feature-aware deep learning architectures using curated naval kinematic features, with LSTM, Bi-LSTM, and Transformer classifiers achieving roughly 97% accuracy on seven behaviors using only initial trajectory segments (CASE 2025). I extended this work to rolling-threat prediction with a sliding-window formulation, reaching 81–88% multiclass accuracy and about 90% hostile–benign accuracy with short 20-second windows. These contributions form the predictive core of my maritime autonomy work and motivate future directions in handling domain shift, determining minimum observation requirements, developing end-to-end raw-sensor models, and evaluating mixed human–AI decision processes.

3.4 Generative Models for Sequential Missing Data and Future Trajectory Prediction

Alongside intent classification, I am developing generative models that reconstruct missing maritime sensor data and predict plausible future trajectories under uncertainty. Real-world streams often contain dropouts and irregular sampling, which degrade early-intent performance. I am designing CVAE-based latent models and LSTM-GAN generators that learn the joint distribution of past and future motion, serving as imputers for incomplete trajectories and simulators for multiple plausible futures. Integrated with *NavySim*, these models support scenario forecasting, counterfactual analysis, and data augmentation for adversarial events.

4. Future Research Agenda, Funding Strategy, and Institutional Fit

My 5-year research program will advance predictive autonomy in maritime, robotic, simulation, and visual domains through integrated modeling, generative methods, and targeted interdisciplinary collaborations.

Thrust 1: Early Maritime Intent Recognition and Generative Sequence Modeling. Extend maritime intent prediction to multi-vessel and ground-robot settings by combining Transformer and graph-based architectures with generative sequence models (CVAE, GAN, Diffusion) for partial-trajectory reconstruction and uncertainty-aware future prediction. This aim addresses early inference under incomplete, noisy, or imbalanced observations.

Thrust 2: Intent Recognition in Human–Robot Collaboration. Model human gaze trajectories, motion cues, and command sequences to infer real-time intent and support interpretable, adaptive robot responses. This research connects temporal intent modeling (LSTMs, Transformers, LSTM-GANs) with human-centered interaction and will be validated both in simulation and on collaborative robotic systems.

Thrust 3: Simulation and Digital Twins. Develop next-generation simulation environments and digital-twin pipelines that integrate realistic vessel dynamics, multi-agent interactions, scenario generation, and continuous alignment with real-world deployments. *NavySim* will serve as the foundation for robust scenario creation, counterfactual testing, and autonomous policy evaluation.

Thrust 4: Multimodal and Temporal Modeling for Medical Image Analysis. Building on my earlier work on multi-view mammography and GCNs for mass detection, I will develop models that fuse multiple imaging views, patient metadata, and longitudinal studies to improve early identification and characterization of breast masses. This work combines multimodal representation learning with temporal anomaly detection to capture subtle structural changes over time. Although mass detection will be an initial focus, these methods will also be extended to other problems in medical AI, image analysis, and computer vision. This thrust leverages the same temporal generative modeling and multimodal fusion techniques that drive my autonomy work, enabling a unified methodological foundation across domains.

Funding and Fit. My research agenda aligns with federal and interdisciplinary funding opportunities that support applied, student-integrated artificial intelligence across autonomy, simulation, imaging, and data-driven decision systems. My immediate funding efforts will target **ONR programs in Science of Autonomy and Bio-Inspired Autonomous Systems**, along with related mission-oriented initiatives. I will also pursue support from the National Science Foundation in areas such as robust and trustworthy AI, cyber-physical systems, cyber-human systems, and intelligent robotics, as well as relevant NIH programs advancing medical image and data analysis. My work on simulation-driven autonomy, intent prediction, and uncertainty-aware modeling advances safety-critical, interpretable, and real-world AI systems.

My research program is structured to integrate interdisciplinary collaboration with teaching and mentoring. I focus on applied, student-centered AI research emphasizing interpretable modeling, evaluation under uncertainty, and real-world impact. I plan to pursue NSF Research Experiences for Undergraduates (REU) Supplements and, longer term, REU Site funding to involve undergraduate students in AI-focused projects, including those leveraging simulation and digital-twin environments. This approach supports a sustainable research program aligned with departmental teaching missions and student career preparation.

5. Long-Term Vision

I aim to build a research group in situation-aware and intent-aware autonomous systems that merges simulation, perception, and predictive modeling. With my lab, I will seek to produce high-impact publications, develop open-source simulation frameworks, train the next generation of ML , vision and robotics researchers, and advance the foundations of anticipatory AI systems that understand their environment, anticipate future states, and act with reliability, transparency, and safety.