Software-In-Loop-Simulation Using VR/Game Environment

- Updates and Future Works -

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AVIATE SEMINAR
04/21, 2023

Credits: NASA / Lillian Gipson

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University of Nevada, Reno
LOCKHEED MARTIN
SIERRA NEVADA CORPORATION

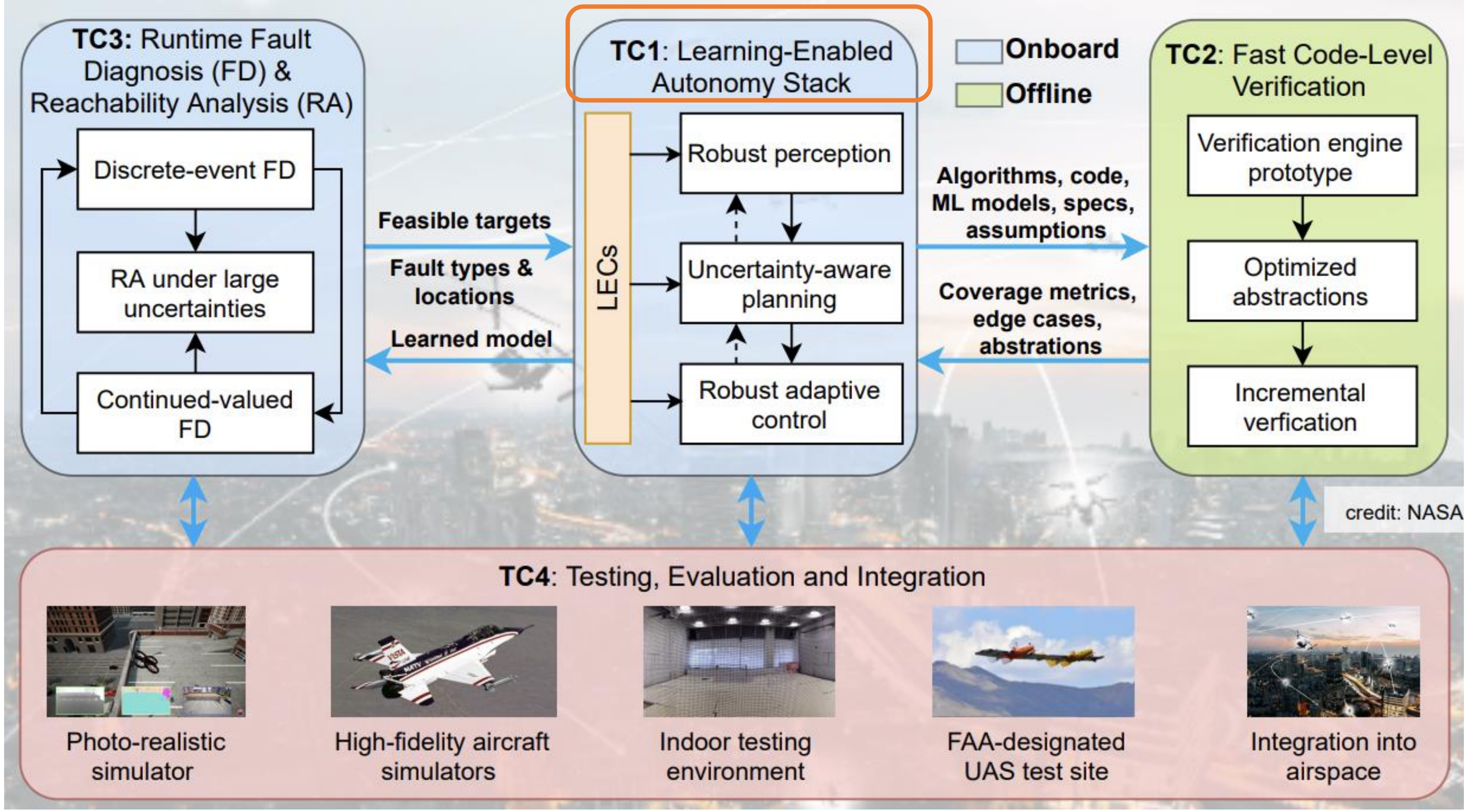
Outline

- **Introduction**
- **The Simulation Tool**
- **Updates:**
  - MATLAB Simulink Integration for NASA's vehicle simulation model.
  - 2D path planning with Lidar sensor.
- **Use Cases of the Game Environment and Future Works**
  - Adversarial Image Perturbations Against Autonomous Vehicles*
  - Robust Control in the UAV Object Detection Autonomy Pipeline
  - Future Works on the Simulator

*Yoon, Hyung-Jin, Hamidreza Jafarnejadsani, and Petros Voulgaris. "Learning When to Use Adaptive Adversarial Image Perturbations against Autonomous Vehicles." IEEE Robotics and Automation Letters (RA-L) *Accepted*.

Introduction

ENGINEERING FRAMEWORK TO BE TESTED



We need methods to implement the

Learning-Enabled Autonomy Stack (TC1)

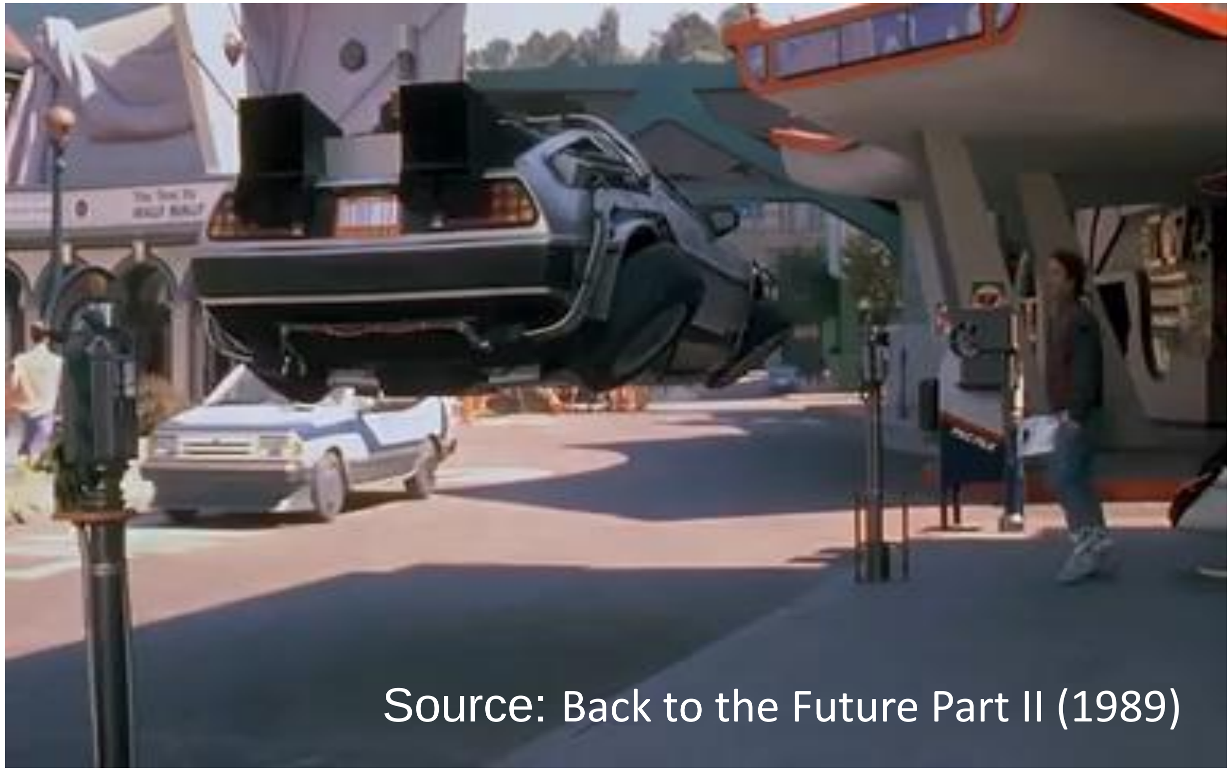
for Testing (TC4), Verification (TC2), and Fault Diagnosis (TC3).

PHOTO REALISTIC SIMULATORS IN AUTONOMOUS CAR

Photo Realistic Simulation using **VR/Game** engine has become an **industry standard** for developing and testing autonomous driving software stacks.

Therefore, we aim to implement the *Learning-Enabled Autonomy Stack (TC1)* with **VR/game environment**.

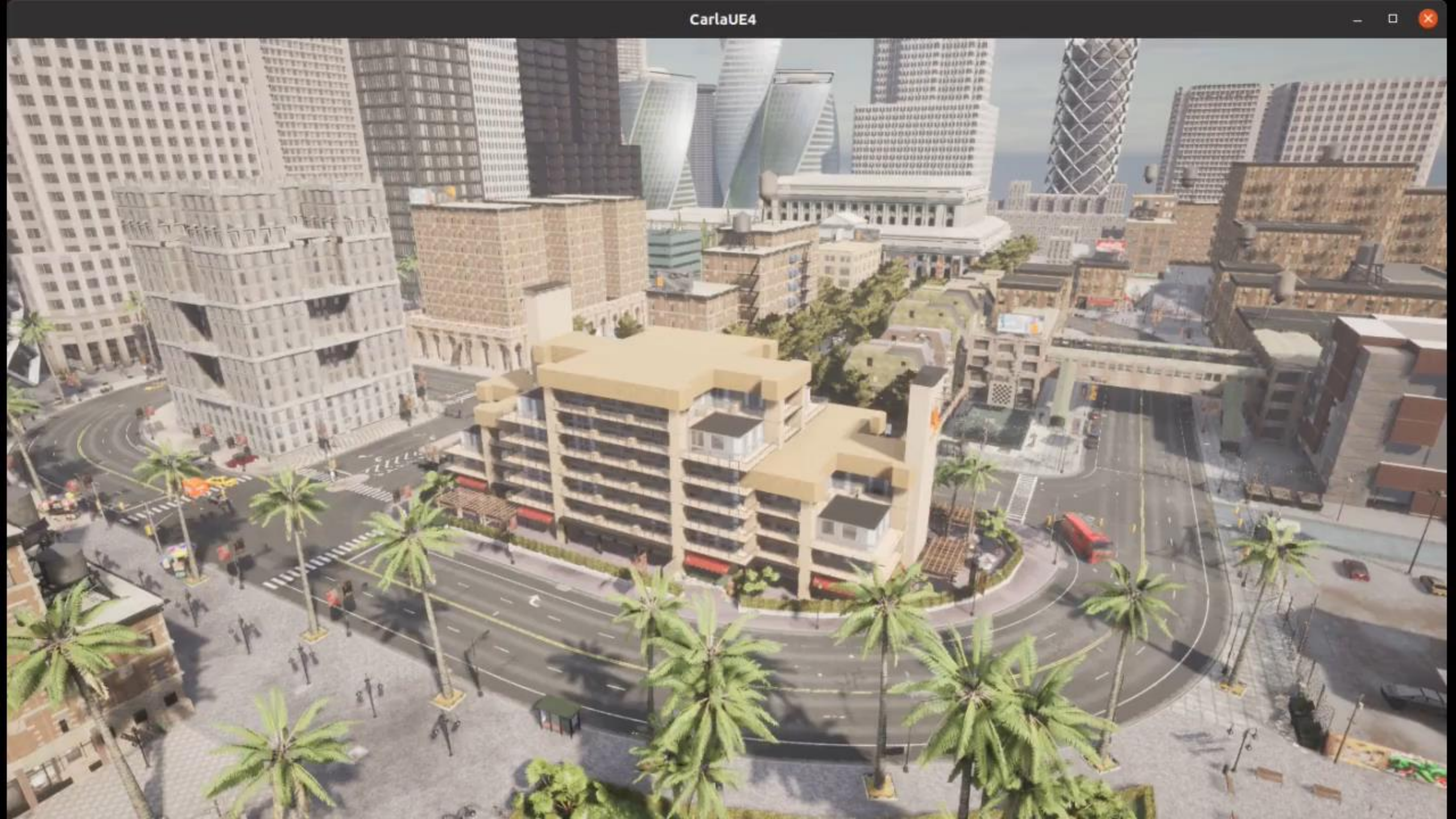
SIMULATION ENVIRONMENT



*Urban Air Mobility (**UAM**) Landing on **Street***

Learning-Enabled Autonomy Stack (TC1) will be tested in simulation for landing and taking-off in **cluttered environments** (see the left) using **perception**, **planning**, and **control methods**.

Therefore, we are using an urban environment developed by ***CARLA***.


CarlaUE4

DISCUSSION

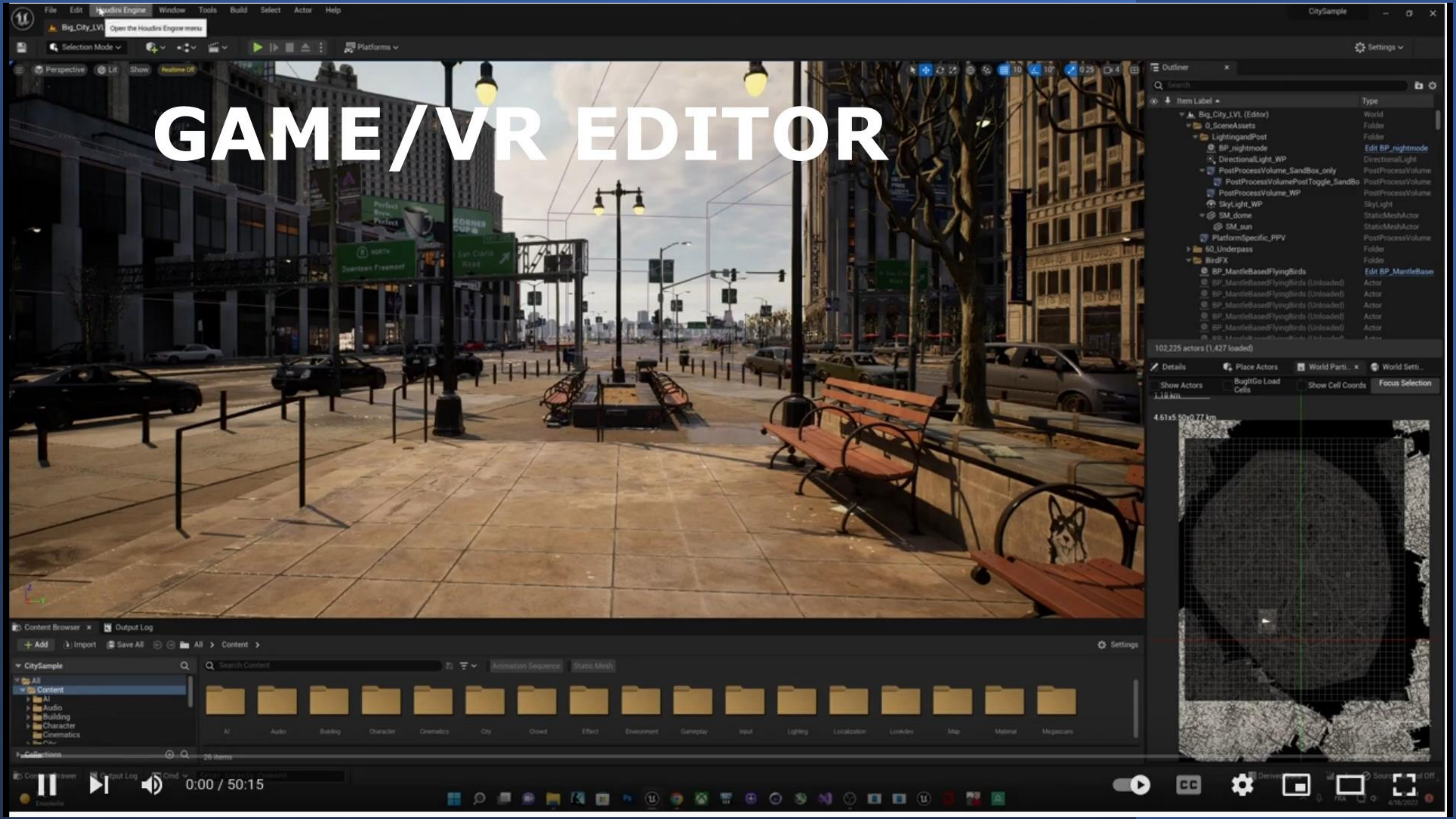
- How far **realistic** and **detailed** simulation do we need?

Figure 1.3 Deterministic vs. stochastic optimization

	Deterministic	Stochastic
Models	System of equations	Complex functions, numerical simulations, physical systems
Objective	Minimize cost	Policy evaluation, risk measures
Searching for	Real-valued vectors	Functions (policies)
Goal	Finding optimal decision	Finding optimal policies
What is hard	Designing algorithms	Modeling

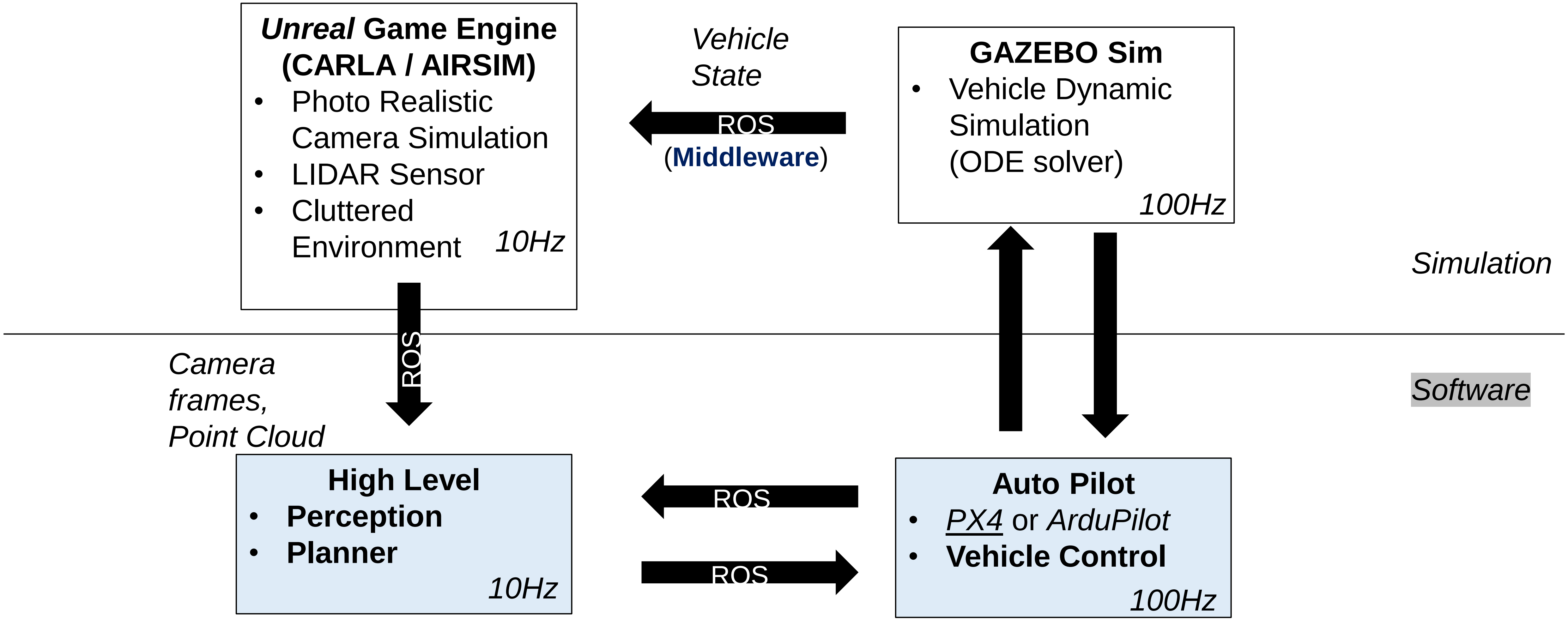
*See the **freely available** (community license?) **VR/Game project** in the next slide.*

From lecture note (or a book draft) titled as "OPTIMIZATION UNDER UNCERTAINTY A unified framework (Draft)" by Warren B. Powell


GAME/VR EDITOR
File
Edit
Houdini Engine
Window
Tools
Build
Select
Actor
Help
Open the Houdini Engine menu
CitySample
Selection Mode
Platforms
Settings
Perspective
Lit
Show
Outliner
Item Label
Type
Big_City_LVL (Editor)
0_SceneAssets
LightingandPost
BP_nightmode
DirectionalLight_WP
PostProcessVolume_SandBox_only
PostProcessVolume_WP
SkyLight_WP
SM_dome
SM_sun
PlatformSpecific_PPV
60_Underpass
BirdFX
BP_MantleBasedFlyingBirds
102,225 actors (1,427 loaded)
Details
Place Actors
Show Actors
Show Cell Coords
Focus Selection
Content Browser
Output Log
Add
Import
Save All
All
Content
Settings
CitySample
Audio
Building
Character
Cinematics
0:00 / 50:15

The Simulation Tool

MODULAR IMPLEMENTATION DIAGRAM

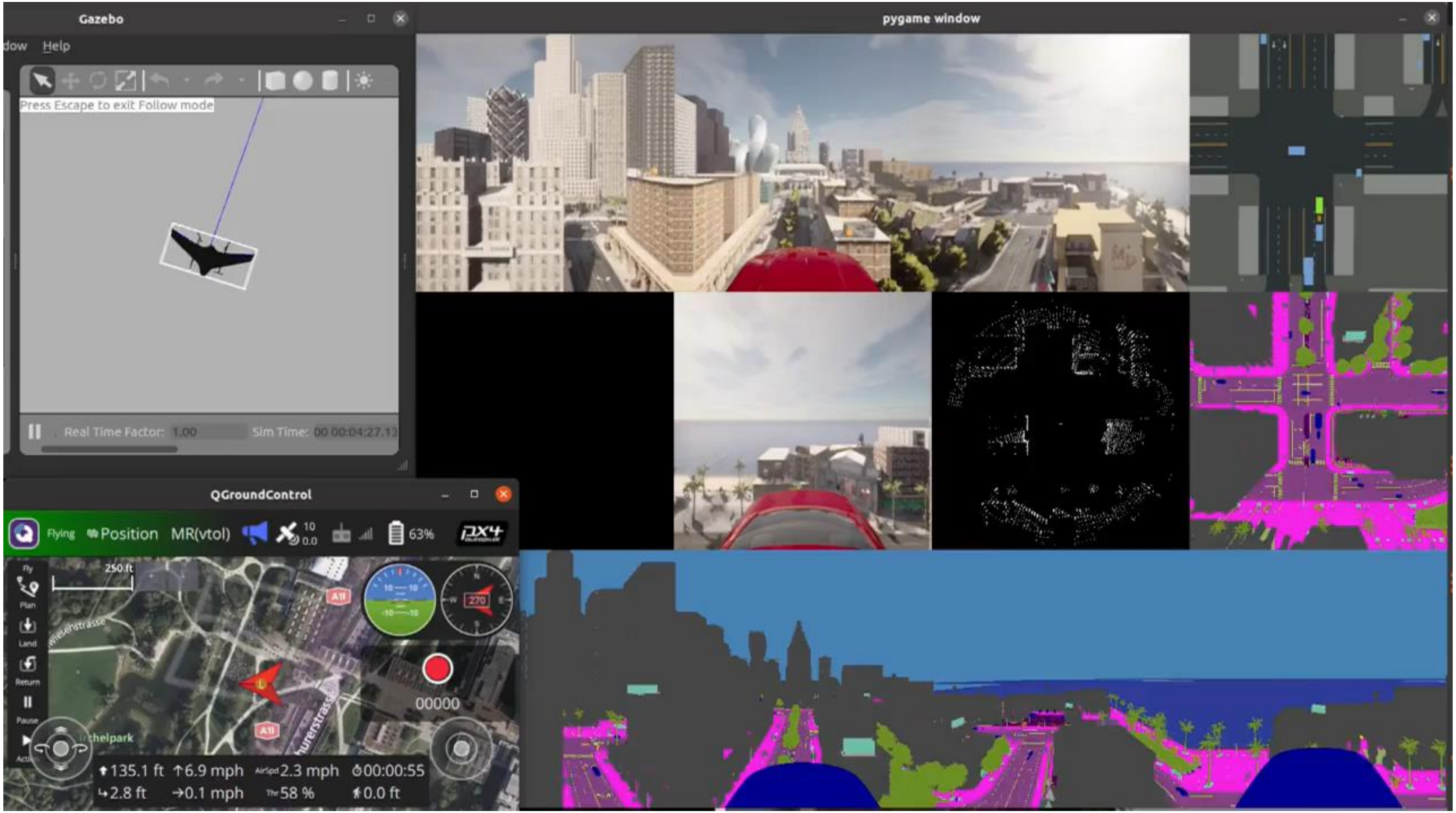


https://github.com/AutoRally/autorally/blob/melodic-devel/autorally_core/CMakeLists.txt

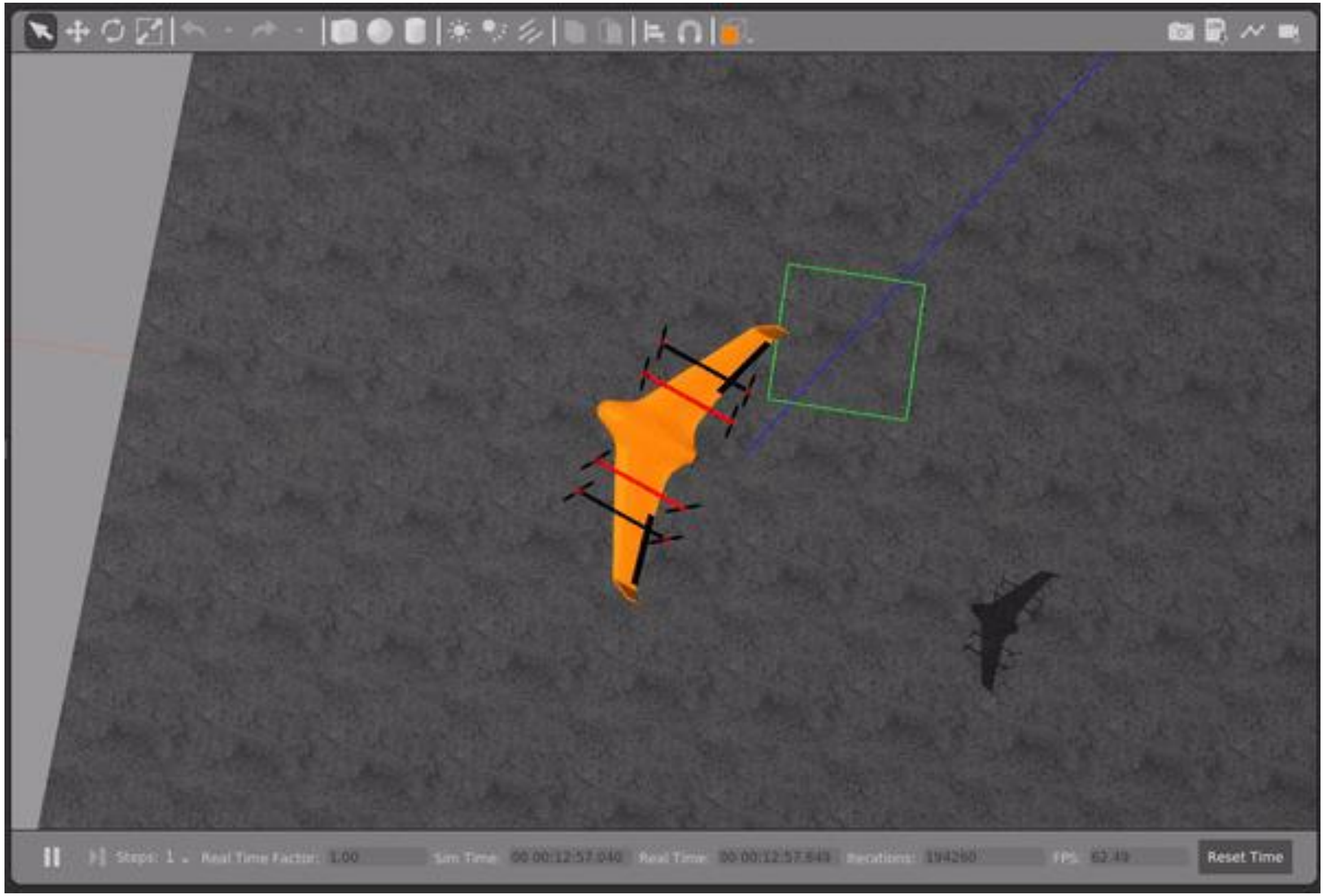
https://px4.io/

VTOL SIM – PX4 AUTOPILOT – UNREAL GAME ENGINE

VTOL SIM – PX4 AUTOPILOT – UNREAL GAME ENGINE



CUSTOMIZING THE VTOL VEHICLE



This customized vehicle has **4 more propellers** for vertical take-off.

The ***Lift+Cruise*** by **NASA** is a full-scale, VTOL, distributed propulsion aircraft concept with **eight fixed-pitch lifting rotors** and **one variable-pitch, rear-mounted pusher propeller.**

COMMERCIAL VTOL SYSTEMS WITH PX4 AUTOPILOT SW

VOLY M20 by *Volansi*

VOLY M20 Specification

Body length: 2.5m
Wingspan: 3.8m
Maximum takeoff weight: 50kg
Maximum payload: 15kg
Flying radius: 200-400km
Maximum speed: 130km/h
Maximum oil load: 12L
Lift limit: 4000m
Maximum wind resistance: 12m/s (6 wind)

https://www.deltaquad.com/

PX4 Autopilot S/W is used for **commercial VTOL** systems that have 2 to 4 meters wingspans.

Updates

MATLAB SIMULATION MODEL INTEGRATION

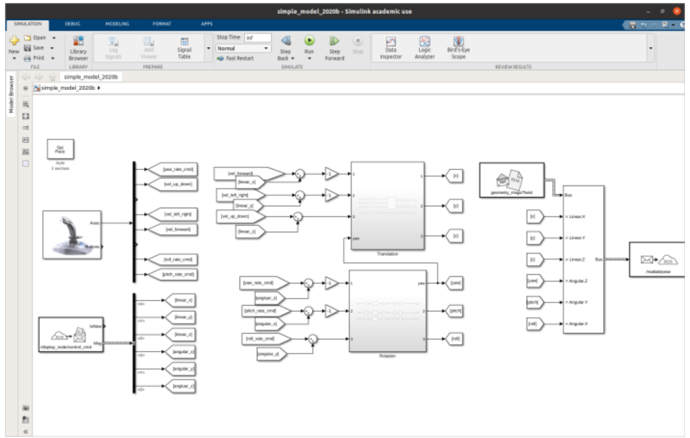
***Unreal* Game Engine**
(CARLA / AIRSIM)
- Photo Realistic Camera Simulation
- LIDAR Sensor
- Cluttered Environment

10Hz

Vehicle State

ROS
(**Middleware**)

MathWorks®
ROS in Simulink



Simulation

ROS

Camera frames, Point Cloud

Software

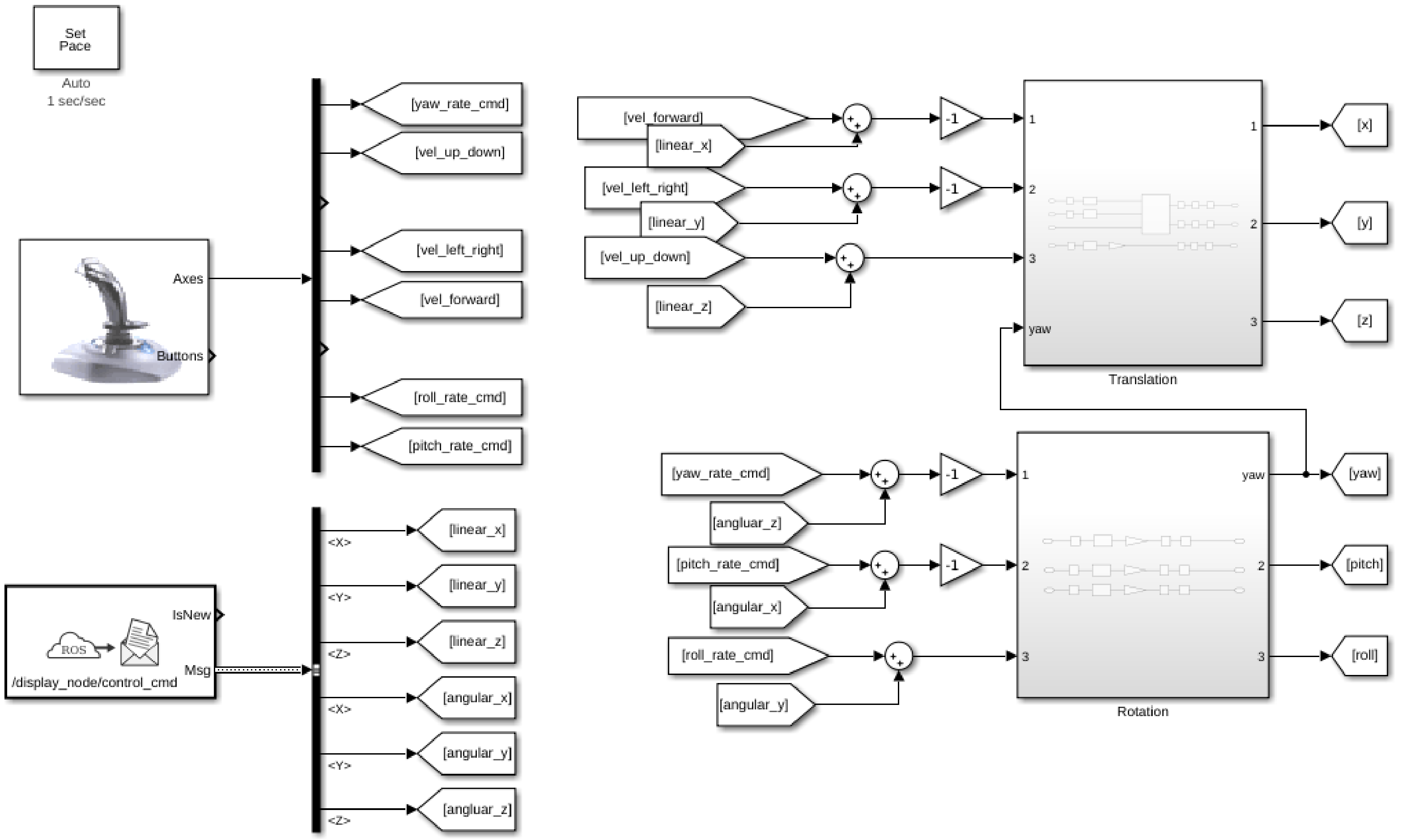
High Level
- **Perception**
- **Planner**

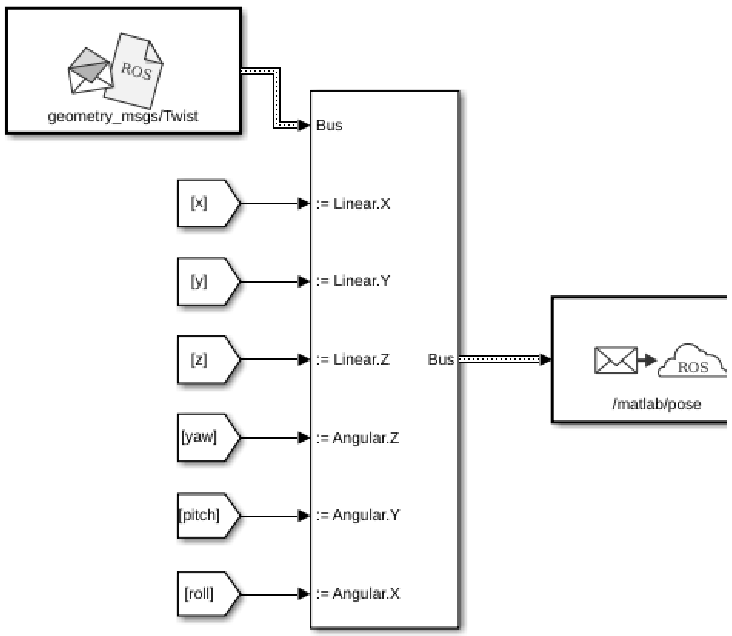
10Hz

ROS

ROS

MATLAB SIMULATION MODEL INTEGRATION



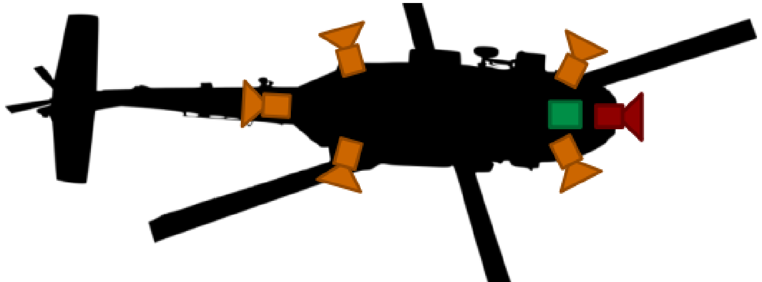


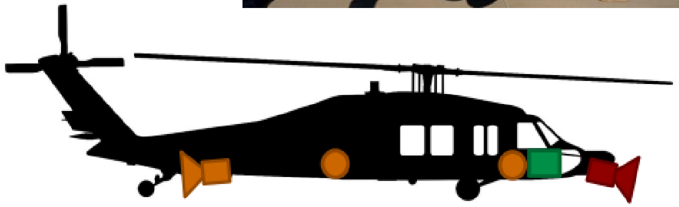
We are preparing to use NASA's Simulink Model.

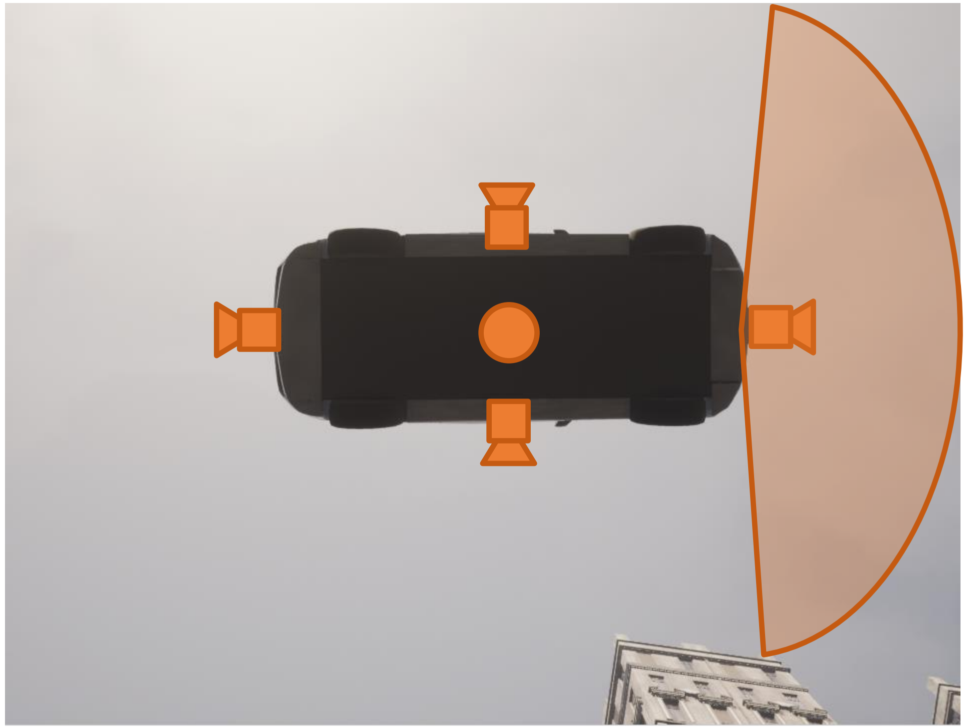
SENSOR CONFIGURATION

Rough Overview of Helicopter

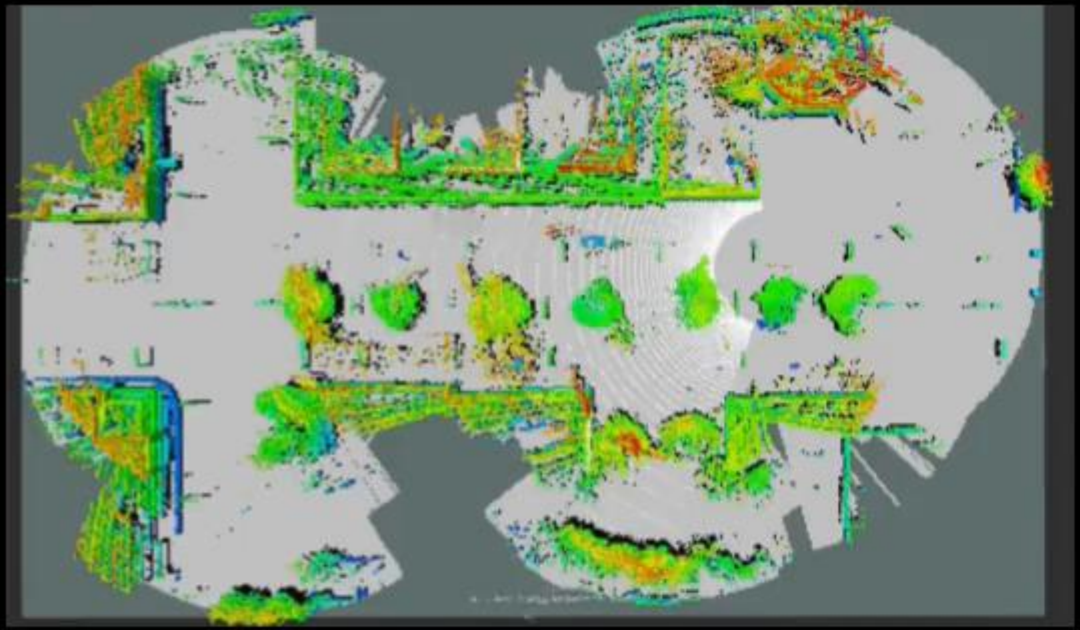
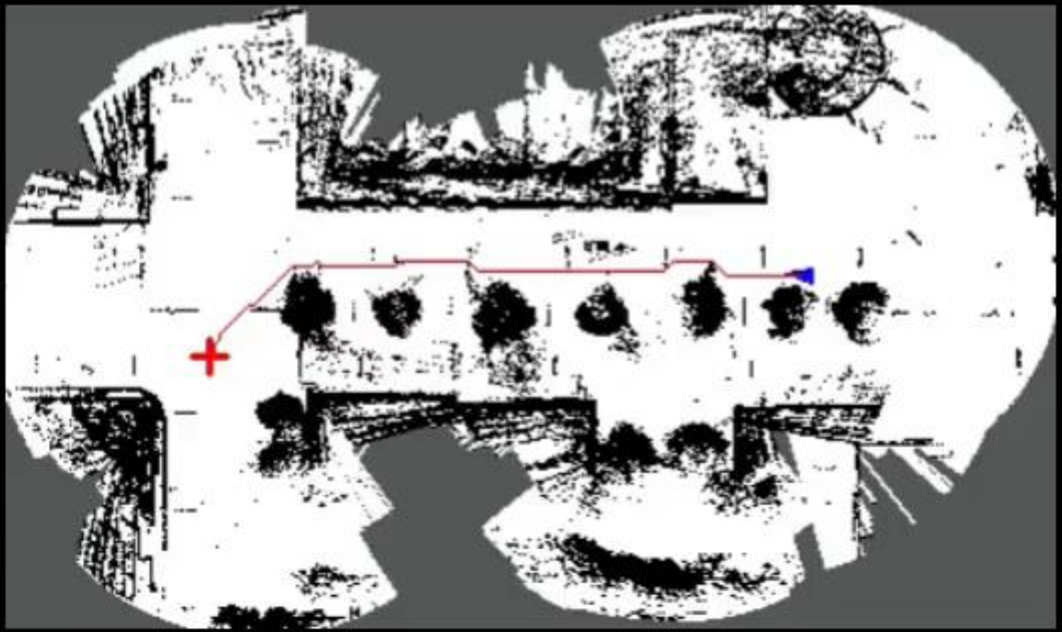
- Primary forward looking primary camera the pilot uses to look ahead
  - Also has forward looking lidar and radar
- Multiple situational awareness cameras for looking around
- Dual INS solution that provide position and orientation







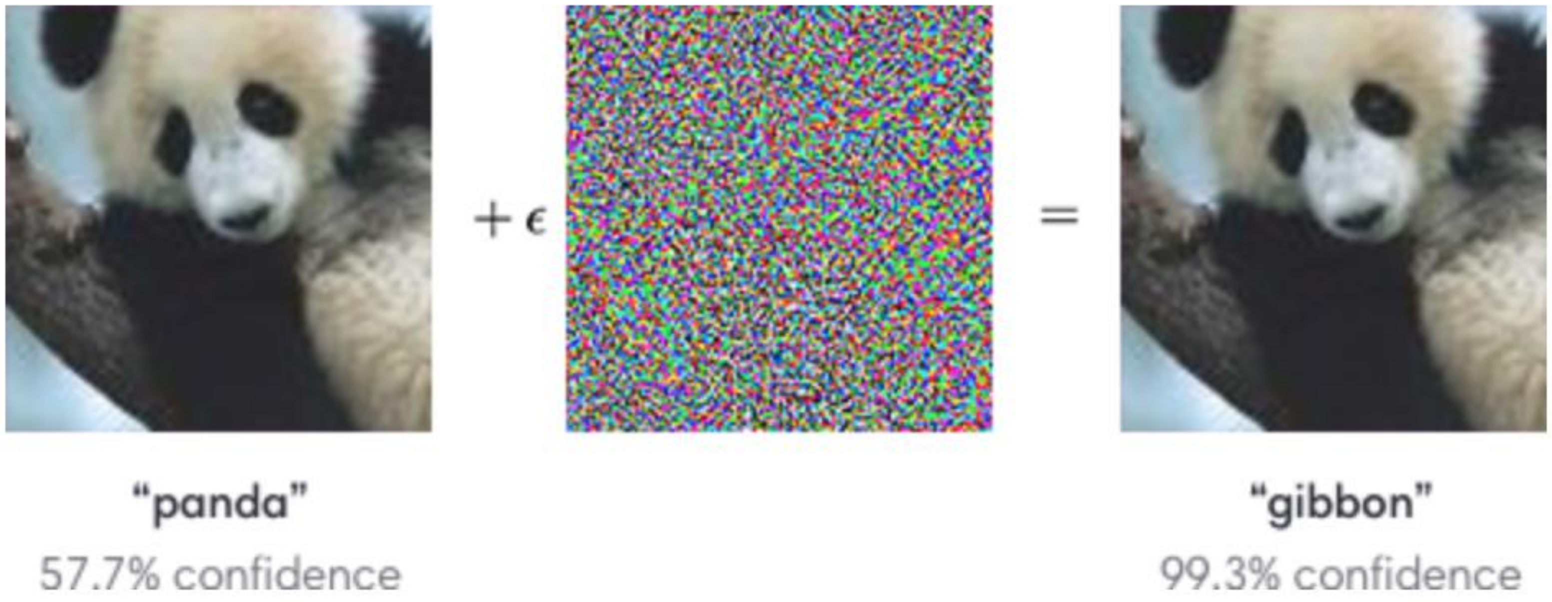
We mimicked SNC's sensor configuration.

Use Cases of the Game Environment and Future Works

Adversarial Image Perturbations Against Autonomous Vehicles

Adversarial Machine Learning (Adv.ML)



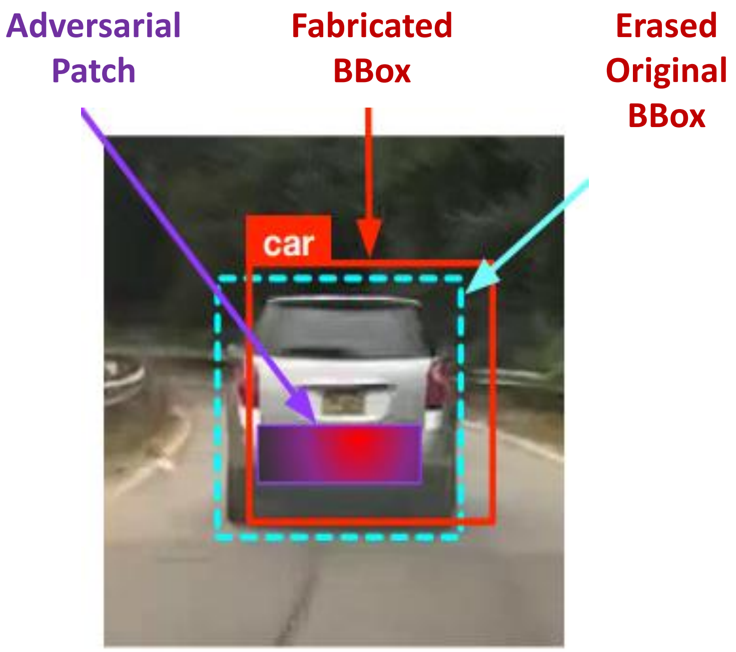
Adv. ML aims to find weakness of ML tool to **make the ML tool robust.**

The deep learning classifier shows ***vulnerability to mere noise****. The deep learning model can have a* ***weak point*** *in terms of performance,* ***depending on the class of the object****.*

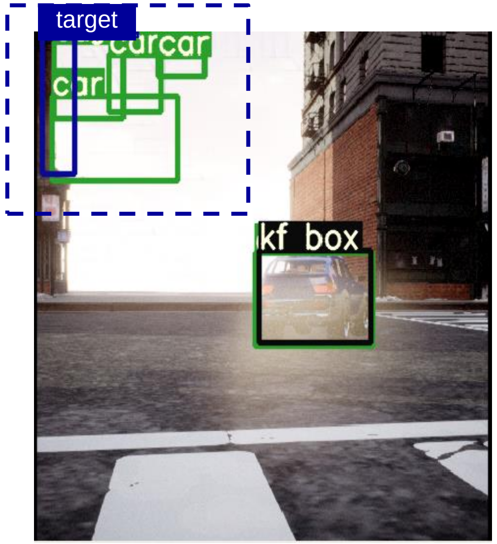
Kurakin, Alexey, Ian Goodfellow, and Samy Bengio. "Adversarial machine learning at scale.“ arXiv preprint arXiv:1611.01236 (2016).

Adversarial Image Perturbations Against Autonomous Vehicles

We propose a stochastic optimization framework that <u>monitors</u> **the attacker's capability** of generating the adversarial perturbations.



Existing Method*



Use image attack

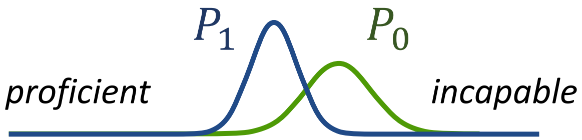
Stochastic Binary Decision

$l_1 \sim P_1[loss|state, attack; \theta]$

$l_0 \sim P_0[loss|state; \theta]$

$if\ l_1 < l_0\ then\ use\ attack$

$else\ do\ not\ use\ attack$



← image attack loss →

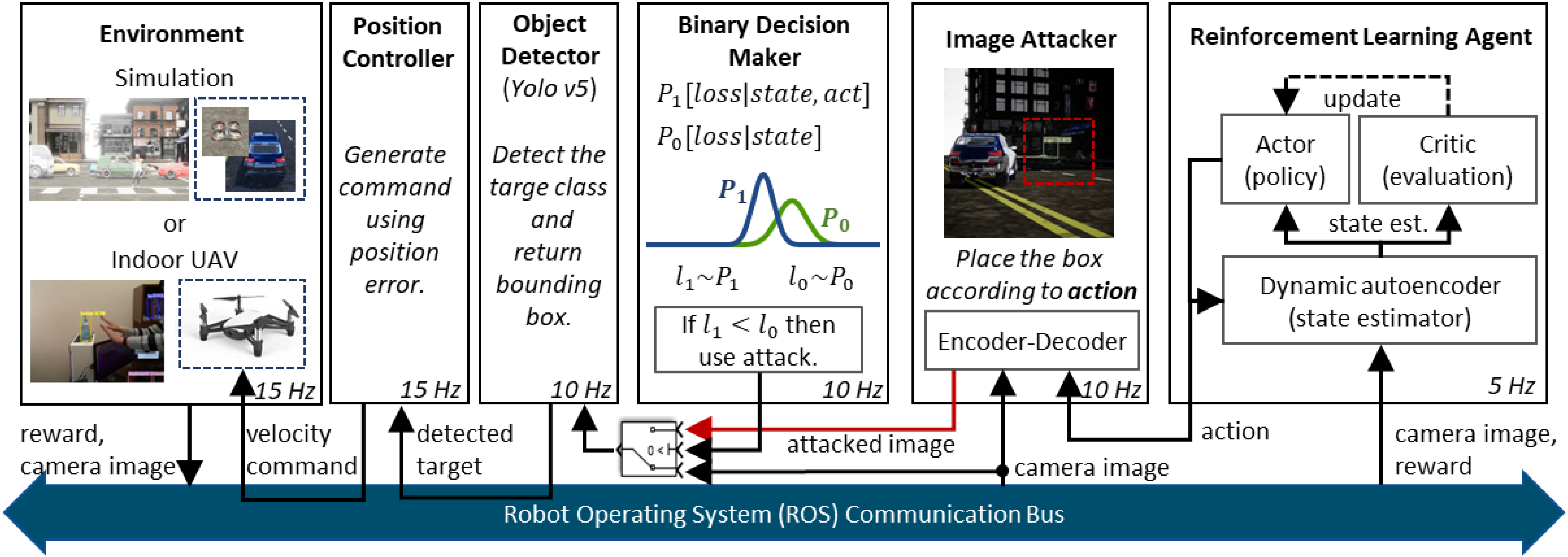
Do not use image attack

Proposed Adaptive Method

**Jia, Yunhan, et al. "Fooling Detection Alone is Not Enough: First Adversarial Attack against Multiple Object Tracking." International Conference on Learning Representations (ICLR). 2020.*

Adversarial Image Perturbations Against Autonomous Vehicles

The proposed framework is implemented using ROS for online communication and simultaneous running of the following modules.

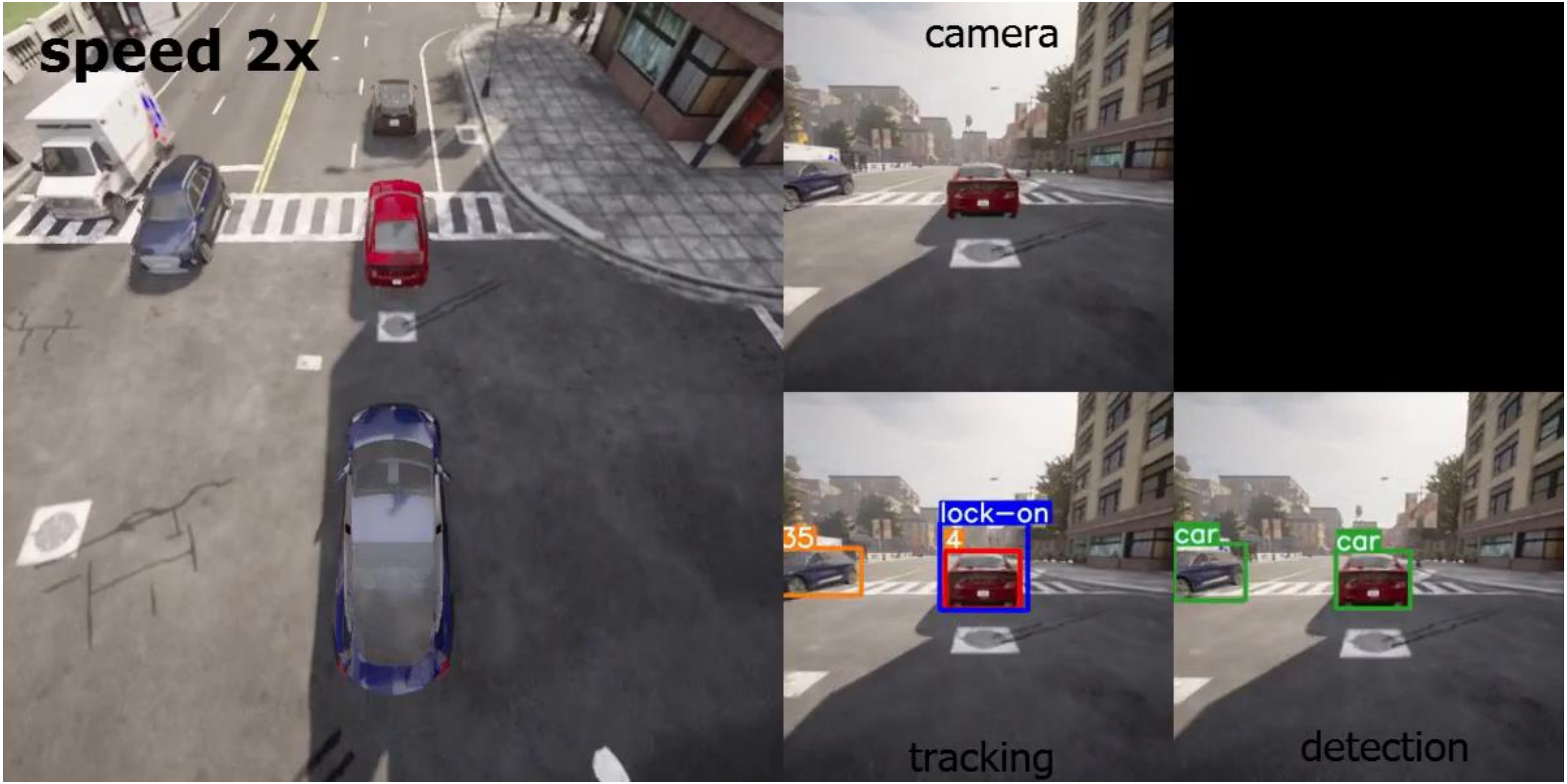


Learning When to Use Adaptive Adversarial Image Perturbations against Autonomous Vehicles

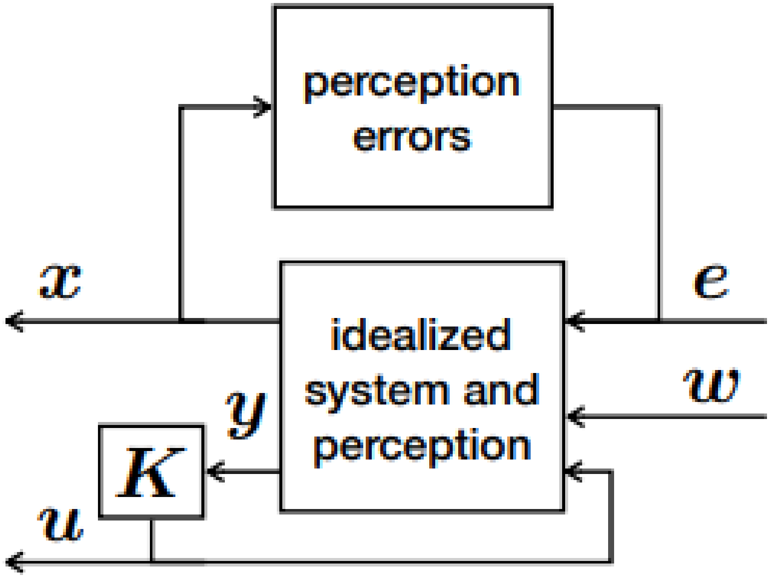
I.Real Time Image Attack with a Simulation

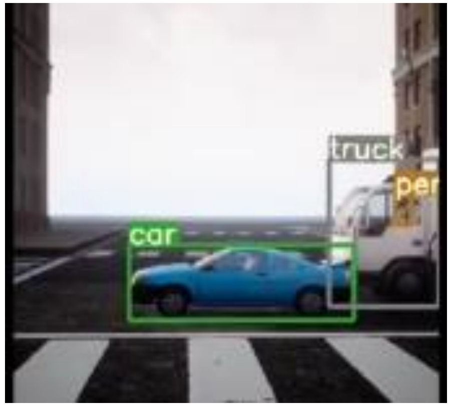
II.Learning Image Attack against an Indoor drone

Adversarial Image Perturbations Against Autonomous Vehicles



Robust Control in the UAV Object Detection Autonomy Pipeline

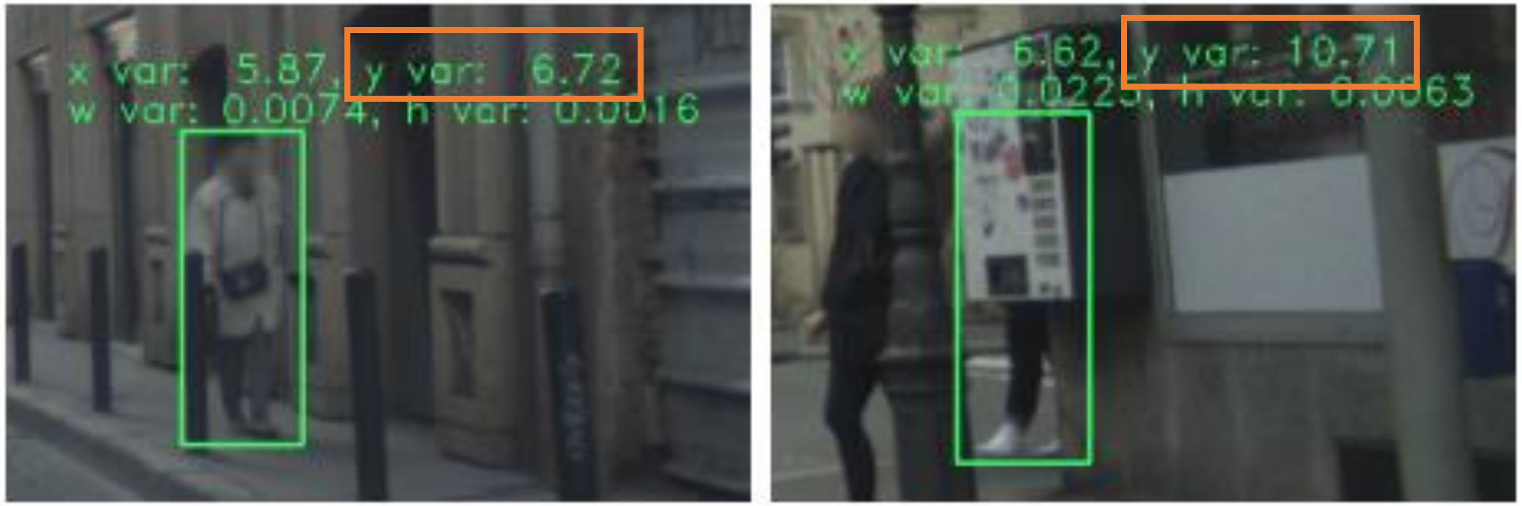




We quantify **robustness against the error** and the **performance** using

$$\mathcal{H}_\infty(\boldsymbol{G_{xe}}) \quad \text{vs.} \quad \mathcal{H}_\infty(\boldsymbol{G_{xw}})$$

**Dean, Sarah, et al. "Robust guarantees for perception-based control." Learning for Dynamics and Control. PMLR, 2020.*



(a) Prediction for fully visible pedestrian.

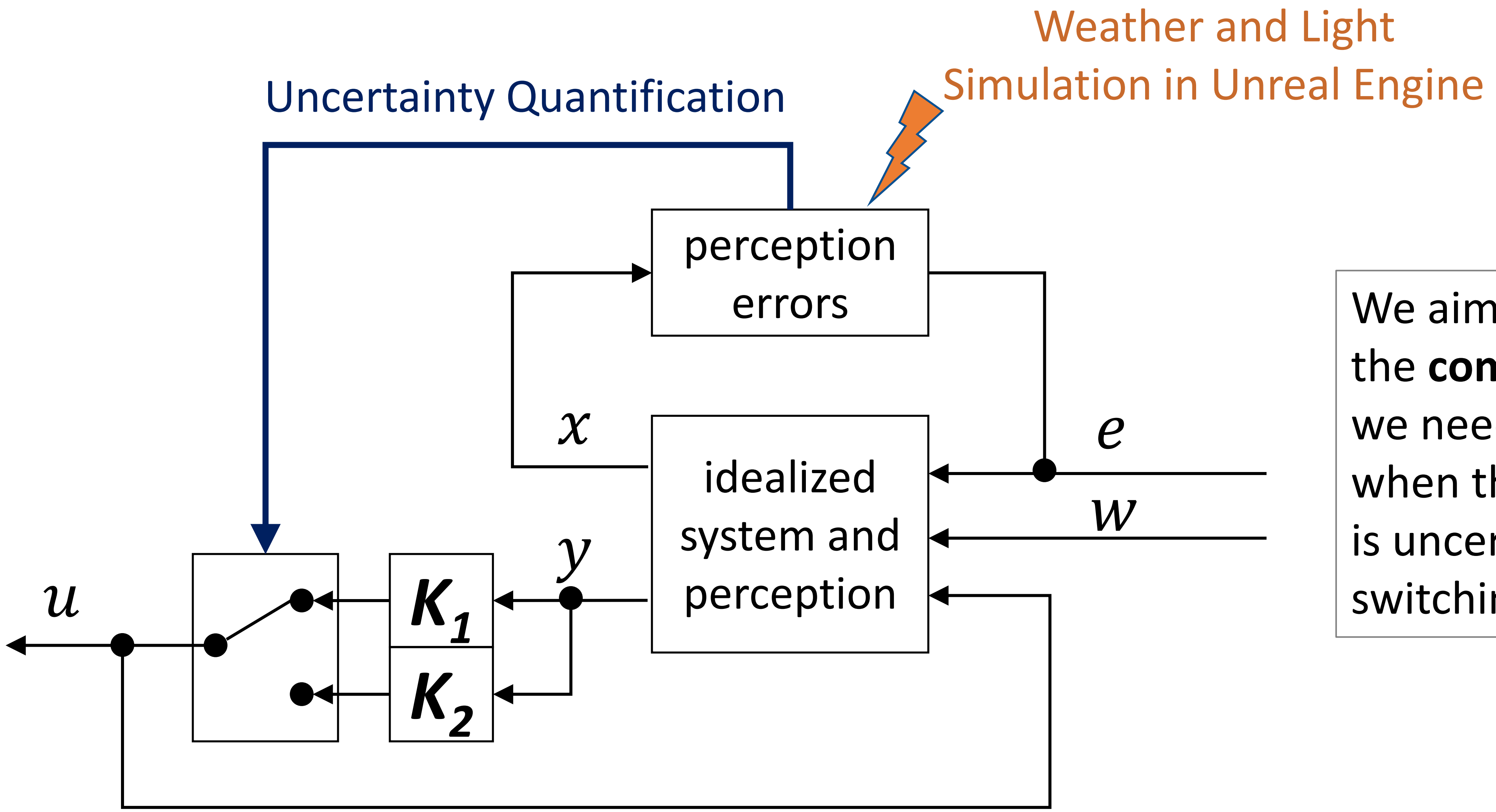
(b) Prediction for heavily occluded pedestrian.

Fig. 4 – Comparing aleatoric uncertainties for occluded and fully visible pedestrians. Both Predictions were produced by prior 3. Note the drastically increased variance in width and height for the heavily occluded pedestrian.

There exist works on the **estimation of uncertainty in object detection**.

**Kraus, Florian, and Klaus Dietmayer. "Uncertainty estimation in one-stage object detection." 2019 IEEE intelligent transportation systems conference (ITSC). IEEE, 2019.*

Robust Control in the UAV Object Detection Autonomy Pipeline



We aim to implement the **common sense** that we need to be cautious when the environment is uncertain using the switching logic.

We plan to present this idea in **AIAA SciTech Invited Session.*

FUTURE WORKS ON THE SIMULATOR

- We need to further organize and clean the GitHub repository at https://github.com/stargaze221/RRAAA-ULI

- Replace the flying car with a better-looking VTOL in the Unreal Engine such as

www.turbosquid.com

- Devise a sensor fusion algorithm to integrate the Lidar sensor with the occupancy grid, the camera sensor with the object detection.

- Devise an estimation method to predict and track the moving obstacle in the environment.

Learning Autonomy and Control Systems Lab

Prof. Petros Voulgaris

MECHANICAL ENGINEERING

Petros Voulgaris

Hyung-Jin Yoon
(Postdoc)

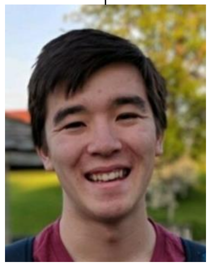
- Decision making under uncertainties
- Autonomous System

Yichuan Li
(Postdoc)

- Multiagent optimization for control and estimation

Antonio Castaño
(Grad. Student)

- UAV Control
- VR simulation



Caleb Patton
(Grad. Student)

- Machine learning
- VR simulation

Jessica Peterson
(Upcoming Grad.)

- UAV - Human Pilot collaboration
- UAV test and verification

Thank you

University of Nevada, Reno

Systems Integration & Field Deployment Verification

AVIATE Seminars

Christos Papachristos
Assistant Professor
Department of Computer Science and Engineering
University of Nevada, Reno

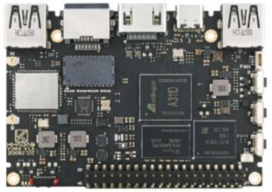
April 20, 2023

Credits: NASA / Lillian Gipson

NASA | AVIATE CENTER | University of Illinois Urbana-Champaign | Massachusetts Institute of Technology | Georgia Tech | North Carolina Agricultural and Technical State University | University of Nevada, Reno | Lockheed Martin | Sierra Nevada Corporation

Small-scale Aerial System w/ Multi-Day Field Deployment Autonomy

Khadas VIM3: 4x 2.2Ghz Cortex-A73, 2x 1.8Ghz Cortex-A53, 5.0 TOPS NPU



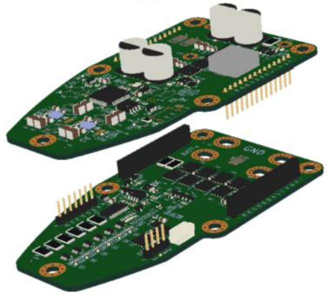
u-Blox Neo-M9N

Intel Realsense T265

FLIR Chameleon 3

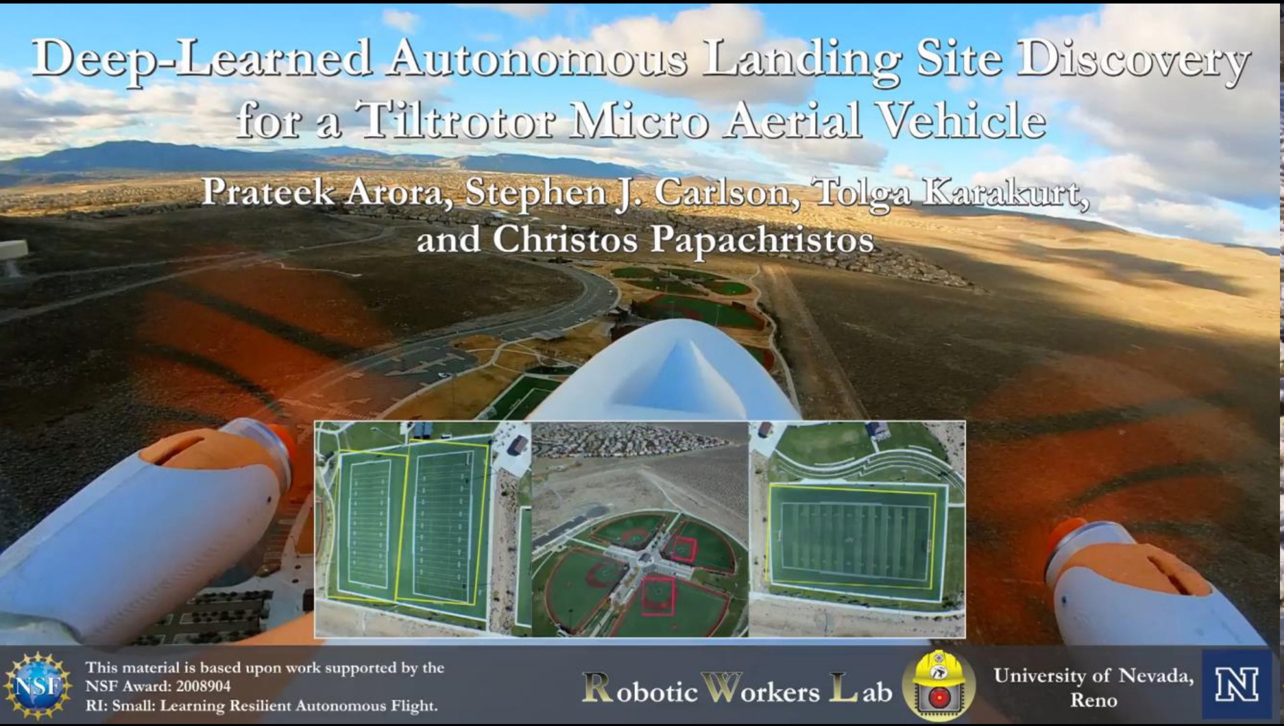
mRo PixRacer Pro

Power Management Board



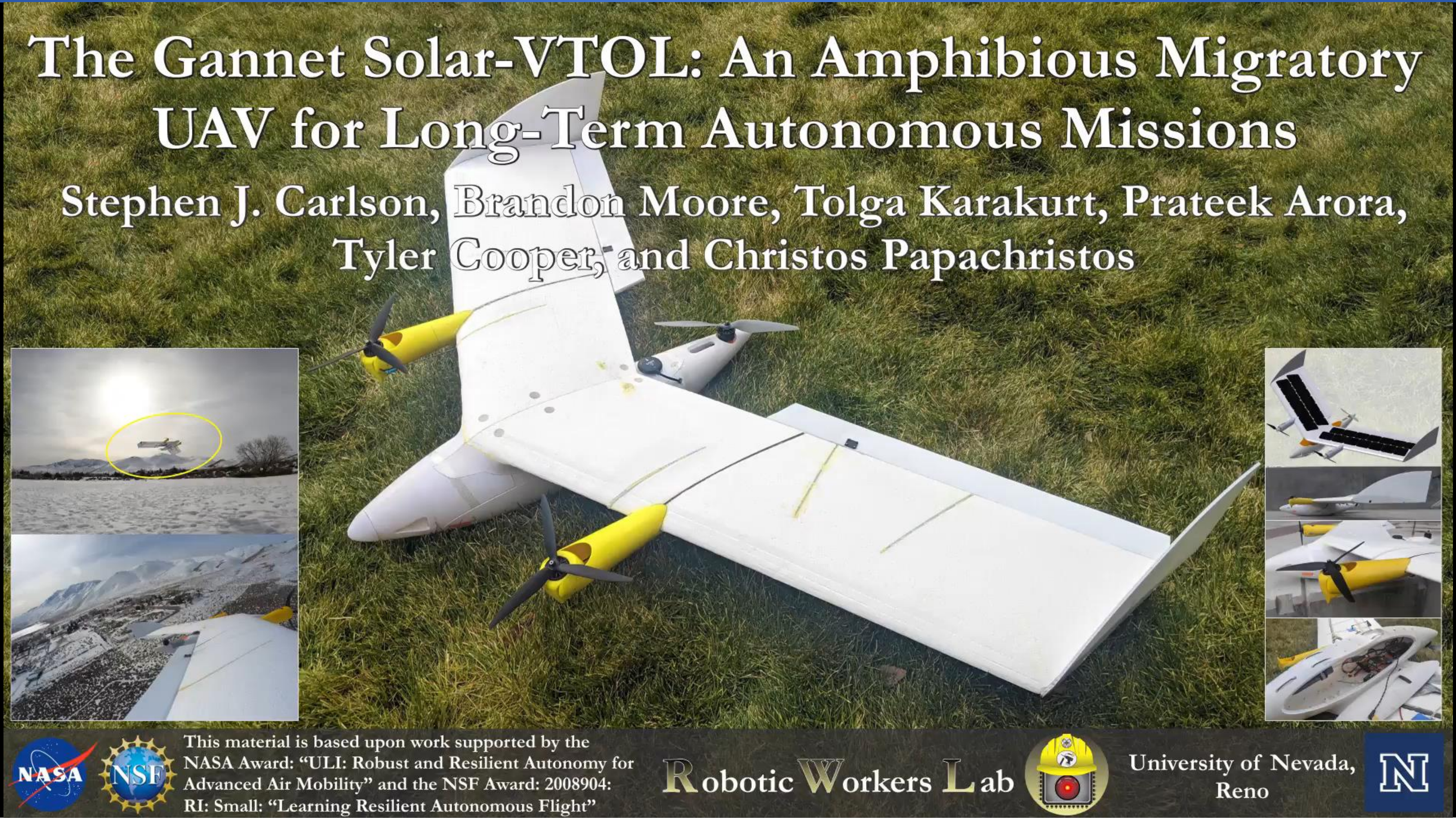
Accepted at **IEEE International Conference on Robotics & Automation 2023**

Accepted at **IEEE International Conference on Robotics & Automation 2023**



Mid-scale Aerial System Development w/ Amphibious Capabilities

Accepted at **IEEE International Conference on Unmanned Aircraft Systems 2023**



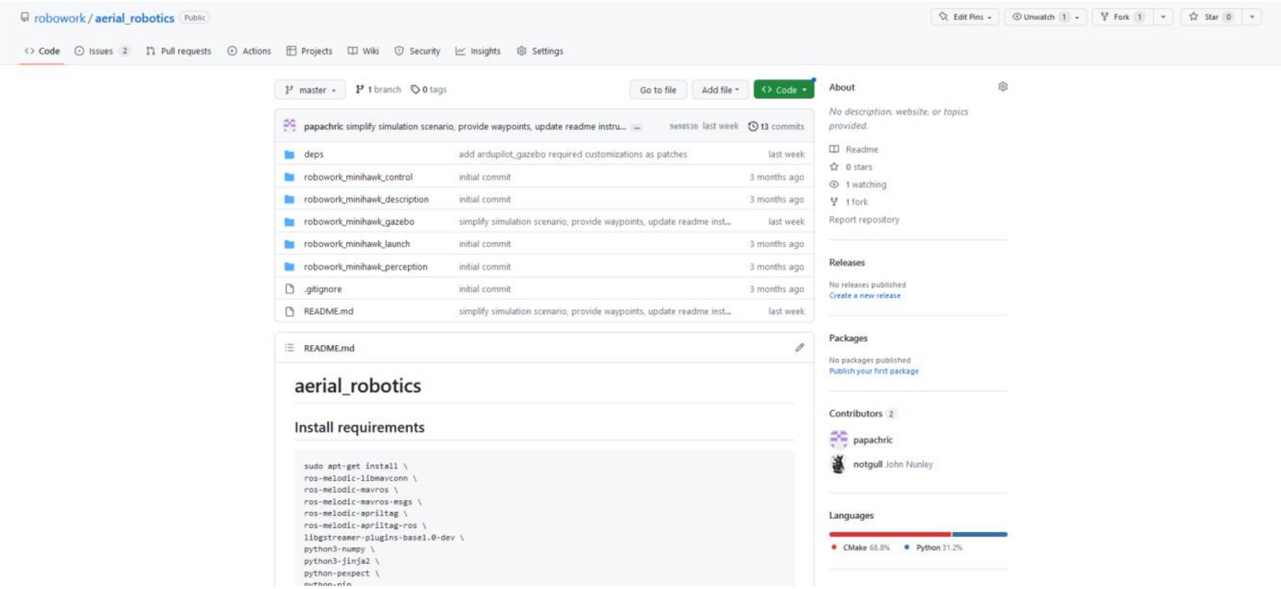
Heavy-Payload commercial Multicopter

Initial Field Testing with Heavy-Payload commercial Multicopter

Educational Content & Digital Twin Simulations

https://www.roboticworkerslab.com/education/courses

https://github.com/robowork/aerial_robotics



GAZEBO ROS