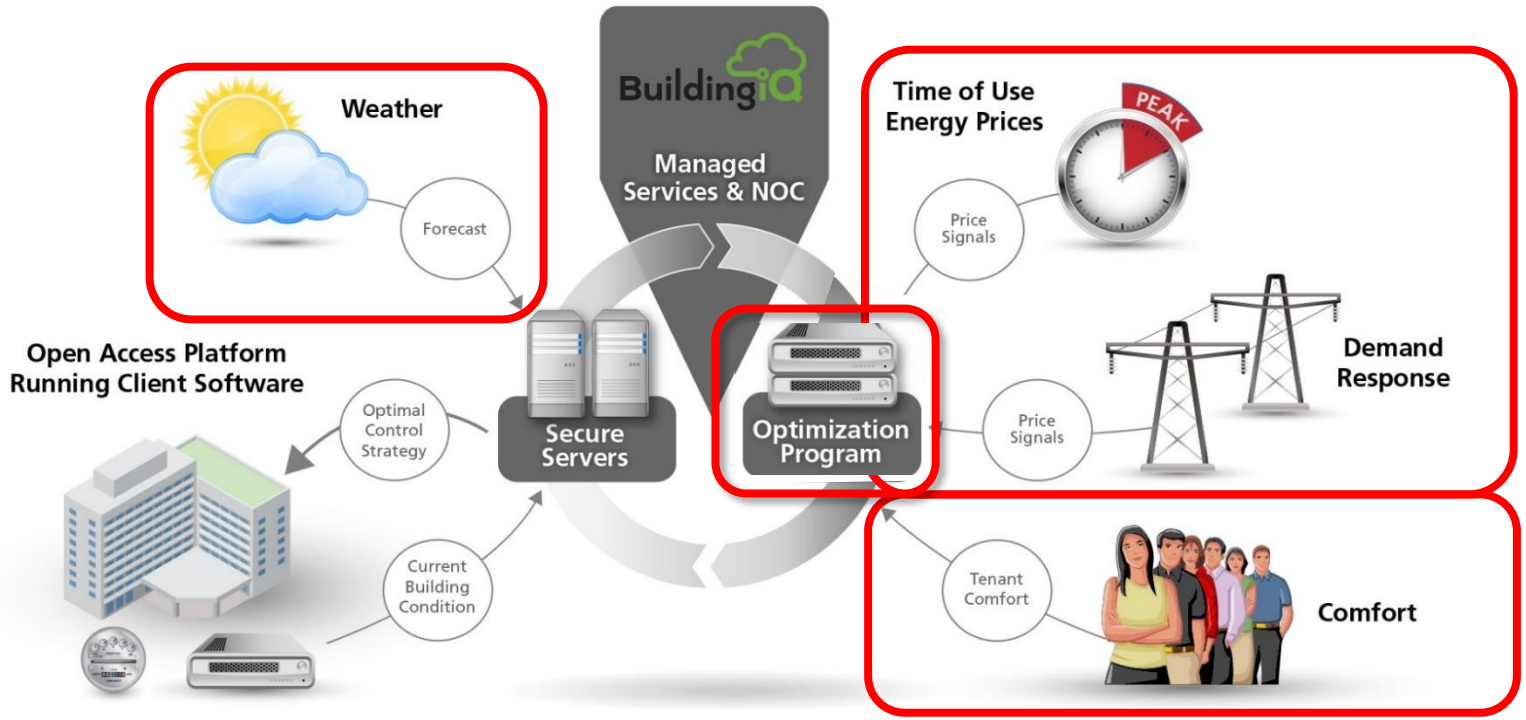
Education Master Class

Preparing Future Engineers and Scientists for the Challenges of Digital Transformation

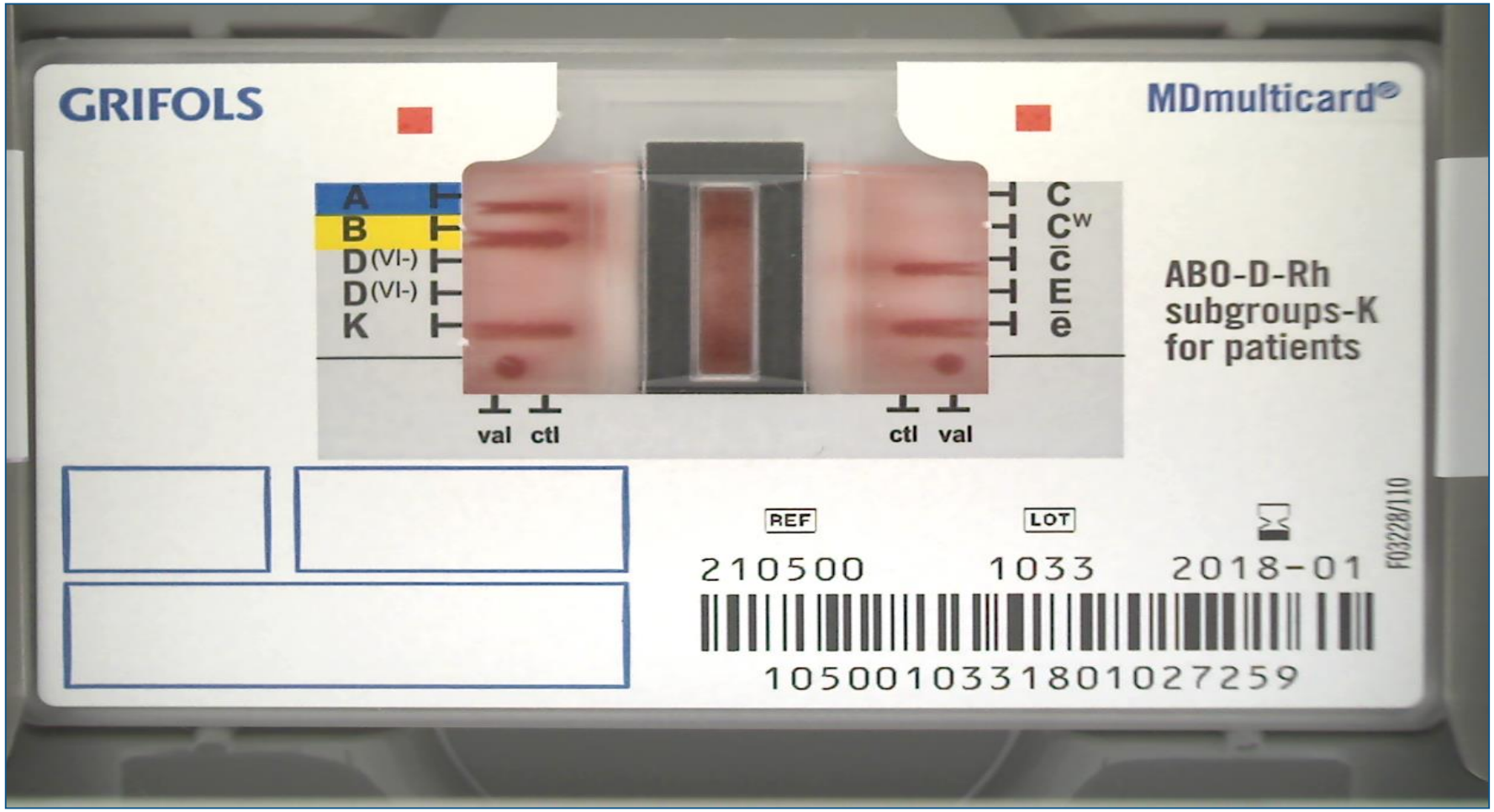
Jim Tung

BuildingIQ



What it does?
SAVES ENERGY

Embedded Algorithms for Interpreting Blood Type Results

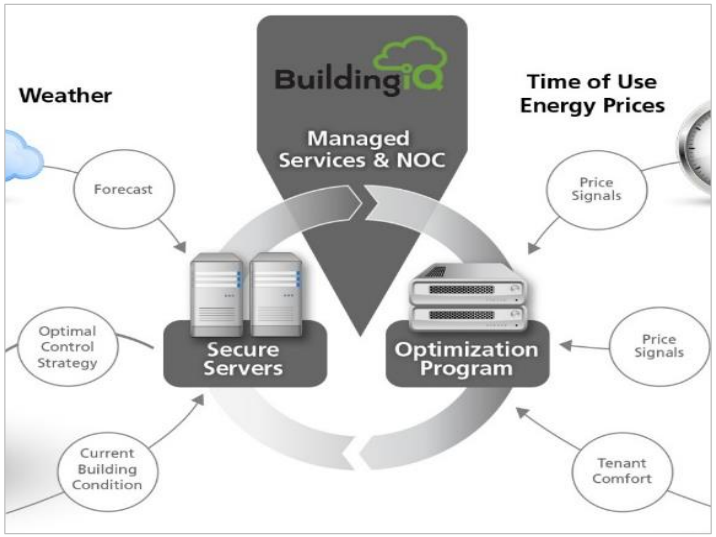


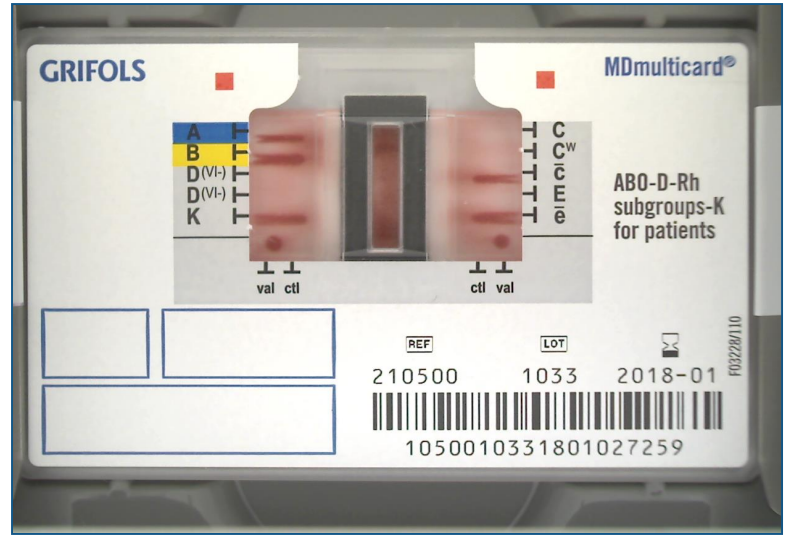
What it does?
SAVES TIME

Augmented reality visualization of blood flow

What it does?
SAVES LIVES

Digital Transformation





Digital Transformation

“Sample-size 1”

- Increasingly individualized products

“Smart products”

- Autonomous machines that do not require costly programming to meet new requirements
- Intelligent products that collect data to optimize processes and develop new products

“Servitization”

- Opportunities for innovative business models and services

What Tomorrow's Engineer Needs to Know

- Algorithms: e.g., Controls, Signal Processing, Optimization, Computer Vision
- Abstraction, Modeling, and Simulation

AND

- Multidomain System Development

AND

- Distributed and Connected Systems
- Using Cloud Platforms and Big Data Processing
- AI and Data Science

Project-Based Learning with MATLAB and Simulink

Treat engineering students like engineers

Hands-on experience of working on hardware and software

Solve authentic problems in myriad contexts

Increase student interest and improve learning

https://www.mathworks.com/hardware-support/home.html

Today's Topics: Three Exercises to Develop That Know-How

Quadcopter Simulation

- Develops Computational Thinking
- Enables comparisons of theory and simulation
- Automatically generates controller code

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Arduino Mobile Rover

- Model-Based Design for autonomous vehicle
- Integrates controls, WiFi, path planning, and localization
- Low-cost hardware

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- Model-Based Design for autonomous vehicle
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Triplex Pump Digital Twin

- Complex industrial application
- Combines engineering and data science
- Can leverage cloud computing
- No hardware required

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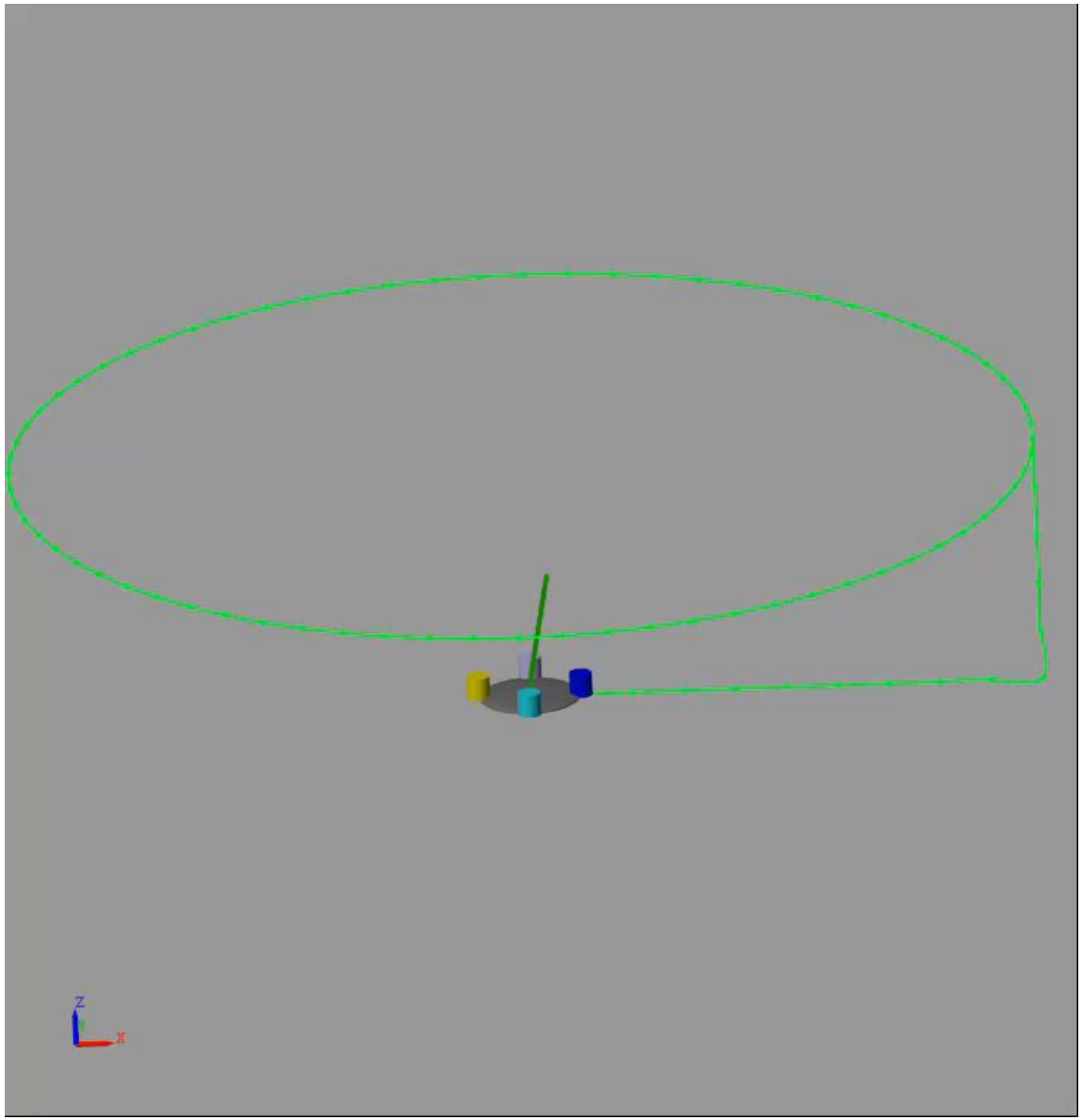
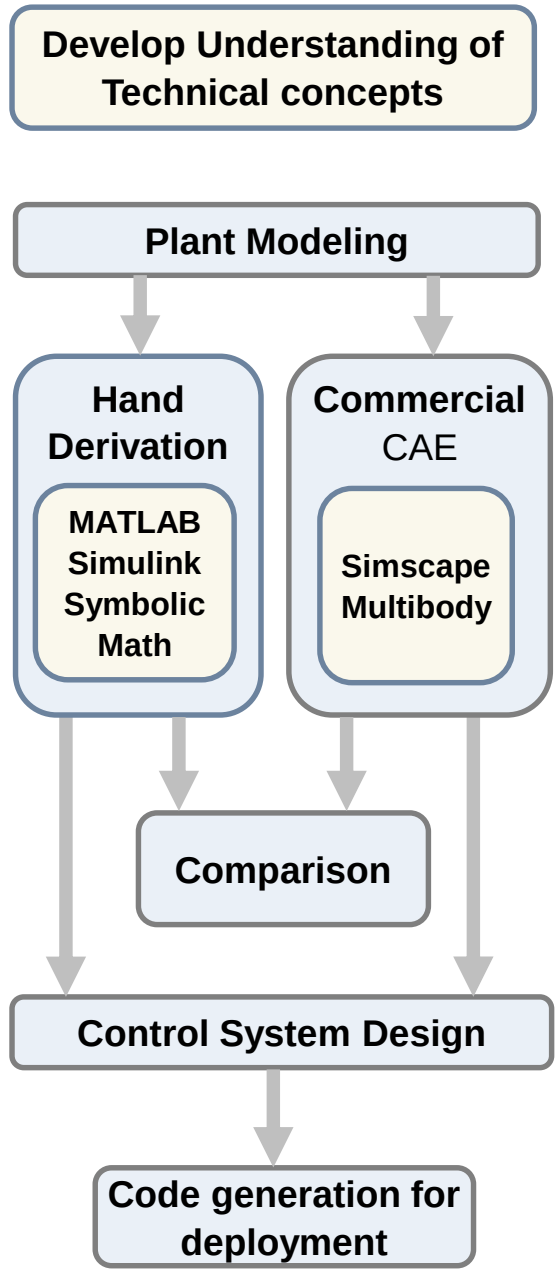
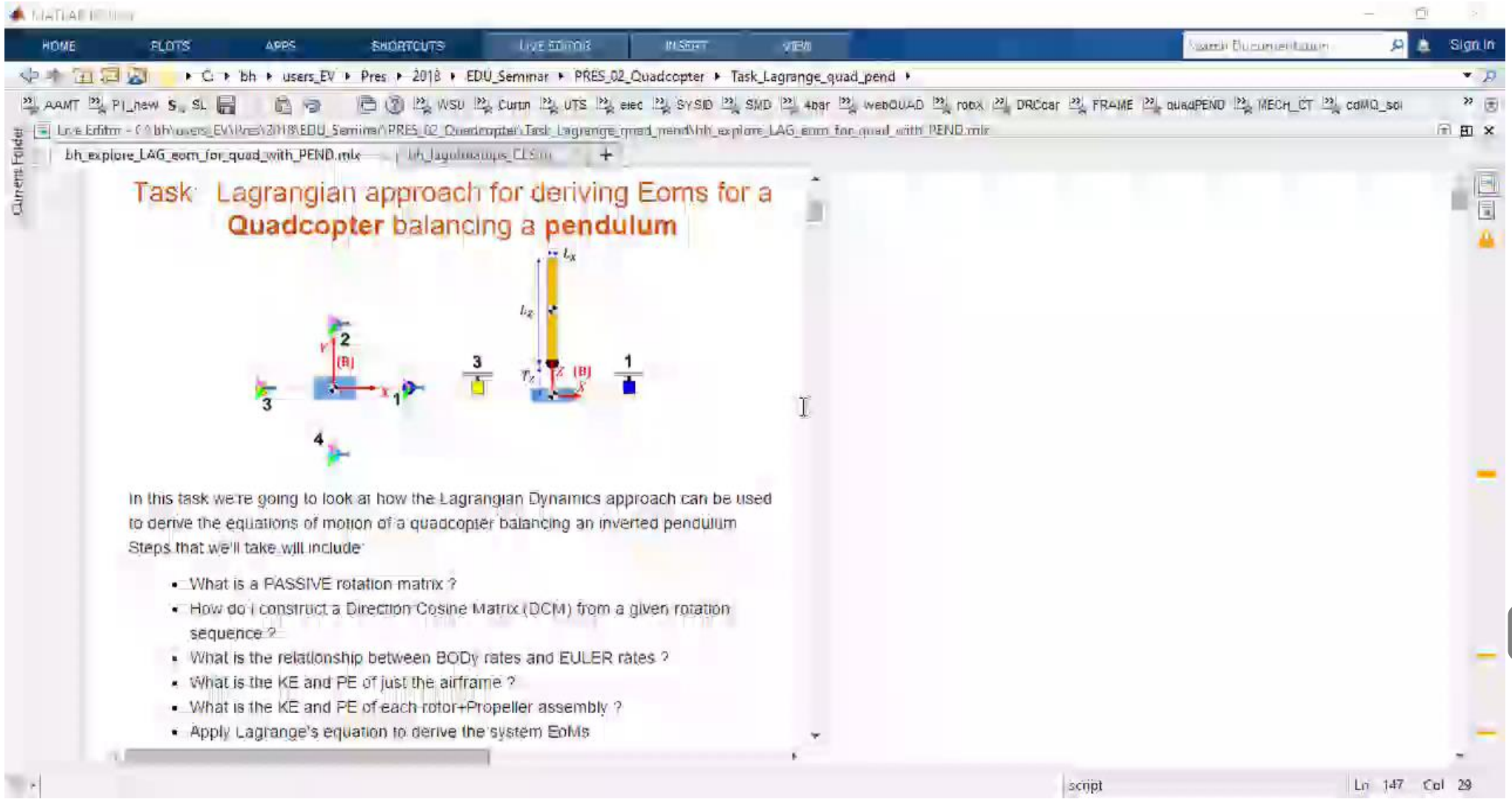
Quadcopter Simulation

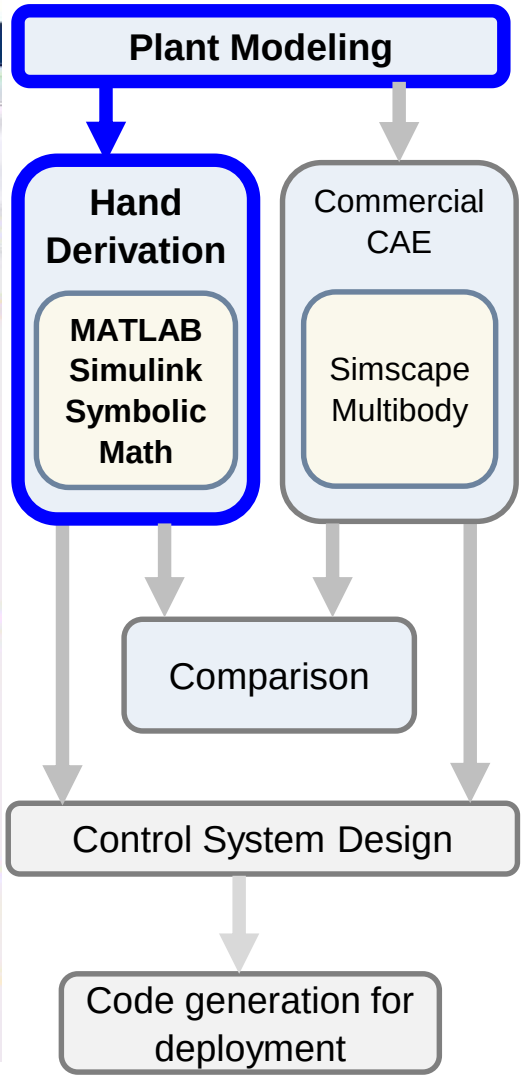




Quadcopter: modeling – part 1

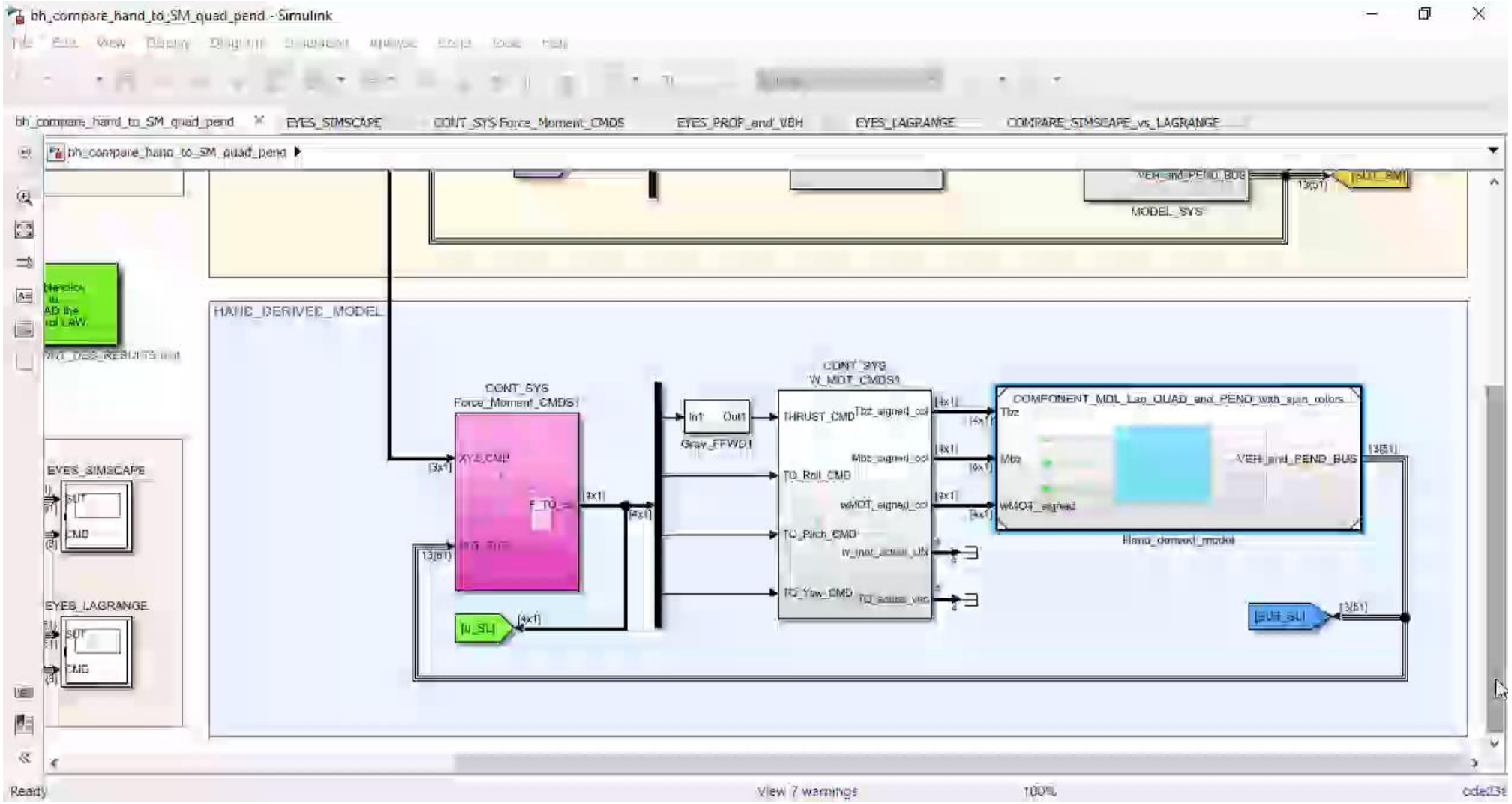
Develop Understanding of Technical concepts

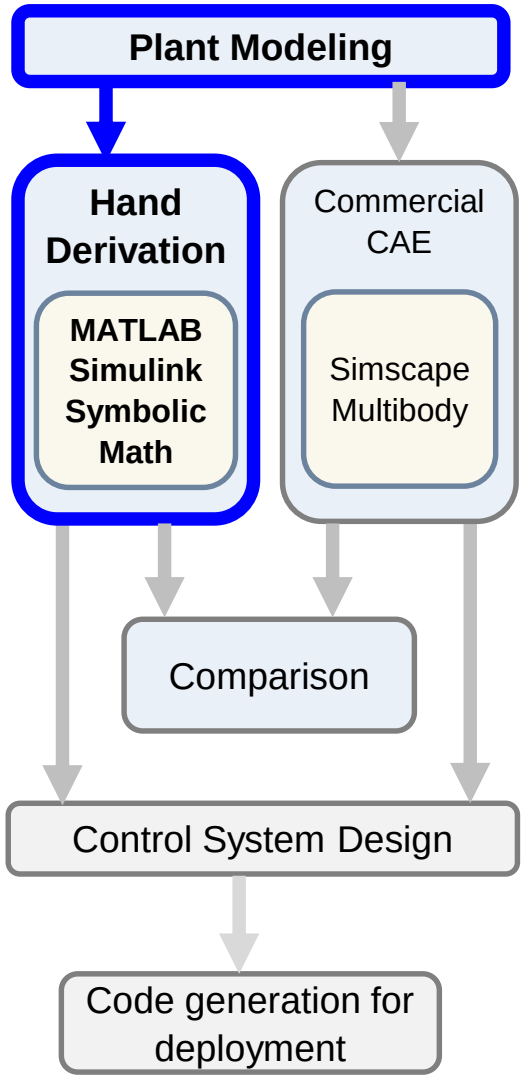




Quadcopter: modeling – part 2

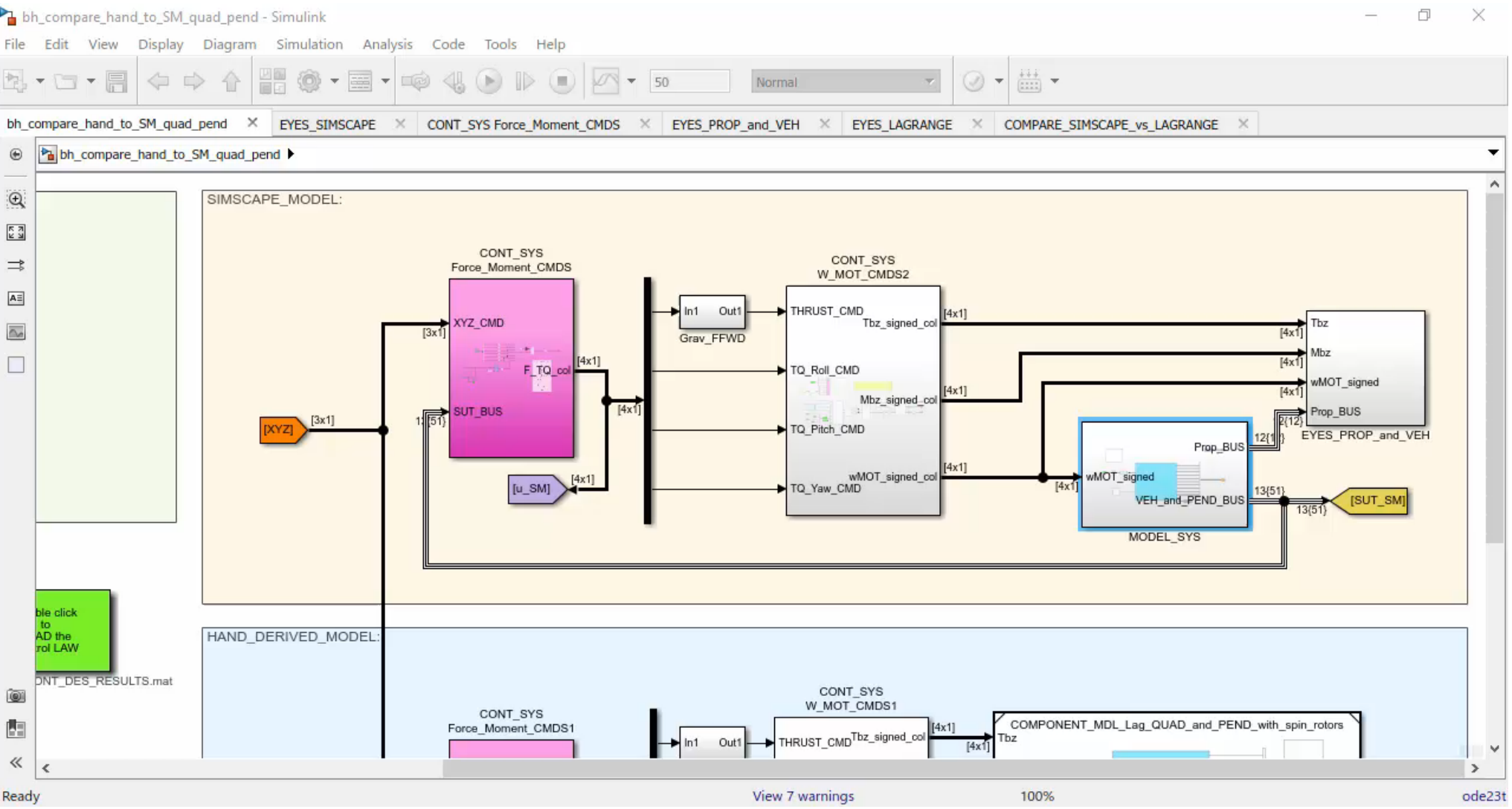
Develop Understanding of Technical concepts

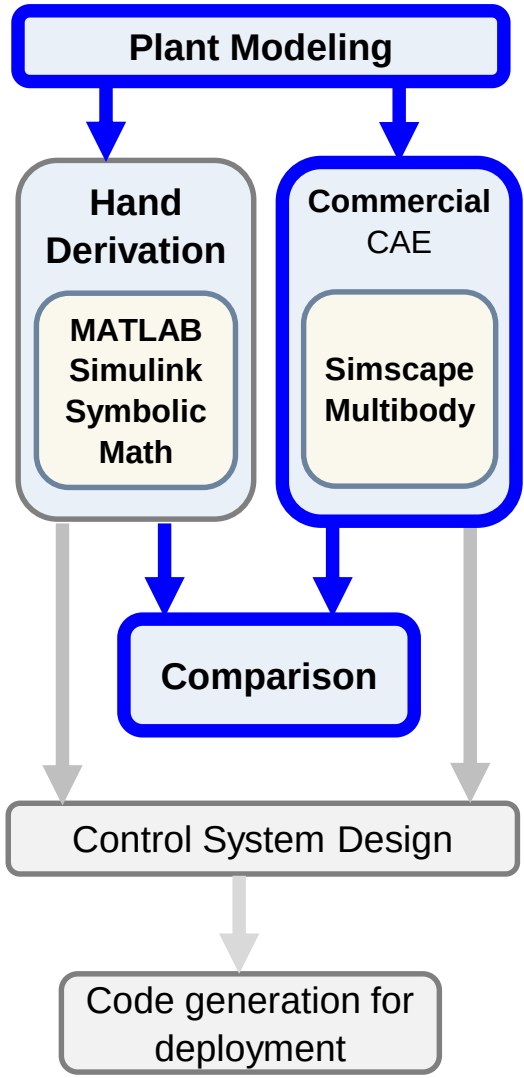




Quadcopter: modeling – part 3

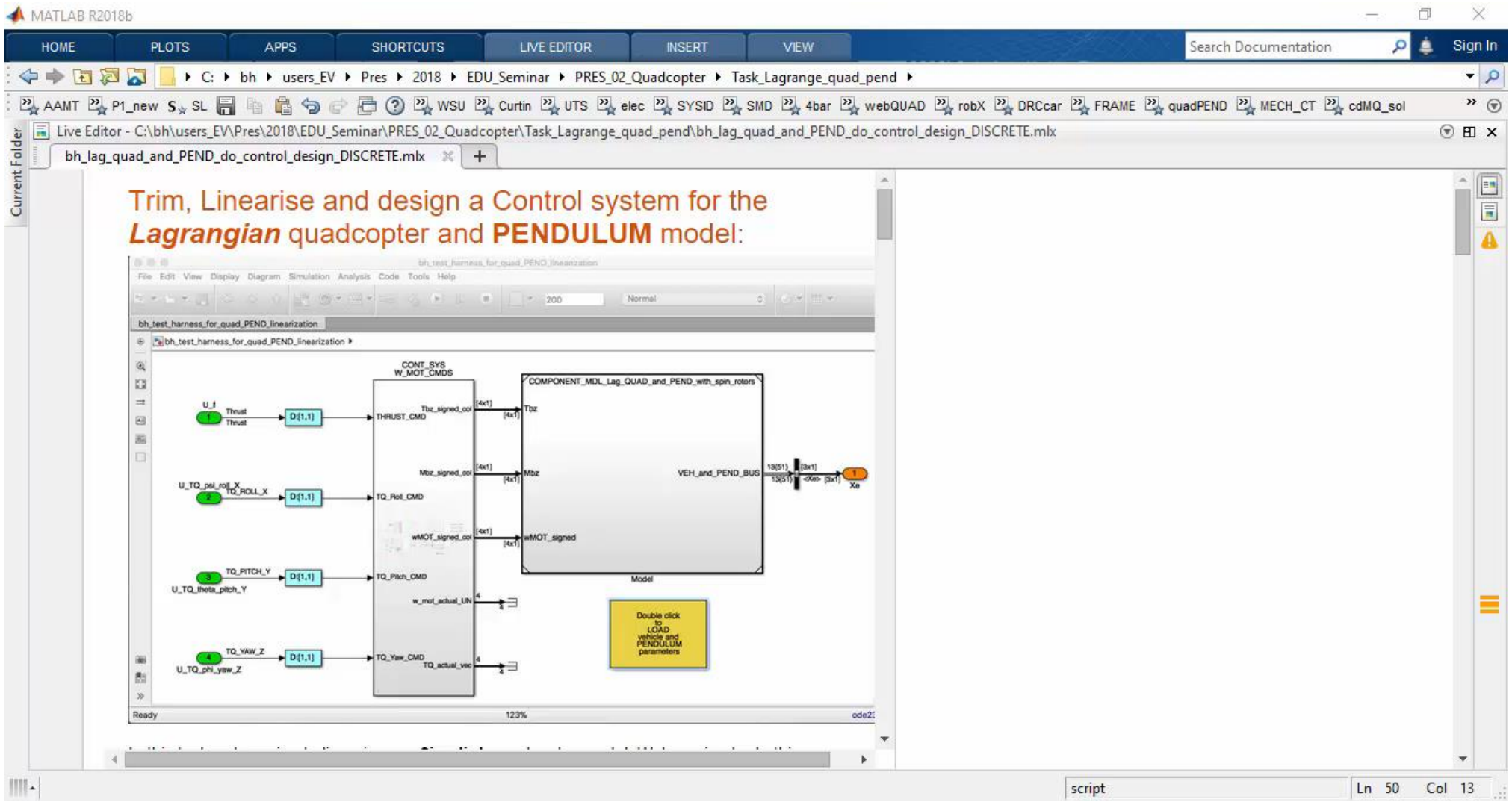
Develop Understanding of Technical concepts

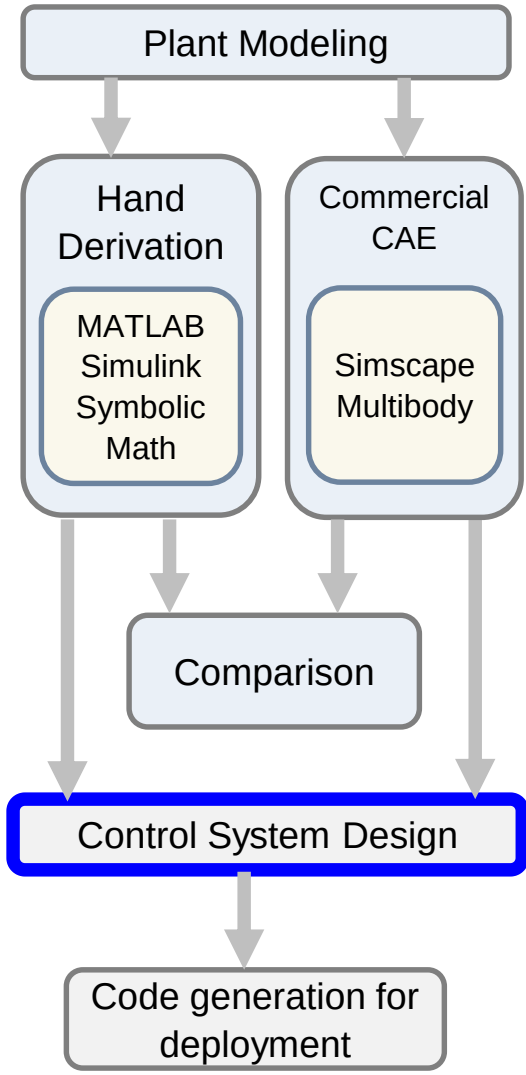




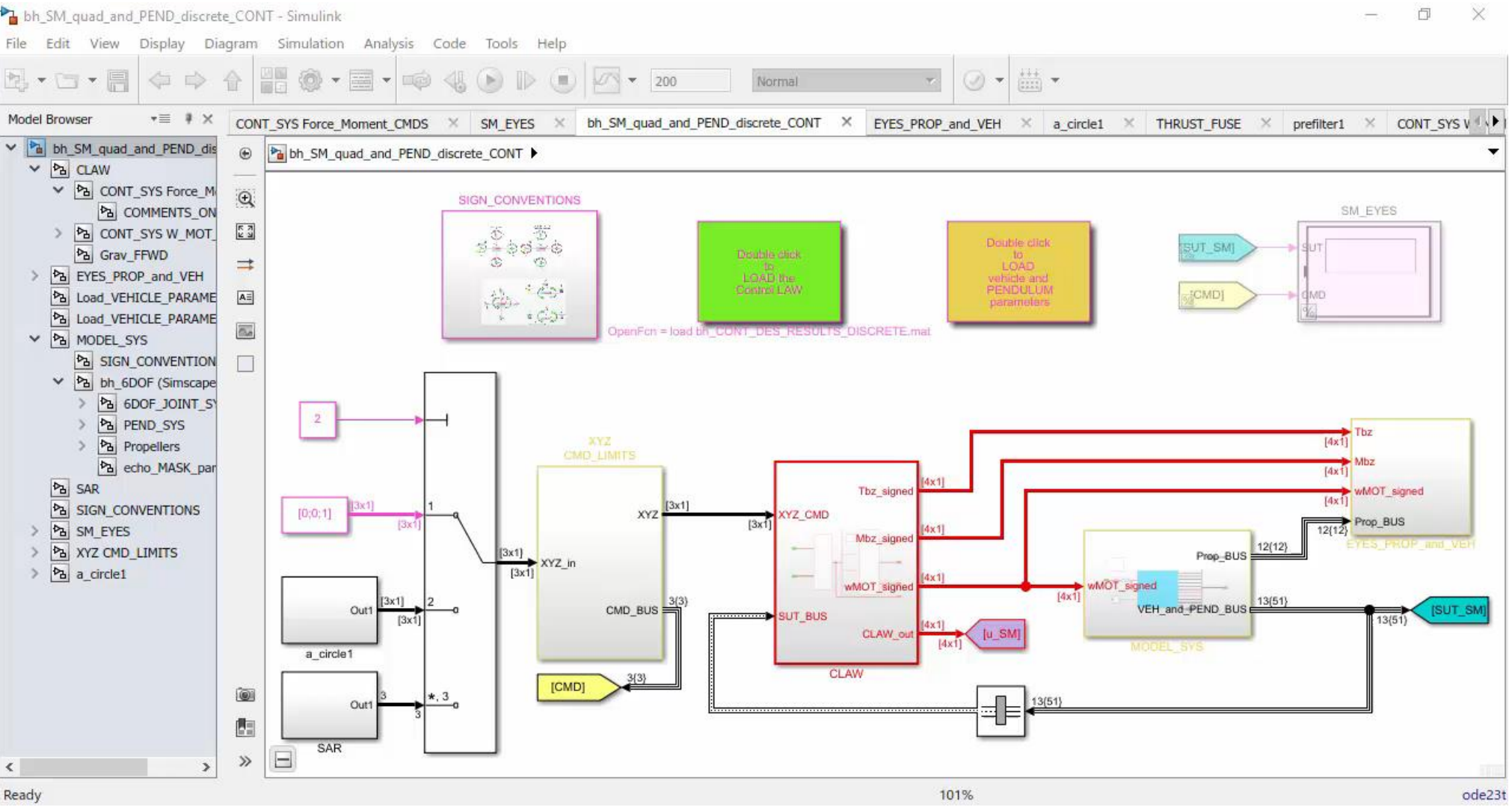
Quadcopter: Control Design

Develop Understanding of Technical concepts





Quadcopter: Code generation for deployment



Develop Understanding of Technical concepts

- Plant Modeling
  - Hand Derivation
    - MATLAB
    - Simulink
    - Symbolic Math
  - Commercial CAE
    - Simscape Multibody
- Comparison
- Control System Design
- **Code generation for deployment**

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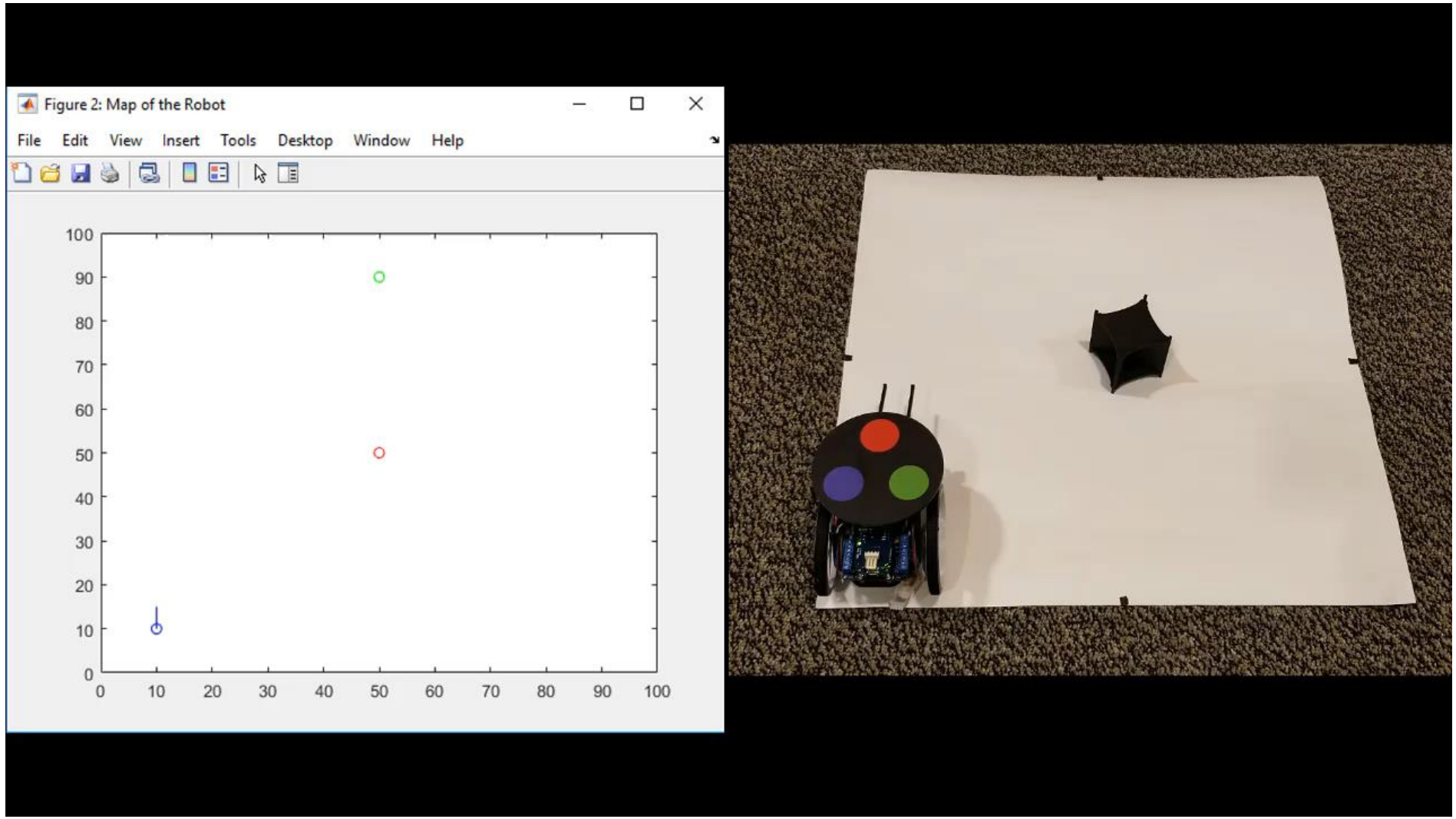
Quadcopter Simulation

Arduino Mobile Rover

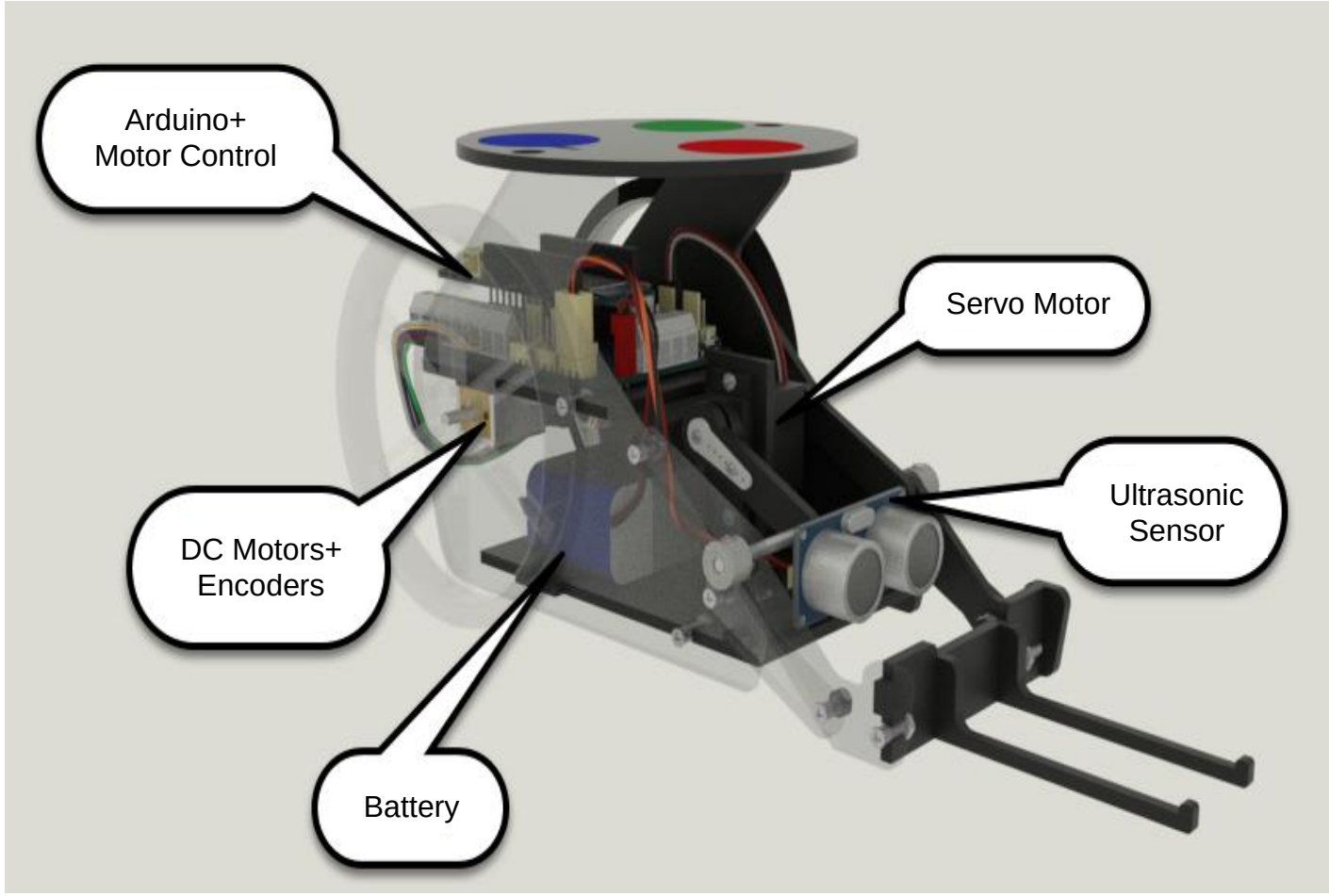
- Model-Based Design for autonomous vehicle
- Integrates controls, WiFi, path planning, and localization
- Low-cost hardware

Triplex Pump Digital Twin

Arduino Mobile Rover in Action

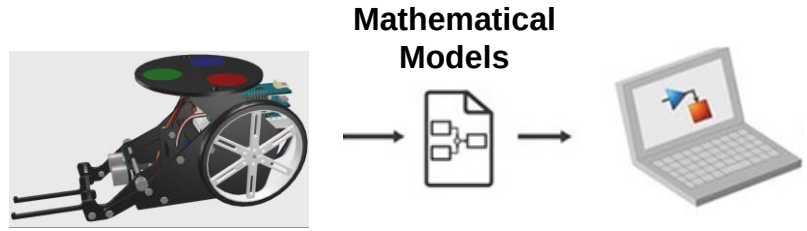


Mobile Rover Basics

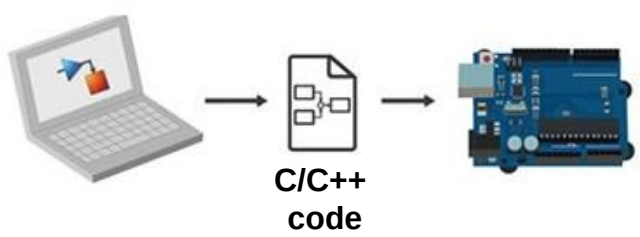


Workflow

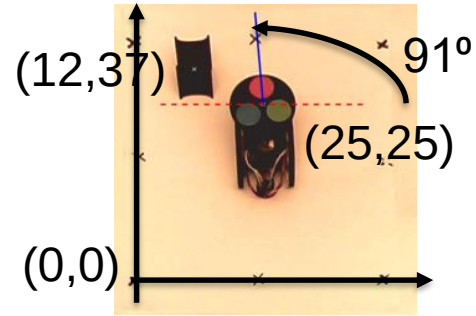
1. Modeling and simulation



2. Deploy to hardware

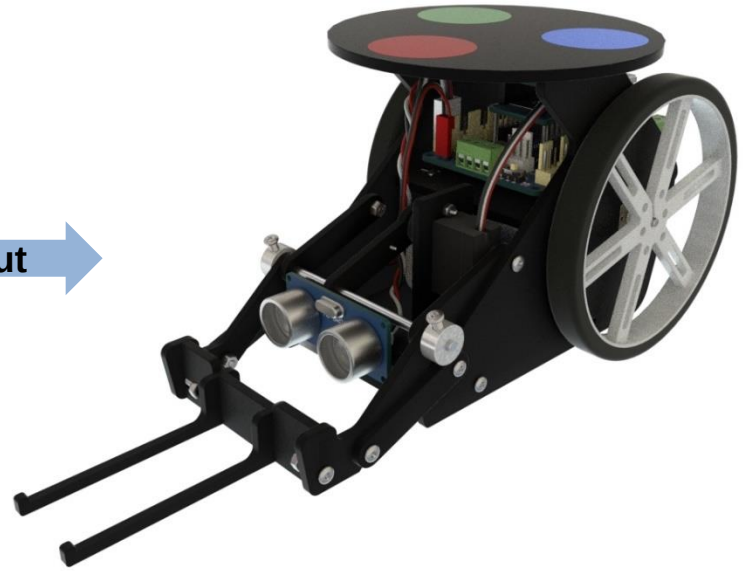


3. Integrate with localization using Wi-Fi

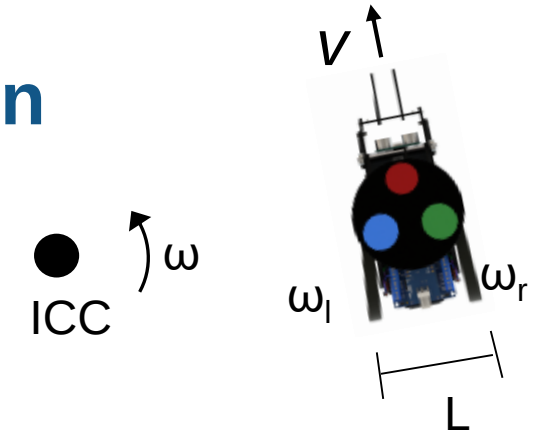


Modeling and Simulation

Rover kinematics

Wheel velocities → **Input** →  → **Output** → Rover trajectory

Modeling and Simulation
Rover kinematics



Rover velocities → **Input** → Wheel velocities → **Output** → Rover trajectory

Forward kinematics

Inverse kinematics

Rate of rotation: ω
Forward velocity: v

$$\begin{bmatrix}\omega_l \\ \omega_r\end{bmatrix} = \frac{1}{r} * \begin{bmatrix}1 & -L/2 \\ 1 & L/2\end{bmatrix} * \begin{bmatrix}v \\ \omega\end{bmatrix}$$

$$x(t) = \int_0^t v * \cos(\theta)\, dt$$

$$y(t) = \int_0^t v * sin(\theta)\, dt$$

$$\theta(t) = \int_0^t \omega\, dt$$

New Input

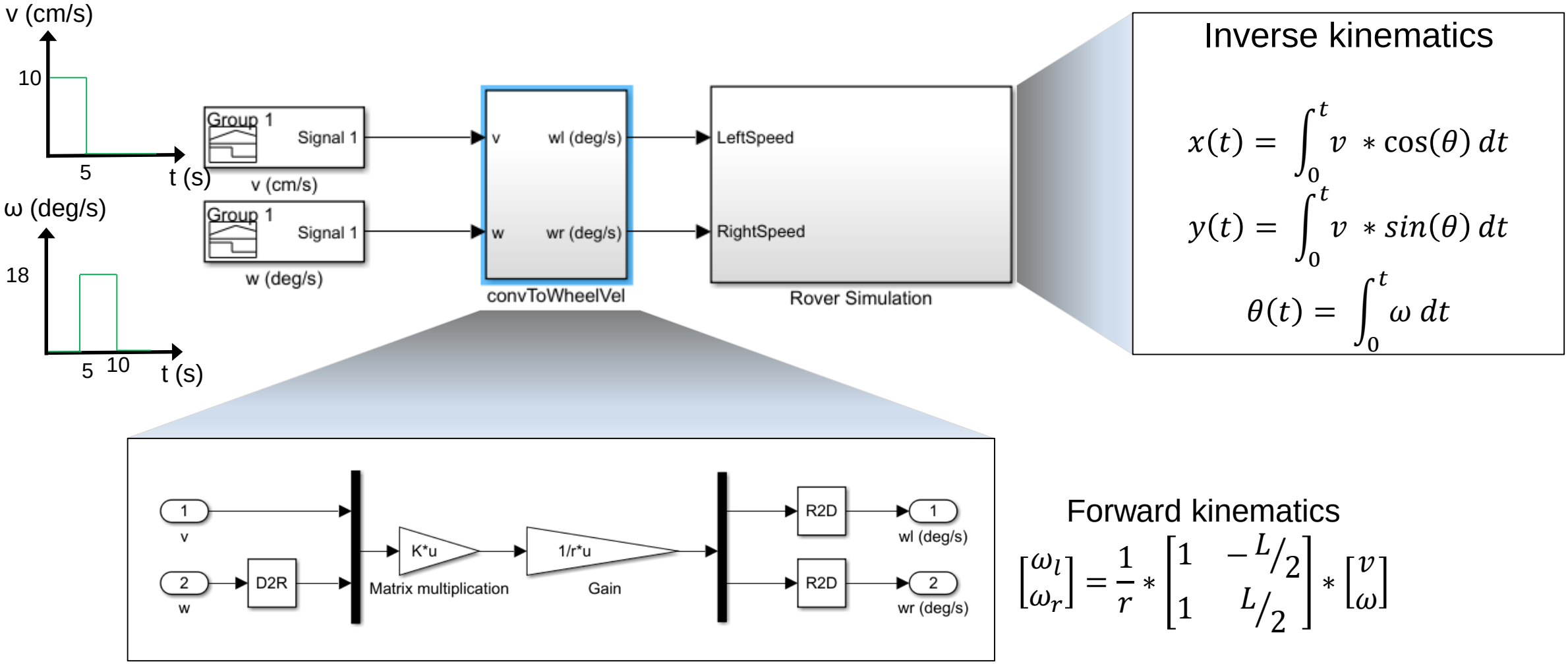
Intermediate Output

Output

Wheel speeds (ω_l, ω_r) $= f($Forward velocity (v), Rate of rotation (ω)$)$

Modeling and Simulation

Rover kinematics



Inverse kinematics

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Forward kinematics

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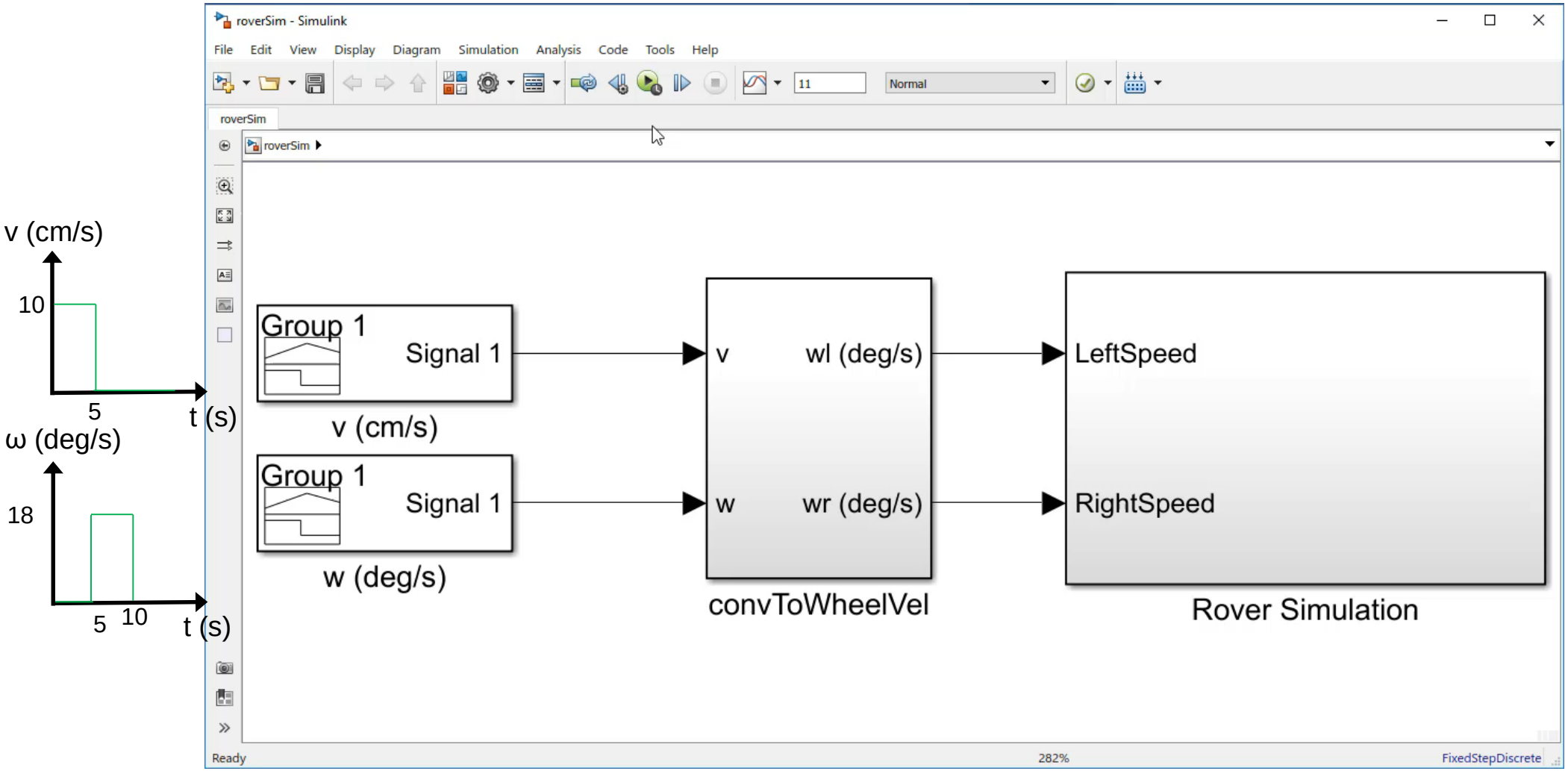
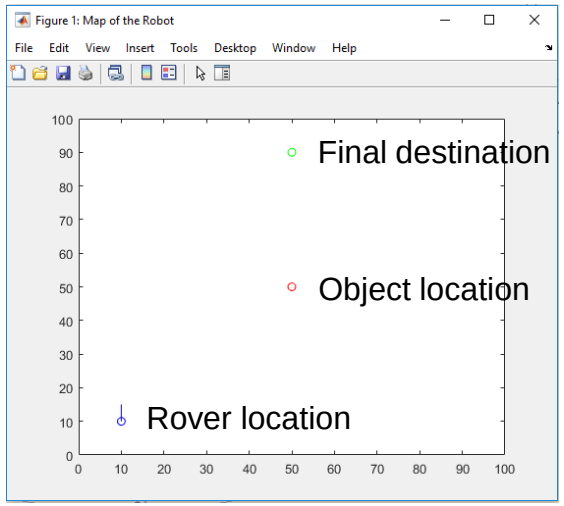
Modeling and Simulation

Rover kinematics



Modeling and Simulation

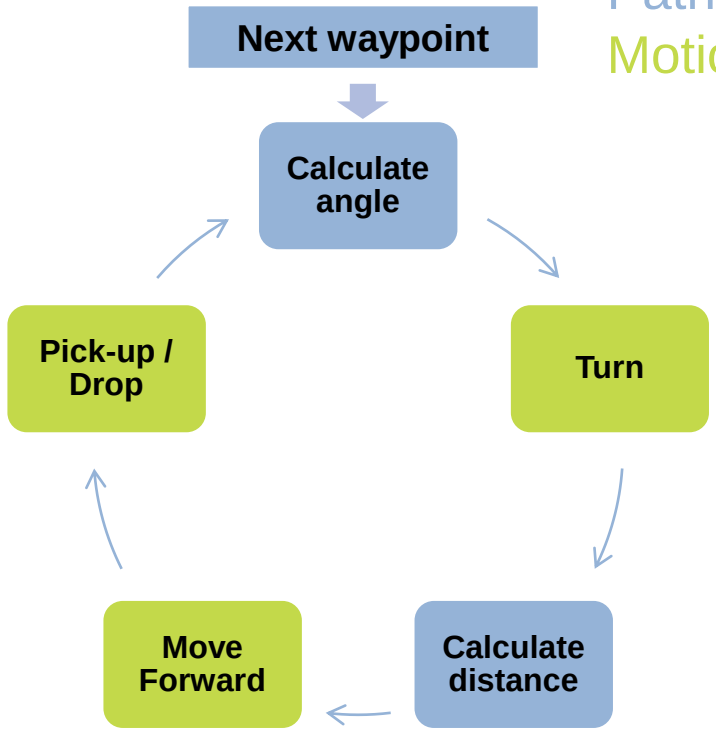
Path Planning and Motion Control

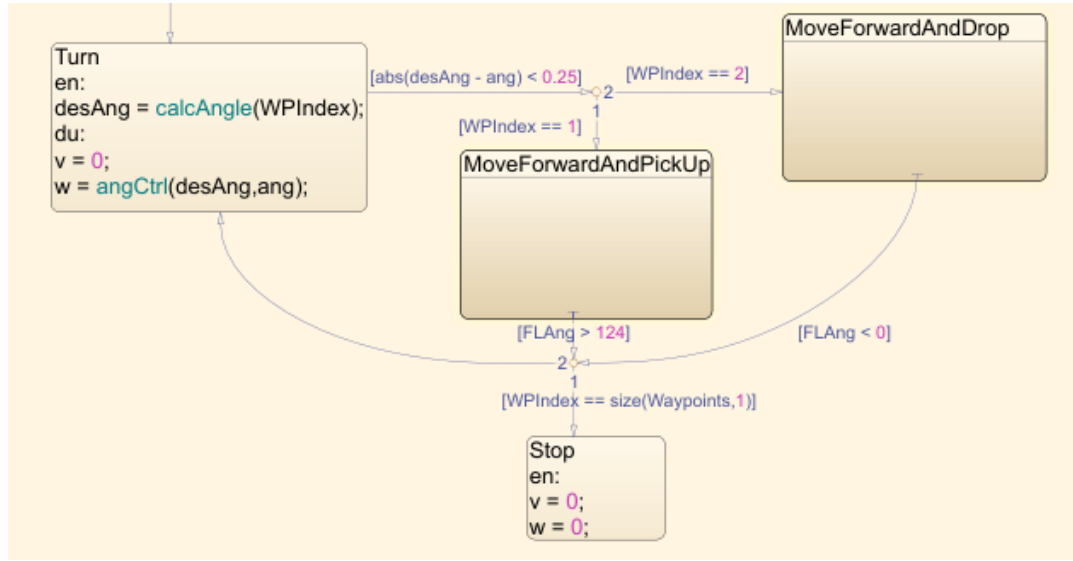


Legend

Path planning

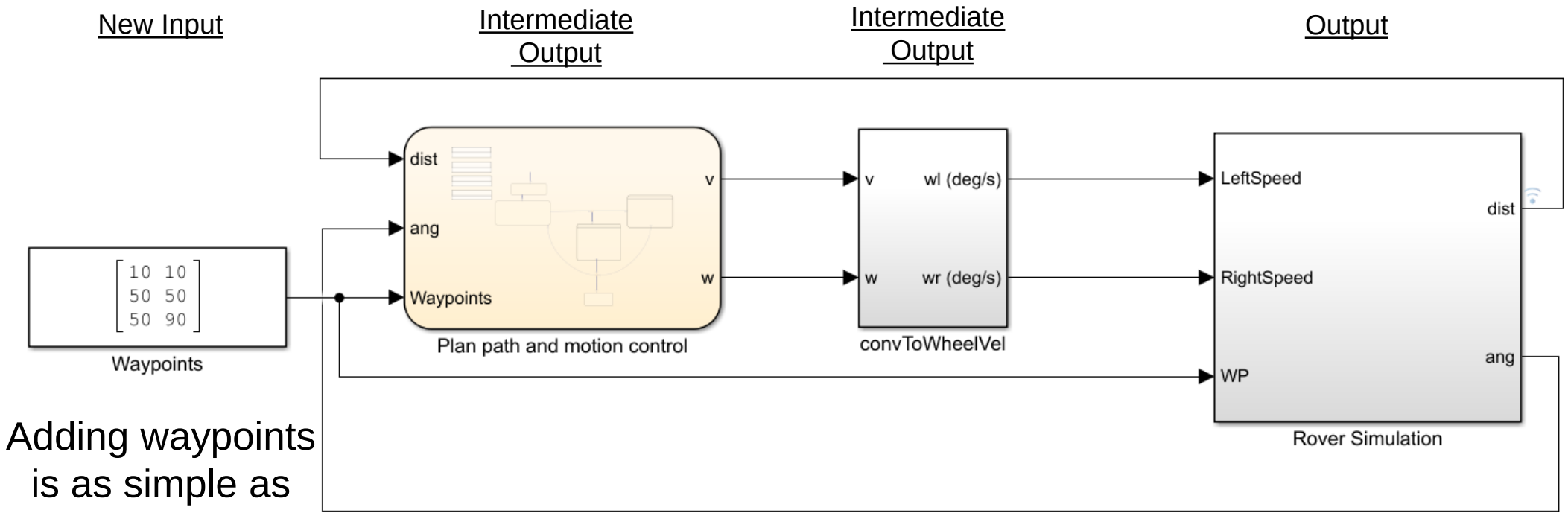
Motion control





Modeling and Simulation

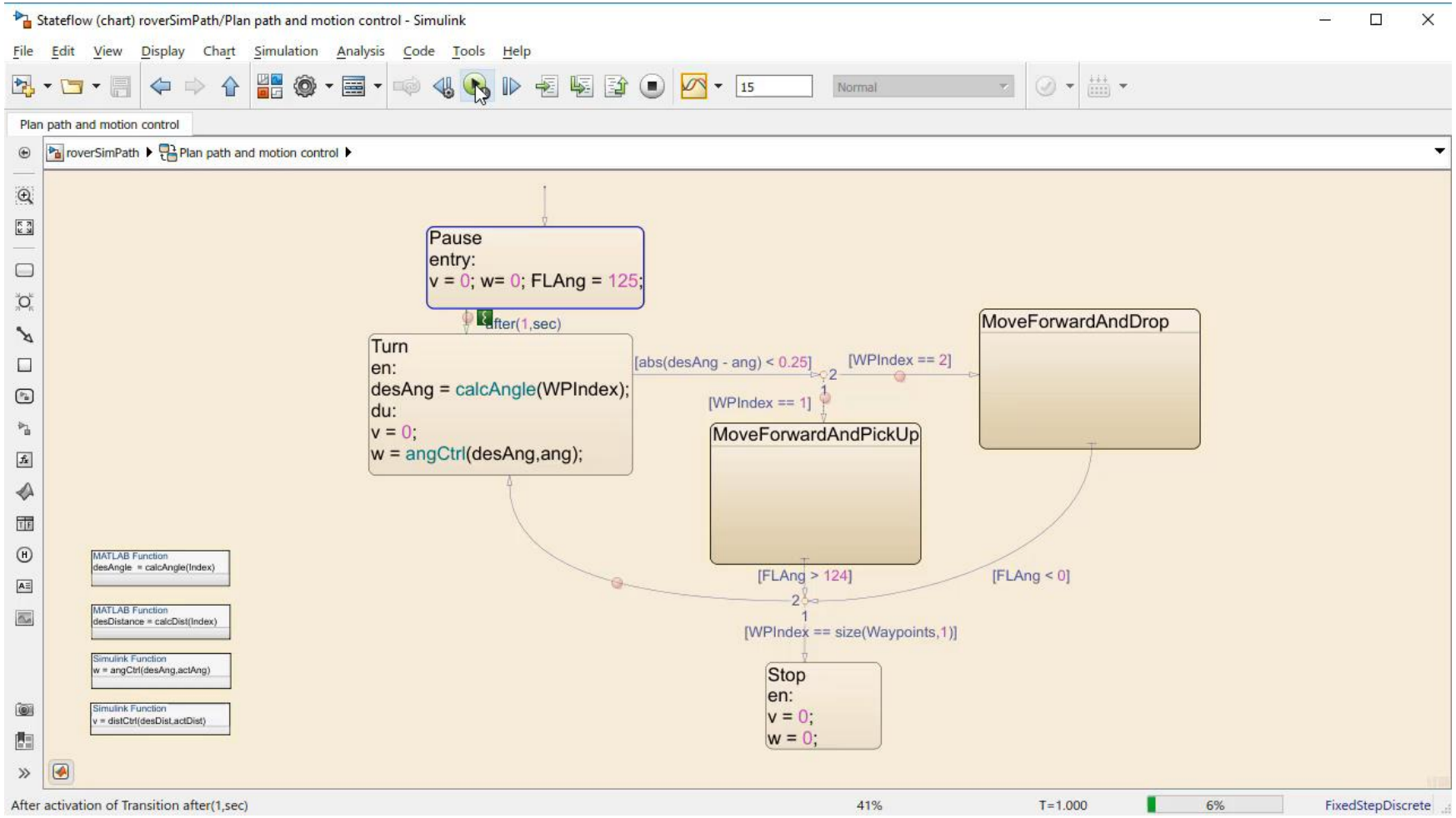
Path Planning and Motion Control



Adding waypoints is as simple as changing this block!

Modeling and Simulation

Path Planning and Motion Control



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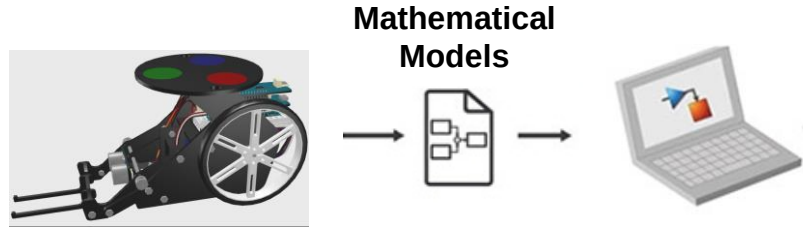
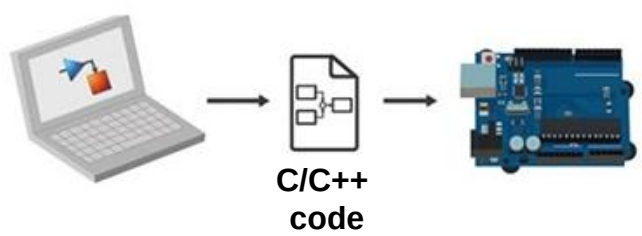
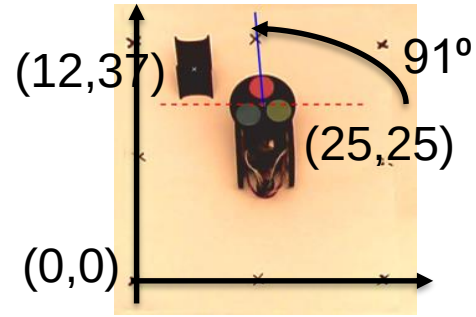


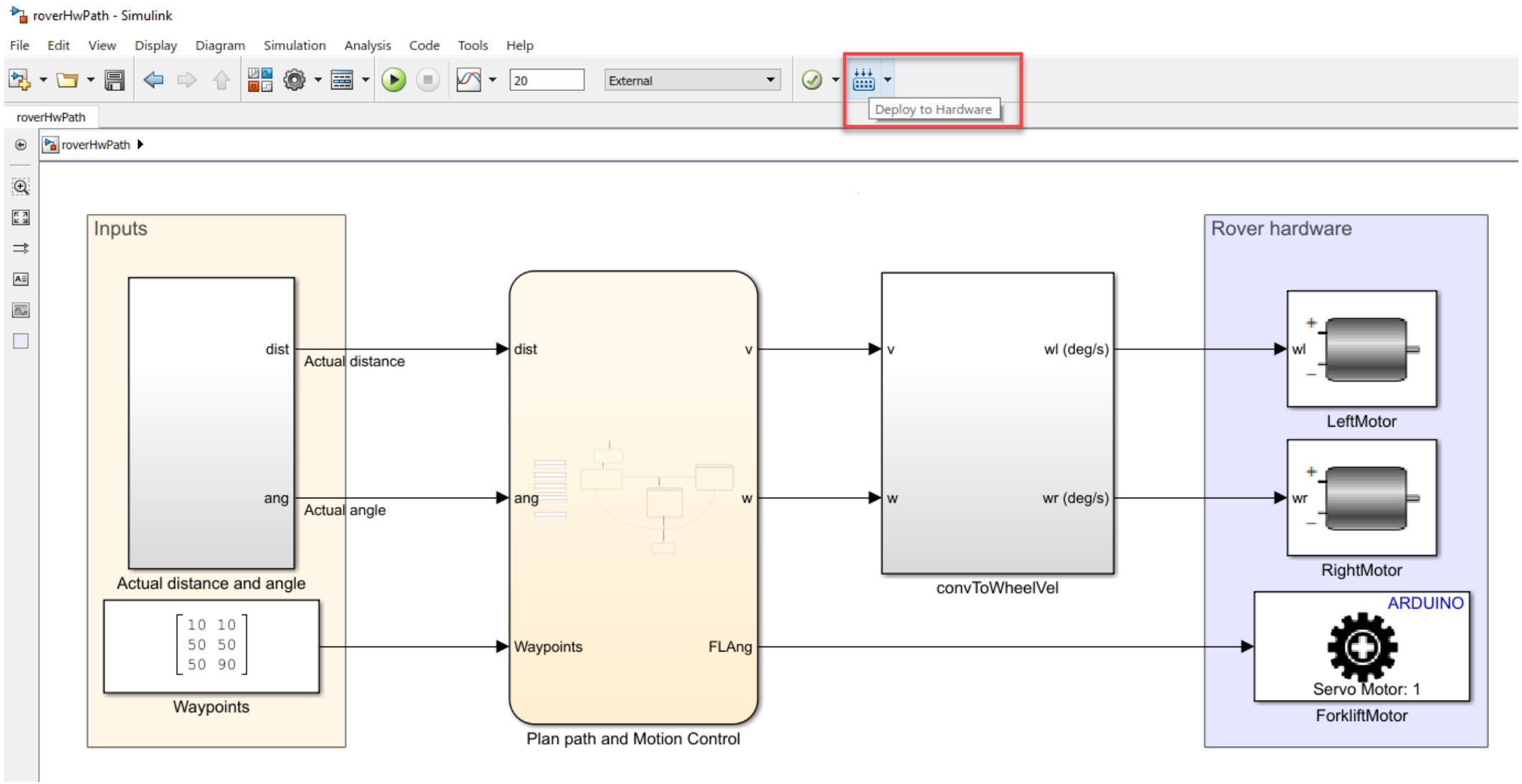
2. Deploy to hardware



3. Integrate with localization using Wi-Fi



Deploy to Hardware



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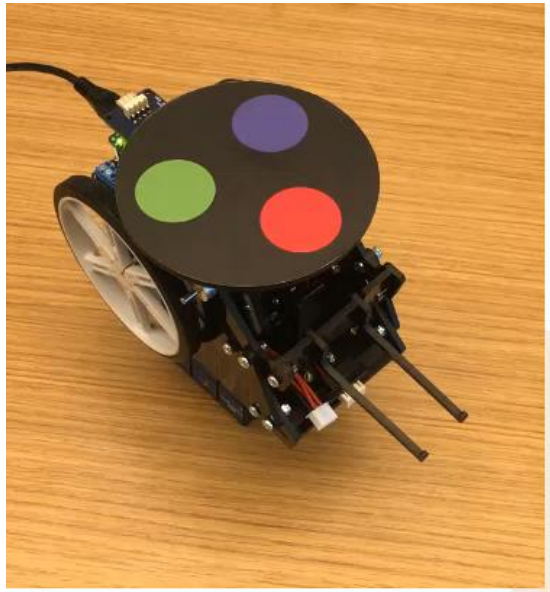

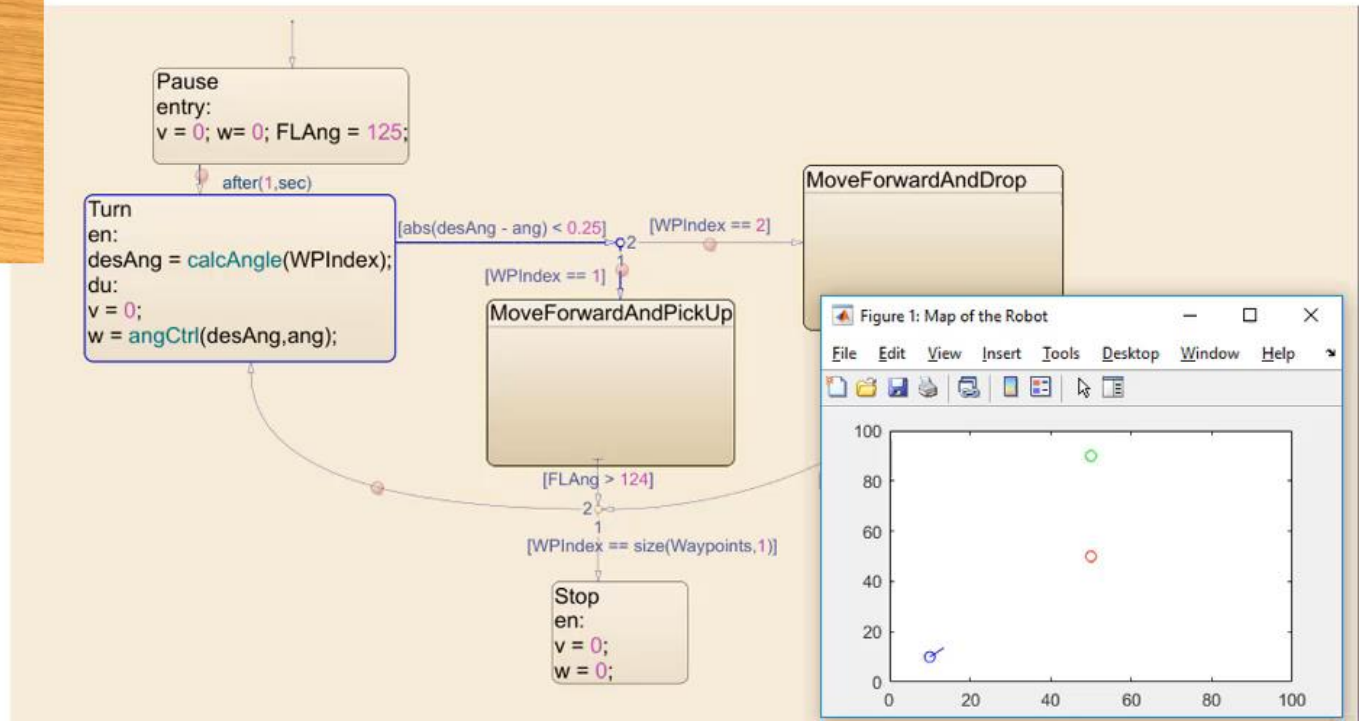

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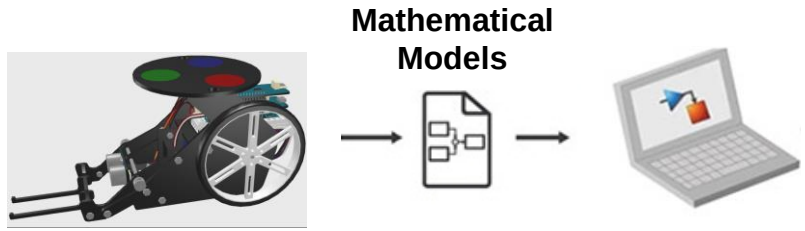

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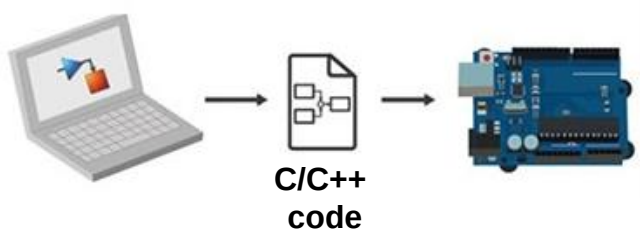

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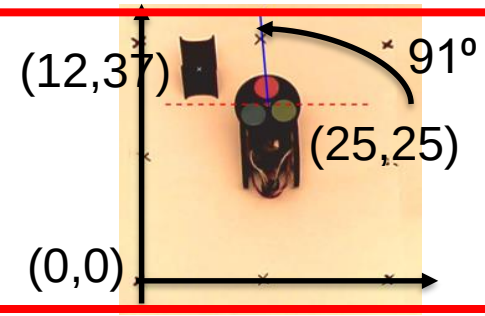


Get Location Data Over Wi-Fi

Webcam on top of a table;
Tethered to PC

Taking picture of arena

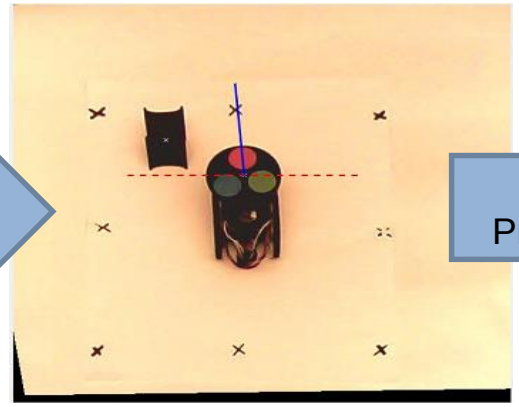
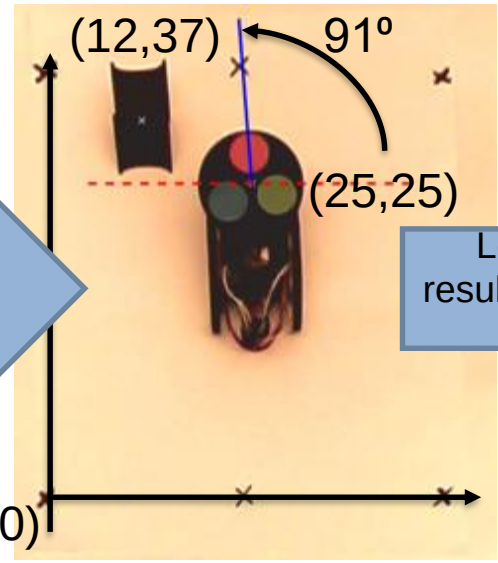
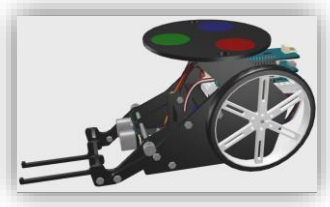


Image Processing



Location results sent via Wi-Fi



Localization Algorithm

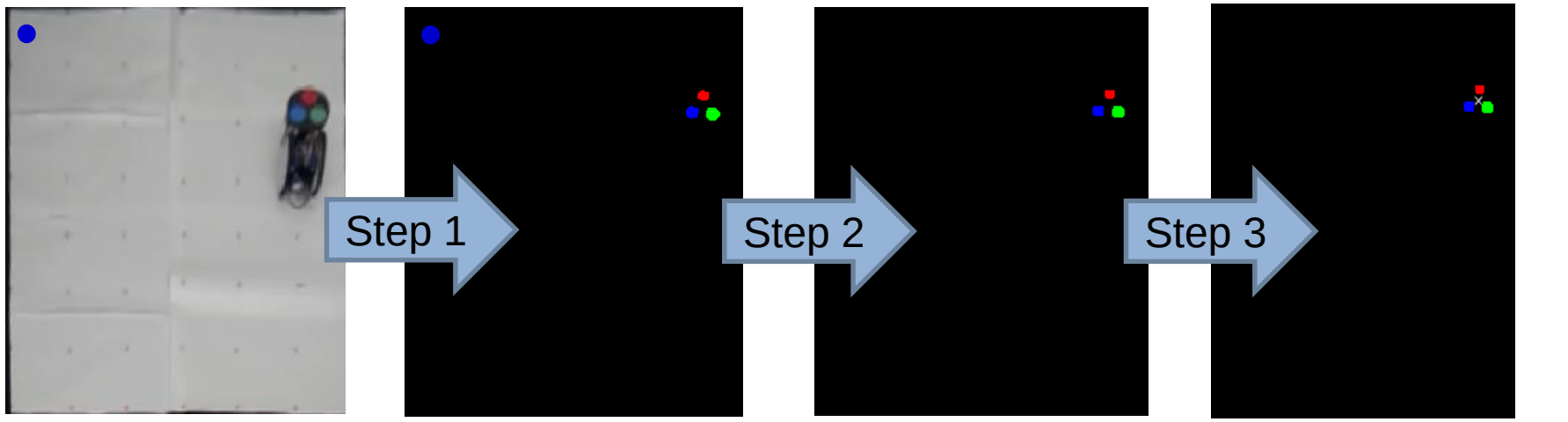
Workflow

Step 1: Use R, G, B colors as threshold

Step 2: Remove noise

Step 3: Find the centroid

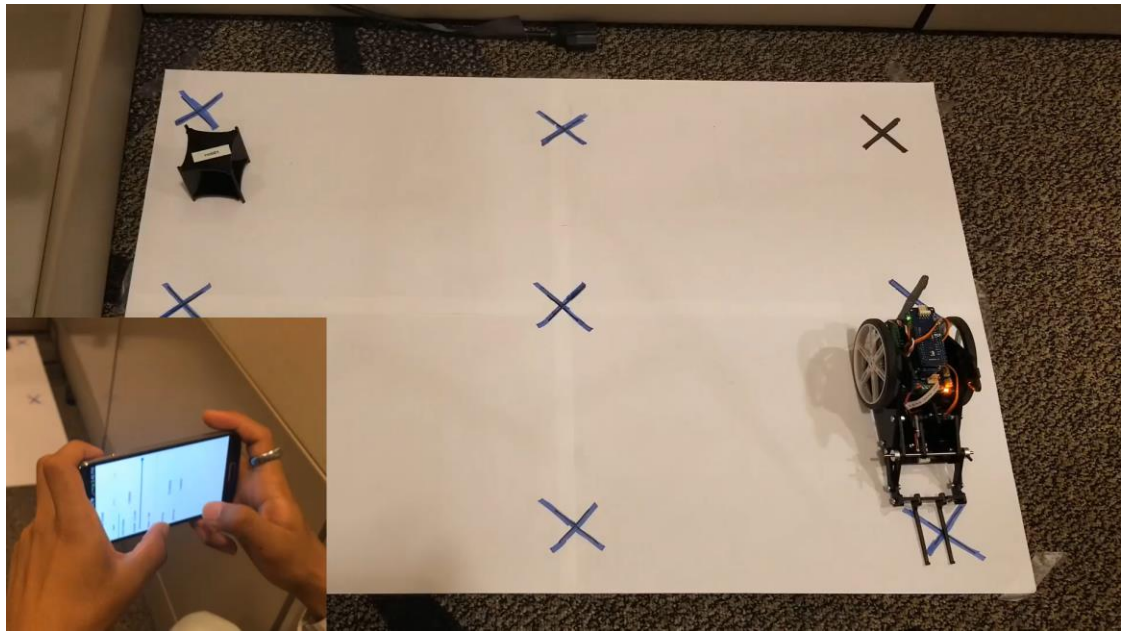
Repeat to track and send results!



Algorithm outputs

Rover
Location: (75,60) cm
Heading: 90 deg

Mobile phone controlling rover

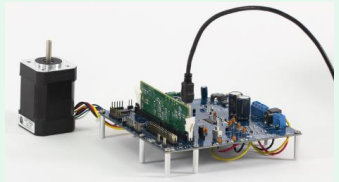


Arduino

Raspberry Pi

Parrot Minidrones

LEGO Mindstorms EV3



TI C2000

ST Micro

Today's Topics: Three Exercises to Develop That Know-How

Quadcopter Simulation

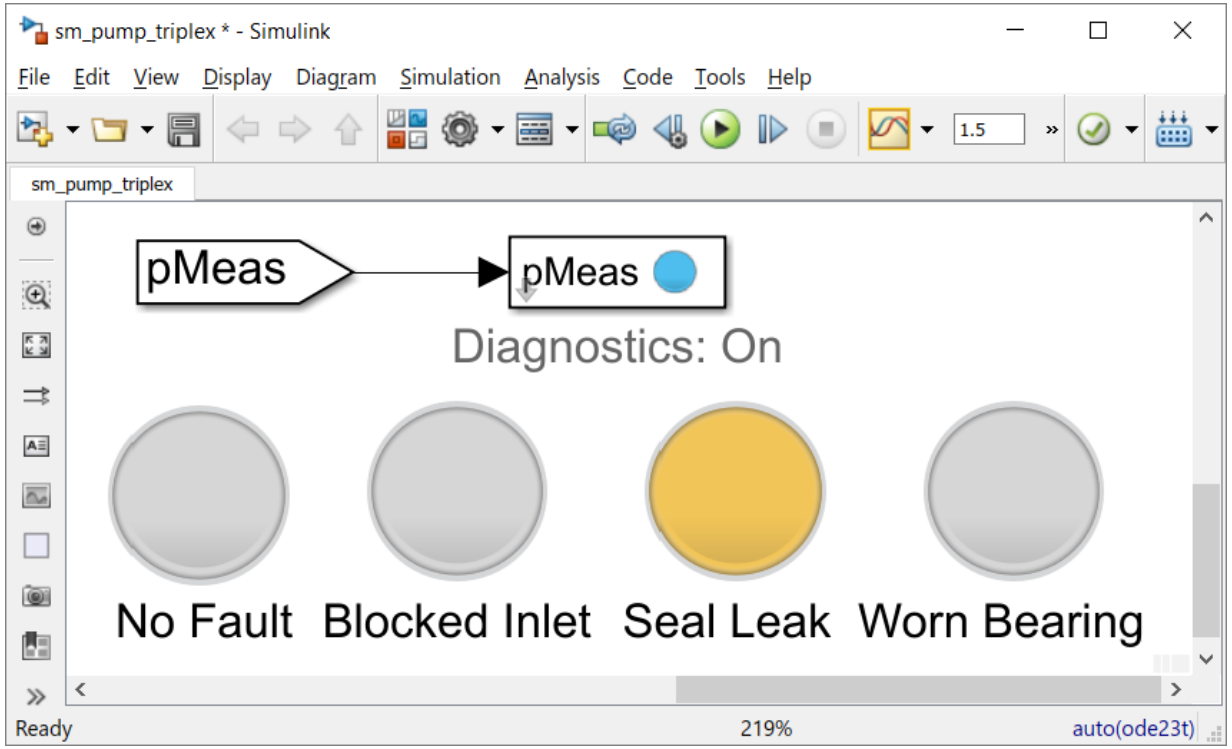
Arduino Mobile Rover

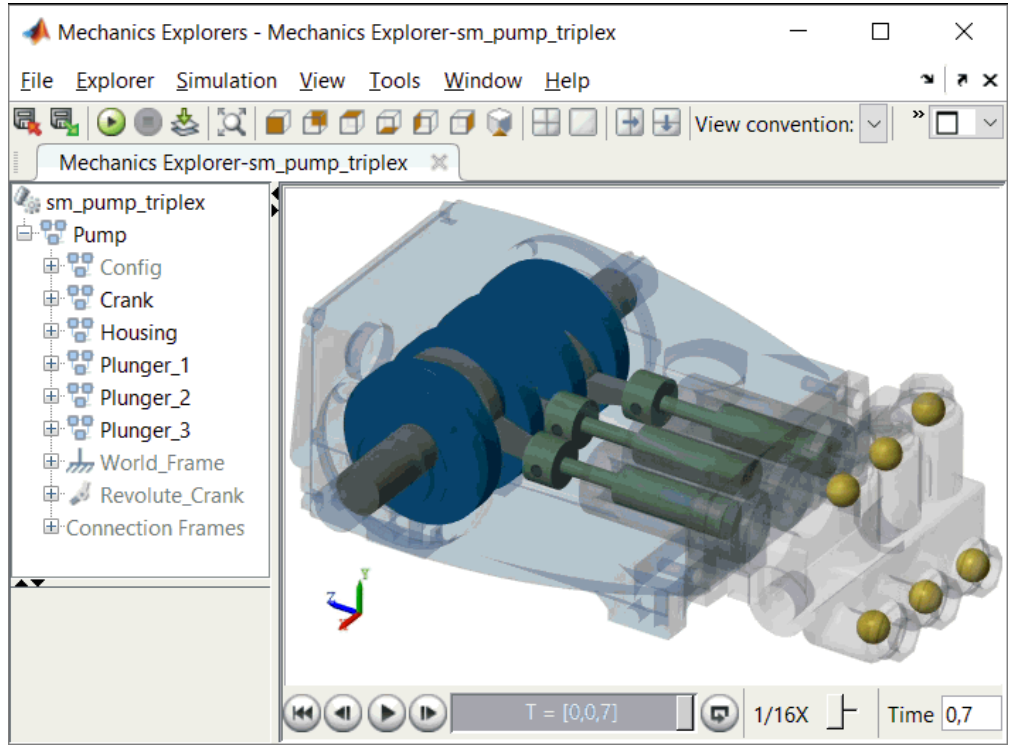
Triplex Pump Digital Twin

- Complex industrial application
- Combines engineering and data science
- Can leverage cloud computing
- No hardware required

Triplex Pump

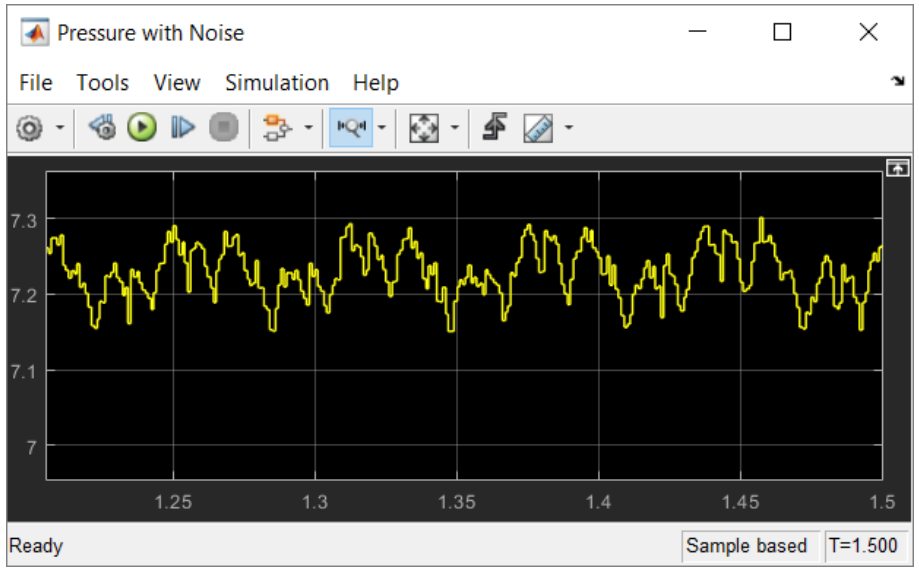
Predictive Maintenance Using Digital Twins





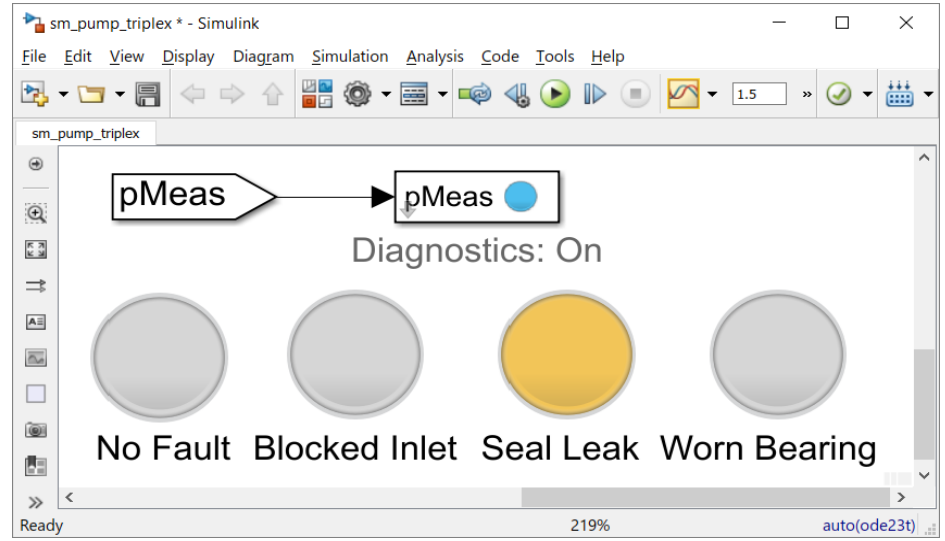
How can I teach students these concepts if I don’t have a real pump?

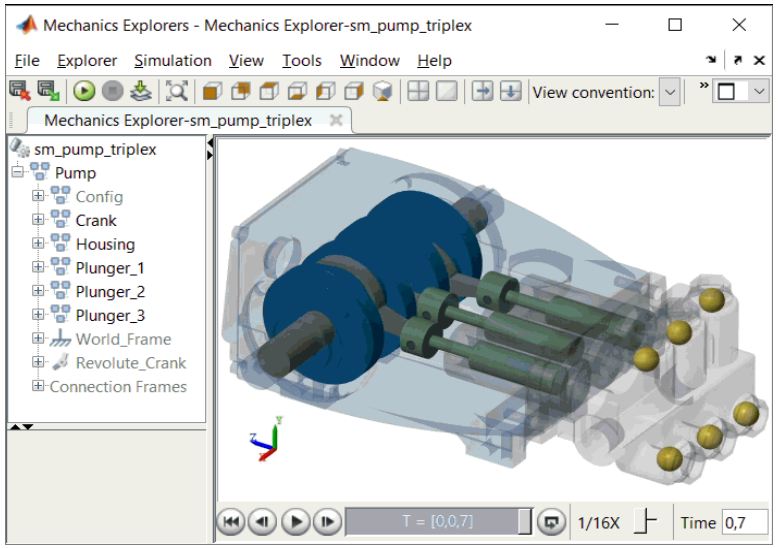
Prevent system downtime



by sending sensor data

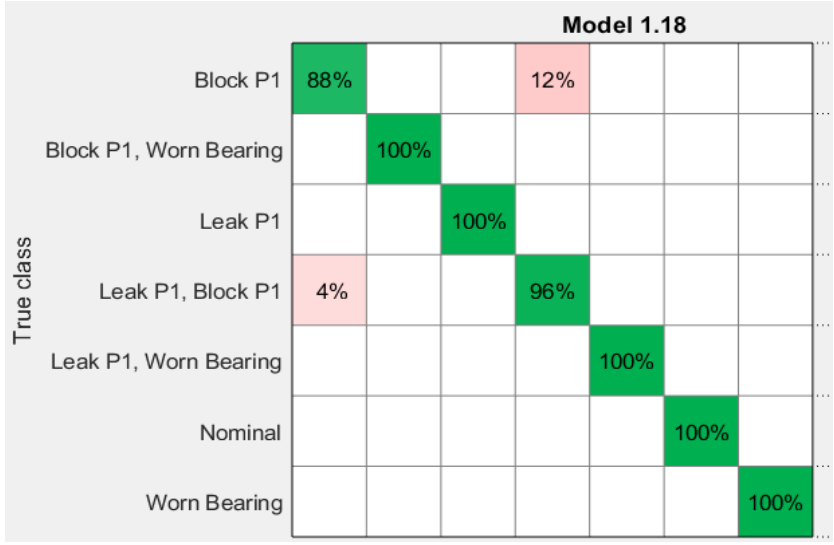
to a predictive maintenance algorithm





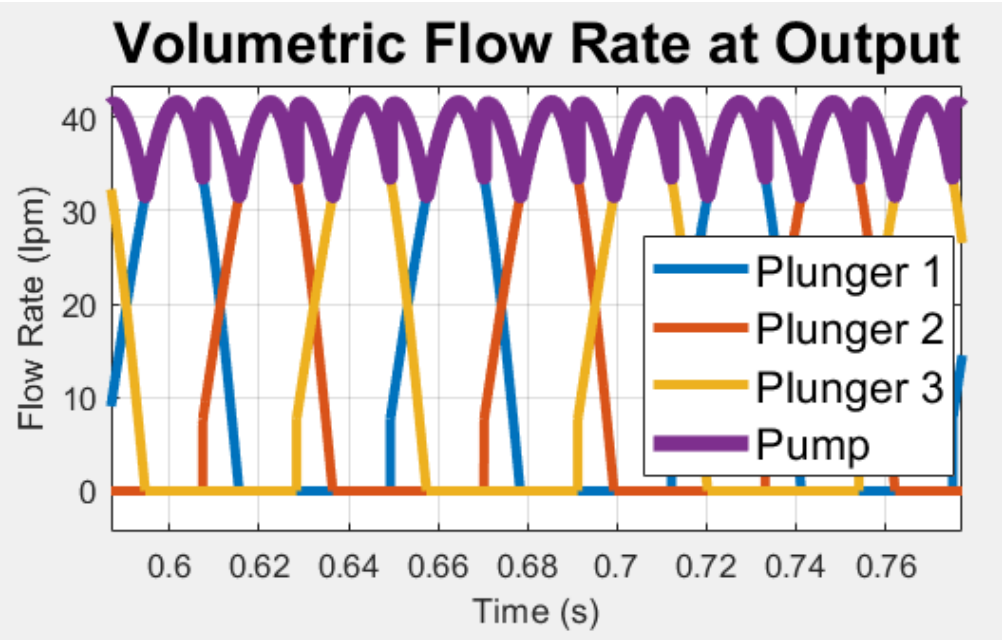
created using a Digital Twin

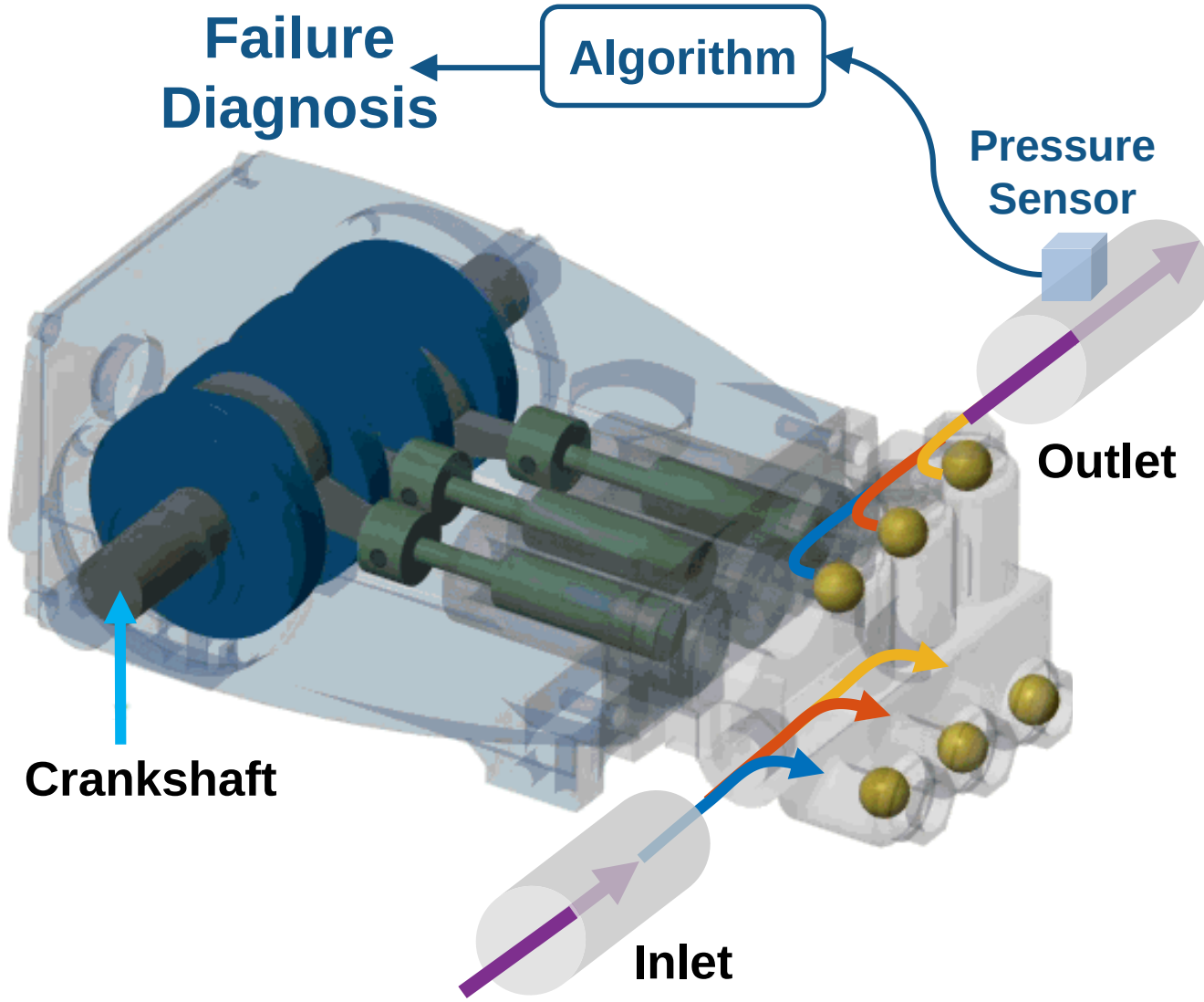
and machine learning in MATLAB.

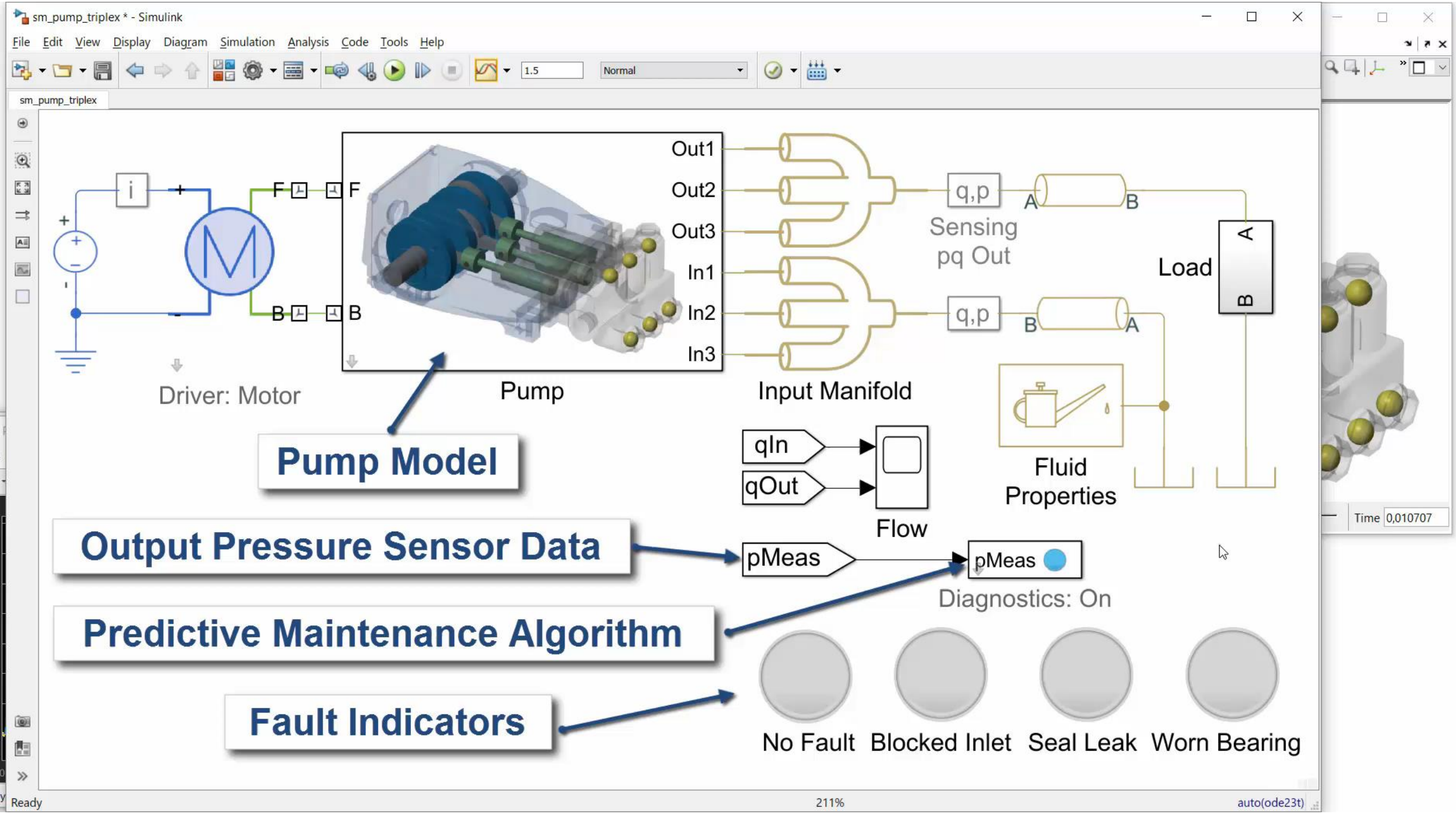


Triplex Pump

- Crankshaft drives three plungers
  - Each 120 degrees out of phase
  - One chamber always discharging
  - Smoother flow than single or duplex piston pumps






sm_pump_triplex * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
sm_pump_triplex
Out1
Out2
Out3
In1
In2
In3
F
B
Driver: Motor
Pump
Input Manifold
q,p
Sensing
pq Out
A
B
Load
Fluid
Properties
qIn
qOut
Flow
pMeas
Diagnostics: On
Pump Model
Output Pressure Sensor Data
Predictive Maintenance Algorithm
Fault Indicators
No Fault
Blocked Inlet
Seal Leak
Worn Bearing
Ready
211%
auto(ode23t)
Time 0,010707

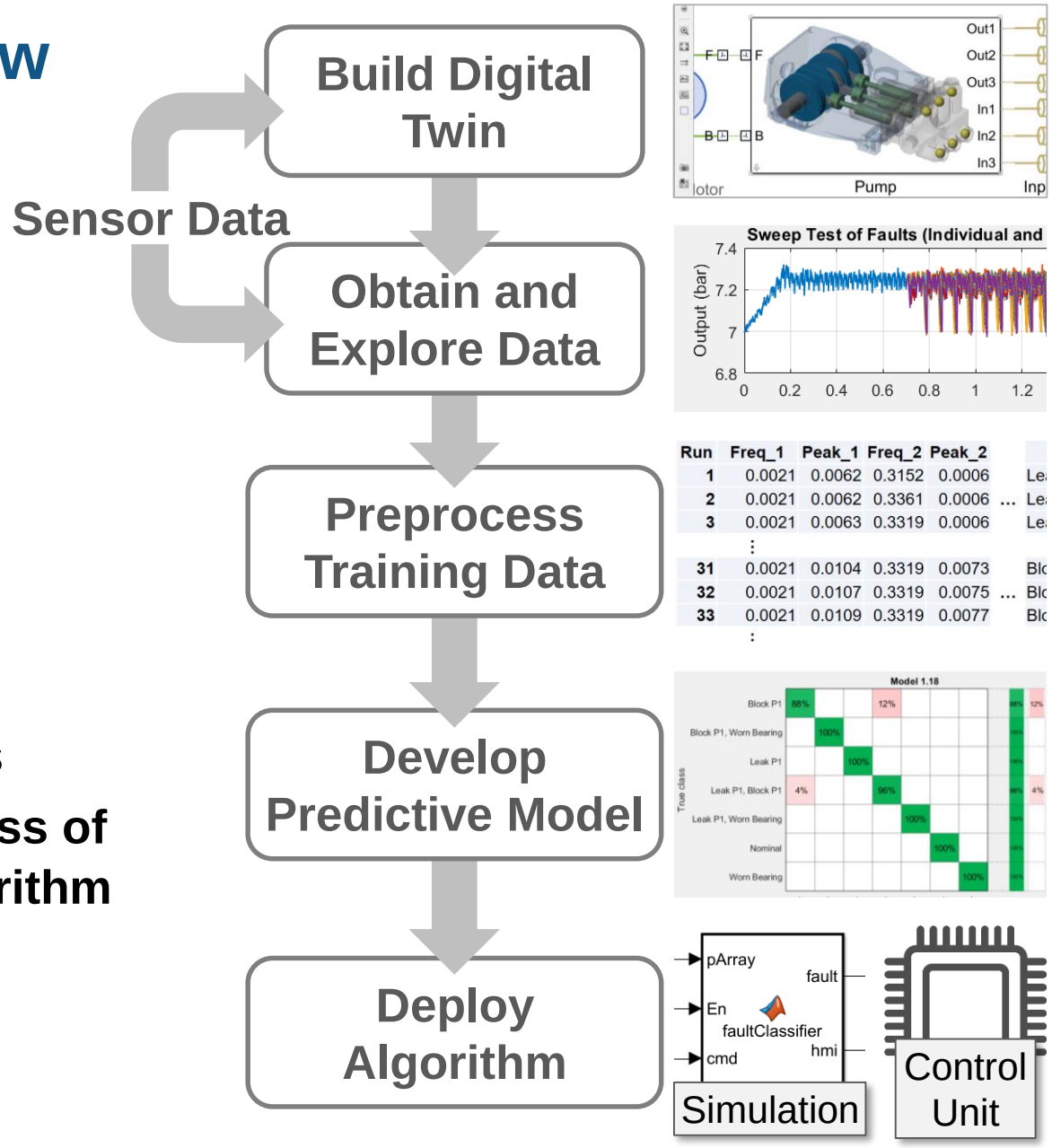
Predictive Maintenance Workflow

- Sensor data isn‘t always available
  - Failure conditions difficult to reproduce
  - Time consuming or costly to generate

  Solution: Build digital twin and generate sensor data using simulation

- Developing algorithm is complex
  - Requires complex concepts and analysis

  Solution: Use MATLAB to simplify process of developing and deploying algorithm



Key takeaways

- IoT is revolutionizing the industry
- New graduates will be expected to address challenges like this
- Experience with tools and workflows used in industry make students more hireable

Today's Topics: Three Exercises to Develop That Know-How

Quadcopter Simulation

- Develops Computational Thinking
- Enables comparisons of theory and simulation
- Automatically generates controller code

Arduino Mobile Rover

- Model-Based Design for autonomous vehicle
- Integrates controls, WiFi, path planning, and localization
- Low-cost hardware

Triplex Pump Digital Twin

- Complex industrial application
- Combines engineering and data science
- Can leverage cloud computing
- No hardware required

Bildungsnetzwerk
Technik Österreich

Vision

2040: Austria is world leader in STEM education

Mission

Strengthen STEM education and secure local industry in Austria

Strategy

Connect stakeholders in academia, industry and government.
Initiate, and support high-impact STEM projects.

Projects

Multicopter for teaching and research

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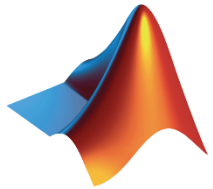

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Turn CHALLENGES into OPPORTUNITIES

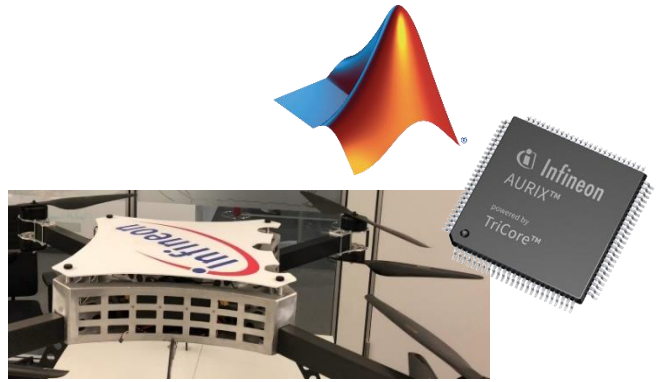
Turn CHALLENGES into OPPORTUNITIES

Market penetration in AERO

Recruiting Hiring

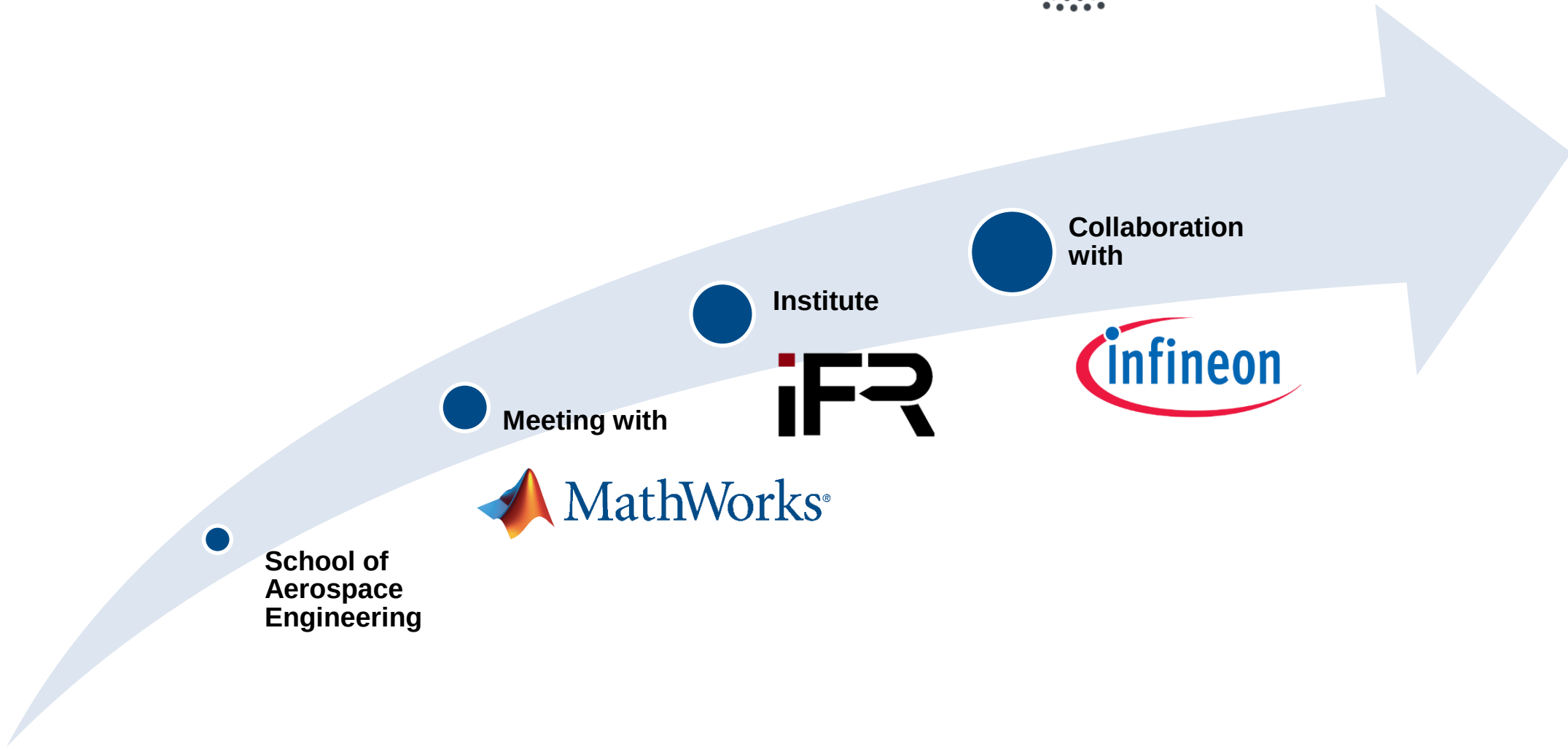
Brand awareness

Courses Research in AERO



Flight robotics seminar

Universität Stuttgart



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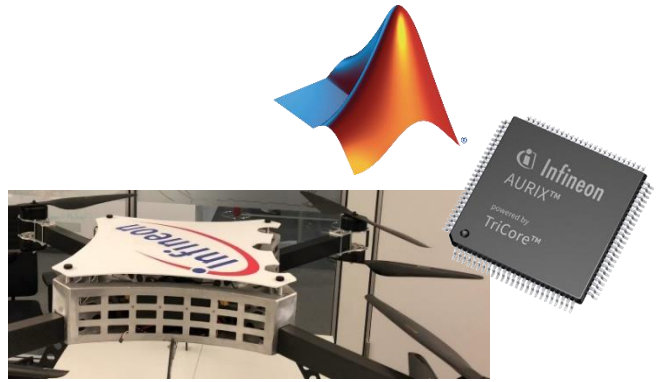
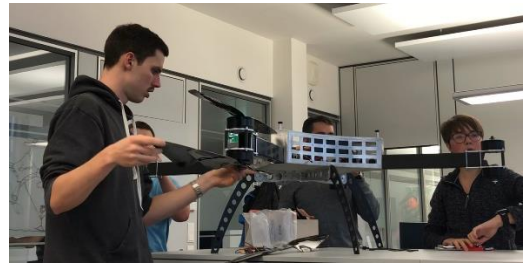


3 Hires in 1 semester




Red Bull

Turn CHALLENGES into OPPORTUNITIES

Brand awareness

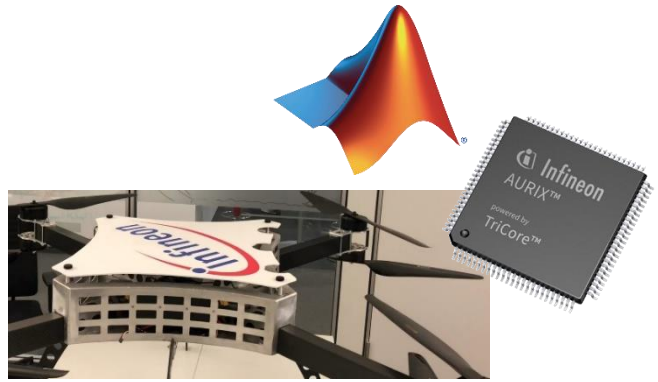
Recruiting Hiring

Market penetration

in AERO

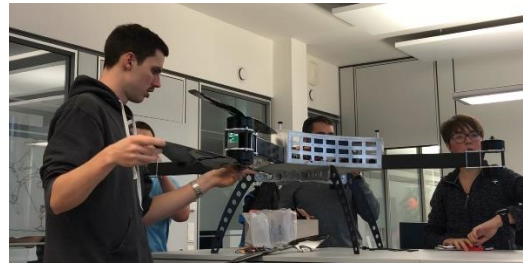
Courses Research

in AERO



3 Hires

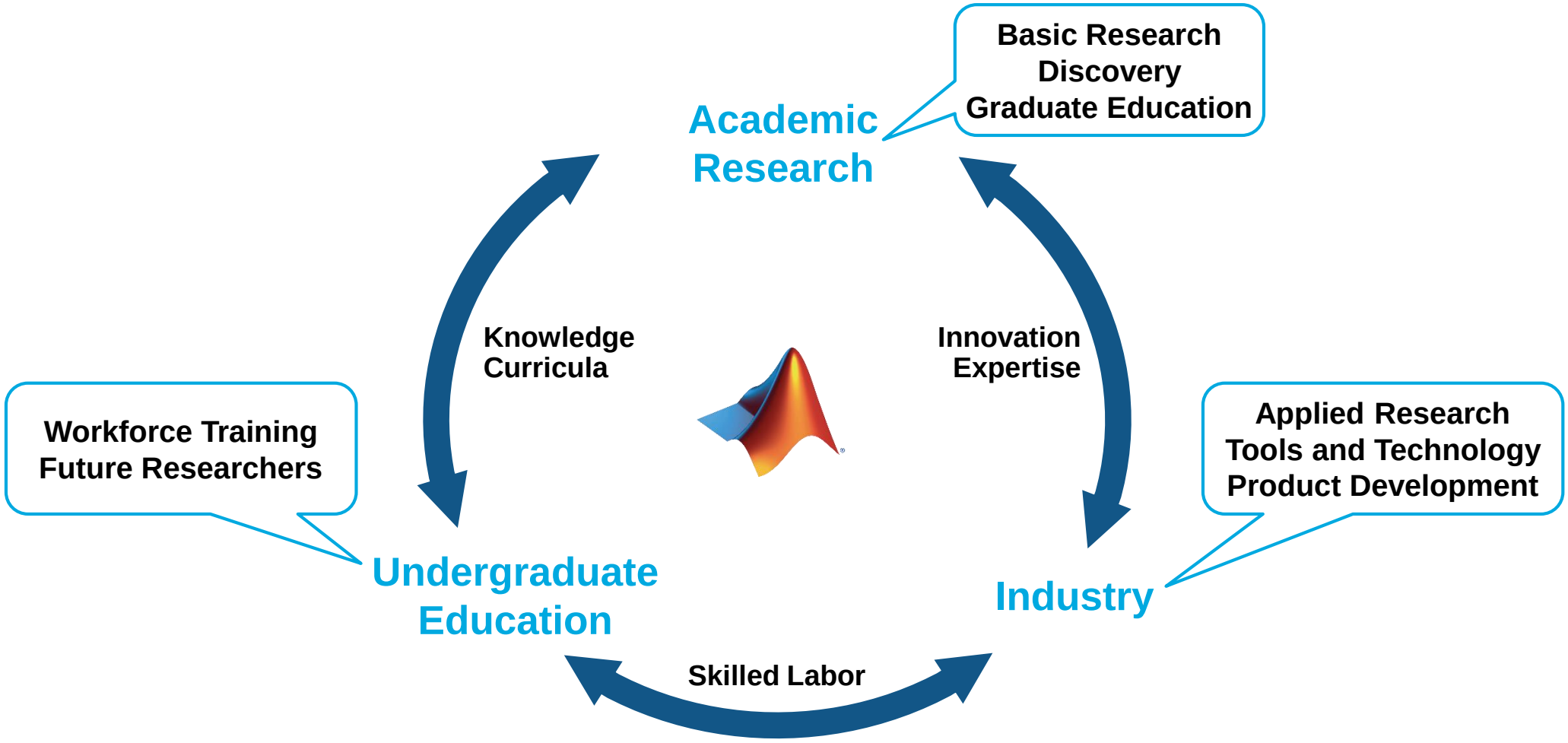
in 1 semester



1 Million

views in 24 hrs

Preparing Students for Digital Transformation



Bring these exercises to your classroom!

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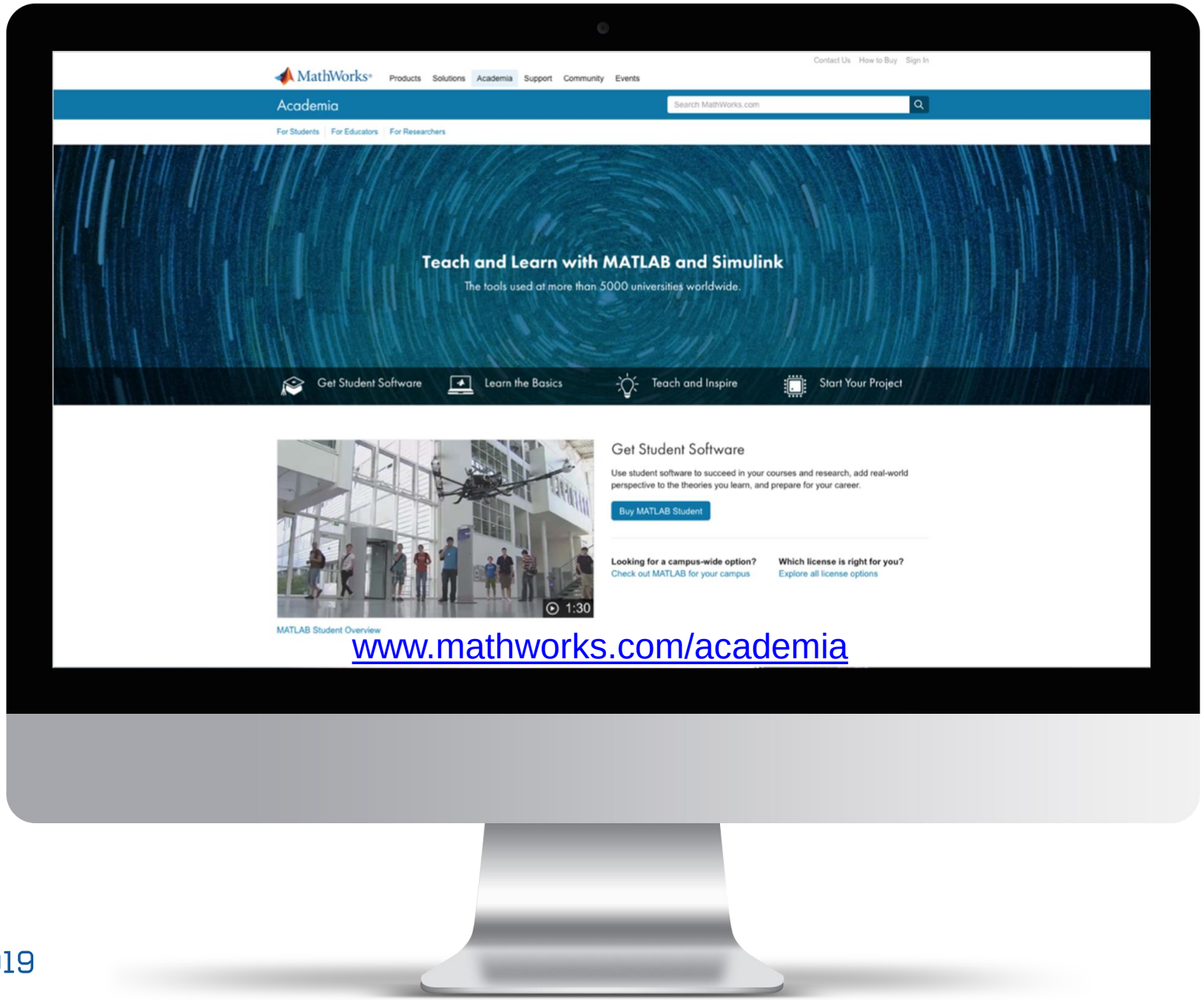
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