MATLAB EXPO

2021

Advancing Engineering Education with Virtual Labs

Will Greenwood, MathWorks
Magnus Egerstedt, Georgia Institute of Technology

MathWorks

Georgia Tech School of Electrical and Computer Engineering
College of Engineering

Digital Transformations in STEM Education

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- Results from a survey of STEM Professors conducted by Bay View Analytics

https://www.insidehighered.com/news/2021/03/11/faculty-still-harbor-concerns-about-teaching-stem-courses-online

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- **2% Canceled** the Laboratory Portion of the Course

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72% Identified the unique need for Online Laboratories

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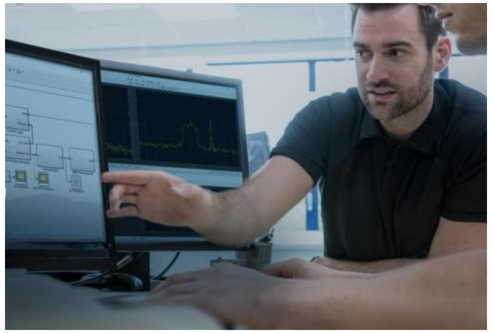
Importance of Labs for Student Development

Reinforce Concepts

Importance of Labs for Student Development



Build Intuition

Reinforce Concepts

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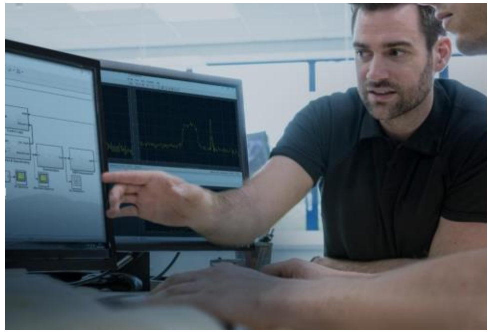

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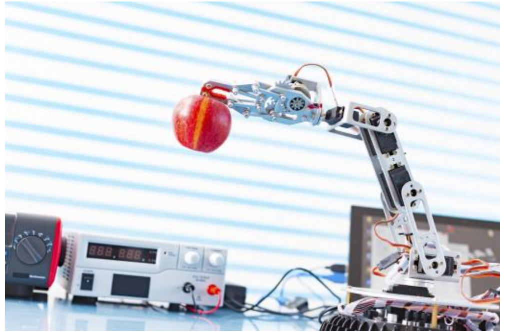
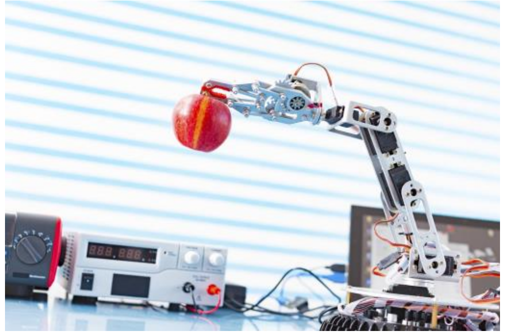
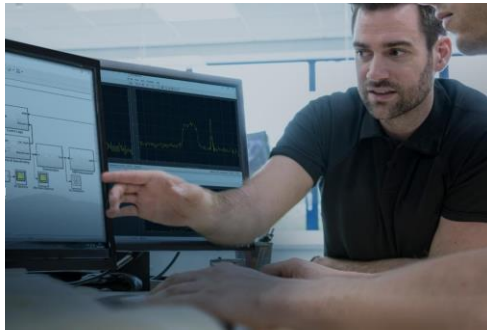


Implement in Design

Importance of Labs for Student Development





Reinforce Concepts

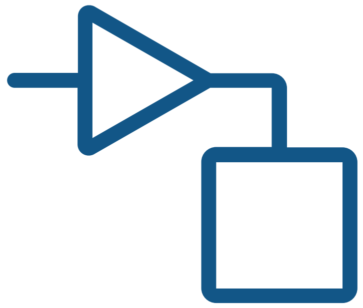
Build Intuition

Implement in Design

Analyze Systems

Online Laboratory Models

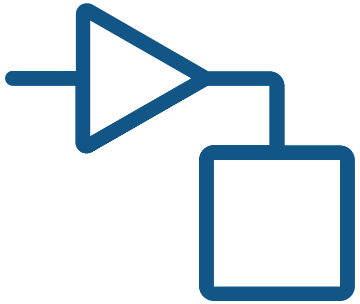
Online Laboratory Models



Virtual

Virtual Labs exist in the virtual space to simulate a process, test, apparatus, or other activity.

Online Laboratory Models



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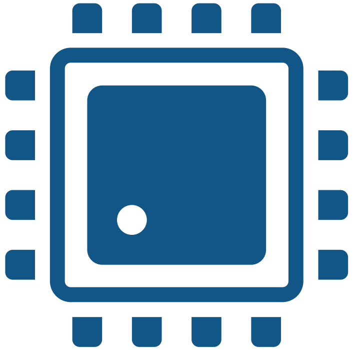

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Hardware Labs incorporates kits, mobile devices, or other components that exist at home or off campus.

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Remote Labs use equipment that exists on campus but is viewed, accessed, or even controlled by students remotely.

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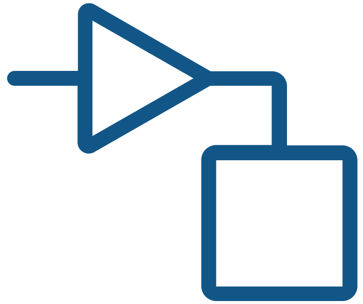

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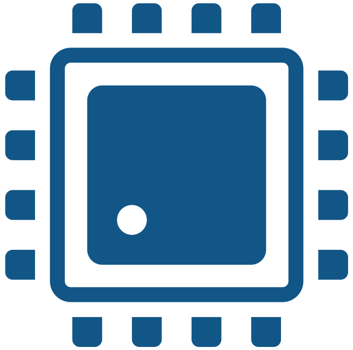

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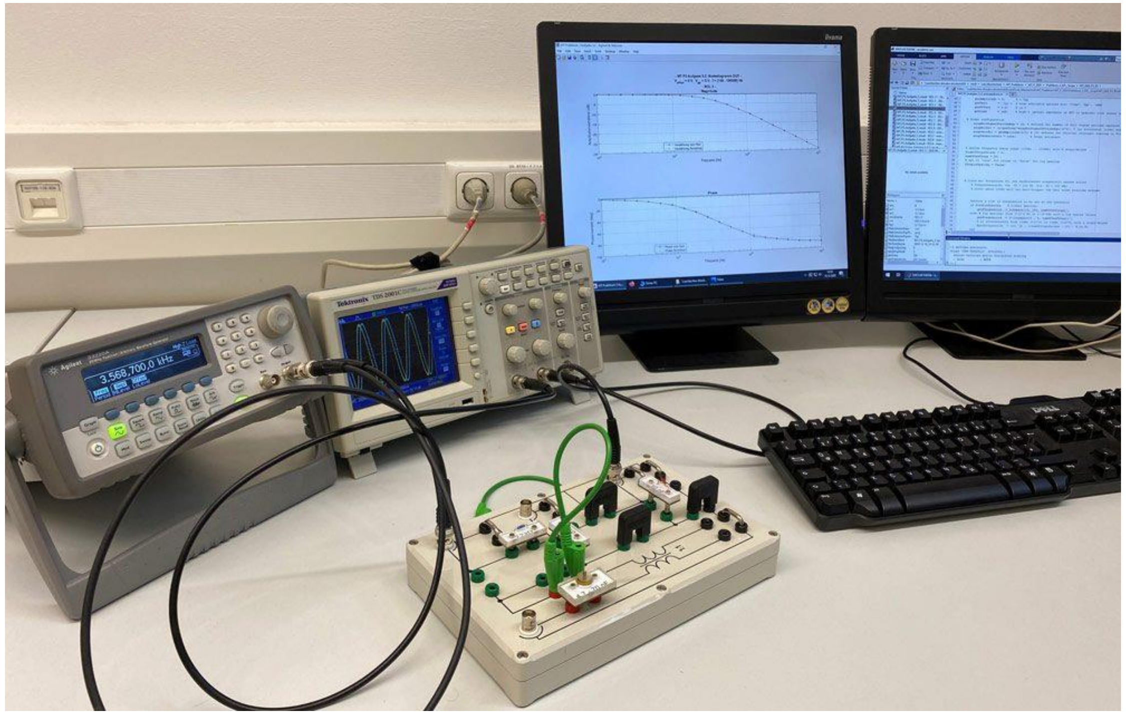
HTW Dresden Virtualizes Electrical Engineering Teaching Labs

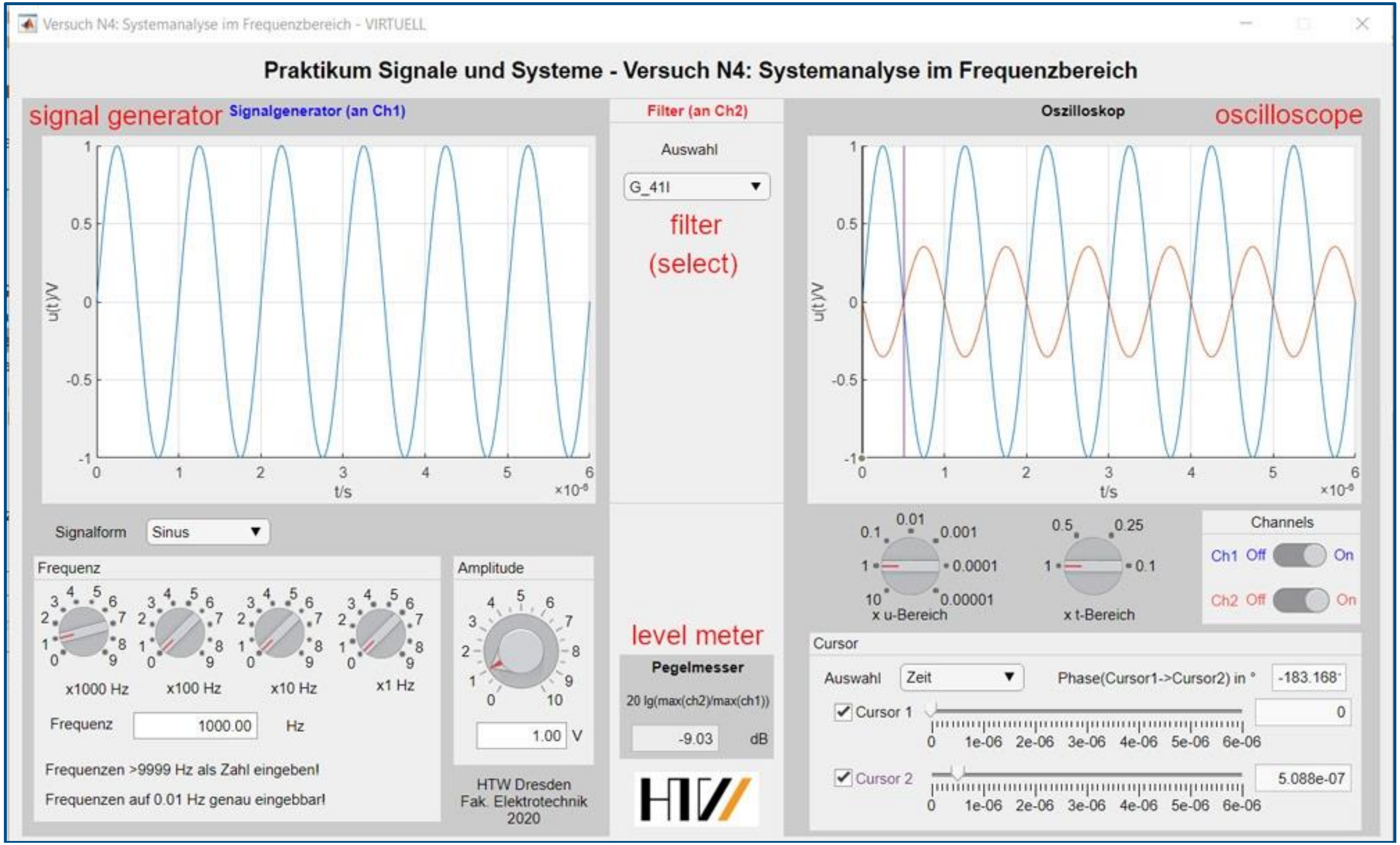
- **Challenge:** Support hybrid online and in-person learning

- **Solution:** Create a MATLAB app representative of the lab hardware



HOCHSCHULE FÜR
TECHNIK UND WIRTSCHAFT
DRESDEN
UNIVERSITY OF APPLIED SCIENCES

HTW Dresden Virtualizes Electrical Engineering Teaching Labs



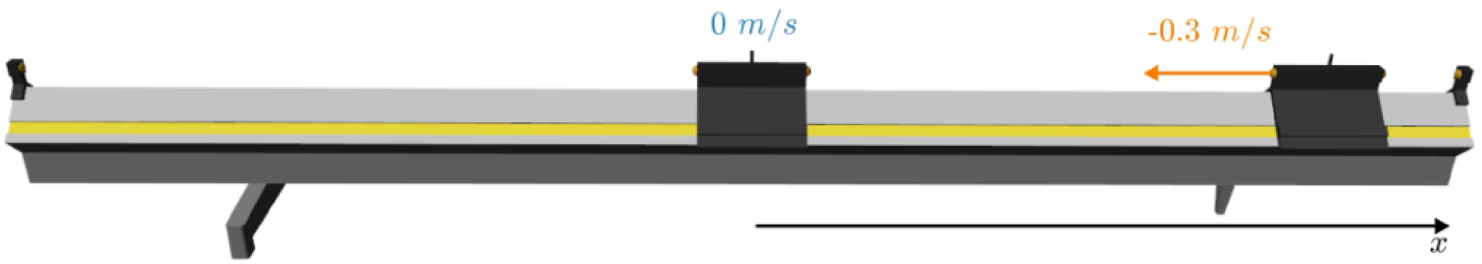
MATLAB app for conducting virtual lab experiments with signal generation, filtering, and visualization.

Virtual Air Track Lab

Question 1. Suppose a cart passes through a photogate in 0.6 seconds. What was the speed of the cart in m/s?

```
v_q1 = 0.25;    % Write the speed in m/s
```

Question 2. Suppose that the carts have no additional weights and have been equipped with rubber bands and flags (resulting in elastic collisions). If cart 1 begins at rest and cart 2 approaches from the $+x$ direction at -0.3 m/s, what velocities will the carts have after collision?



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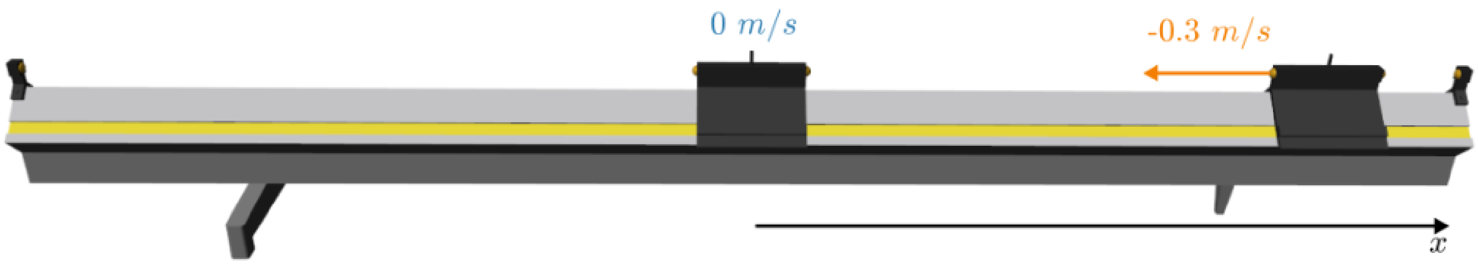

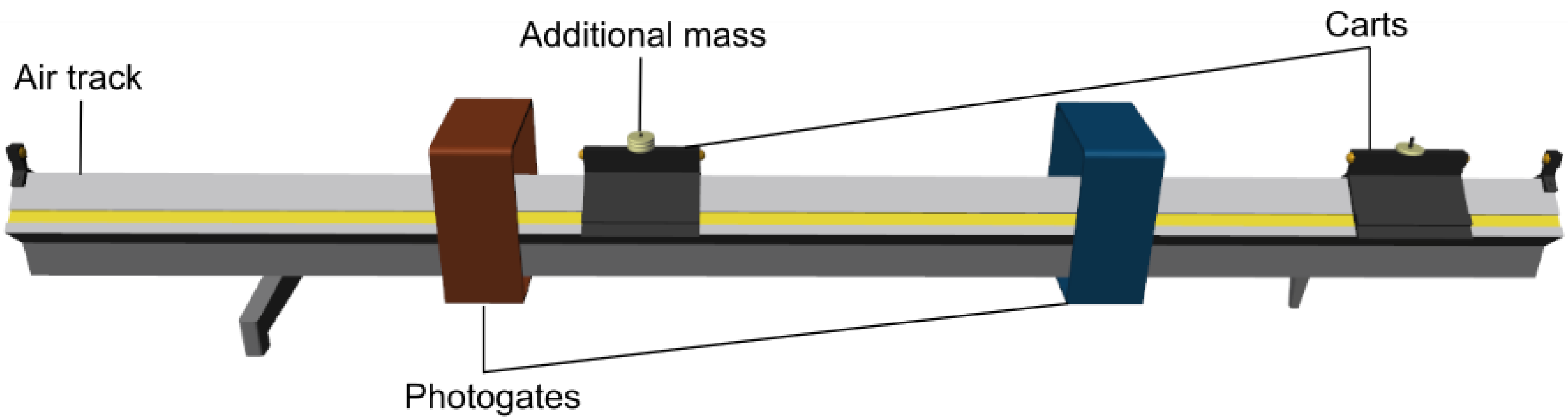

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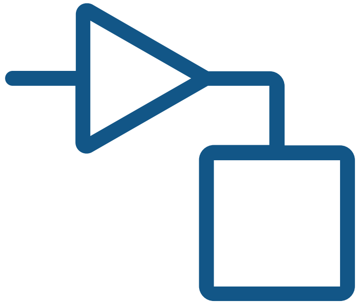

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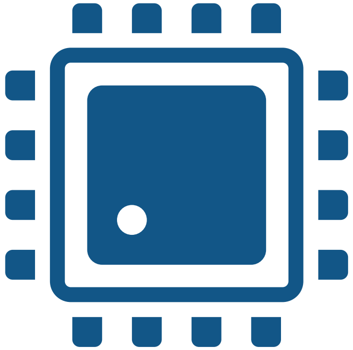

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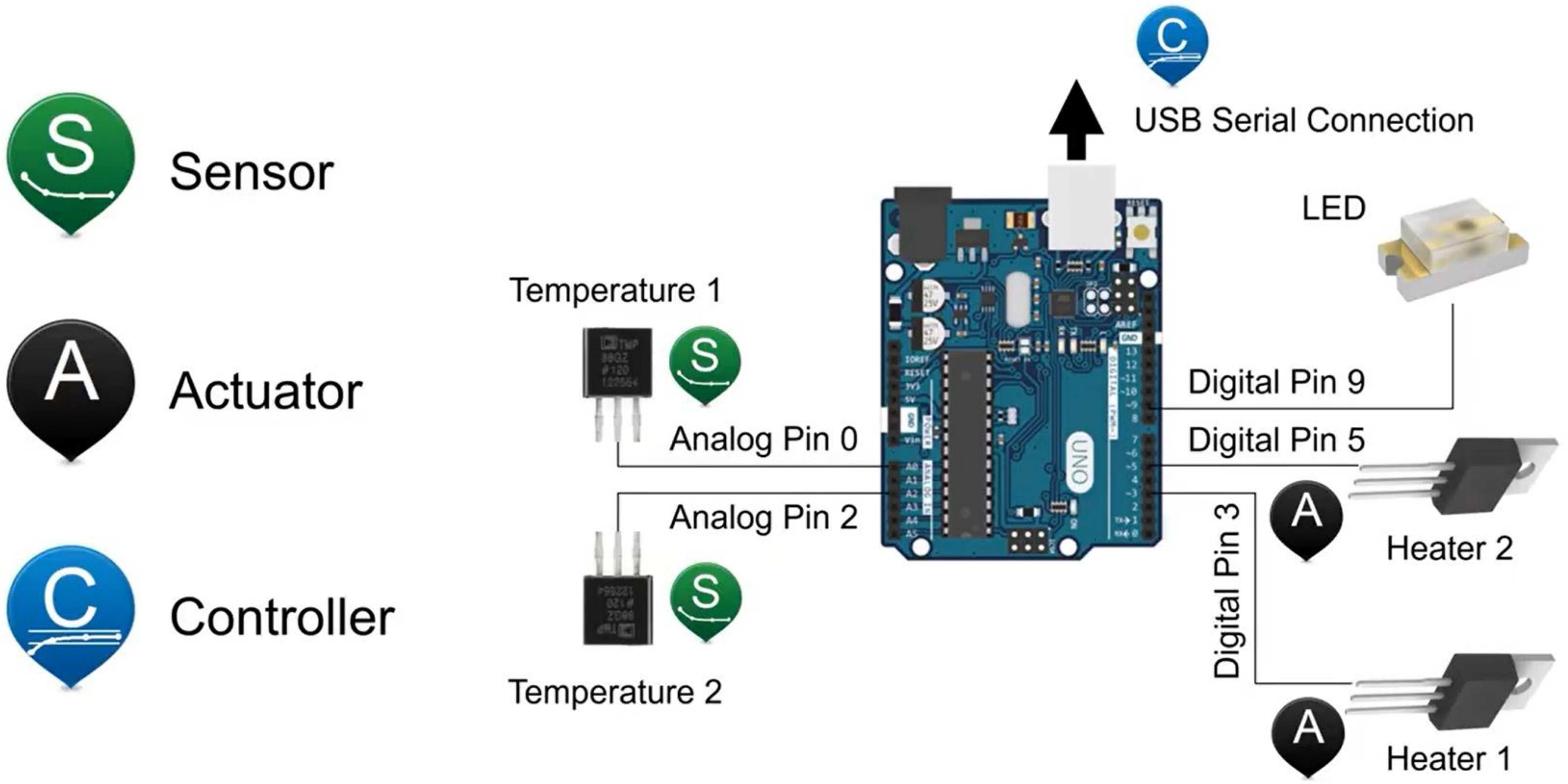
Teaching Dynamics and Control with Arduino Based TCLab



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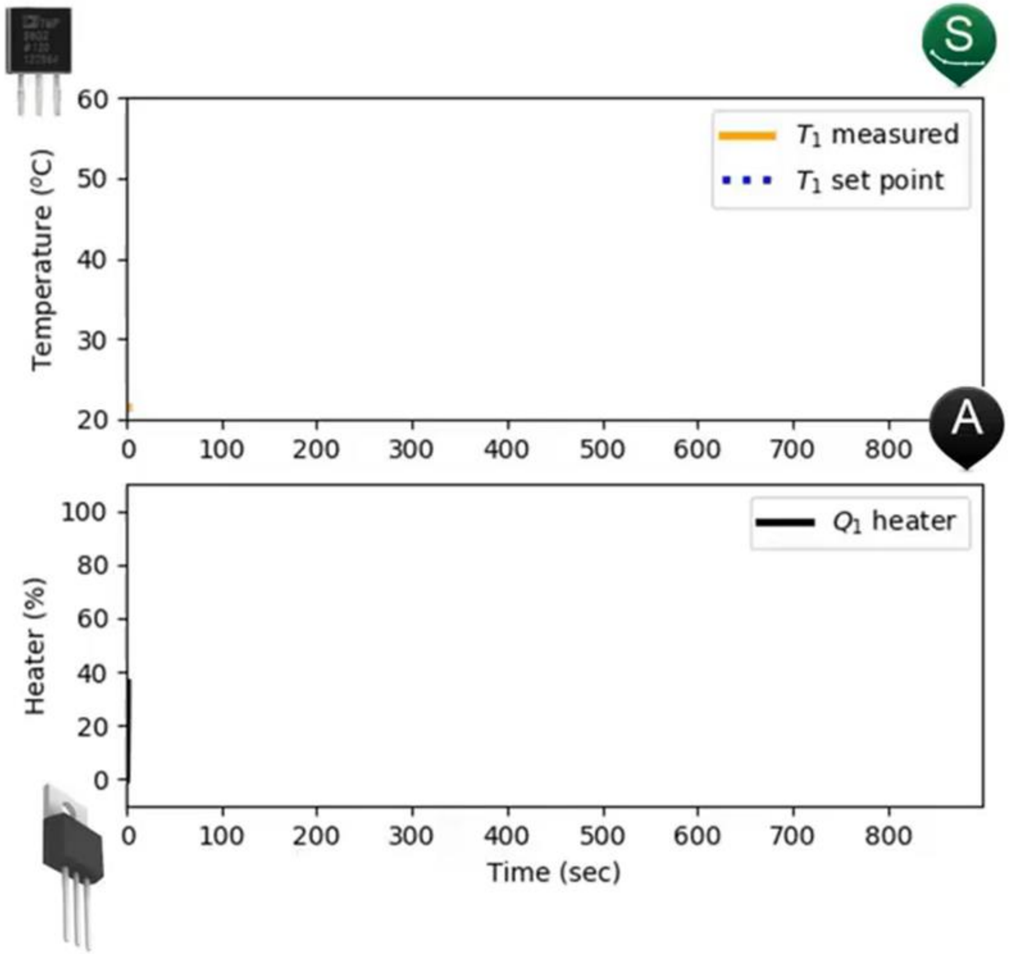

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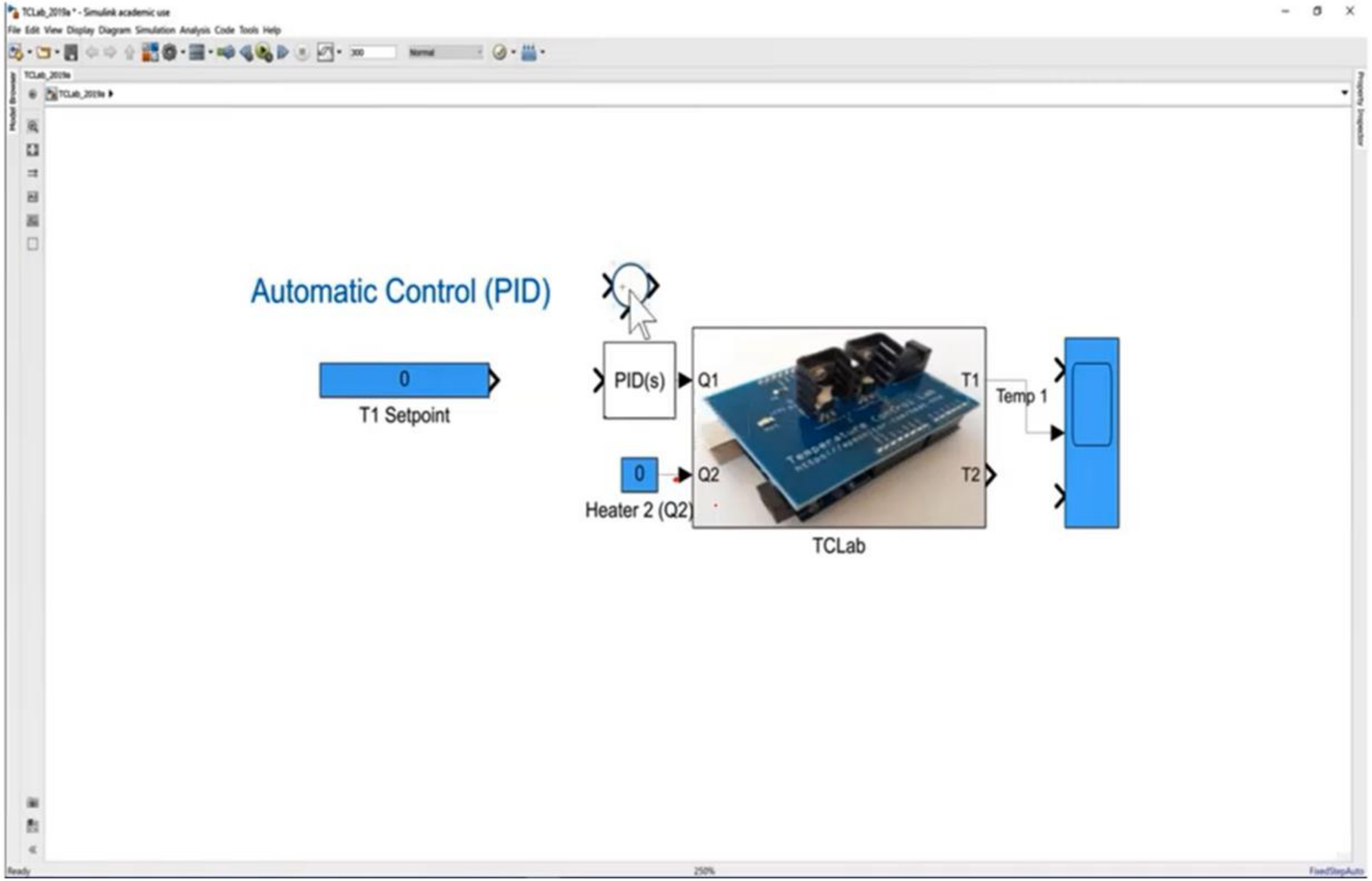
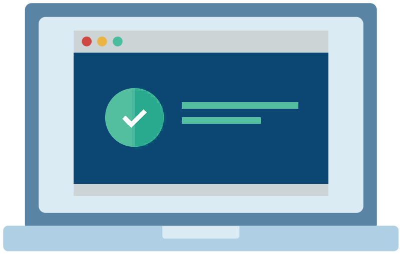
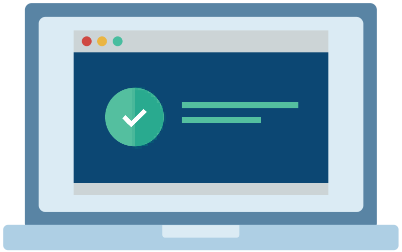


Lessons Learned from Teaching Online



Short Term

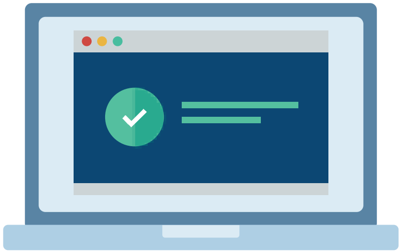
Lessons Learned from Teaching Online



Short Term

Long Term

Lessons Learned from Teaching Online

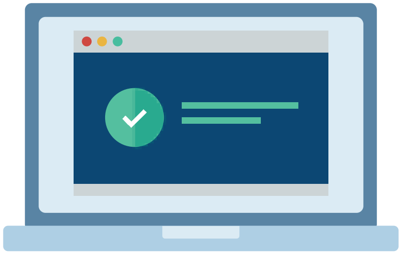


Short Term

Long Term

- Expand on the experience of the physical lab by using a hybrid teaching approach

Lessons Learned from Teaching Online



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- There are opportunities to enable students and instructors over larger geographical distances and of different backgrounds

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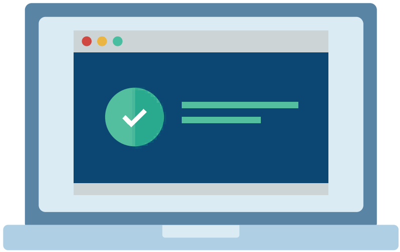

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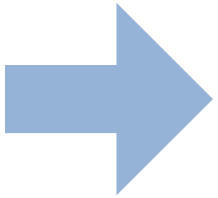
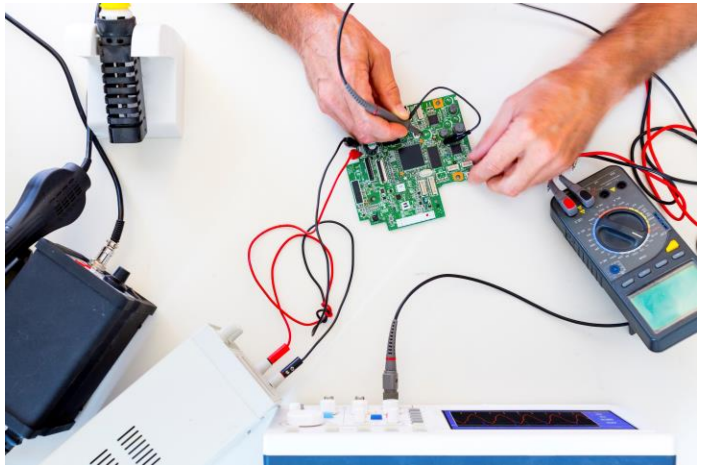


Long Term

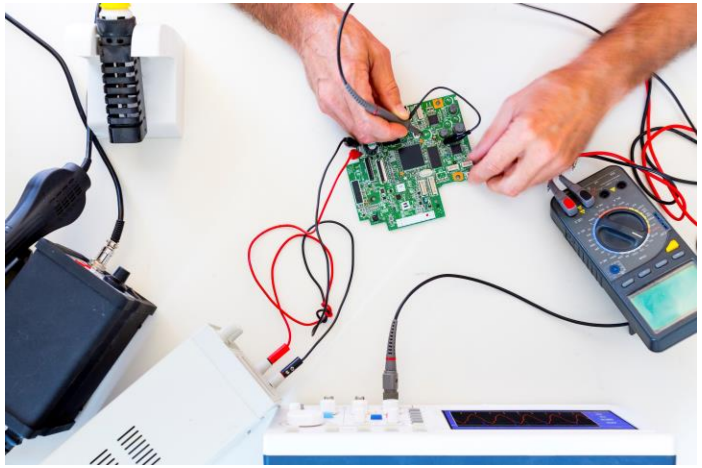
- Expand on the experience of the physical lab by using a hybrid teaching approach
- There are opportunities to enable students and instructors over larger geographical distances and of different backgrounds
- Extend access to more students and for more time

Constraints on University Labs



Physical Laboratory Space

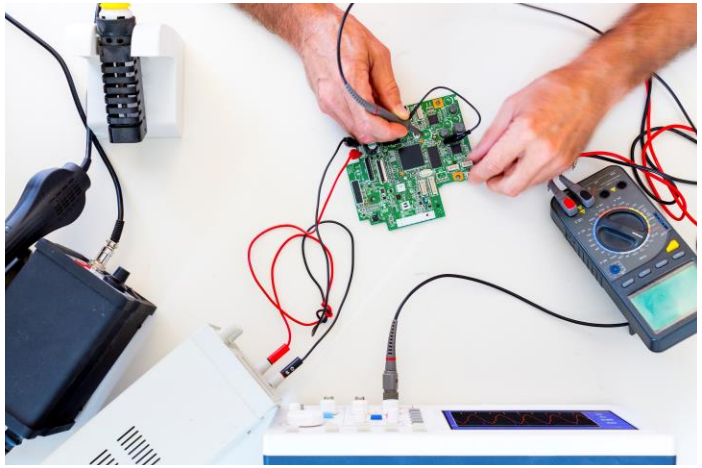
Constraints on University Labs



Physical Laboratory Space

Competition for Scheduling

Constraints on University Labs

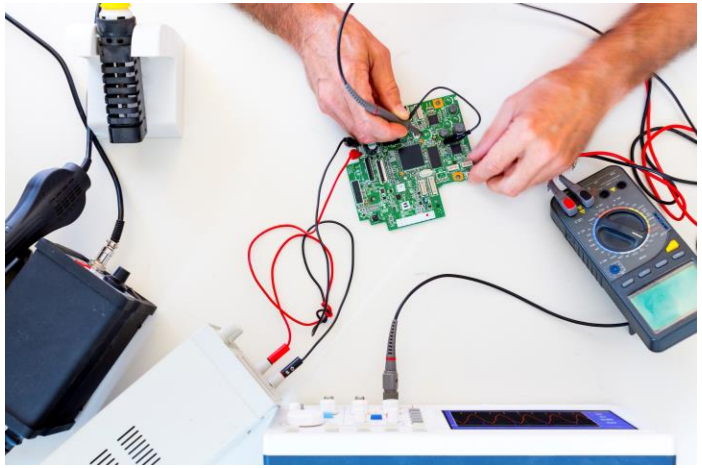


Physical Laboratory Space

Competition for Scheduling

Teaching and Research Needs

Constraints on University Labs



Physical Laboratory Space

Competition for Scheduling

Teaching and Research Needs

- **Address these challenges by improving access:**
  - Complement existing lab activities
  - Expand the potential learning outcomes
  - Extend laboratory contact time for students

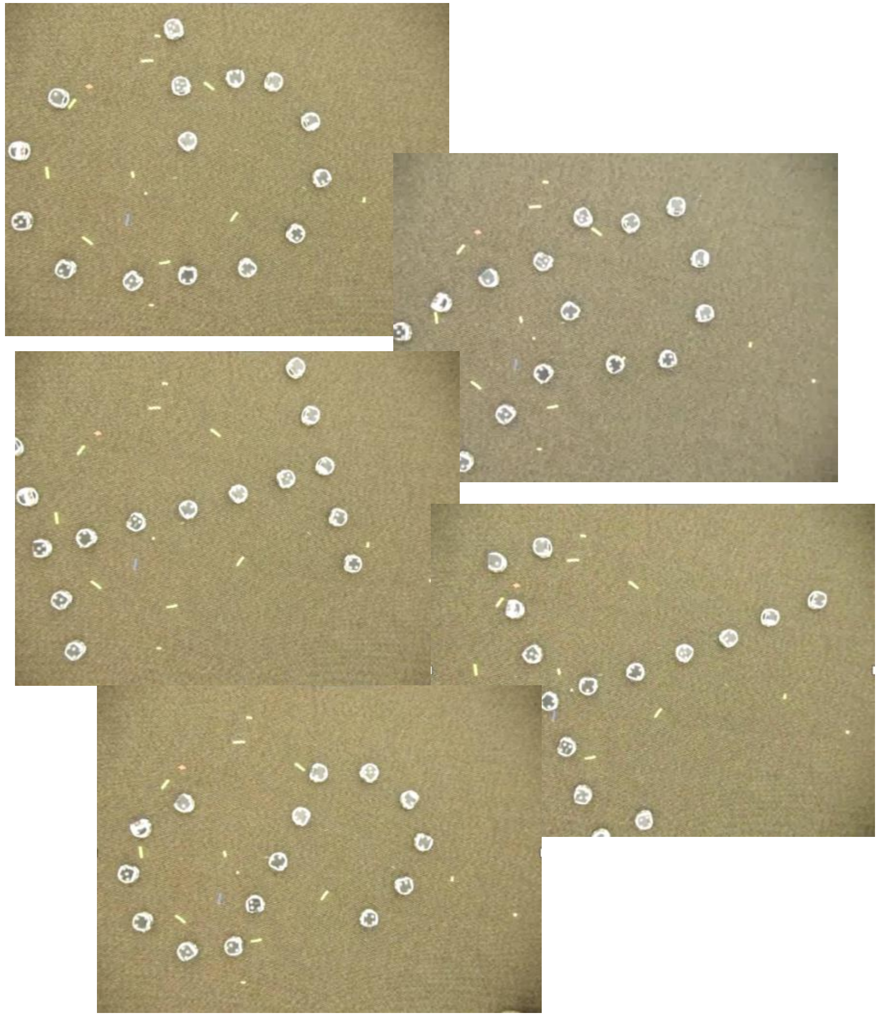
MATLAB EXPO 2021

Remotely Accessible Research in Georgia Tech's Robotarium

Magnus Egerstedt, Georgia Institute of Technology

Georgia Tech School of Electrical and Computer Engineering
College of Engineering

Backdrop: Swarm Robotics



Backdrop: Swarm Robotics

Barrier to entry:

- Resource intense

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Barrier to entry:

- Resource intense

Speedbumps:

- Duplication of effort
- Underutilized labs
- Hard to compare, leverage, and collaborate

A Solution: The Robotarium

- Overarching vision: an open, remote-access swarm robotics testbed!

MRI: A Shared, Remote-Access Multi-Robot Laboratory

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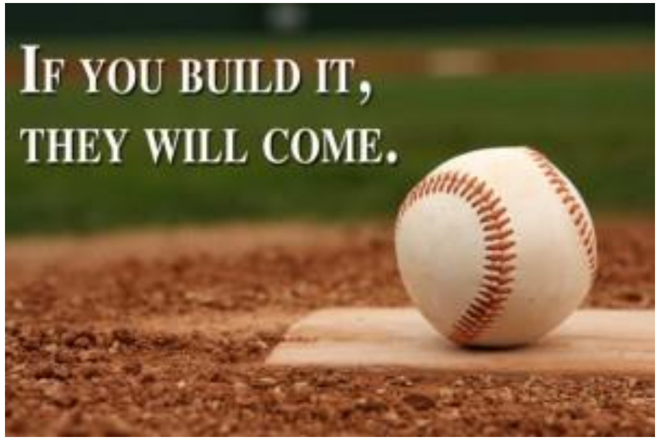
Remote Access Research?



Remote Access Research?

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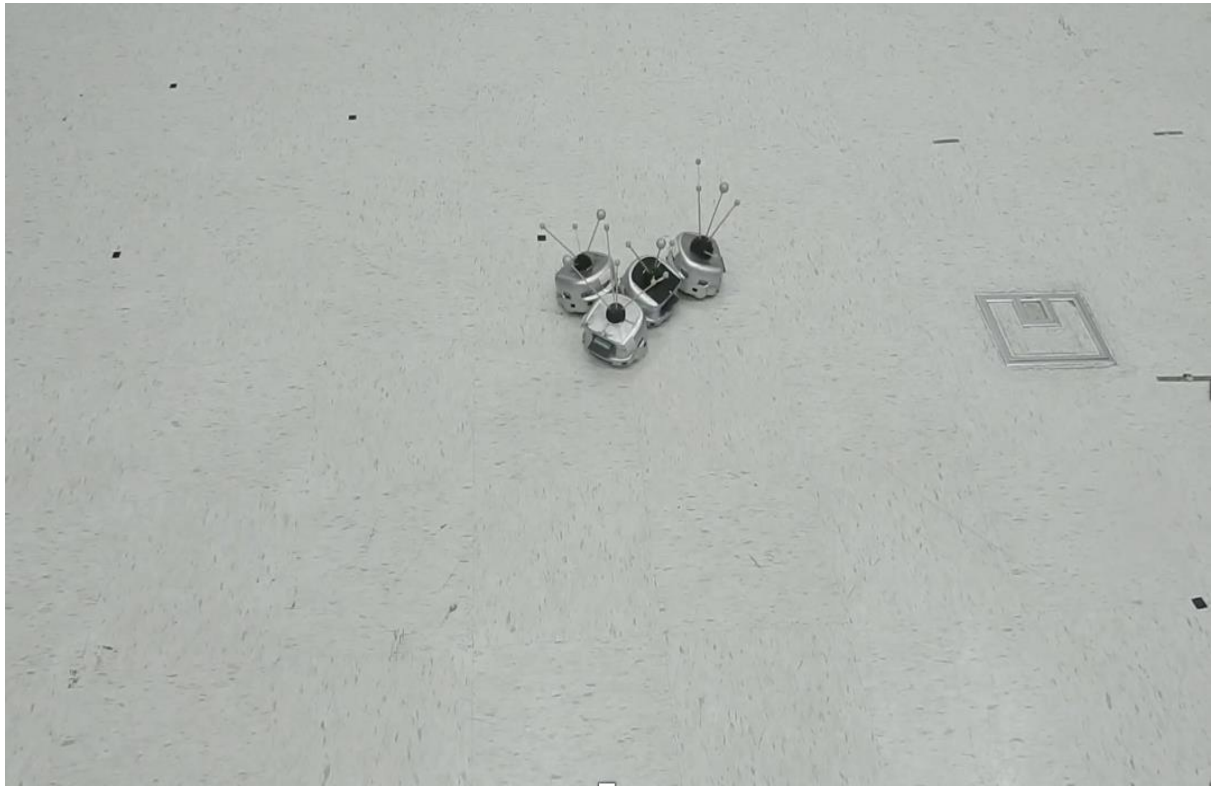

- Security?
- Research vs. Education?
- Funding Models?

M. Egerstedt and M. Govindarasu. NSF Report on Accessible remote testbeds: Opportunities, challenges, and lessons learned. 2015.

Collision-Avoidance

Hasn't This Already Been Done?

"collision avoidance"

About 323,000 results (0.06 sec)

The dynamic window approach to collision avoidance
D Fox, W Burgard, S Thrun - IEEE Robotics & Automation …, 1997 - ieeexplore.ieee.org
This approach, designed for mobile robots equipped with synchro-drives, is derived directly from the motion dynamics of the robot. In experiments, the dynamic window approach safely controlled the mobile robot RHINO at speeds of up to 95 cm/sec, in populated and dynamic …
Cited by 2048 Related articles All 37 versions

Aircraft trajectory planning with collision avoidance using mixed integer linear programming
A Richards, JP How - American Control Conference, 2002 …, 2002 - ieeexplore.ieee.org
Describes a method for finding optimal trajectories for multiple aircraft avoiding collisions. Developments in spacecraft path-planning have shown that trajectory optimization including **collision avoidance** can be written as a linear program subject to mixed integer constraints …
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Reciprocal *n*-Body Collision Avoidance
J Van Den Berg, SJ Guy, M Lin, D Manocha - Robotics research, 2011 - Springer
In this paper, we present a formal approach to reciprocal n-body **collision avoidance**, where multiple mobile robots need to avoid collisions with each other while moving in a common workspace. In our formulation, each robot acts fully independently, and does not …
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[PDF] **Research advances in intelligent collision avoidance and adaptive cruise control**
A Vahidi, A Eskandarian - IEEE transactions on intelligent …, 2003 - cecas.clemson.edu
This paper looks into recent developments and research trends in **collision avoidance**/warning systems and automation of vehicle longitudinal/lateral control tasks. It is an attempt to provide a bigger picture of the very diverse, detailed and highly …
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"obstacle avoidance"

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Real-time obstacle avoidance for manipulators and mobile robots
O Khatib - Autonomous robot vehicles, 1986 - Springer
This paper presents a unique real-time **obstacle avoidance** approach for manipulators and mobile robots based on the artificial potential field concept. Collision avoidance, traditionally considered a high level planning problem, can be effectively distributed between different …
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Real-time obstacle avoidance for manipulators and mobile robots
O Khatib - Robotics and Automation. Proceedings. 1985 IEEE …, 1985 - ieeexplore.ieee.org
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The vector field histogram-fast obstacle avoidance for mobile robots
J Borenstein, Y Koren - IEEE transactions on robotics and …, 1991 - ieeexplore.ieee.org
A real-time **obstacle avoidance** method for mobile robots which has been developed and implemented is described. This method, named the vector field histogram (VFH), permits the detection of unknown obstacles and avoids collisions while simultaneously steering the …
Cited by 2713 Related articles All 33 versions

Real-time obstacle avoidance for fast mobile robots
J Borenstein, Y Koren - IEEE Transactions on systems, Man …, 1989 - ieeexplore.ieee.org
A real-time **obstacle avoidance** approach for mobile robots has been developed and implemented. It permits the detection of unknown obstacles simultaneously with the steering of the mobile robot to avoid collisions and advance toward the target. The novelty of this …
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Related searches

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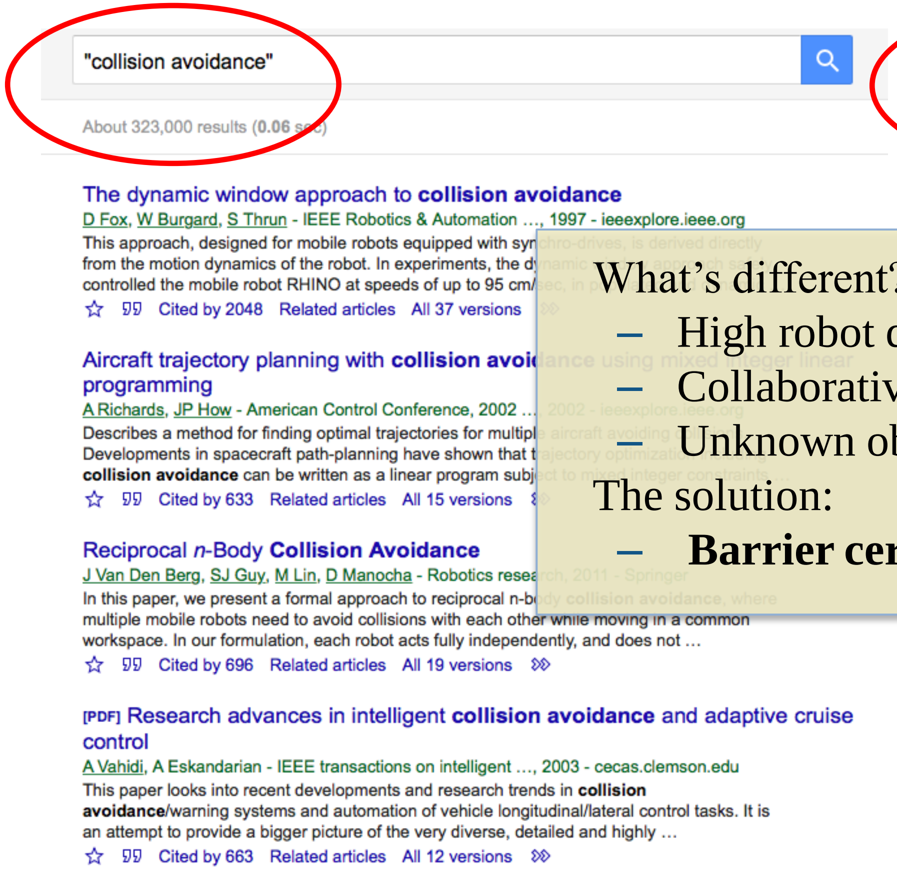

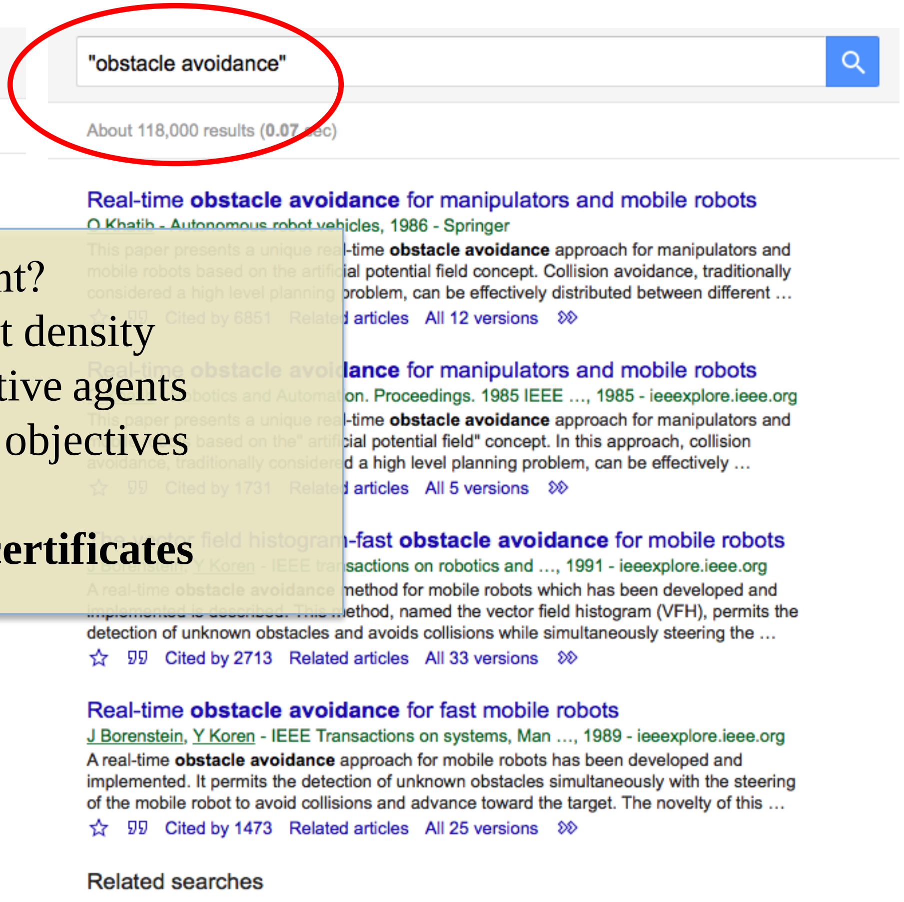

What's different?

- High robot density
- Collaborative agents
- Unknown objectives

The solution:

- **Barrier certificates**

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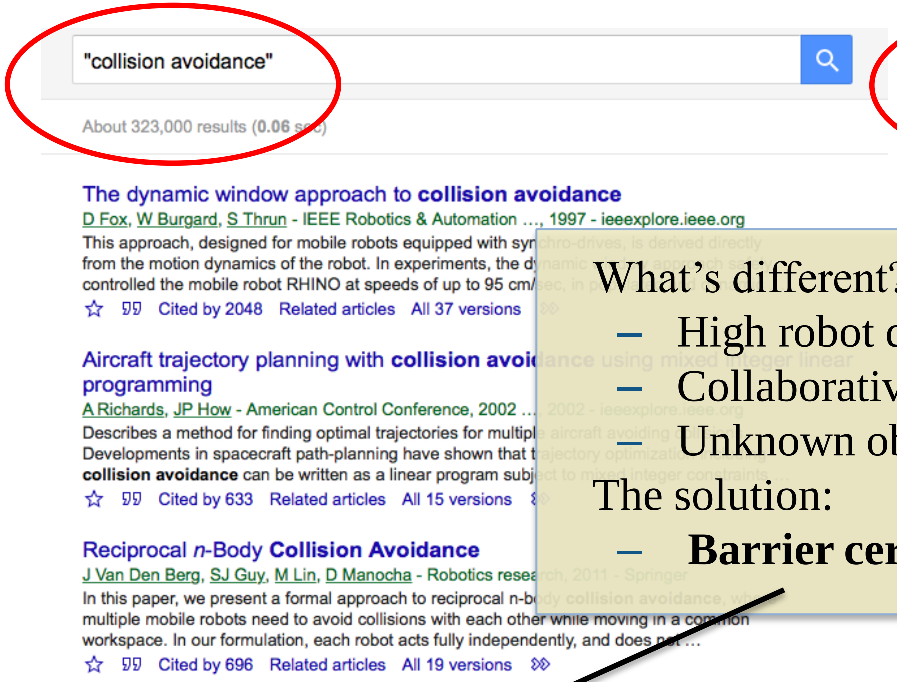

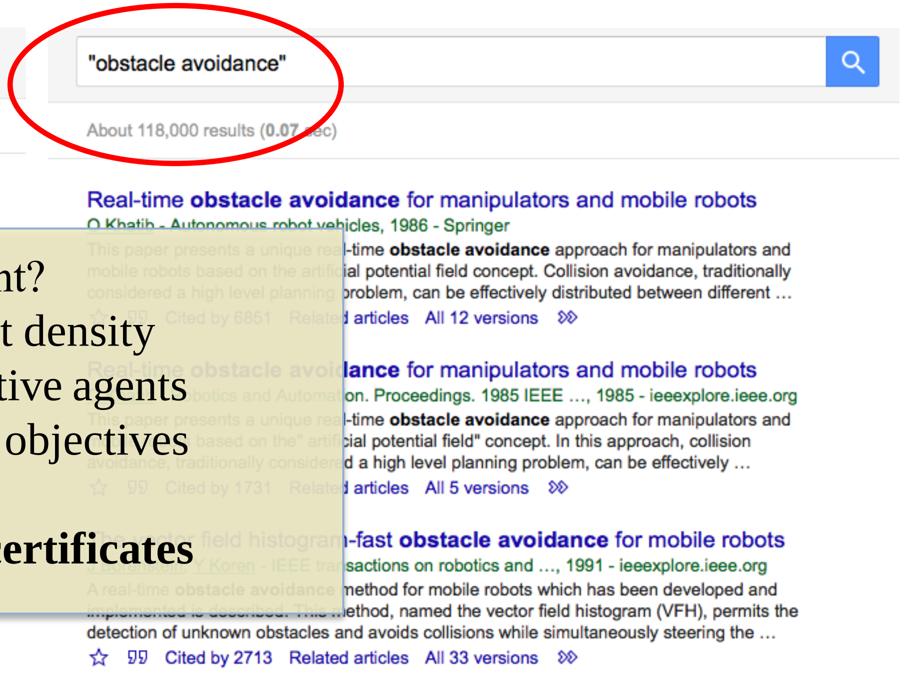

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The solution:

- **Barrier certificates**

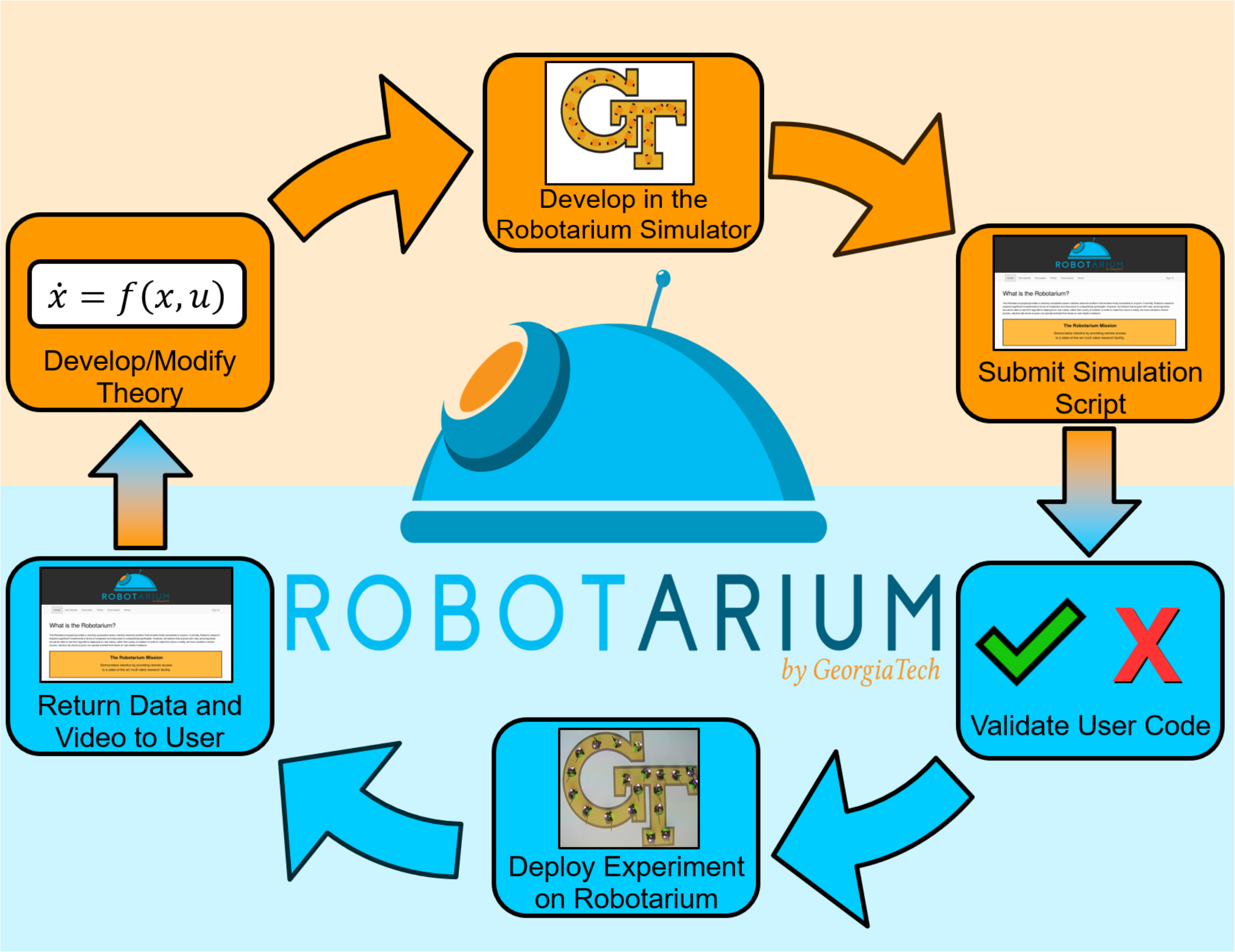
minimize: "**distance**" between actual input and user specified input

subject to: always stay "**safe**"

Wang, Ames, Egerstedt, TRO'17

Robotarium With Safety

Submission Process Using MATLAB



Submission Process Using MATLAB

```
% Set the number of robots used in the experiment
N = 20;

% Set up the Robotarium object
r = Robotarium('NumberOfRobots', N, 'ShowFigure', 'true');

% Set the number of iterations for the experiment. Each time-step
% when deployed on the Robotarium is ~0.033s
iterations = 1000;   % ~30 second experiment

for i = 1:iterations

    % Get the current poses of all the robots
    x_uni = r.get_poses();

    % Convert to single integrator dynamics
    x = uni_to_si(x_uni);

    %%% MAIN CODE GOES HERE %%%
    %%%
    %%% produces velocities dx
    %%%

    % Map to unicycle control inputs
    dx_uni = si_to_uni_dym(dx, x);

    % Set the velocities of the robots
    r.set_velocities(1:N, dx_uni);

    % Send the velocity commands to the robots
    r.step();

end

r.debug();   % Prints errors that can cause the submission to be rejected
```

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% Set up the Robotarium object
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for i = 1:N

    % Initialize velocity to zero for each agent.
    dx(:, i) = [0 ; 0];

    % Get the topological neighbors of agent i based on the graph
    % Laplacian L
    neighbors = r.getTopNeighbors(i, L);

    % Iterate through agent i's neighbors
    for j = neighbors

        %%% CONSENSUS %%%

        % For each neighbor, calculate appropriate consensus term and
        % add it to the total velocity
        dx(:, i) = dx(:, i) + (x(1:2, j) - x(1:2, i));

        %%% END CONSENSUS %%%

    end
end
    % Send the velocity commands to the robots
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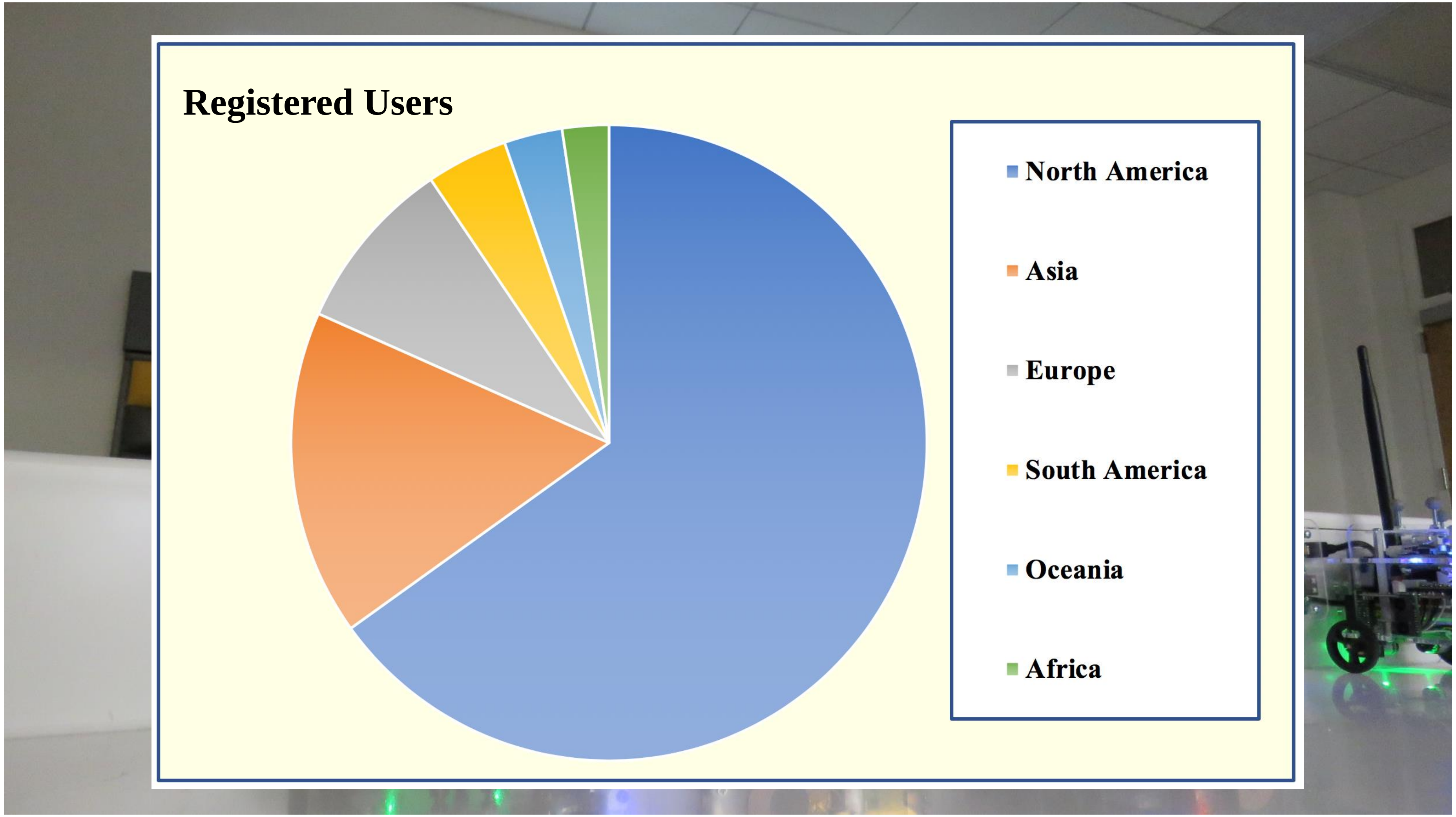

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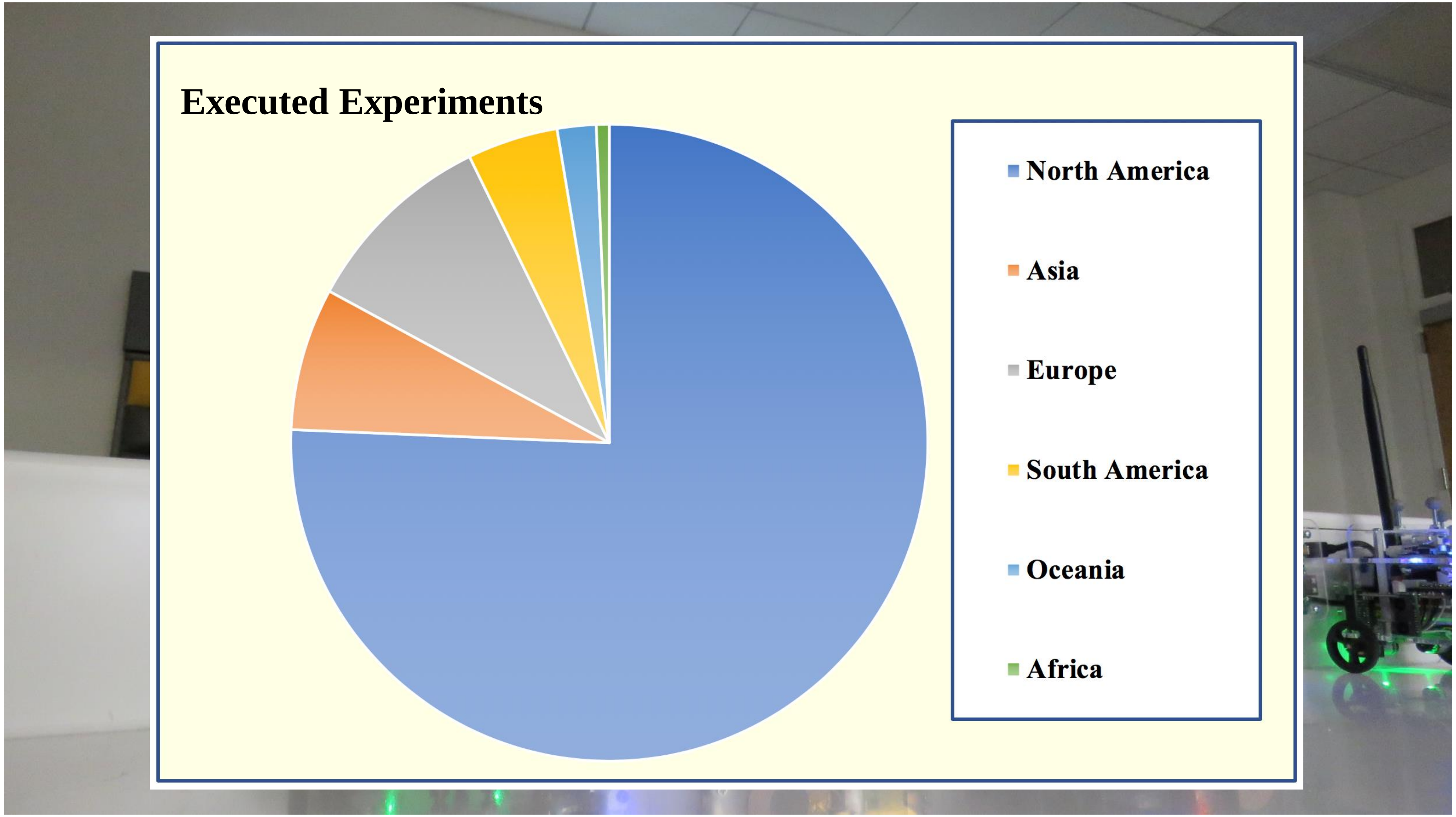
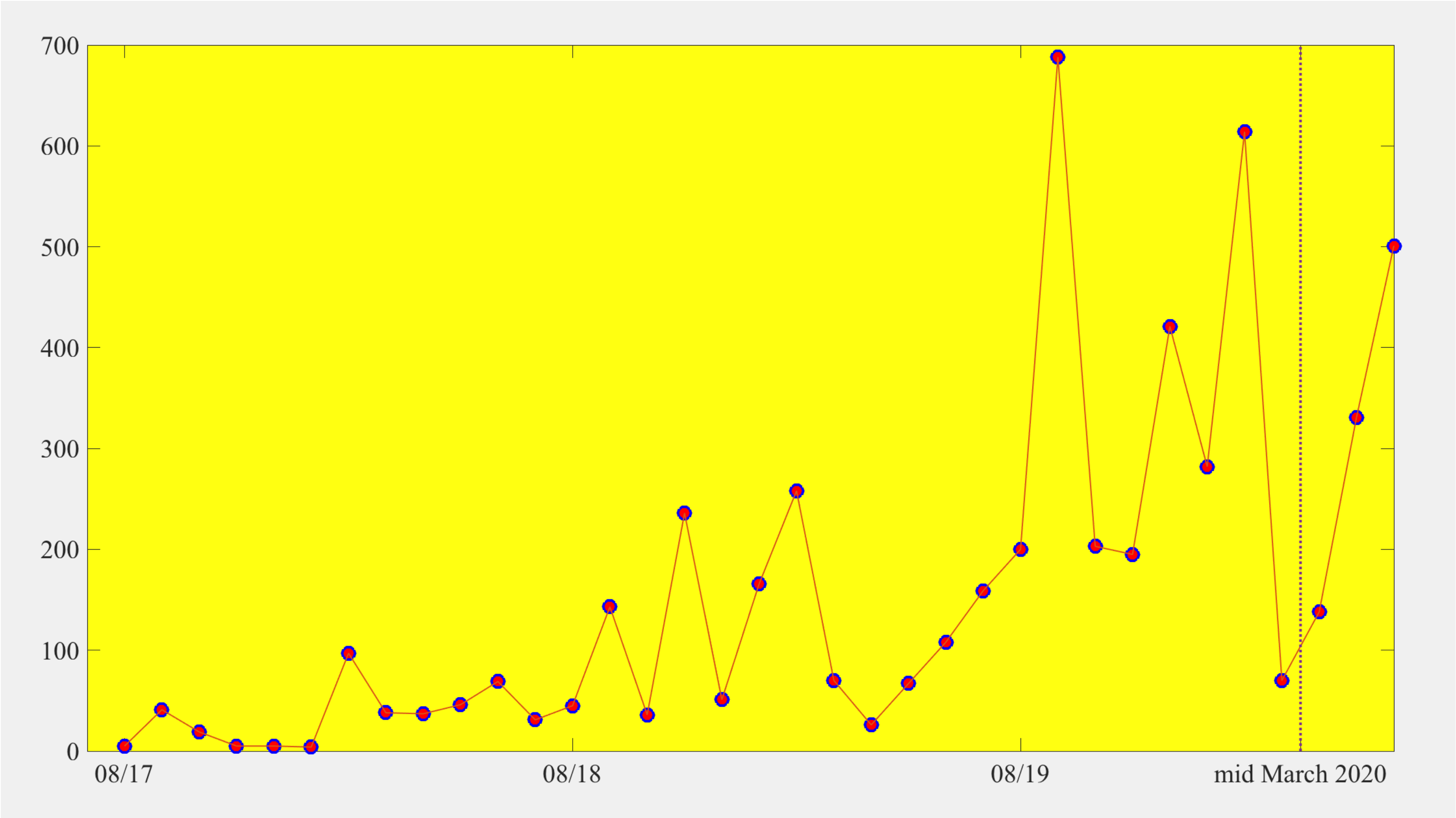


During the Pandemic – Critical Activity



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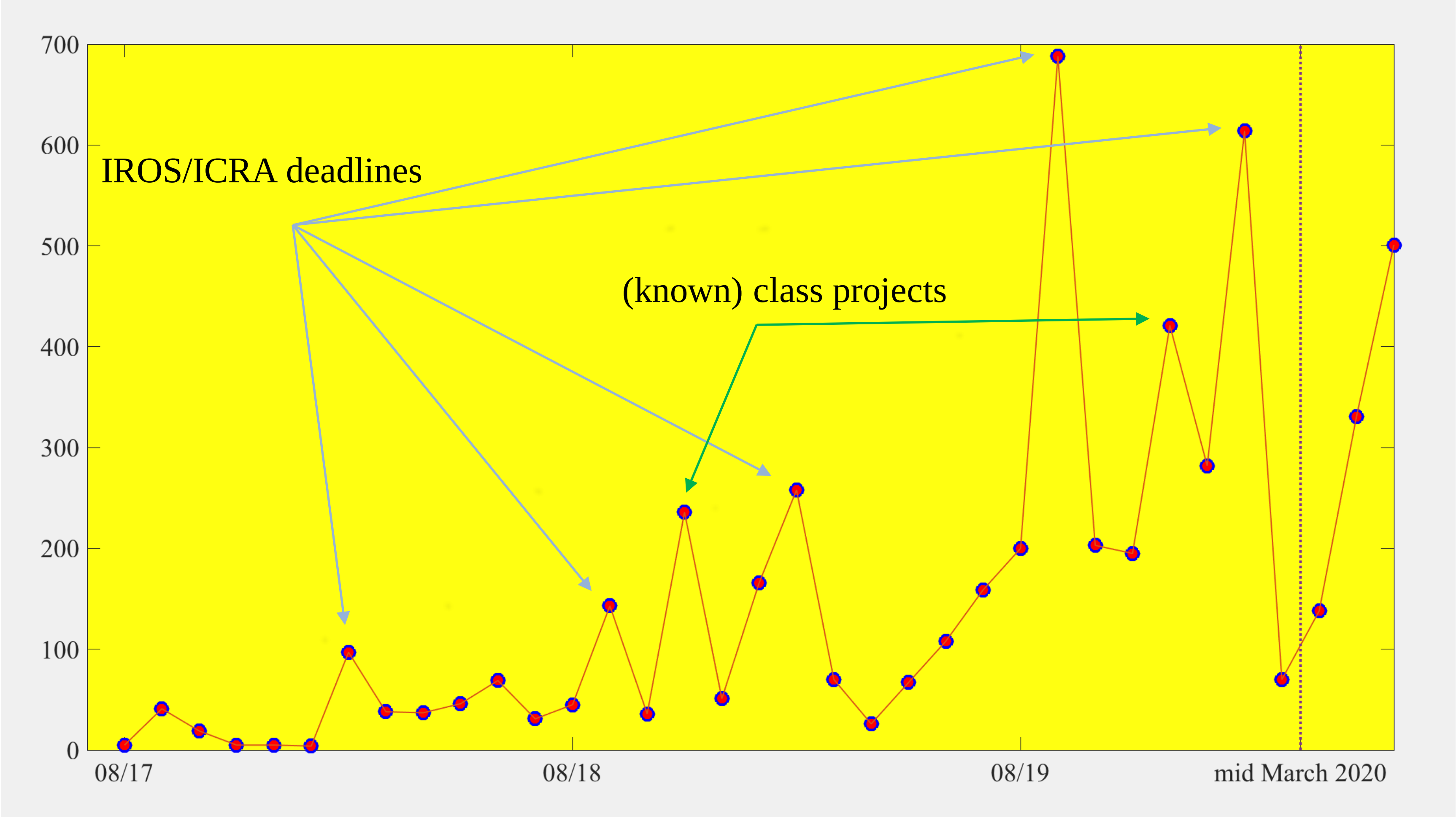
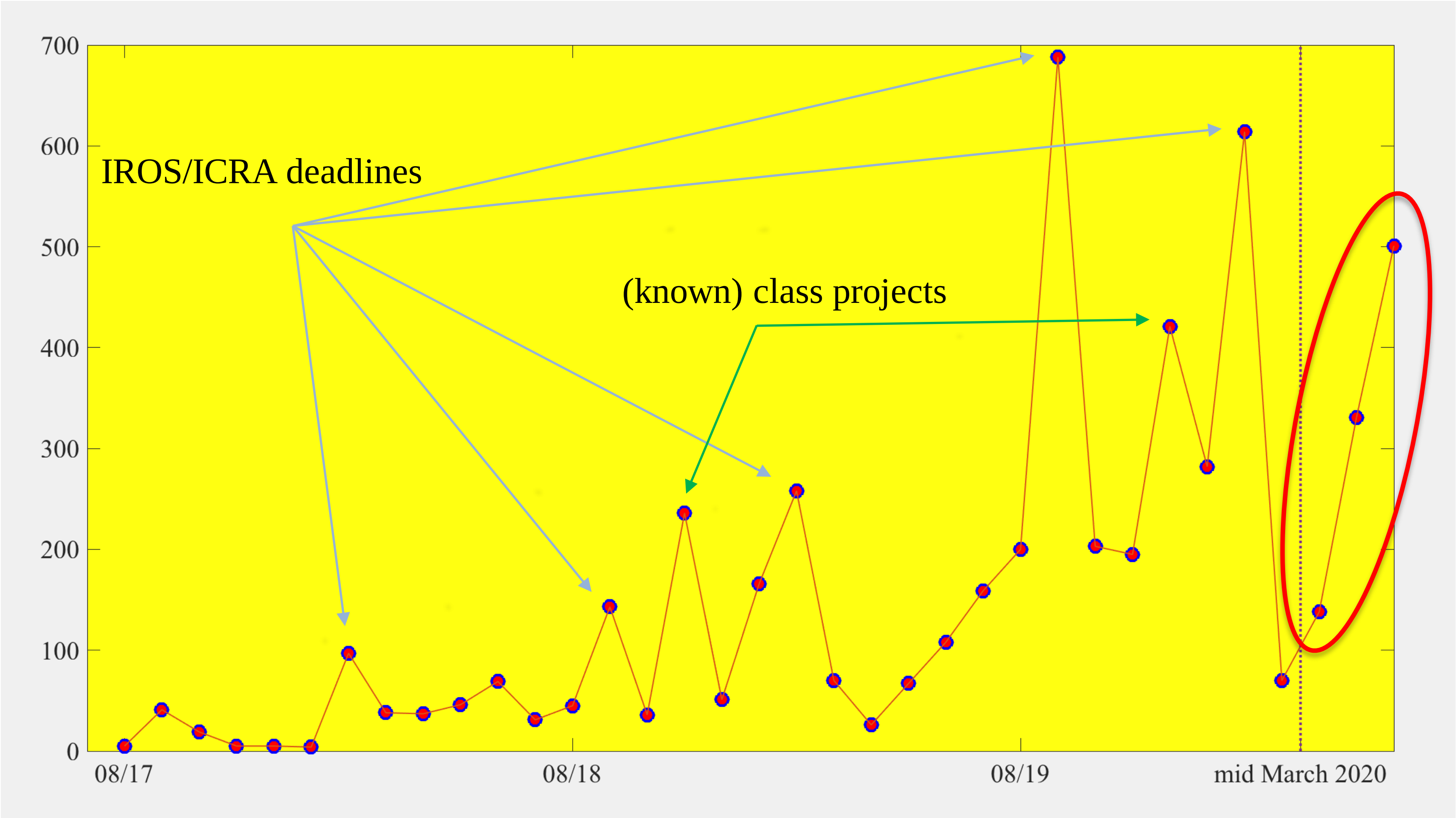


During the Pandemic – Critical Activity



Making Lemonade

- 20+ submissions/day since mid March

- Federation of remote labs
- Lessons learned – translations to other labs/domains

- ***Democratized access to world-class lab***: girl scout troops, public high schools, labs in Africa and South America, robotics hackaton in Nepal

Thank You

ROBOTARIUM
by GeorgiaTech

MathWorks

robotarium.gatech.edu


Daniel Pickem


Li Wang


Yancy Diaz


Smriti Chopra


JP de la Croix


Amy LaViers


Rowland O’Flaherty


Aaron Ames


Eric Feron


Raheem Beyah

Educators

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Virtual Labs and Projects with MATLAB and Simulink

You can bring interactive labs to your online courses to enable student participation and active learning. Use MATLAB and Simulink to build engaging virtual labs by incorporating modeling and simulation.

See how Mondragon University used MATLAB and Simulink to model a laboratory turbine and other system components.

"Simulation with Simulink is a valuable stepping stone between theory and implementation that saves considerable time and money, particularly when a project involves a turbine or other costly system hardware."

– Carlos García, Mondragon University

Online Laboratories

Use MATLAB and Simulink to teach virtual or remote labs, or teach with hardware kits. As the format of lab activities varies between topics, MATLAB and Simulink contain tools to support your instruction by deploying apps, streaming data from your hardware, and utilizing mobile devices.

Virtual

Simulates a process, test, apparatus, or other activity.

Examples:

- PID Tuner app
- Using simulation in dynamic systems labs at the University of Pittsburgh

Remote

Campus-based hardware is accessed, viewed, or operated.

Examples:

- Analyzing vehicle traffic with ThingSpeak
- Robotarium remote-access robotics lab

Hardware at Home

Students use kits or mobile devices, or collect data.

Examples:

- Arduino Engineering Kit
- Classifying images using deep learning with MATLAB Mobile

Simulate Laboratory Equipment and Processes with Simulink

Create a representative model of your laboratory equipment or processes in a visual environment with Simulink. Add components to your model to introduce new course concepts. Simulink can also help students derive and understand the system-level equations used in your course assignments.

Run simulations of your hardware or system to demonstrate behavior to students. Simulations can be accompanied by graphical outputs and 3D animations to help facilitate student understanding. Results can be exported to MATLAB for further analysis during lectures, homework, and future labs. Virtualizing labs also enables you to augment courses that do not have devoted laboratory space or scheduled time and avoid physical hardware limitations.

See how the University of Toronto used Simulink to model reconfigurable industrial robots.

"With MATLAB and Simulink we developed a low-cost design and simulation environment that enables students to apply theoretical aspects of kinematics, dynamics, and controls of robot manipulators in a realistic way, optimize their designs, and see those designs in action."

– Dr. Reza Emami, University of Toronto

Have you had success building virtual labs with MATLAB and Simulink?

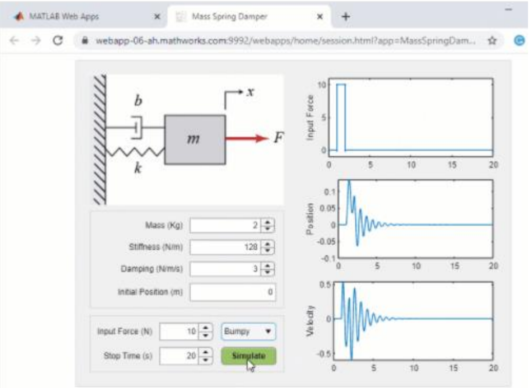
Share your experience with our Distance Learning Community.

Build Your Own Lab Interfaces

MATLAB and Simulink support the construction of user interfaces to customize virtualized lab environments. Use existing apps inside MATLAB and Simulink as the basis for a virtual laboratory or create your own using App Designer.

MATLAB apps allow your students to experiment and learn engineering concepts without focusing on the code or software-specific skills. Students interact with apps within MATLAB or MATLAB Online. Apps can be shared in a browser with MATLAB Web App Server.

Watch video: MATLAB Apps (1:45)



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MATLAB EXPO 2021

Thank you

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