ECOR 1055 Engineering Disciplines I

Robotics and Control

Dr. Chao Shen

Department of Systems and Computer Engineering
Carleton University

Agenda

- About the Instructor
- Robotic Systems and Automatic Control

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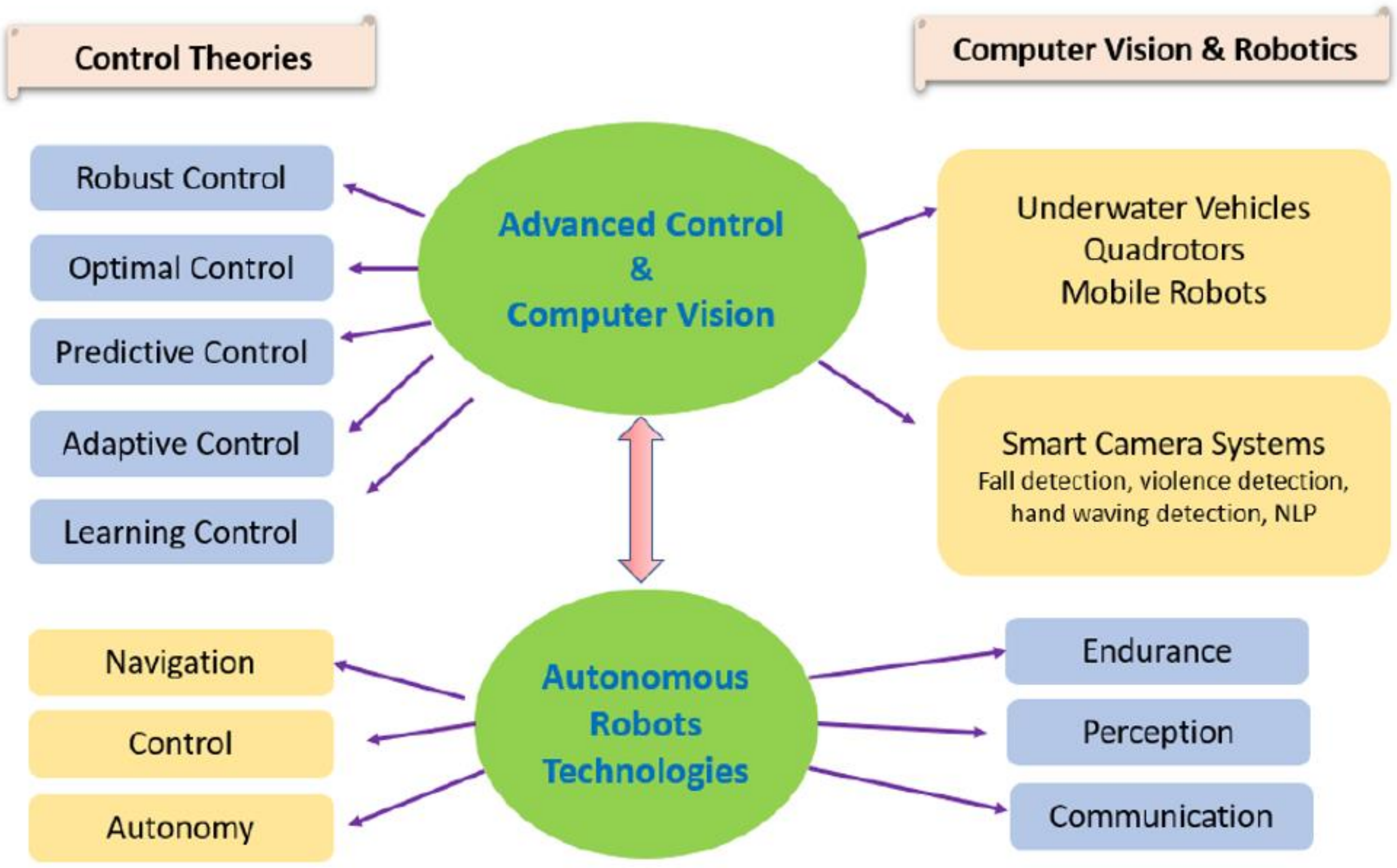
- **Robotic Systems and Automatic Control**

About the Instructor

- **Dr. Chao Shen, Assistant Professor**
    - Department of Systems and Computer Engineering
    - Website: https://carleton.ca/sce/people/shen/
    - Email: shenchao@sce.carleton.ca
    - Undergraduate Research Opportunities Available

Research Interests



Agenda

- About the Instructor
- **Robotic Systems and Automatic Control**

Robotics

❑ What is robotics?

“Robotics is an **interdisciplinary** branch of electronics and communication, computer science and engineering. Robotics involves the **design**, **construction**, **operation** and **use** of robots. The field of robotics develops machines that can **automate** tasks that a human may or may not be able to do.”

https://images.google.com/

Robotics

❑ What is robotics?

Although being diverse in application and form, robots share three basic similarities when it comes to their construction:

- Robots all have some kind of mechanical construction, a frame, form or shape designed to achieve a particular task.

- Robots have electrical components that power and control the machinery.

- All robots contain some level of computer program code. A program is how a robot decides when or how to do something.

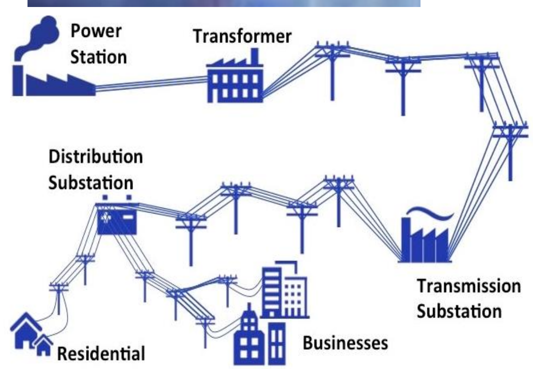
“A robotic system is a **computer system**, a system of systems, and a (automatic) control system.”

Systems

❑ Definition of a System

"A ***system*** is a combination of components acting together to perform a specific objective. A ***component*** is a single functioning unit of a system." (K. Ogata, 2004)

- Examples
  - Robots
  - Epidemics
  - Stock market
  - Thermostats
  - Traffic system
  - Power grids
  - Chemical processes



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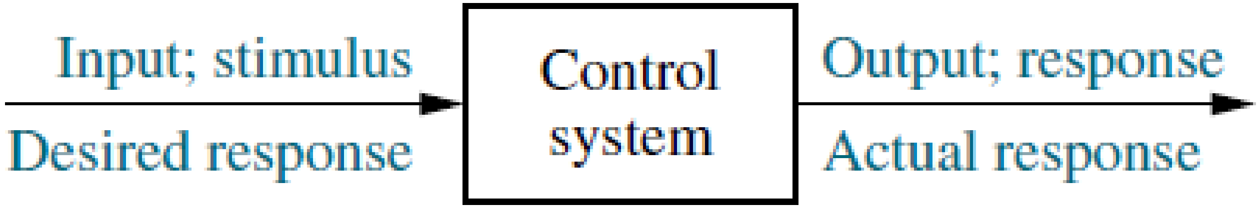
Control Systems

❑ Definition of a Control System

"A ***control system*** consists of subsystems and processes (or plants), assembled for the purpose of obtaining a desired output with desired performance." (N. Nise, 2010)



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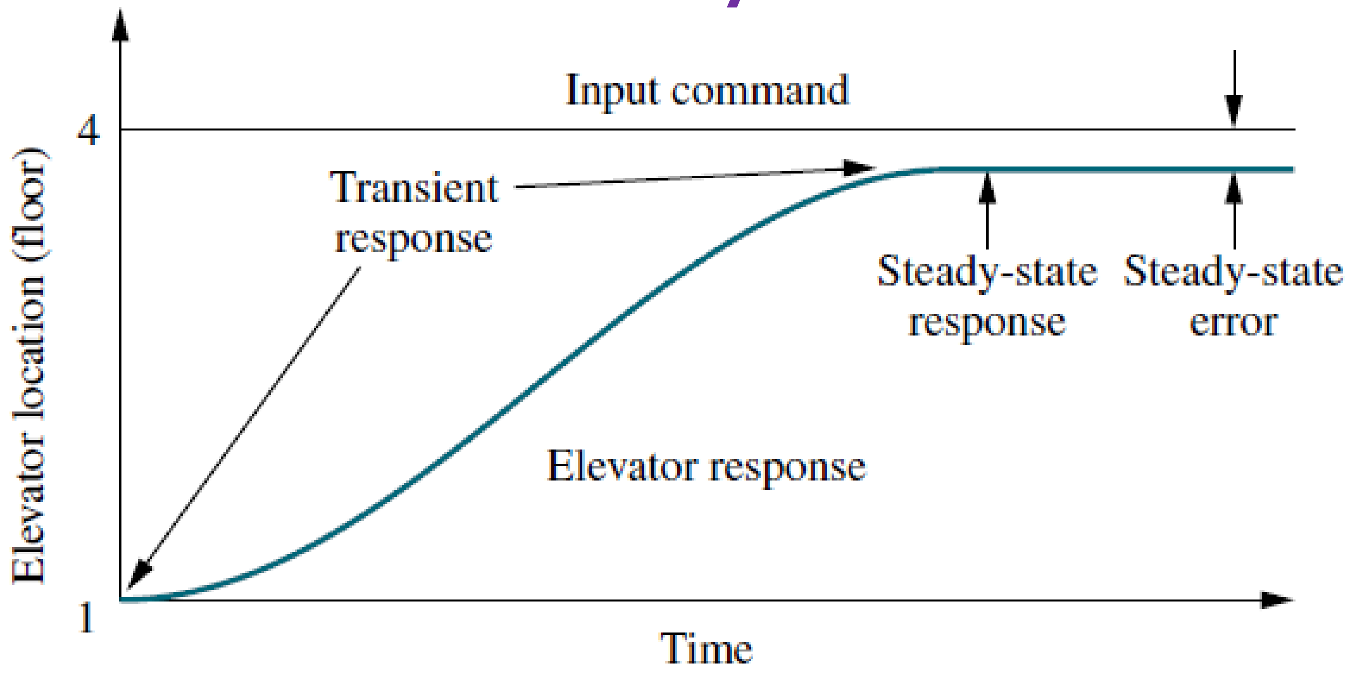
Elevator System



Systems

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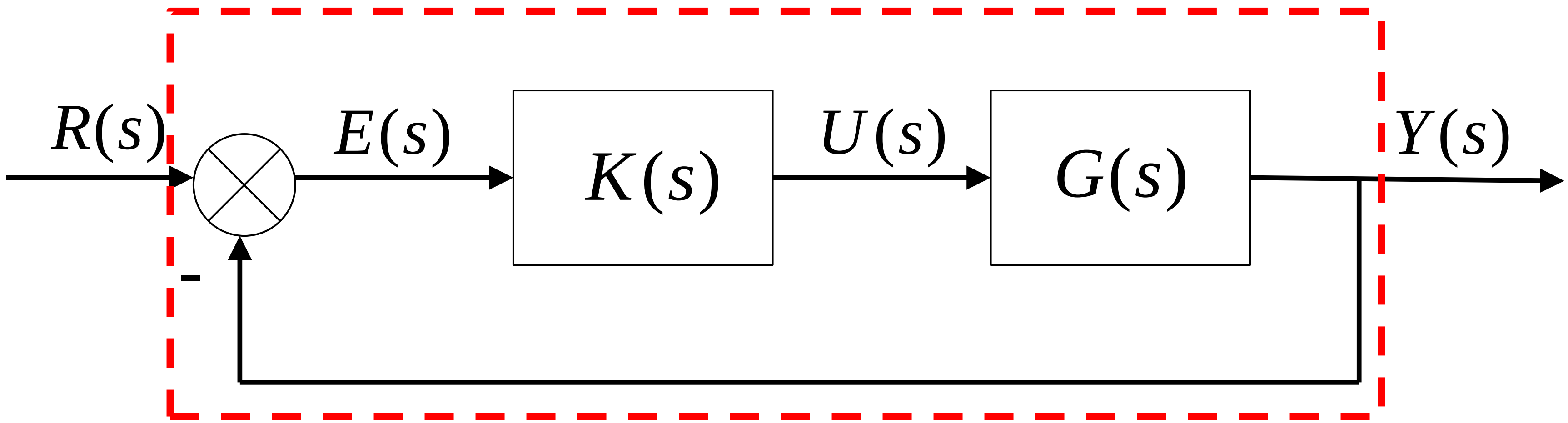
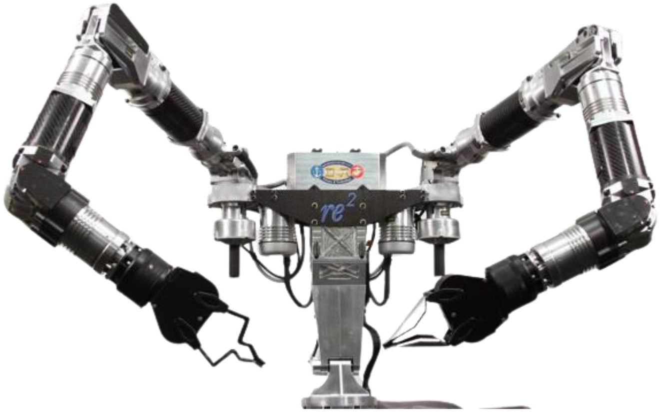


Control Systems

- **How do we control these robotic systems?**



SYSC3600 Systems and Simulation

SYSC4505 Automatic Control Systems

Modeling

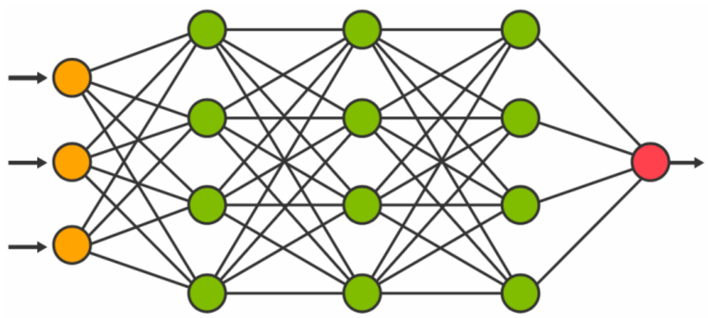
- **Two types of modeling methods**

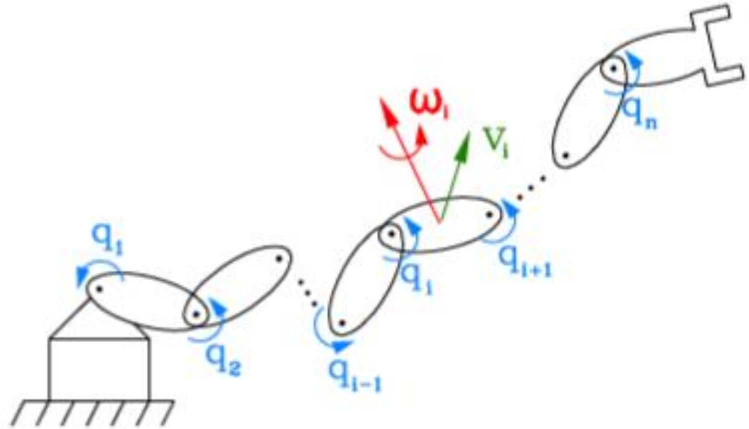
  - **First-principle methods** (Mathematical models)
    Based on physics: Newton's law, Kirchhoff laws, Conservation of energy/momentum, etc.

$$\tau = \mathrm{D}(\mathrm{q})\,\ddot{\mathrm{q}} + \mathrm{C}(\mathrm{q}, \dot{\mathrm{q}})\,\dot{\mathrm{q}} + \mathrm{G}(\mathrm{q})$$

  - **Data-driven methods** (Empirical models)
    Based on data: curve fitting, regression, interpolation, extrapolation, etc.

$$\tau = \mathrm{Y}(\mathrm{q}, \dot{\mathrm{q}}, \ddot{\mathrm{q}})\,\theta_b$$



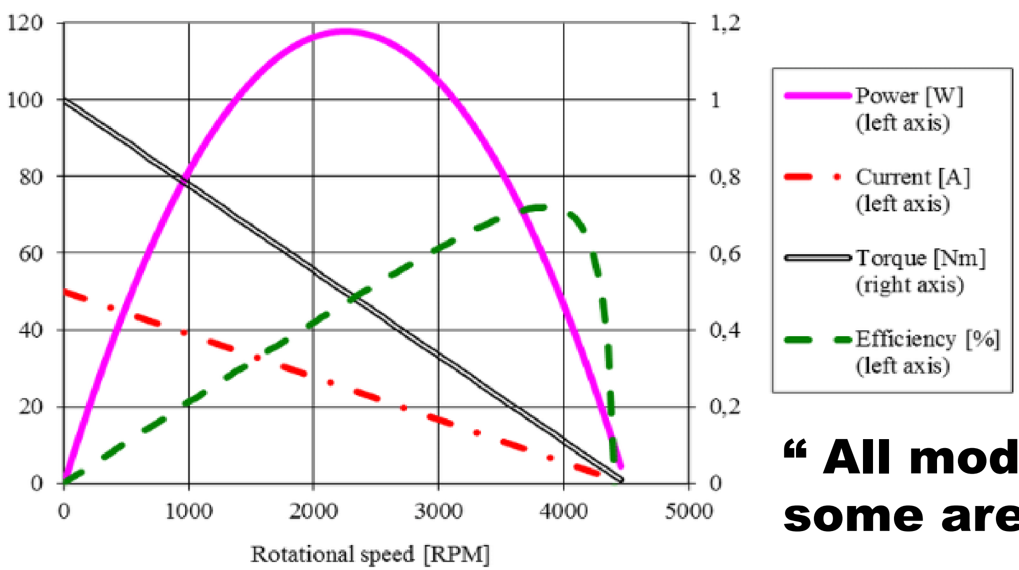


Modeling

- **Two types of modeling methods**

  - **First-principle methods** (Mathematical models)
    Pros: exact math equations, interpretability, robustness
    Cons: subject knowledge needed, simplicity vs. accuracy

  - **Data-driven methods** (Empirical models)
    Pros: no subject knowledge needed, routine procedure
    Cons: poor interpretability, unknown working range



“ All models are wrong, but some are useful! ”

Modeling

- **Two types of modeling methods**

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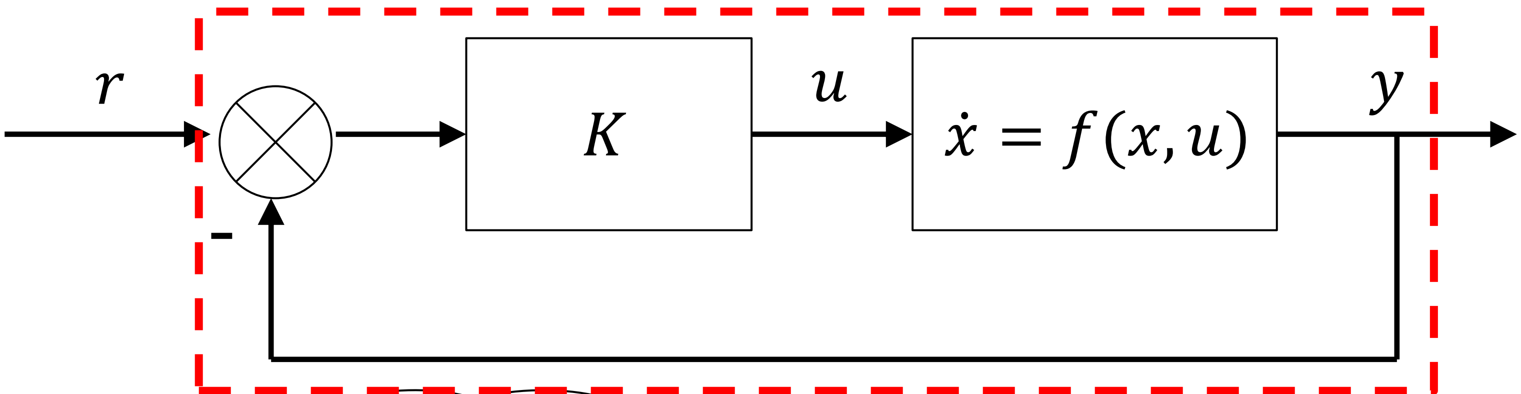


Feedback loop helps!

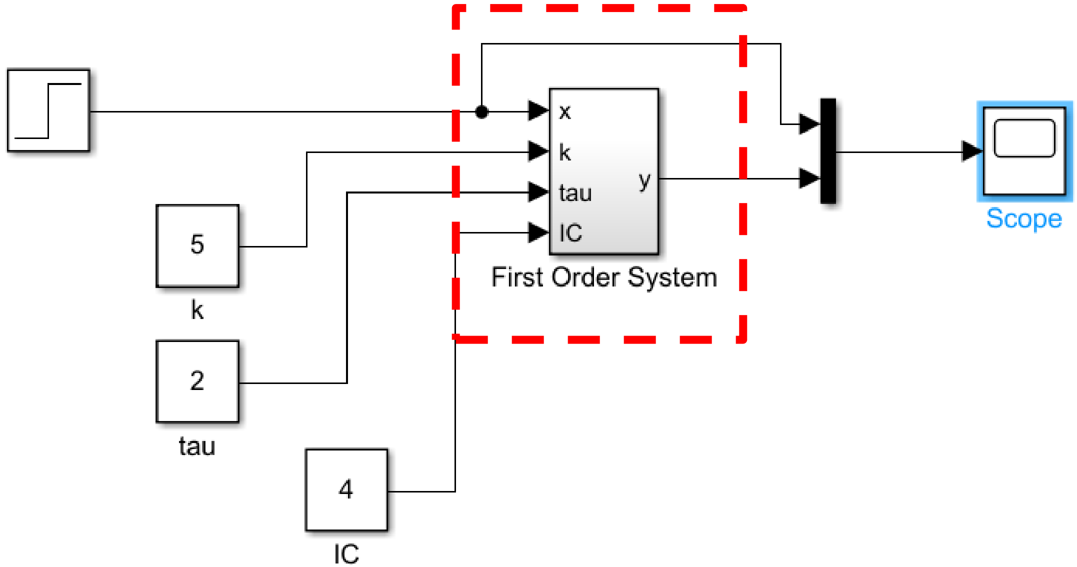
“ All models are wrong, but some are useful! ”

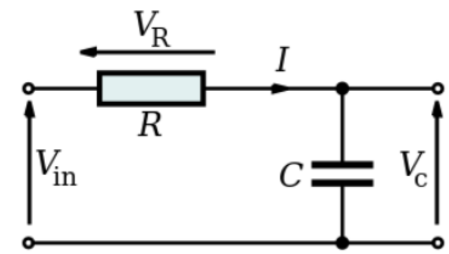
Simulation

❑ What is simulation?

- Implementation of the **mathematical model** of the system in computer programs to determine the response of the system to different inputs of interest and system parameters to help the system design.

- It is cost effective to verify your design in simulator first.





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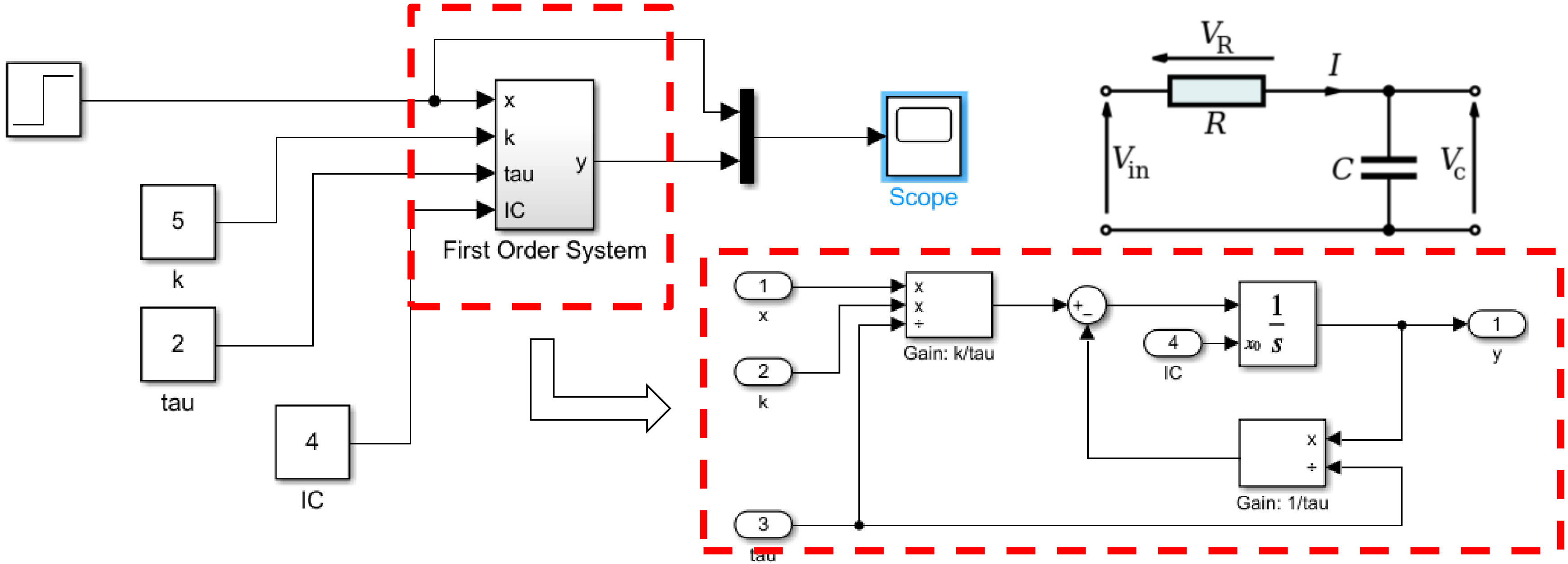
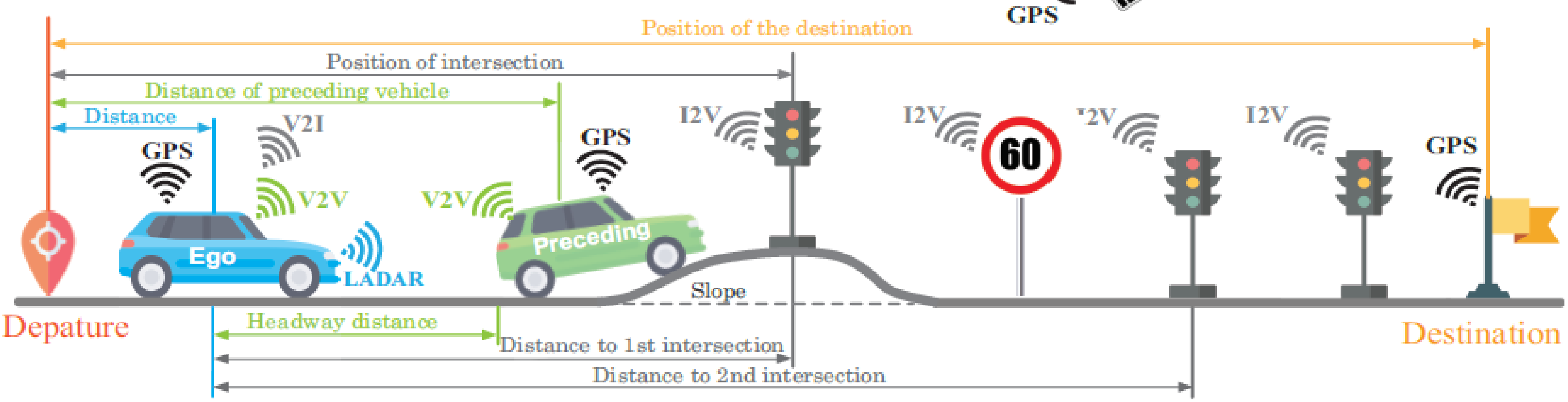


Simulation

❑ HEV Optimal Control in Connected Environment

A benchmark challenge problem in 6th IFAC conference on Engine and Powertrain Control, Simulation and Modeling (ECOSM 2021)

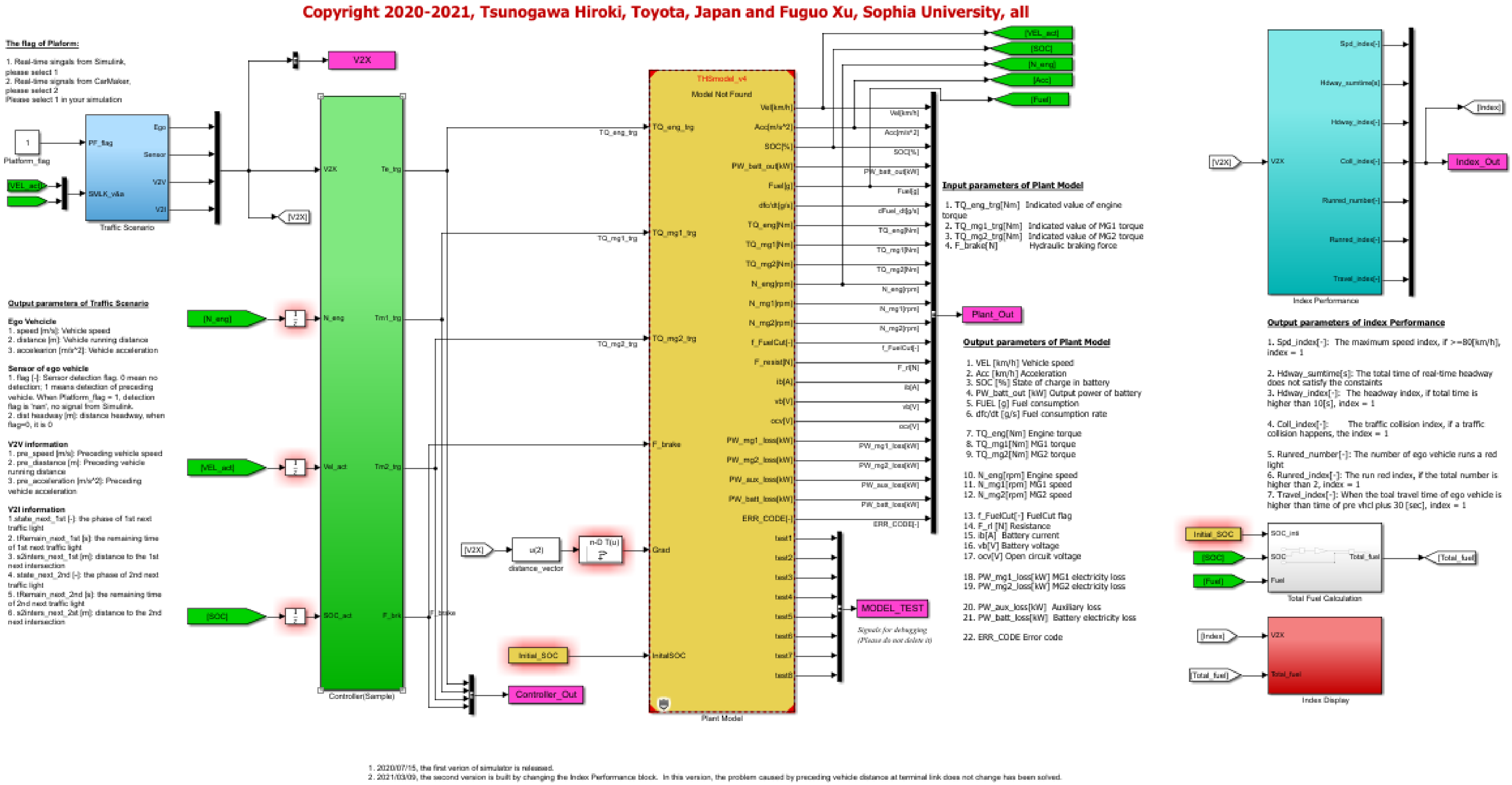
http://shenlab.jp/ecosm2021/program/benchmark-challenge.html



X. Gong, *et al*., "Benchmark study on real-time energy optimization of HEVs under connected environment", IFAC-PapersOnline, vol.54, no. 10, pp. 356-362, 2021

Simulation

❑ A Simulink model for HEV Optimal Control



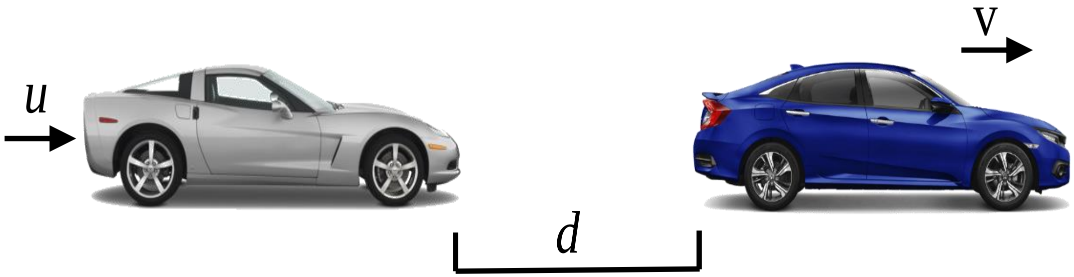
Experiment

- ❑ **Experimental validation and iterative design.**

Performance Evaluation

❑ Performance Evaluation

- Control Theory = How do we pick the input signal u?
- Objectives:
    - Stability
    - Tracking
    - Robustness
    - Disturbance Rejection
    - Optimality



Performance Evaluation

- ARS applications are often **Safety Critical**

(a) Autonomous Driving

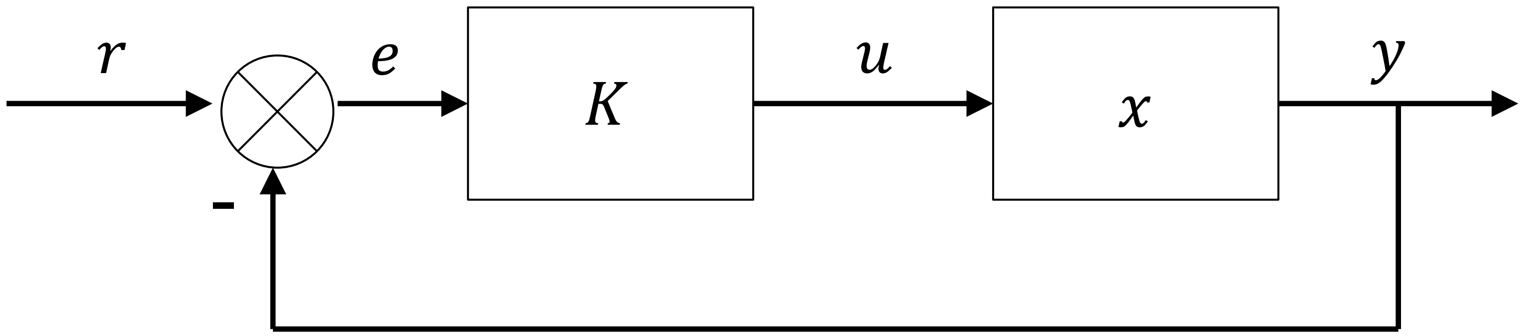
(b) UAVs

- We strive to develop the systematic design methodology for ARS to guarantee safety.

Control System Design

❑ The Basic Building Blocks

- State = Representation of what the system is currently doing
- Dynamics = Description of how the state changes
- Reference = What we want the system to do
- Output = Measurement of (some aspect of the) system
- Input = Control signal
- Feedback = Mapping from outputs to inputs



Autonomous Robotic Systems

- Why ARS?
  - Efficient and capable
  - Cost-effective and safe
- Examples of ARS

(a) UAVs (b) MRs (c) AUVs

Autonomous Robotic Systems

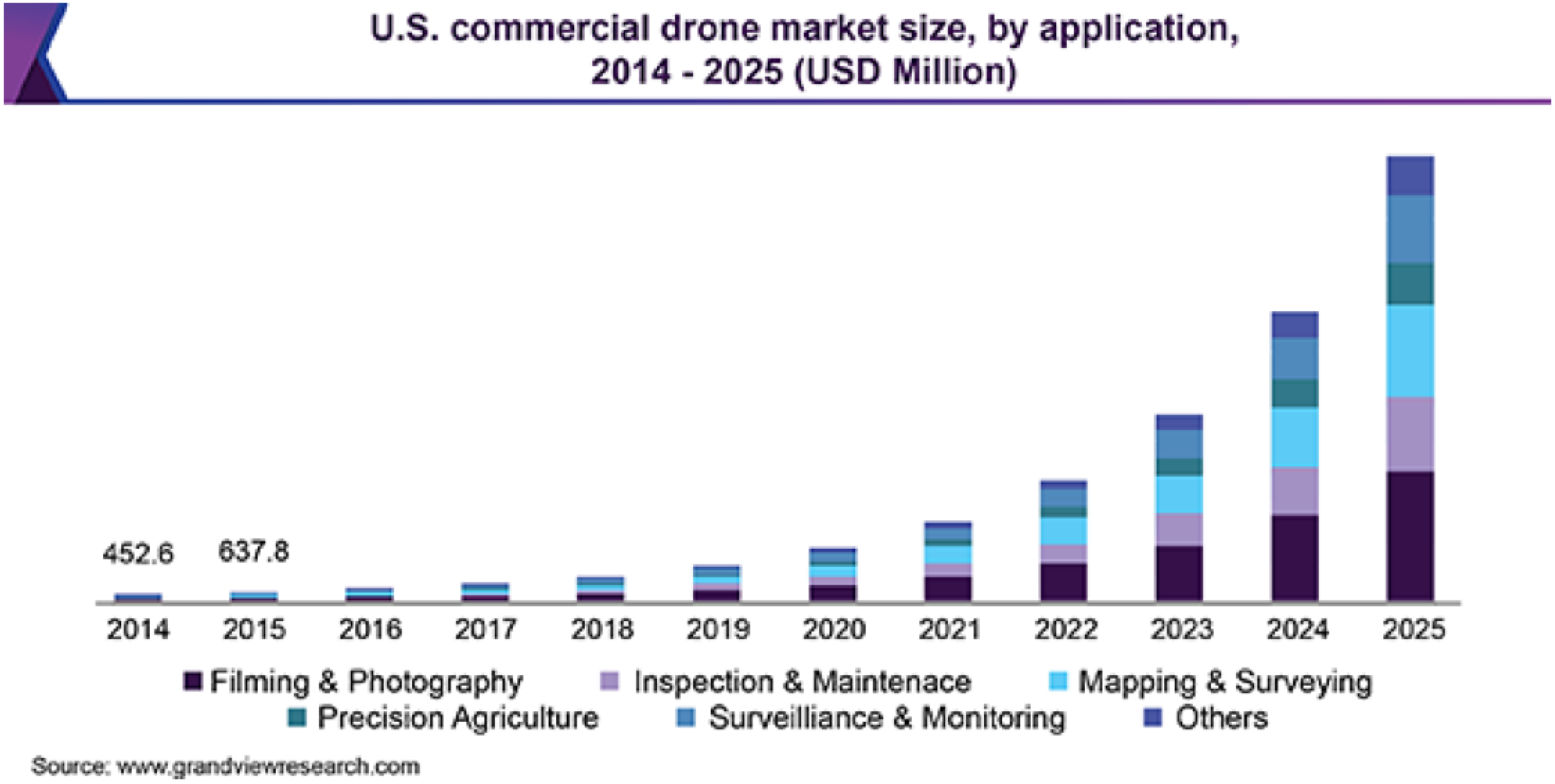


Figure: The exploding size of UAV market.

Autonomous Robotic Systems

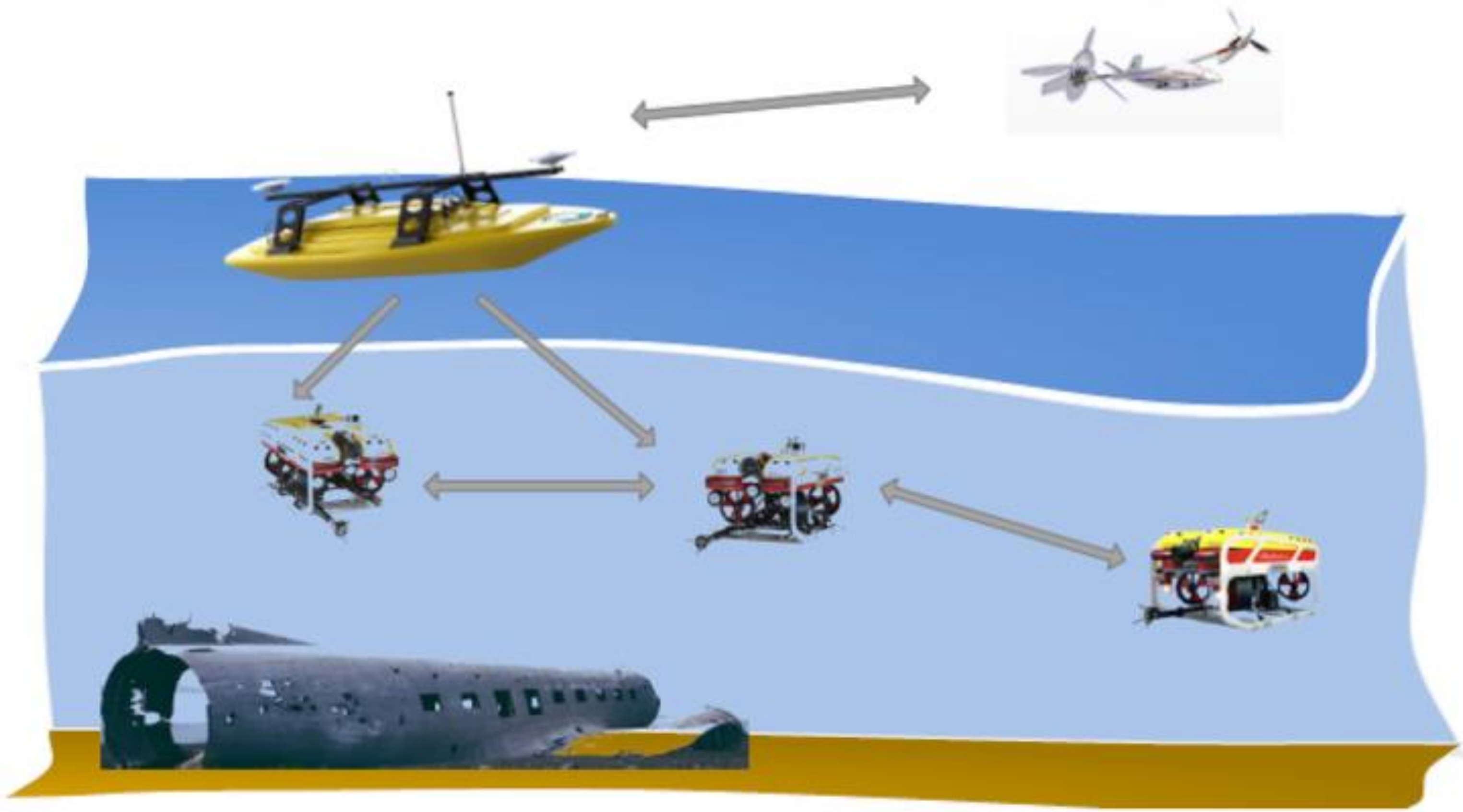


Figure: A search and rescue mission for multi-robot systems.

Autonomous Robotic Systems

Navigation
Where am I?

Which way should I take to get to the destination?

Control
How can I follow the way?

How do I take maneuvers to adapt to the surroundings?

Endurance
How do I mange my power?

Can I work longer by optimizing the use of power?

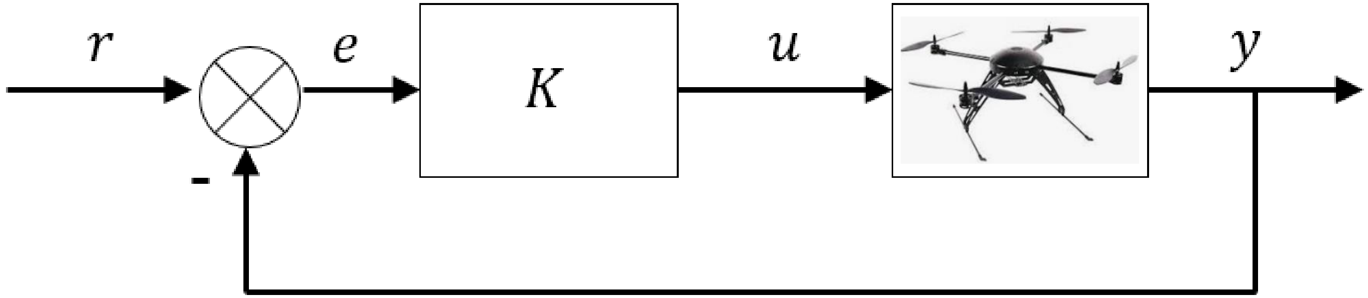
Communication
How do I communicate with my coworkers?

How do I handle the latency?

Perception
How do I fuse sensor information?

What can I interpret from the sensor information?

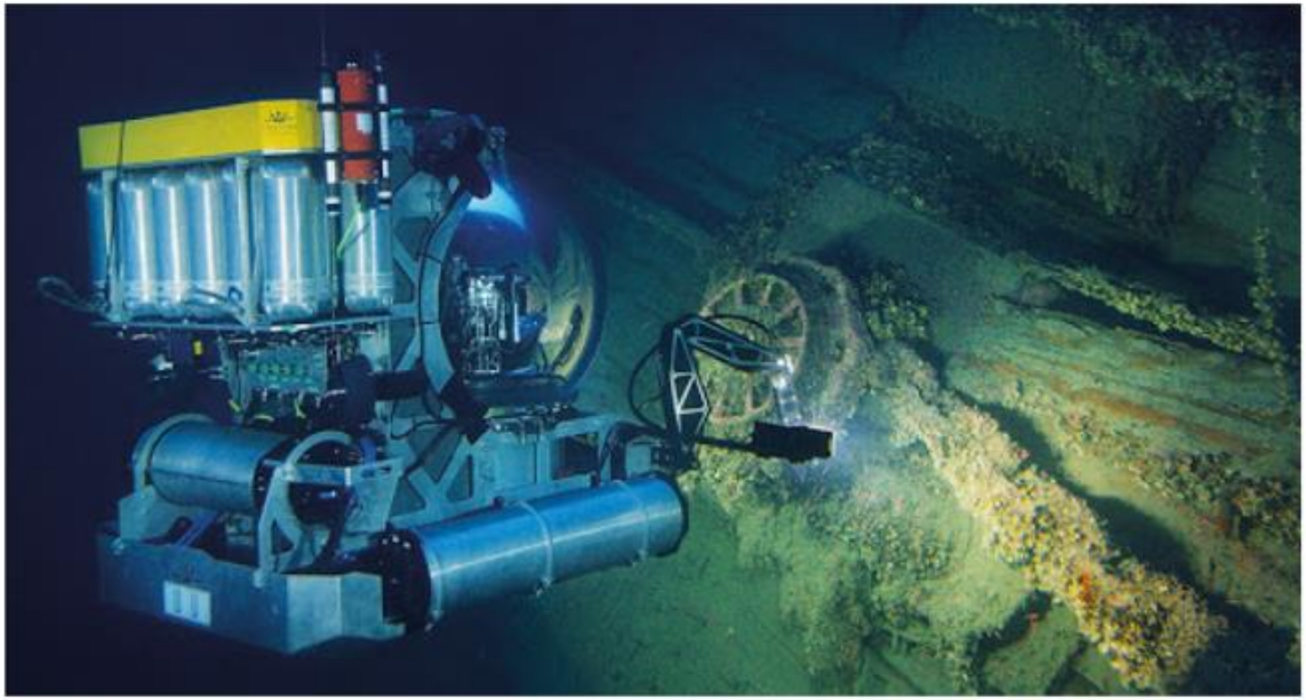
Autonomy
How do I make decisions based on all information I have to better perform a task?



Robotic Systems Applications

The Integrated Planning and Control Problem

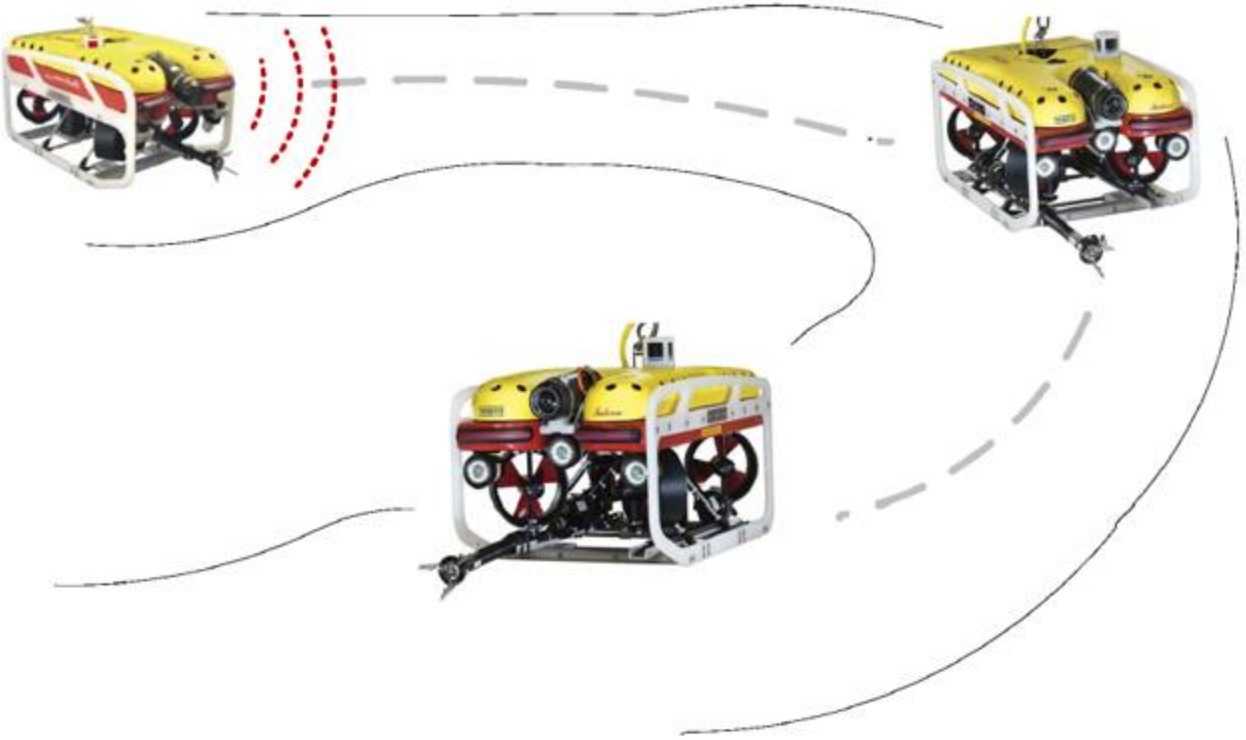
- In marine archaeological applications, we encounter the problem of autonomous navigation in a constrained workspace.



Robotic Systems Applications

The Integrated Planning and Control Problem

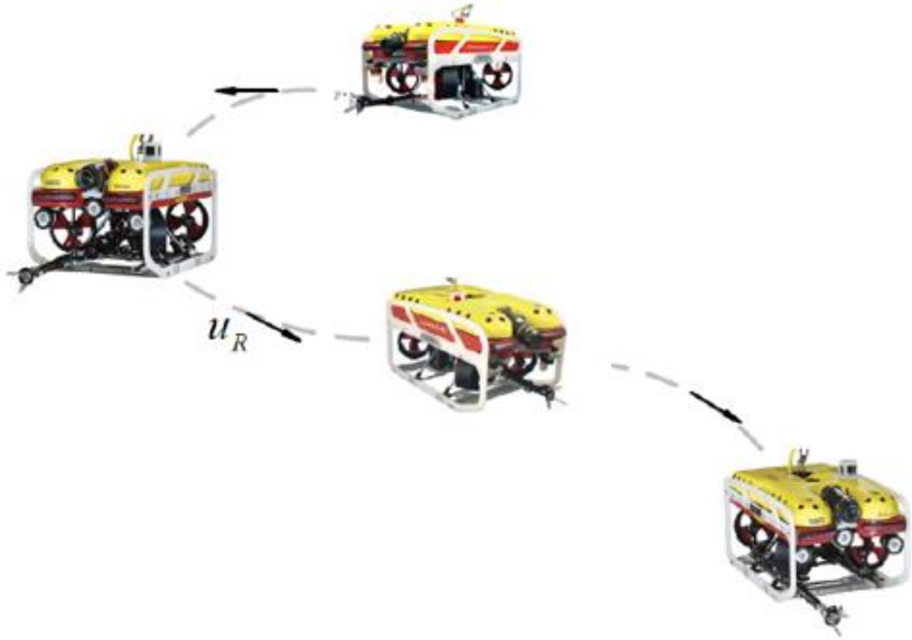
- Planning: To avoid collisions, limited sensing, good for tracking
- Tracking: Complex dynamics, limited actuation, convergence



Robotic Systems Applications

The Integrated Planning and Control Problem

- With appropriate choice of reference velocity, the system dynamics can be partially **decoupled**.



- We could solve the original problem by **distributed optimization**.

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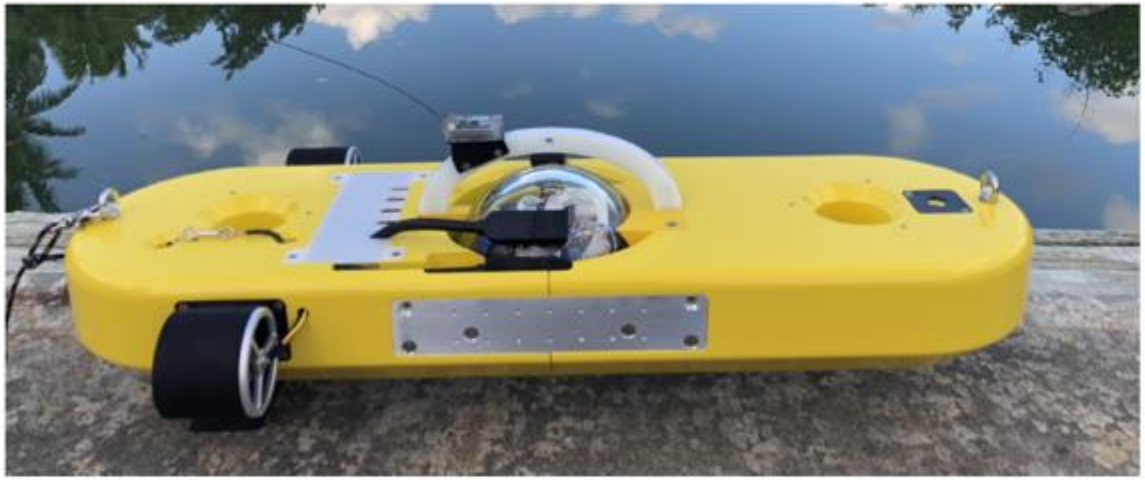
[1] **C. Shen** and Y. Shi, "Distributed Implementation for Nonlinear Model Predictive Tracking Control of an AUV", *Automatica*, vol. 115, pp. 108863, 2020

Robotic Systems Applications

Energy Efficient Control System Design Problem

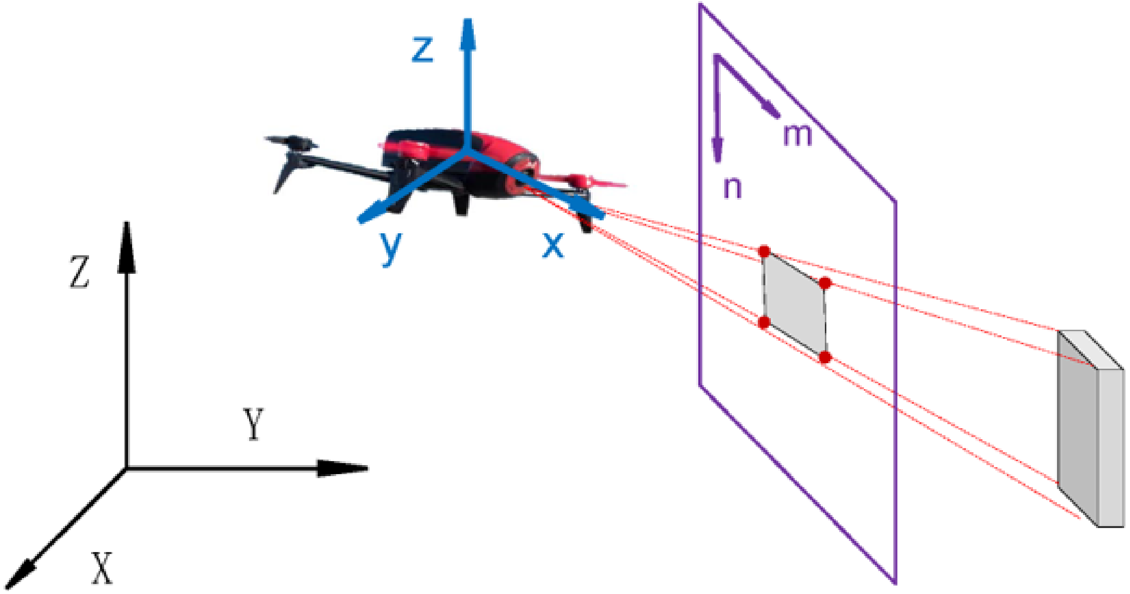
- The Control System Could Be Energy-Aware to Improve the Endurance of AUVs



Robotic Systems Applications

Vision-Based Control for UAVs

- Pose-Based Visual Servo and Image-Based Visual Servo



- Maintaining the object in FOV is important.

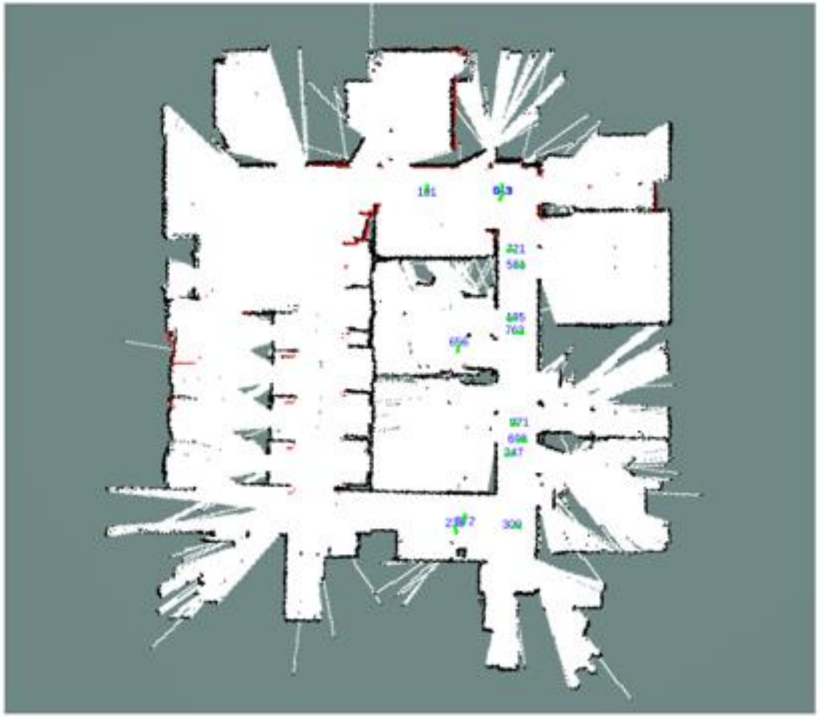
Robotic Systems Applications

[1] Y. Gao, X. Wang, E. Honsch, R. Ma, **C. Shen**, M. Chen, Y. Lu, J. Liang, and J. Wu, "High-Performance Visual Object Tracking for Embedded Vision Systems", AltumView Systems Inc., Canada. *Published in October 2019*, US20190304105A1.

Robotic Systems Applications

AI-Enhanced Visual Simultaneous Localization and Mapping

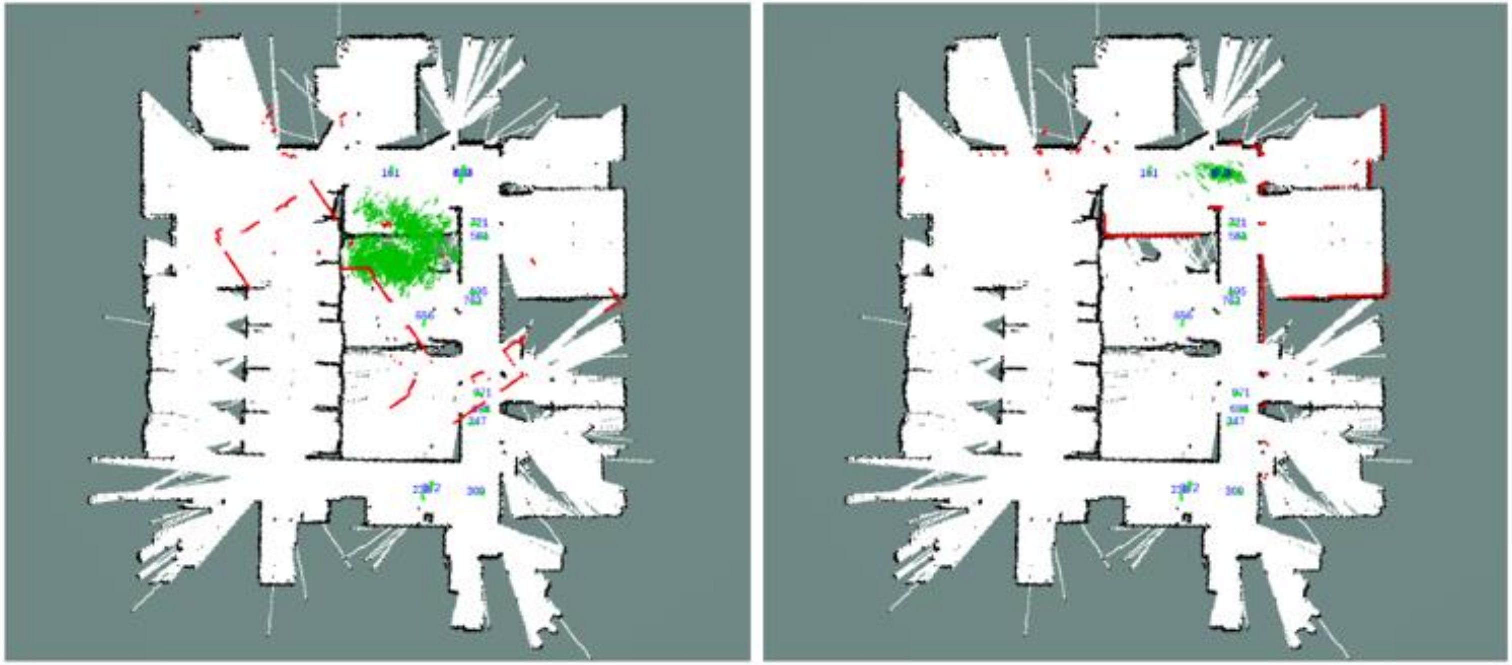
(e) The robot to perform SLAM



(f) SLAM result with text detection

AI in Robotic Systems

AI-Enhanced Visual Simultaneous Localization and Mapping



(g) The robot is lost track (h) Recover the localization

[1] R. Ma, **C. Shen**, M. Chen, Y. Lu, J. Liang, and J. Wu, "Semantic SLAM based on Robust Scene Text Detection and Recognition", AltumView Systems Inc., Canada. *Submitted to US Patent and Trademark Office*, 2020.

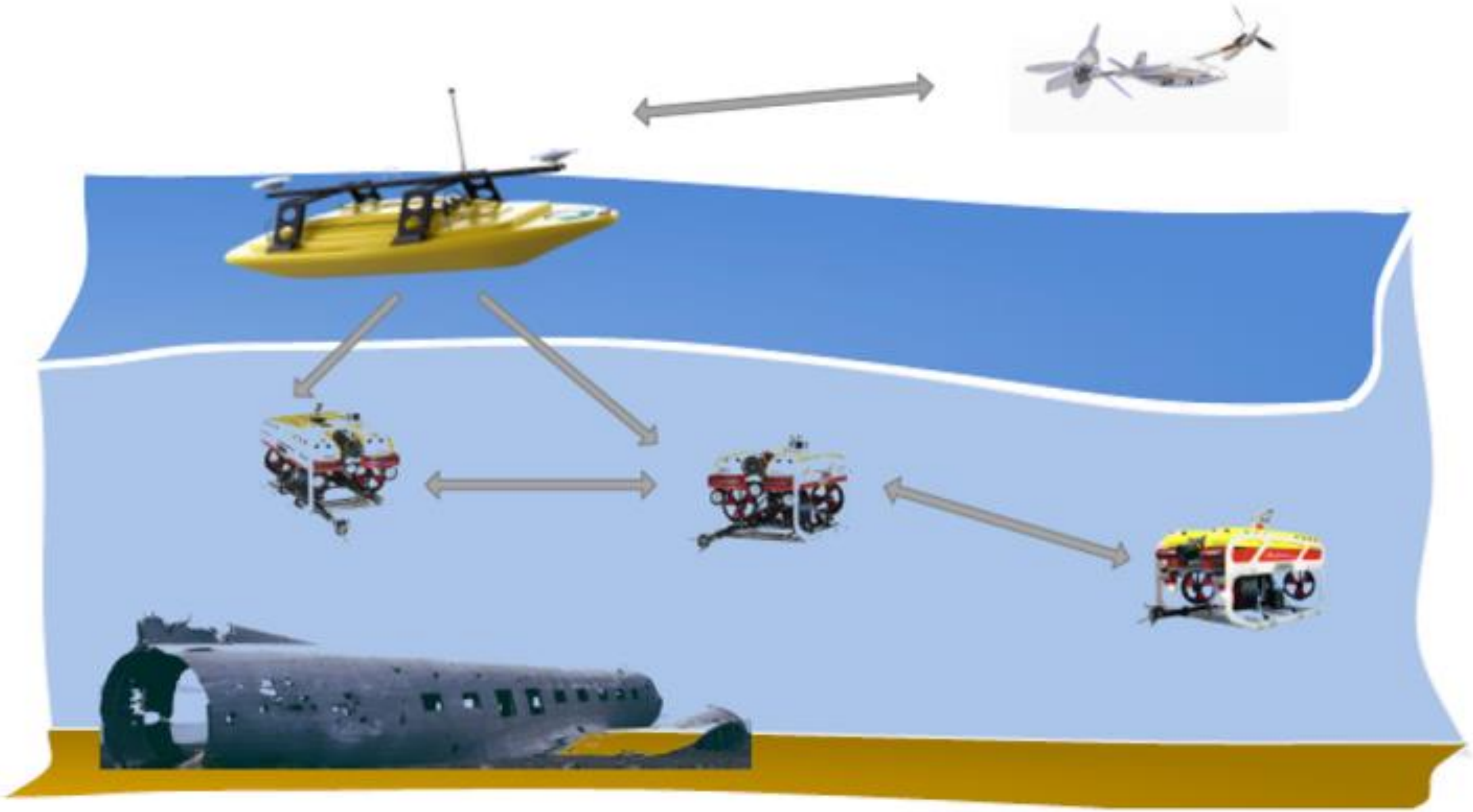
Human Behavior Understanding

Original Camera View

[1] **C. Shen**, Y. Gao, J. Zheng, A. Au, D. Zhang, E. Honsch, M. Chen, and J. Liang, “Real-Time Violence Detection using AI-enabled Computer Vision”, AltumView Systems Inc., Canada. *Submitted to US Patent and Trademark Office*, 2020.

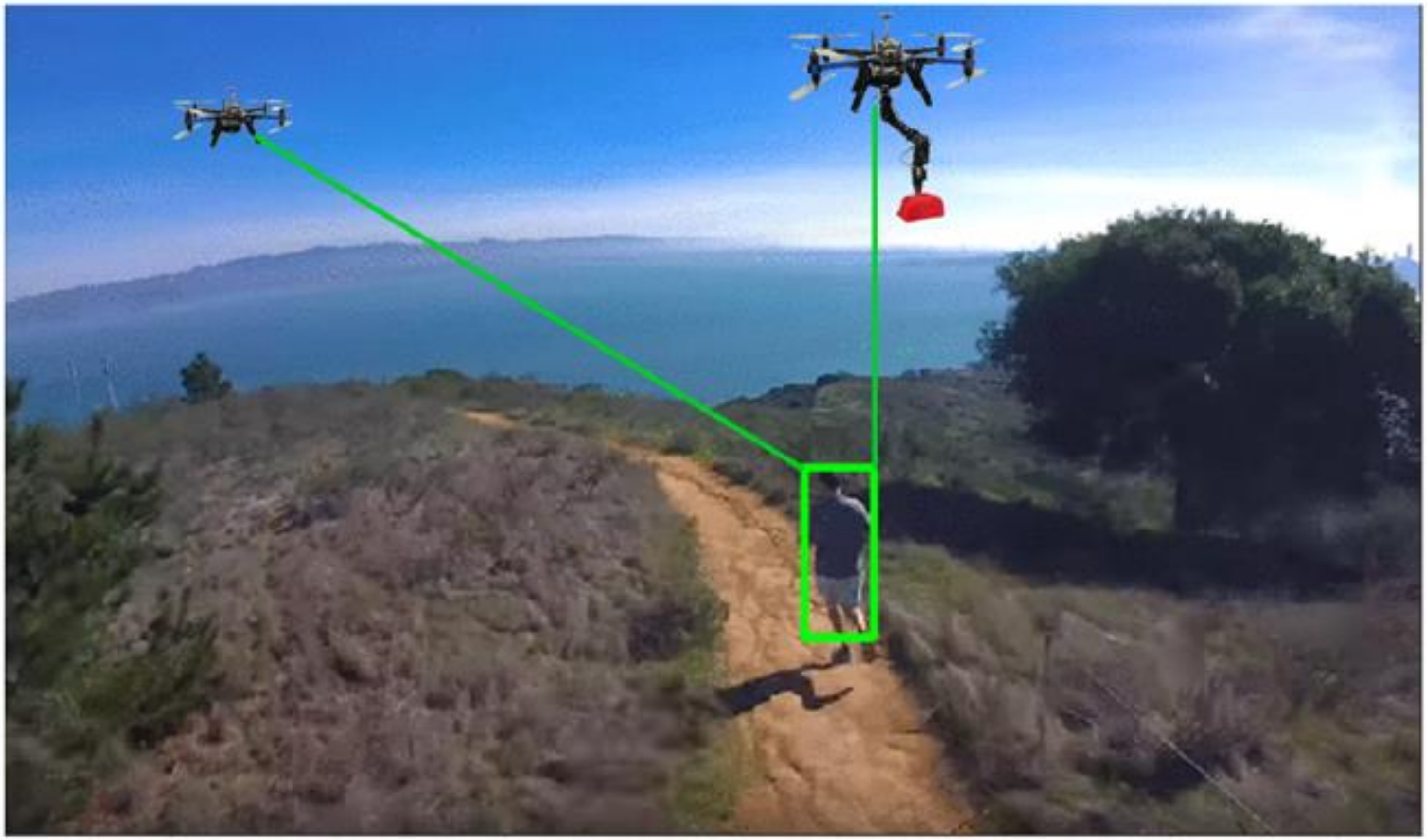
Intelligent Robotic Team

Autonomy of Cooperative ARS



Autonomous Robotic Systems

AI-based CV and advanced control opened up new dimensions for UAV applications



Summary

- **Introduction of robotic systems from a control system perspective.**
- **Robotic applications and related design problems.**

Takeaway Messages

- Robotic systems are inherently computer systems.
- Robotics are machines that automate the tasks, which essentially describe an automatic control system.
- The broad robot control system design needs to solve many complex problems including sensing, perception, navigation, planning, and control.
- AI and advanced control theories present powerful tools to extend the robot ability and improve performance.