(Form 5)

Forefront Physics and Mathematics Program to Drive Transformation (FoPM)

Report for the International Research Experience

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During my international research stay, I conducted research and technical exploration on industrial vertical cleaning robots, with a particular focus on perception, sensing robustness, and system-level integration under real-world constraints. My background lies at the intersection of opto-mechanics, image-based sensing, and computational decision-making, and this stay provided an opportunity to place these skills into a practical, deployment-oriented context. Rather than pursuing isolated laboratory experiments, my activities focused on understanding how physics-informed sensing and data-driven reasoning can be translated into reliable robotic behavior in challenging industrial environments.



CNTY Shanghai office

A central part of my experience involved close observation and analysis of vertical cleaning operations and robotic workflows in realistic conditions. Vertical cleaning presents a uniquely demanding scenario for robotic systems: operations occur at height, often on reflective or curved surfaces, with the presence of water films, detergents, mist, and variable illumination. These factors complicate perception and introduce uncertainty into both sensing and control. During my stay, I systematically examined how such environmental factors affect visual and optical signals, and how these effects propagate through downstream decision processes. This hands-on exposure deepened my understanding of why many seemingly effective laboratory vision approaches struggle when transferred to industrial settings.

Building on these observations, I spent significant time investigating strategies for stabilizing optical observations under wet and reflective conditions. This work did not aim to produce novel sensor hardware, but rather to evaluate practical combinations of illumination geometry, observation timing, and signal interpretation that remain informative despite glare, scattering, and transient disturbances caused by spray or motion. Through iterative testing and discussion with engineers and operators, I gained insight into which cues are operationally meaningful and which are too fragile for sustained deployment. This experience reinforced the importance of physics-aware thinking when dealing with real-world perception problems.

In parallel, I explored how machine learning–based inference can be framed to respect industrial uncertainty rather than mask it. Instead of treating cleanliness as a binary concept, I focused on understanding how continuous quality indicators and confidence measures could be integrated into robotic decision-making. During my stay, I analyzed

representative image data and operational scenarios to conceptualize how a robot might estimate not only surface conditions but also its own level of certainty in those estimates. This perspective aligns closely with safety-critical robotics, where knowing when the system is uncertain is often as important as making an accurate prediction.

Another important aspect of my experience was engaging with system-level thinking. Vertical cleaning robots do not operate in isolation; they are part of a broader operational ecosystem involving scheduling, monitoring, maintenance, and data logging. I examined how perception outputs could be structured so that they are not only useful in real time for robot control, but also meaningful for long-term monitoring and iterative improvement at the fleet level. This involved considering how quality-related signals could be logged, visualized, and interpreted within an existing digital infrastructure without introducing excessive complexity. Through this process, I gained a clearer appreciation of how research ideas must be shaped to fit operational realities.

From a personal and professional perspective, this stay was valuable in sharpening my ability to communicate across disciplinary boundaries. I regularly interacted with individuals from different technical backgrounds, including robotics engineers, system integrators, and operational staff. Explaining sensing and inference concepts in a non-academic setting required me to distill ideas to their essentials and to focus on practical implications rather than theoretical elegance. This experience strengthened my ability to translate abstract scientific reasoning into language that supports real-world decision-making.

The outcomes of my stay are best described as conceptual and methodological rather than as finalized research results. I developed a clearer framework for thinking about quality-aware perception loops in industrial robotics, including how sensing, inference, and decision policies can be coupled in a closed-loop manner. I also produced internal documentation outlining possible sensing configurations, data interpretation strategies, and system-integration considerations that can serve as references for future development. These materials are intended as foundations for continued work rather than as standalone research conclusions.

Equally important were the broader lessons learned. Working in an applied industrial context highlighted the gap between academic performance metrics and operational success. Robustness, interpretability, and maintainability often outweighed marginal gains in accuracy. This realization has influenced how I think about research problems: not only in terms of what is theoretically possible, but also in what is sustainable, verifiable, and safe when deployed at scale.

In summary, my international research stay provided an invaluable opportunity to connect physics-informed sensing, computational inference, and robotics within a real-world industrial application. The experience strengthened my technical judgment, broadened my perspective on applied research, and clarified how my skills can contribute to developing safer, more reliable robotic systems for urban infrastructure maintenance. While no unpublished research outcomes are disclosed in this report, the knowledge and experience gained during this period will strongly inform my future academic and professional work.