Assignment – Active Safety

Group number: K

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Remember: Use SI units (MKS) as primary units. Define abbreviations and acronyms the first time they are used in the text. Include all values and equations (incl. derivations). Insert labels in each graph. Add captions to all Figures, Tables and Graphs. Cite sources correctly and completely. Proofread spelling and grammar. Finally, state the contribution of each student in the group at the end of the report.

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1. Introduction and Background

This chapter aims at giving a small overview about the experiment this report is looking at. In addition, two papers about drivers overtaking bicyclists and comfort zone boundaries are discussed and reflected on our experiment. Those papers will give a better understanding for the topic that is discussed in this report.

1.1 The experiment

In this experiment, we used several equipment that were installed in the electric bicycle which was ridden on a certain decided path for 11 minutes (side-mounted) and 12 minutes (back-mounted). The first one is the (Hokuyo UXM-30LXH-EWA; 20 Hz) Light Detection and Ranging (LIDAR) which is mounted on two different settings, either on the side or rear face of the bicycle. The other equipments used were the two cameras facing backward and forward, the IMU and the GPS which were located at the front of the bicycle. However, since the only data that will be analyzed in this experiment is only the one related to the LIDAR system, we will not explain further on the other equipment's (e.g. cameras, IMU and GPS) methodology and their results.

In the first side mounting set-up, the LIDAR equipment is mounted on a rigid mounting facing the left side of the bicycle with its center located 0.61 m from the ground, facing perpendicularly to the direction of the travelling vehicles. Since the variable of interest in this experiment is the lateral clearance, we need to consider the offset between the outermost point of the bicycle (the tip of the left handlebar) and the LIDAR system in order to accurately calculate the lateral clearance. In this case, the offset of the LIDAR setting and the handlebar for the side and back mounted setting was about 0.09 m and 0.3 m respectively.

In the pilot experiment, the mounting is divided into two different position to see what the effects were of having two different positions of LIDAR on the lateral clearance of the vehicle. It is assumed that having the LIDAR on the side will provide better view for lateral clearance measurement since the laser beam will be better directed on the moving vehicles on *its passing and returning stage* of the overtaking maneuver. However, it could also be assumed that it will make the equipment very visible to the eye of the passing vehicle driver and it could possibly have an effect on their behavior knowing that the overtaken bicycle is measuring the behavior of the driver. [1]

On the other hand, putting the LIDAR in the back was assumed to be optimal for *approaching and steer away phase* data analysis of the bicycle overtaking. Moreover, since less additional structure was used in the back mounted LIDAR, it could be assumed that it will be less visible to the driver compared to the one with the side mounted LIDAR, therefore reducing the possibility of having an altered behavior of the driver in overtaking the experimental bicycle.

The aim of the pilot experiment is to find out, which position of the LIDAR on the bicycle gives the most representative results. With that knowledge the "main" experiment can be done. That experiment will aim at studying comfort zone boundaries in the same scenario. Those boundaries will be explained in chapter 1.4 in more detail. This report is only about the pilot experiment.

1.2 The overtaking maneuver

-> good that you had a closer look at that!

The maneuver we are looking at in this report is the overtaking of a bicyclist by a vehicle. For a better understanding, this maneuver can be divided into four phases. [1][2]

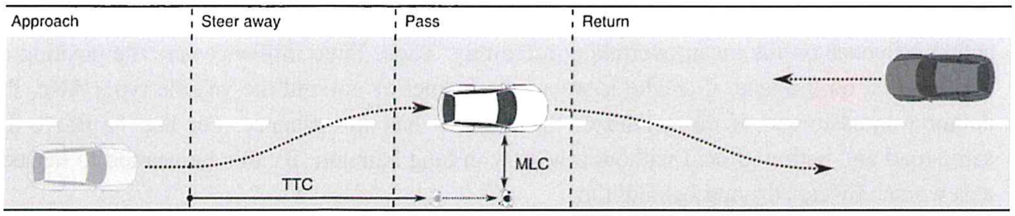

Figure 1. Representation of the Phases in Overtaking Maneuver [1]

Approaching Phase. This phase represents the point when a vehicle is following the bicycle from the rear until it was just about to initiate the lateral movement to the dashed center line. At the end of this phase, we could measure the time to collision (TTC) at the instantaneous moment when the vehicle was just about to steer away.

Steer Away Phase. This phase represents the point when a vehicle is starting to move laterally to the dashed line of the lanes and longitudinally closer to the bicycle in order to prepare for the passing phase and avoid the collision with the bicycle.

Passing Phase. This phase represents the point when a vehicle is actually passing the bicycle after the vehicle entered the passing zone. At this phase, the vehicle might have to consider the opposite lane vehicle when passing through the zone. Thus, they have a limited time in order to get to the returning phase.

Returning Phase. This phase starts when the vehicle leaves the passing zone and starting to maneuver laterally to return to the original center of the lane. This phase marked the end of the whole overtaking maneuver of the bicycle.

1.3 Drivers overtaking bicyclists

For a better understanding of the overtaking maneuver, the paper from Ian Walker can be used. The author of that paper wanted to analyze the behavior of the motorist, when she/he is overtaking a bicyclist. He prepared a bike with a temperature-compensated ultrasonic distance sensor, which was mounted 0.77 m from the ground, facing perpendicular to the direction of travel. On that bike, there was also a data-logger and a forward-facing camera. The equipment was not visible for passing motorists. The author rode 320 km with that bike. He always wore the same clothes, trying to look like something between a "professional" and a young "stunt"-cyclist.

Compared to the experiment this report is looking at, the equipment in this experiment is not hidden from the driver of the overtaking vehicle. The LIDAR is visibly mounted on the side or the rear of the bicycle. This can be a strong influence for the outcome of this experiment, because the driver of the overtaking vehicle could react differently, when she/he sees the equipment mounted on the bike. The driver could assume that she/he is getting measured for various reasons and that this could have negative outcomes for her/him. Due to this fact the ability for the experiment to be representative can be doubted. It would be more representative, if the LIDAR is not visible for the drivers.

Another difference is that there is a backwards-facing camera as well in our experiment. This was not the case in the experiment in the paper of Ian Walker. Having this camera offers the possibility to have more visual data from the back of the bike. The vehicles and their drivers behind the bike can be analyzed. One example what could be analyzed is the behavior of the driver, while she/he is behind the bike waiting to overtake. This can be used for the discussion of the results, if the time that the driver spends behind the bicycle waiting to overtake has an influence on the distance left to the bicycle, while overtaking.

The author of the paper found out that the three possible influences he wanted to test, have an actual influence on the mean overtaking proximity. Those three influences are the position of the bicyclist on the lane, if she/he is wearing a helmet or not and the vehicle type. Also, the author wanted to test, if the gender of the bicyclist has an influence. For that he drove the same road and path with and without a wig (with long hair) on. By this he wanted to be seen as a woman by cars driving behind him.

The position of the bicyclist has an influence, because the author found out that the more space the bicyclist leaves to the edge of the road, the less space the motorists leave to the bicyclist. This indicates that driving near the edge of the road could be safer, which is not always the case due to potential risks like opening doors of parking cars, drainage grates or road debris. Also, the gender and the use of the helmet have an influence on the proximity left to the bike. The author assumes that the driver is believing that if the bicyclist has a helmet on, she/he is more experienced in riding a bike and therefore less likely to act erratically. Because of that the driver is leaving less space to the bicyclist, if she/he is wearing a helmet. In addition, drivers leave more space to bicyclist who seem to be female. The author assumes that the drivers are thinking that female bicyclist are less predictable and therefore leave more space. Another influence on the proximity is the vehicle type. Buses and heavy goods vehicles are leaving less space to bicyclists. The author assumes that this is strongly related to the vehicle dimensions. Those vehicles are bigger than usual cars and take longer to overtake the bicyclist. For the drivers of those, the bicyclists are out of sight before the overtake is completed, which leads to the drivers to pull back across too early, creating danger for the bicyclist. [3]

The results Ian Walker got are reasonable and understandable. With an additional rear-facing camera the drivers behind the bicyclist could have been analyzed as well, like mentioned earlier in the text. This could have given another proof of the results and maybe more information about the overtaking maneuver itself. The influence of the position of the LIDAR in our experiment regarding the visibility of it will be examined later in this report. /7

1.4 Comfort Zone

An important aspect to consider when analyzing and understanding various maneuvers and therefore building active safety systems is defining the comfort zone of the driver of the vehicle. The comfort zone describes a "zone" in the driver-vehicle-environment space (DVE space), in which the driver is neither feeling nor predicting discomfort and so chooses to stay within. For example, when the driver keeps a certain distance at a certain speed to the lead vehicle with which she/he feels no discomfort with. The driver is trying to be as close as possible to the comfort zone boundary. By doing so, she/he is achieving the best performance, while staying comfortable and not taking too much effort to keep that performance, since people tend to trade off performance against effort.

If the driver is feeling discomfort and thereby leaving the comfort zone due to a specific reason (for example, if the lead vehicle is suddenly braking and the distance gets lower fast), the driver can be able to regain control and get back into the comfort zone. If the driver cannot regain control due to the action capabilities of the driver-vehicle system, she/he crosses the safety zone boundary. The safety zone describes the zone in which no crash will occur (for example, because the distance to the leading vehicle is so large that the driver has enough time to avoid a crash). The difference between the safety zone boundary and the comfort zone boundary is called the safety margin.

Not every driver has the same comfort zone boundary, which means that not every driver feels comfortable with the same distance to the leading car at a certain speed. For designing active safety systems, it is important to know those comfort zone boundaries. Also, the safety zone boundary is important, but that is more vehicle and environment specific. The purpose of active safety systems is to prevent crashes or at least mitigate their outcome. This can be achieved in different ways regarding the comfort and the safety zone. The active safety system can be used to keep the driver in the comfort zone (for example by a distance alert), to get the driver back in the comfort zone (i.e. by a frontal collision warning) or to have a less severe crash, when the safety zone boundary is crossed (i.e. by autonomous emergency braking). To know when the active safety system should be activated, the comfort zone boundary has to be known.

Regarding this experiment, the comfort zone of the drivers overtaking the bicyclist is crucial for the proximity between the vehicle and the bicyclist. The bicyclist also has a comfort zone, but since she/he cannot directly influence that proximity, the comfort zone of the driver is crucial for that. The proximity is depending on the comfort zone of each driver. Crashes can happen, when the comfort zone and the safety zone boundaries are crossed. This can happen, when the situation is misjudged by the driver, i.e. when she/he is approaching the bicyclist with a speed that is too high and the steering away from the bicyclist is too late. [4]

This experiment aims at finding out, if the position of the LIDAR has an influence on the proximity between the driver and the bicyclist. In other words, if the comfort zone of the driver is changing, when she/he is seeing the LIDAR and thereby eventually change the proximity. It could be the case that the driver chooses a different proximity, when she/he is seeing the LIDAR, because she/he is not feeling comfortable with the proximity chosen, when the LIDAR is not recognized. /5

2. Methodology

For analyzing the behavior of the driver, the proximity/lateral clearance has to be analyzed. The lateral clearance itself could be defined as the distance between the outermost point of the bicycle (e.g. left handlebar tip) and the outermost point of the car (e.g. side mirror tip). It could be calculated by the following formula [5]:

$$c = d - \textit{handlebar width} - \textit{side mirror width} \quad (1)$$

↳ refer to Figure 2

where d is the lateral spacing (distance between the right most body of the car excl. mirror and the center of the bicycle) and c is the calculated lateral distance.

However, using these formulas was not suitable in this experimental result since we could not distinguish the side mirror from the whole body of the vehicle. Therefore, we could not use the side mirror width as a variable in the calculation of the lateral clearance. Instead, we use only the handlebar width which is a parameter of 0.3 m long. Thus, any measurement we made in the back mounted LIDAR will be calculated as:

$$c = d - 0.3\ \text{m} \quad (2)$$

Moreover, since there is an offset between side mounted LIDAR with the handlebar tip which is a different parameter than back mounted LIDAR case, the lateral clearance in the side mounted LIDAR could be calculated as:

$$c = \textit{side mounted result} - 0.09\ \text{m} \quad (3)$$

The LIDAR in side mounted setting was not assumed to be located in the center of the bicycle. Thus, we used direct measurement result in lateral clearance calculation. The visual representation of these variables and parameters are shown in Figure 5 below.

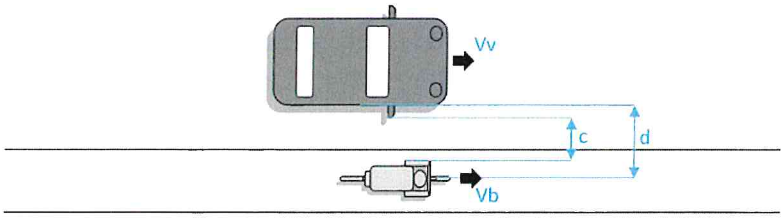

Figure 2. Representation of the lateral clearance variables and parameters in the passing maneuver [5]

The data that was acquired from the experimental set-up was processed with the *UrgBenriPlus* Software which is a very convenient way to process the sensor data that we have obtained previously. From this software the variables that was of interest to us were the timestamps of the test run and distance to the outermost point of the car in the Y-axis (side mounted) and in the X-axis (rear mounted). After using the software, we recorded all the values of timestamps and the distance in the excel and calculate according to the equation (1), (2) and (3) above.

After recording those values, we calculate the Mean, Minimum, Maximum and Standard Deviation of the values and performed t-test using the SPSS Statistical Software. The t-test is used to find out, if the data measured with the different LIDAR positions is significantly different. The formulae used are discussed below.

Mean: $$\bar{x} = \frac{\Sigma x.}{n} \quad (4)$$

Standard Deviation: $$\sigma = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n}} \quad (5)$$

Where x are the values of which the mean has to be calculated and n is the number of values.

For using the SPSS software, we put in the lateral clearances from the LIDAR data. The SPSS software provides us with three kinds of t-tests, namely Independent Sample t-test, One Sample t-test and Paired Sample t-test. One Sample t-test is used to compare a sample mean with a known mean of different values, on the other hand Paired Sample t-test is used to calculate and compare the means which comes from a same source but has more than one collected value. Independent Sample t-test is used to measure and compare the means of two different groups having two different sets of values. So, for our task we choose the Independent Sample t-test to calculate the mean and compare it. For carrying out the Independent Sample t-test we need to make two separate groups for the rear and the side mounted LIDAR system. The data from the LIDAR positioned in the back is put into one group and the data from the LIDAR positioned on the side is put into another group. After that we use the Independent-Samples t-test to compare the data. The results obtained from the Independent Sample t-test is discussed in the results section.

good !

3. Results

In this section, the report will explain the results of the experiment and the advantages and disadvantages of the current experimental set-up as well as several different overtaking strategies which could be analyzed through the LIDAR data.

3.1 Main result of the LIDAR measurement in both mounting conditions

Table 1. Descriptive Statistics Result of the Pilot Experiment

LIDAR Mounting	Mean	Minimum	Maximum	Standard Deviation
Side	1490.13	745	2345	489.65
Back	1580.36	786	2790	497.23

maneuvers are okay but distance measures seem a bit too small

The table 1 above shown that the mean of the Side and Back mounted LIDAR case was about 1490 and 1580 respectively and the Standard Deviation for Side and Back mounted LIDAR was around 489 and 497 respectively. Initial observation from table 1 shown a non-significant difference between the two of them. However, this result has to be corroborated further with the independent t-test result to evaluate the significance.

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3.2. Individual t-Test of LIDAR Measurement Result

What are prerequisites for the t-test? Have you checked them?

Table 2. Independent t-test of the LIDAR measurements results

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LIDAR	Equal variances assumed	.706	.405	-.633	46	.530	-90.22957	142.61836	-377.30544	196.84631
	Equal variances not assumed			-.633	45.777	.530	-90.22957	142.52514	-377.15558	196.69645

Based on the above table 2, it could be inferred that the t-test results in a similar conclusion from the above statement that the difference between the side mounted LIDAR and back mounted LIDAR was not significant. Since the Levene's Test for Equality of Variance showed that the resulting value was **0.405**, equal variances could be assumed. In order for the 2 variables to be assumed to have inequal variance, normally it should have value lower than 0.05. → Significance level α p-value

In addition, for the difference in the 2 variables to be statistically significant, normally p-value has to be lower than 0.05. Here, since the t-value at the degree of freedom of 46 corresponds to value of -0.633(**t(46) = -0.633**) and **the p-value bigger than 0.05 (p = 0.530)**, we concluded that the difference in the Mean result of the two different mounting variables (Side vs Back Mounted LIDAR) will be insignificant. This result also means mounting the LIDAR in the side or at the back of the bicycle is not resulting in a statistically significant difference.

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3.3 Limitations of the LIDAR data and Possible Improvements of Set-up

One of the limitations that we found in the LIDAR data was that it has moments where the experimenter is standing in front of the LIDAR system, so it created a moment where the LIDAR does not function properly as to the extent the full captured data is about the vehicle overtaking the bicycle.

This situation occurred for about the first 101 timestamps and 500 timestamps in the back and side mounted LIDAR respectively. The evidence of this could be observed in Figure 8 below.

Improvement could be done by making sure the LIDAR is only capturing the relevant data (excluding experimenter) to smoothen the analysis process of the data. → this was the start of the experiment, so this is totally fine :)

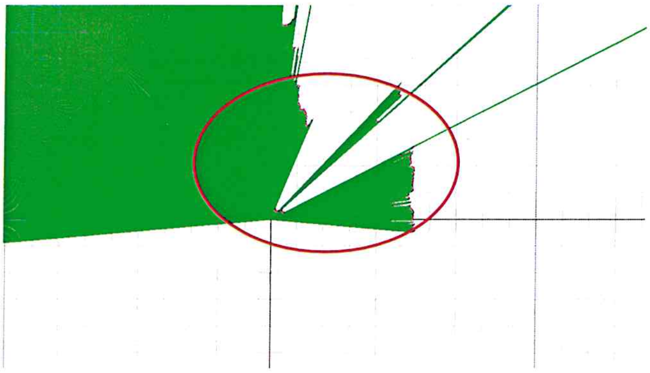

Figure 3. Moments where the experimenter is standing in front of the LIDAR system.

The second limitation was that it was impossible to determine the outermost point of the vehicle as there was no clear distinction in all the test runs over where the side mirror was located, which theoretically should be the outermost points of the car. Instead, in one of the cases, the laser beam went through the mirror or possible the tire rather than reflecting back. One possible solution to this is by placing the LIDAR a bit higher from the ground so that the scanning range could include the side mirror as well. → more problematic as the LIDAR will look "through" the window (we tried) ↳ data will be more messy and harder to interpret

Figure 4. The supposed location of the side mirror

The third problem is that the bicycle seems to be unstable during several occasions especially in the back mounted LIDAR. The LIDAR detected objects results were oscillating and going up and down abnormally. During these occasions, it is very hard to analyze the coming vehicle. → any suggestion on how to improve this? e.g. gimble

One possible reason was that there seems to be an effect which may be caused by the unstable mounting bracket for the back mounted case which in turn will cause instability to the LIDAR system during travelling in a gravy/bad road condition. There is also a possibility of having an effect of the wind blowing in the opposite direction of the travelling bicycle. This may also cause instability to the LIDAR system. One solution might be to use a better mounting bracket for both case since it is proven in section 3.1 that slightly more visible equipment in the bicycle will have negligible effect on driver behavior.

Another problem was that there were some occasions where the accuracy of the object detected was questionable. One concrete example would be as shown in figure 10. It is shown by the red circle that there was an unknown object existed beside the overtaking car that hinder the laser beam to reach its maximum reachability. This unknown object existed for the most of the back mounted LIDAR data hence indicating beam reflection problem of the LIDAR.

This proof that despite of the stated guaranteed detection of object in the specification paper for the LIDAR is up to 30 m, which if we compared it with the range used in this experiment where it is barely 1/3 of the full range, the LIDAR detection did not result in a satisfying accuracy. One possible improvement in this case would be to use different LIDAR sensor which has a better accuracy (e.g. higher scanning frequency) than the one used in this experiment. It will improve the accuracy of the overall test result.

→ 3D LIDAR might help, but the problem for detection was not the LIDAR system itself

→ what do you think this is?

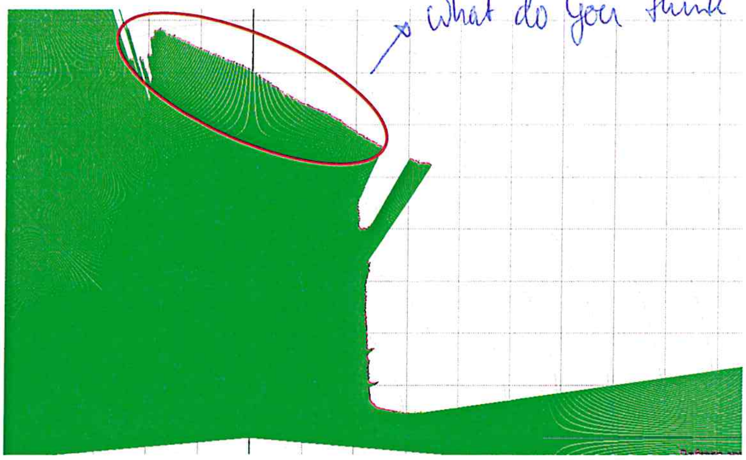

Figure 5. Unknown object during passing phase of an overtaking maneuver.

3.4 Overtaking Analysis

With the data of the LIDAR we also expected to be able to analyze different overtaking maneuvers regarding the phases explained in chapter 1.1. Expected overtaking maneuvers could be:

- the driver is slowing down while approaching the bicyclist, then steers away and overtakes
- the driver is driving onto the opposite lane while approaching the bicyclist and overtakes (staying on that lane)
- the driver is approaching the bicyclist staying on the same lane while maintaining the velocity and steers away without slowing down and then overtakes (stays behind the bicyclist as long as possible, while keeping safe distance)

According to figure 5, it was not possible to analyze the approaching and steer-away phase, which results in too less information about for categorizing overtaking. The information about the overtakes we got from the LIDAR data was almost always the same. The passing vehicle was staying on a straight line with a certain proximity to the bicyclist.

→ and with the mounting on the side?

4. Conclusion

The report showed that there is no significant difference between the LIDAR data measured in the back and on the side of the bicycle. Both of the positions could be used for the "main" experiment. We suggest putting the LIDAR on the side of the bicycle, because of the better ability to measure the lateral clearance due to the better view to the side of the bicycle.

In addition, it should be made sure that the video data from the back of the bicycle is available for analyzing the LIDAR data. This definitely helps identifying objects.

Besides the appearing object shown in figure 5, the LIDAR used in the pilot experiment is performant enough. It could be the case that using a LIDAR with a higher scanning frequency would result in a more accurate result, especially for identifying side mirrors of vehicles. For that another test would be required. But having a higher scanning frequency would also result in more data, which could cause storage problems and much longer analysis of the data.

It would!

A test with another LIDAR would also be a good idea, because it can be checked, if that LIDAR also shows something like in figure 5 in the data. This also indicates that camera data taken from the back of the bicycle is a better way to analyze overtaking strategies. Furthermore, an additional radar mounted on the bicycle could be a good option for measuring the speed of the passing vehicles for further analysis. But it must be checked, if that would result in packaging problems.

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5. Conclusion on the assignment

We met for every task and discussed how we solve the task. For Task 1 and 2 everyone read the paper, we took notes and Jan-Hendrik wrote it in the report. For Task 3 and 4 we met and discussed it and afterwards Adipta and Fikri wrote those in the report. The conclusion and the structure were discussed and done by everyone as well.

We liked about this assignment that the software was easy to handle and the introduction to the assignment helped a lot with understanding the experiment and the tasks. The instructions on the paper with the questions to the tasks gave good points to think about and discuss afterwards, so no key info was missed. The tasks followed a good structure, which helped a lot structuring the report. The workload was reasonable for the time we had for doing the assignment.

Report: good

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Σ 54

+1 bonus point

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