Research Statement: An Intelligent Design Framework for Deployable, Human-Centered, and Measurable Systems

Yihan Zhang

The University of North Carolina at Chapel hill

I. Introduction: Research Motivation & Core Philosophy

I have always firmly believed that cutting-edge technology should ultimately serve the general public and solve real-world problems. This is the research path I pursue as a **"pragmatic idealist"**—dedicated to transforming rigorous academic methods into socially valuable, deployable, and scalable solutions. My academic focus is on human-centered intelligent systems, which combines behavioral and social data modeling with multi-source sensing, simple and reliable decision-making and execution (e.g., "full-coverage + in-situ avoidance"), and incentive-driven human-machine interfaces. My goal is to form a closed loop from source reduction and front-end sensing to on-site execution and data governance. My approach emphasizes rapid, low-cost prototyping (3D printing, laser cutting, Arduino/edge AI) and clear, reproducible evaluation. My prior experiences with TEMPEST (the "Roomba for lakes" concept), SmartCan (behavioral prompts for compliance), Chill by 'U', and the Smart Bird Feeder allowed me to establish a stable work methodology that integrates system design, human perception, and deployable prototypes.

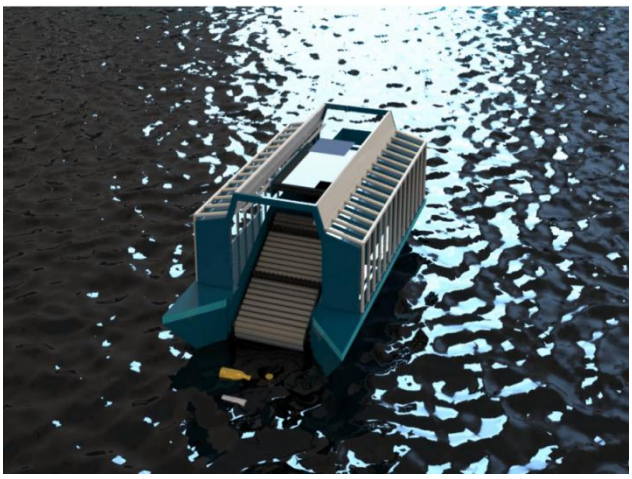
II. Research Thesis & Framework

I propose to systematically develop and refine an

"Intelligent Design Framework for Urban Micro-Interaction Systems." Urban micro-interactions refer to the high-frequency, lightweight, yet highly impactful interactions between residents, devices, and public services in the last mile: from dropping off trash and inspecting shorelines to reporting minor faults and receiving risk alerts. My research work itself assumes no particular problem to solve but relies instead upon a series of representative examples of urban living conditions in order to develop a general approach through practical example. For this, the small cleaning vessel represents just one of a number of "execution components" contributing, together with other execution strategies, to a single perception-decision-execution-evaluation loop.

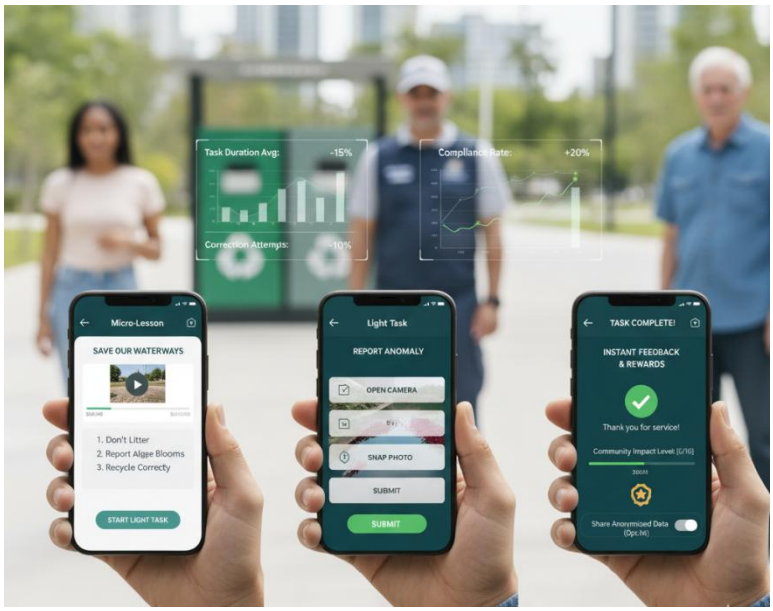
III. Representative Application Scenarios (for Framework Refinement and Validation)

1. **Near-shore Collection and Inspection:** Targeting narrow waterways, under bridges, and near-crowd scenarios, emphasizing low noise, avoidability, and rapid return visits (a small cleaning vessel is just one execution method).



2. **Waste Sorting and Operational Compliance (SmartCan Upgrade):** Through behavioral prompts and a concise interface, this aims to reduce incorrect disposals, shorten task times, and improve first-time accuracy.

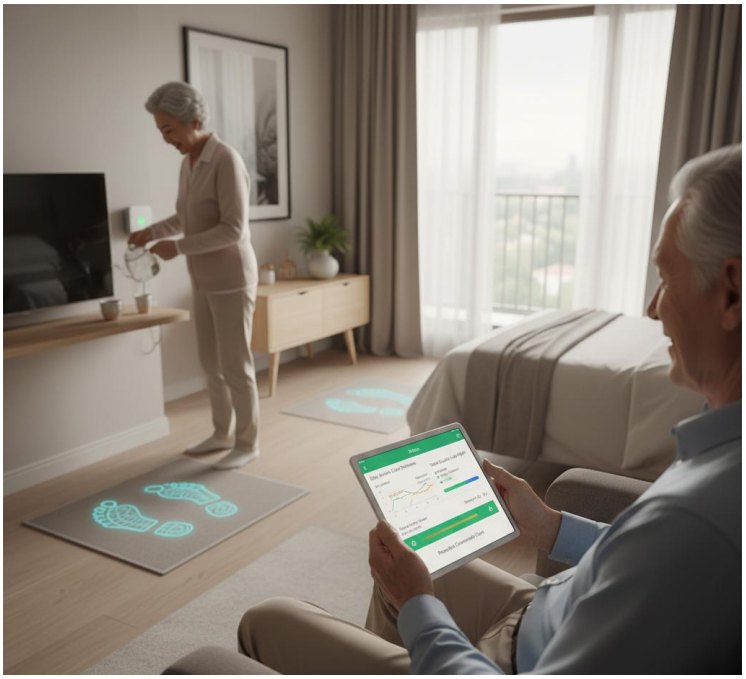
3. **Citizen Education and Compliance Improvement (App-as-a-Service + Measurement):** Through the use of a light app/mini-program, my approach links public services to the creation of light actions, achieved through micro-lessons (60-90 seconds) → light tasks (3 steps or less) → immediate feedback + rewards. Moreover, the app itself serves as more than just an interaction platform but also as a "**data collection tool**" where, upon consent, it collects information like the time spent, clicks, attempts, time of day, as well as coarse location. In this way, there can be always improving designs and strategies based on actual data while also developing publishable, actual-world results like the improvement in compliance levels, the learning curve, as well as calibration of trust, directly applicable in the realm of city-wide governance as well as academia.



4. **Open Channel/Shoreline Anomaly and Red Tide Early Detection:** This connects "seeing an anomaly" with "immediate action," institutionalizing small-scale, high-frequency patrols and follow-up visits.

5. **Community Facility Micro-Maintenance:** Such as seasonal leaf cleanup, mosquito breeding site treatment, and “last-mile” usage and maintenance of public equipment.

6. **Citizen Health & In-home Monitoring (Human-Centered + Measurable):** Creating an affordable smart home solution, such as the use of Pressure sensors in doormats/mattresses, to monitor the geriatric population in a non-intrusive way based on daily activity parameters. T**he goal would be early warnings for potential falls & anomalies in the behavior of the elderly.** Using a light-touch mobile app, the information needs to be converted into meaningful health messages, connecting the community healthcare facilities to move from the concept of “passive health management” to “proactive prevention.”



IV. Research Questions & Methodological Highlights

My research will focus on a lightweight App/mini-program for residents and frontline personnel: using micro-lessons (60–90 seconds) → light tasks (≤3 steps) → and instant feedback and rewards to make public services into sustainable "light actions". The key point is that the App is not just an interaction portal; it's a **"data collection instrument"** that, with explicit user consent, records anonymized metrics such as task time, prompt clicks, correction attempts, time of day, and coarse location. On one hand, this uses real user data to iterate on interaction and strategies (making the design continuously better to use), and on the other hand, it forms publishable, real-world evidence (e.g., compliance improvements, learning curves, trust calibration), directly informing urban governance and academic research.

Research Questions and Methodological Highlights

- RQ1 Accurate Perception:
  In high-glare, noisy conditions, use simple sensors (camera + polarizing filter, ultrasound/sonar) along with light learning mechanisms, as well as hard-case retraining.
- RQ2 Safe & Complete Navigation:
  Adopt a strategy of **'full coverage + in-situ avoidance' using teach-and-repeat routes**, seeking to achieve optimal coverage efficiency while also taking into consideration safety as well as courtesy towards people, other ships, and animal life.
- RQ3 Usability & Willingness-to-Use:
  Use behavior-guiding prompts, as well as the design of incentives, to create usable HMIs, turning "seeing" into "acting" while improving continuously based upon actual interaction data from the App.
- RQ4 Measurable & Reproducible Outcomes:
  Develop a set of repurable experiment scripts and result dashboard pages (such as coverage per hour, FA/correction rate, return visit success rate, CI improvement delta, burden assessment, etc.), beginning with small-scale A/B tests & walk-throughs, working up to actual communities/campuses.

Methodology:

1. Rapid prototyping (hardware + software), taking small, quick steps for real-world scenarios;
2. Hybrid evaluation: usability walkthroughs (n≈8–12) + A/B testing (n≈30–50 per group);
3. Data & ethics: minimal collection, anonymization, revocable consent, and publishing only aggregated statistics;
4. Openness & reusability: establishing datasets, baselines, and toolchains to ensure transferability across scenarios/cities.

V. Near-Term Plan & Expected Outcomes

- **0–6 months:** MVP for two to three scenarios (e.g., “waste sorting + near-shore inspection”), complete usability walkthroughs and initial A/B tests; launch a metrics dashboard and reproducible experiment scripts.
- **6–12 months:** Expand to campus/community pilots, engage with government and operations teams (e.g., published reports and workflows from marine, environmental, and fisheries departments); produce initial empirical papers/technical reports.
- **12–24+ months:** Explore multi-component collaboration (human labor/equipment/vessels), refine the general methodology and tools; release open-source data and baselines.

VI. Summary

My goal is not to isolatedly build a “smarter device.” Instead, by continuously solving a set of real urban micro-interaction problems, I aim to refine and validate a transferable “intelligent design framework.” This framework uses simple and reliable sensing and execution, human-centered interfaces that people are willing to use, and continuous optimization driven by real-world data to make a demonstrable impact on daily operations and citizen experience in high-density cities. A small cleaning vessel is just one interchangeable “execution module” within this framework; the same methods and evaluations can also be applied to various other scenarios like waste sorting, early red tide detection, and facility micro-maintenance. Through the

deployable + measurable + publishable triad, I hope to truly connect academic rigor with the efficiency of urban governance.