### Question 1.1

**Your company decided to use ROS for the development of a commercial self-driving vehicle. One of your colleagues had some questions. Answer the questions and explain your answer.**

#### Question 1:

If we communicate our sensor messages with ROS 1 publish subscribe, how is it guaranteed that our messages reach their goal?

*Answer: The reliability is achieved with the TCP protocol behind ROS if both the publisher and the subscriber are initialized properly (i.e. publish and subscribe to the same topic).*

*Assuming that the publisher was initialized before the subscriber and connection didn’t drop.*

#### Concern 2:

Considering open source frameworks, name and explain one upside and one downside of using open source frameworks for autonomous vehicle development.

*Answer:*

* *Upside: saves time, a lot of ready packages that enable rapid prototyping*
* *Downside: debugging required, our goal is to make a vehicle that's safe and not cause accidents. [I think debugging is a part of software engineering and not a downside to FOSS]. I would rather suggest things like it’s ever evolving nature, anyone can contribute to its change, limited support and software is not tested or validated to any particular standard*
  + *(But since anyone can contribute to its change it could be possible some bug might be introduce in framework which could be dangerous when using it directly in your autonomous vehicle.)*
  + *Open source system is probably not specialised to our specific use case.*
  + *Open source software might be unsuitable for mass production (license issues and/or different middlewares provided by the Tier 1 manufacturers.)*

### Question 1.2

**Your management decided that they want to buy a new development vehicle for their autonomous driving efforts. They are selecting the sensors to buy. You are supposed to answer the following sensor related questions.**

*Answer:*

* *Group a) camera, radar, LiDAR, ultrasonic sensors*
* *Group b) IMU, battery charge state sensor, steering angle sensor, turn indicators (any sensors connected to CAN bus should be correct)*
* *Group a definition: Exteroceptive*
* *Group b definition: Interoceptive*

***1.3. Your Robinos compliant overtaking behavior module that allows you to overtake a vehicle on a multi-lane highway road, faces the following situation properties. Which four behavior relevant parameters are affected and how? Choose a different parameter for each scenario property, express your answer numerically, explain your reasoning.***

*The overtaking lane is very bumpy and causes loud driving noises:*

*Affected robinos parameter: Comfort*

*How is it affected: It would consider not going into the overtaking lane for the comfort of the passengers. (e.g. it would set the comfort scalar to a lower amount of percent (e.g. 30%))*

*The vehicle ahead of you drives faster than your selected preferred travel velocity:*

*Affected robinos parameter: Desire*

*How is it affected: The space in front of the vehicle is cleared, thus it would have 100% desire to maintain the selected preferred travel velocity and stay in the lane.*

*Your sensors are malfunctioning:*

*Affected robinos parameter: Risk*

*How is it affected: A malfunctioning sensor may give false negative object detection (or road boundary, free zone, traffic light) results and cause collisions. (e.g. if the sensor is in charge of detecting the left lane, might set the risk to 100% as it cannot really distinguish if vehicles are approaching)*

*The overtaking lane is blocked:*

*Affected parameter: Applicability*

*How is it affected: It cannot overtake any car as the overtaking lane is blocked, thus the passing anyone is impossible to apply, applicability would be 0%.*

***Question 1.4.***

***You are supposed to design a sensor-set for a self-driving car. You are told that the self-driving function will only be used for city driving in Germany. How does this restriction to city driving change the requirements for your sensor-set design, as opposed to highway driving? List 4 specific properties of this scenario and how they impact the sensor-set design.***

*Answer:*

*(Short range sensor will be required as opposed to long range used on highways)*

*1: Limited Speed: it may not be necessary to have the sensor which has a very high detection range to detect other vehicles at super early time.*

*2: Has intersection: the sensors should have a wide field of view (e.g. rotation 3D LiDAR) which covers the crossing width of the intersection.*

*3: Has parking scenarios: Needs sensors that are precise at low distances, such as FMCW radars and bird-eye-view cameras.*

*4: Traffic lights/signs (RGB cameras are required to detect them) Color detection of the lights with a camera is necessary to determine if the vehicle should pass (green light), ready to stop (yellow light), and stop (red light).*

*5: Multiple object detection (Pedestrians, traffic lights, etc): Better quality on object recognition and faster reaction as pedestrians can cross in front of the car suddenly.*

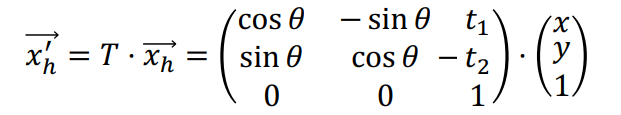
***Question 2.1***

***Your student implemented the following approaches and models for your autonomous vehicle simulation. Assess the correctness of the following and predict the outcome if this is applied in your simulation to fulfill the described purpose. Explain your answer.***

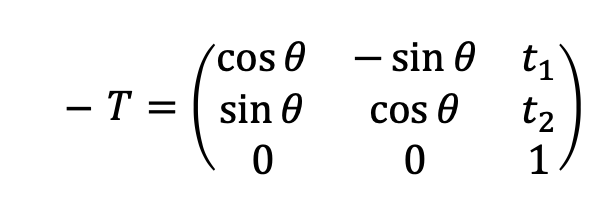
***Arithmetic mean is used to average vehicle pose angles***

*Not valid, refer to example in Lecture 5 slide 36 (negative angles)*

***Affine transformation matrix is used in the simulation***

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*There is an error in the calculation: second line “-t\_2” has to be “t\_2”.*

*Correct Equation:*

***Separating axes theorem is applied to assess collision with the displayed obstacle configuration:***

*Separating Axis Theorem is not applicable for concave polygons so it will provide incorrect results in this case. However, there is a work-around: splitting the polygons into several convex polygons and applying the theorem to them*

***Developed non-holonomic constraint to ensure that each wheel can move in only one direction:***

*The function is a holonomic constraint, not a non-holonomic one. As it can be written without its derivative.*

***Question 2.2***

***The single track model you used to simulate your vehicle motion is supposed to be applied to a motor bike instead. Explain how the model needs to be modified in order to be applied to a motor bike instead of a vehicle. Provide the resulting mathematical model.***

*𝑢𝑣 and 𝑢Φ action variables would be considered different for a motor bike than a car.*

*Maybe add another variable that captures the balance angle (roll) of the motor bike, which changes when you turn. Would be maybe like (theta)’* ***𝑢𝑣 ∙ tan 𝑢Φ’ /L’***

***Question 2.3.***

***You are using the Minkowski sum for your obstacle avoidance. However, your obstacles are moving. How do you have to adapt your utilization of the Minkowski sum to cope with the moving obstacles? Your management also asked you how the Minkowski sum could be adapted to ensure that your vehicle is only allowed to drive close to obstacles?***

***Moving obstacles:***

*Capture the velocity of the object and adapt the minkowski sum so it reflects the area according to its speed.*

***Driving only close to obstacles:***

*You would consider the area created by adding your car into the obstacle map no longer as outside your configuration space but as your driving space. And you would set the object map and the area which is outside this driving space outside your configuration space.*

***Question 2.4.***

***The following algorithm is applied for your path planning. Provide the name of the algorithm in its long form. Is it effectively implemented? How should it be improved? Please mark the changes directly in the pseudo code below.***

***Pgoal = goal area***

***current = 0***

***limit = 20***

***graph(E,V) = ()***

***While current < limit:***

***Zn = SamplePos()***

***Zm = SamplePos()***

***if collision(Zn) == True***

***continue***

***Zclosest = Closest(G(E,V),Zn)***

***Connection = Connect(Zn,Zclosest)***

***G.add(Connection)***

***G.add(Zm) # traversed nodes***

***if Zn in Pgoal:***

***Return G***

***Return G***

*Answer :*

*PRM( probabilistic roadmaps)*

*(It's not a RRT bcoz we are connecting nearest neighbor to Zn while in RRT we get intermediate config Zi that is connected to Zn, I can be wrong please correct it if anyone think otherwise)*

*(In PRM we add one sample to multiple nearest-neighbors. We’re not doing that here?)*

*Pgoal = goal area*

*current = 0*

*limit = 20*

*graph(E,V) = () // maybe replace with G(E,V) = ()*

*While current < limit:*

*Zn = SamplePos()*

*if collision(Zn) == True*

*continue*

*Zclosest = Closest(G(E,V),Zn)*

*Connection = Connect(Zn,Zclosest)*

*G.add(Connection)*

*G.add(Zn)*

*if Zn in Pgoal:*

*Return G*

*current=current+1*

*Return G*

*Zm is pointless as you should not deal with two sample positions in one iteration and it doesn’t perform any action with it, just sampling and add it to the graph, which doesn’t make any sense either.*

***Question 3.1***

***You are given responsibility for a team of multi-sensor-data-fusion experts. Management wants you to define requirements and tasks for the team to achieve good results for a self-driving agricultural robot that collects potatoes on a field and removes weeds. Following, you find a number of design options that you are supposed to process. Explain your choices for the specific potato and weed use case.***

***Occupancy grid map – Define 3 useful grid map layers (level of abstraction?) and choose a cell layout for each. Explain the goal that the layer should help achieve.***

*1: Potatoes: Defines the position of detected potatoes*

*2: Weed: Defines the position of detected weed*

*3: Unknown: Defines the position of an unknown object.*

***Weed detection – Define your algorithmic approach and any data requirements that you have for potential training and runtime detection.***

*Algorithm: You could use a deep convolutional network, as this architecture works really well for classifying images and achieved good results for similar tasks (MINST, AlexNet, VGG, etc.)*

*Data: You would require to have a considerable amount of pictures to train the network, pictures of weed and not weed so the network can learn to classify them.*

***Question 3.2***

***The management heard at a conference that Kalman filters are important. They want more information from you. Out of 20 objects on the road, how many objects does one Kalman filter typically track? Is the Kalman filter suitable for tracking the motion of a stationary object? How does the Kalman filter solve the data association problem? How does the Kalman filter cluster multiple objects?***

***20 Objects:*** *Tracks a single object.*

***Motion tracking:*** *Kalman used for dynamic system motion prediction*

***Data association:*** *The standard formulation of Kalman filter-based SLAM*

*assumes that the associations between measurements and*

*landmarks are known, which is rarely the case in real*

*world applications. In this context, several techniques and*

*extensions have been proposed to deal with unknown data*

*associations in SLAM [22]. For example, the Nearest Neighbor (NN) approach [1], [25] assigns the nearest measurement*

*to each landmark with respect to the Mahalanobis distance.*

*More precise methods find joint compatible associations such*

*as in the Joint Compatible Branch and Bound (JCBB) [25]*

*method. These methods have in common that a single data*

*association hypothesis is used to update the joint state vector.*

*If this association is wrong, e.g., due to high noise, the*

*Kalman filter may diverge.*

***Clustering:*** *Since Standard Kalman Filters do not capture relationships between different obstacles clustering is not possible since it relies on the distance metric between similar objects. (Please correct if you find anything wrong with this answer)*

***Question 3.3***

**Your camera based vehicle detection algorithm is showing a bad Receiver Operating Characteristic curve performance. What could this mean? What can you do to improve this performance?**

This would mean that we have a lot of false positives on our detection algorithm.

Use another algorithm, get more training data, increase the thresholds (f.e. for lidar), etc.

***Question 3.4***

***Your manager wants to know which weather effect reduces the range of your lidar more strongly, fog or rain? The manager also wants to know, which data you require in order to calculate your lidar’s detection range during rain. Provide a sensible answer.***

*Fog vs Rain:*

*Rain can reflect the light of the Lidar and it is also more dense so it can damage the detection range more than fog.*

*Data: We could fuse data from a radar*

***Question 3.5***

***Describe how you would implement a lane detection module for an autonomous vehicle in a cooperative, a redundant and a complementary data fusion approach. Highlight the differences. Choose concrete scenarios and sensors for your example, assuming a multi-lane highway driving scenario. The explanation must be specific for the scenario.***

***Complementary****: Providing the set of images of the same target lane from the different angle/ field of view. A camera on the side and on the top of the car.*

***Redundant****: Adding two similar sensors (f.e. lidar and radar) to have a good level of accuracy even during bad weather conditions (i.e. wet road reflecting lidar)*

***Cooperative****: Using multi-modal data fusion (2D camera and LiDAR as lane lines can be detected by LiDARs -- can detect the intensity of the road surface points). You could use a microphone with sound recognition for horns as an additional detection to see if you are going out of the lane and a camera to detect the lane.*