The Robotarium: A Remotely Accessible Swarm Robotics Research Testbed

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Motivation

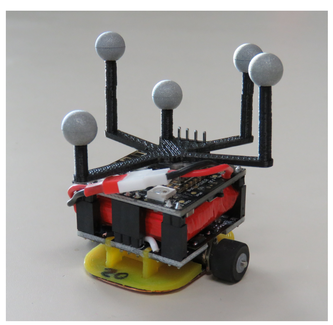
The Robotarium is a **remotely accessible, multi-robot research facility**. The impetus behind the Robotarium is that multi-robot testbeds constitute an integral and essential part of the robotics research cycle, yet they are:

- Expensive to start
- Complex to construct
- Time-consuming to develop, operate, and maintain

Robotarium remedies these issues by **providing users with remote access to a state-of-the-art multi-robot testbed.**

Testbed

The Robotarium testbed provides a 12×14 foot area equipped with wireless charging coils allowing multi robot experiments to be executed autonomously 24/7.



The Robotarium's main inhabitant: the GRITSbot is a small, differential-drive robot equipped with:

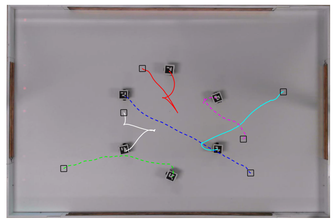
- Small footprint (3 cm)
- Wireless charging
- Wifi-enabled ESP8266

Users

The Robotarium has engaged **over 210 users** from countries and institutions across the world. Since the grand opening of the official test bed on August 22, **over 110 users** have registered to use the platform.

University of Illionis Urbana-Champaigne

UIUC deployed a **fault-tolerant rendezvous** algorithm onto the Robotarium, in which robots met while ignoring influence from other malicious/malfunctioning robots.

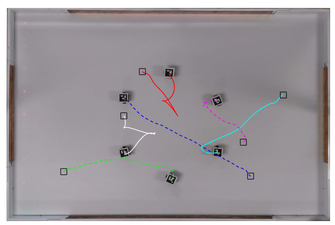


Utilized the Robotarium's:

- Single-integrator-to-uniycycle mapping

University of Texas Austin

UTA deployed a **distributed formation-control** algorithm onto the Robotarium, in which robots achieved a formation in a distributed manner.

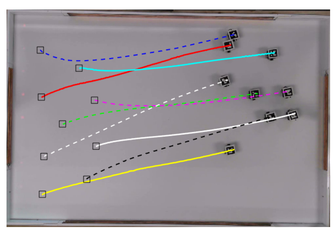


Utilized the Robotarium's:

- Single-integrator-to-uniycycle mapping
- Collision avoidance

Tokyo Tech

Tokyo Tech deployed a **heading consensus** algorithm onto the Robotarium, in which robots used a passivity-based controller to achieve heading consensus.



Utilized the Robotarium's:

- Collision avoidance

Science of Remote Access

Simulator: Users interact with the Robotarium via the simulator, which is written in MATLAB. The user workflow is:

- Download MATLAB simulator
- Prototype code
- Submit scripts via website

All simulator code can be **deployed directly onto the Robotarium.**

Access via Abstractions: The Robotarium provides access at various levels of abstraction including:

- Single-integrator-to-unicycle mappings
- Go-to-goal behaviors
- Communication topologies

Cyber-Physical Safety (CPS): Since anyone can access the Robotarium, CPS becomes a concern. The Robotarium handles CPS-based threats via **safety barrier certificates**.

Safety barrier certificates allow **fast, safe, minimally invasive modification of user's controllers.**

Mathematically,

- $\frac{d}{dt}x = f(x) + g(x)u$ (dynamics)
- $u^{user} : \mathbb{R}^n \to \mathbb{R}^m$ (user's controller)
- $h : \mathbb{R}^n \to \mathbb{R}$ (barrier certificate)
- $\mathcal{C} = \{x \in \mathbb{R}^n \mid h(x) \geq 0\}$ (safe set)

The set $\mathcal{C}$ is forward invariant if

$$\frac{\partial h}{\partial x}(f(x) + g(x)u) \geq -\bar{\alpha}(h(x)),$$

where $\bar{\alpha} : \mathbb{R} \to \mathbb{R}$ is an extended class-$\mathcal{K}$ function. The Robotarium **enforces this requirement through the quadratic program:**

$$\min_{u \in R^m} \|u^{user} - u\|$$
$$\text{s.t. } \frac{\partial h}{\partial x}(f(x) + g(x)u) \geq -\bar{\alpha}(h(x)).$$

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