Enabling Real-time Dynamic Control and Adaptation of Networked Robots in Resource-constrained and Uncertain Environments

Mehdi Rahmati, PhD Candidate, Dept. of Electrical and Computer Engineering, Rutgers University, NJ

Investigators: Drs. Dario Pompili (PI), *Jingang Yi (Co-PI), and *Francisco Diez-Garias (Co-PI)

Dept. of Electrical and Computer Engineering; *Dept. of Mechanical and Aerospace Engineering

Rutgers University–New Brunswick, NJ , E-mails: {pompili, jgyi, diez}@rutgers.edu

Motivation

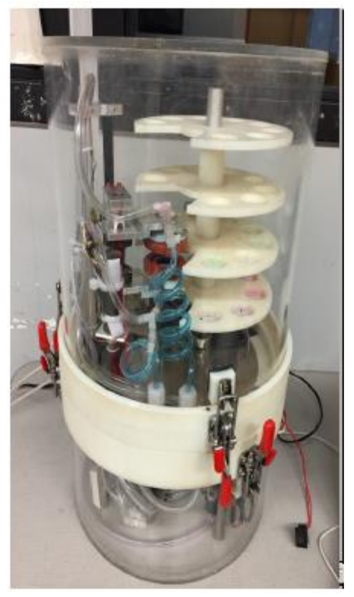
- **Near-real-time water-quality monitoring of physical variables** in rivers, lakes, and water reservoirs is critical since contaminated water should be prevented from reaching the civilian population
- **Optimal decisions and timely closed-loop solutions** should be deployed, or at least early warnings should be issued, so as to prevent damage to human and aquatic life

Goal

- **Design a Cyber Physical System (CPS)** where drones and autonomous underwater robots can identify in near real time *Regions of Interest (RoIs)* and collect biosamples from them
- Perform in-situ transformation of the measurements/raw data into valuable information and then into knowledge through *collaborative information fusion* and *integration*
- Solve the problem of uncertainties (*model*, *resource*, and *data*) that arises in in-situ processing of data from sensors in any CPS
- Provide greater autonomy, robustness, and cooperation in CPSs while improving on their scalability, reliability, and timeliness in comparison to traditional sensing systems

Research Tasks

- **Task 1:** achieve dynamic collaboration between local and cloud resources to minimize the sampling cost of a RoI (w.r.t. time or energy expenditure)
- **Task 2:** handle model uncertainties in the local resources caused by the unpredictable behavior of computational models (often because of the data)
- **Task 3:**
  - **(i)** develop a biosampler, i.e., a "lab-on-robot," that uses in-situ measurements and communicates with the cloud resources
  - **(ii)** optimize the Rutgers Naviator's current hybrid air/water multirobot platform/propulsion system in order for it to be able to carry and perform testing with the biosampler while also increasing the Naviator's endurance



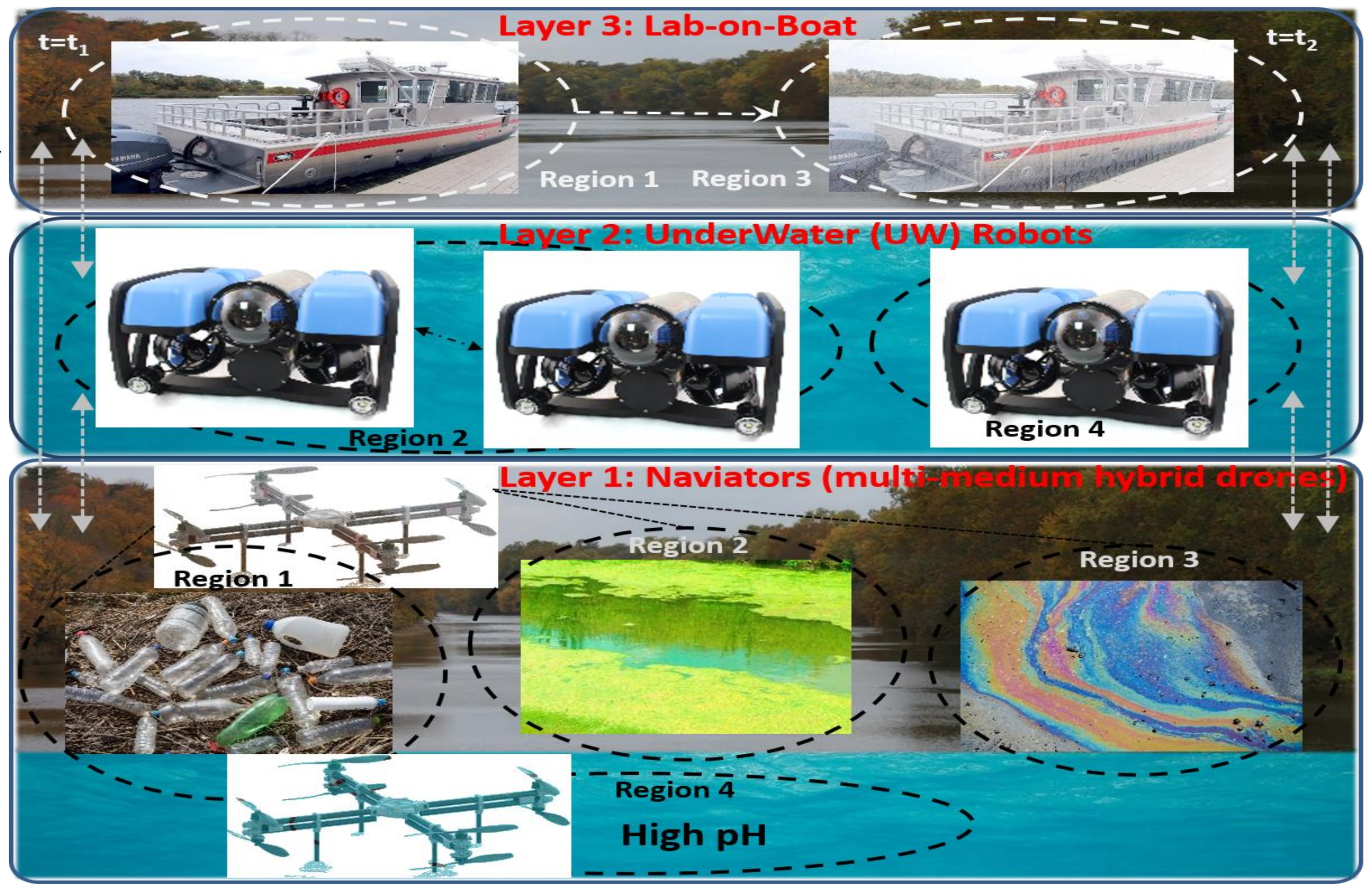
Prototype of the on-board biosampler

The recent version of our Rutgers Naviator

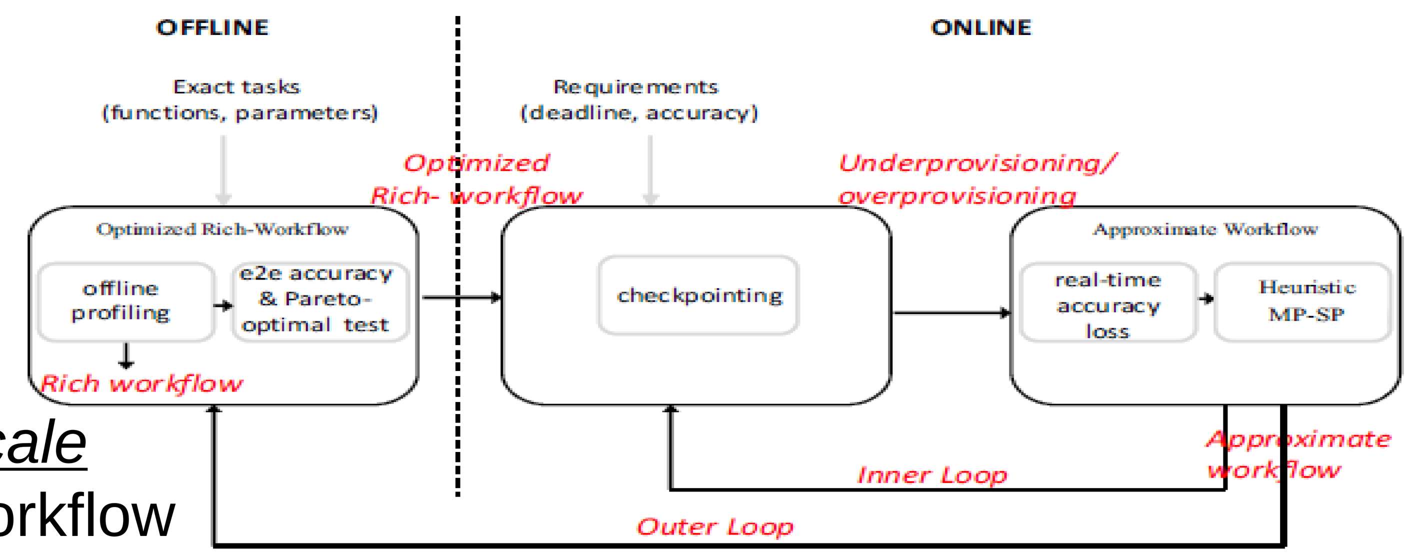
- **Task 4:** perform integrated field testing on the Raritan River, NJ (1) to validate our algorithms, (2) to analyze their scalability (from an economical and feasibility perspective) as well as (3) to assess their performance confidence/accuracy

Methodology: A Three-layer CPS Sensing Architecture

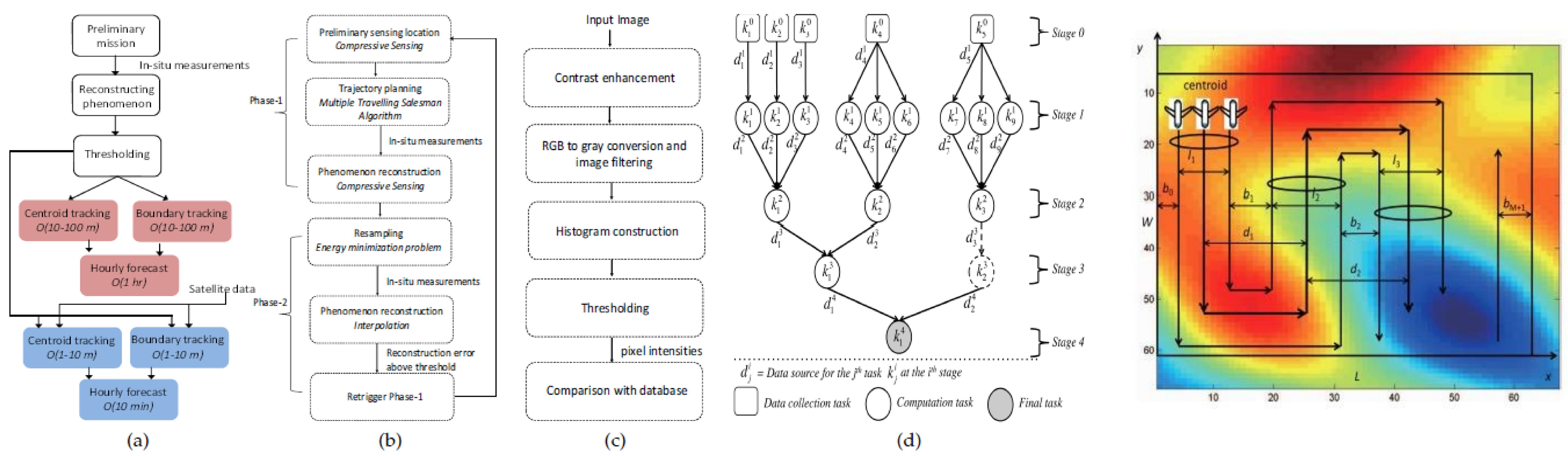
- **Three-layer CPS sensing architecture** using heterogeneous and autonomous mobile sensors for near-real-time, energy-, and time-efficient water-quality monitoring *over time and space*
- **Physical variables of interests** are:
  - ✓ pH, temperature, dissolved oxygen and metals, (micro)plastic, algae concentration, turbidity, chlorophyll, pathogenic microorganisms, etc.
- ➢ **Layer 1:** multi-medium drones (Rutgers Naviators), with *narrow-spectrum sensing* capabilities but with *fast moving* and quick triage abilities
- ➢ **Layer 2:** autonomous underwater robots with *narrow spectrum sensing* but with *high temporal- and spatial-resolution* capabilities
- ➢ **Layer 3:** few Lab-on-Boats with *broad and accurate spectrum sensing* capability but *slow moving* and low spatial- and temporal-sensing resolution



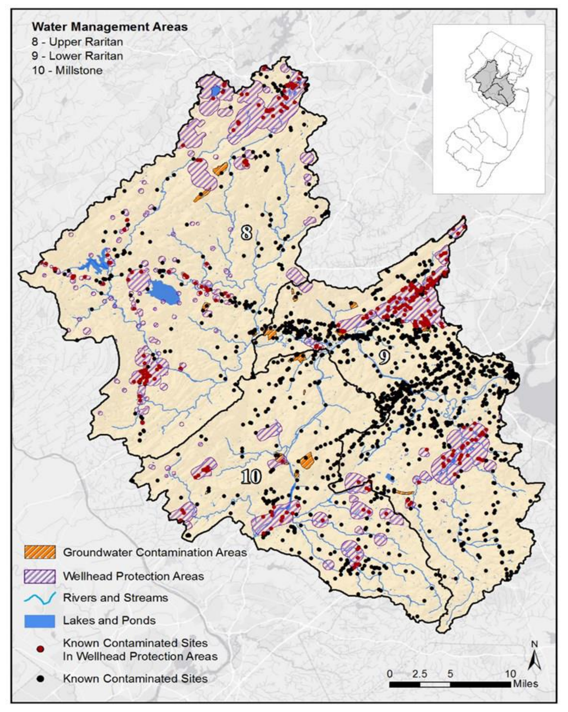
- **Handling CPS model uncertainty** via *distributed multi-scale (cloud) computing* with transformation of computational workflow



Preliminary Results



(a) Detection and tracking of algae bloom in water bodies (blue-colored boxes indicate tasks that are executed at a higher spatial/temporal resolution than those in red); (b) Adaptive sampling solution; (c) Measuring the turbidity of water in the Region of Interest (RoI) using image-processing techniques; (d) Example 5-stage workflow of computational tasks.



A perfect case study: contamination in the Raritan River (2016)

References

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