Self Driving Car - Learning

Module 1

Week 1

Lessons 1 : Practice Quiz

1. Which of the following are components of **longitudinal control**? (Select all that apply) 1 / 1 point

- [x] Accelerating

Correct
Correct, accelerating is a component of longitudinal control.

- [x] Braking

Correct
Correct, braking is a component of longitudinal control.

- [ ] Planning
- [ ] Steering

2. Which of the following is **not** an example of OEDR? 1 / 1 point

- ○ Slowing down when seeing a construction zone ahead
- ○ Stopping at a red light
- ◉ Finding a route from your current location to a goal location
- ○ Pulling over upon hearing sirens

Correct
Correct, finding routes between locations is a long term planning problem and not OEDR.

3. Which of the following tasks would you expect a **Level 2 system** to perform? (Select all that apply)

1 / 1 point

- [x] Maintain constant speed

Correct
Correct, maintaining speed is part of longitudinal control for the level 2 system.

- [x] Stay within a lane

Correct
Correct, maintaining speed is part of lateral control for the level 2 system.

- [x] Change lanes

Correct
Correct, changing lanes is part of lateral control for the level 2 system.

- [ ] Swerve and slow down to avoid a pedestrian

4. What is the **distinction** between Level 3 autonomy and Level 4 autonomy?

1 / 1 point

- ○ Level 3 systems cannot perform OEDR, Level 4 systems can
- ○ Level 3 systems only have lateral or longitudinal control, Level 4 systems have both
- ○ Level 3 systems cannot drive on highways, Level 4 systems can
- ◉ Level 3 systems require full user alertness, Level 4 systems do not

Correct
Correct, level 3 systems cannot handle emergencies automatically and as a result require full user alertness.

5. What distinguishes Level 5 Autonomy from Level 4?

1 / 1 point

- ○ Level 5 autonomy can operate on any road surface and road type, while Level 4 cannot.
- ○ Level 5 has OEDR capability, while Level 4 does not.
- ◉ Level 4 has a restricted operational design domain, whereas Level 5 is unrestricted.
- ○ Level 5 autonomy can operate on any weather condition, while Level 4 cannot.

Correct
Correct, level 5 systems can operate in any weather condition, on any road type or surface and in any scenario and remain safe.

Lessons 2 : Practice Quiz

1. Which of the following tasks are associated with perception? (Select all that apply)

1 / 1 point

- [x] Identifying road signs

Correct
Correct, perception deals with object identification.

- [x] Estimating the motion of other vehicles

Correct
Correct, perception deals with position and motion estimation.

- [ ] Responding to traffic light state changes
- [ ] Planning routes on a map

2. Which of the following can be on road objects? (Select all that apply)

1 / 1 point

- [x] Potholes

Correct
Correct, potholes in the drivable surface are on road objects.

- [x] Vehicles

Correct
Correct, vehicles can be on road objects. They can also be off road.

- [ ] Stop signs
- [ ] Sidewalks

3. Which of the following tasks pose challenges to perception? (Select all that apply)

1 / 1 point

- [x] Detecting, tracking and predicting dynamic object motions

Correct

- [x] Handling sensor uncertainty

Correct

- [x] Handling sensor occlusion and reflection

Correct

- [x] Having sensors work in adverse weather conditions

Correct

4. Which of the following sensors are used for ego localization? (Select all that apply)

1 / 1 point

- [x] Inertial Measurement Unit (IMU)

Correct
Correct, an IMU provide acceleration and rotation rate measurements from accelerometers and gyroscopes, and can be used to estimate vehicle orientation and aid in localization in general.

- [x] Global Navigation Satellite System (GNSS)

Correct
Correct, a GNSS sensor provides position and velocity measurements, and can be used to estimate vehicle position and orientation for localization.

- [ ] Radar
- [ ] Barometers

5. Which of the following objects would be relevant for perception in adaptive cruise control?

1 / 1 point

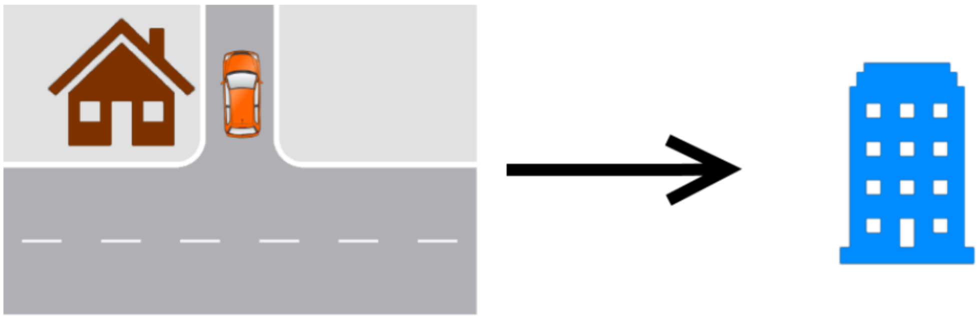
- ○ Lane markings
- ◉ Other vehicles
- ○ Road signs
- ○ Traffic lights

Correct
Correct, adaptive cruise control detects vehicles ahead to control speed and to maintain safe driving distances.

Module 1 : Graded Quiz

1. **Scenario 1: You're at home and need to drive to work**

0 / 1 point



During the trip, you will be performing OEDR tasks. Of the tasks below, which of the following is **not** an example of OEDR?

- (●) Stopping at a red light
- ( ) Maintaining a distance to a vehicle ahead
- ( ) Slowing down when seeing a construction zone ahead
- ( ) Pulling over upon hearing sirens

Incorrect
Incorrect. Please review OEDR in lecture 1 on Taxonomy of Driving Automation.

B. maintaining distance

2. Which of the following tasks are associated with **perception**?

1 / 1 point

- [x] Estimating the motion of other vehicles

Correct
Correct! Estimating the motion of other vehicles is associated with perception

- [x] Identifying road signs

Correct
Correct! Identifying road signs are associated with perception

- [ ] Responding to traffic lights
- [ ] Planning routes on a map

3. Before leaving, you decide to check the weather. The forecast states that over the next few days there will be both sun and rain along with some fog. Assuming your vehicle exhibits Level 5 autonomy, which of the following **weather conditions** can your vehicle operate?

1 / 1 point

- ○ Clear and sunny
- ○ Windy heavy rainfall
- ○ Heavy Fog
- ○ Light rainfall
- ◉ All of the above

Correct
Correct! Level 5 autonomy can operate in any weather condition.

4. You enter your autonomous vehicle and it drives your usual route to work. While the vehicle is driving, you decide to take a nap. For **which levels of autonomy** is this safe? (Select all that apply)

1 / 1 point

- [ ] 1
- [ ] 2
- [ ] 3
- [x] 4

Correct
Correct! Only level 4 and 5 autonomy can handle emergencies autonomously.

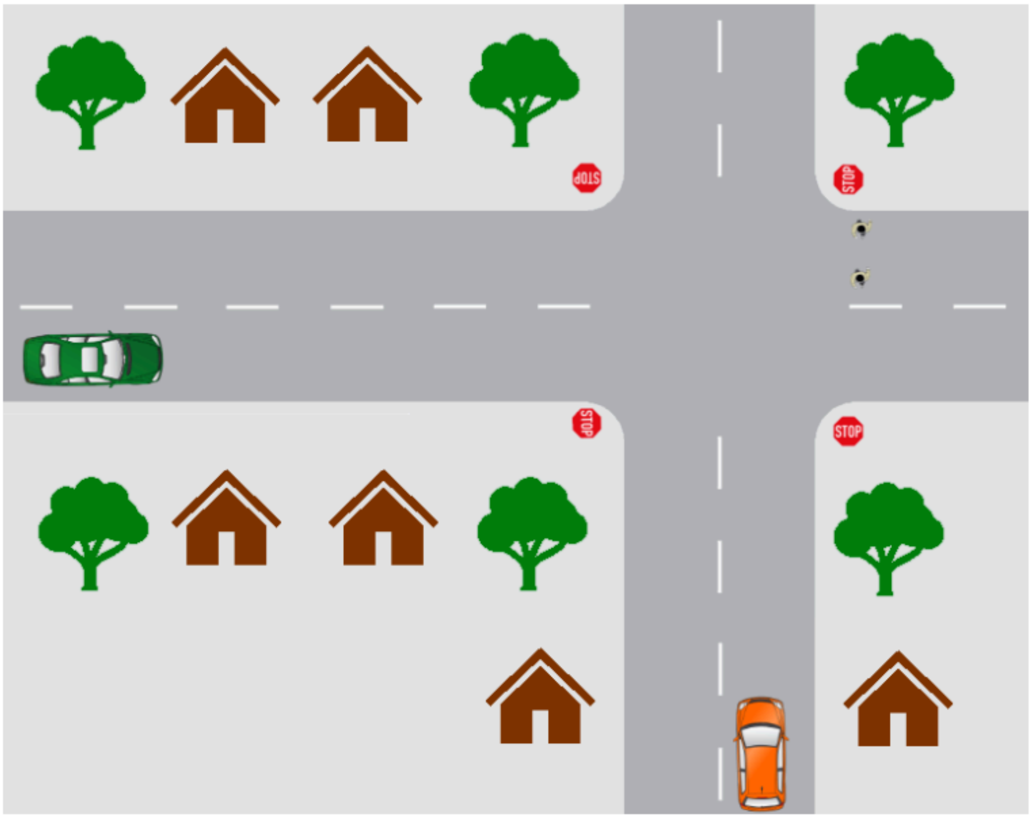
- [x] 5

Correct
Correct! Only level 4 and 5 autonomy can handle emergencies autonomously.

5. **Scenario 2:** (Assume the car is driving on the right-hand side of the road) .

1 / 1 point

You're approaching an all ways stop sign and you want to make a right turn. Your vehicle is denoted in orange. There are 2 pedestrians currently crossing and another vehicle (denoted in green) approaching the stop sign from the left.



This task involves multiple considerations, which of them are **predictive planning**? Select all that apply.

- [x] The green car arrives at the stop sign after you and plans to travel straight through the intersection. You choose to move first.

Correct
Correct! Predictive planning deals with planning based on predictions of the actions of others.

- [x] Wait for the pedestrians to finish crossing before turning

Correct
Correct! Predictive planning deals with planning based on predictions of the actions of others.

- [ ] Gradually decelerate while reaching the stop sign
- [ ] At a stop sign, stop and look both ways before proceeding

6. Here are some rules for driving at a stop sign. Which of the following is an appropriate **priority ranking**?

1 / 1 point

1) For non all-way stop signs, stop at a point where you can see oncoming traffic without blocking the intersection

2) If there are pedestrians crossing, stop until they have crossed

3) If you reach a stop sign before another vehicle, you should move first if safe

- ○ 1, 2, 3
- ○ 3, 2, 1
- ◉ 2, 1, 3
- ○ 3, 1, 2
- ○ 1, 3, 2

Correct
Correct! Prioritize safety.

7. Which of the following are **off-road objects**? (Select all that apply)

0.6 / 1 point

- [ ] Curbs
- [x] Trees

Correct
Correct! These are examples of off road objects.

- [ ] Pedestrians
- [x] Road markings

This should not be selected
Incorrect. Please review off road objects in lecture 2 on Requirements for Perception.

- [x] Stop signs

Correct
Correct! These are examples of off road objects.

8. Suppose your vehicle has **lane keeping assistance**, which of these objects are relevant for its performance? (Select all that apply)

1 / 1 point

- [ ] Pedestrians
- [ ] Stop signs
- [ ] Trees
- [x] Road markings

Correct
Correct! Detecting road markings and curbs are needed for lane keeping.

- [x] Curbs

Correct
Correct! Detecting road marks and curbs are needed for lane keeping.

9. Which of the following sensors are used for the **lane keeping assistance**? (Select all that apply)

1 / 1 point

- [x] Cameras

Correct
Correct! Detection and localization is needed for lane keeping.

- [ ] Barometers
- [x] GPS

Correct
Correct! Detection and localization is needed for lane keeping.

- [x] LIDAR

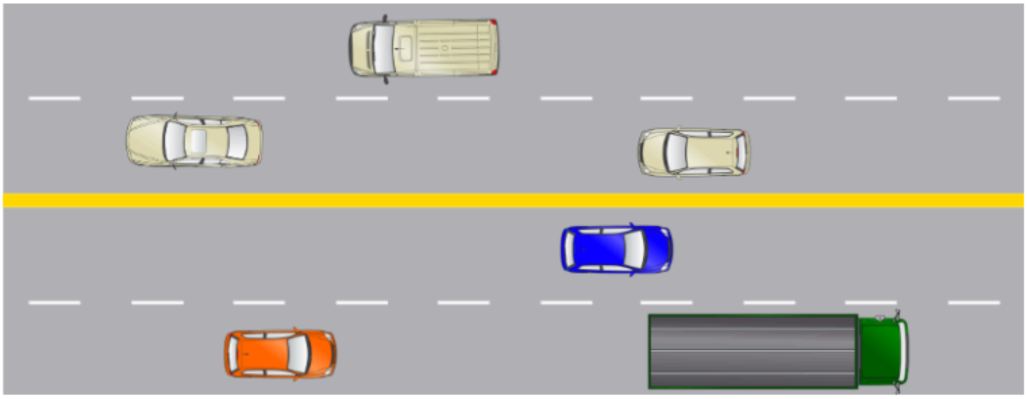
Correct
Correct! Detection and localization is needed for lane keeping.

- [x] IMU

Correct
Correct! Detection and localization is needed for lane keeping.

10. **Scenario 3:** You are on the highway and you see a truck in front of you. Assume the car is driving on the right-hand side of the road. There is also a blue car beside the truck in the other lane.

1 / 1 point



Your vehicle follows the truck and maintains a constant distance away. What kind of **control** is this?

- ○ OEDR
- ○ Lateral
- ◉ Longitudinal
- ○ Fallback

Correct
Correct! Distance keeping is a longitudinal control problem.

11. You decide to **change lanes** to pass a truck. What kind of decision is this?

1 / 1 point

- ◉ Short term planning
- ○ Rule-based planning
- ○ Long term planning
- ○ Immediate
- ○ Reactive

Correct
Correct! Lane changing is a short term task.

12. Which of the following tasks are **rule-based planning**? (Select all that apply)

1 / 1 point

- [ ] If the vehicle in front is going to slow down sharply, then avoid performing a lane change.
- [x] During a lane change, maintain our current speed or accelerate slightly

Correct
Correct! Rule based planning only considers the present state, not what vehicles will do next.

- [x] If there are vehicles directly beside us on the lane, it is unsafe to lane change.

Correct
Correct! Rule based planning only considers the present state, not what vehicles will do next.

13. Suppose the blue vehicle suddenly brakes and you decide to abort the lane change. If your vehicle can **respond automatically and remain in its own lane**, what is the minimum level of autonomy of your vehicle?

1 / 1 point

- ○ 1
- ○ 4
- ◉ 3
- ○ 2
- ○ 5

Correct
Correct! Level 3 autonomy can perform OEDR.

14. The blue vehicle returns to normal speed and you can now safely change lanes. Your car is **performing the lane change**, what kind of control is this?

1 / 1 point

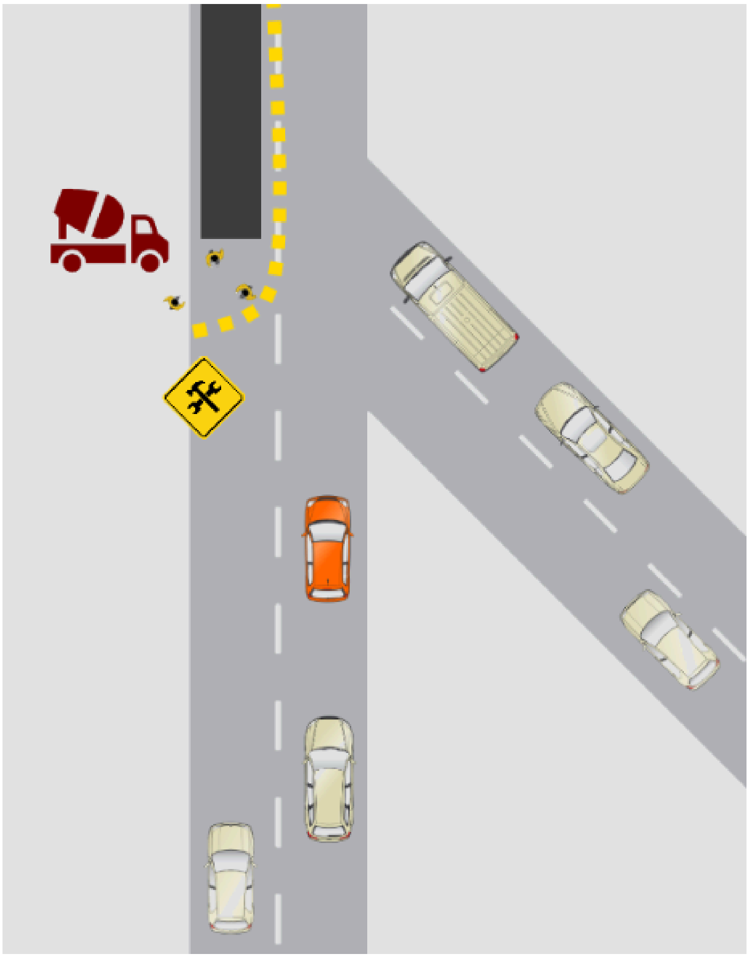
- ◉ Lateral
- ○ Fallback
- ○ OEDR
- ○ Longitudinal

Correct
Correct! Lane changing is a lateral control problem.

15. **Scenario 4:** You are almost at work but encounter a construction site.

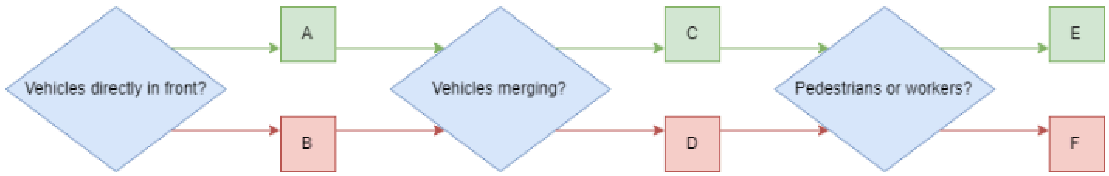
1 / 1 point

Assume the car is driving on the right-hand side of the road. Your vehicle is denoted in orange.



You see a construction site where the workers are repaving a road full of potholes. They are using jackhammers which can cause dust clouds.

You create the following decision tree for getting through the construction site. From the diagram, which of the following decisions should you make? **(green is true, red is false)**



- [ ] A (True)
- [x] B (False)

Correct
Correct!

- [x] C (True)

Correct
Correct!

- [ ] D (False)
- [x] E (True)

Correct
Correct!

- [ ] F (False)

16. Here are a set of rules for making these decisions, **arrange them in an appropriate prioritization**.

1/1 point

1) If there are no vehicles ahead, accelerate to the speed limit

2) Drive slowly in construction zones

3) If there are pedestrians or workers directly ahead in the current lane, stop

4) Yield to merging vehicles, if necessary

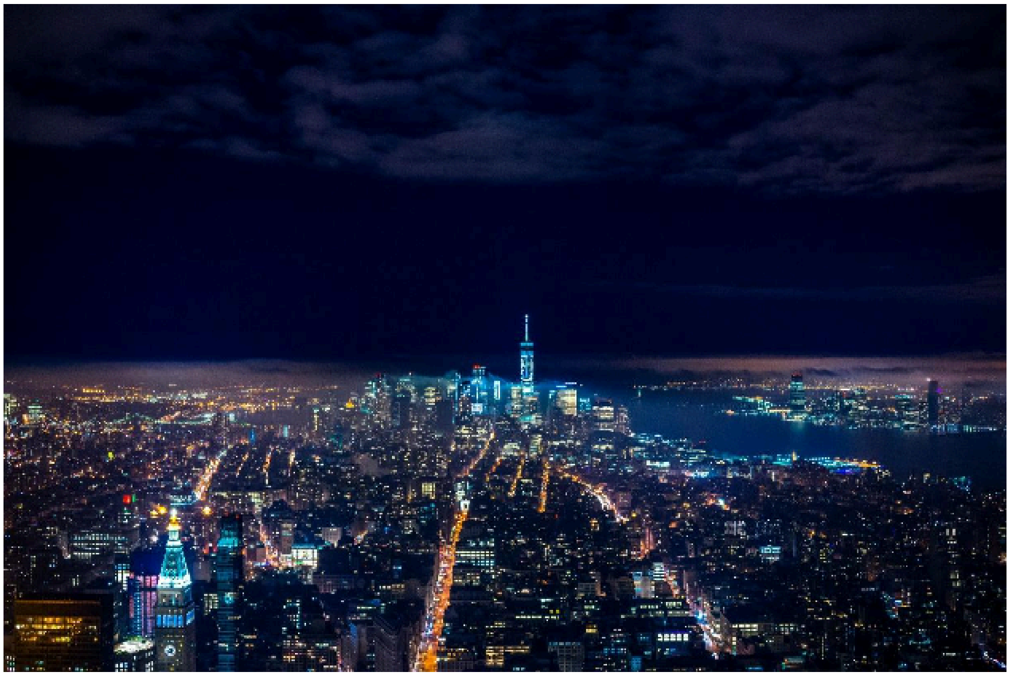
- ○ 1, 2, 3, 4
- ○ 2, 3, 4, 1
- ○ 3, 4, 1, 2
- ◉ 3, 4, 2, 1

Correct

Correct! Prioritize safety in each case, yielding to pedestrians and then vehicles first, before defining acceptable travel speed.

17. **Scenario 5:** You're finished work and need to drive back home, but it's nighttime.

1 / 1 point



You plan a new path home on your GPS application to avoid the construction site, **what type of planning is this**?

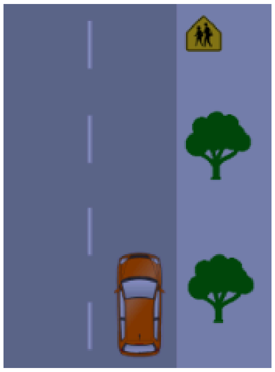
- ○ Reactive
- ◉ Long term planning
- ○ Immediate
- ○ Rule based planning
- ○ Short term planning

Correct

Correct! Setting a path before driving is long term planning.

18. Your new path goes through a school zone and you see the school zone sign. You decide to slow down despite there being no pedestrians or children (it's nighttime). What sort of **planning** is this?

1 / 1 point



- (selected) Rule based planning
- Short term planning
- Immediate planning
- Long term planning
- Reactive planning

Correct

Correct! The rule to slow down in school zones is being followed.

Week 2

Module 2 : Graded Quiz

1. What are the differences between **exteroceptive sensors** and **proprioceptive sensors**? (Select all that apply) **0.6 / 1 point**

- [ ] Proprioceptive sensors can determine distance traveled by the vehicle, whereas exteroceptive sensors cannot.
- [x] Exteroceptive sensors can determine obstacle size and distance away, whereas proprioceptive sensors cannot.

  Correct
  Proprioceptive sensors do not observe nor measure environment surroundings.

- [ ] Exteroceptive sensors can determine distance traveled by the vehicle, whereas proprioceptive sensors cannot.
- [x] Proprioceptive sensors are used to determine vehicle position, whereas exteroceptive sensors are used for sensing the environment.

  This should not be selected
  Please review types of sensors in lecture 1 on Sensors and Computing Hardware. Hint: exteroceptive sensors can be used for mapping as well.

- [ ] Proprioceptive sensors do not interact with the environment, whereas exteroceptive sensors do.

2. Which of the following exteroceptive sensors would you use in **harsh sunlight**? **1 / 1 point**

- [ ] Cameras
- [x] Radar

  Correct
  Radar is unaffected by harsh sunlight.

- [x] Sonar

  Correct
  Sonar is unaffected by harsh sunlight.

- [ ] Lidar

3. Why is synchronization and timing accuracy important in the self driving system? **Choose the primary reason.**

1 / 1 point

- ○ Synchronization is important to ensure that sensors measure the environment at the same time.
- ○ Synchronization is important to ensure organized computation.
- ◉ Synchronization is important to ensure correct sensor fusion.
- ○ Synchronization is important to check sensor failure.

Correct
Correct!

4. Your autonomous vehicle is driving on the German autobahn at 150 km/h and you wish to maintain safe following distances with other vehicles. Assuming a safe following distance of 2s, **what is the distance (in m) required between vehicles**? Round your answer to **2 decimal places**.

1 / 1 point

83.33

Correct
150*2/3.6

5. Using the same speed of 150 km/h, **what is the braking distance (in m) required for emergency stops**? Assume an aggressive deceleration of 5 m/s^2. Round your answer to **2 decimal places**.

1 / 1 point

173.64

Correct
(150/3.6)^2/(2*5)

6. Suppose your vehicle was using long range cameras for sensing forward distance, but it is now nighttime and the images captured are too dark. **Which of the following sensors can be used to compensate**?

1 / 1 point

- ☐ IMU
- ☑ Radar

Correct
Radar can be configured for long range detection and can also operate in darkness.

- ☑ Lidar

Correct
Lidar can be configured for long range detection and can also operate in darkness.

- ☐ Sonar

7. What are the differences between an **occupancy grid** and a **localization map**? (Select all that apply)

1 / 1 point

- [x] An occupancy grid uses a dense representation of the environment, whereas a localization map does not need to be dense.

Correct
Since localization mapping is only concerned with identifying the vehicle pose in the environment, it can use point features or object locations and does not need to densely cover the entire environment, whereas occupancy grid mapping must capture the locations of all obstacles to be avoided and must therefore be dense.

- [x] The localization map is primarily used to estimate the vehicle position, whereas the occupancy grid is primarily used to plan collision free paths.

Correct
Correct. The vehicle position is a critical measurement to estimate how the ego vehicle is moving through the environment, and relies on matching sensor measurements at the current time to the localization map. The occupancy grid map stores live collision avoidance data in the form of occupied and unoccupied cells around the vehicle.

- [ ] The localization map uses only lidar data, whereas the occupancy grid can use both lidar and camera data.
- [ ] The occupancy grid only contains static objects, while the localization map contains only dynamic objects.

8. The vehicle steps through the software architecture and arrives at the controller stage. What information is required for the **controller** to output its commands to the vehicle?

1 / 1 point

- [x] Planned paths

Correct
The controller commands the vehicle to follow the planned paths.

- [x] Vehicle state

Correct
The controller requires the vehicle position and velocity to determine the appropriate amount of steering, throttle, and brake.

- [ ] Environment maps
- [ ] Locations of obstacles and other vehicles

9. What is (are) the role(s) of the **system supervisor**? (Select all that apply)

1 / 1 point

- [x] To ensure that the sensors are working correctly

Correct
The system supervisor is responsible for monitoring hardware and ensuring that the sensors are not broken.

- [ ] To ensure that the planned paths are collision free
- [x] To ensure that the maps update at the correct frequencies

Correct
The system software is responsible for monitoring software and ensuring operation at correct frequencies.

- [ ] To ensure that the controller outputs are within operating range

10. Which of the following tasks should be assigned to the **local planner**?

1 / 1 point

- ( ) Planning a lane change to turn left
- (•) Planning to avoid a parked car in the ego vehicle's lane
- ( ) Planning a merge onto the highway
- ( ) Planning a route to a destination

Correct
This is a reactive planning task, so it should be designated to the local planner.

11. What common objects in the environment appear in the **occupancy grid**?

1 / 1 point

- (•) Parked vehicles
- ( ) Traffic lights
- ( ) Other moving vehicles
- ( ) Lane boundaries

Correct
The occupancy grid contains static obstacles which block vehicle movement.

12. Which of the following maps contain **roadway speed limits**?

1 / 1 point

- ○ Occupancy grid
- ○ Localization map
- ◉ Detailed roadmap

Correct

The detailed roadmap contains traffic regulations.

Week 3

Module 3 : Graded Quiz

1. Which from the below options is the most **ACCURATE** and **COMPLETE** definition of **risk** in terms of self-driving vehicles?

1 / 1 point

- ○ Risk is any exposure to possible loss or injury
- ○ Risk is a probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal factors
- ◉ Risk is a probability that an event occurs combined with the severity of the harm that the event can cause
- ○ Risk is a condition in which there is a possibility of an adverse deviation from the desired or expected outcome
- ○ None of the above

Correct
Correct! Any autonomous driving team should focus on the most likely and the most severe events first.

2. Which of the following are **major components** of an autonomous driving system? (Select all that apply)

1 / 1 point

- [ ] Adaptation
- [ ] Configuration
- [x] Planning

Correct
Correct! This aspect of the autonomous driving system is extremely important. A mistake in this component can lead to failures and crashes.

- [x] Control

Correct
Correct! This aspect of the autonomous driving system is extremely important. A mistake in this component can lead to failures and crashes.

- [x] Perception

Correct
Correct! This aspect of the autonomous driving system is extremely important. A mistake in this component can lead to failures and crashes.

3. What are the most common categories of autonomous vehicle **hazard sources**? (Select all that apply)

0.6 / 1 point

- [ ] Driver fallback
- [x] Perception and planning

Correct
Correct! This is a major hazard source.

- [x] Hardware and software

Correct
Correct! This is a major hazard source.

- [x] Electrical and mechanical

Correct
Correct! This is a major hazard source.

- [ ] Malicious software

You didn't select all the correct answers

4. Is the following statement TRUE or FALSE?

1 / 1 point

The safety framework to structure safety assessment for autonomous driving defined by NHTSA is **MANDATORY** to follow.

- ( ) TRUE
- (•) FALSE

Correct
Correct! NHTSA safety framework was released as a suggestion, and it is not mandatory to follow. The main objective of the NHTSA is to guide companies building self-driving cars without overly restricting innovation or pre-selecting technologies.

5. Which categories are included in the **safety framework** to structure safety assessment for autonomous driving defined by NHTSA? (Select all that apply)

0.75 / 1 point

- [ ] Digital vehicle model design
- [x] Well-organized software development process

Correct
Correct! This is what any autonomous driving company should focus on according to NHTSA.

- [x] Testing and crash mitigation

Correct
Correct! This is what any autonomous driving company should focus on according to NHTSA.

- [ ] Autonomy design

You didn't select all the correct answers

6. Which actions are needed to be performed **in the event of an accident** by an autonomous vehicle? (Select all that apply)

1 / 1 point

- [x] Alerting first responders

Correct
Correct! An autonomous vehicle should quickly alert first responders in the event of an accident.

- [x] Returning car to a safe state

Correct
Correct! An autonomous vehicle's post crash behavior should include returning the car to a safe state, for example, stopping.

- [ ] Locking all doors
- [x] Securing fuel pumps

Correct
Correct! Securing fuel pumps in the event of a crash is critical for preventing further potentially dangerous situations.

- [x] Data recording to a black box

Correct
Correct! An autonomous vehicle needs to have an automated data recording function or black box recorder. It is very helpful to have this crash data to analyze and design systems that can avoid this specific kind of crash in the future.

7. What are the **most common** accident scenarios? (Select all that apply)

0.3333333333333333 / 1 point

- [x] Rollover

This should not be selected
Incorrect, please review Lesson 2: Industry Methods for Safety Assurance and Testing.

- [ ] Lane change
- [ ] Crosswalk
- [ ] Intersection
- [x] Rear-end

Correct
Correct! All the correct accident scenarios from this question account for over 84% of all crashes.

- [ ] Road departure

8. What kind of **safety system** is described by the following definition? This system can be analyzed to define quantifiable safety performance based on critical assessment of various scenarios.

1 / 1 point

- ( ) Data driven safety
- ( ) Test driven safety
- (•) Analytical safety
- ( ) None of the above

Correct
Correct! Analytical safety can provide strong guidance on which aspects of a system are the biggest contributors to overall safety.

9. According to the report by Rand Corporation, autonomous driving of 8.8 billion miles is required to demonstrate human-level fatality rate of an autonomous vehicle fleet using a 95% Confidence Interval. **How many years** is required to perform this testing with a fleet of 100 vehicles running 24 hours a day, 7 days a week at an average of 25 miles per hour? Your answer should be an integer.

0 / 1 point

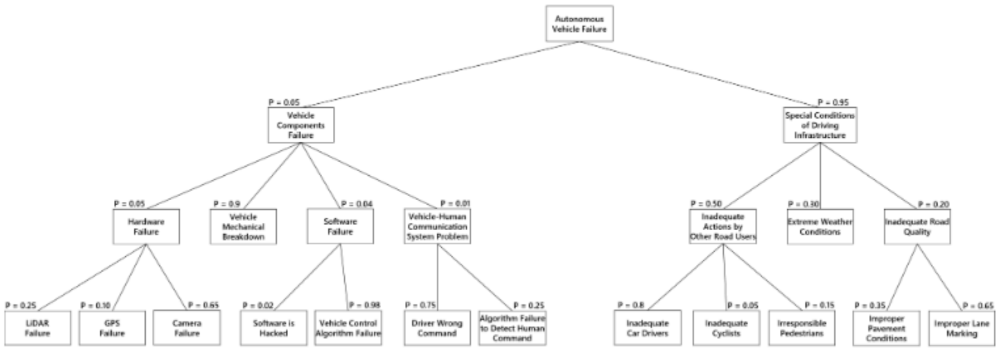
436

Incorrect
Incorrect, please review Lesson 2: Industry Methods for Safety Assurance and Testing. The numbers are approximate and may be hard to compute if not using the same assumptions as we used, so refer to the video to find the correct answer.

10. Given that an autonomous vehicle failure has happened and based on this tree, **what is the probability** that the failure happened because of Vehicle Control Algorithm Failure OR Inadequate Car Drivers? Please give your answer with the precision of 3 decimal places.

1 / 1 point

Please use this probabilistic fault tree for your computation:



0.382

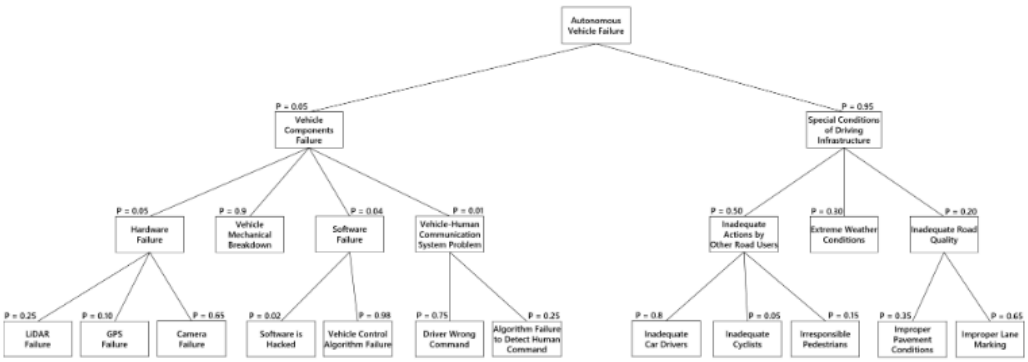
Correct

Correct! The operations used to propagate the probabilities on probabilistic fault trees upwards are the same as the rules of probability when events follow set theory. So, the OR probabilities would be the sum of children node probabilities, assuming independence of the events.

11. Given that the autonomous vehicle failure has happened, and based on this tree**, what is the probability** that the failure happened because of Software Failure AND Extreme Weather Conditions at the same time? Please give your answer with the precision of 3 decimal places.

1 / 1 point

Please use the probabilistic fault tree from the previous question for your computation:



0.001

Correct

Correct! The operations used to propagate the probabilities on probabilistic fault trees upwards are the same as the rules of probability when events follow set theory. So, the AND probabilities would be the product of children node probabilities, assuming independence of the events

12. A computer vision algorithm is responsible for extracting meaningful data from the onboard camera. A computer vision failure restricts the vehicle's ability to navigate the environment around it, hence a problem with this system is a serious failure. However, LiDAR and radar sense similar environment data, so a computer vision failure does not leave the vehicle completely blind. A Computer vision algorithm failure can be considered a somewhat severe failure as it decreases vehicle sensing ability and it gets a severity score of 5. This could happen regularly in low light situations, hence the occurrence number is assigned 4. Computer vision algorithm failure is fairly detectable in majority of the situations, so the detectability score is 3.

1 / 1 point

What is the risk priority number for a Computer vision algorithm failure according to FMEA and based on the description above? Your answer should be an integer.

60

Correct

Correct! The risk priority number is a product of the severity, frequency and detectability of an event. Each feature of the risk priority number is assessed on the scale from 1 to 10, where 10 is being the most severe, the most frequent and the most difficult to detect.

13. There are failures listed below. Which failures should we focus on **solving first** according to FMEA?

1 / 1 point

- ○ Vehicle motion prediction failure (risk priority score of 150)
- ○ Computer vision algorithm failure (risk priority score of 60)
- ○ GPS synchronization failure (risk priority score of 300)
- ◉ Vehicle driving onto a gravel road (risk priority score of 400)

Correct
Correct! The higher the risk priority score is, the higher priority of this failure is.

14. Which of the following options is the most **ACCURATE** and **COMPLETE** definition of **functional safety** in terms of self-driving vehicles?

1 / 1 point

- ○ Functional safety is the process of avoiding unreasonable risk of harm to a living thing.
- ◉ Functional safety is the detection of a potentially dangerous condition resulting in the activation of a protective or corrective device or mechanism to prevent hazardous events arising or providing mitigation to reduce the consequence of the hazardous event
- ○ Functional safety is a deterministic algorithm outlining the procedures that are carried out to prevent hazardous events from happening or minimizing the harm caused by hazardous events to the vehicle passengers and third parties involved in the situation
- ○ Functional safety is a part of the vehicle operation management aimed to minimizing hazards, risks, accidents and near misses
- ○ None of the above

Correct
Correct!

15. Which of the following standards defines **functional safety terms** and **activities for electrical and electronic systems** within motor vehicles?

1 / 1 point

- ○ ISO/TC 204
- ○ ISO 39001
- ○ ISO/PAS 21448
- ◉ ISO 26262
- ○ None of the above

Correct
Correct! The ISO 26262 standard defines functional safety terms and activities for electrical and electronic systems within motor vehicles, and as such addresses the hardware and software hazards that can affect autonomous vehicle safety.

Week 4

All assignments are in this github repository: https://github.com/adeirman46/Self-Driving-Car

Module 4 Programming Exercise: Kinematic Bicycle Model

```
class Bicycle(Bicycle):
    def step(self, v, w):
        # ==================================
        #  Implement kinematic model here
        # ==================================
        xc_dot = v * np.cos(self.theta + self.beta)

        yc_dot = v * np.sin(self.theta + self.beta)

        theta_dot = (v * np.cos(self.beta) * np.tan(self.delta))/self.L

        if w > self.w_max:
            delta_dot = self.w_max
        else:
            delta_dot = w

        self.beta = np.arctan((self.lr * np.tan(self.delta))/self.L)

        self.xc = xc_dot * self.sample_time + self.xc
        self.yc = yc_dot * self.sample_time + self.yc
        self.theta = theta_dot * self.sample_time + self.theta
        self.delta = delta_dot * self.sample_time + self.delta

        pass
```

```
sample_time = 0.01
time_end = 30
model.reset()

t_data = np.arange(0,time_end,sample_time)
x_data = np.zeros_like(t_data)
y_data = np.zeros_like(t_data)
v_data = np.zeros_like(t_data)
w_data = np.zeros_like(t_data)

R = 8
delta = np.arctan(2/8) * 0.995
v_data[:] = 2 * np.pi * R * 2 / 30

for i in range(t_data.shape[0]):
    x_data[i] = model.xc
    y_data[i] = model.yc
```

```
    if i <= t_data.shape[0]/8:
        if model.delta < delta:
            model.step(v_data[i], model.w_max)
            w_data[i] = model.w_max
        else:
            model.step(v_data[i], 0)

    elif i <= 5.08*t_data.shape[0]/8:
        if model.delta > -delta:
            model.step(v_data[i], -model.w_max)
            w_data[i] = -model.w_max
        else:
            model.step(v_data[i], 0)
    else:
        if model.delta < delta:
            model.step(v_data[i], model.w_max)
            w_data[i] = model.w_max
        else:
            model.step(v_data[i], 0)

plt.axis('equal')
plt.plot(x_data, y_data)
plt.show()
```

Module 4 Programming Exercise: Longitudinal Vehicle Model

```
class Vehicle(Vehicle):
    def step(self, throttle, alpha):

        # Engine torque
        Te = throttle * (self.a_0 + self.a_1 * self.w_e + self.a_2 * self.w_e**2)

        # F load
        Faero = self.c_a * self.v**2
        Fg = self.m * self.g * np.sin(alpha)
        Rx = self.c_r1 * self.v
        Fload = Faero + Fg + Rx

        # Wheel angular speed
        w_w = self.GR * self.w_e
        s = ((w_w * self.r_e) - self.v)/self.v
        if abs(s) < 1:
            Fx = self.c * s
        else:
            Fx = self.F_max

        # w_e dot
        self.w_e_dot = (Te - self.GR*self.r_e*Fload)/self.J_e

        # acceleration
```

```
        self.a = (Fx - Fload)/self.m

        # get pos and vel
        self.v += self.a * self.sample_time
        self.x += self.v * self.sample_time - 1/2*self.a*self.sample_time**2

        # get w_e
        self.w_e += self.w_e_dot * self.sample_time

        pass
```

```
time_end = 20
t_data = np.arange(0,time_end,sample_time)
x_data = np.zeros_like(t_data)

# reset the states
model.reset()

# incline angle (in radians)
alpha_1 = np.arctan(3/60)
alpha_2 = np.arctan(9/90)

for i in range(t_data.shape[0]):
    if i <= t_data.shape[0]/4:
        v_data[i] = model.v
        model.step(0.2 + 0.3/5*t_data[i], alpha_1)
        x_data[i] = model.x
    elif i <= t_data.shape[0]*3/4:
        v_data[i] = model.v
        model.step(0.5, alpha_2)
        x_data[i] = model.x
    else:
        v_data[i] = model.v
        model.step(2 - 0.1*t_data[i], 0)
        x_data[i] = model.x

# Plot x vs t for visualization
plt.plot(t_data, x_data)
plt.show()
```

Week 5

Module 5 : Graded Quiz

1. What is the **order** of the following transfer function? **1 / 1 point**

$$G(s) = \frac{s - 10}{s^2 + 2s + 1}$$

- ○ This is the first order transfer function
- ◉ This is the second order transfer function
- ○ This is the third order transfer function
- ○ This is the fifth order transfer function
- ○ None of the above

Correct
Correct! This transfer function contains a first order numerator and a second order denominator. The order of the function is the highest exponent in the transfer function, so that this is the second order transfer function.

2. What are the **poles and zeros** of the following transfer function? **1 / 1 point**

$$G(s) = \frac{s^2 + 3s - 10}{s^2 - s - 12}$$

- ◉ The poles are -3 and 4; the zeros are 2 and -5
- ○ The poles are -4 and 3; the zeros are 5 and -2
- ○ The poles are 2 and -5; the zeros are -3 and 4
- ○ The poles are 5 and -2; the zeros are -4 and 3
- ○ None of the above

Correct
Correct! The zeros of a system are the roots of the numerator, and the poles of a system are the roots of its denominator.

3. What might be your action as a system control engineer if you need to **increase the overshoot** of a control loop system? (Select all that apply)

1 / 1 point

- [ ] Decrease K_P
- [x] Decrease K_D

Correct
Correct! Decreasing derivative gain leads to an increase of overshoot.

- [x] Increase K_I

Correct
Correct! Increasing integral gain leads to an increase of the overshoot.

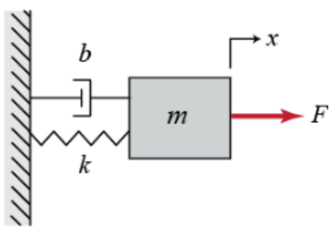
- [ ] Decrease K_I
- [x] Increase K_P

Correct
Correct! Increasing proportional gain leads to an increase of the overshoot.

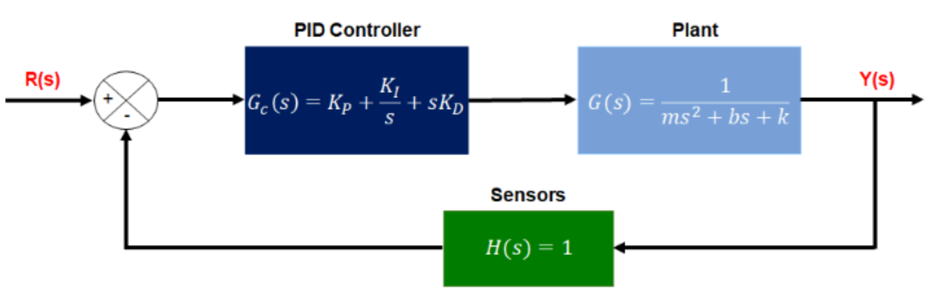
- [ ] Increase K_D

4. Recall the Mass-Spring-Damper System example form the video on PID Control. This system is shown in the figure below.

1 / 1 point



As a system control engineer, you constructed the following closed loop transfer function to represent the Mass-Spring-Damper System. What is the **correct transfer function** for this closed loop?



○ Transformation function 1

$$G(s) = \frac{K_D s^2 + sK_P + K_I}{K_P + \frac{K_I}{s} + K_D s}$$

○ Transformation function 2

$$G(s) = \frac{K_P + \frac{K_I}{s} + K_D s}{K_D s^2 + sK_P + K_I}$$

○ Transformation function 3

$$G(s) = \frac{ms^2 + bs + k + K_P + \frac{K_I}{s} + K_D s}{K_P + \frac{K_I}{s} + K_D s}$$

◉ Transformation function 4

$$G(s) = \frac{K_D s^2 + sK_P + K_I}{ms^3 + (b + K_D)s^2 + (k + K_P)s + K_I}$$

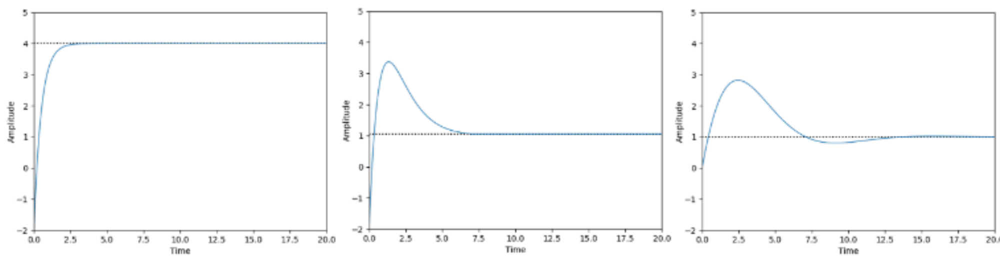
○ None of the above

Correct

Correct!

5. You are given the step response of a few different PID controllers using the same gains for the same first order transfer function. **Determine a possible set of controllers** that generated these step responses:

1 / 1 point



- ○ 1st response by PI; 2nd response by PD; 3rd response by PID
- ○ 1st response by PD; 2nd response by PI; 3rd response by PID
- ○ 1st response by PI; 2nd response by PID; 3rd response by PD
- ◉ 1st response by PD; 2nd response by PID; 3rd response by PI
- ○ None of the above

Correct

Correct! Adding derivative control improves the step response in terms of overshoot and settling time, but slows down the rise time. Adding the integral term instead maintains a short rise time, and is able to reduce oscillation and overshoot, leading to a fast settling time as well. Adding both derivative and integral control terms brings the advantages of both these approaches.

6. What is the output of a typical output of a Longitudinal control module? (Select all that apply)

1 / 1 point

- [ ] Reference velocity
- [x] Throttle angle

Correct

Correct! A longitudinal control module takes a reference velocity as an input and outputs throttle angle and brake pedal position.

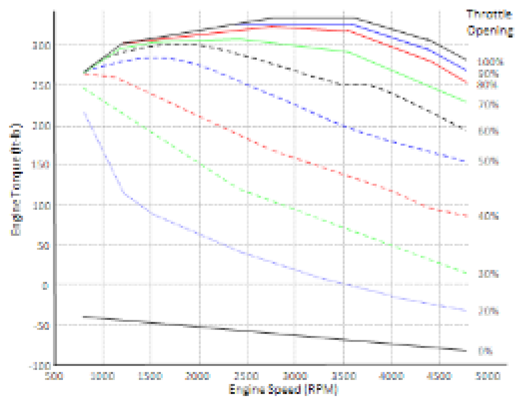
- [ ] Steering angle
- [x] Brake position

Correct

Correct! A longitudinal control module takes reverence velocity as an input and outputs throttle angle and brake pedal position.

7. Based on the engine map in the figure below, **determine the throttle angle** needed to produce 250 ft-lb of torque given that the current engine speed is 3500 RPM.

1 / 1 point

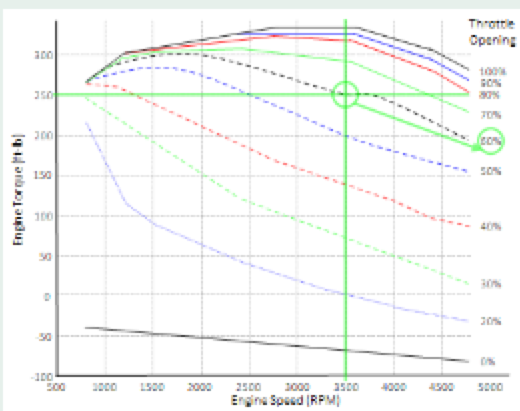


If you need help formatting math functions, [read this article](#).

0.6

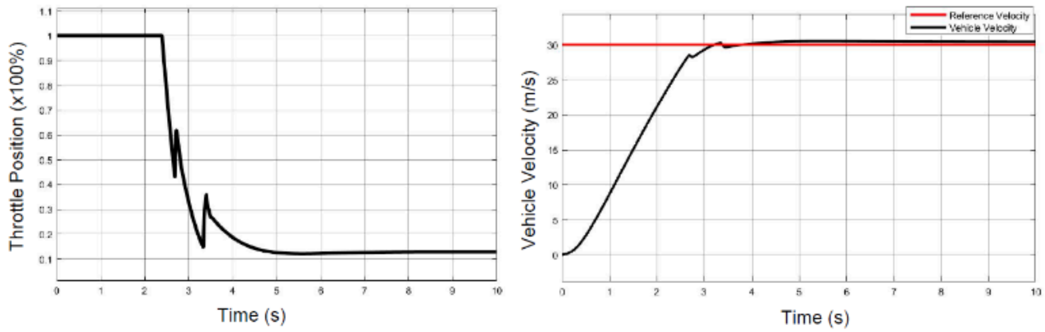
Correct

Correct!



8. The results of a simulation of the control response to a step change in desired speed of a dynamic vehicle model with a PID controller are shown in the figures below. There are two spikes on these figures: one spike is between 2 and 3 seconds, another spike is between 3 and 4 seconds. **What is the reason of these spikes?**

1 / 1 point



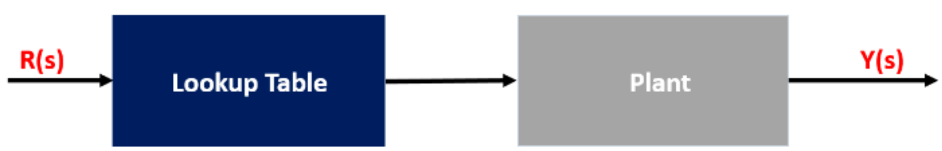
- ○ Engine-transmission torque loss
- ○ Tire slip
- ◉ Nonlinear engine map
- ○ High level controller simplification: changing the integral to a summation over fixed length time steps in the Integral term
- ○ None of the above

Correct

Correct! These artefacts are caused by the engine map nonlinearities.

9. What type of **control system** is shown in the figure below?

1 / 1 point



- ○ Feedback control
- ◉ Feedforward control
- ○ Feedback-feedforward control
- ○ None of the above

Correct

Correct! This diagram represents a feedforward controller. It show an open loop structure, where the reference signal is directly fed into the feedforward controller, which generates the inputs to the plant.

10. What types of inaccuracies are corrected by a feedback controller?

1 / 1 point

- [x] Disturbances

Correct
Correct! The feedback controller corrects for errors that result from disturbances.

- [ ] Nonlinear engine map
- [x] Errors in the plant model

Correct
Correct! The feedback controller corrects for errors that result from inaccuracies in the plant model.

- [ ] High level controller simplification: changing the integral to a summation over fixed length time steps in the Integral term

11. What assumptions are essential for creation of a **longitudinal feedforward input**? (Select all that apply)

1 / 1 point

- [ ] The tire slip angle and ratio are negligible
- [x] The vehicle is at steady state

Correct
Correct! Modelling feedforward block requires converting the entire longitudinal dynamics model into a fixed lookup table or reference map, that maps the reference velocity to the corresponding actuator signals assuming the vehicle is at steady state.

- [ ] The plant system is linear
- [ ] Torque from the engine passes directly to the transmission without loss

12. What are the sources of the load torque considered for a **longitudinal feedforward look-up table computation**? (Select all that apply)

1 / 1 point

- [ ] Static friction
- [ ] Cornering force
- [x] Rolling resistance

Correct
Correct! Rolling resistance is a force acting opposite to the relative motion, so that it is a part of the load torque acting on the vehicle.

- [x] Aerodynamic resistance

Correct
Correct! Aerodynamic resistance is a force acting opposite to the relative motion, so that it is a part of the load torque acting on the vehicle.

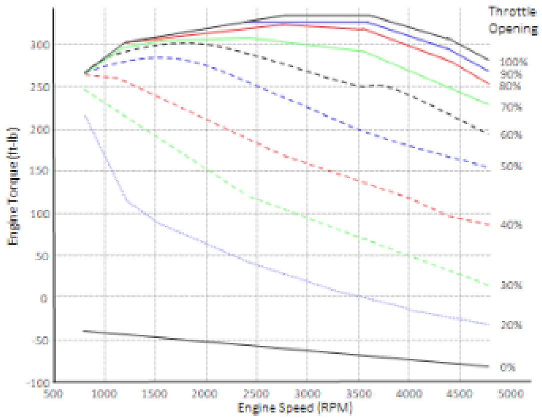
- [ ] Sliding resistance
- [x] Gravitational resistance

Correct
Correct! Gravitational resistance is a force acting opposite to the relative motion, so that it is a part of the load torque acting on the vehicle.

13. A vehicle is being operated on a highway with the reference velocity of 126 km/h (35 m/s) in gear 4 and it overcomes the total load torque of 300 ft-lb. This vehicle specification includes effective wheel radius of 0.35 m and 4th gear ratio of 2. **What throttle angle** is required for maintaining the the current speed of the vehicle?

1 / 1 point

Please use the below engine map for your computation.



If you need help formatting math functions, read this article.

0.7

Correct

Correct!

$$\omega_w = \frac{V_ref}{r_eff} = \frac{35[m/s]}{0.35[m]} = 100[1/s] = 100[hertz]$$

$$\omega_e = \frac{\omega_w}{GR} = \frac{100[hertz]}{2} = 50[hertz]$$

$$\omega_e = 50[1/s] \cdot 60[s/min] = 3000RPM$$

An intersection of $\omega_e = 3000[RPM]$ and $T_{engine} = 300$[ft-lb] falls on the green line on the chart, where the green line defines the throttle angle of 70%.

Week 6

Module 6 : Graded Quiz

1. Which reference path is the **most compact** and **easy to construct**?

1 / 1 point

- (selected) Track straight line segment
- Track waypoints
- Track parameterized curves
- None of the above

Correct

Correct! The easiest approach is to define a sequence of straight line segments, by requiring a sequence of endpoint vertices that are connected linearly. This path definition can be very compact and easy to construct, assuming points are well spaced and the environment allows for mostly straight line motion.

2. What is the most **ACCURATE** and **PRECISE** definition of the crosstrack error?

1 / 1 point

- The crosstrack error is the difference between path heading and the vehicle heading at a reference point along the path
- (selected) The crosstrack error is the distance between the vehicle reference point and the closest point on the reference path
- The crosstrack error is the sum of the absolute difference between each coordinate of the vehicle reference point and the corresponding closest point on the desired path
- None of the above

Correct

Correct! It is the principle measure of how close the vehicle's position is to the desired position along the path.

3. What vehicle reference frame is used in a **pure pursuit controller**?

1 / 1 point

- ○ Center of gravity
- ○ Center of the front axle
- ◉ Center of the rear axle
- ○ None of the above

Correct

Correct! In this method, the centre of the rear axle is used as the vehicle reference frame. Also, recall that we define the line that connects the centre of the rear axle to the target reference point as the lookahead distance.

4. **Compute the radius** from the instantaneous center of rotation to the center of the vehicle rear axle (in m) required for an autonomous vehicle to follow the desired path based on the information below.

1 / 1 point

The lookahead distance is 10 m; the car length is 4 m; the angle between the vehicle's body heading and the lookahead line is 30°. Your answer should be an integer.

10

Correct

Correct!

$$R = \frac{l_d}{2sin\alpha} = \frac{10}{2sin30^\circ} = \frac{10}{2 \cdot 1/2} = 10$$

5. **Compute the steering angle (in degrees)** required for an autonomous vehicle with pure pursuit lateral control for following the desired path based on the information below.

1 / 1 point

The lookahead distance is 15 m; the car length is 5 m; the angle between the vehicle's body heading and the lookahead line is 60°.

If you need help formatting math functions, read this article.

30

Correct

Correct!

$$\delta = arctan(\frac{2Lsin\alpha}{l_d}) = arctan(\frac{2 \cdot 5 \cdot sin60^\circ}{15}) = arctan(\frac{2 \cdot \sqrt{3}/2}{3}) = arctan(\frac{1}{\sqrt{3}}) = 30^\circ$$

6. Consider a situation in which a vehicle traveling speed has decreased from 100 km/h to 50 km/h. This vehicle lateral control is implemented with a pure pursuit controller where l_d is assigned as a function of vehicle speed. **How should l_d change in this situation?**

1 / 1 point

- ○ l_d should increase
- ◉ l_d should decrease
- ○ l_d should stay the same
- ○ l_d can increase or decrease depending on how the controller is tuned
- ○ None of the above

Correct

Correct! The pursuit controller with a fixed value of ld does not take into account the vehicle speed. This means that the selected steering angle would be the same regardless of whether the vehicle is going 10 km/h or 100 km/h, leading to very different lateral accelerations. A controller tuned for high speed would be far to sluggish at low speed, and one tuned for low speed would be dangerously aggressive at high speed. To overcome this limitation, we define the lookahead distance to increase proportional to vehicle forward speed.

7. What are **major components** of the Stanley controller? (Select all that apply)

1 / 1 point

- [x] Proportional control is introduced for minimizing the crosstrack error

Correct
Correct! This is a major component of the Stanley controller that differs it from the pure pursuit controller.

- [x] Steering angle is set equal to the heading direction to eliminate heading error relative to the path

Correct
Correct! This is a major component of the Stanley controller that differs it from the pure pursuit controller.

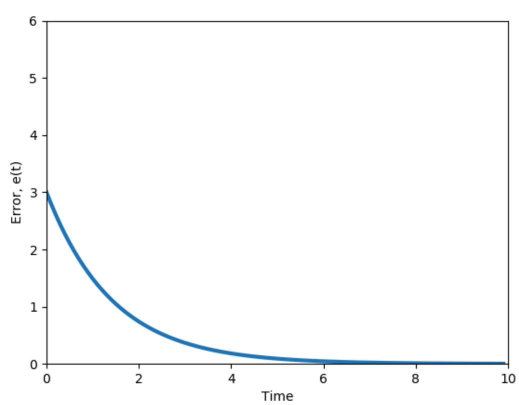
- [ ] Derivative control is introduced for minimizing the heading error
- [ ] Crosstrack error is eliminated
- [ ] Integral control is added for both the heading and the crosstrack errors optimization
- [x] Steering angle command is restricted to the min and max steering angles

Correct
Correct! This is a major component of the Stanley controller that differs it from the pure pursuit controller.

8. **What is the correct figure** of the crosstrack error dynamics for a small error value(where $e'(t) = -ke(t)$)?

1 / 1 point

(•) Figure 3:



Correct
Correct! Solving the differential equation of the crosstrack error dynamic results in the following function $e(t) = e(0)e^{-kt}$ and this function is plotted above

9. **What is the value of the crosstrack error**, governed by the ODE $e'(t) = -ke(t)$, at $t = 2$ given that $e(0) = 4$ and $k = 1$?

Please give your answer with the precision of 2 decimal places.

0.54

Correct

Correct! Solving the differential equation of the crosstrack error results in the following function:

$$e(t) = e^{-kt} \cdot e(0)$$

Next, using the given values we get:

$$e(2) = e^{-2} \cdot 4 = 0.54$$

10. Which of the statements below about Model Predictive Control (MPC) are **TRUE**? (Select all that apply)

0.25 / 1 point

- [x] MPC works for both linear and nonlinear models

Correct

Correct! The controller can be explicitly applied to the linear or nonlinear models of the vehicle and its subsystems, meaning that we can use the same approach even as our models change or improve over time.

- [x] MPC is an optimized version of Receding Horizon Control

This should not be selected

Incorrect, please review Lesson 4: Advanced Steering Control Methods.

- [ ] The formulation of an MPC controller is straightforward
- [ ] MPC can impose constraints on the states and the input simultaneously

11. What is the typical way of finding the solution for a **nonlinear vehicle dynamics model** given an input function?

1 / 1 point

- ○ Laplace transform
- ◉ Numerical optimization
- ○ Using existing closed form solution
- ○ None of the above

Correct

Correct! No closed form solution exists for a nonlinear dynamic model, and so we rely on numerical optimization to find a solution.

12. What is the output of the **Model Predictive Controller** described in this course? (Select all that apply)

1 / 1 point

- [ ] Throttling/braking
- [ ] Steering angle
- [x] Longitudinal forces

Correct

Correct! The Model Predictive Control takes the reference path, velocity and the vehicle states at each time step as an input and outputs the longitudinal force needed to follow the desired trajectory.

- [x] Lateral forces

Correct

Correct! The Model Predictive Control takes the reference path, velocity and the vehicle states at each time step as an input and outputs the lateral force needed to follow the desired trajectory.

- [ ] None of the above

Week 7

Module 7 : Carla - How to Run

1. **Loading the Simulator with the Race Track Map**

```
\> CarlaUE4.exe [ /Game/Maps/<map_name> ] [ <args> ]
```

```
\> C:
\> cd \Coursera\CarlaSimulator
\> CarlaUE4.exe /Game/Maps/RaceTrack -windowed -carla-no-networking
```

2. **Loading the Simulator with a Fixed Time-Step (20 fps)**

```
\> C:
\> cd \Coursera\CarlaSimulator
\> CarlaUE4.exe /Game/Maps/RaceTrack -windowed -carla-no-networking
-benchmark -fps=20
```

3. **Testing CARLA in Server-Client Mode**

```
\> C:
\> cd \Coursera\CarlaSimulator
\> CarlaUE4.exe /Game/Maps/RaceTrack -windowed -carla-server
-carla-world-port=2003
```

```
\> C:
\> cd \Coursera\CarlaSimulator\PythonClient
\> python manual_control.py --port=2003
```

4. **Longitudinal Control**

```
kp = 2.0
ki = 0.4
kd = 0.1
```

```
# compute error
error = v_desired - v
dt = t - self.vars.t_previous
integral_error = self.vars.integral_error_previous + error * dt
derivative_error = (error - self.vars.error_previous) / dt

# compute PID
a_desired = kp * error + ki * integral_error + kd * derivative_error

throttle_output = 0
brake_output    = 0

if a_desired > 0:
    #relationship between acceleration and throttle follows tanh characteristics
    throttle_output = np.tanh(a_desired)
else:
    throttle_output = 0
```

5. **Lateral Control**

```
# Change the steer output with the lateral controller.
steer_output    = 0

# stanley controller
k_e = 0.1

# yaw path
yaw_path = np.arctan2(waypoints[-1][1] - waypoints[0][1], waypoints[-1][0] -
waypoints[0][0])

# heading error
yaw_diff_heading = yaw_path - yaw
# if heading error greater than 180 degrees, then turn the other way
if yaw_diff_heading > np.pi:
    yaw_diff_heading -= 2 * np.pi
if yaw_diff_heading < -np.pi:
    yaw_diff_heading += 2 * np.pi

# cross track error
current_xy = np.array([x, y])
crosstrack_error = np.min(np.sum((current_xy - np.array(waypoints)[:, :2])**2, axis=1))
yaw_cross_track = np.arctan2(y-waypoints[0][1], x-waypoints[0][0])
yaw_path_to_crosstrack = yaw_path - yaw_cross_track
# if yaw_path_to_crosstrack greater than 180 degrees, then turn the other way
if yaw_path_to_crosstrack > np.pi:
    yaw_path_to_crosstrack -= 2 * np.pi
```

```
if yaw_path_to_crosstrack < -np.pi:
    yaw_path_to_crosstrack += 2 * np.pi
# sign of crosstrack error
 if yaw_path_to_crosstrack > 0:
    crosstrack_error = abs(crosstrack_error)
else:
    crosstrack_error = -abs(crosstrack_error)
# yaw cross track
yaw_cross_track = np.arctan(k_e * crosstrack_error / v)

# steering angle
steer_angle = yaw_diff_heading + yaw_cross_track
# if steering angle greater than 180 degrees, then turn the other way
if steer_angle > np.pi:
    steer_angle -= 2 * np.pi
if steer_angle < -np.pi:
    steer_angle += 2 * np.pi
steer_output = np.clip(steer_angle, -1.22, 1.22)
```

6. Grading

```
python grade_c1m7.py racetrack_waypoints.txt trajectory.txt
```