Safe Navigation

Our Team

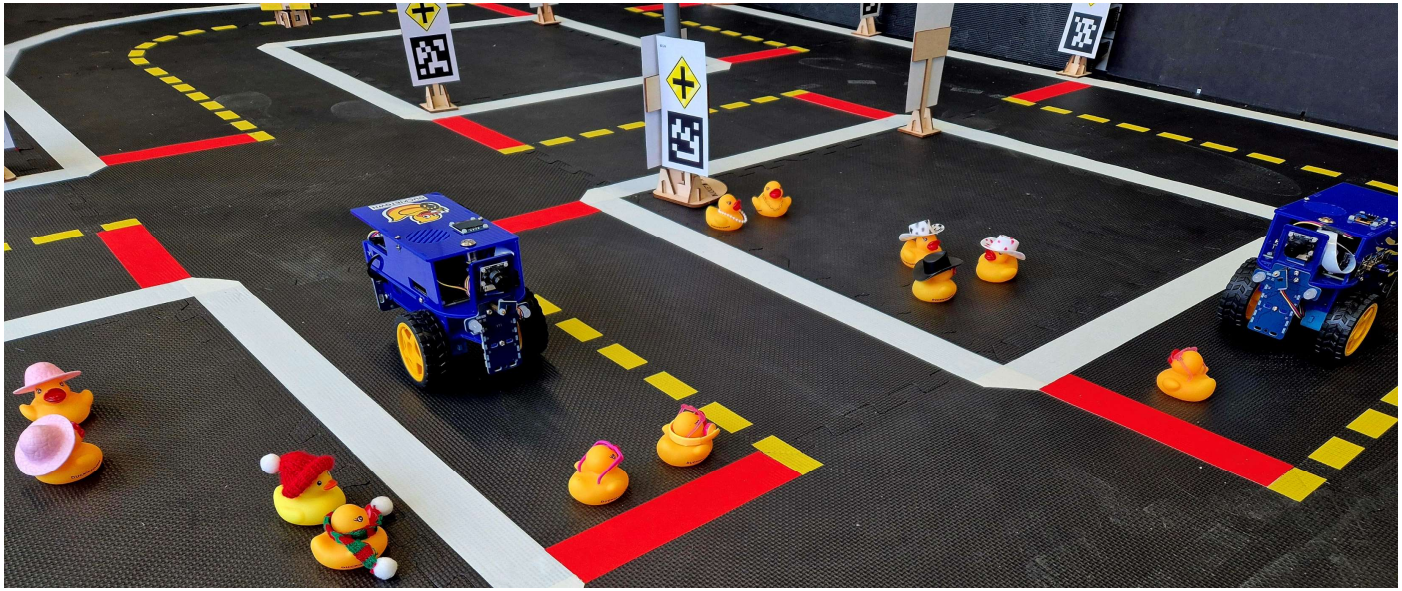
Ilia Panayotov

Esra Mehmedova

Esin Mehmedova

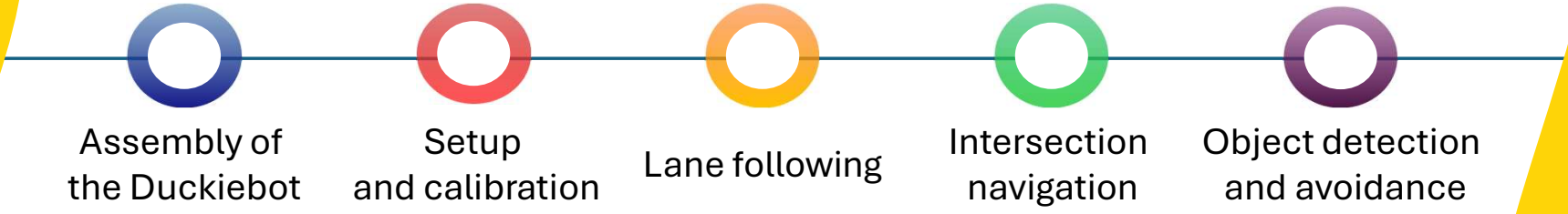
Our Goal

Develop a robot that can safely navigate a town, avoiding other Duckiebots and ducks



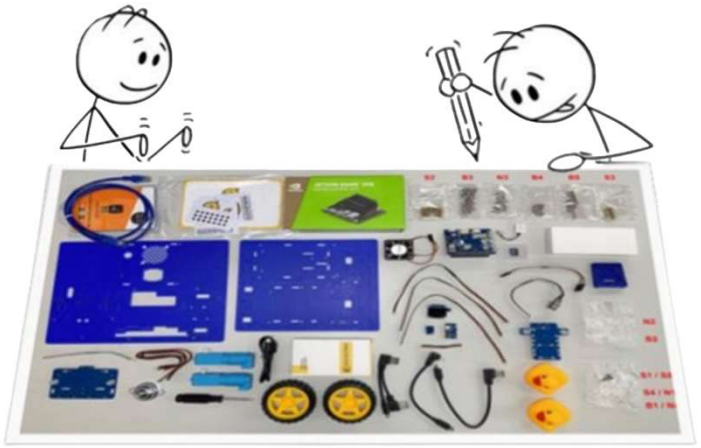
Milestones

Over the course of this project
we have successfully accomplished the following:



Assembly of the Duckiebot

We have assembled the Duckiebot, transforming individual components into a fully functional robot



Milestones

Over the course of this project
we have successfully accomplished the following:

Assembly of the Duckiebot

Setup and calibration

Lane following

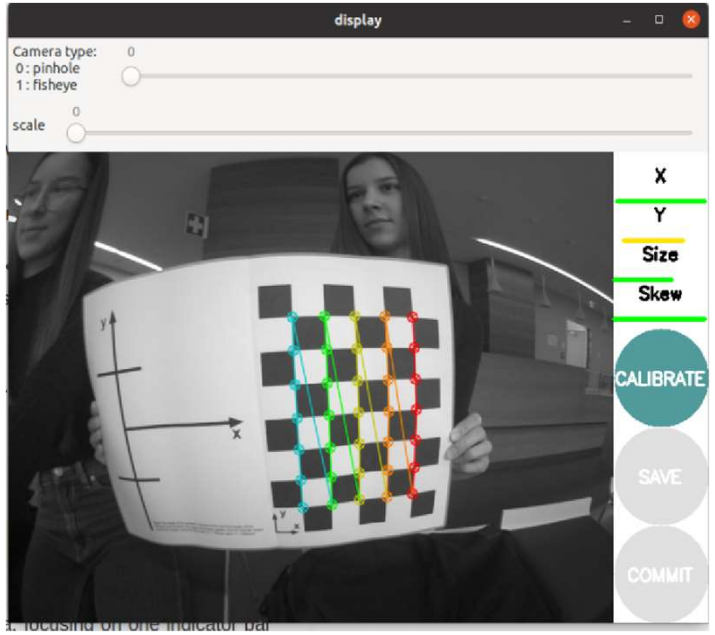
Intersection navigation

Object detection and avoidance

Setup and calibration

Following the tutorials, we have:

- set up our laptop and accounts
- flashed the SD card
- calibrated the Duckiebot's wheels and camera



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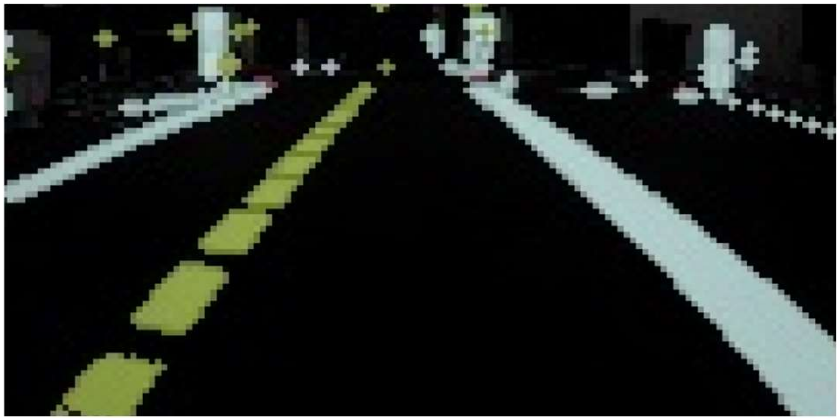
Lane following

We used the provided line-following demo

- The **camera** captures real-time images of the road and processes them to identify lane markings:

  Yellow lines mark the left boundary
  White lines mark the right boundary



- Once the lanes are detected, the system determines the **relative position of the Duckiebot** on the road

- The **PID controller** is used to adjust the Duckiebot's angle and direction based on the lane position error

- The PID controller's output is converted into **motor** commands

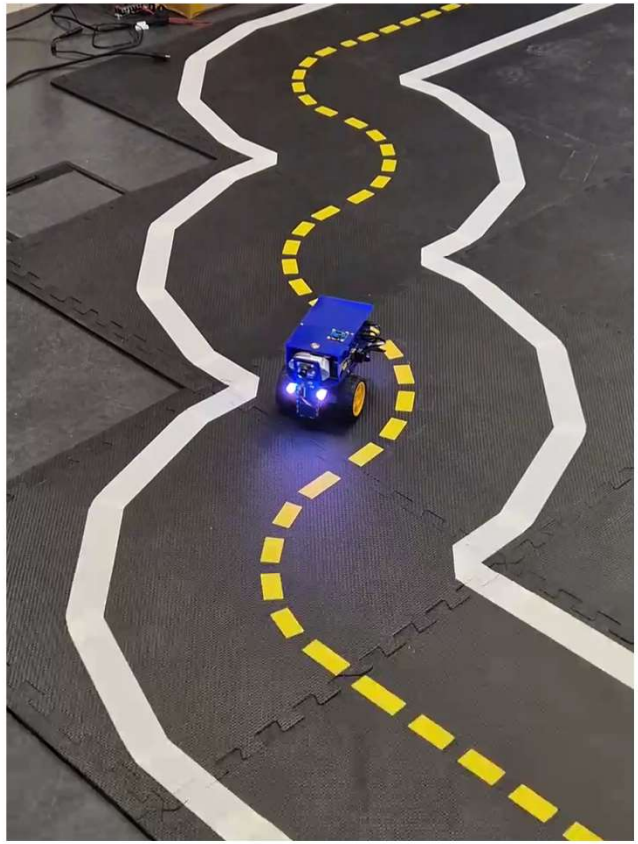
Lane following

We modified the PID controller and color ranges

```
v_bar: 0.10       # The robot's normal speed.
k_d: -7.0         # Adjusts for how far off-center the robot is.
k_Id: -0.3        # Helps correct long-term drift off-center.
k_Dd: -0.3        # Helps smooth out sudden changes in position.
k_theta: -1.7     # Adjusts for the robot's angle.
k_Iphi: -0.0      # Helps correct long-term drift in angle.
k_Dphi: -0.0      # Helps smooth out sudden changes in angle.

theta_thres: 0.523  # The angle limit before the robot corrects itself.
d_thres: 0.2615     # The distance limit before the robot corrects itself.
```

```
colors:
  RED:
    low_1: [0,140,100]
    high_1: [20,255,255]
    low_2: [165,140,100]
    high_2: [180,255,255]
  WHITE:
    low: [0,0,150]
    high: [180,100,255]
  YELLOW:
    low: [23,120,80]
    high: [45,255,255]
```



Milestones

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Intersection navigation

1. Stopping at stop lines

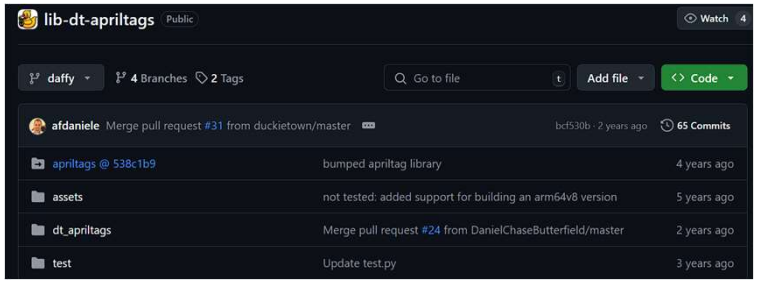
```yaml
colors:
  RED:
    low_1: [0,140,100]
    high_1: [20,255,255]
    low_2: [165,140,100]
    high_2: [180,255,255]
```

```yaml
stop_distance: 0.22  # Distance to stop line in meters
min_segs: 2          # Minimum number of segments to detect a stop line
off_time: 3          # Time in seconds to wait before rechecking stop line
max_y: 0.3           # Maximum y-coordinate value for stop line detection
```

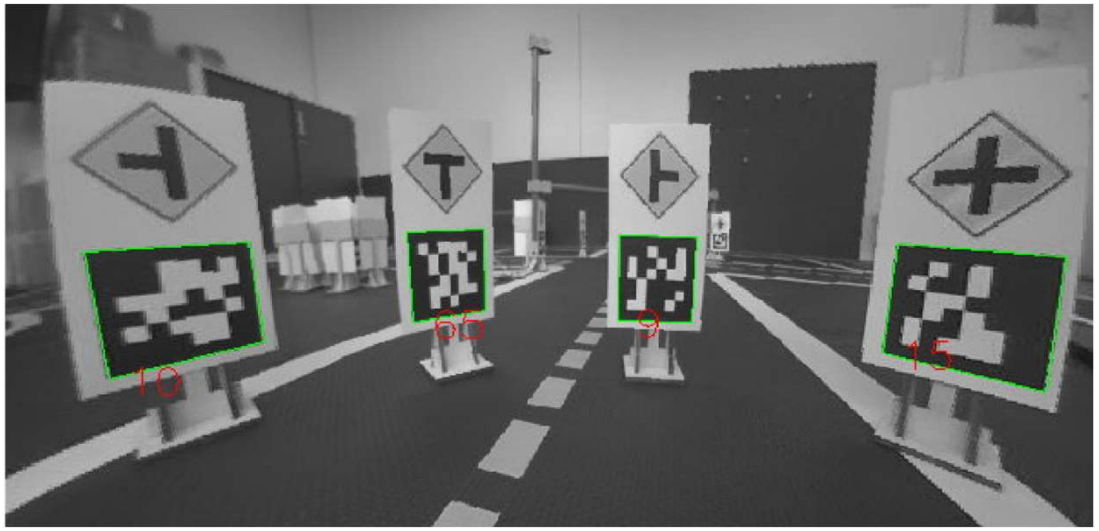
```python
# Wait at the stop line
sleep_sec = 3
rospy.loginfo(f"Sleeping for {sleep_sec} seconds")
rospy.sleep(sleep_sec)  # wait at stop line
```

Intersection navigation

2. Detecting signs




```
self.possible_turns = [0, 1, 2]  # left, straight, right
self.tags_to_turns = {
        67: [0, 2],
        65: [0, 2],
        11: [0, 2],
        63: [0, 1],
        10: [0, 1],
        61: [0, 1],
        59: [1, 2],
        9: [1, 2],
        57: [1, 2],
        13: [0, 1, 2],
        14: [0, 1, 2],
        15: [0, 1, 2],
        19: [0, 1, 2],
}
```



```
def _detect(self, detector_id, msg):
    # turn image message into grayscale image
    with self.profiler("/cb/image/decode"):
        img = self._jpeg.decode(msg.data, pixel_format=TJPF_GRAY)
    # run input image through the rectification map
    with self.profiler("/cb/image/rectify"):
        img = cv2.remap(img, self._mapx, self._mapy, cv2.INTER_NEAREST)
    # detect tags
    with self.profiler("/cb/image/detection"):
        tags = self._detectors[detector_id].detect(img, True, self._camera_parameters, self.tag_size)
```

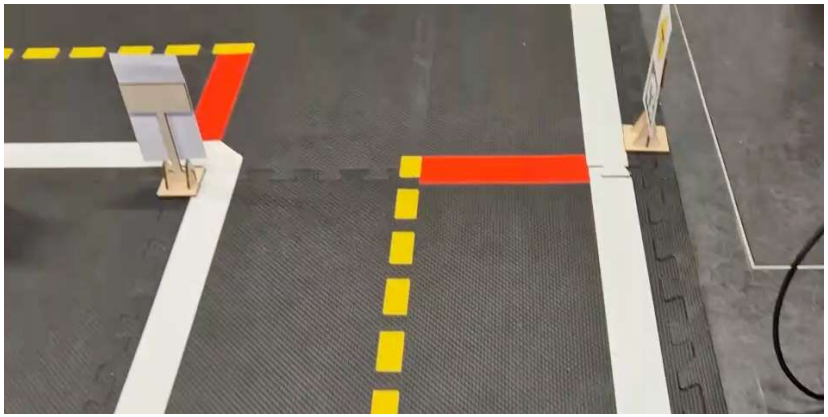
Intersection navigation

3. Activating the turn signal

```
colors: # All triplets should be ordered [R,G,B]
  switchedoff: [0,0,0]
  white: [0.5,0.5,0.5]
  yellow: [1,0.8,0]
  red: [1,0,0]
frequencies:
  f0: &f0 0.5
  f1: &f1 1.9

CAR_SIGNAL_RIGHT:
  color_mask: []
  color_list: ["white","yellow","white","red","yellow"]
  frequency_mask: [0,1,0,0,1]
  frequency: *f1

CAR_SIGNAL_LEFT:
  color_mask: []
  color_list: ["yellow","red","white","yellow","white"]
  frequency_mask: [1,0,0,1,0]
  frequency: *f1

CAR_SIGNAL_STRAIGHT:
  color_mask: []
  color_list: ["white","red","white","red","white"]
  frequency_mask: [0,0,0,0,0]
  frequency: *f1
```

```
self._led_signals = [
    String("CAR_SIGNAL_LEFT"),
    String("CAR_SIGNAL_STRAIGHT"),
    String("CAR_SIGNAL_RIGHT"),
]
```

```
# Set the LED signal lights
if self.params["~use_LEDs"].value:
    leds = self._led_signals[turn]
    rospy.loginfo(f"Setting leds: {leds}")
    msg = ChangePatternRequest(leds)
```



Intersection navigation

4. Executing the turn

```
self.l_turn_v = DTParam(
    "~l_turn_v", default = 0.1,
)
self.l_turn_omega = DTParam(
    "~l_turn_omega", default = 1.3,
)
self.l_turn_secs = DTParam(
    "~l_turn_secs", default = 4,
)

self.r_turn_v = DTParam(
    "~r_turn_v", default = 0.1,
)
self.r_turn_omega = DTParam(
    "~r_turn_omega", default = -1.75,
)
self.r_turn_secs = DTParam(
    "~r_turn_secs", default = 3,
)

self.s_turn_v = DTParam(
    "~s_turn_v", default = 0.1,
)
self.s_turn_omega = DTParam(
    "~s_turn_omega", default = 0.0,
)
self.s_turn_secs = DTParam(
    "~s_turn_secs", default = 3.0,
)
```

```
self.turn_params = [
    (self.l_turn_v, self.l_turn_omega, self.l_turn_secs),
    (self.s_turn_v, self.s_turn_omega, self.s_turn_secs),
    (self.r_turn_v, self.r_turn_omega, self.r_turn_secs),
]
```

```
def _available_turns(self):
    avail_turns = self.tags_to_turns.get(self.current_tag_id, [1])
    return avail_turns
```

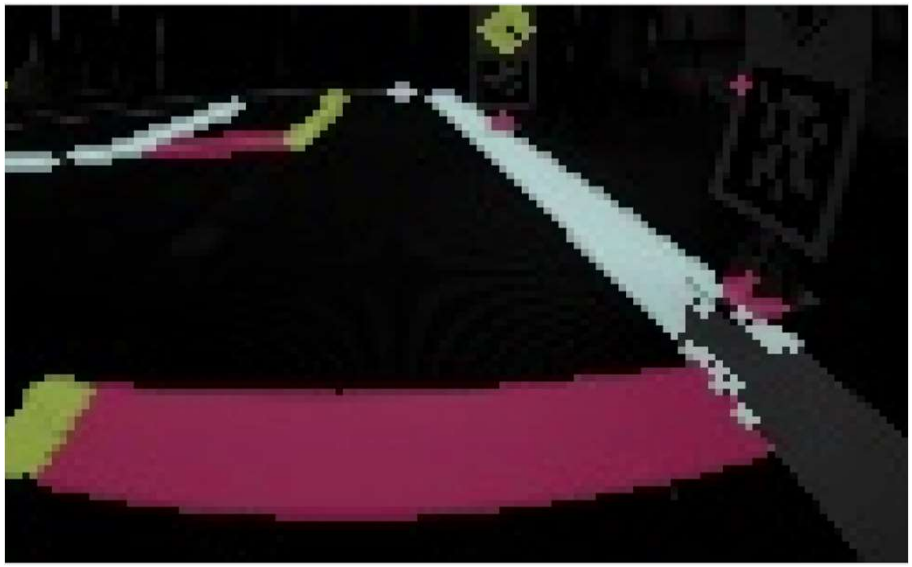
```
def selectTurn(self):
        # Take a random turn from the available turns (based on apriltag
        # detection)
        turn = self._available_turns()
        return int(np.random.choice(turn))
```

```
# Construct turning command
v, omega, sleep_time = self.turn_params[turn]
car_control_msg = Twist2DStamped()
car_control_msg.header.stamp = rospy.Time.now()
car_control_msg.v = v.value
car_control_msg.omega = omega.value

# Turn
rospy.loginfo(f"v: {v}, omega: {omega}, time: {sleep_time.value}")
self.publishCmd(car_control_msg)
rospy.loginfo("Turning now")
rospy.sleep(sleep_time.value)
```

Intersection navigation

Duckiebot's perspective

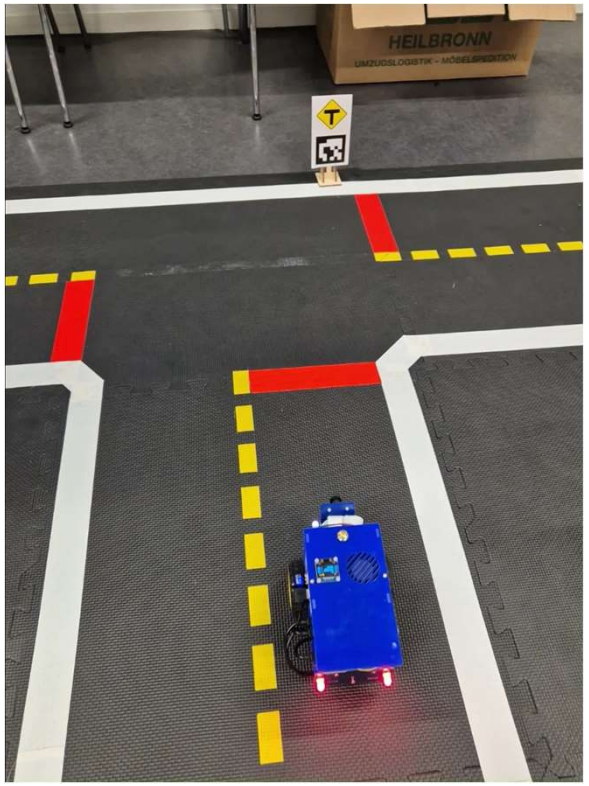
Line Detection

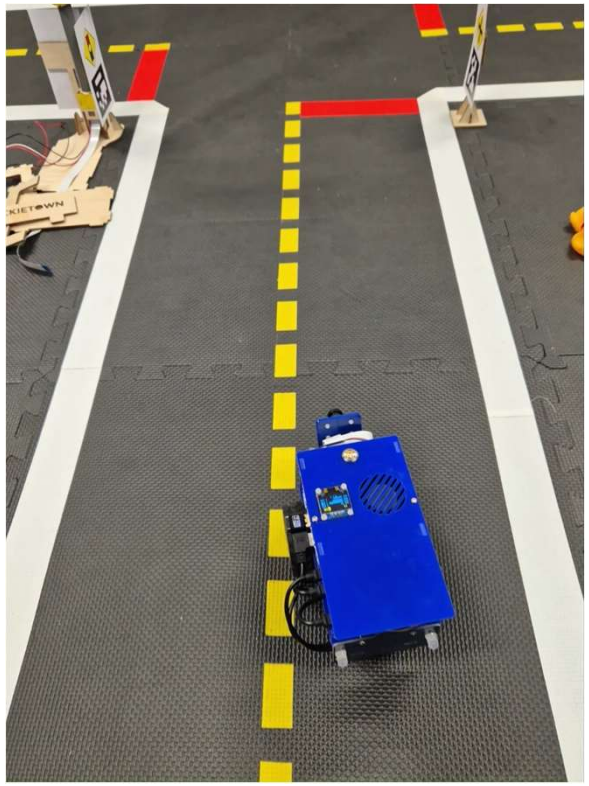


Sign Detection

Intersection navigation

Demo Videos





Milestones

Over the course of this project
we have successfully accomplished the following:

Assembly of the Duckiebot

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Lane following

Intersection navigation

Object detection and avoidance

Object detection and avoidance

Duckietown's implementation

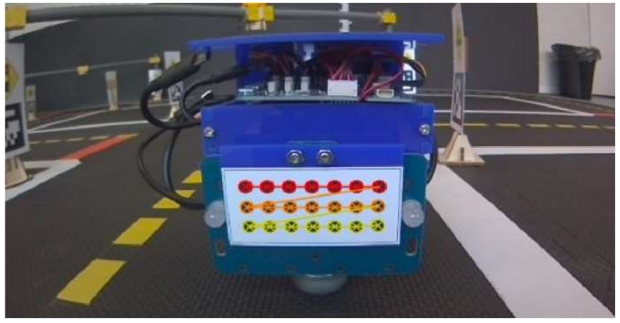
1. Detect if there is another Duckiebot by recognizing the pattern of circles

```
process_frequency: 2                    # Frequency at which to process the incoming images
circlepattern_dims: [7, 3]              # Number of dots in the pattern
blobdetector_min_area: 10               # Minimum area for the dot pattern
blobdetector_min_dist_between_blobs: 2  # Minimum distance between dots
```

2. Publish a stop line message if the other vehicle is too close

```
distance_between_centers: 0.0125            # Distance between the centers of the dots, in meters
max_reproj_pixelerror_pose_estimation: 1.5  # Maximum tolerable reprojection error for pose estimation
virtual_stop_line_offset: 0.5               # Distance before the stop, in meters
```

```
if self.at_obstacle_stop_line:
    rospy.loginfo("at obstacle stop line")
v = 0
omega = 0
car_control_msg = Twist2DStamped()
car_control_msg.header = pose_msg.header
self.publishCmd(car_control_msg)
```

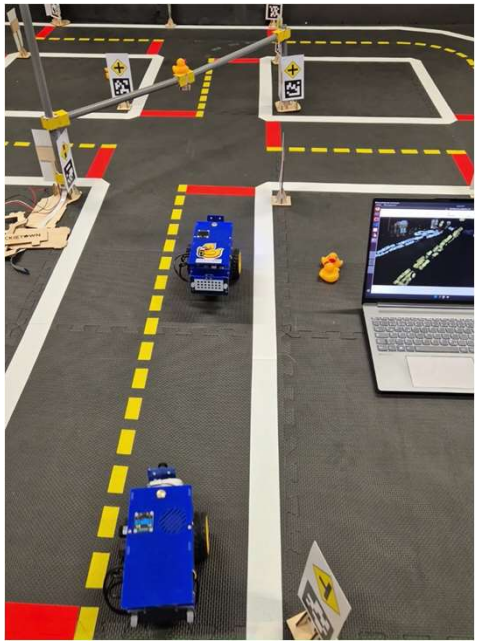


Object detection and avoidance

Duckietown’s implementation

Duckiebot's perspective

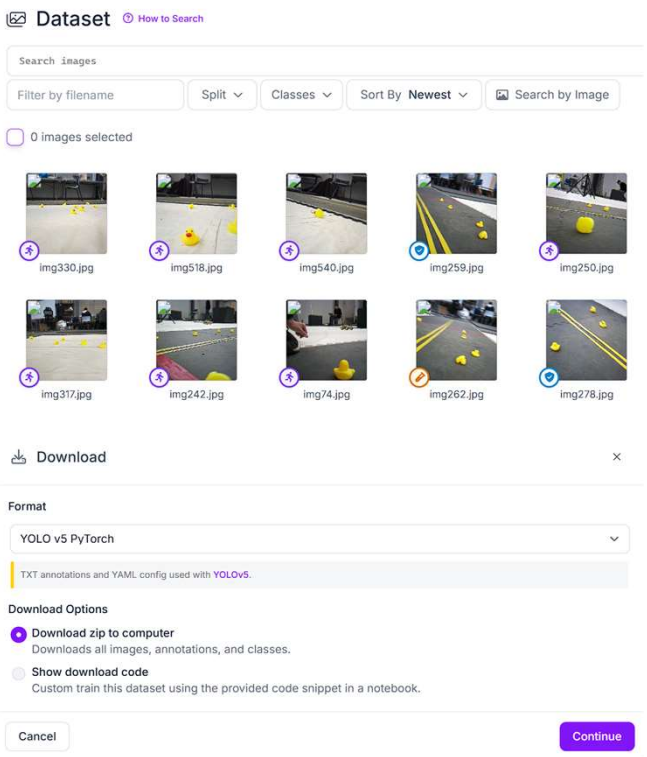
Vehicle detection

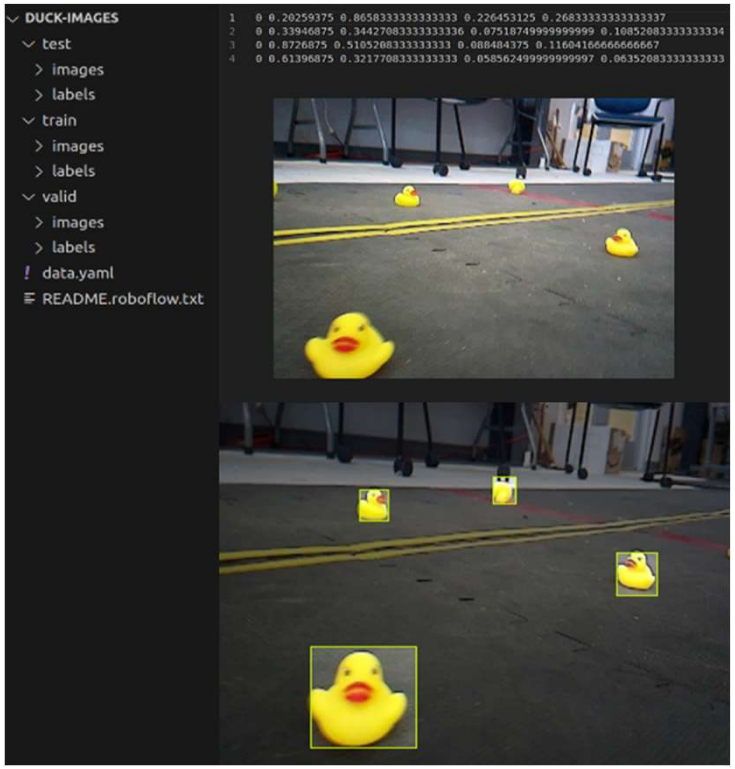


Object detection and avoidance

Our YOLOv5-Based Approach

1. Data Collection





Object detection and avoidance

Our YOLOv5-Based Approach

2. Training

dt_object_detection_training.ipynb

File Edit View Insert Runtime Tools Help

+ Code + Text Copy to Drive

And we're ready to train! This step will take about 5 minutes.

Notice that we're only training for 10 epochs. That's probably not enough!

```
[ ] !cd yolov5 && python3 train.py --cfg ./models/yolov5n.yaml --img 416 --batch 32 --epochs 10 --data duckietown.yaml
```

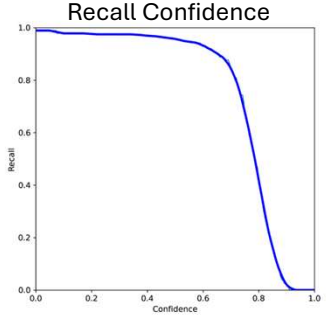
```
[ ] import numpy as np

    all_exps = os.listdir("yolov5/runs/train")
    all_exps_filtered = map(lambda x: int(x.replace("exp", "1")), filter(lambda x: x.startswith("exp"), all_exps))
    all_exps_filtered = np.array(list(all_exps))
    latest_exp_index = np.argmax(all_exps)
    latest_exp = all_exps[latest_exp_index]
    print(f"Latest exp is {latest_exp}")

    prun(f"cp yolov5/runs/train/{latest_exp}/weights/best.pt yolov5/best.pt")
    print(f"Marked the model from the latest run ({latest_exp}) as yolov5/best.pt.")
```

Next, we can upload your model to Duckietown's cloud!

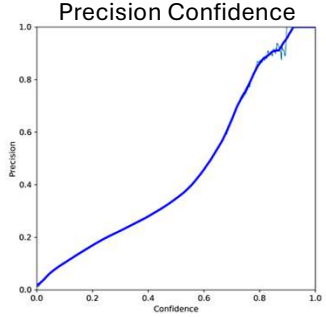
We will need our token to access our personal cloud space.

```
[ ] # TODO: Fill in the duckietown token here
    YOUR_DT_TOKEN = "YOUR_TOKEN_HERE"
```

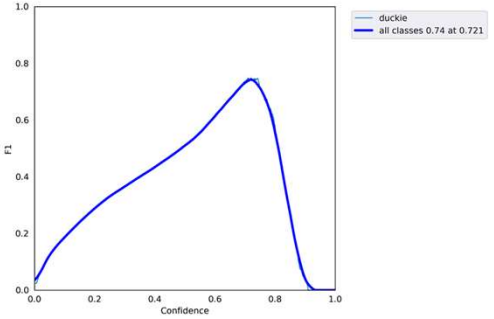
Recall Confidence



Precision Confidence



F1 Confidence



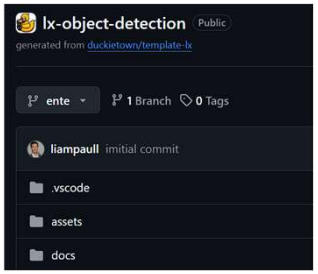
Object detection and avoidance

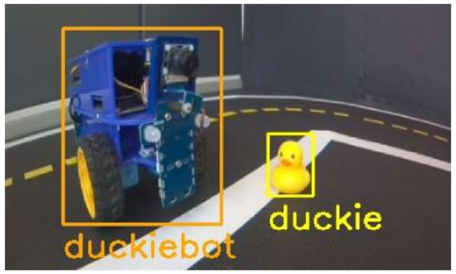
Our YOLOv5-Based Approach

3. Implementation

```python
def DT_TOKEN() -> str:
    # TODO: change this to your duckietown token
    dt_token = "dt1-3nT7FDbT7NLPrXykNJmqrVWv9QTz2jy2yYj
    return dt_token
```

```python
bboxes, classes, scores = self.model_wrapper.predict(rgb)

# Separate stop logic for ducks and duckiebots
stop_signal = False
large_duck = False
large_duckiebot = False

# Define the left and right boundaries of the center region
left_boundary = int(IMAGE_SIZE * 0.33)
right_boundary = int(IMAGE_SIZE * 0.75)

for cls, bbox, score in zip(classes, bboxes, scores):
    # Calculate center of bounding box
    center_x = (bbox[0] + bbox[2]) / 2

    if cls == 1 and score > 0.7:  # Duckiebot
        area = (bbox[2] - bbox[0]) * (bbox[3] - bbox[1])
        if area > 10000 and left_boundary < center_x < right_boundary:
            stop_signal = True
            large_duckiebot = True
            self.log(f"Duckiebot detected. Area: {area}")

    if cls == 0 and score > 0.7:  # Duck
        area = (bbox[2] - bbox[0]) * (bbox[3] - bbox[1])
        if area > 2000 and left_boundary < center_x < right_boundary:
            stop_signal = True
            large_duck = True
            self.log(f"Duck detected. Area: {area}")
```





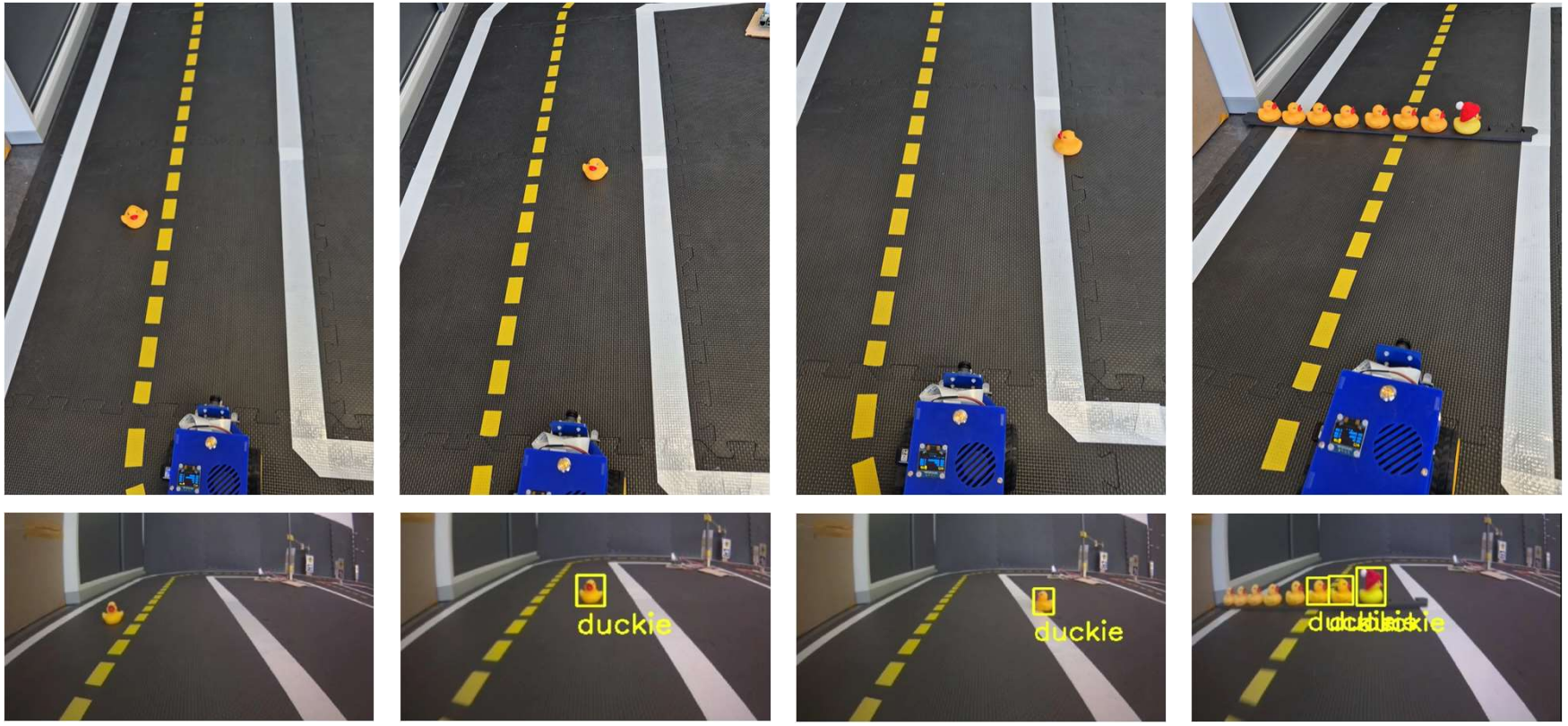

```python
# Create velocity command
vel_cmd = Twist2DStamped()
vel_cmd.header.stamp = rospy.Time.now()

if stop_signal:
    vel_cmd.v = 0.0
    vel_cmd.omega = 0.0
    if large_duck and not large_duckiebot:
        self.log("Stopping for Duck.")
    elif large_duckiebot and not large_duck:
        self.log("Stopping for Duckiebot.")
    else:
        self.log("Stopping for duck and duckiebot.")
else:
    vel_cmd.v = 0.2
    vel_cmd.omega = 0.0
    self.log("Driving...")

self.pub_vel.publish(vel_cmd)
```

Object detection and avoidance

Duckiebot Detection Demo

Object detection and avoidance

Duck Detection Demo



Milestones

Over the course of this project
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Challenges

1. Camera not turning on
2. LEDs showing unexpected colors

3. Storage full

```
  copyfile(src, dst, follow_symlinks=follow_symlinks)
 File "/usr/lib/python3.8/shutil.py", line 264, in copyfile
   with open(src, 'rb') as fsrc, open(dst, 'wb') as fdst:
SError: [Errno 28] No space left on device: '/code/catkin_ws/logs/lane_filter/build.cmak
.000.log'
build] Note: Workspace packages have changed, please re-source setup files to use them.
025-01-22 19:55:22 esra-VirtualBox dts[655876] ERROR The command '/bin/bash -c . /opt/ro
/${ROS_DISTRO}/setup.sh &&    catkin build      --workspace ${CATKIN_WS_DIR}/' returned a
on-zero code: 1
025-01-22 19:55:22 esra-VirtualBox dts[655876] ERROR An error occurred while building th
 project image.
```


Thank you
for the attention!
Questions?