Shreyas Prabhakar
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AUE 8930: AUTONOMOUS DRIVING TECHNOLOGIES

HOMEWORK 1

Problem 1

(1) Briefly explain the six levels of vehicle autonomy in SAE standard?
The Society of Automotive Engineers (SAE) has categorized vehicles to 6 different levels (level 0 to level 5) based on the level of automation –

1. Level 0 – No automation. Human driver controls the vehicle. There is no automation at this level.
2. Level 1 – Driver assistance. Human driver has the main control of the vehicle, the human can disengage either the hands(steering) or feet (acceleration and braking) but never both. The driver needs to be aware of what is happening at all times and be ready to step in when needed.
3. Level 2 – Partial automation. The human driver can disengage both his hands and feet. The vehicle will take care of acceleration, braking and steering by using information about the driving environment. Human needs to monitor the surroundings. Examples for this level are cruise control and lane-keeping.
4. Level 3 – Conditional automation. Vehicle takes care of steering, accelerating and breaking, along with monitoring of the surrounding environment. The human driver is required to intervene only for safety critical functions.
5. Level 4 – High automation. This is a fully autonomous vehicle. But, the vehicle is limited to Operational Design Domain(ODD), meaning, the vehicle does not cover all possible scenarios.
6. Level 5 – Full automation. This is true autonomous vehicle, in the sense, its performance is expected to be equal to or better than that of human drivers.

(2) Search four autonomous vehicles made by different companies, assess their autonomous levels, and justify your assessments.

1. Volvo XC60 – Level 3. Manages braking, steering and acceleration at speeds up to 80 mph on well-marked roads. Steering support to help avoid collisions. (i.e., it monitors surroundings)
2. BMW Series 5 2018 –Remote control parking system that parks the vehicle without a driver in the car. It is fully autonomous in a particular domain i.e., parking. This makes it level 4 because it completely removes human from the operation but restricted to a particular operational domain.
3. Audi A8 2019 –Audi claims that the driver will be able to take his hands off the steering for extended periods and asks for the user to take over under certain condition which makes it Level 3. It will be equipped with auto-pilot parking
4. Tesla Model S and Model X – Level 2. It can manage steering, braking and acceleration on freeways. Including tasks like centre itself within the lanes, change lanes when asked.

Problem 2

(1) List five advantages of autonomous vehicles and explain the reason(s) for each.

1. There will be fewer traffic collisions.
2. Increased road capacity and reduced traffic congestion.
3. Increased fuel efficiency and increased productivity.
4. Reduction of space required for parking.
5. Reduction in the need for traffic police and vehicle insurance.

(2) List five challenges for autonomous vehicles and explain the reason(s) for each.

1. Software reliability and cyber security.
2. Implementation of legal framework and establishment of government regulations for self-driving cars.
3. Loss of driver-related jobs.
4. Reliance on autonomous drive produces less/no experienced drivers when actual manual driving is required.
5. Human trust and acceptance.

Problem 3

(1) List five sensors in autonomous vehicles and explain what autonomous driving functions they can be applied to.

1. Ultrasonic sensors – It is used mainly for parking-assistance and when backing-up the vehicle.
2. Radars – They have longer range than ultrasonic sensors. They can be used for adaptive cruise control where the speed needs to be adjusted based on the speed of the vehicle in the front. It can also be used for lane-change assistance and blind spot detection.
3. Cameras – Cameras are used for various tasks like sign/pedestrian detection, collision avoidance, lane keeping/ departure warnings etc., where the camera continuously records the scene and the objects in the scene are interpreted using computer vision.
4. Speed sensors – They are used mainly to determine the speed of the vehicle. It may be used in speed governors and cruise control.
5. GPS – The GPS systems give the exact location of the vehicle. It can be used for navigation of the vehicle.

(2) Describe the principles of three types distance sensors (ultrasonic, radar, and lidar). List the advantages and disadvantages of each.

All the three distance sensors pretty much work on the same principle, where the transmitted emits the signal, the signal bounces off the object of interest and is received back by the sensor receiver. The delay between transmission and reception is used to calculate the distance.
The ultrasonic sensors work with ultrasound, the radars transmit and receive radio waves, and the lidars works by transmitting a pulse of laser light.

The ultrasonic sensors have very short range, low resolution, but is robust to noise.
Lidar can be used for long distances, has high resolution, but is very sensitive to noise by small particles in the air like rain, smoke, fog etc.
Radars can be used for long/very long distances, they are robust to noise, but have low resolution.

Problem 4 (30 pts)

(1) How does a radar detect distance and speed respectively?

The radars work in Radio frequency range. They work by transmitting radio wave and waiting for the reflected signal. The delay or frequency associated with the reflected signal can be correlated to the distance and speed of the reflecting object (the object of interest).

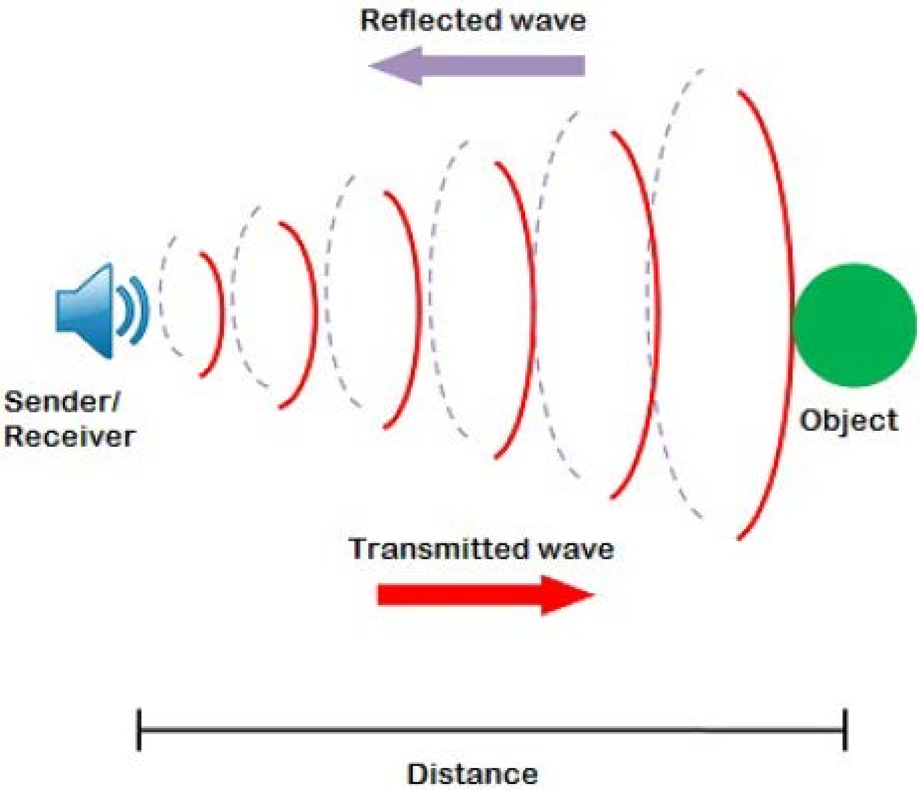
Distance detection –

The distance detection of radars works based on the total time required for the transmitted radio wave to be received back by the sensors after bouncing back from the object.

The distance is calculated using –

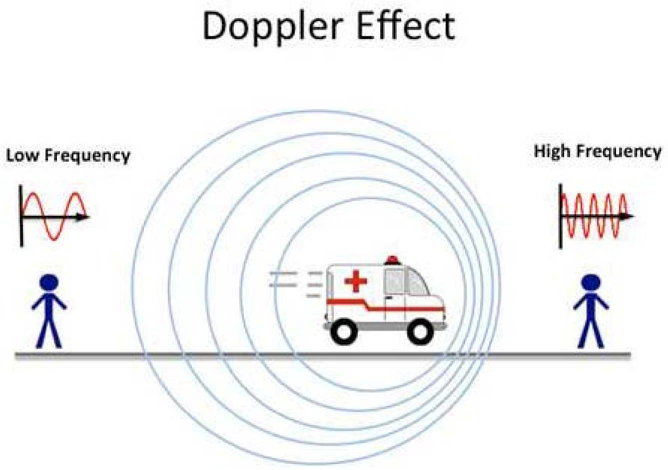
$$distance, D = round\ travel\ time * speed\ of\ radio\ wave/2$$

where, $speed\ of\ Radio\ Wave\ \approx 3 * 10^8\ m/s$



Speed Detection –

Speed Detection in Radar Sensors work on the principle of Doppler Effect. The Doppler Effect is the change in frequency or wavelength of the wave for an observer moving relative to the source. The vehicle approaching the observer has higher frequency and the vehicle receding has lower frequency than the transmitted frequency.



The relationship between the observed frequency f and emitted frequency f^0 is given by

$$f = (\frac{c + v_r}{c + v_s})f_0$$

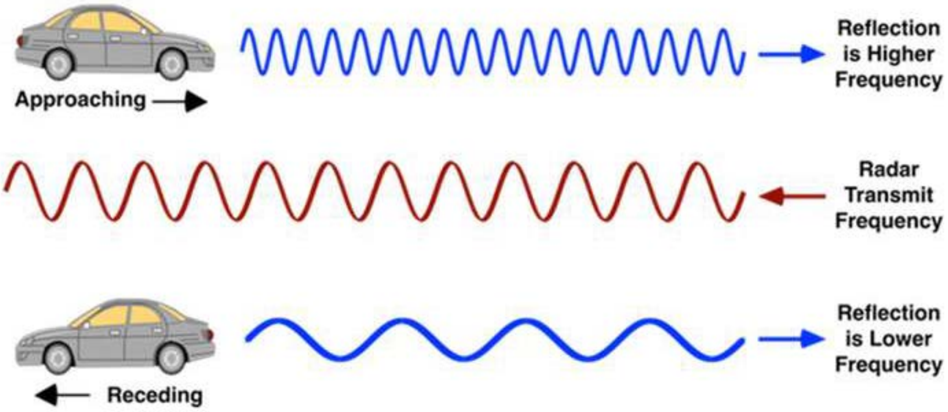
where c – velocity of waves in the medium ($3*10^8$ m/s)

v_r – velocity of receiver relative to medium. Positive if receiver is moving towards the source

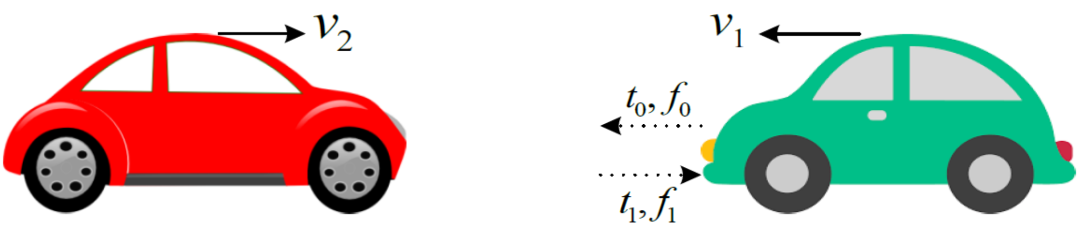
v_s – velocity of source relative to medium. Positive if source is moving away from the receiver.

If the speeds, v_r and v_s, are small compared to the speed of the wave c, the relationship between the observed frequency f and emitted frequency f0 can be approximated by

$$\Delta f = \frac{\Delta v}{c} f_0$$



(2) Two cars (a green car and a red car shown in the figure below) are driving in the opposite way with constant speeds v_1 and v_2. The green car can measure its speed v_1 using an onboard speed sensor. The green car emits a radar signal with a frequency f_0 at time t_0 and receives the reflected signal with a frequency f_1 at time t_1. Please answer the two questions with your derivation processes:



a. What is the speed of the red car v_2?
b. What is the distance between the two cars at time t_1?

Given –
Speed of green car = v_1
Emitted frequency = f_0
Emission time = t_0
Observed frequency = f_1
Reception time = t_1
Speed of radio wave = $c \approx 3*10^8$ m/s

To Calculate –

a. Speed of Red car v_2 –
The equation of doppler effect is given by

$$f_1 = (\frac{c + v_2}{c + v_1})f_0$$

Solving for v_2,

$$\frac{f_1}{f_0} = 1 + \frac{v_2 - v_1}{c}$$

$$\frac{f_1 - f_0}{f_0} = \frac{v_2 - v_1}{c}$$

$$\boldsymbol{v_2 = v_1 + \frac{f_1 - f_0}{f_0}} \quad \textbf{m/s}$$

b. Distance between the two cars at time t_1 –

$$d = round\ travel\ time * speed\ of\ radio\ wave/2$$

$$\boldsymbol{d = (t1 - t2) * c/2} \quad \textbf{m}$$