MATLAB® AI Robotics Workshop

Line Following Robot with Deep Learning

MathWorks

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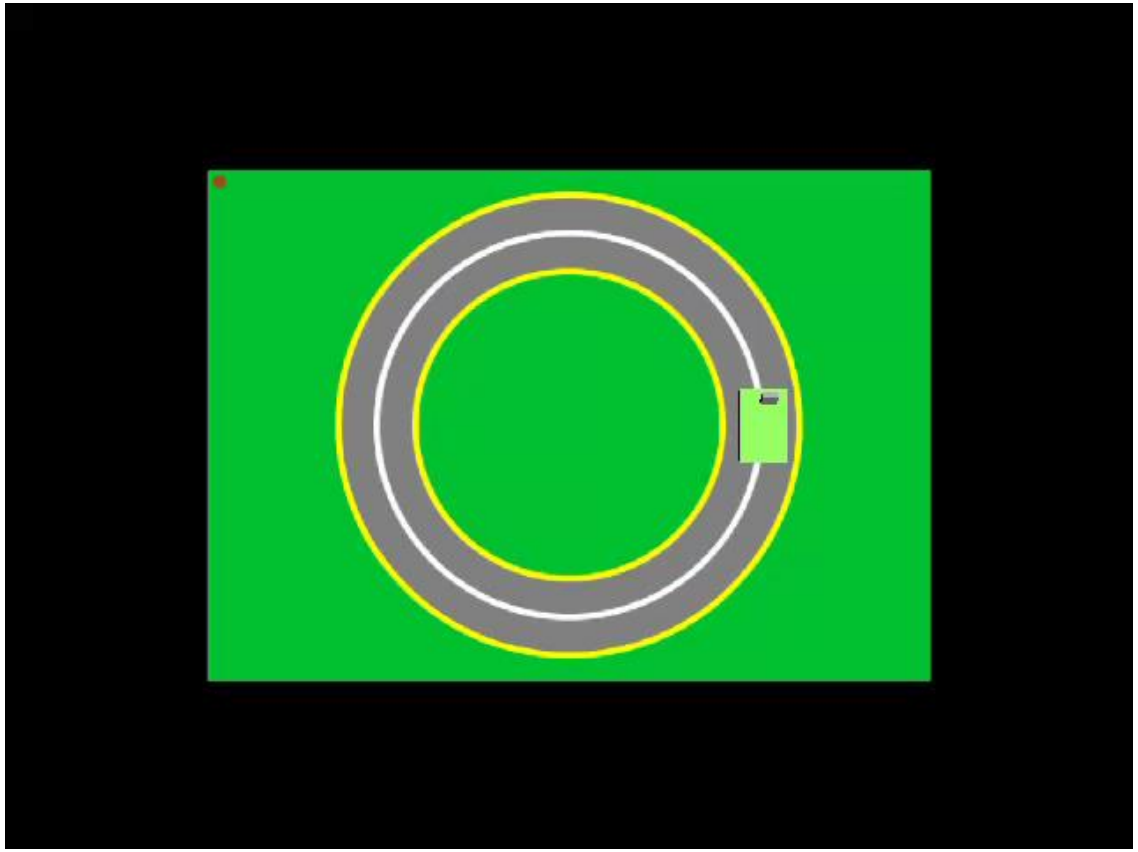
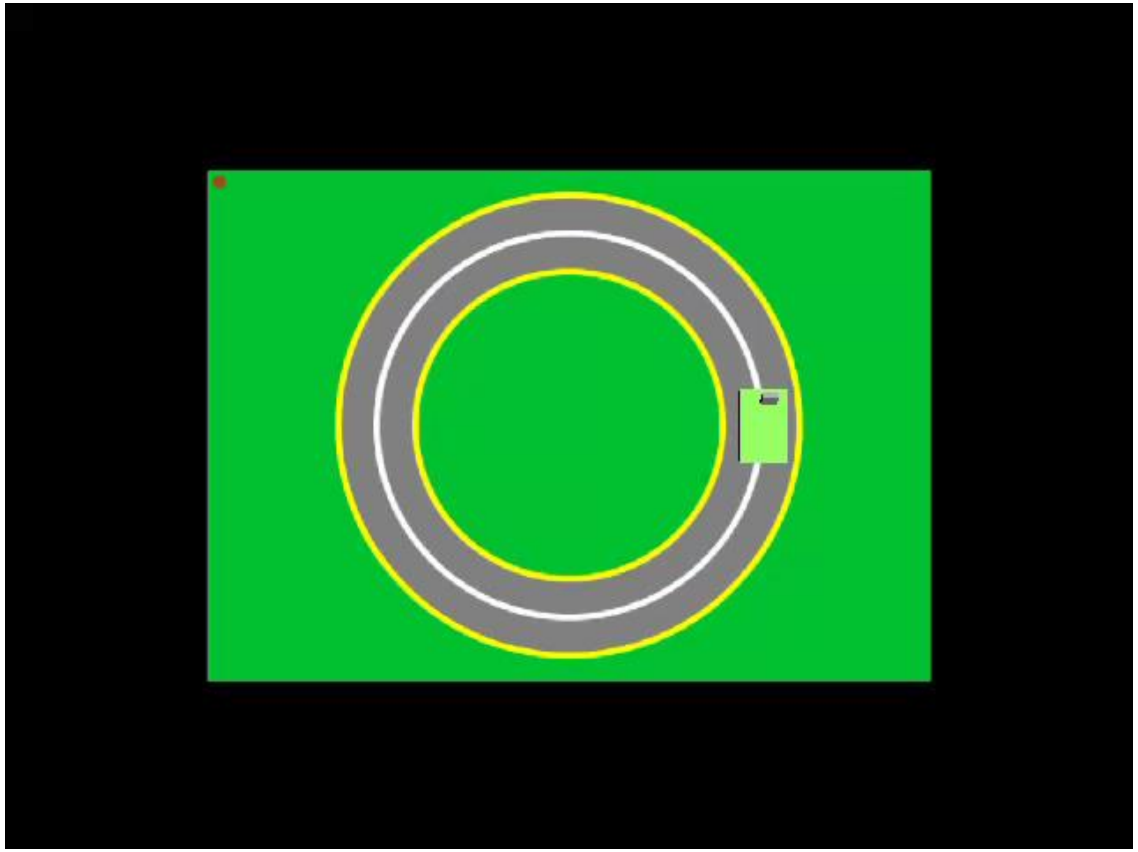
Demo: Line Following Robot with Deep Learning



Failure case

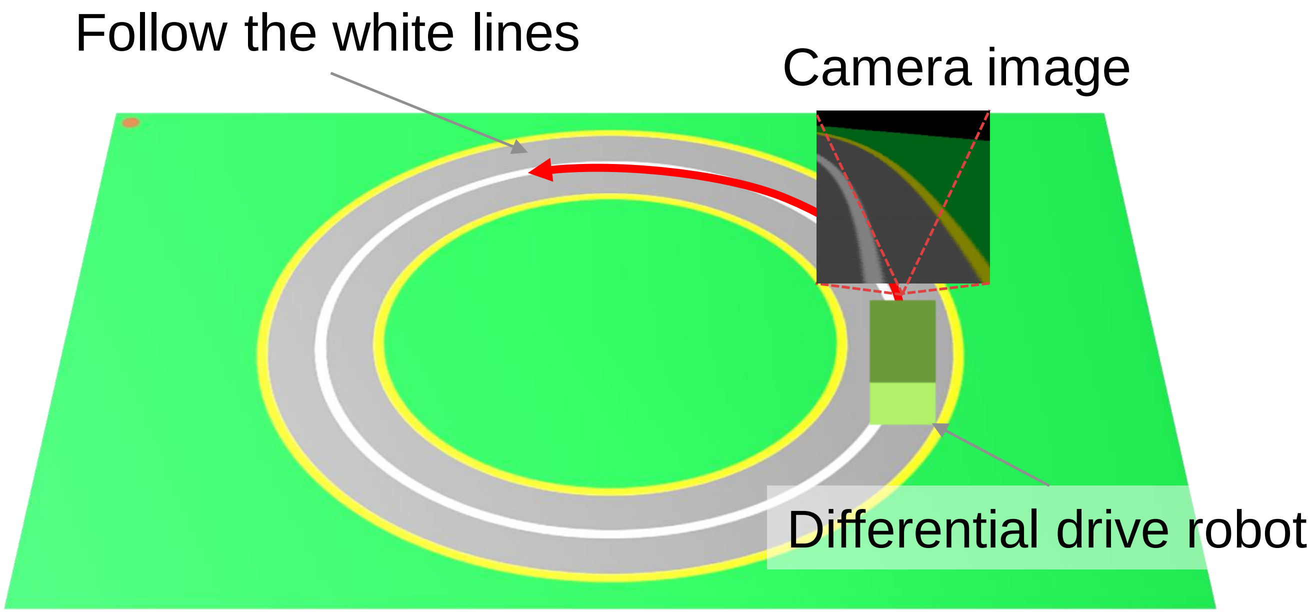


Success case

Objectives

Goal: Learn how to implement an AI based autonomous system combining deep learning-based object detection and classic control algorithms

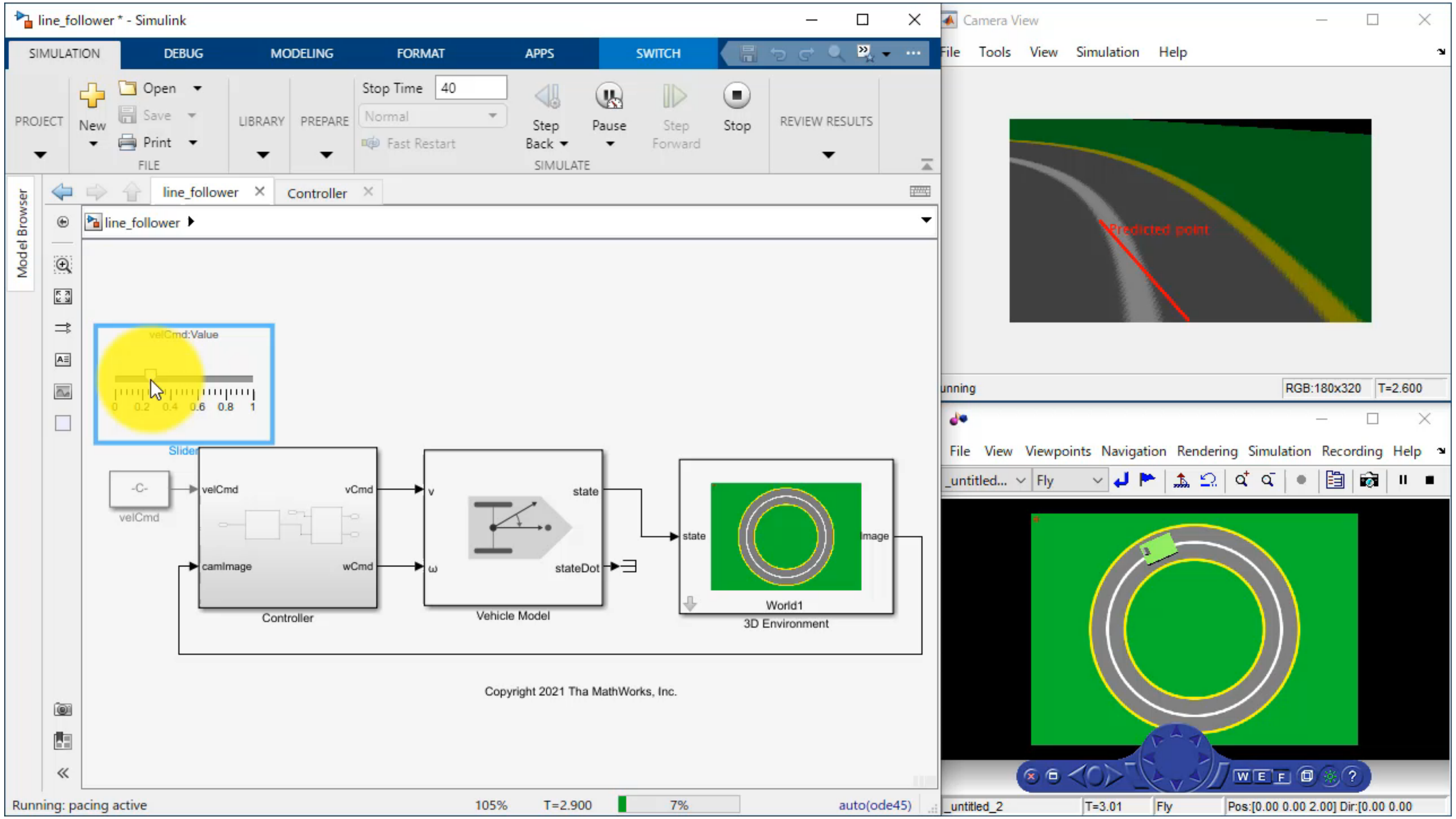
- What's line following?
  - Robot uses a sensor to detect lines on the floor and move along the lines.
- Challenge in line following
  - Rule-based image processing algorithms for line detection is not robust for variation of environmental lighting.
- Solution with deep learning
  - Robust line detection against changing of lighting conditions
  - Need additional tasks
    - Collect bunch of images
    - Annotation
    - Explore training hyper parameters



System overview

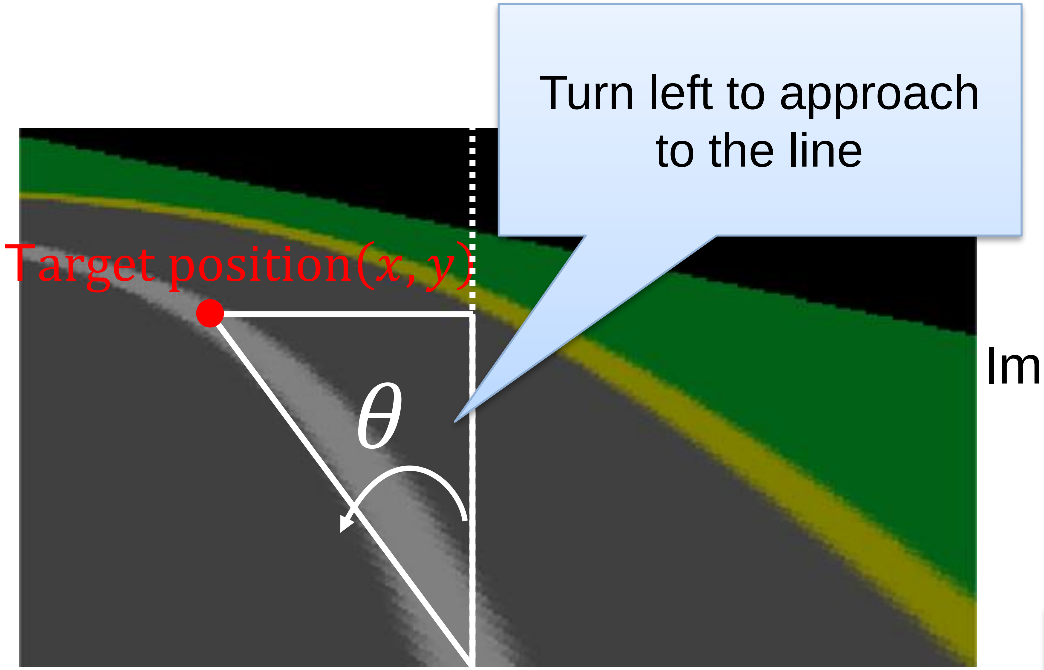
Simulink Model for Line Following

Goal: Line following with monocular camera image

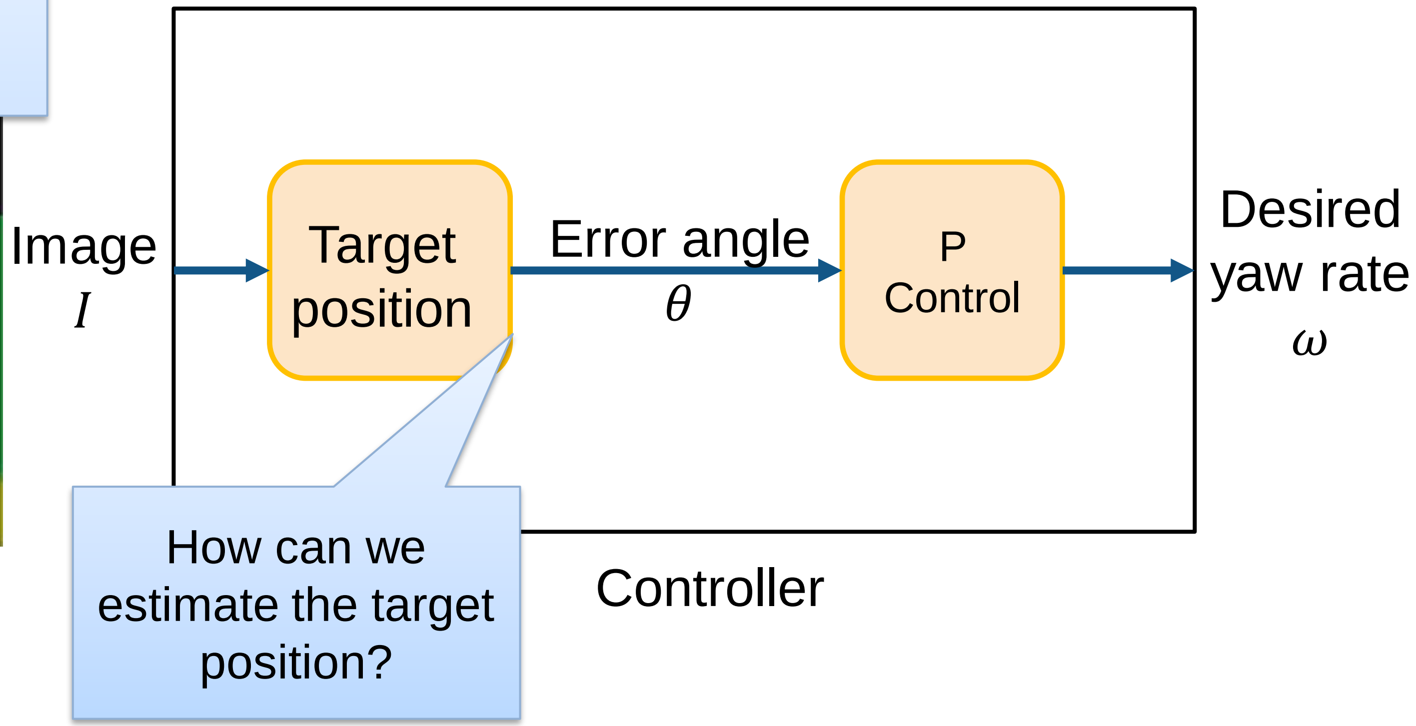


Concept of Line Following

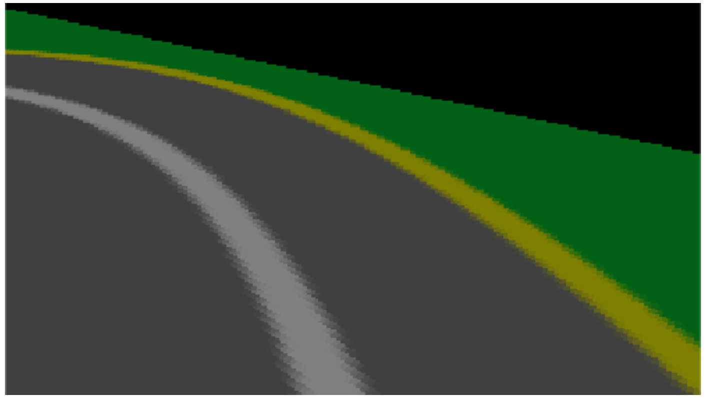
- Calculate an error angle θ between the ego-vehicle center and target position
- Control the steering to make the error angle to be zero



Vehicle center



Predict Target Position using Deep Learning



Deep Neural Network

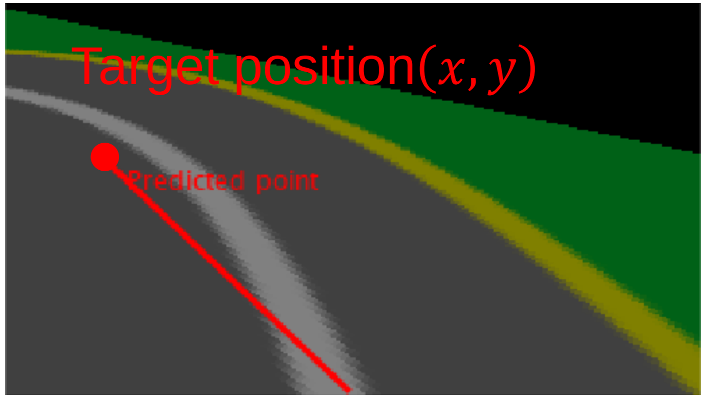


Image from camera
(224 x 224 x 3)

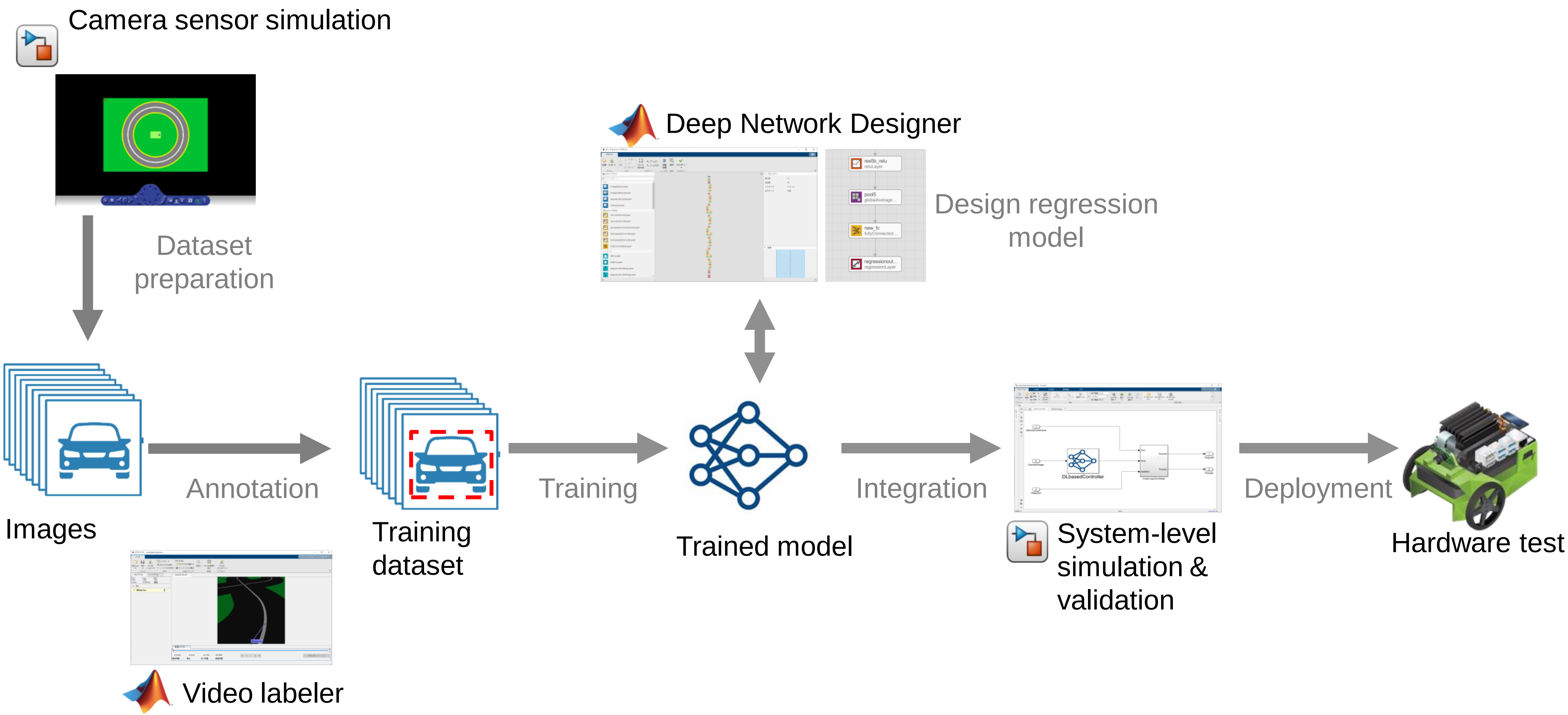
Target position(x, y)
(1 x 2)

Predict target position using a deep neural network model

Why deep learning?

- Not easy to extract low-dimensional features from high-dimensional data like images using classical image processing and machine learning
- Deep learning is flexible and can handle those high-dimensional data

AI-based Autonomous System Development Workflow



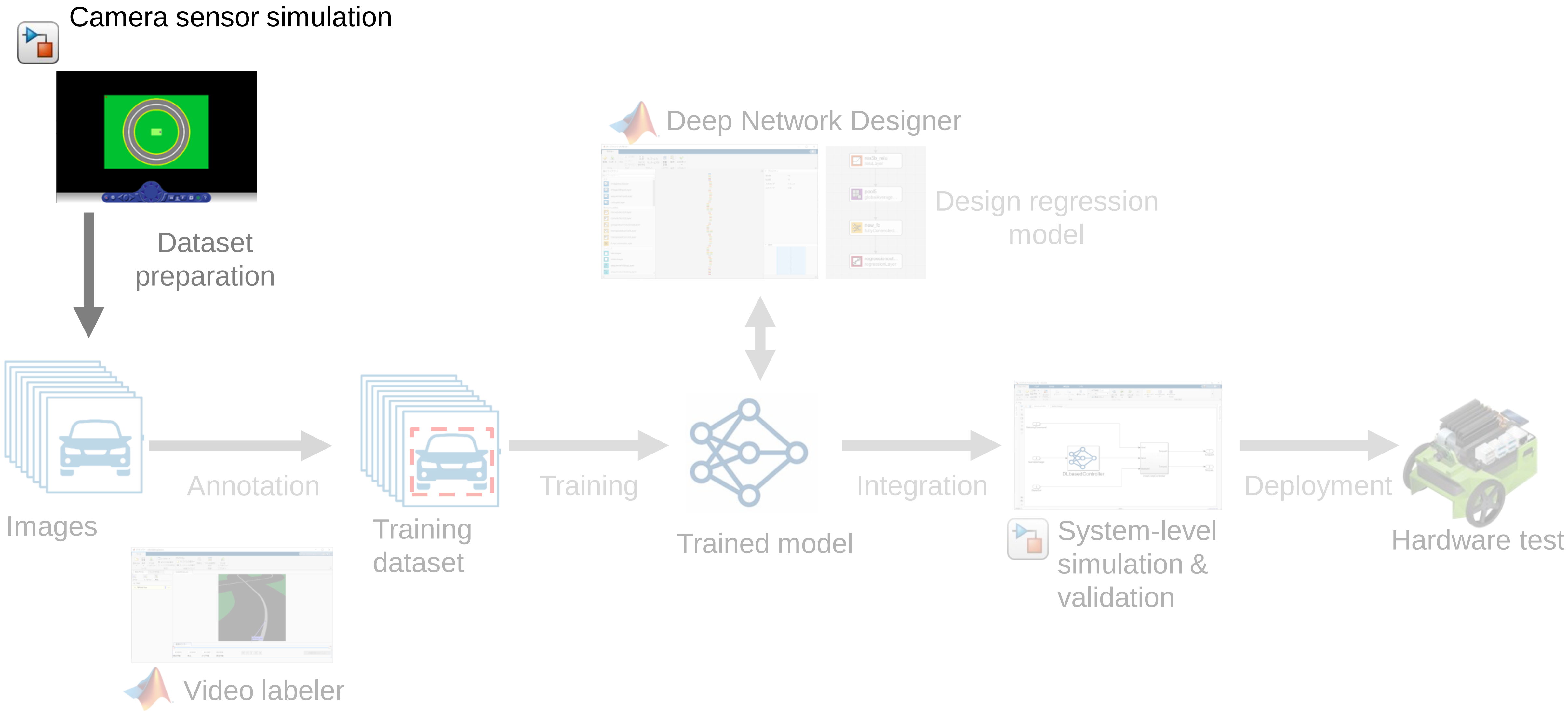
Workshop preparation

1. Launch "MATLAB R2024a"

2. Move to the demo folder
   `>> cd c:¥ai-robotics-workshop`

3. Open the project file
   `>> ai_robotics_workshop.prj`

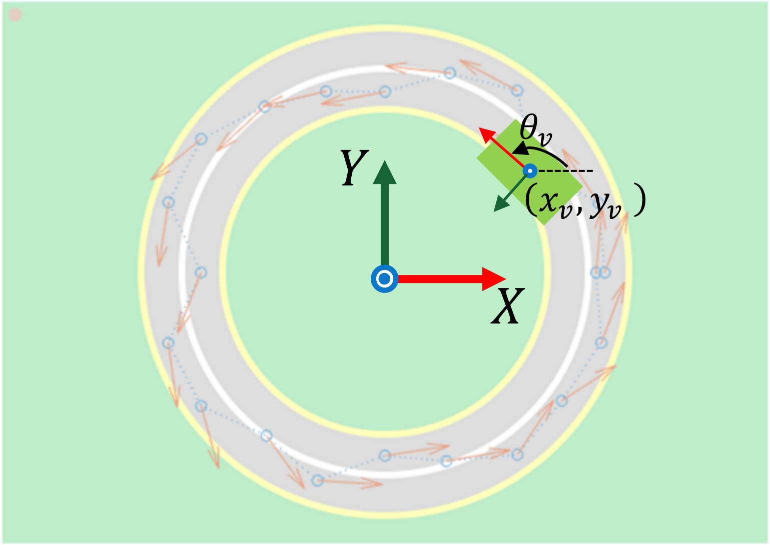
AI-based Autonomous System Development Workflow



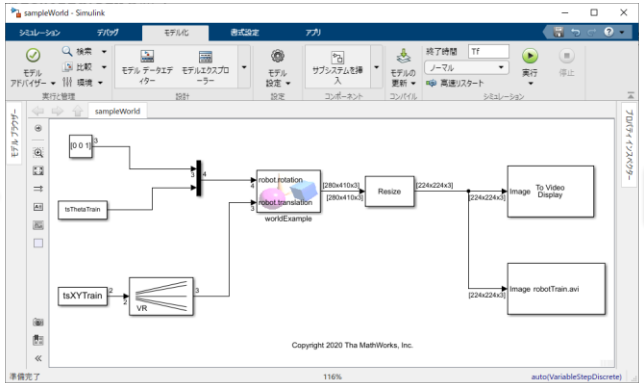
Generating Video Dataset using Simulation Model

- Deep neural networks require bunch of training dataset including varied camera angles
- Generate vehicle positions randomly and then generate training dataset

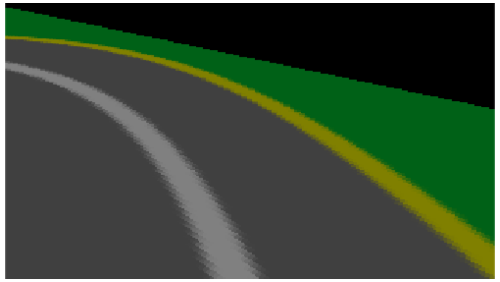
Generate vehicle position and orientation (x_v, y_v, θ_v) randomly.



Camera sensor simulation



Generate as a video file



`robotTrain.avi`

Coordinate System

3-D coordinate systems

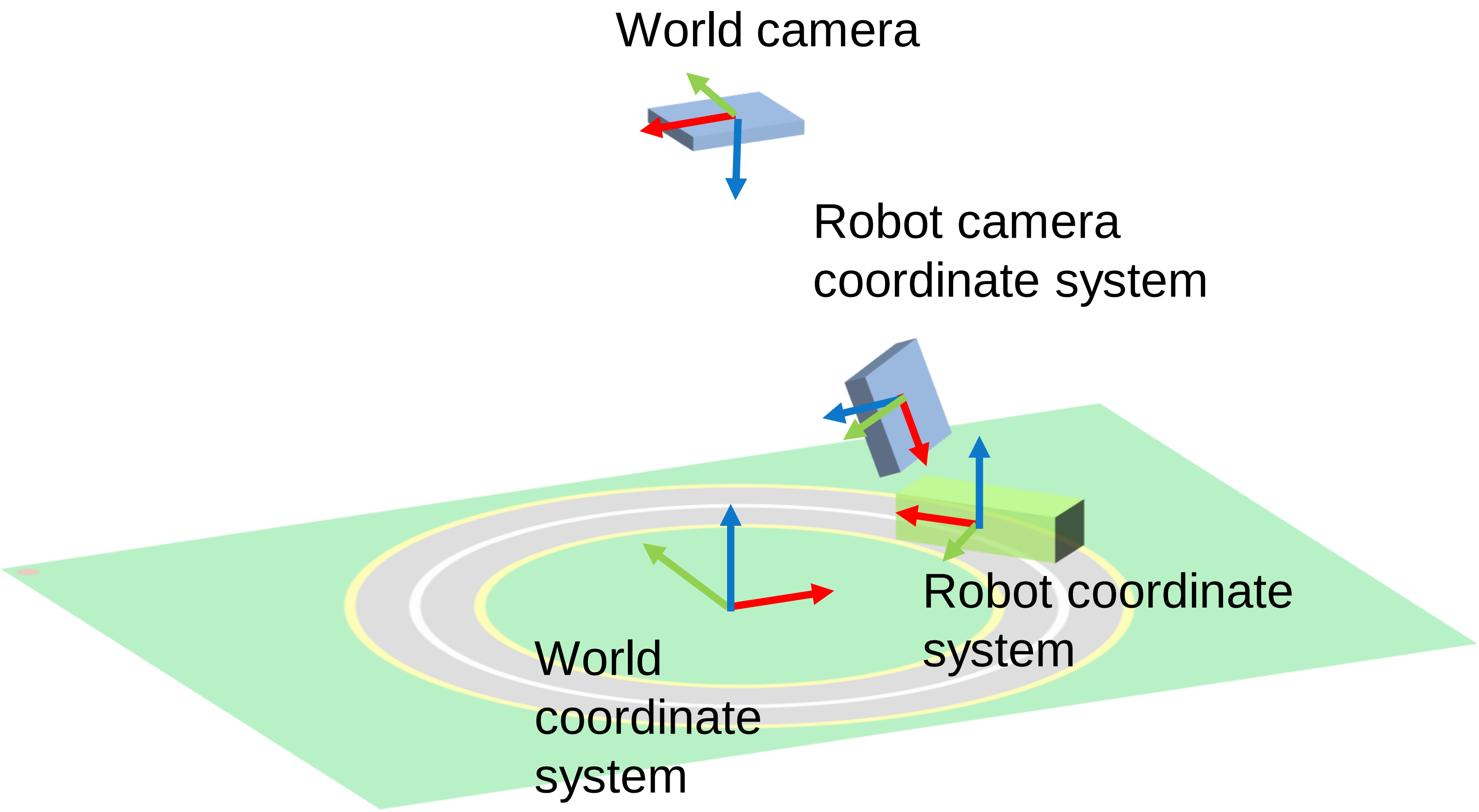
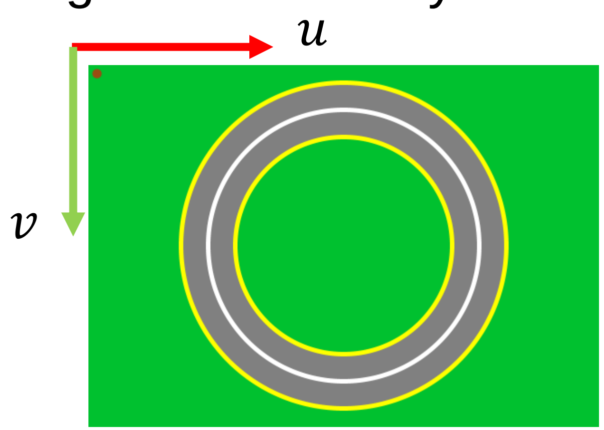
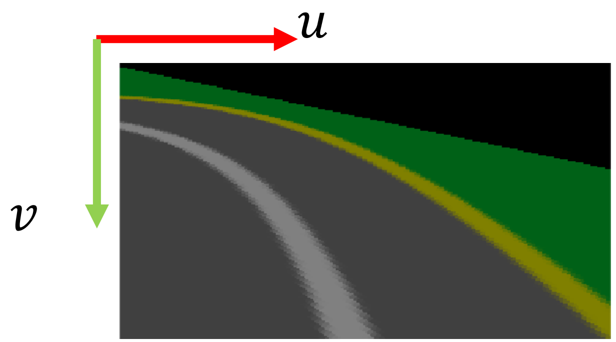


Image coordinate system



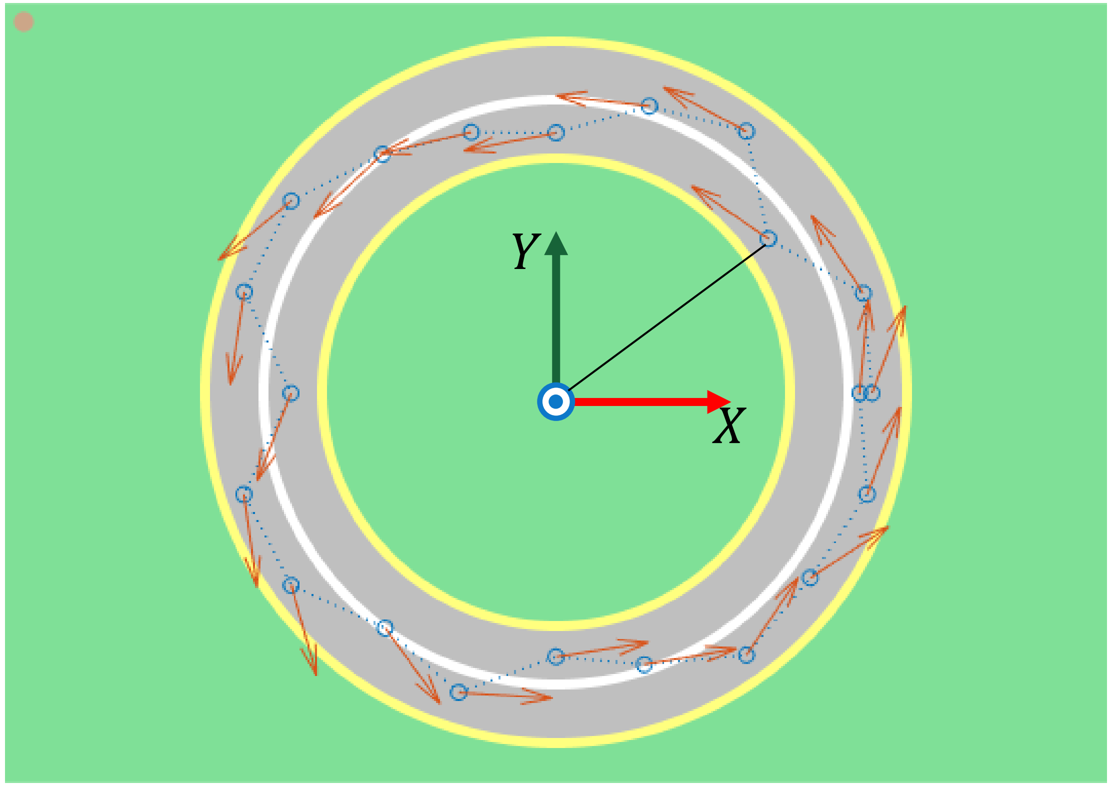
World camera



Robot camera

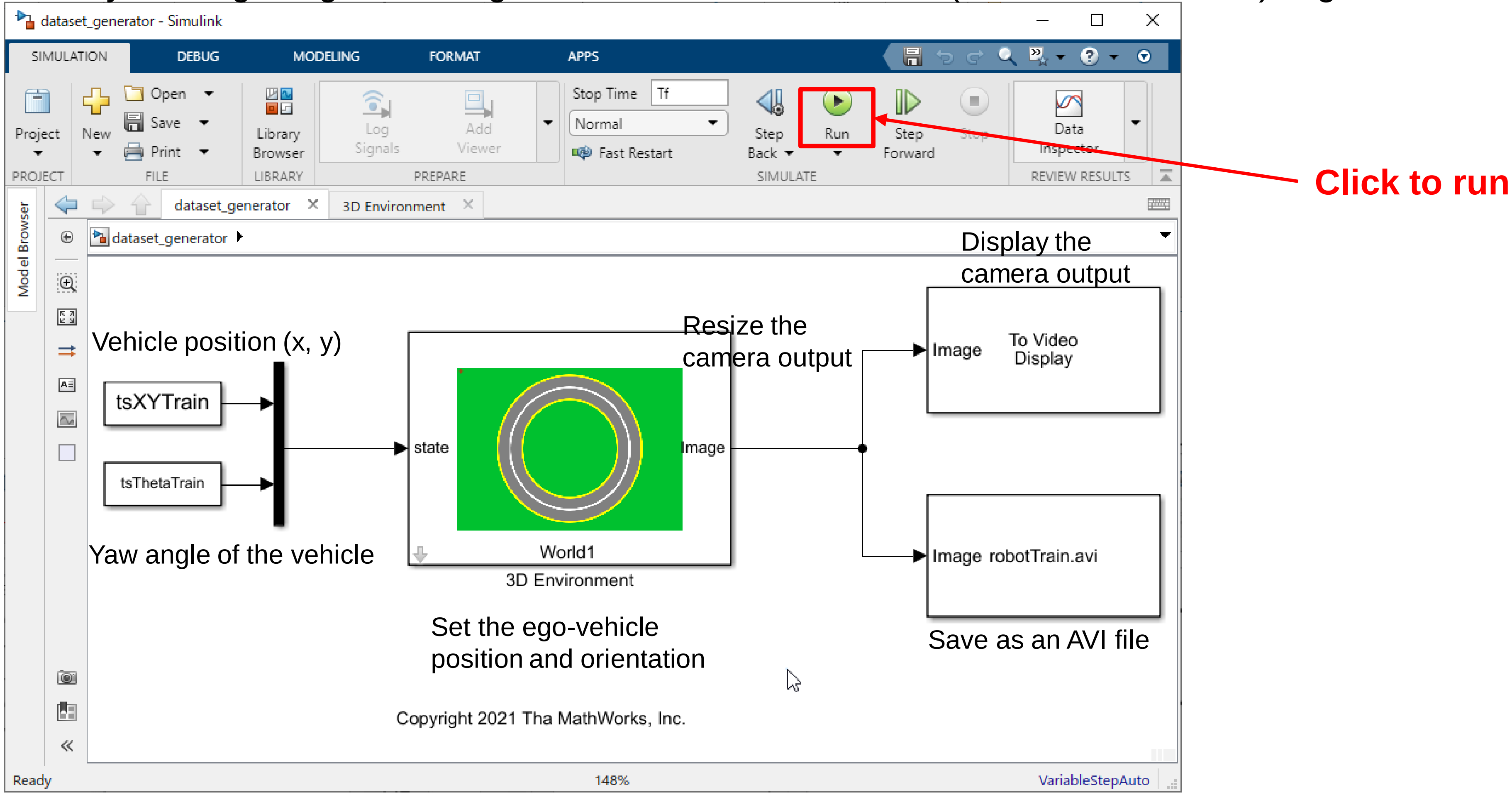
Exercise 1. Generate Video File

1. Open **genCourseTraj.mlx** and run it to generate trajectories.
   `>> edit genCourseTraj.mlx`

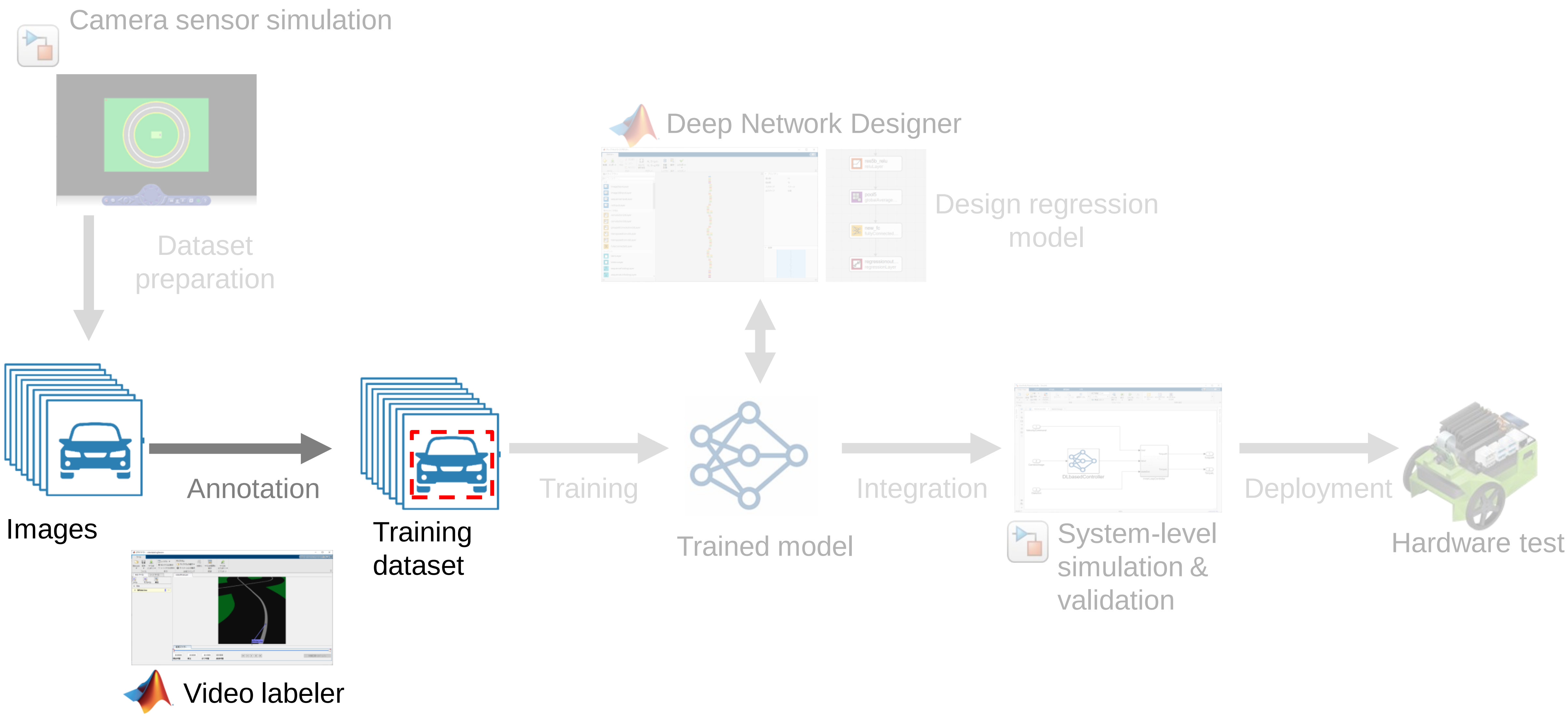


Exercise 1. Generate Video File

1. Oepn sampleWorld.slx and simulate the camera sensor outputs
   `>> dataset_generator.slx`
2. Run the simulation by clicking the green triangle button so that a video file (**`robotTrain.avi`**) is generated.

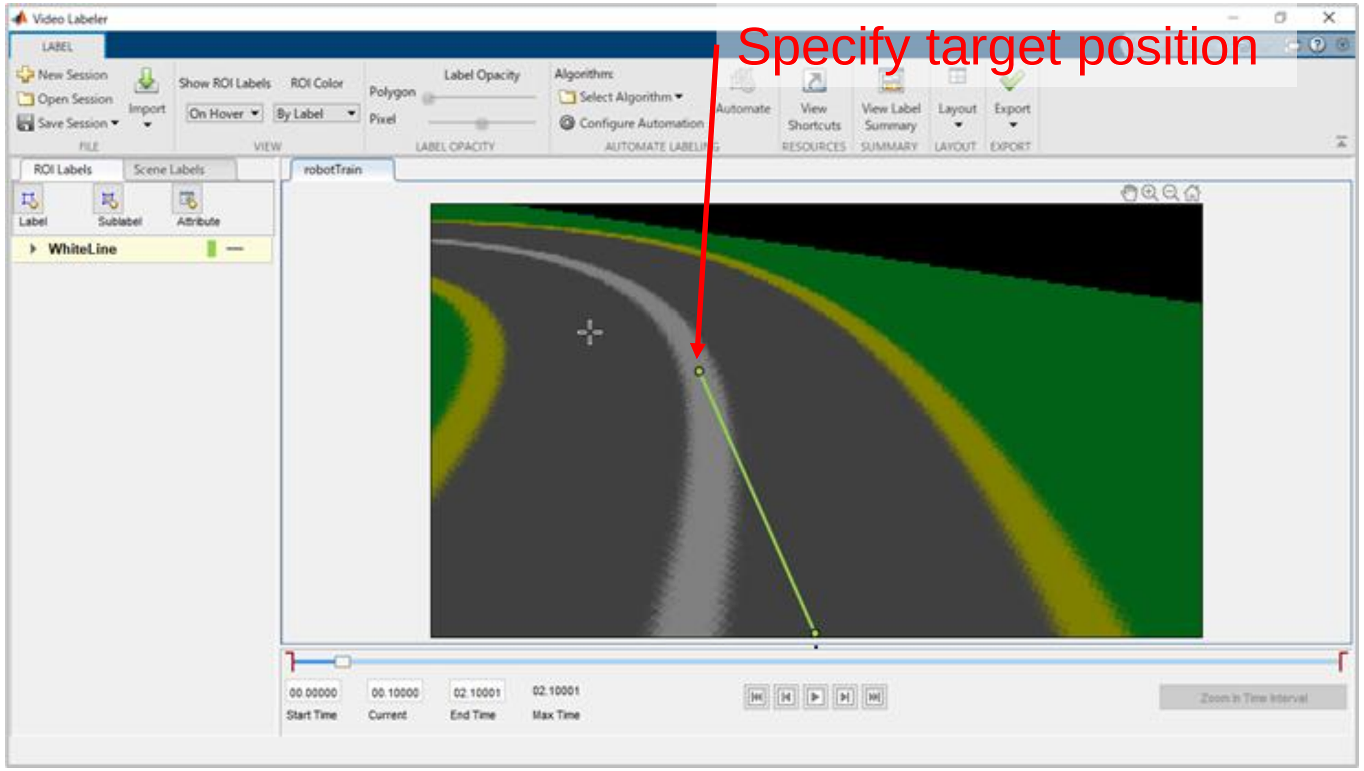


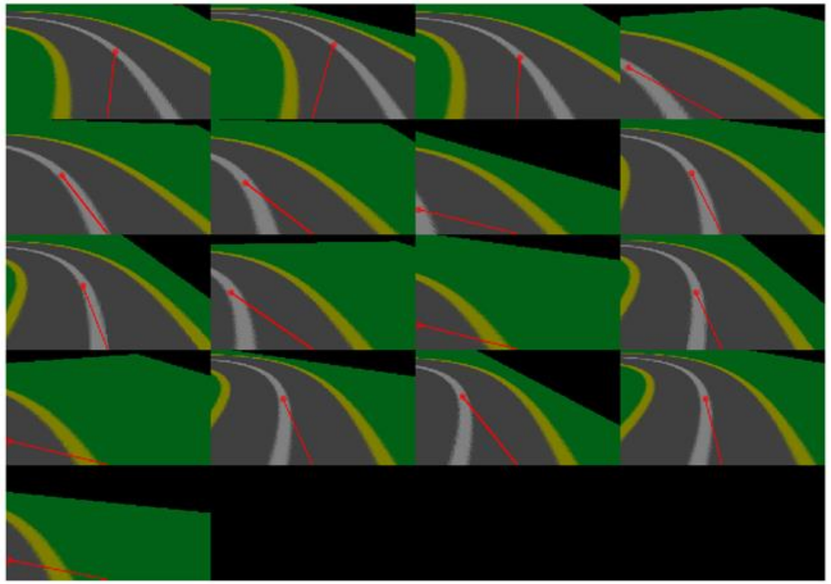
AI-based Autonomous System Development Workflow



Annotating Video File

- Annotate target position each frame using Video Labeler in Computer Vision Toolbox to create training dataset

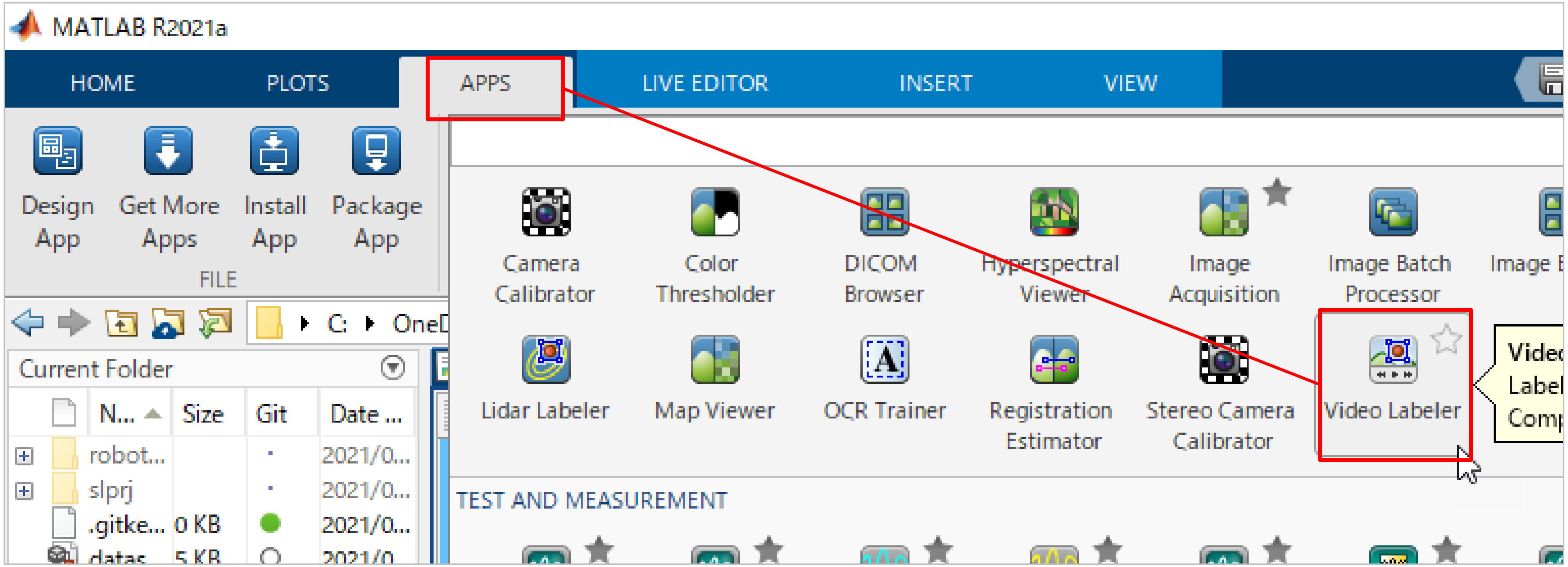




Training dataset
(Combined dataset with images and target positions)

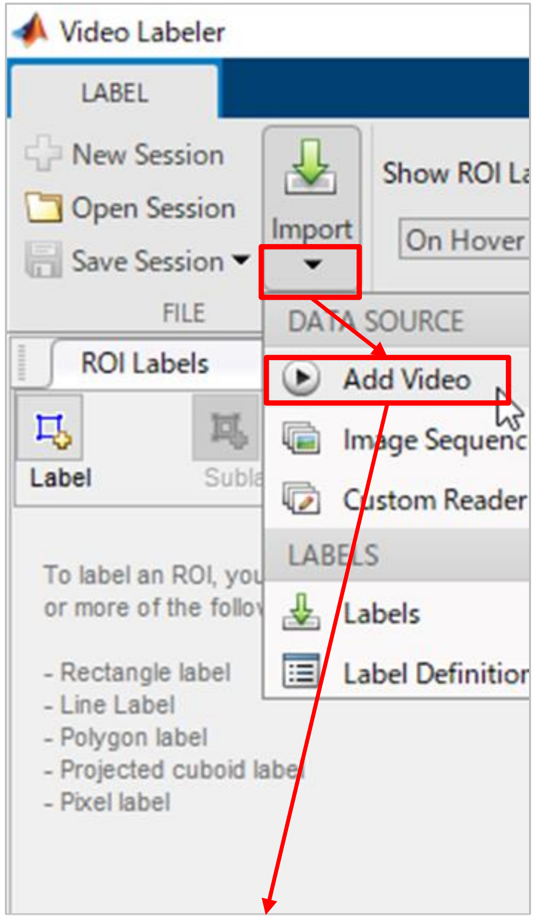
Exercise 2. Annotate Video File using Video Labeler

1. Launch "Video Labeler" as below.



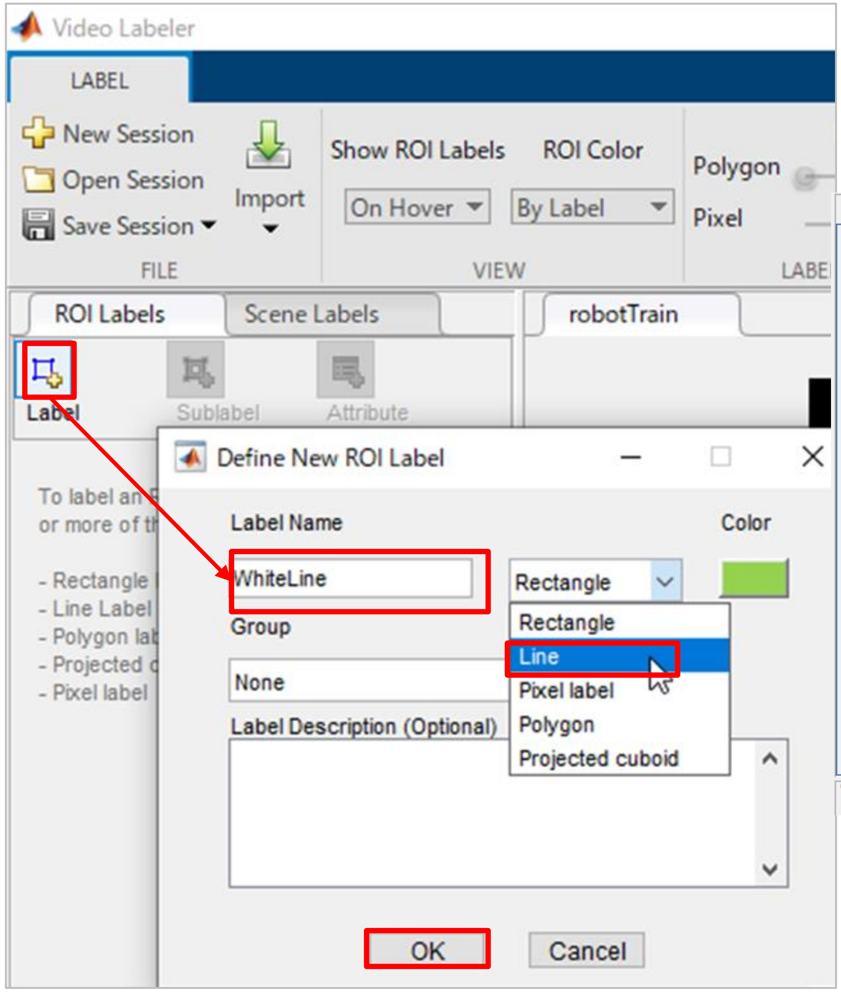
Exercise 2. Annotate Video File using Video Labeler

2. Load the video file



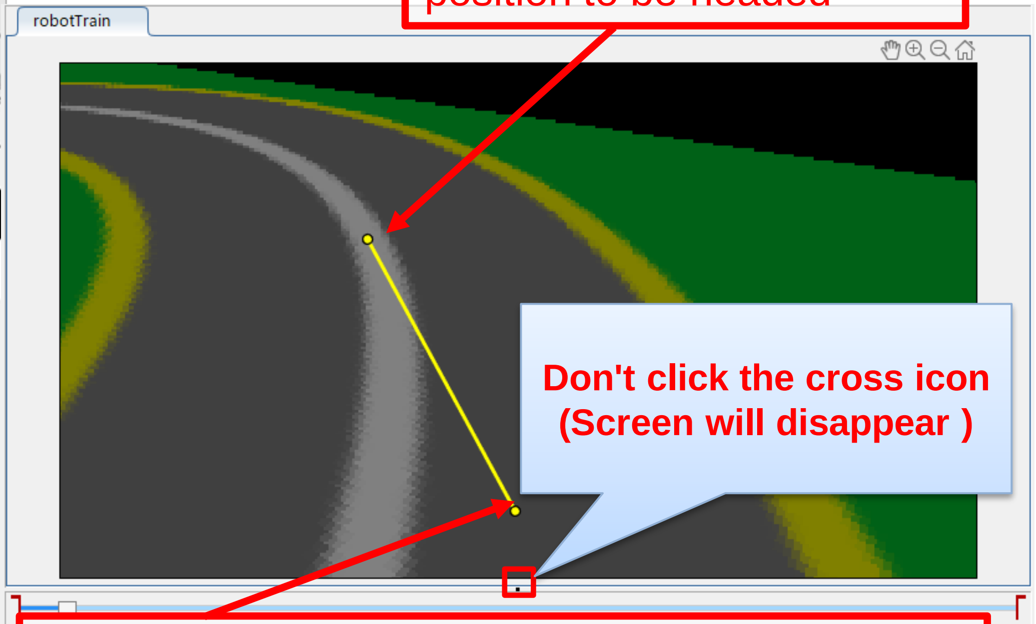
Open robotTrain.avi

3. Define a label



4. Annotate about 20 images from the bottom-center of the image to the target position

2. Double click the target position to be headed



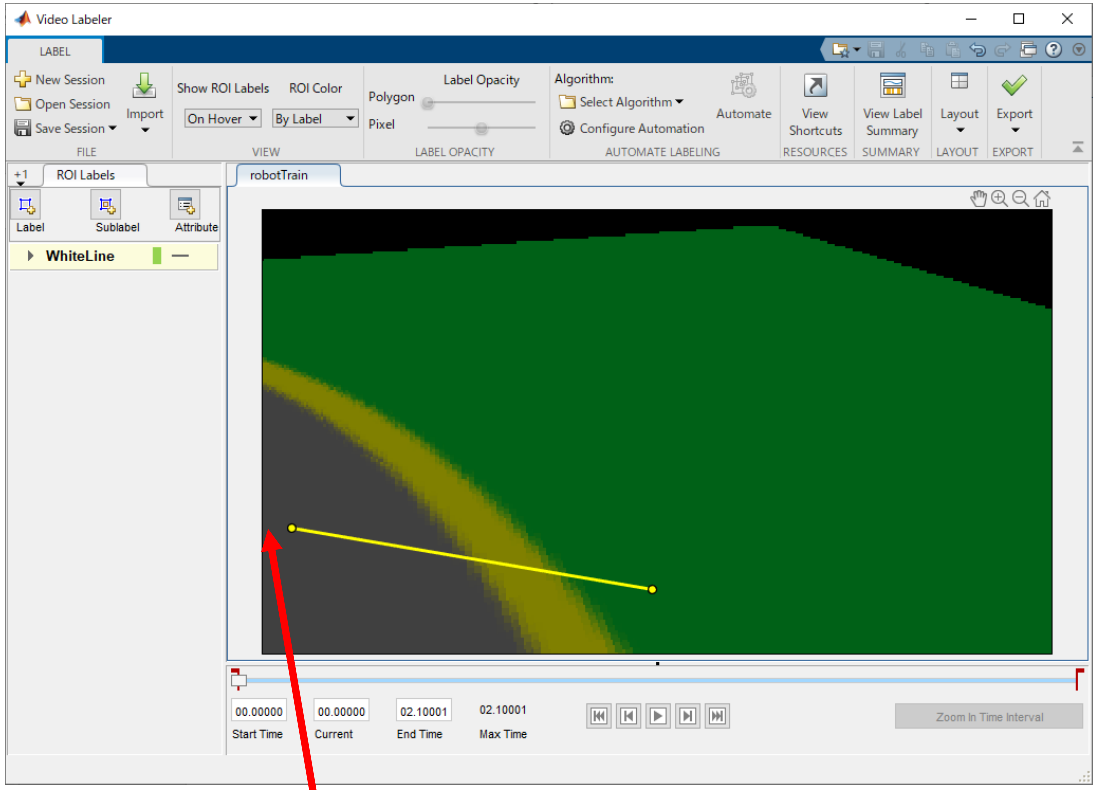
Don't click the cross icon (Screen will disappear)

1. Click the bottom-center of the image (Note: this point will not be used in the training but just needed as a line annotation.)

If there three points or more, remove the all points and annotate again.

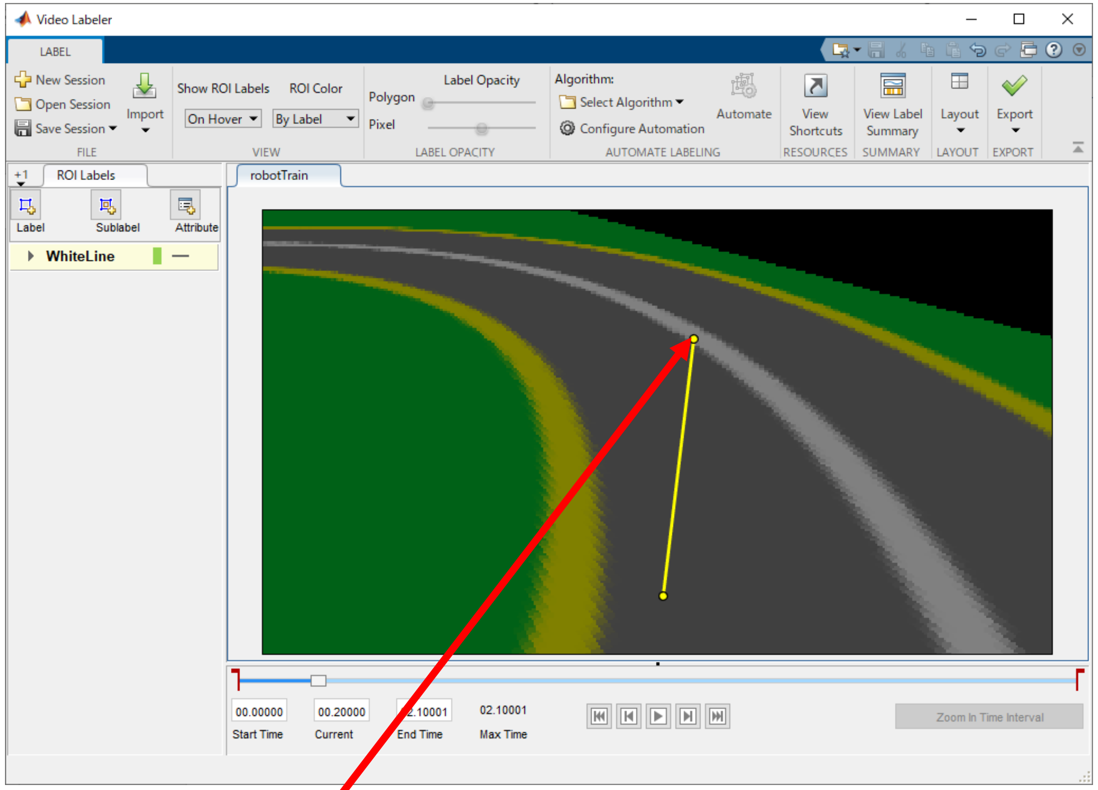
Exercise 2. Annotate Video File using Video Labeler

Annotation example 1:



Click the point to be headed even if white line is not appeared
(This brings the ego-vehicle to inside of the course)

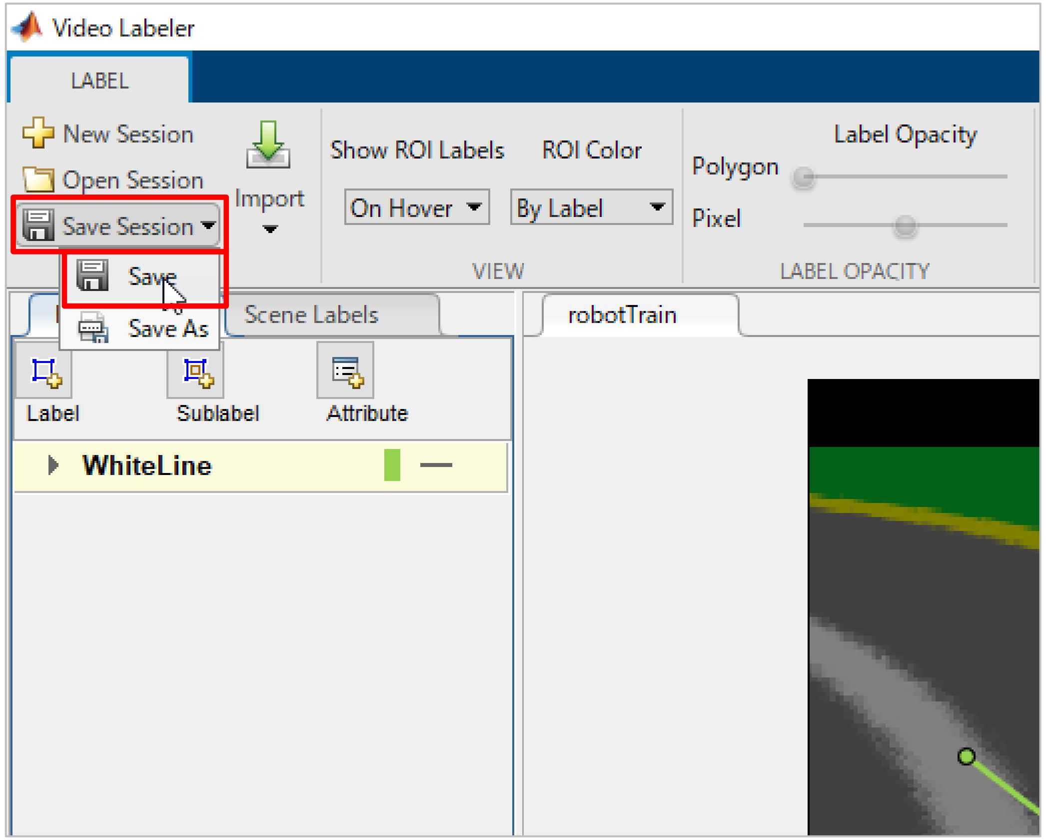
Annotation example 2:



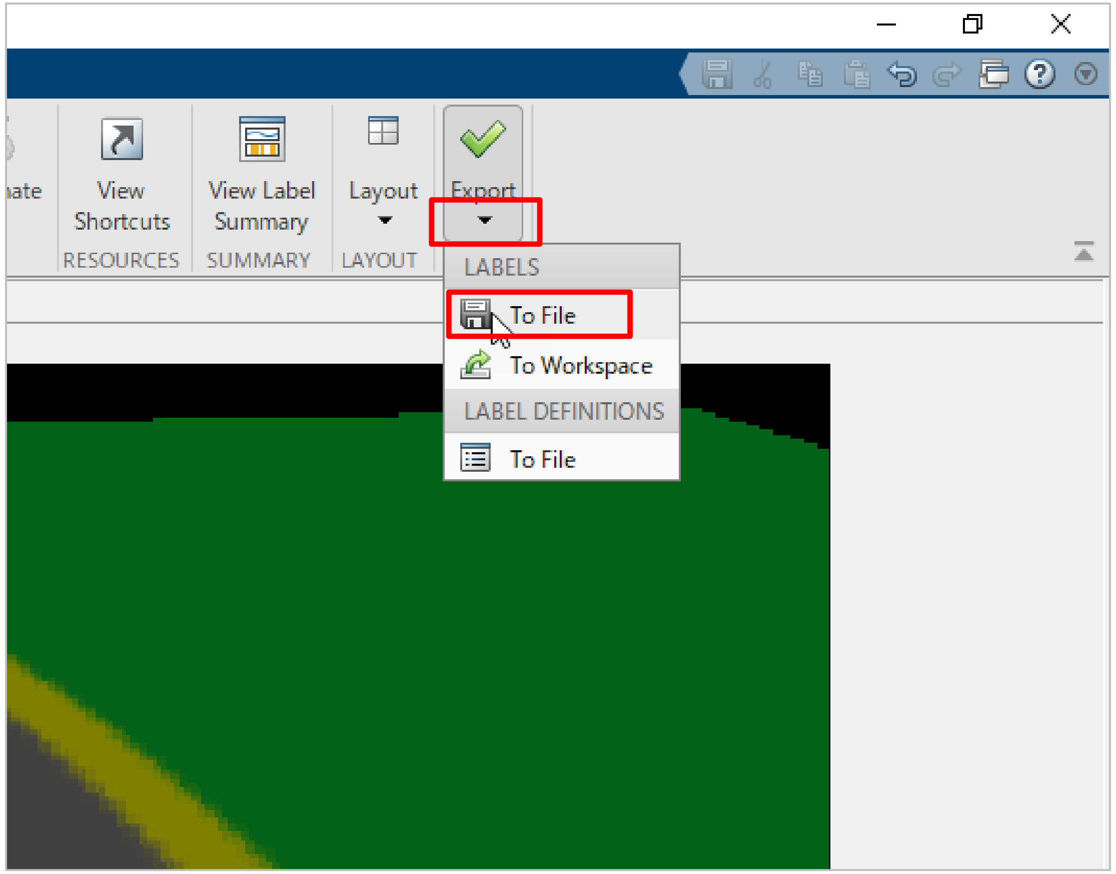
Specify the point to lead the vehicle to the right side.

Exercise 2. Annotate Video File using Video Labeler

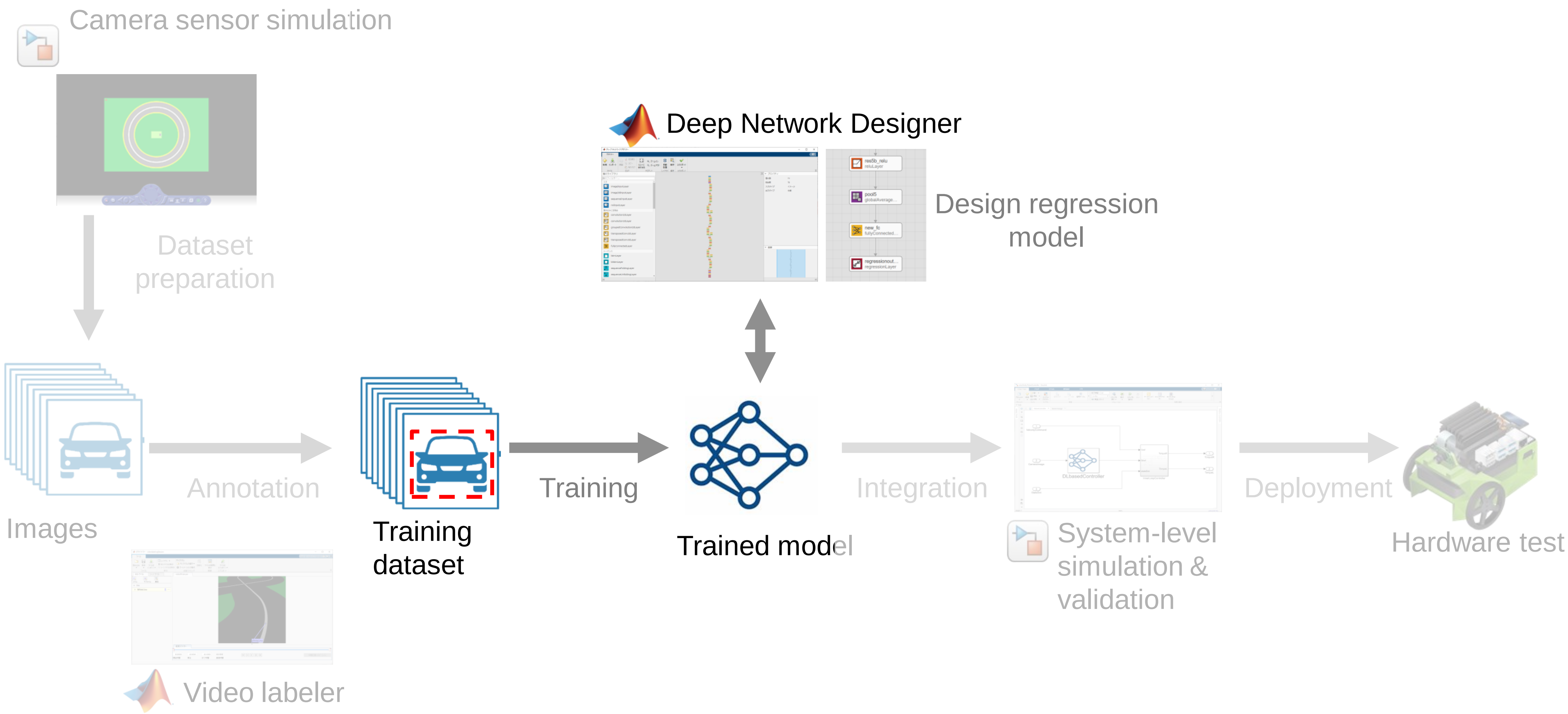
5. Save the session as needed
(Just leave the file name as default)



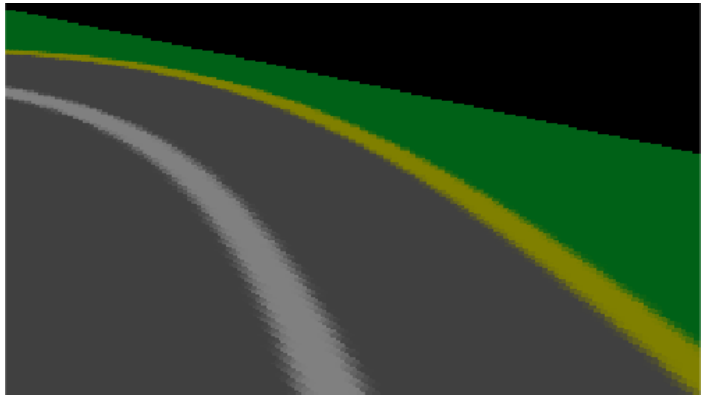
6. Export the annotated data as 「`exportedLabels.mat`」 once finish the annotation



AI-based Autonomous System Development Workflow



Predict Target Position using Deep Learning



Deep Neural Network

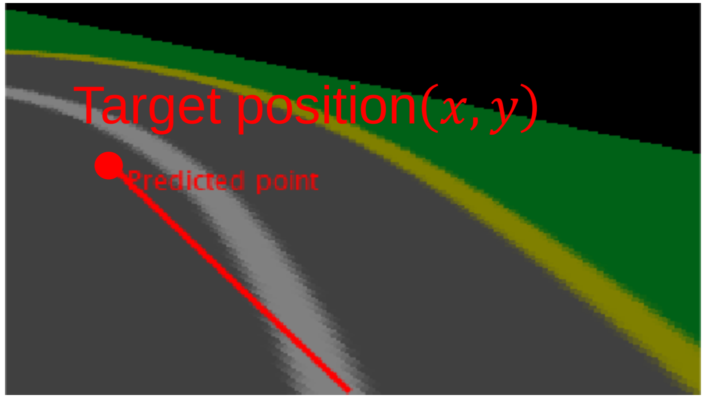


Image from camera
(180 x 320 x 3)

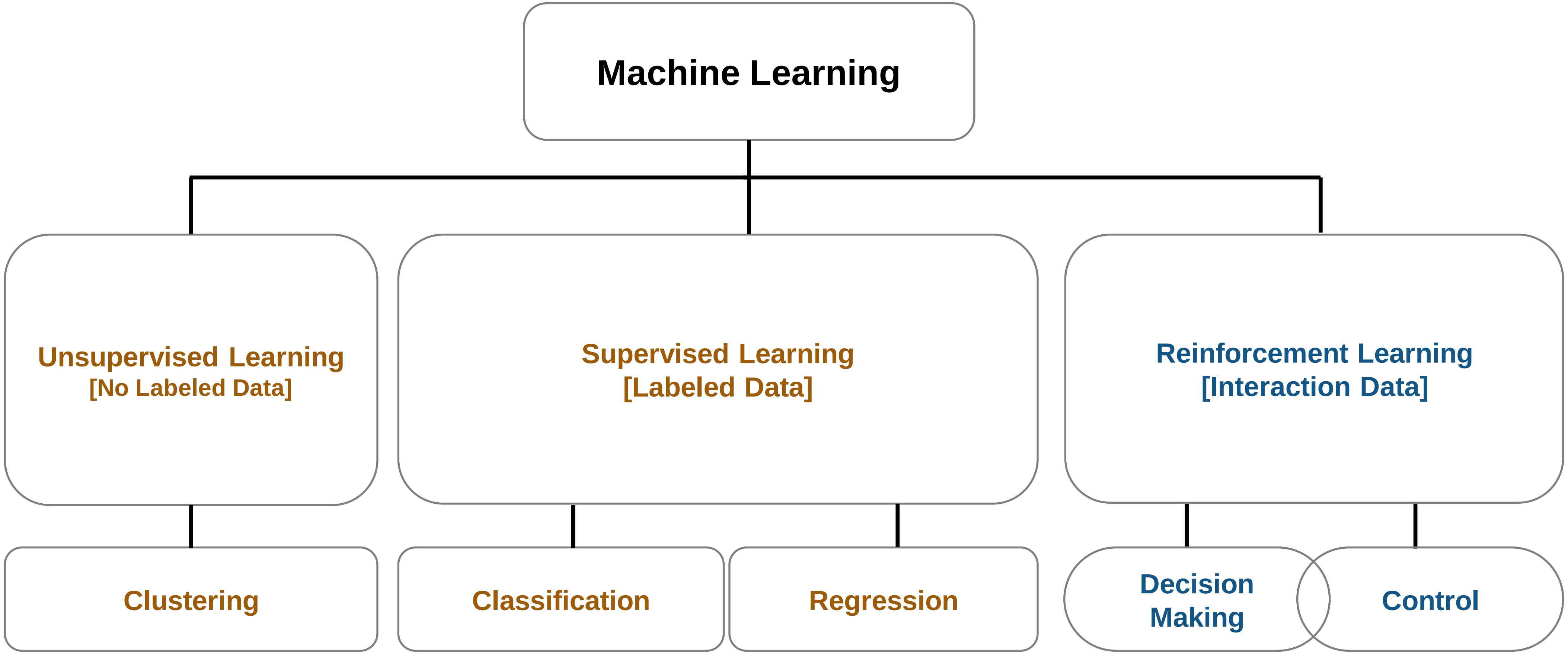
Target position(x, y)
(1 x 2)

Predict target position using a deep neural regression model

Why deep learning?

- Not easy to extract low-dimensional features from high-dimensional data like images using classical image processing and machine learning
- Deep learning is flexible and can handle those high-dimensional data

What is Regression?



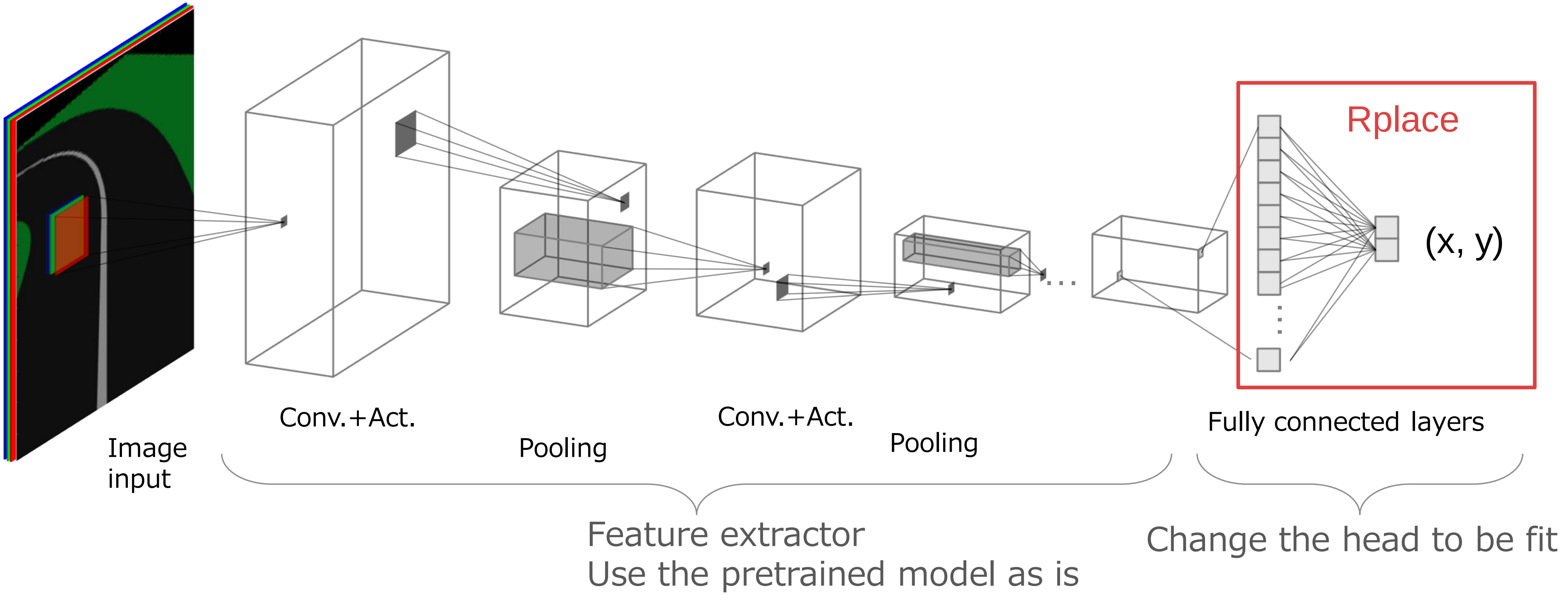
Predict discrete values
ex. Red apple or green apple

Predict continuous values
ex. Diameter of an apple

Predicting target position (x,y) as continuous values
from image is a regression problem

Deep Neural Regression with Transfer Learning

Use a pretrained image classification model as a feature extractor
Change the head of the model to a regression layer

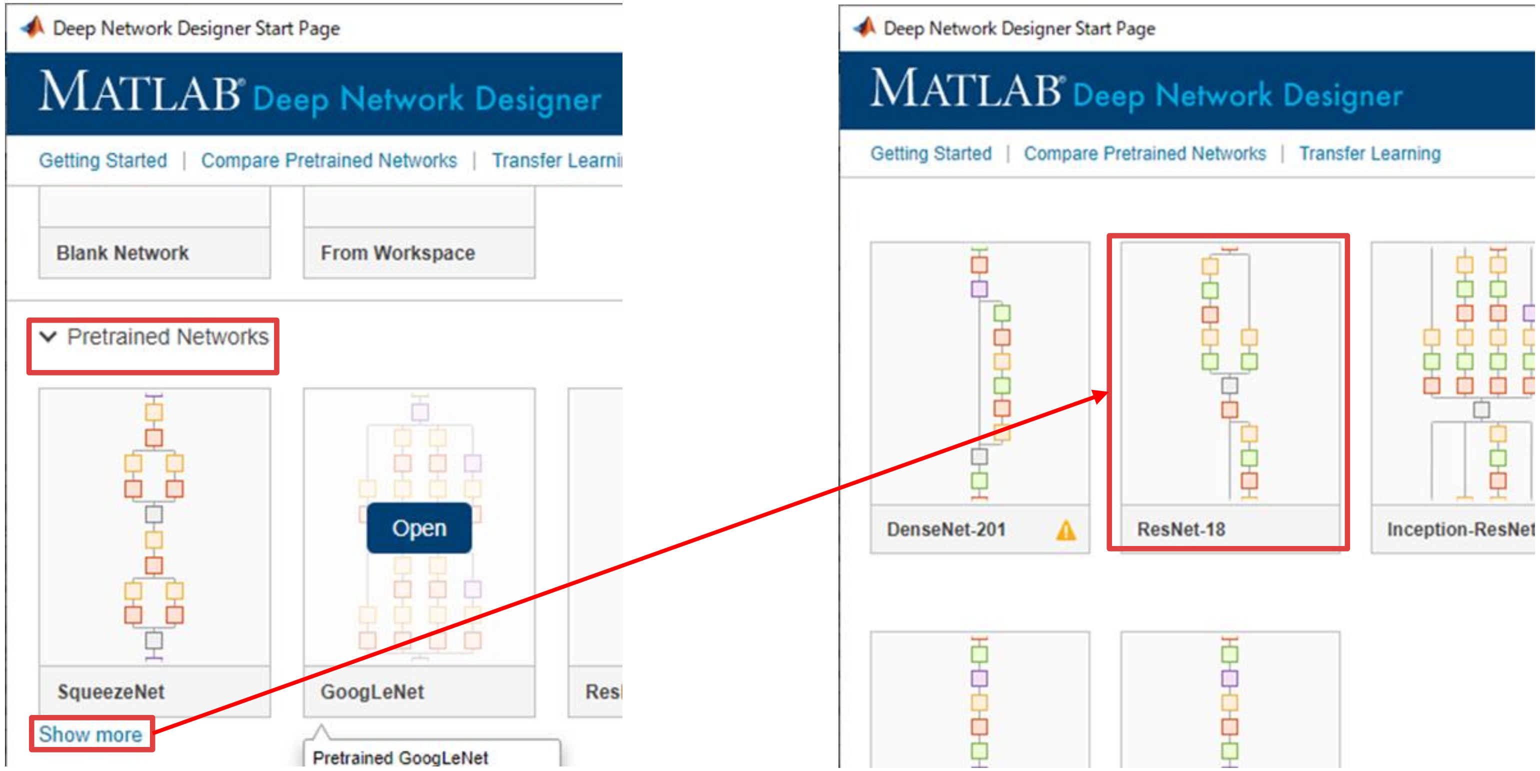


Reference : Convert Classification Network into Regression Network
https://jp.mathworks.com/help/deeplearning/examples/convert-classification-network-into-regression-network.html

Exercise 3. Design and Train Regression Model

Train a regression model by modifying the last classification layers in the pretrained image classification model.

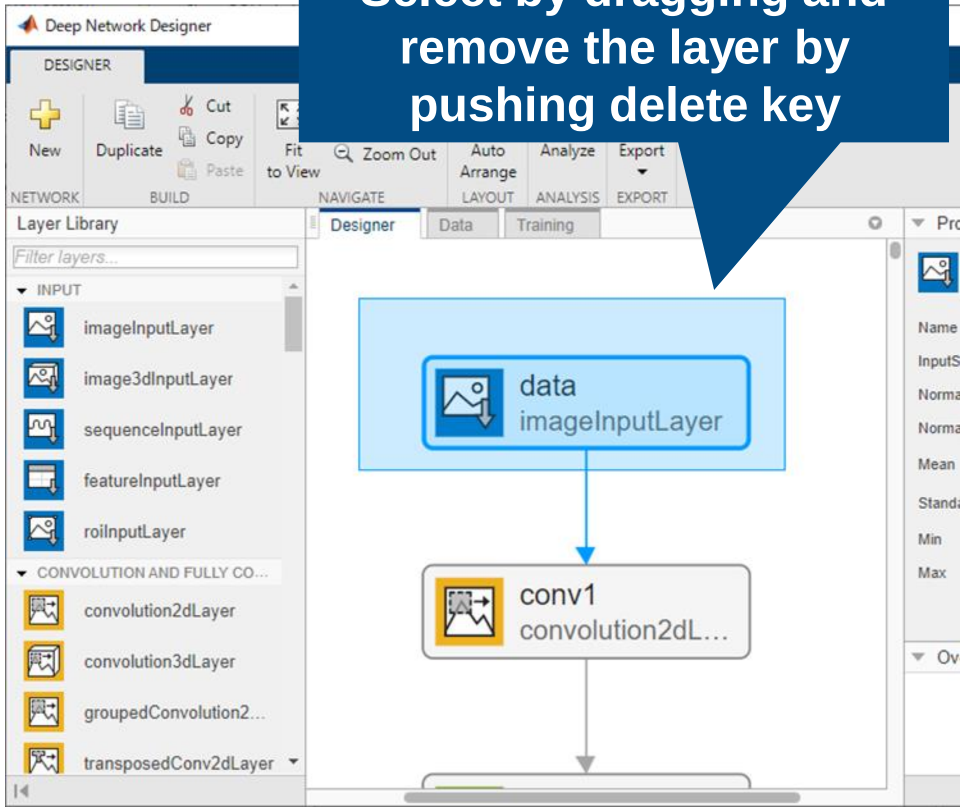
1. Open the live script as below
   `>> edit trainWhiteLine.mlx`
2. Click "Run and Advance" in the "Live Editor" ribbon to line 71
3. Run line 72 and then Deep Network Designer will be launched. Click "ResNet-18".

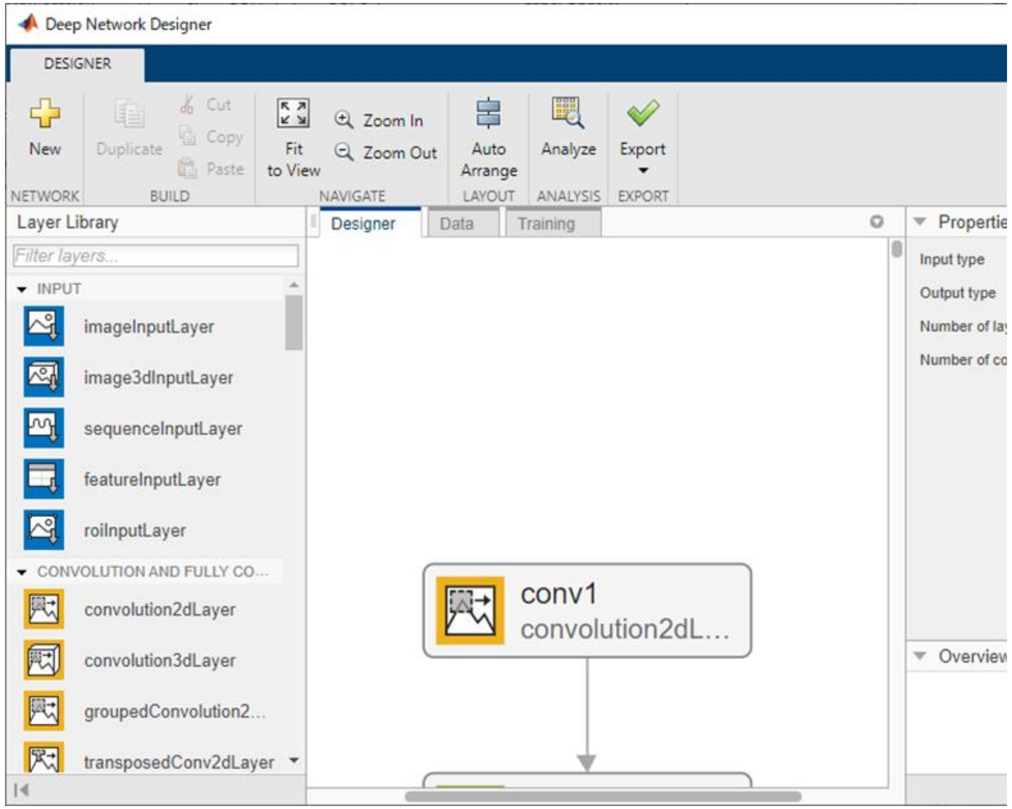


Exercise 3. Design and Train Regression Model

4. Select data layer by dragging and then remove them by pushing delete key
(Need to replace the input layer because the input size of the pretrained ResNet18 is 224 x 224 x 3 while the size of the training images is 180 x 320 x 3)

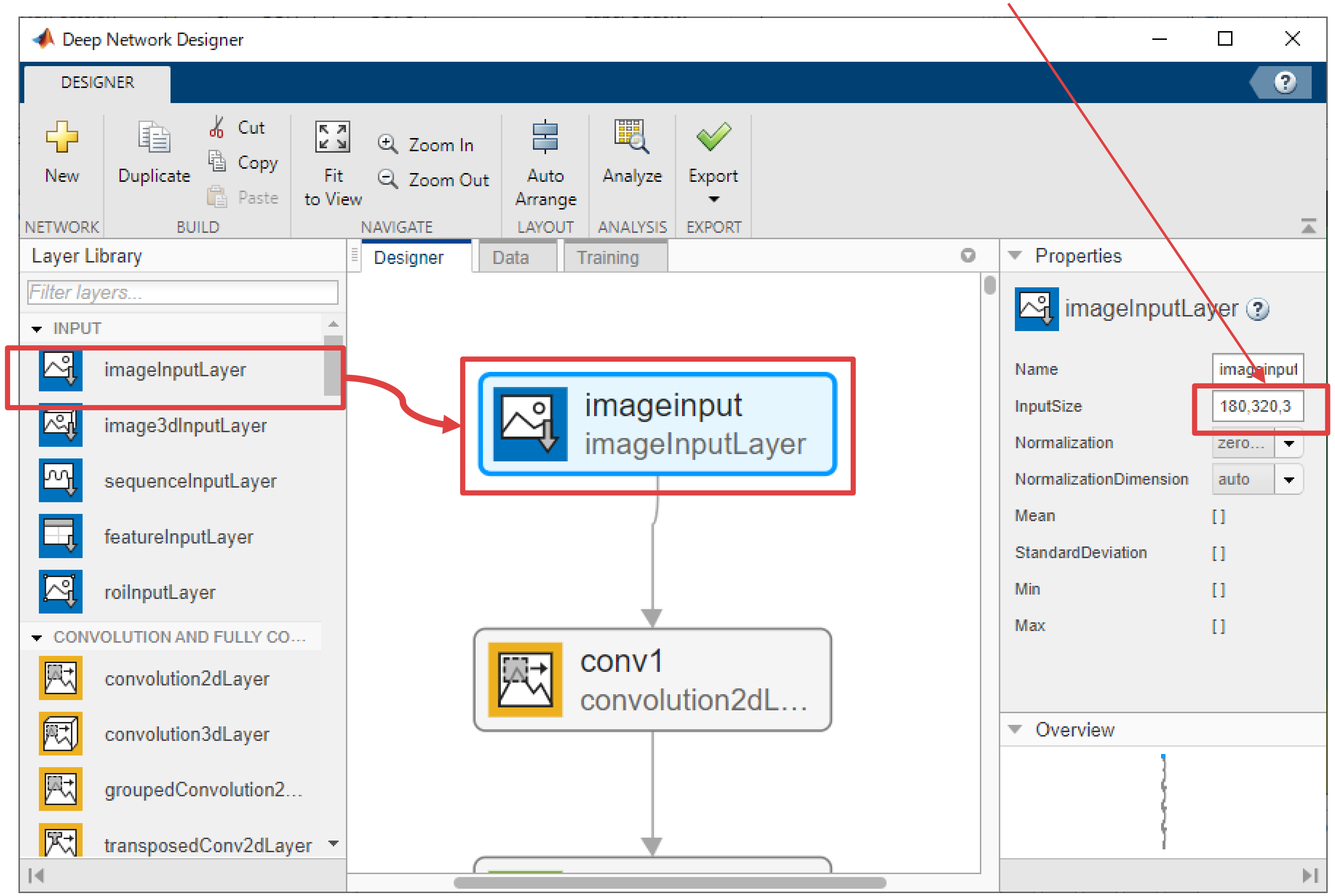
Select by dragging and remove the layer by pushing delete key





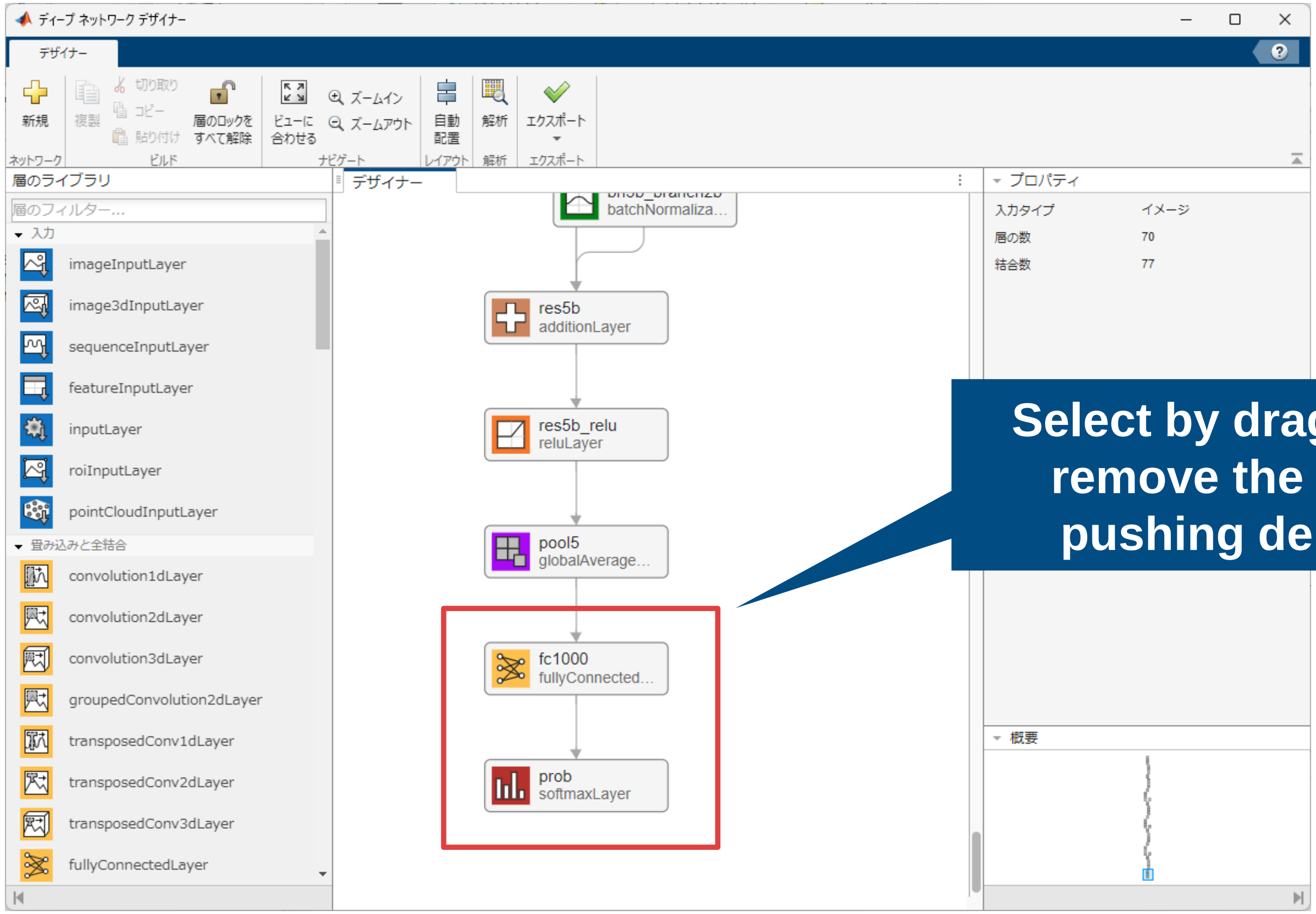
Exercise 3. Design and Train Regression Model

5. Drag & drop the "imageInputLayer" in the "INPUT" group in the "Layer Library" tab to the designer campus.
Drag the edge of the **`imageinput`** layer to connect to the **`conv1`**.
Set the "**`InputSize`**" property in the **`imageinput`** layer to "**`180,320,3`**".



Exercise 3. Design and Train Regression Model

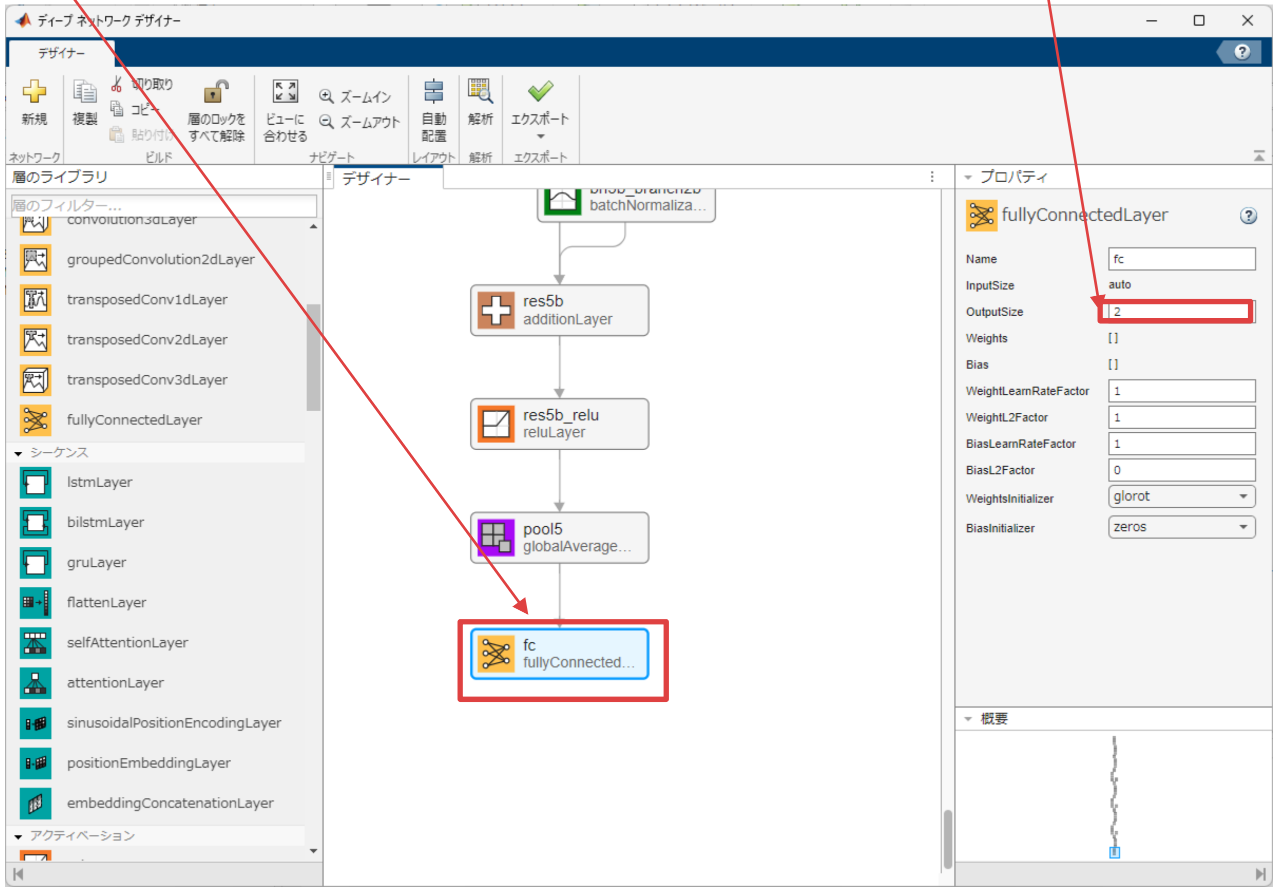
6. Select "**`fc1000`**" layer and the successive layers by dragging and then remove them by pushing delete key (Need to change the 1,000 classes classification model to a 2 outputs regression model)



Select by dragging and remove the layer by pushing delete key

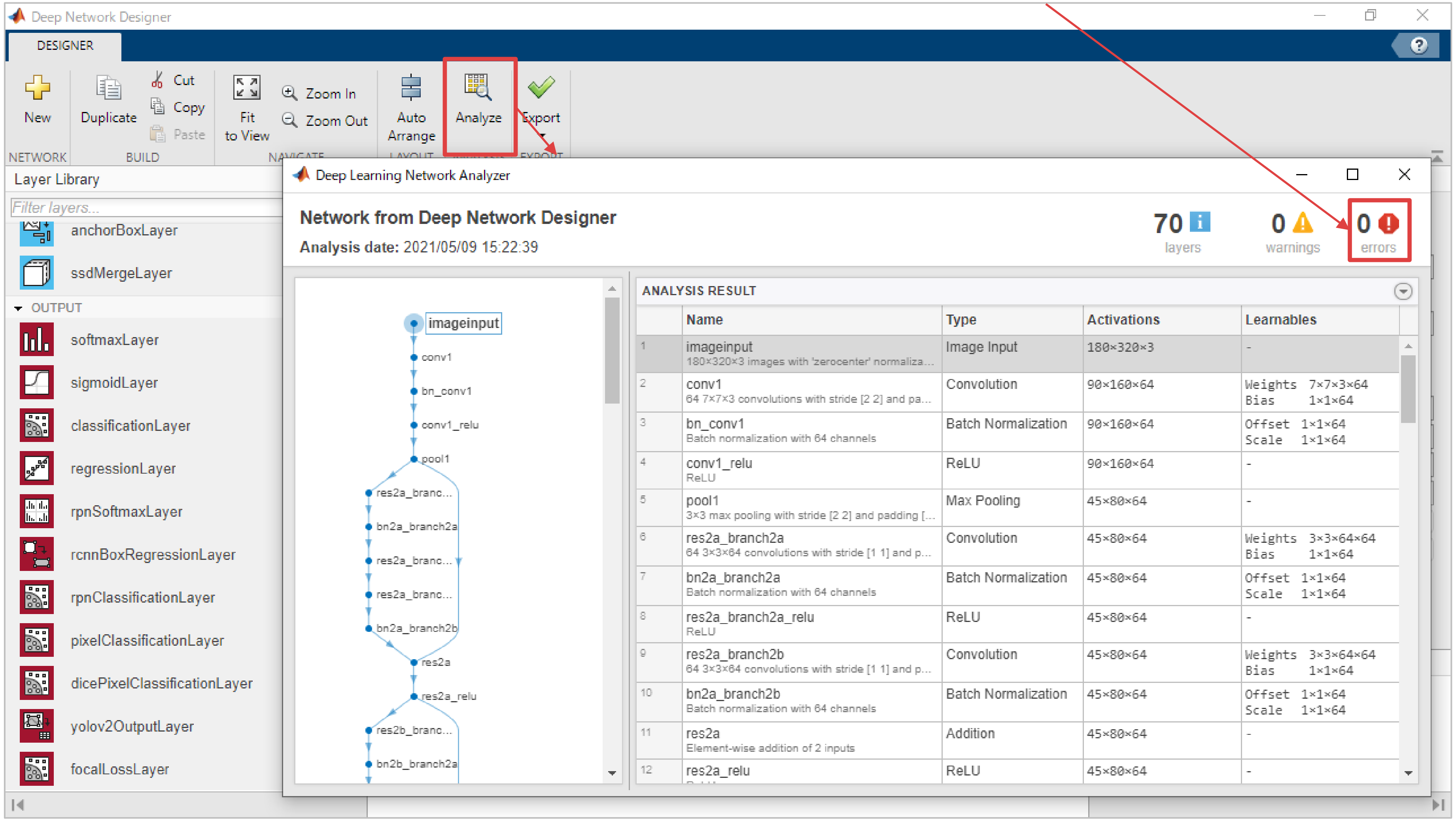
Exercise 3. Design and Train Regression Model

7. Add **`fullyConnectedLayer`** from "Convolution and fully connected layers" in "Layer Library" located in the left panel.
8. Change the **`OutputSize`** to 2 because the number of output values are two (x, y)
9. Connect **`pool5`** to **`fc`**



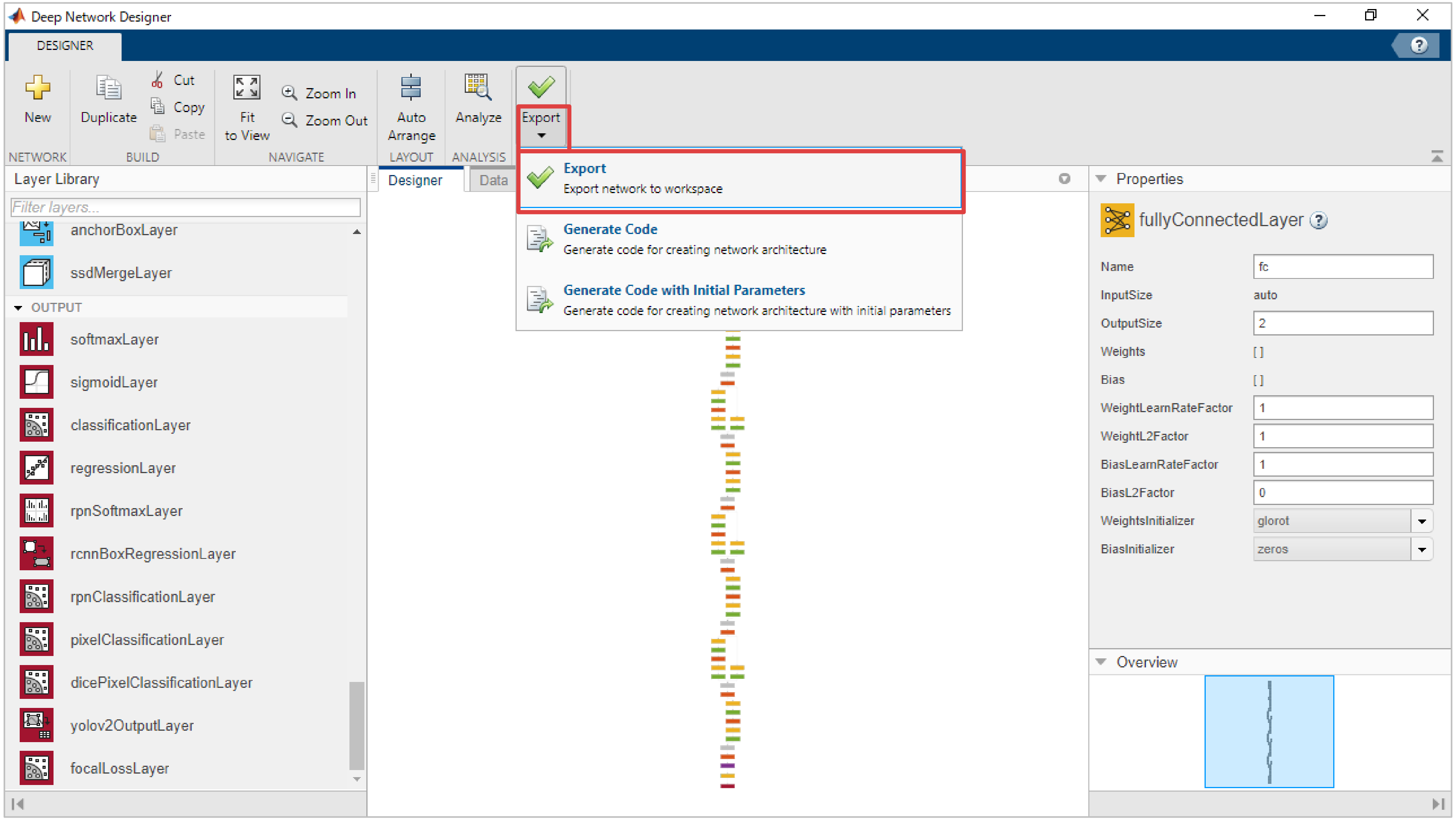
Exercise 3. Design and Train Regression Model

8. Make sure the network is consistent and the number of errors is zero by clicking "Analyze" button



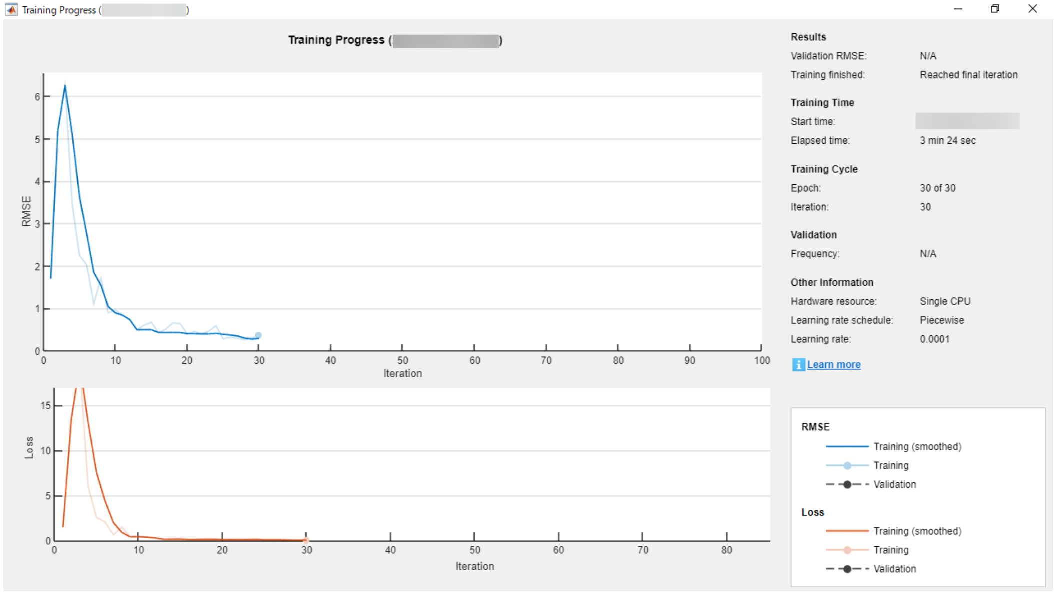
Exercise 3. Design and Train Regression Model

9. Export the model to workspace by clicking "Export" in "Export" button.

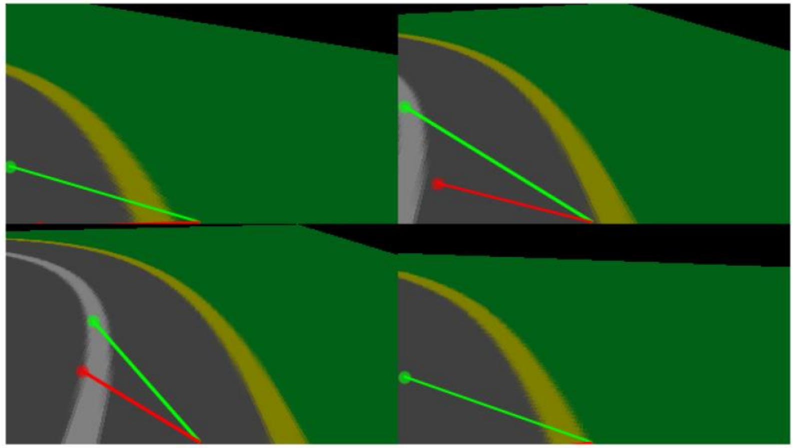


Exercise 3. Design and Train Regression Model

10. Run the rest of the code to end
The training progress will be shown up as below when training begins (It may take 5 minutes with CPU)
11. **`mynet_new.mat`** is generated once the training is completed

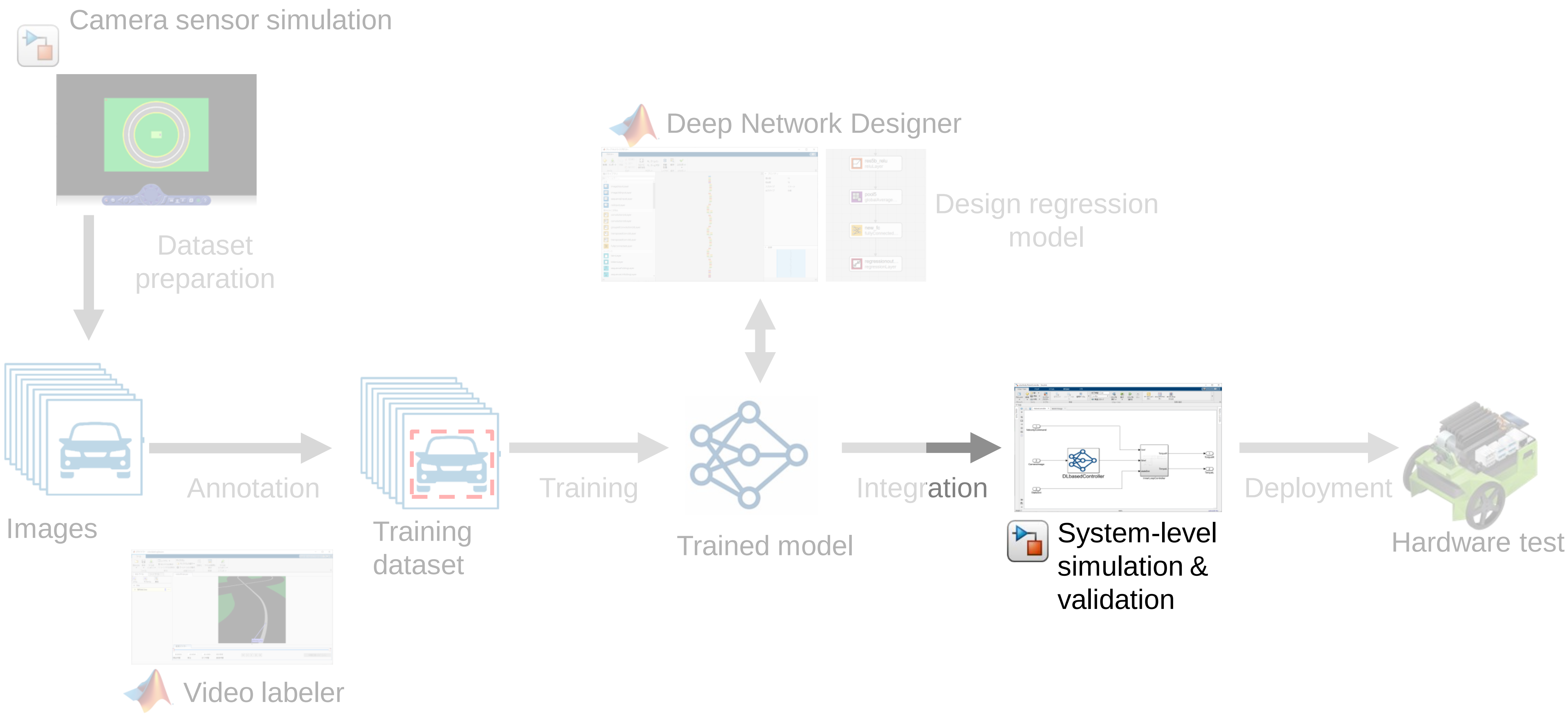


Training progress

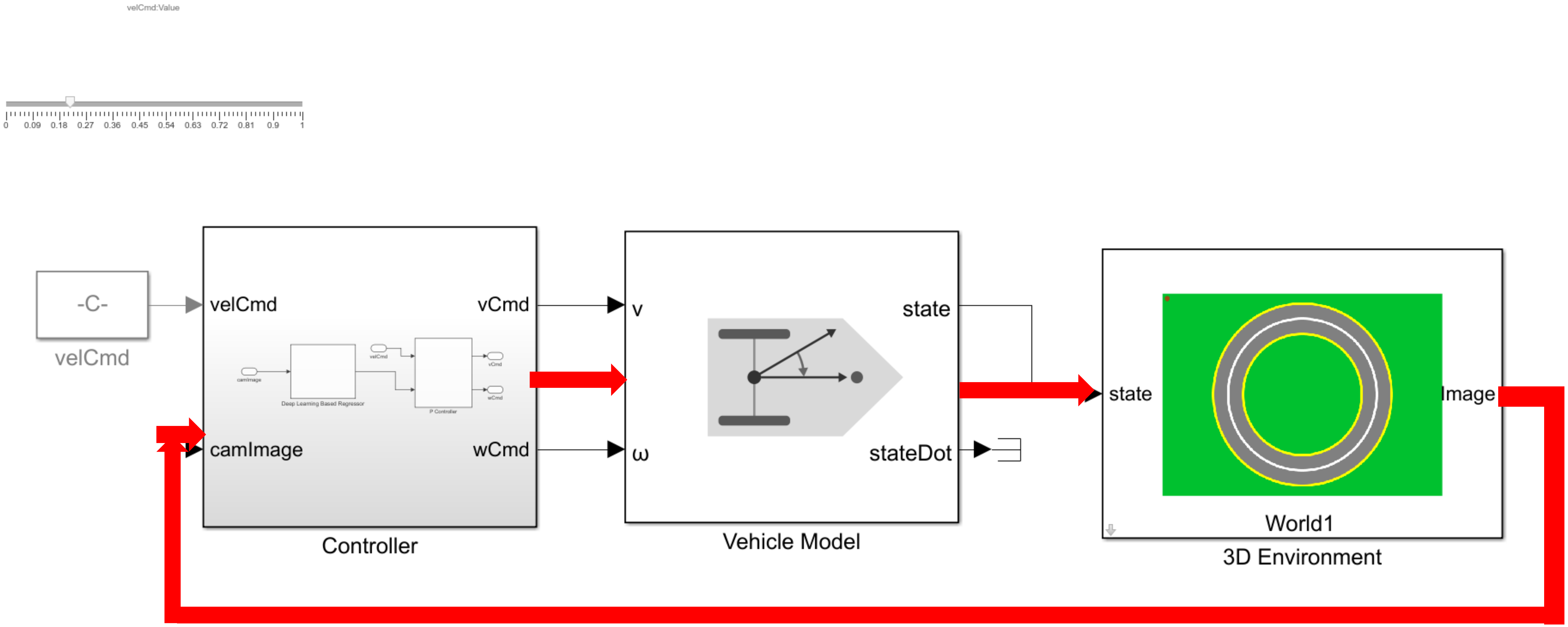


Predicted results
(Green: ground truth
Red: predicted)

AI-based Autonomous System Development Workflow



Test Line Following Algorithms Integrating Components as System



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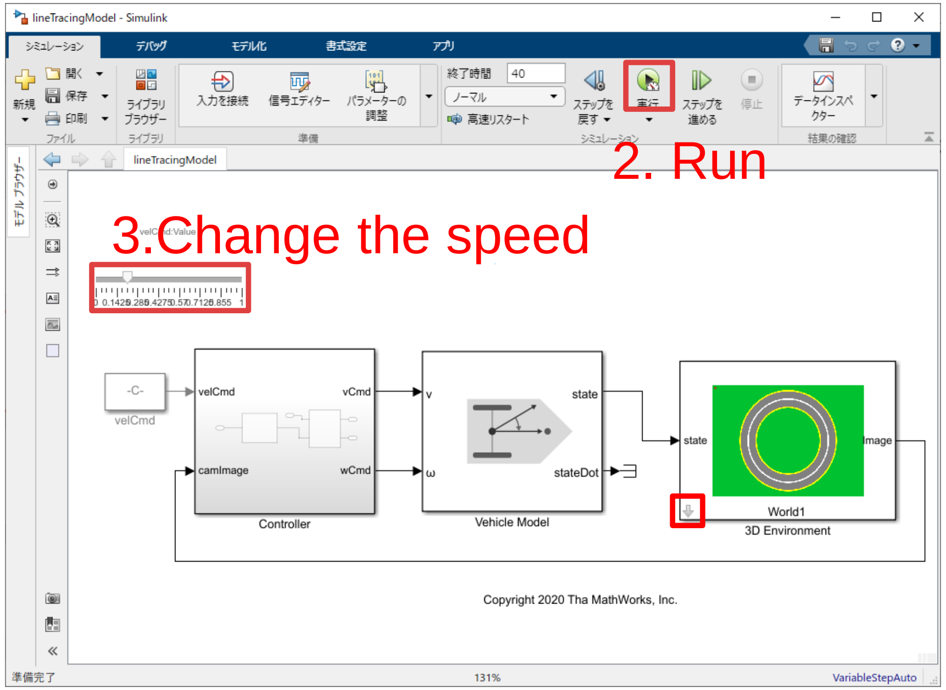
Autonomous system can be a closed loop system

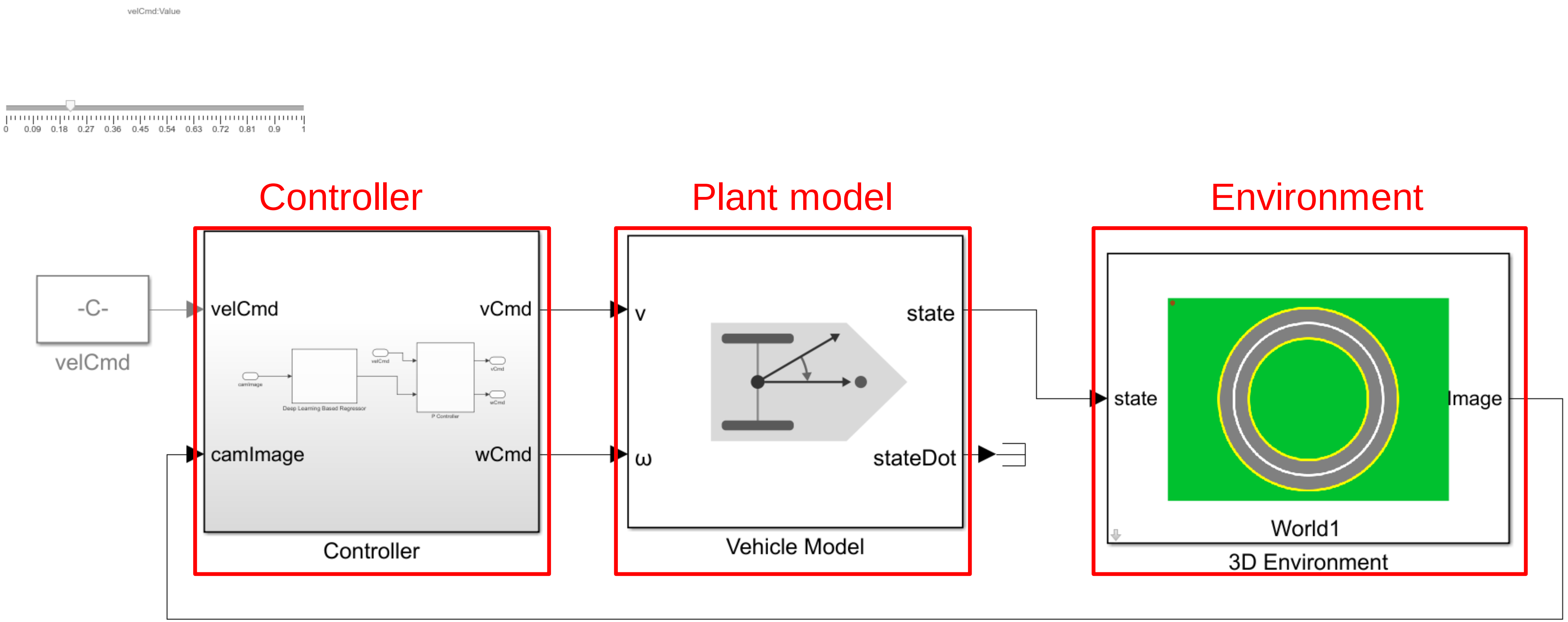
Performance test and validation as a system are required

Exercise 4. Test Line Following Algorithm as System

1. **`Open line_follower.slx`** and click run button in "Simulation" tab
   Click stop button (gray square button) if you want to stop the simulation
   `>> line_follower.slx`
2. Change the bar for speed and then observe what will be happened in the line following
3. Try to change the initial position and observe what will be happened (See p.35)
4. Try to change the P gain and see how the following performance changes (See p.34)
5. Try to change the map data for 3-D world and see how the following behavior changes (See p.36)
6. Save the simulation results as a video (See p.37)



System Overview



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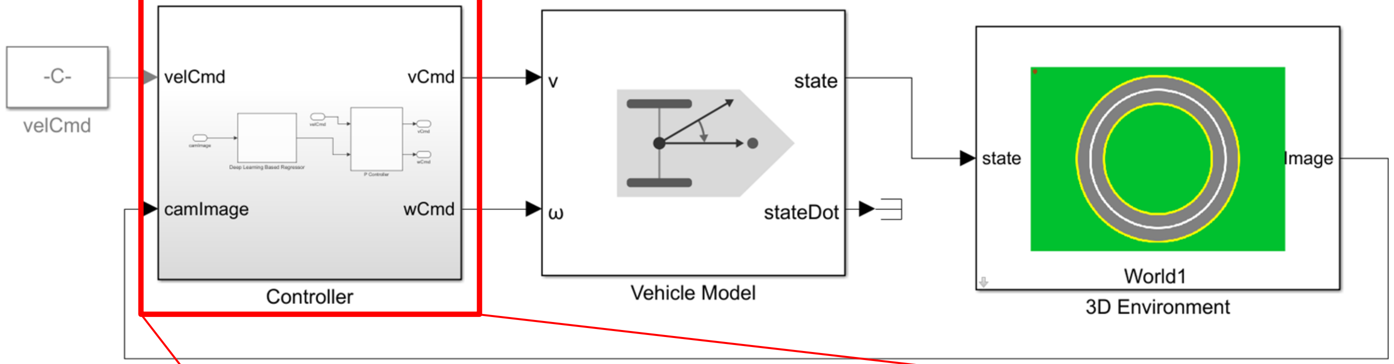
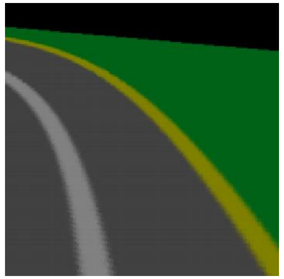
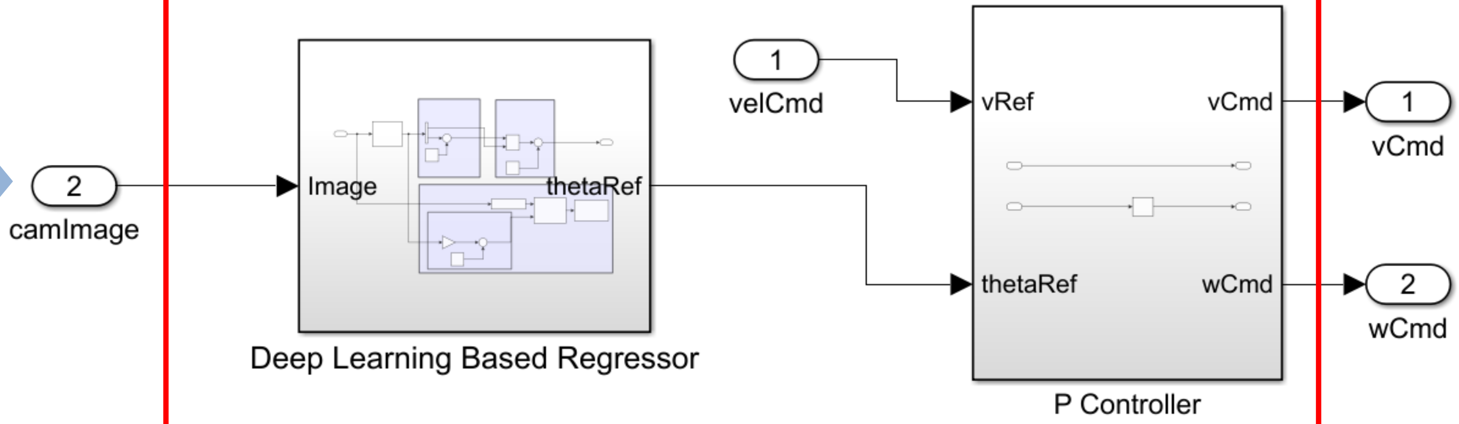
System-level Simulation : Controller





Image

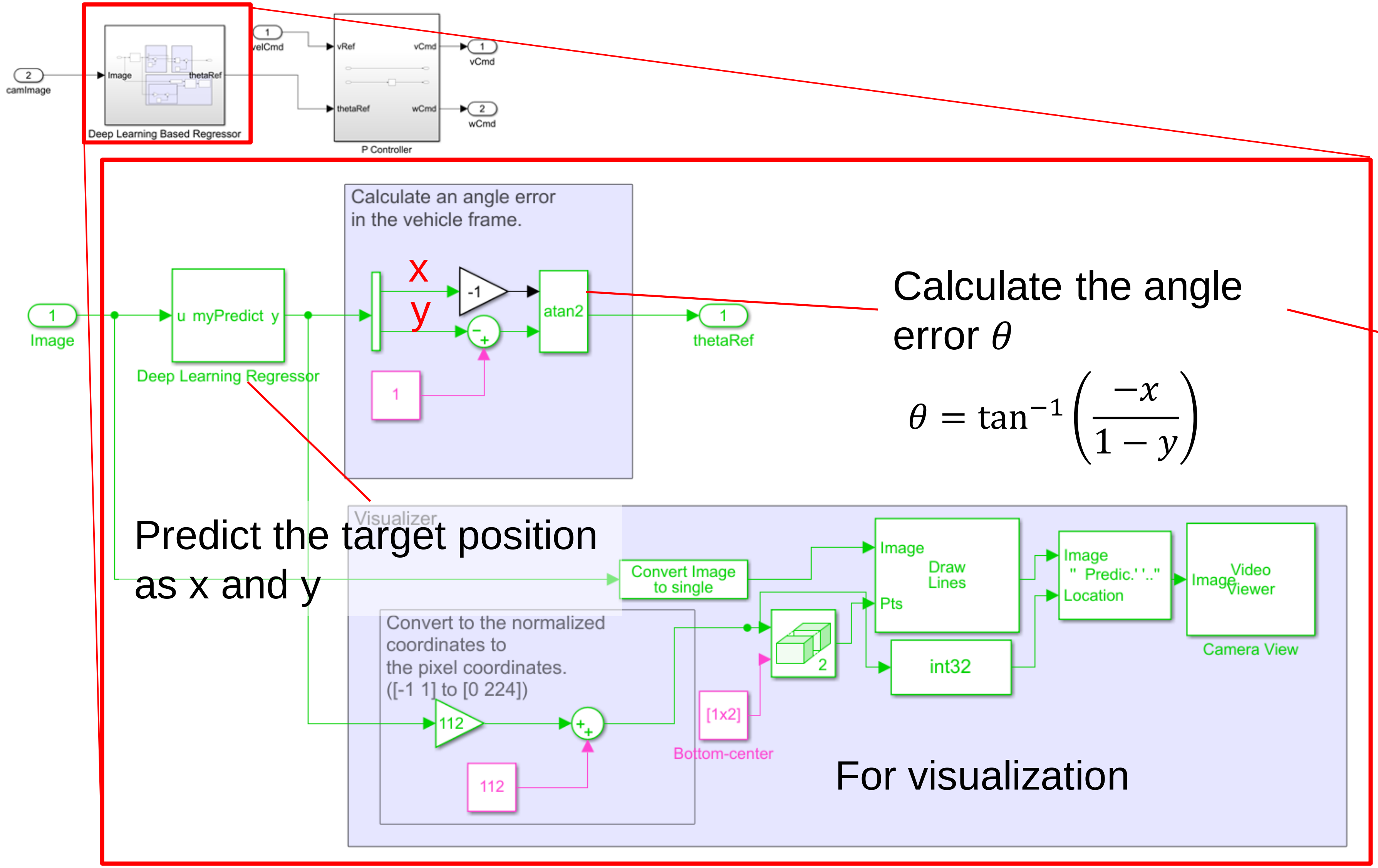


Calculate target angle using deep neural network

P controller

Target linear velocity
Target angular velocity

System-level Simulation : Calculate Angle Error

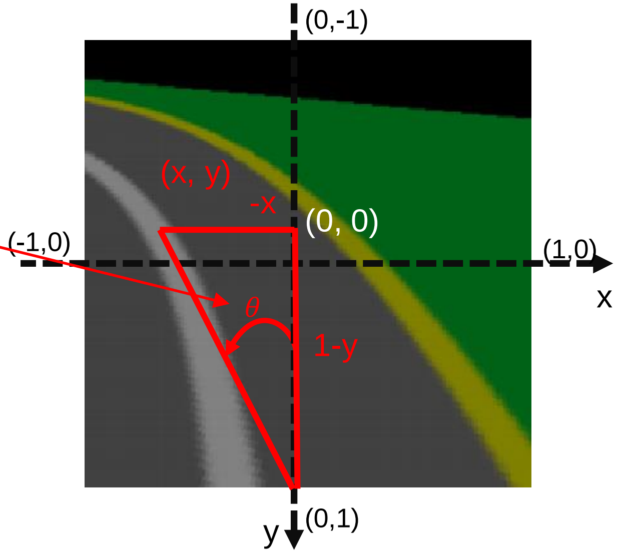


Calculate the angle error θ

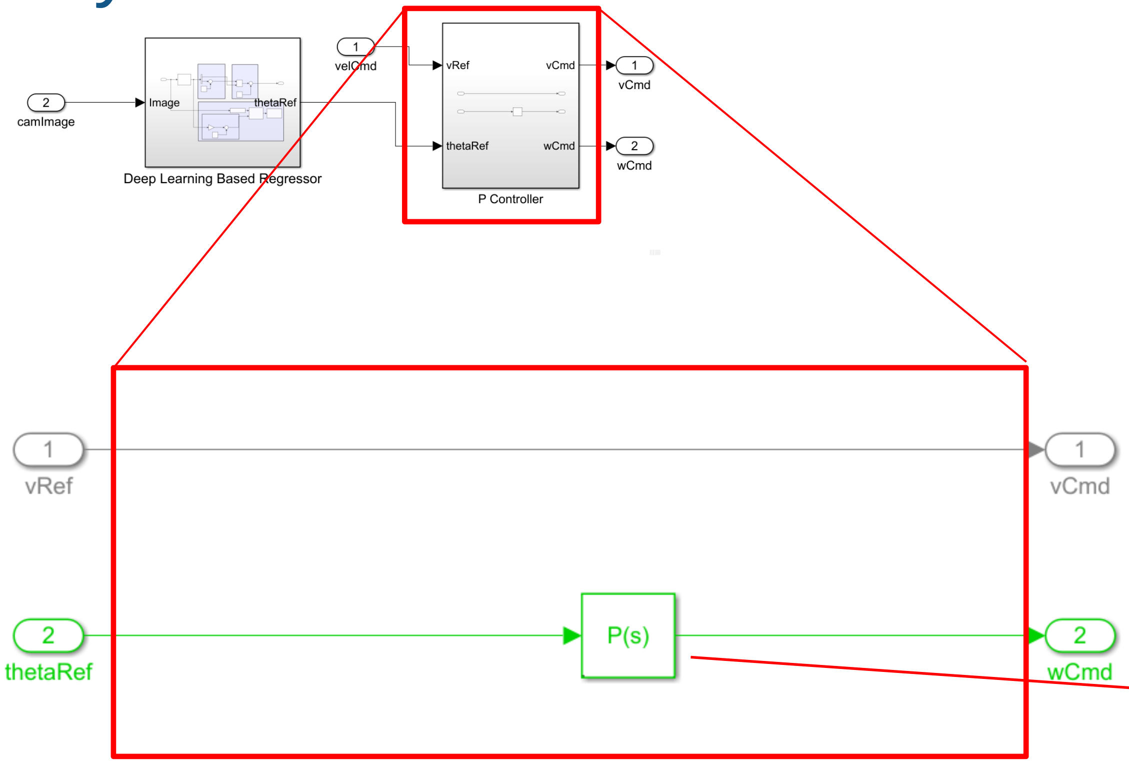
$$\theta = \tan^{-1}\left(\frac{-x}{1-y}\right)$$

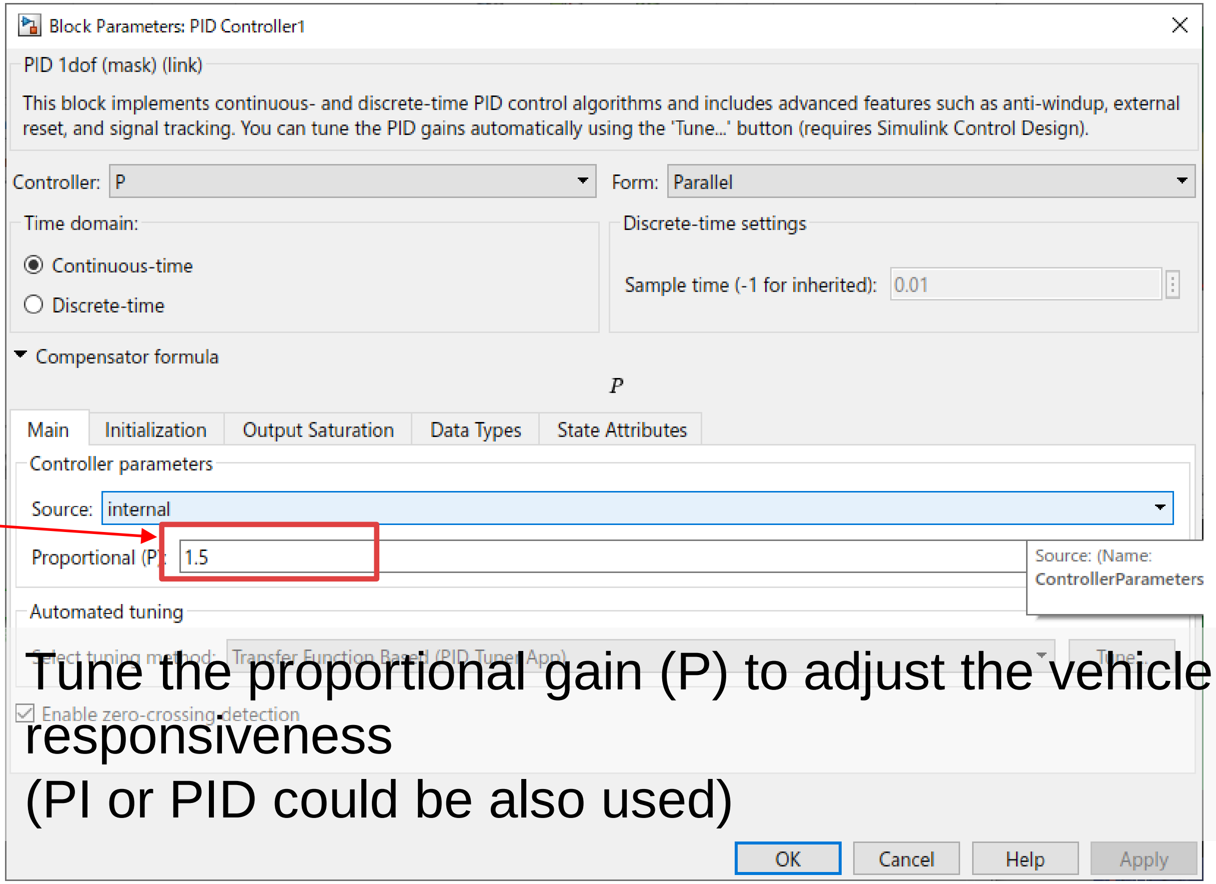
Predict the target position as x and y

For visualization



System-level Simulation : Feedback Controller

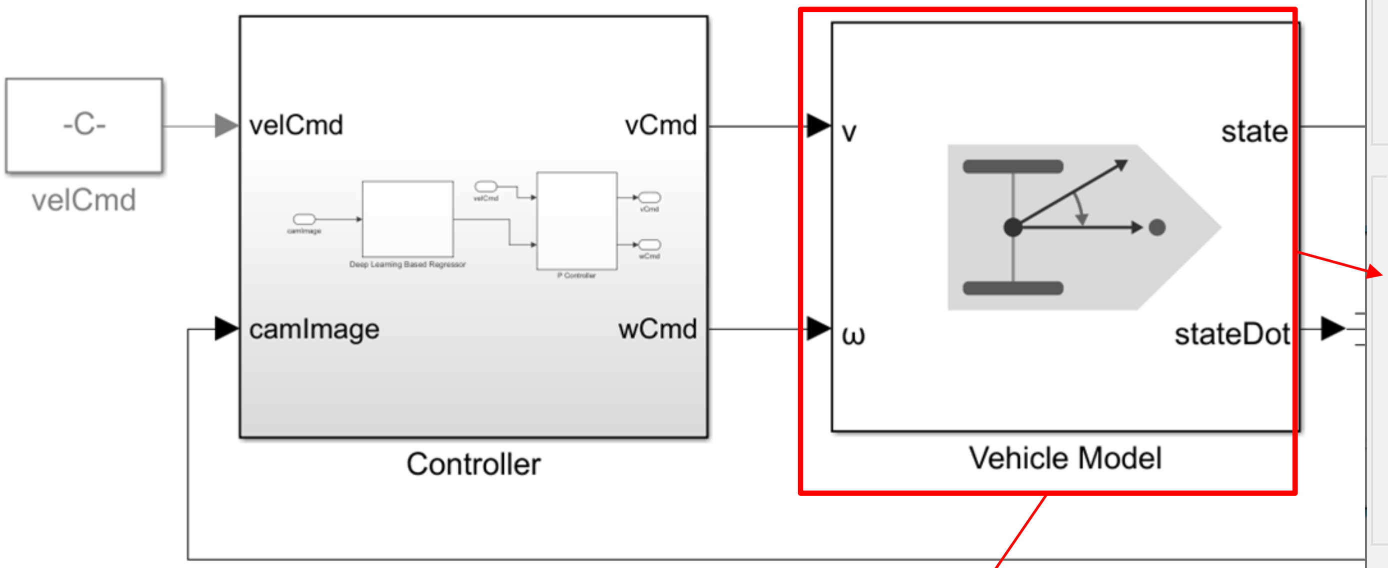


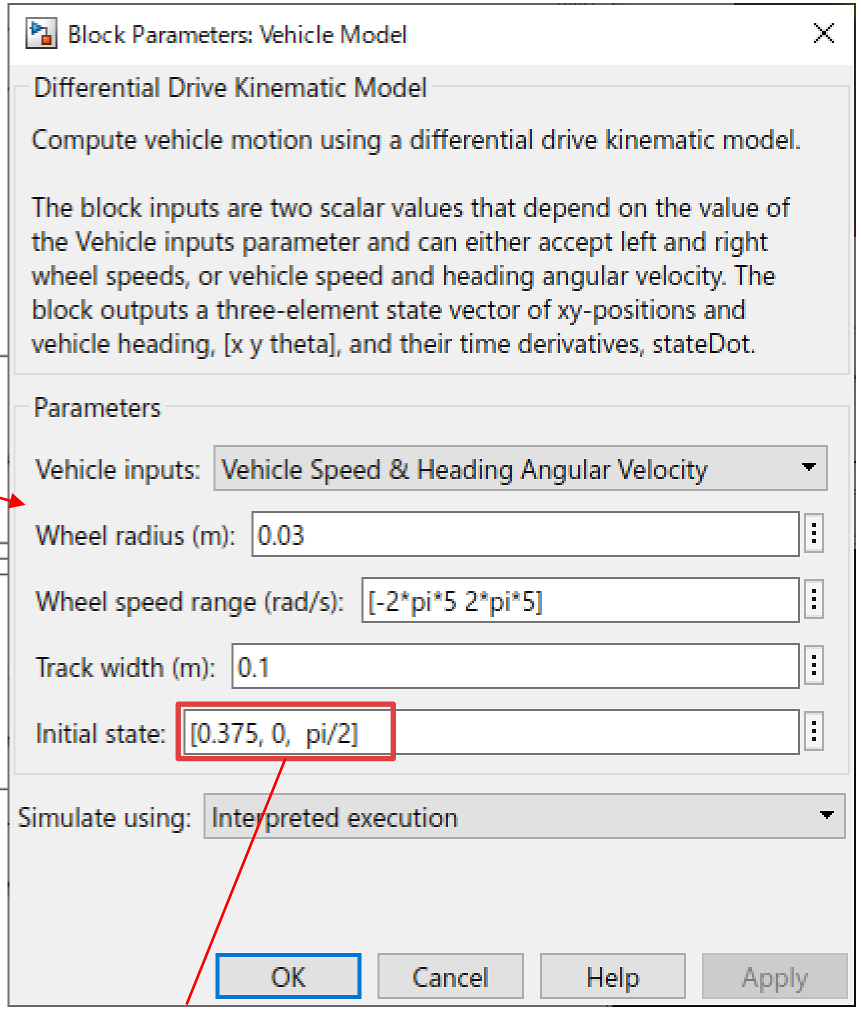


Feedback to make the error angle to be zero
Control only steering
Linear velocity is constant

Tune the proportional gain (P) to adjust the vehicle responsiveness
(PI or PID could be also used)

System-level Simulation : Plant Model

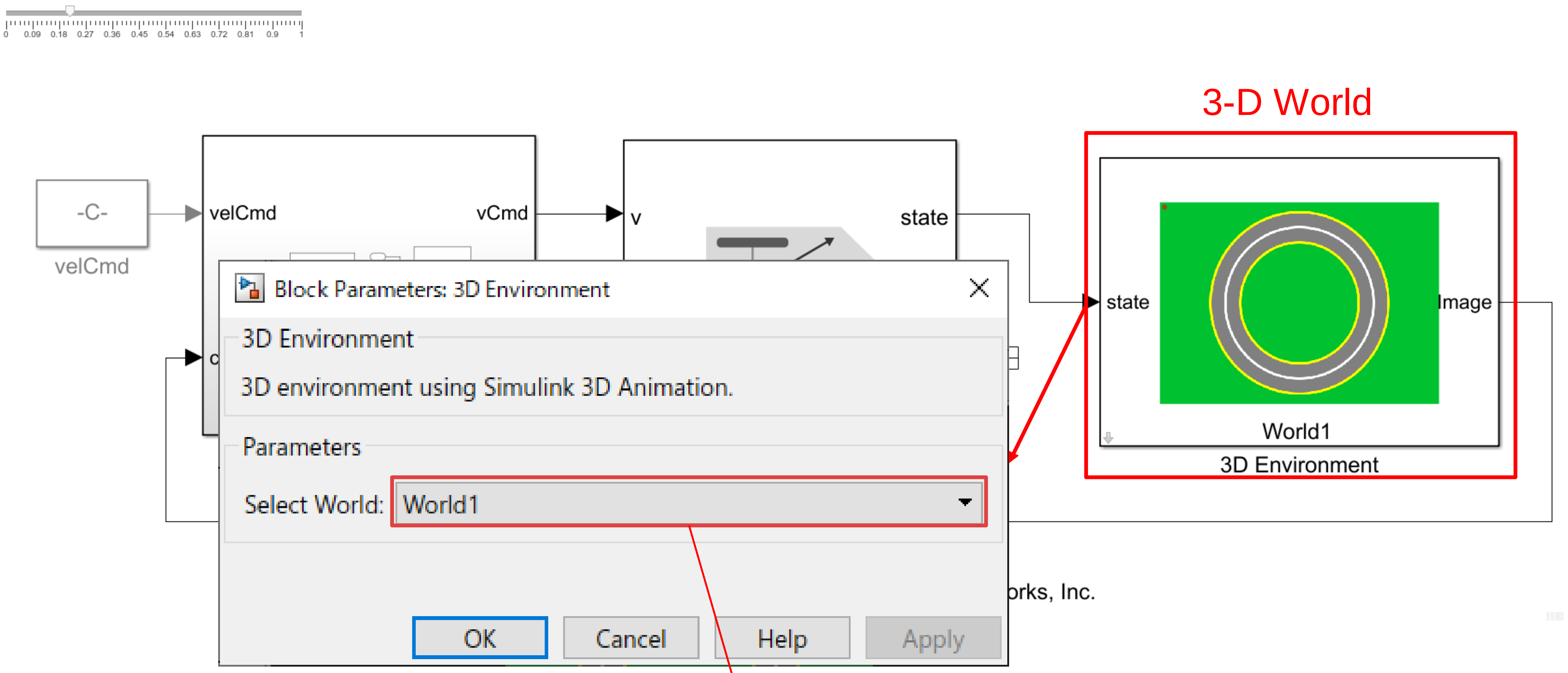




Use a differential drive model which receives linear velocity and angular velocity as inputs then outputs position and orientation (x_v, y_v, θ_v)

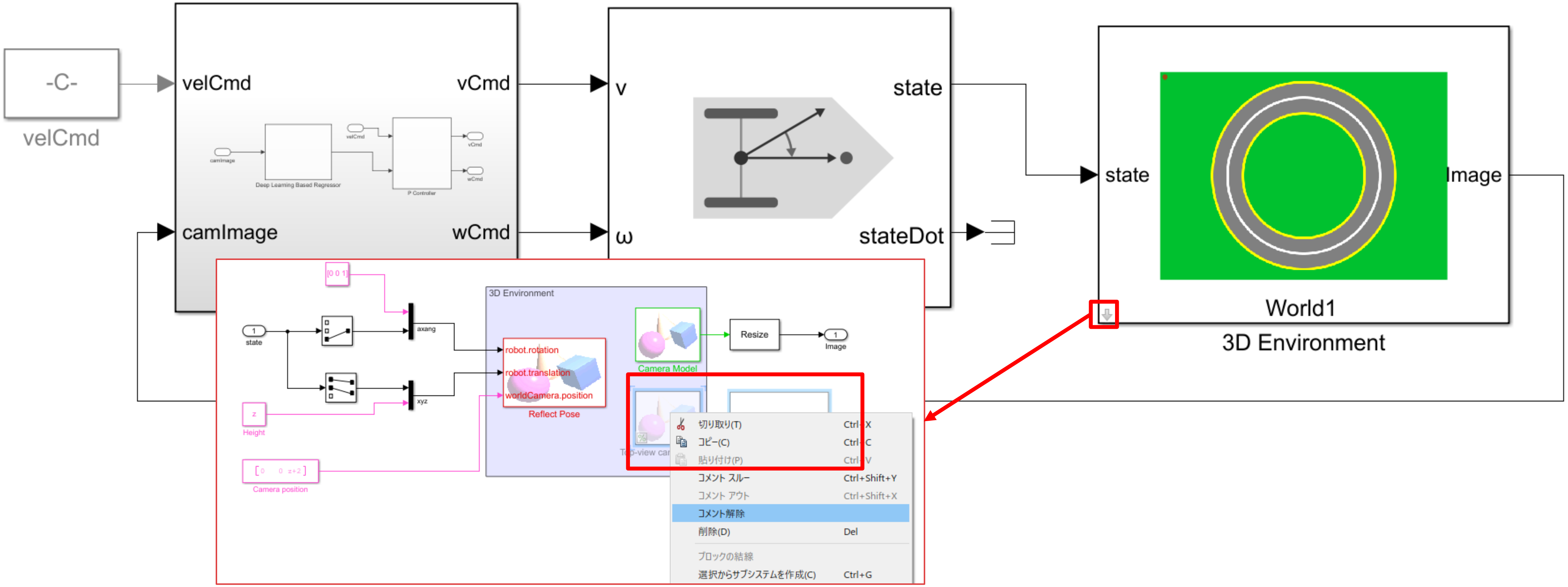
Change the initial states (x_v, y_v, θ_v) and observe how the line following works

System-level Simulation : Change Map in 3D Environment



Change the map data

System-level Simulation : Save Simulation Results

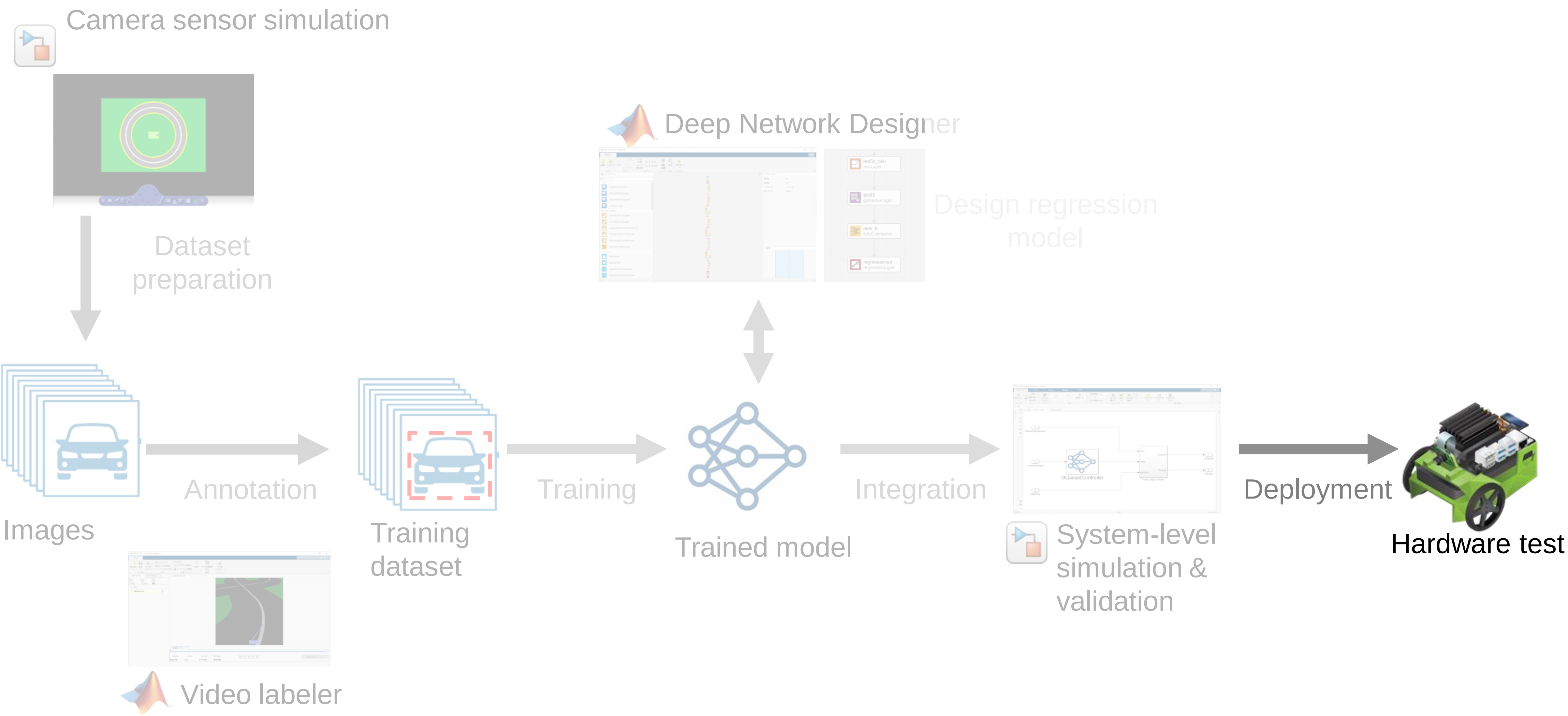


Enabling "Top-view camera" and "To Multimedia File" allows to generate a video file during simulation

Hints : Improve Line Following Performance

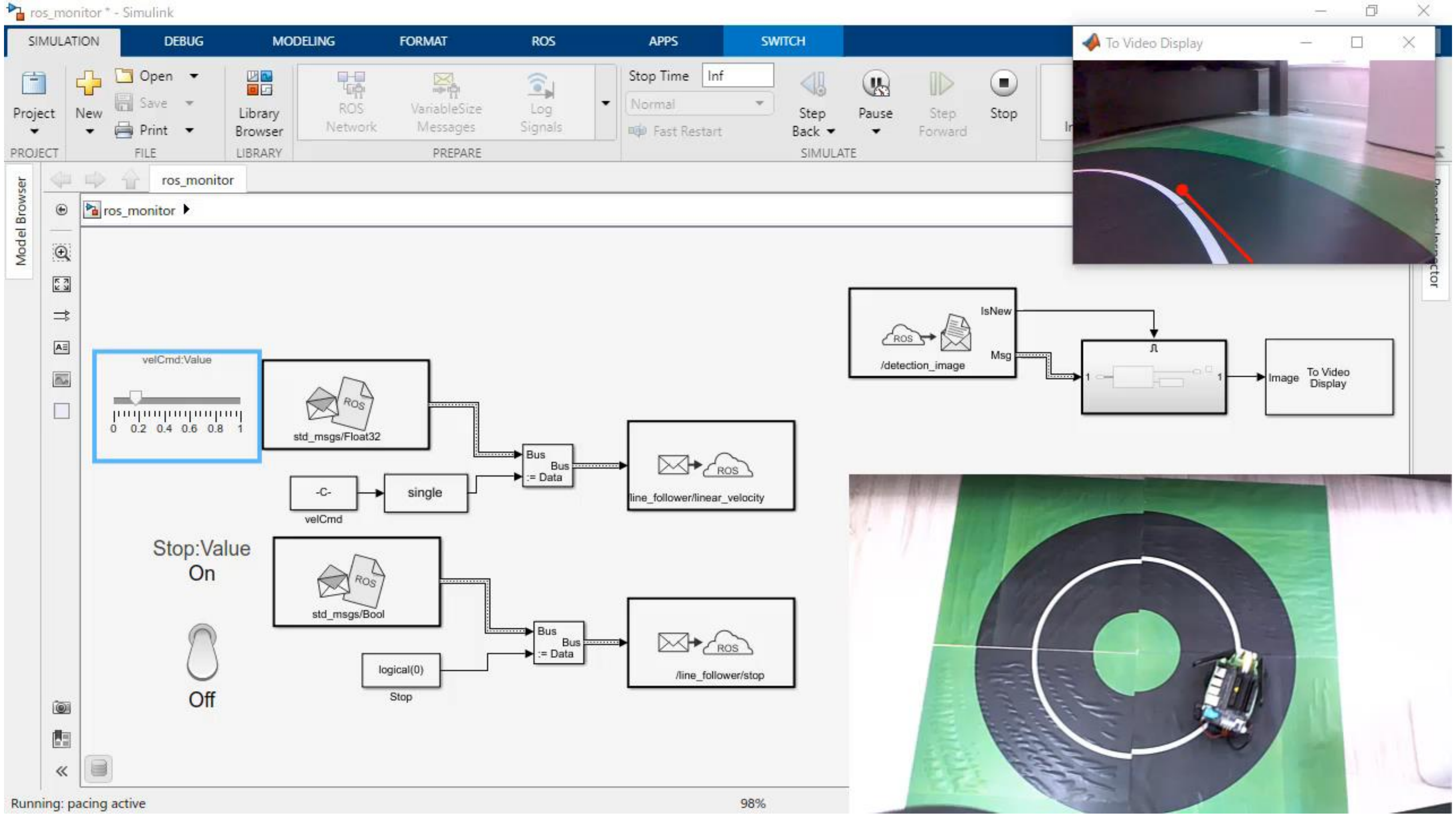
- Increase the training dataset (See ex. 1)
  - Generate more trajectories to generate different perspectives
- Improve the annotation (See ex. 2)
  - Reduce the variation of the target points
- Change the training options (See ex.3)
  - Increate the max number of epochs
  - Change the learning rate and the scheduling
- Change P gain (See ex.4)
  - Tune the P gain in Controller/P Controller block
  - Increase the P gain to improve the following performance
  - Decrease the P gain if oscillating

AI-based Autonomous System Development Workflow

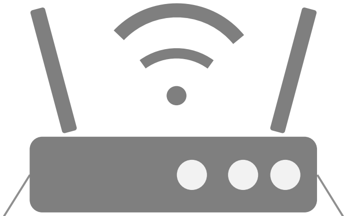


Goal: Hardware Testing of Line Following Algorithm

Deploy the line tracing algorithm integrating into a middleware, ROS



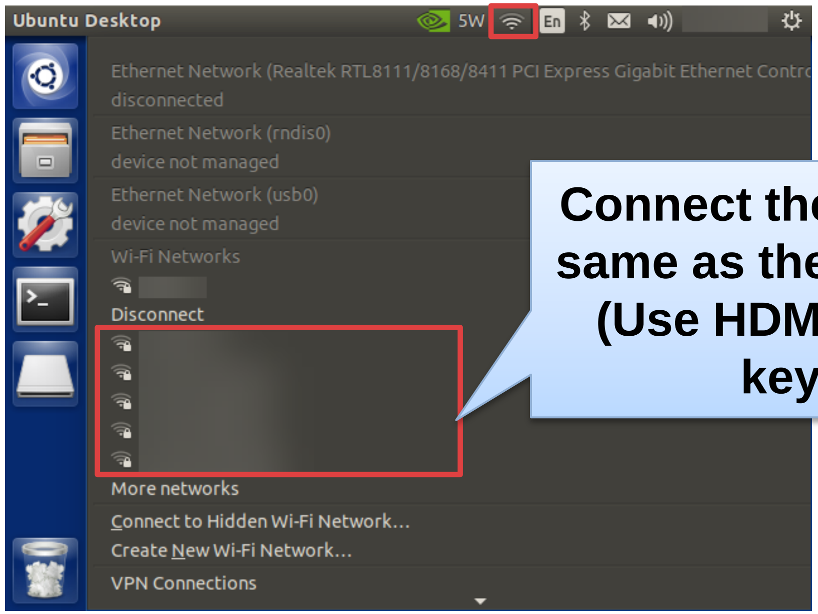
Connect MATLAB and JetBot*



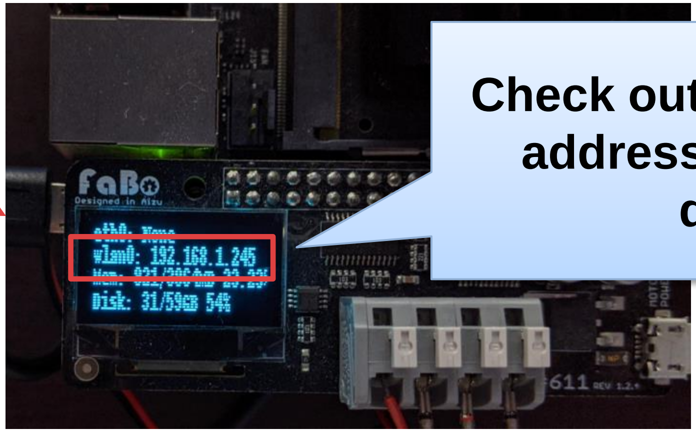
WiFi router

MATLAB host machine
192.168.1.50

JetBot (Jetson Nano™)
192.168.1.245
user: jetbot
password: jetbot



Connect the WiFi network same as the host machine (Use HDMI display and keyboard)



Check out the acquired IP address on the OLED display.

*JetBot setup instruction can be found in the appendix section

What is NVIDIA® Jetson Nano™ and NVIDIA® JetBot?

- NVIDIA® low-cost embedded GPU
  - ARM® Cortex®-A57 + NVIDIA® Maxwell
  - GPIO, CSI and other peripherals and I/Os
  - 5W/10W mode, 5V DCin
  - Linux OS
  - NVIDIA® CUDA/cuDNN/TensorRT
- MATLAB Coder/GPU Coder hardware support package for NVIDIA Jetson is available
- Applications
  - Image classification
  - Object detection
  - Segmentation
  - Audio processing

- Open robot hardware platform
  - NVIDIA® Jetson Nano™ based
  - Simple monocular camera and differential drive robot
  - The BOM list is opened in the GitHub repository
  - Can build the JetBot from scratch
  - https://jetbot.org/
- Application
  - Obstacle avoidance
  - Line following
  - Object recognition

What is ROS?

- ROS = Robot Operating System
  - Not an operating system – it's middleware
  - Messaging/distributed computing tools
  - Packaging and build management system
  - Vibrant open-source community for application-related code (drivers, simulation, motion planning, perception, etc.)
  - ROS2 was recently released, and the community is moving to ROS2

Easy to develop autonomous systems by leveraging ROS

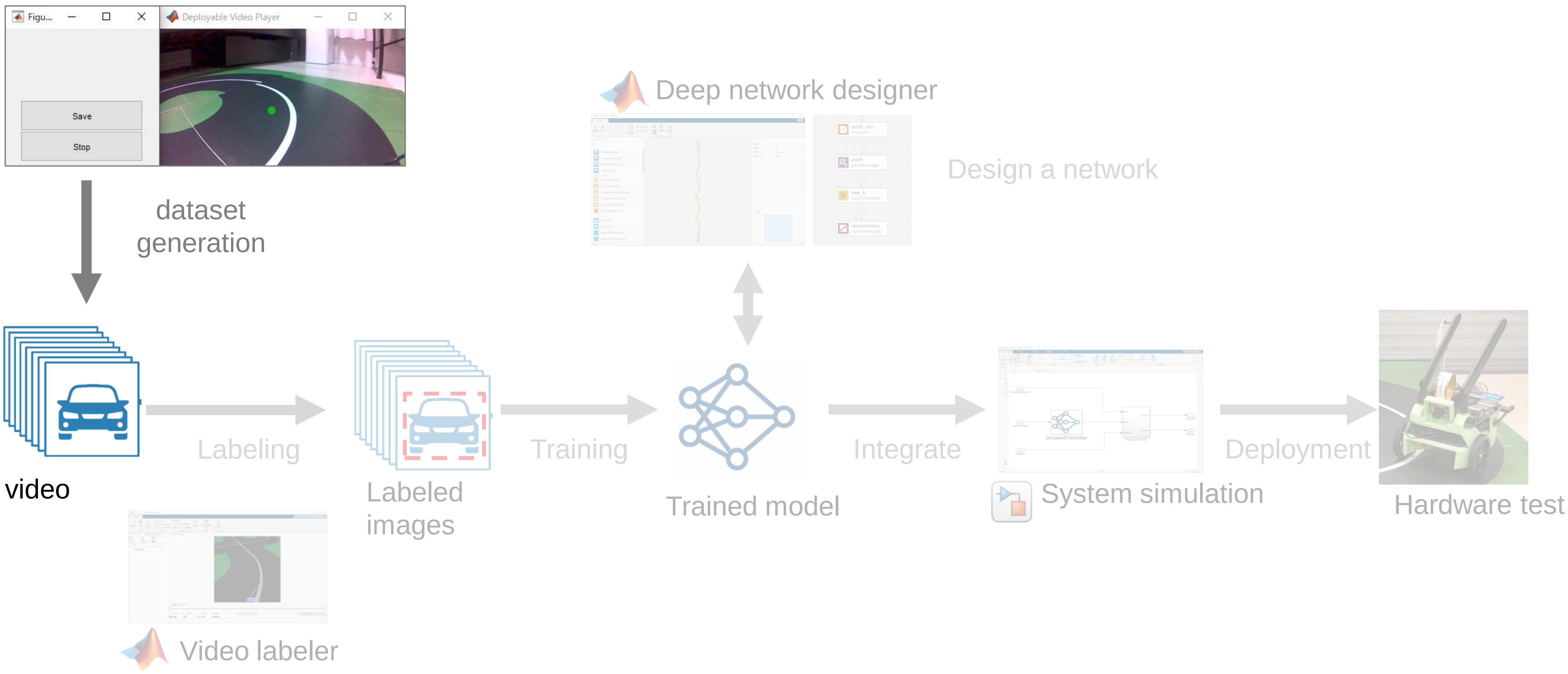
https://www.ros.org/about-ros/

ROS integration using ROS Toolbox

Used in this workshop

	ROS	ROS 2
	• Topic – Publish / Subscribe • Service – Server / Client • Action – Client • Parameter – Get / Set • custom message • rosbag reading • ROS node generation R2021a	• Topic – Publish / Subscribe • custom message • ros2bag reading R2021a
	• Topic – Publish / Subscribe • Service – Call • Parameter – Get / Set • ROS Time • rosbag playback • ROS node generation	• Topic – Publish / Subscribe • ROS node generation
ROS Distro	• ROS Melodic R2020b	• ROS2 Dashing R2020a

Step1: ROS connection and collecting training images

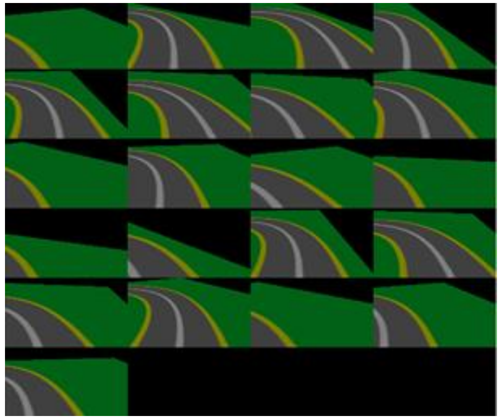


Difference between simulation and real

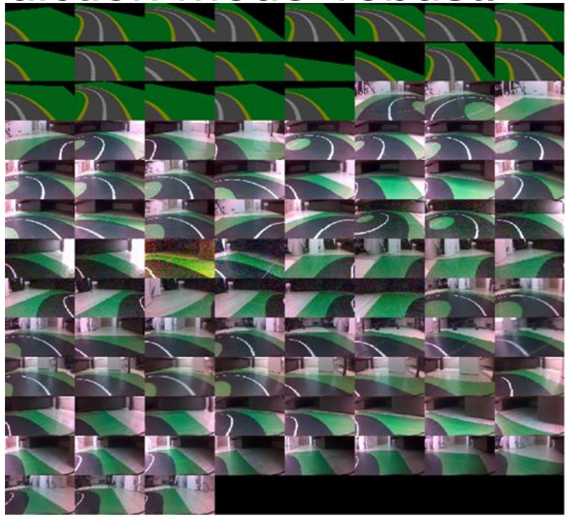
Trained model with the dataset from simulation may not work for the real environment due to the following factors:

- Background objects
- Lighting condition
- Image sensor noise

Collect images from the hardware to make the prediction model robust.



Collected in simulation

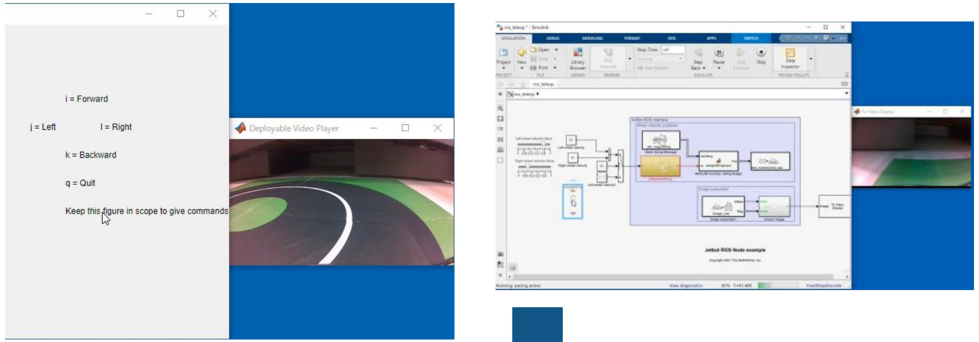


Images taken from the hardware added

*High fidelity simulation for training is also researched area.

ROS connection and colleting training images

Connect MATLAB and Simulink with JetBot
- Send the motor rotation speeds
- Receive the camera images



.avi

Windows/Mac/Linux

ROS
ROS Core

ROS node

Motor node

Camera node

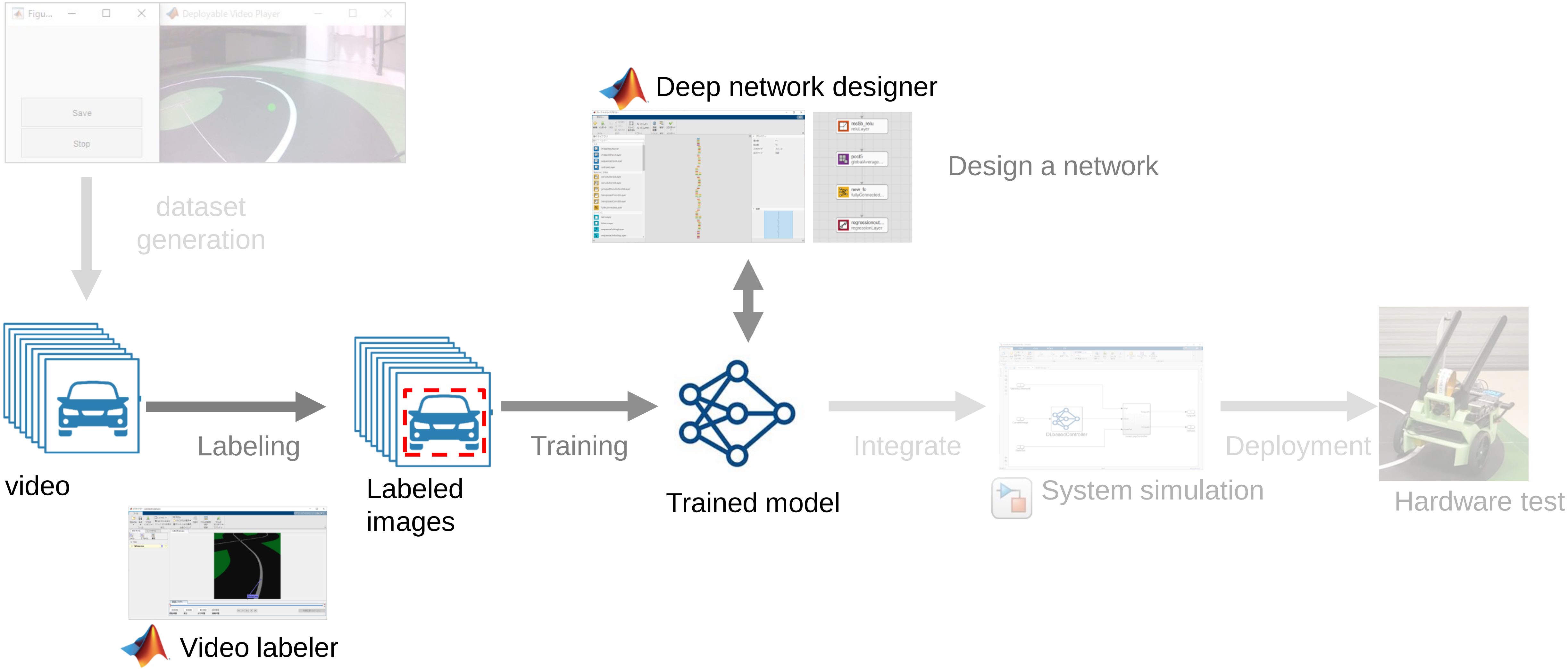
Ubuntu Linux

Development Machine

```
>> edit teleopTestJetBot.mlx
```

Locate the JetBot to get the variety of the images
or
Drive the JetBot

Step2: Improve line detector

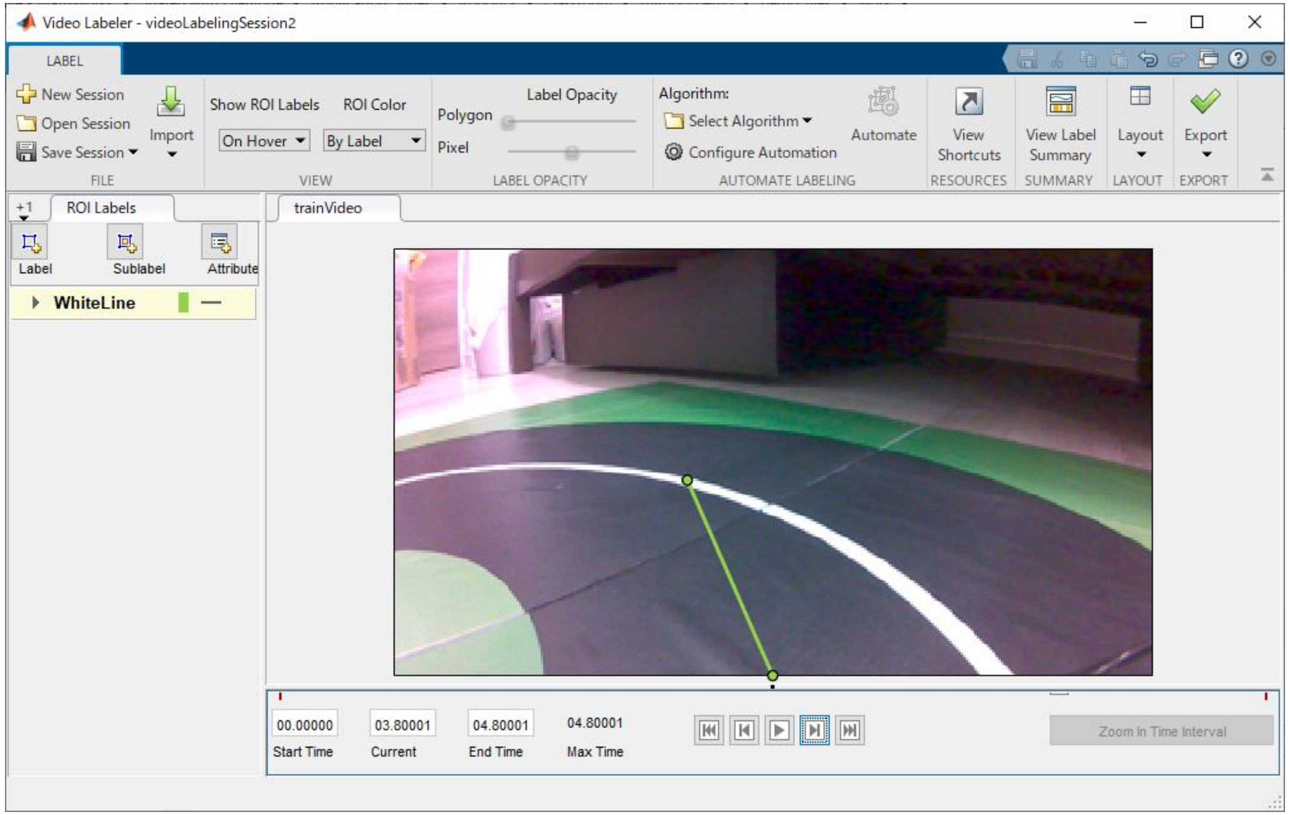


Labeling

- Annotate the images taken from the hardware as well as simulation's one

.avi

Collected videos



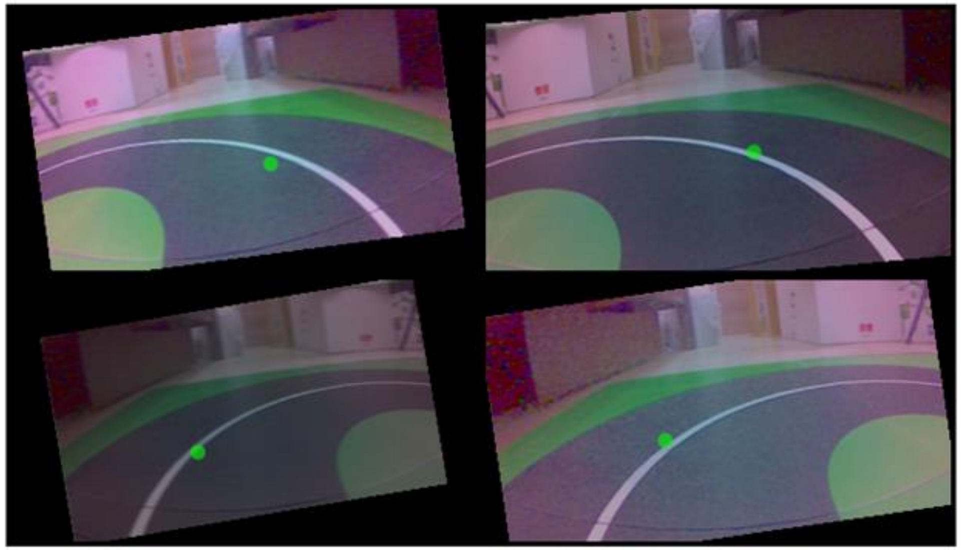
.mat

Annotation data

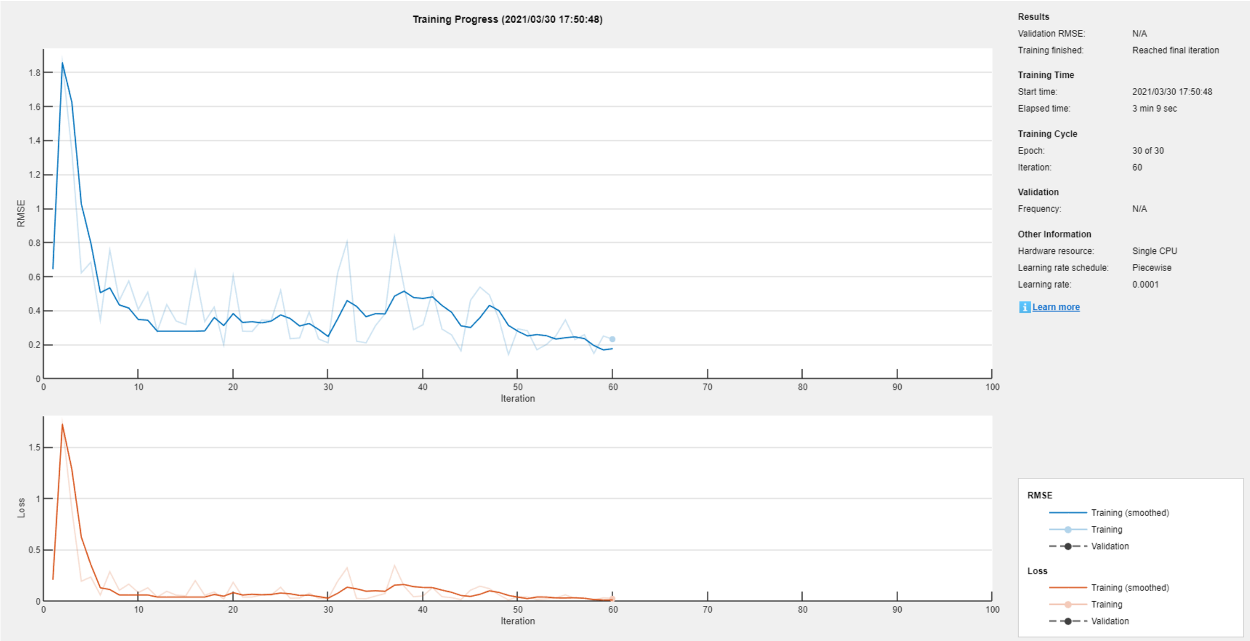
```
>> edit trainWhiteLineWithHardware.mlx
```

Data augmentation and retraining

- Retraining the line detector
- Augment the image to mimic the environment change



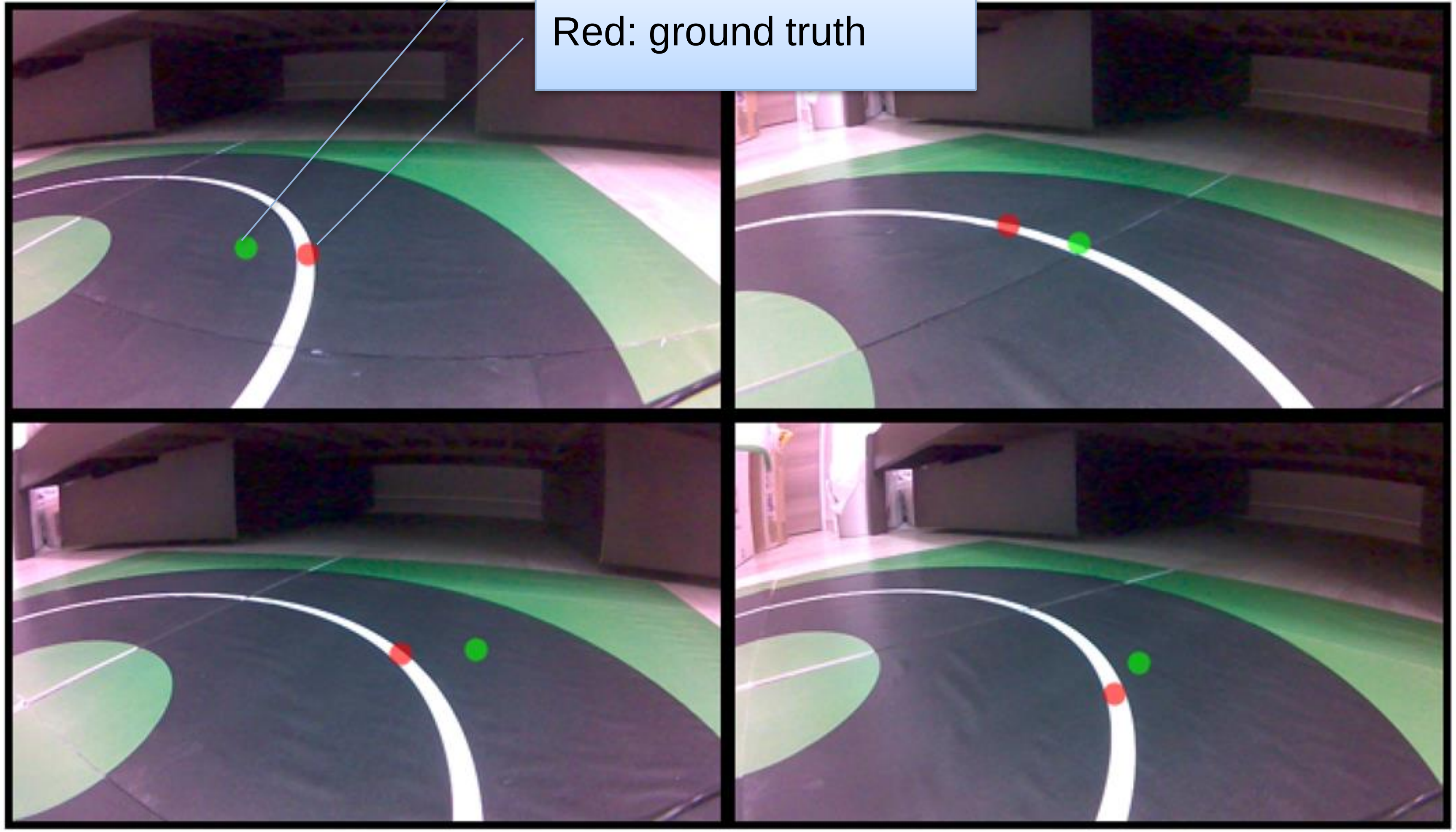
Augment the images



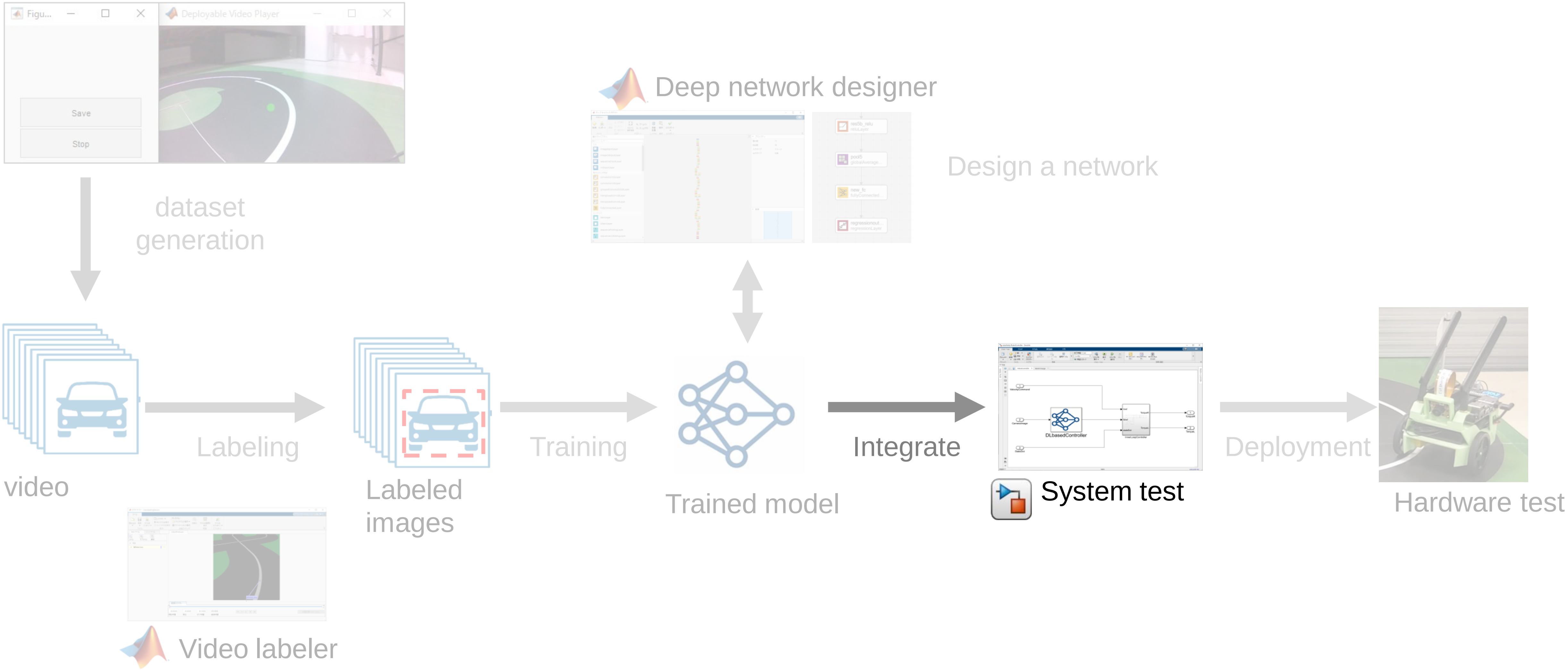
Training results

Green: predicted

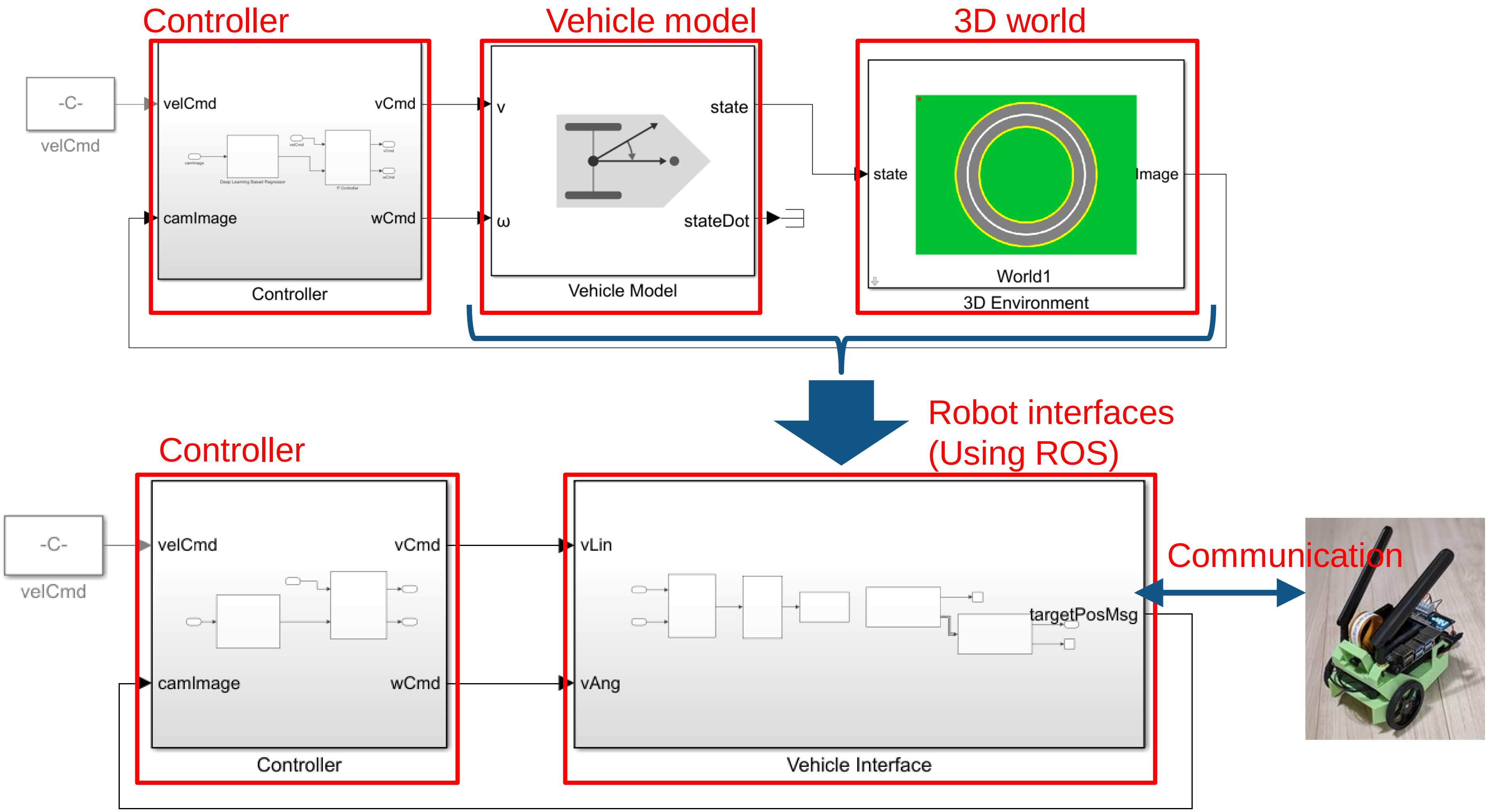
Red: ground truth



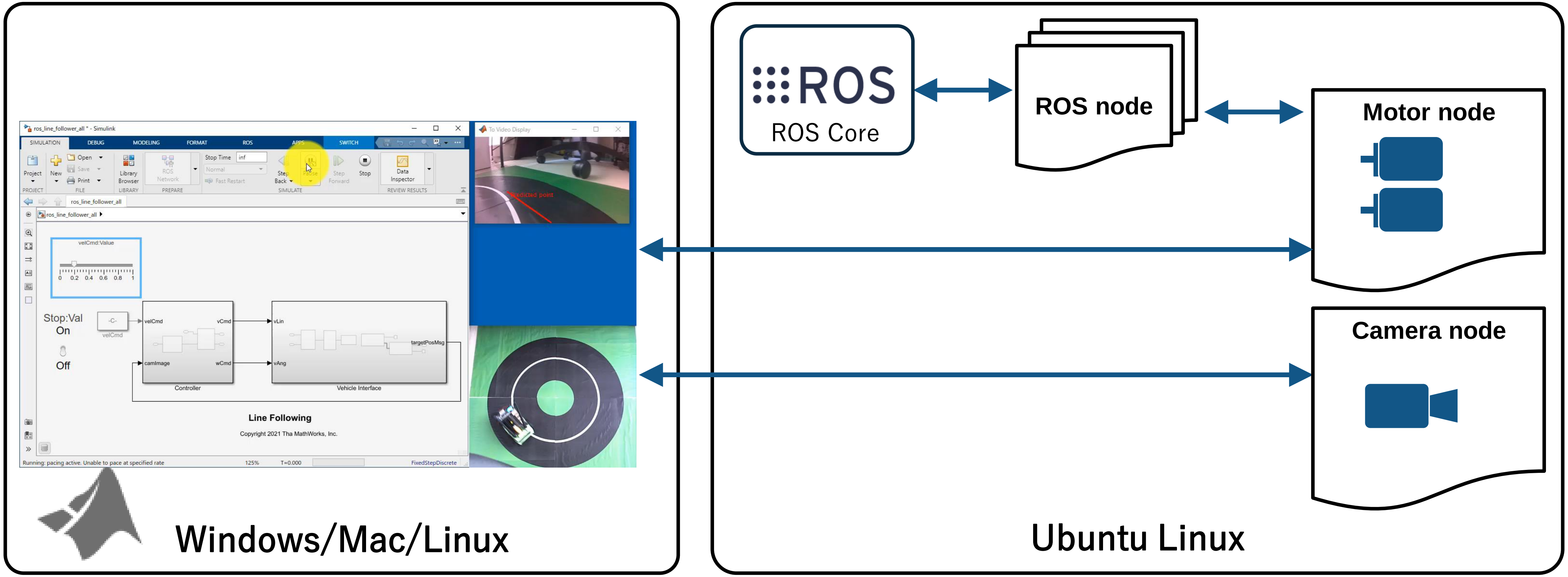
Step3: Test algorithms through hardware connection



Replace the simulation models with ROS interfaces



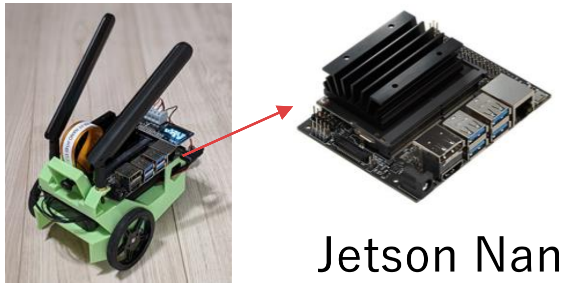
Algorithm test through hardware communication



Development Machine

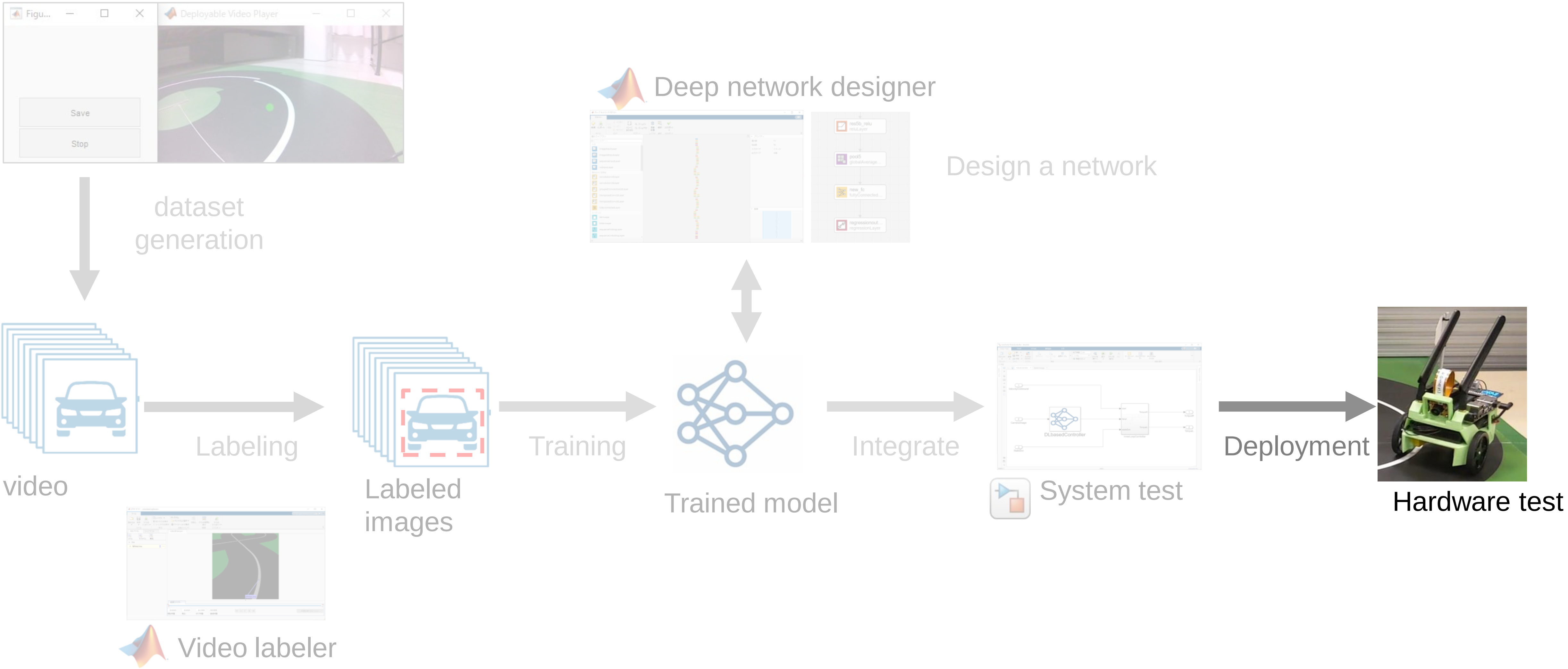
`>> edit testLineFollowerWithROS.mlx`

Communication delay may affect, but the functional algorithm test can be done.

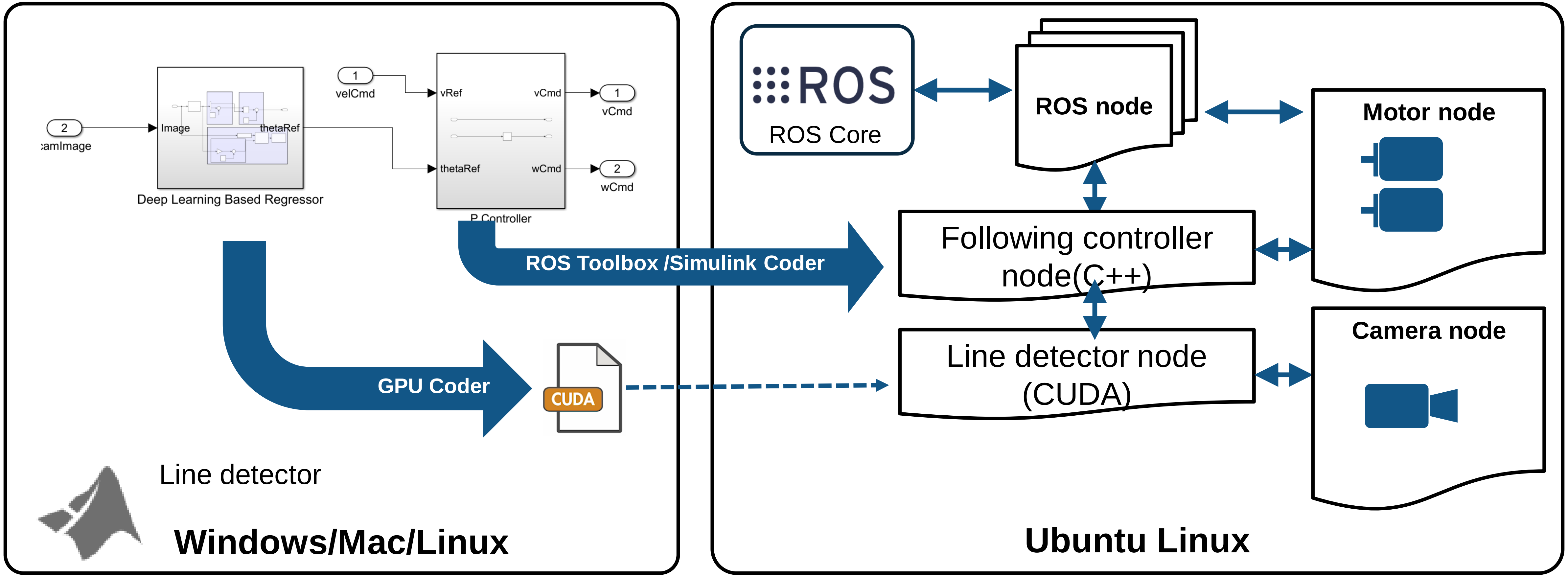


Jetson Nano™

Step4: Standalone hardware deployment using code generation

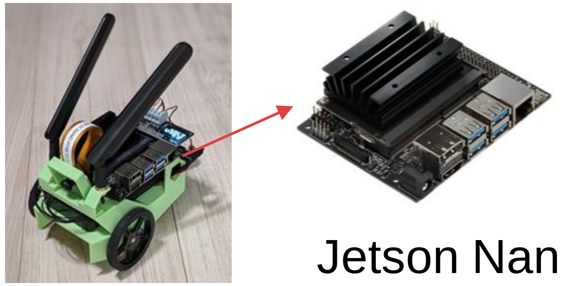


Generate ROS nodes and run them on the hardware



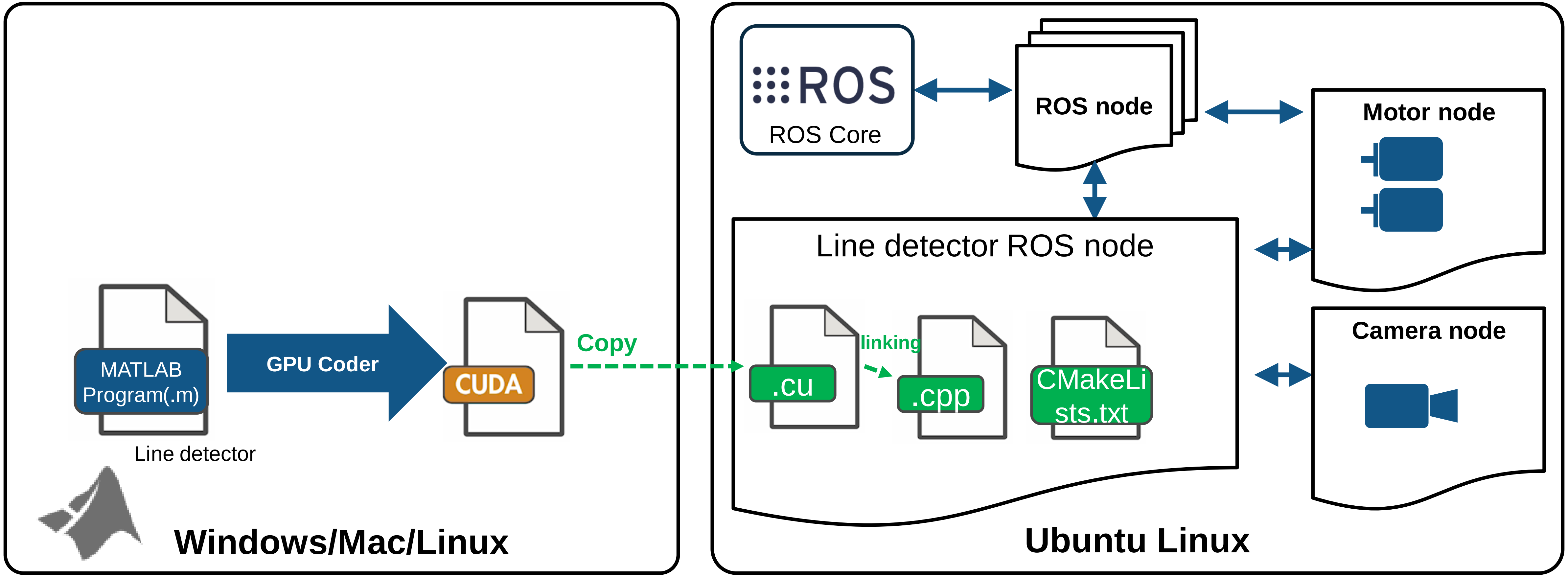
Development Machine

Split the original Simulink model into the detector part and the following controller part and then generate ROS nodes, respectively.



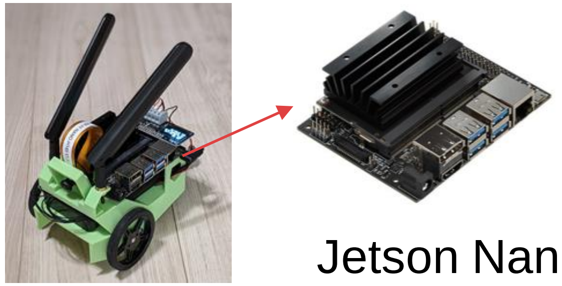
Jetson Nano™

CUDA code generation and wrap it as ROS node



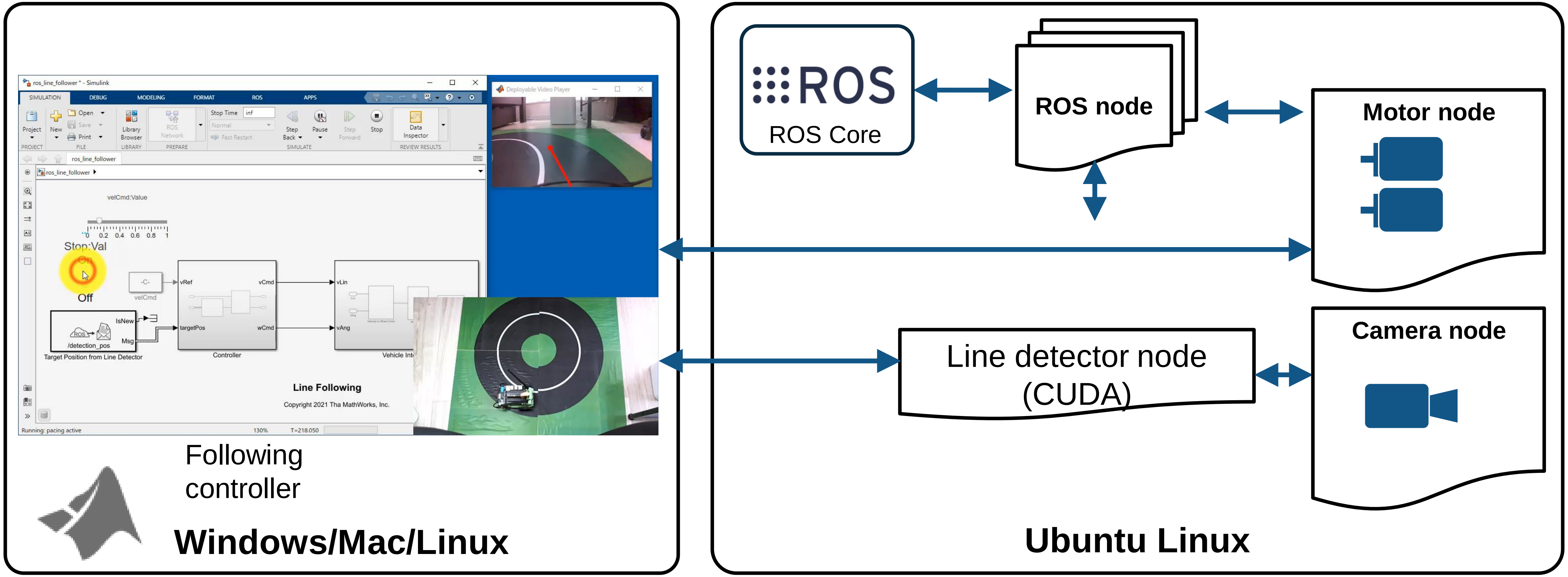
Development Machine

CUDA code generation using GPU Coder and wrap the CUDA code as a ROS node



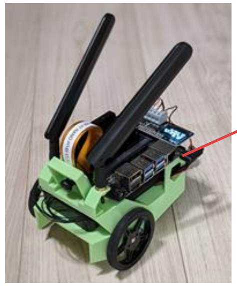
Jetson Nano™

Co-execution with deployed line detector



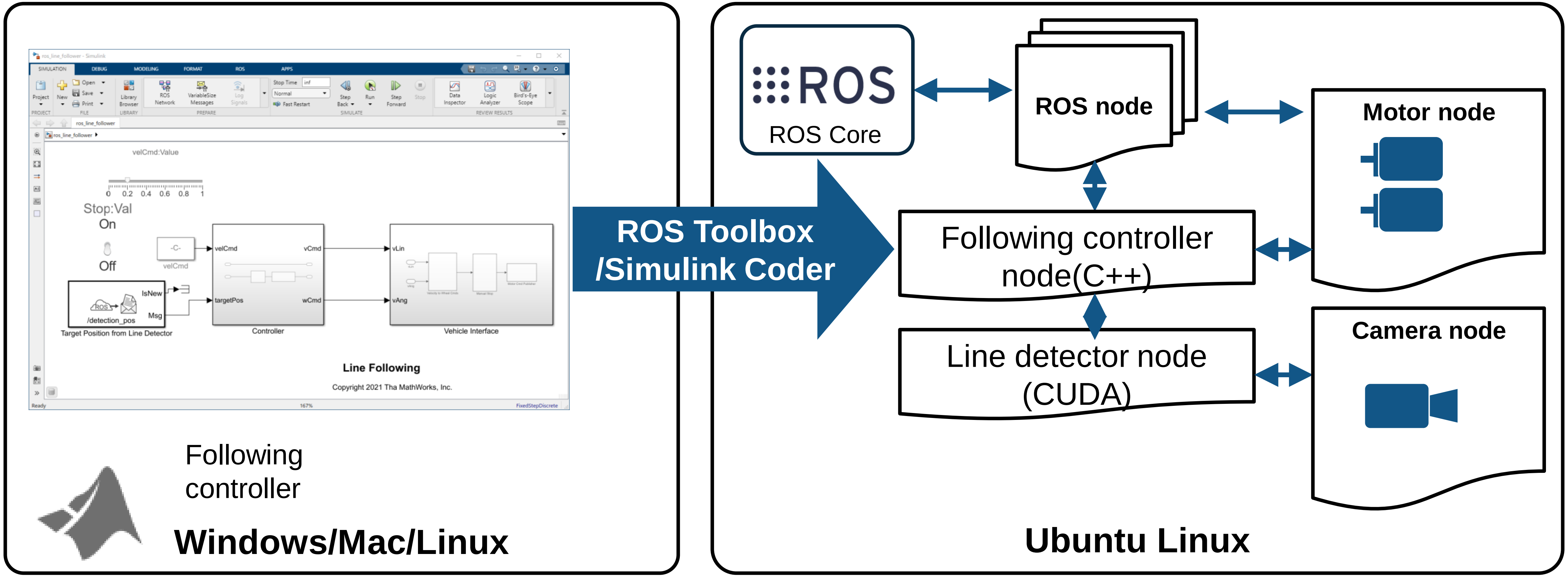
Development Machine

Co-execution with the deployed line detector to check the behavior of the following controller model.



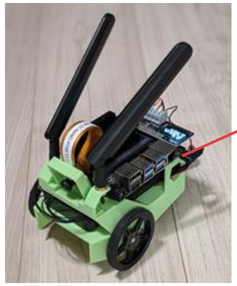
Jetson Nano™

Deploy the following controller model as ROS node



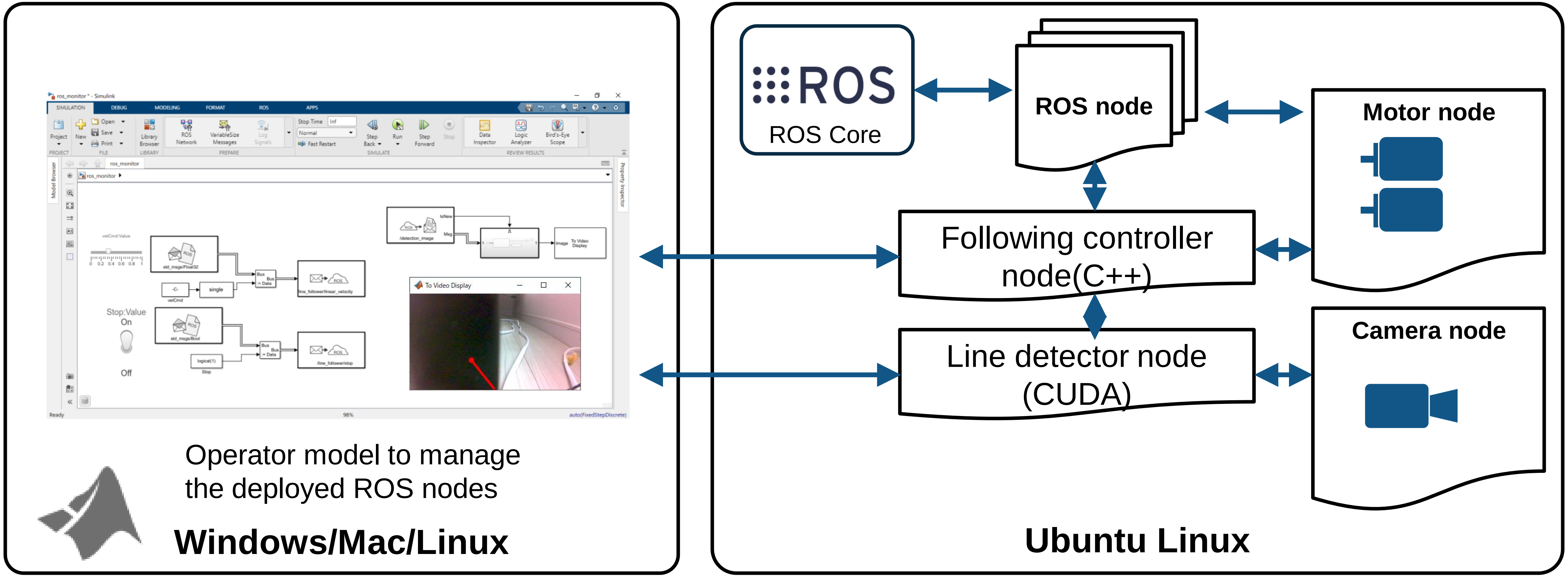
Development Machine

Deploy the following controller model as ROS node using ROS Toolbox and Simulink Coder



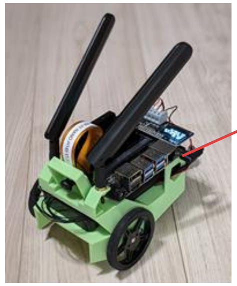
Jetson Nano™

Standalone execution with all deployed ROS nodes



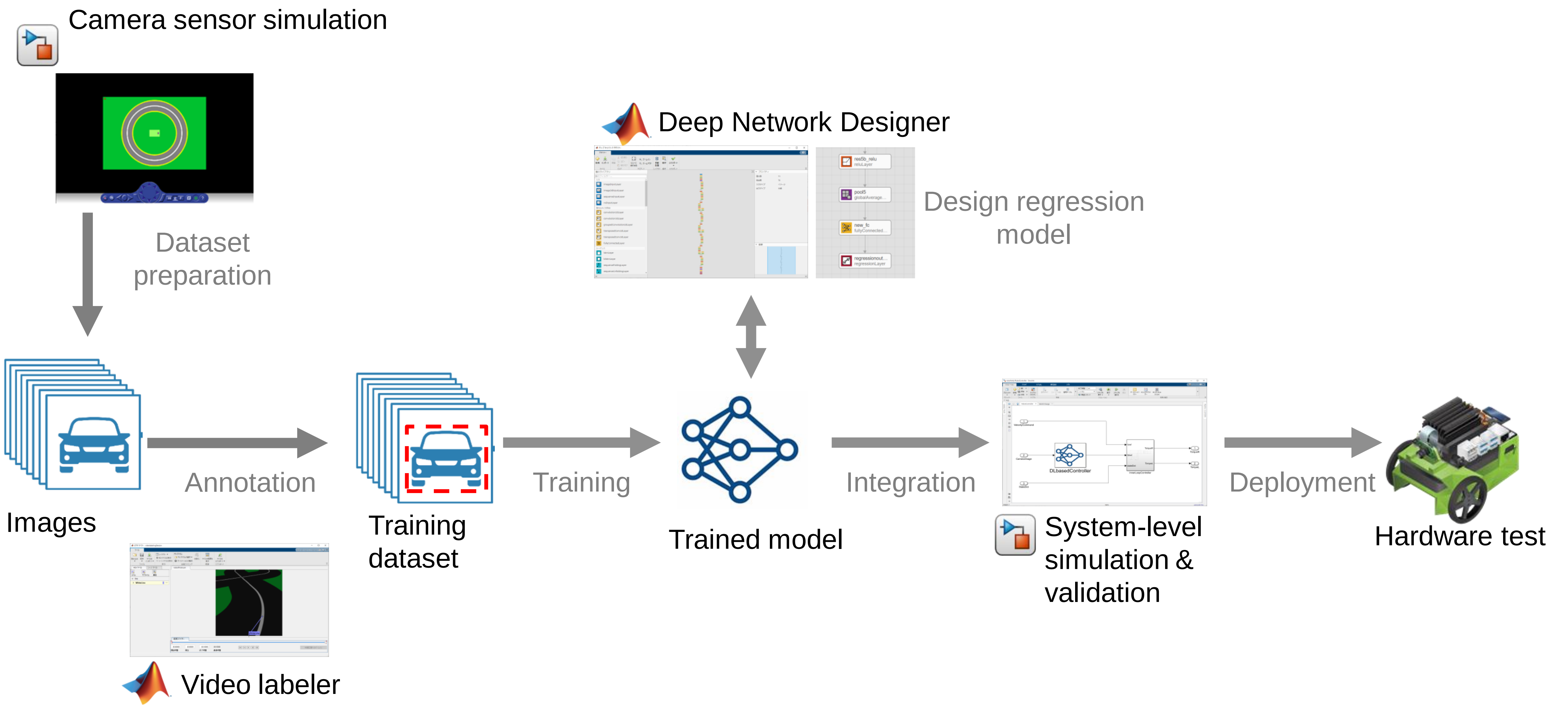
Development Machine

Standalone execution on the target
Another Simulink to specify the target velocity and the start/stop operation.



Jetson Nano™

Recap: AI-based Autonomous System Development Workflow



Appendix A. Preparation for simulation

Workshop host machine

- System requirements
  - https://mathworks.com/support/requirements/matlab-system-requirements.html
- Required software
  - MATLAB R2021a or later
  - Simulink
  - Image Processing Toolbox
  - Computer Vision Toolbox
  - Deep Learning Toolbox
  - Robotics System Toolbox
  - Simulink 3D Animation
  - Deep Learning Toolbox Model for ResNet-18 Network
    - Type the below command and follow the appeared instruction
    - `>> resnet18`
  - Parallel Computing Toolbox (if NVIDIA® GPU is available)

Appendix B. hardware deployment
(Setting up a JetBot)

Development environment : MathWorks Products

- The following toolboxes are additionally required to the simulation part
- Toolbox
  - MATLAB Coder
  - GPU Coder
  - Simulink Coder
  - ROS Toolbox
- Add-ons
  - MATLAB Coder Support Package for NVIDIA® Jetson™ and NVIDIA® DRIVE™ Platforms
    - The installation procedure can be found below
    - https://www.mathworks.com/help/supportpkg/nvidia/ug/install-support-for-nvidia-devices.html
  - GPU Coder Interface for Deep Learning Libraries

Development environment for hardware deployment

- Hardware
  - NVIDIA® JetBot (Tested with FaBo JB-4GB-S-G)
    - Jetson Nano™ 4GB
- Software
  - JetPack 4.3, JetBot 0.4.0 (jetbot_image_v0p4p0.zip)
    - L4T R32.3.1 (K4.9)
    - Ubuntu 18.04 LTS aarch64
    - CUDA 10.0
    - cuDNN 7.6.3
    - TensorRT 6.0.1
    - OpenCV 4.1
  - JetBot ROS package
    - https://github.com/dusty-nv/jetbot_ros
    - Tested with the revision c7d0e611b037947a0df855293c9848a7c8bc6e90 by patching
    - ROS Melodic + JetBot's camera and motor ROS driver nodes
  - Jetson CSI camera ROS nodelet package
    - https://github.com/sfalexrog/jetson_camera
    - Tested with rev. 7ec8e364880fceb5bbe31800bd6224af2370ca1b

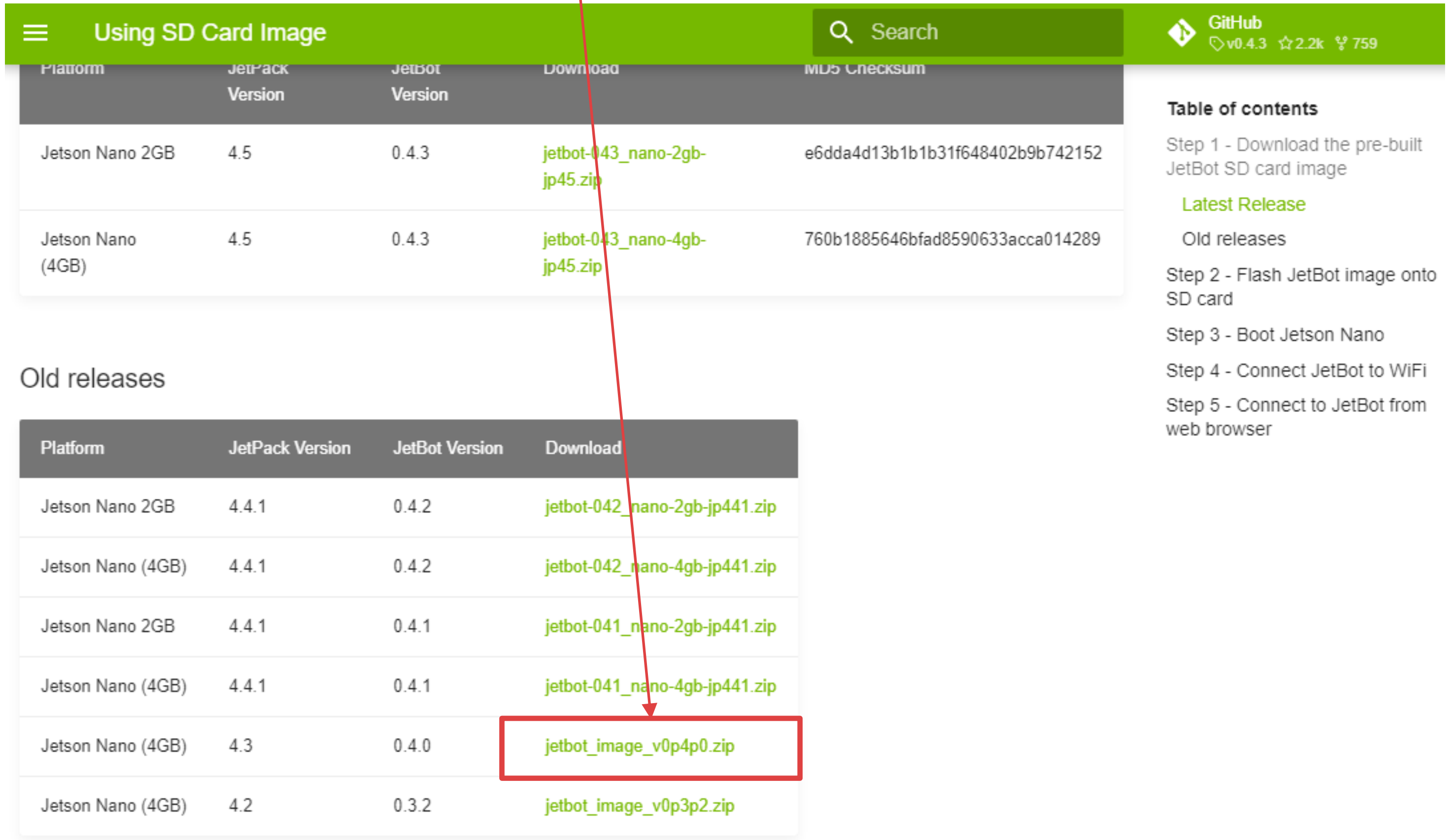
Setting up JetBot

- Setup JetBot by following vendor's instructions
  - Tested with FaBo's JB-4GB-S-G
  - Follow vendor's instruction manual to setup

- Setup JetBot's software
  - https://jetbot.org/v0.4.3/software_setup/sd_card.html
  - Use jetbot_image_v0p4p0.zip (7.3GB) as an SD card image

Setting up JetBot

- Download "jetbot_image_v0p4p0.zip"



Using SD Card Image

Search

GitHub
v0.4.3 2.2k 759

Platform	JetPack Version	JetBot Version	Download	MD5 Checksum
Jetson Nano 2GB	4.5	0.4.3	jetbot-043_nano-2gb-jp45.zip	e6dda4d13b1b1b31f648402b9b742152
Jetson Nano (4GB)	4.5	0.4.3	jetbot-043_nano-4gb-jp45.zip	760b1885646bfad8590633acca014289

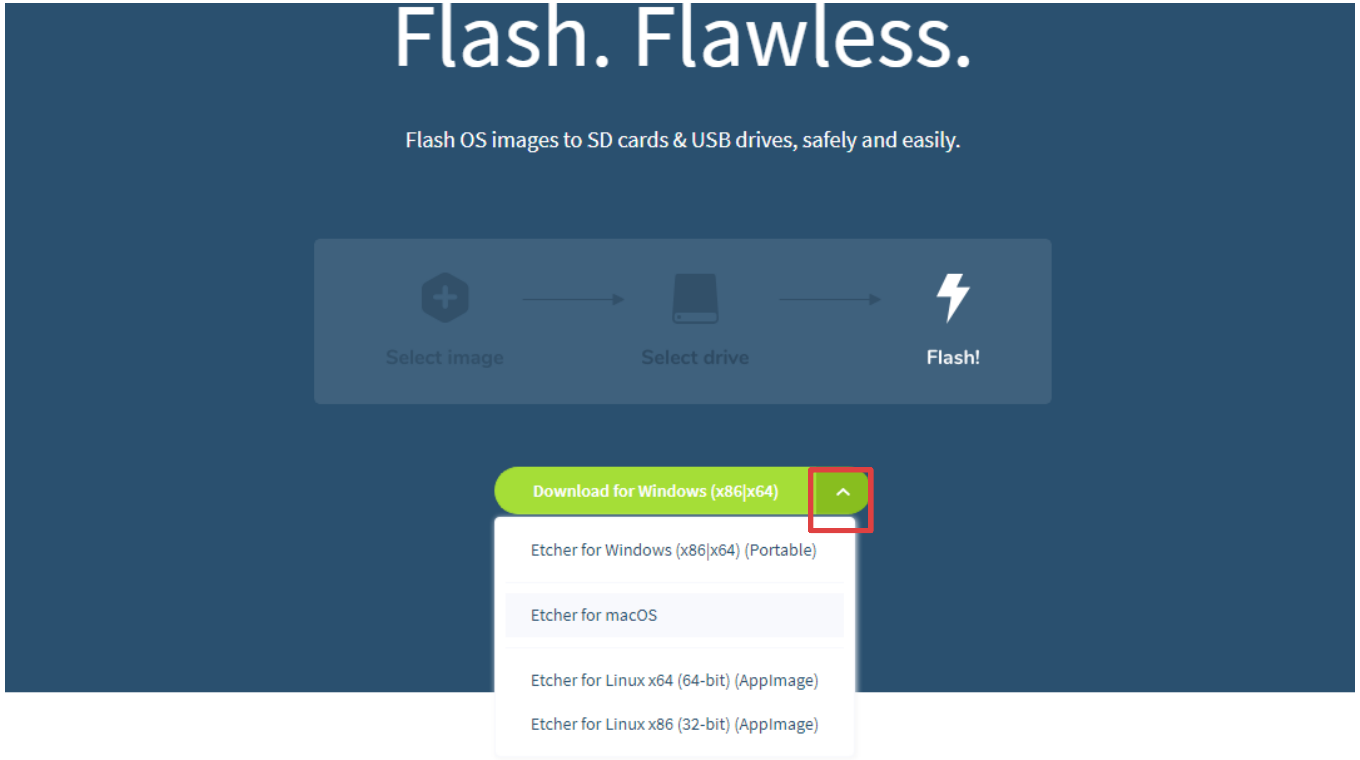
Old releases

Platform	JetPack Version	JetBot Version	Download
Jetson Nano 2GB	4.4.1	0.4.2	jetbot-042_nano-2gb-jp441.zip
Jetson Nano (4GB)	4.4.1	0.4.2	jetbot-042_nano-4gb-jp441.zip
Jetson Nano 2GB	4.4.1	0.4.1	jetbot-041_nano-2gb-jp441.zip
Jetson Nano (4GB)	4.4.1	0.4.1	jetbot-041_nano-4gb-jp441.zip
Jetson Nano (4GB)	4.3	0.4.0	jetbot_image_v0p4p0.zip
Jetson Nano (4GB)	4.2	0.3.2	jetbot_image_v0p3p2.zip

Table of contents

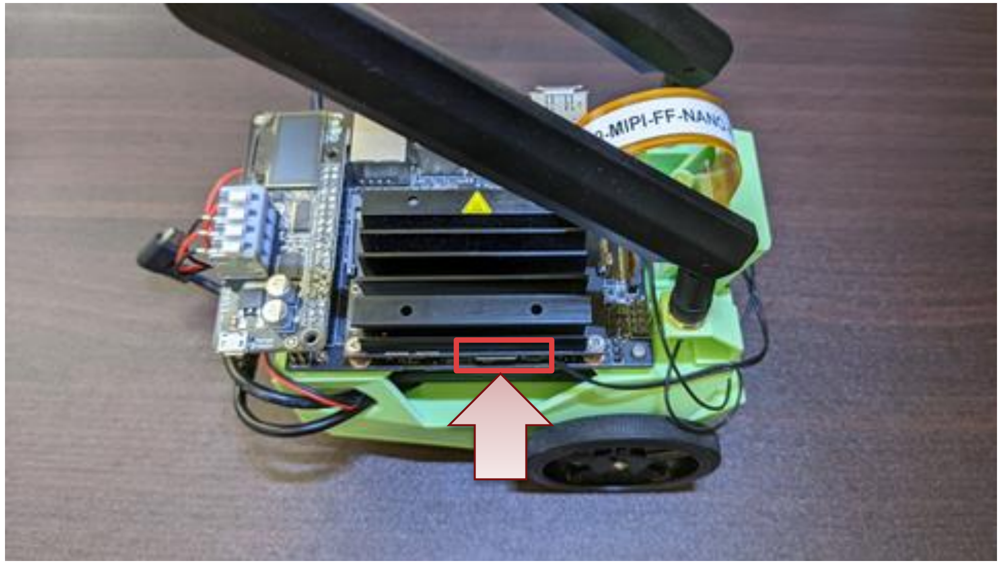
Setting up JetBot

- Insert a micro SD card to your machine (The volume of the micro SD card should be 32GB or more)
- Write the downloaded image to the card through Etcher

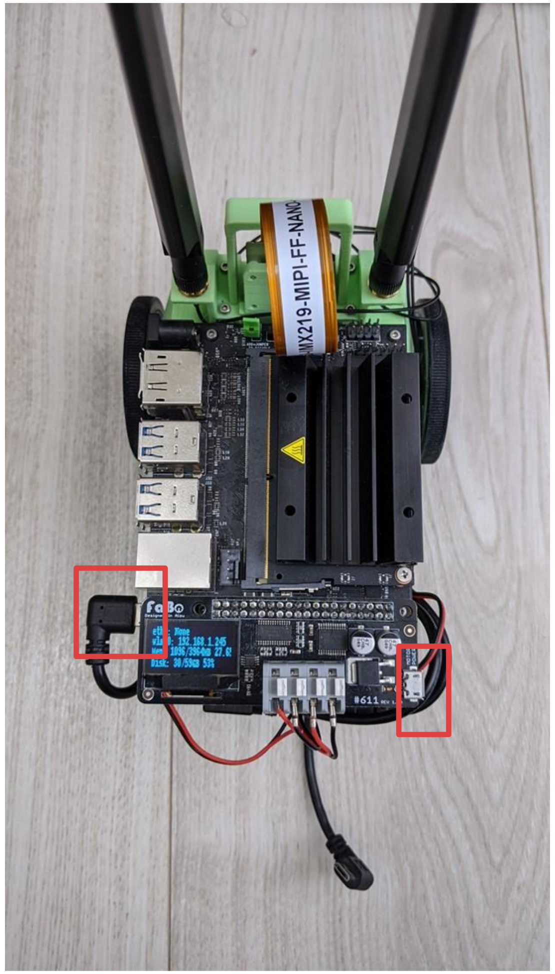


Setting up JetBot

- Insert the micro SD card to your Jetson Nano on JetBot



- Turn on the JetBot



Setting up JetBot

- Setup ROS package for JetBot
  - Complete "Build ros_deep_learning" section from the beginning in the following repository.
  - https://github.com/dusty-nv/jetbot_ros

Setting up JetBot

- In the "Build jetbot_ros" section, you'll need to follow the below instructions due to patching
  - `$ cd ~/workspace/catkin_ws/src`
  - `$ git clone https://github.com/dusty-nv/jetbot_ros`
  - `$ cd jetbot_ros/`
  - `$ git checkout c7d0e611b037947a0df855293c9848a7c8bc6e90`
  - `$ cd ~`
  - `$ git clone https://github.com/mathworks-robotics/ai-robotics-workshop.git`
  - `$ cd ~/workspace/catkin_ws/src/jetbot_ros`
  - `$ patch -p1 < ~/ai-robotics-workshop/setup/jetbot_ros_for_c7d0e61.patch`

    ```
    patching file CMakeLists.txt
    patching file launch/jetbot_ros.launch
    patching file package.xml
    patching file scripts/jetbot_motors.py
    patching file src/jetbot_camera.cpp
    ```

    Make sure no errors
  - `$ cd ~/workspace/catkin_ws`
  - `$ catkin_make`

    Make sure no build error

Reasons for the patch:

Motor velocity control is not implemented in the original code
Need to downscale the image to reduce the communication delay between MATLAB and JetBot

Setting up JetBot

- If you come across 'Adafruit_MotorHAT is not found' error, you'll need to specify 'pip2' instead of 'pip'
  - `$ pip2 install Adafruit-MotorHAT`
  - `$ pip2 install Adafruit-SSD1306`

- Add environment variables to the end line of ~/**`.bashrc`**
  - `$ gedit ~/.bashrc`
  - `export ROS_IP=$(hostname -I | awk '{print $1;}' | tr -d [:blank:])`
  - `export ROS_MASTER_URI=http://$ROS_IP:11311`

  - You can fix the IP address as needed

Setting up JetBot

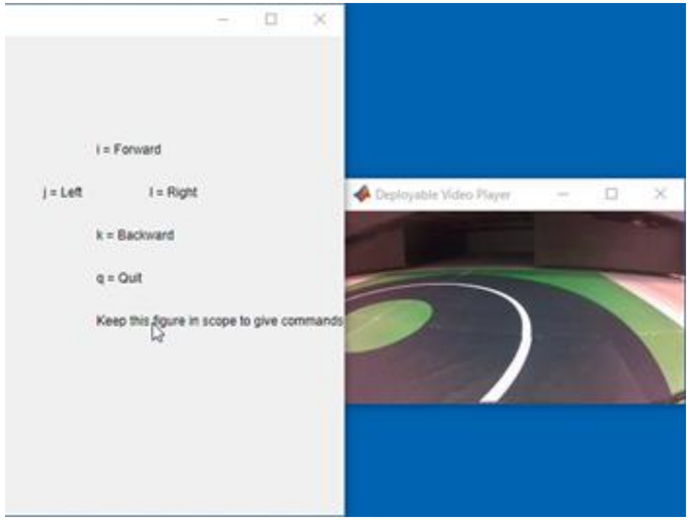
- Setup Jetson CSI camera ROS nodelet for standalone deployment
  - `$ cd /home/jetbot/workspace/catkin_ws/src/`
  - `$ git clone https://github.com/sfalexrog/jetson_camera.git`
  - `$ cd /home/jetbot/workspace/catkin_ws`
  - `$ catkin_make`

  - If you see 'OpenCV3 is not found' error, you'll need to remove "3" for OpenCV4
  - (because JetPack4.3's default is OpenCV4)
    - `$ gedit ~/workspace/catkin_ws/src/jetson_camera/CMakeLists.txt`
      `find_package(OpenCV ~~3~~ REQUIRED)`

  - `/usr/include/opencv is not found error`
  - Create a symbolic link to opencv4 as below
    - `$ cd /usr/include/`
    - `$ sudo ln -s opencv4 opencv`

Setting up JetBot

- Connection test from MATLAB
  - Launch MATLAB R2021a
  - **`>> cd c:¥ai-robotics-workshop`**
  - **`>> matlab_ai_robotics_workshop.prj`**
  - **`>> edit teleopTestJetBot_jp.mlx`**
- Success if JetBot is moving and the camera image is shown up



Setting up JetBot

If the rotation direction of wheels are opposite or wheels are side to side:

1. Open **`jetBotKeyboardControl.m`**

Uncomment in the line 144

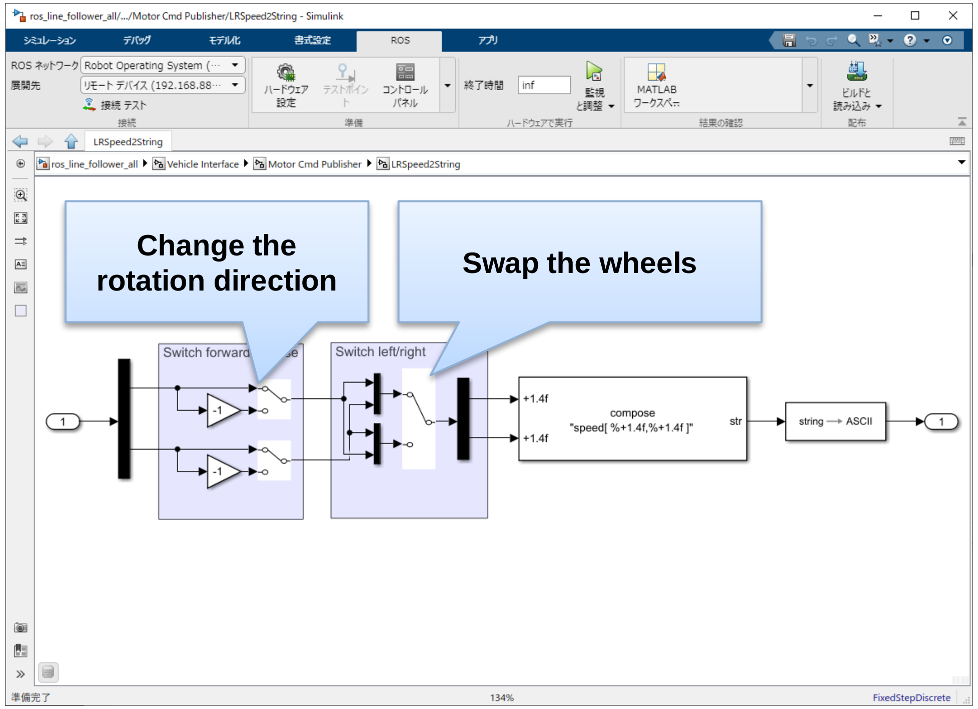
```
>> edit jetBotKeyboardControl.m
        % Change rotation direction forward/reverse
        % wlCmd = -wlCmd;
        % wrCmd = -wrCmd;

        % Swap wheels side to side
        % tmp = wlCmd;
        % wlCmd = wrCmd;
        % wrCmd = tmp;
```

2. Open **`teleopTestJetBot_jp.mlx`** and run **`jetBotKeyboardControl`** to test

Setting up JetBot

If the rotation direction of wheels are opposite or wheels are side to side:

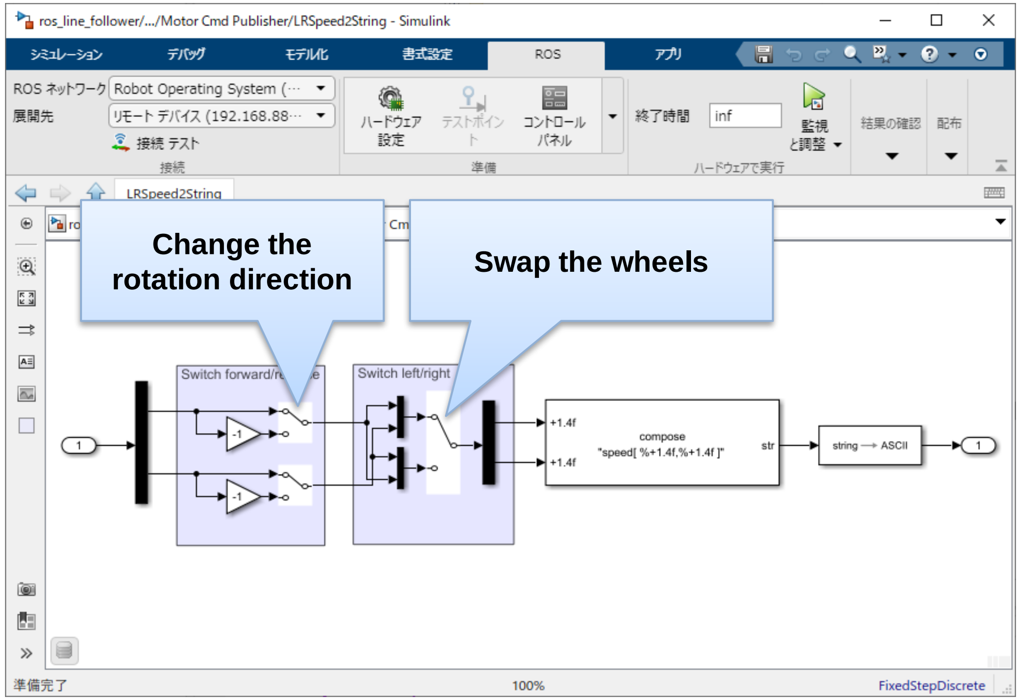
1. Open **`ros_line_follower_all.slx`**
   `>> open_system('ros_line_follower_all');`
2. Open "Vehicle Interface"->"Motor Cmd Publisher"->"LRSpeed2String"
3. Change the rotation direction and/or swap the wheels as needed
4. Run **`testLineFollowerWithROS_jp.mlx`** and make sure the line following works



Setting up JetBot

If the rotation direction of wheels are opposite or wheels are side to side:

1. Open **`ros_line_follower.slx`**
   `>> open_system('ros_line_follower');`
2. Open "Vehicle Interface"→"Motor Cmd Publisher"→"LRSpeed2String"
3. Change the rotation direction and/or swap the wheels as needed
4. Run **`deployLineFollower_jp.mlx`** and make sure the line following works



Setting up JetBot

If the camera image is upside down:

1. Open **`jetBotKeyboardControl.m`** and uncomment the line 79

`>> edit jetBotKeyboardControl.m`

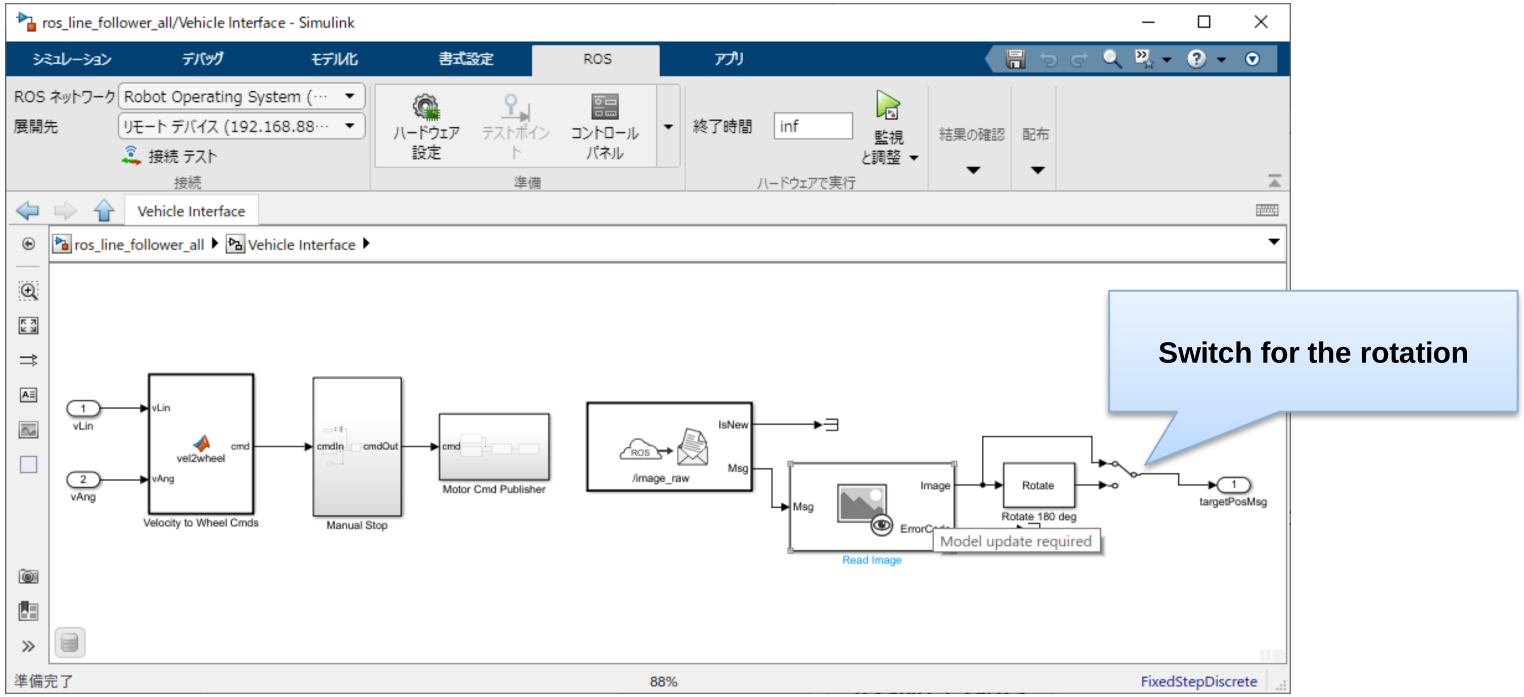
```
75
76        % Subscribe image
77        imMsg = receive(camSub);
78        I = rosReadImage(imMsg);
79        %I = imrotate(I,180);
80
```

2. Open **`teleopTestJetBot_jp.mlx`** and run **`jetBotKeyboardControl`** to test

Setting up JetBot

If the camera image is upside down:

1. Open **`ros_line_follower_all.slx`**
   `>> open_system('ros_line_follower_all');`
2. Open "Vehicle Interface"
3. Change the switch to enable 180 deg rotation
4. Run **`testLineFollowerWithROS_jp.mlx`** to check if the line following works



Setting up JetBot

If the camera image is upside down:

1. Open **`line_detection.m`** **and uncomment the line 15**

`>> edit line_detection.m`

```
12    % Convert image data format OpenCV BGR
13 -  img = ocv2mat(I);
14
15    %img = imrotate(img,180)
16
17 -  sz = size(img);
18 -  sizeWH = sz([2 1]);
19
```

Setting up standalone deployment

- Setup "MATLAB Coder Support Package for NVIDIA Jetson and NVIDIA DRIVE Platforms"
  - https://www.mathworks.com/help/releases/R2021a/supportpkg/nvidia/ug/install-and-setup-prerequisites.html

- Install SDL and V4L-utils
  - `$ sudo apt-get install libsdl1.2-dev v4l-utils sox libsox-fmt-all libsox-dev`

Setting up standalone deployment

- Configure environment variables on Jetson
  - To enable 'nvcc' command through SSH, need to add relevant environment variables to .bashrc

```
$ gedit ~/.bashrc
```

```
# If not running interactively, don't do anything
case $- in
    *i*) ;;
      *)
         export PATH=$PATH:/usr/local/cuda/bin
         export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/usr/local/cuda/lib64
         export LIBRARY_PATH=/usr/local/cuda/lib64
         return;;
esac
```

  - Note: environment variables should be passed even for non-interactive shell

https://www.mathworks.com/help/releases/R2021a/supportpkg/nvidia/ug/install-and-setup-prerequisites.html