



What key technologies contributed the most to the rise of safety in autonomous vehicles in the past ten years?

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ABSTRACT

There has been an influx in the number of autonomous vehicles that are on the road. These vehicles have become very popular because of their improved accuracy and ability to drive through most conditions without human correction. To further improve these vehicles, manufacturers need to focus their finances and resources on factors that make an impact. The lack of information in this space has created the goal for this research study: to determine the key technologies that have contributed the most to the increase in the safety of autonomous vehicles in the past ten years.

To study this topic, I researched a group of spatial mapping and AI-related technologies by prompting Gemini, a conversational AI, and utilizing sentiment analysis of the responses generated. It was concluded that spatial mapping technologies had the largest impact on the safety of autonomous vehicles, and it was also concluded that AI-related technologies remain a crucial part of the safety as well.

INTRODUCTION

Almost everyone has been inside some sort of vehicle, whether it be a car, motorcycle, or even a bus. According to the Centers for Disease Control and Prevention (CDC), these vehicles, though inherently safe and benign, “are a leading cause of death in the United States ages 1-54 and the leading cause of unnatural death for U.S. citizens residing or traveling abroad”. (CDC, 2023)

In fact, in 2021, according to the Insurance Institute for Highway Safety, there were nearly 40,000 fatal car crashes in just the US, from which more than 42,000 people were killed, which is surprisingly higher than what we have been seeing for the past ten years. (IIHS, 2023) Throughout this time, we have seen advancements in cars, safety standards, crash ratings, and overall safety in cars, but why is the number of deaths higher than the previous year? Is it the availability of cars or the growing number of distractions or a mix of both? Although safety remains one of the most important features of a vehicle, we haven’t researched much about what attributes to the safety of vehicles the most.

There are several different types of safety systems in vehicles. Some safety systems prevent the likelihood of accidents, like emergency braking or backup cameras that alert drivers when objects are too close. Other safety systems reduce the seriousness of accidents, like airbags, safety belts, and heads-up displays. Each of these systems helps not only reduce the number of crashes but also the number of fatalities and casualties. As stated by an article on Kelly Blue Book, a popular car valuation and advice company, “Most of the advanced car safety technologies, like blind-spot monitoring and lane-keeping assist, were developed on the road to creating self-driving cars”. (Heaps, 2023)

Autonomous vehicles, also known as self-driving cars or automated vehicles, are the future of on-road vehicles. They combine artificial intelligence, automation, and an algorithmic approach to driving to create an efficient and safe driving experience. HG, one of the largest databases of legal non-subscription information, lists the top seven causes of crashes in Texas in order from most to least impactful: Speeding, distracted driving, substance abuse, violating rules of the road, defects in vehicles, poor roads, and harsh weather conditions. Out of these, at minimum, the top four causes are almost entirely preventable when self-driving vehicles are in the same situation.

Artificial intelligence is the backbone of self-driving capabilities and also many of the safety features. Many of the AI technologies used in self-driving vehicles are weak AI and use machine learning or neural networks. These technologies allow for the cameras and sensors to make judgments on how fast or slow the vehicles need to go to ensure the safety of the passengers. In the past few years, AI has improved at both predicting accurately and learning a high volume of data quickly. This can be attributed to the rise in power in computational components like the random access memory (RAM) modules, the central processing unit (CPU), and the graphical processing unit (GPU). Each of these has taken big leaps in recent years, especially when coupled with modern terminal regulation systems that allow these systems to work at their maximum capacity for longer without overheating. Many of the self-driving AI models require high-volume RAM modules and extremely quick GPU and CPU speeds.

The recent craze over autonomous vehicles isn't just from their ability to promote increased safety, rather they utilize cutting-edge technology to promote our ability to multitask. Ten years ago, these autonomous vehicles' max potential was just keeping drivers in their lanes, and now they provide a fully hands-off experience for most. Several companies have made self-driving taxis and are starting to bring self-driving technology to the consumer market. One of these companies is Cruise, a self-driving taxi company under General Motors. Their vehicles are fully operational in several cities across the US, including Austin, Texas, and San Francisco, California.

Automation isn't entirely new, rather it is a somewhat old concept. Automation is, according to Merriam-Webster, "a technique of making an apparatus, process, or system operate automatically" (Merriam-Webster, n.d.). Therefore, the idea itself is quite simple and is something applicable in almost all known fields of study. The first working automated object was created in the 1500s by DaVinci. It was a self-propelled cart that could be programmed to move in a predetermined path. This rate of advancement in autonomous vehicles and objects being created increased from that point. By the middle of the 1800s, we saw the Whitehead Torpedo, which could remain at the same depth at different pressures. In the 1900s, we saw several technologies emerge including the Mechanical Mike aircraft autopilot, the Stanford Cart, the VaMoRs van, the Teetor Cruise Control, and the General Atomics MQ-1 Predator Drone. Up to 2016 in the 2000s, we have seen Tesla Autopilot in commercial Tesla vehicles, the DARPA challenges, and the University of Michigan's MCity.



Different levels of automation indicate the amount of control that a driver would have to exert to enable their vehicle to travel to their desired location. Level 0 includes no automation and drivers will have to handle every situation, steering, acceleration, and braking. Level 1 has cruise control capabilities, automatic braking, and lane centering. Level 2 has adaptive cruise control technology with lane centering. This technology keeps drivers in their lane and at the right speed while adjusting to traffic in front of them, which makes it essentially hands-free in some places. Level 3 is limited to self-driving automation, so vehicles in this category expect extremely minimal input from the driver. The time accepted for inattentiveness also increased to 15-20 seconds. This means the vehicle can drive for 15-20 seconds without human interaction. The last level of automation is full self-driving, where the driver only inputs the destination, and the vehicle drives itself there entirely. Due to the condition that vehicles at level 4 automation must be fully autonomous, the jump from level 3 to level 4 takes the most time. Currently, most vehicles on the road are only at levels 2 and 3, but companies expect to start creating level 4 vehicles in just a couple of years.

An overwhelming number of automakers and transportation companies have started to have more autonomous vehicles. For example in 2018, Waymo's Fiat Chrysler Automobiles and Lyft's Aptiv vehicles started to produce self-driving cars. In 2019, Honda started to add more self-driving features. In 2020 we saw Amazon, Baidu, Daimler, Mitsubishi, PSA, Renault-Nissan, Tesla, Toyota, and Zoox all release more automated vehicle technologies. In 2021, BMW, Ford, Hyundai, and Volvo released their automated vehicle technologies.

Several different improvements can be enacted with autonomous vehicles. An article in the IEEE journal suggests implementing policies for improving efficiency, time, traffic congestion, and fuel consumption. For example, one of these policies would entail the use of "platooning on the highway". This policy would create safer traffic merging, coordinated braking, and streamlining. This would reduce the fuel usage of all the cars, and reduce brake usage and speeding crashes. (Loke, 2019) Several other policies will impact not only the safety of self-driving vehicles but also their utility.

We are currently at the most difficult point of time for automation, as we have to convert vehicles that have some autonomous components and create a fully autonomous vehicle that should be able to do everything. Therefore, to increase our rate of progression, we need to find the most effective and economical piece of technology used in autonomous vehicles that contributes to safety. An analysis of car crash information, key technologies implemented in cars, and their area of assistance, will allow us to understand what technologies we should improve in the future to enable a cost-effective approach to developing safer autonomous vehicles. This raises the importance of discovering what key technologies contributed the most to the rise of safety in autonomous vehicles in the past ten years.

Not only does focusing on key technologies improve the progression of automation, but it also significantly improves safety. Being able to lower the mortality rate from vehicular collisions is the main goal of improving safety in vehicles.

Improvements in the safety of autonomous vehicles will significantly reduce the number of deaths annually, and provide better road conditions for all, which is why focusing on finding key technologies that improve safety is a high priority.

METHODOLOGY

Kelly Blue Book, a popular vehicle valuation and vehicle research company, classifies several types of safety features and components that are in vehicles today. The four main categories are Standard Car Safety Features, Collision Prevention Safety Features, Speed Control Safety Features, and Vision Safety Features. Most categories of features are present in both autonomous and standard vehicles.

Standard Car Safety Features are government-mandated features such as Airbags, Anti Lock Brakes, Backup Cameras, Electronic Stability Control, Seat Belts, Lower Anchors and Tethers for Children, Tire Pressure Monitoring System, and Traction Control. Each of these has different functionalities and therefore focuses on improving safety in different areas. These features are in both non-autonomous and autonomous vehicles.

Collision Prevention Safety Features are features that prevent an accident by applying brakes or corrective steering. These features are the first stepping stone towards autonomous vehicles, as they are some of the hardware components that we need for autonomy to occur in vehicles. Features in this section would include Blind-Spot Monitoring, Brake Assist, Forward Collision Warning, Intersection Turn Assistance, Lane-Centering Assist, Lane-Departure Warning, Lane-Keeping Assist, Lane-Tracing Assist, Pedestrian Detection, Rear Automatic Emergency Braking, Rear Cross-Traffic Alert, and Semi-Autonomous Driving.

Speed Control Safety Features are features that enable vehicles to maintain, increase, and decrease speed based on the proximity of vehicles in front of them. This is also a category of safety features that was used as a stepping stone in creating safe autonomous vehicles. Features in this category include Adaptive Cruise Control, Automatic Emergency Braking, and Traffic Sign Recognition.

The last main category of safety features as listed by Kelly Blue Book is vision safety features. Features in this category include automatic high beams, adaptive headlights, night vision, and heads-up display. These features are one of the most common safety features in a vehicle.

Artificial Intelligence is a large component used in autonomous vehicles. The most popular Artificial Intelligence models used in autonomous vehicles include Recurrent Neural Networks, Convolutional Neural Networks, and Reinforcement Learning. (Alexander, 2023) Each of these models uses a design similar to a human brain, and wouldn't be possible without the increase in processing power and speed that we've seen in the past ten years. Furthermore, there needs to be a lot of unbiased data to ensure that an AI model works well.

I have selected several different components to analyze. I will consider the advancements they had in the past ten years, and how that has affected autonomous

vehicles. I will analyze the impact these had on autonomous vehicles, and how they change the safety of autonomous vehicles. I will find the safety features and components used by autonomous vehicles listed on the NHTSA and IIHS, and compare and contrast the crash safety ratings of them together. Also, it is important to get the experts' opinion on the safety and reliability of the components because the crash ratings might not be a great measure of the importance of the technology in autonomous vehicles.

I hypothesize that components that relate to computer vision and spatial mapping will be the most key safety features. I believe that features that helped the safety of the artificial intelligence component of autonomous vehicles. After researching several articles, I've noticed that these features are one of the most important for improving the safety of autonomous vehicles because having a larger dataset can improve the accuracy and safety of autonomous vehicles by making the artificial intelligence model less generalized. An issue AI models can run into is being overfit or underfit to the data, which is where the model learns to act only to the scenarios it's tested on or where the model learns very general information that isn't accurate at all. Having a large dataset of different scenarios can help make this more accurate because there is more data for the model to be trained and tested on. Some of the best AI models have large datasets with both testing and training data that allow them to be so accurate.

According to US News, a website that categorizes a wide range of things including cars, colleges, and schools, some of the most popular vehicles with autonomous features include the Tesla Model S, the Cadillac Escalade, the Genesis G90, and the Ford F-150. I analyzed the different sensors and AI models that these vehicles used, to find out what features I needed to focus on. Each vehicle is unique, as they are produced by different manufacturers, they use different AI models, and they use different types of sensors to navigate. I was able to shortlist technologies to focus on in my research through this process, which includes ultrasonic sensors, cameras, NVIDIA DRIVE System, Tesla Dojo System, convolutional neural networks (CNN), and LiDAR Sensors.

I prompted Gemini, a popular conversational artificial intelligence, to answer 14 questions about these technologies. Seven of these questions, which are shown on the right, were also rephrased with autonomous instead of self-driving, this was to create more diversity in the responses. Gemini was prompted with each of these questions three times, to prevent the biases present in the phrasing of the answers. I created a program in Python that would analyze the sentiment of the responses, and give it a sentiment score using a database called SentiWords from an NLP research group as a part of Fondazione

Prompts
Describe _'s role in self-driving applications
Describe the limitations with _ in self-driving applications
Describe the _'s ability to detect lanes in self-driving vehicles
Describe the benefits that _ provides in self-driving applications
Explain the benefits of utilizing _ in self-driving vehicles
Describe the improvements _ has faced in the past ten years in self-driving vehicles
Describe the _'s ability to detect obstacles in self-driving vehicles

Table 1: Table that displays the template prompts for each technology.

Bruno Kessler, a reputable research institute based in Italy. Then I averaged the sentiment scores for all three responses in each question.

RESULTS

The scores generated represent how positive or negative Gemini's responses were when describing a technology. The answers generated by Gemini typically had scores that were around five away from the mean score created by prompts from the same questions. Though there were several outliers present, these scores had a more drastic difference than the other scores present for the same question, which is why I decided to prompt multiple responses from Gemini. I graphed the score average from each prompt in a histogram. On the right, there is an example of this for ultrasonic sensors. To ensure that there isn't any bias from looking at the histograms, all histograms were graphed from 0 to 45 and had bin sizes of 5. These histograms show the mean, distribution, and spread of the scores, which highlight the outliers and trends present in each histogram. (See Appendix A).

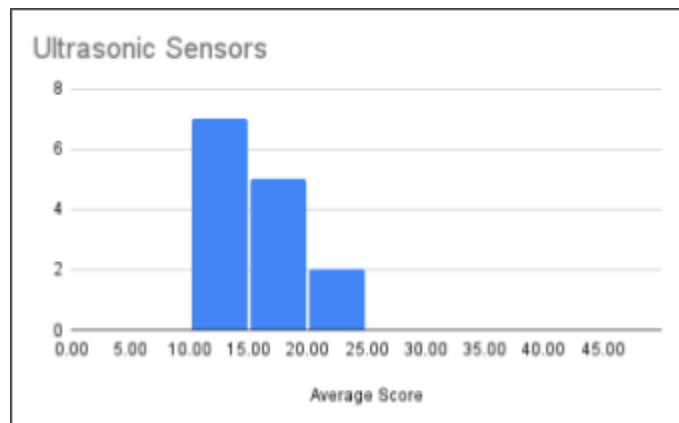


Figure 1: Histogram that plots the scores from ultrasonic sensor questions.

There are several crucial trends present in these histograms that should be considered before concluding anything. One of the most important features to look for is outliers, which can skew data, explain why the average could be higher or lower than expected, and determine how accurate the answers to the questions were in perspective with the mean and median of the data. The technologies that had outliers in their data are the convolutional neural network, NVIDIA Drive, and LiDAR sensors.

The shape of the histogram tells us if data was skewed either right or left, which can highlight the reliability of this method as it can show if it was volatile in the responses it made and its tone, or if there was a structure to it. The optical camera, LiDAR sensor, and NVIDIA Drive have normal distributions in their scores. The convolutional neural network, Tesla Dojo System, and Ultrasonic sensor have right-skewed data, which has more data on the lower end of the distribution.

Ultrasonic sensors were the first technology that was evaluated. Each question was prompted three times to Gemini (See Appendix H, Appendix I, and Appendix J). These three responses are Gemini's answers to "Describe ultrasonic sensors's role in self-driving applications.", which are similar to the types of responses found throughout the rest of my data. I wasn't able to attach all of the responses that were created by Gemini due to the size of the responses and the number of them, because there were

close to 160 responses and each of them was between 200 and 600 words. When I attached this to the paper it extended the length by 200 pages. The formatting and wording were quite similar between the three responses, but there were differences in the key claims in the responses and how it was presented, which is a trend present in a significant majority of the responses. The lowest score that was determined was 7.84057 and the highest score was 24.75397. The lowest average score for the question was 10.69056, and the highest score was 23.45941. The process of creating answers to the questions for this technology was identical to the process that was used to create the answers to the questions for all other technologies. This gives a sense of uniformity and reduces biases that might arise from researching similar technologies like biases in the semantics of the answers produced by Gemini and also the wording of the questions and how it could be influenced by how positive or negative the overall answers are, along with the content of the response itself.

Optical cameras were the second technology that was evaluated (See Appendix C). The lowest individual score was 5.91355 and the highest was 31.54138. The lowest average score was 12.98542 and the highest was 30.91878333.

The third technology that was evaluated was NVIDIA Drive (See Appendix D). The lowest individual score was 11.06444 and the highest was 39.97115. The lowest average score was 16.72367333 and the highest was 38.10617333.

The fourth technology that was evaluated was the Tesla Dojo System (See Appendix E). The lowest individual score was 3.11056 and the highest was 30.88264. The lowest average score was 7.303406667 and the highest was 23.00226667.

The fifth technology that was evaluated was Convolutional Neural Networks (See Appendix F). The lowest individual score was 3.81994 and the highest was 34.95272. The lowest average score was 5.742656667 and the highest was 33.20306.

The sixth technology that was evaluated was LiDAR sensors (See Appendix G). The lowest individual score was 12.4525 and the highest was 49.7291. The lowest average score was 12.82787333 and the highest was 46.24105333.

General trends are present across all of the data and important statistics to consider as it enables us to see what is considered standard for the scores. One of the biggest trends is that there aren't any negative scores. Typically answers that have more words have higher scores. For example, the second answer for "Explain the benefits of utilizing LiDAR Sensors in autonomous vehicles" had the highest score at 49.7291, and also had one of the highest word counts at 651 words. This is a greater amount than some of the initial responses that Gemini provided, which were in the 200 to 400 words range.

I averaged the scores from each of the technologies and generated a score to represent each of the technologies, which is displayed in the table below.

Technology	Score (Rounded to 2 decimals)
Ultrasonic Sensor	15.554
Camera	22.053
NVIDIA DRIVE	23.035
Tesla Dojo System	15.000
Convolutional Neural Network	21.605
LiDAR Sensor	24.060

Figure 2: Table that displays the average scores from each technology.

The three highest average technology scores in order were LiDAR sensors, NVIDIA DRIVE, and cameras. The lowest average technology score was the Tesla Dojo System. Therefore, the overall most positive technology was LiDAR sensors, and the least positive technology was the Tesla Dojo System.

Describing something in more positive terms correlates to how positive that thing that is being described is. Therefore, the greater the score, the more positive that technology was.

DISCUSSION

There are five main conclusions that I was able to conclude from the information. The first conclusion is that the LiDAR Sensor was the most impactful technology in the rise in safety for autonomous vehicles in the past ten years. The second conclusion is that technologies that relate to spatial mapping and spatial positioning are the technologies that are the most impactful in the rise of safety in autonomous vehicles in the past ten years. The third conclusion is that the technologies that relate to artificial intelligence and pattern recognition are still important for the rise in safety in autonomous vehicles in the past ten years, though they may not be the most important technology. The fourth conclusion is that improving spatial navigation, mapping, and positioning technologies can improve safety for occupants in autonomous vehicles. The fifth conclusion is it is still crucial that we focus on improving artificial intelligence-related technologies, even though these aren't the most influential in the rise of safety in autonomous vehicles.

LiDAR sensors calculate "distances to obstacles by using laser range finders, which emit light beams and calculate the time-of-flight until a reflection is returned by objects in the environment" (Anderson et al., 2014). The LiDAR sensor was the

technology that had the highest score, which was 24.060. This means that Gemini was able to describe this technology more positively than the other technologies on average. This means that Gemini found that this technology was more impactful in autonomous vehicles than the other technologies that were evaluated in general. The questions prompted Gemini to support the conclusion that this technology has been the most impactful in the rise in safety for autonomous vehicles in the past ten years. These questions focused on the correlation between autonomous driving and the technology, safety and autonomous driving, and improvements and the technology. The more positive the score, the better the technology performed in these aspects. Furthermore, the better the technology performed in these aspects, the more impactful they were in improving the safety of autonomous vehicles in the past ten years.

In the top three scores for technologies, two technologies relate to spatial mapping and spatial positioning: LiDAR sensors and optical cameras. This means that Gemini was able to describe these two technologies more positively than most of the other technologies that were evaluated. This was not just a trend I noticed with only the top three scores. The other technology that is related to spatial mapping had the fifth-highest score, out of six. This follows the hypothesis that I predicted, which was “components that relate to computer vision and spatial mapping will be the most key safety features.” Considering we know that there is a correlation that shows that as the score increases the impact on safety in the past ten years increases, we know that these spatial mapping and spatial positioning technologies are the most impactful category of technologies for the rise of safety in the past ten years.

Though the spatial mapping and spatial positioning technologies were found to have the greatest impact on safety in autonomous vehicles in the past ten years, artificial intelligence and pattern recognition were still very impactful in improving the safety of autonomous vehicles in the past ten years. The scores for the technologies were close to each other. The lowest was 15.000 and the highest was 24.060. This difference in 10 points isn't too large, which means that all of the technologies that were chosen were very impactful in the safety of autonomous vehicles in the past ten years. These technologies are used to enforce following conventional driving styles and rule-following, which is important on the road, as it makes it safer since other drivers can better predict the autonomous vehicles' decisions and what they might do next. Furthermore, it also enables the vehicle to know what signs mean, how to drive between the lanes, take turns, and do the other crucial tasks of driving.

The technologies that are used for spatial navigation, mapping, and positioning had the largest impact on improving safety in autonomous vehicles in the past ten years. Improving these technologies further by improving the resolution of the data collected, increasing the speed of the data traveling from the sensor to the processor, or reducing the cost of these technologies could improve the safety of autonomous vehicles through several means. It could affect the vehicle itself by improving its sensors through one of these methods. It could also affect the vehicles around it by improving the technologies that are used in those vehicles, which would make them safer by



reducing the chance of an accident by giving “smart” features to cars that aren’t even autonomous, such as more accurate emergency braking, lane keeping assist, and lane changing assistance. The final way it could improve safety in autonomous vehicles is by improving the communication between vehicles that are autonomous by improving features relating to spatial navigation, which allows autonomous vehicles to drive to their destination safely. These features would include predicting the speed of the vehicles around it and predicting the next action for vehicles around it. This would enable autonomous vehicles to understand how they can drive more efficiently by adjusting their driving style and speed to avoid a chance of an accident and in the process reducing fuel consumption and travel time.

Artificial intelligence-related technologies are still a large part of autonomous vehicles, as they provide the basis of many of the important features that are used in these vehicles. The artificial intelligence technologies that were evaluated include NVIDIA Drive, the Tesla Dojo System, and convolutional neural networks. These are used to analyze the data that is collected through the various sensors around the vehicle and create events and actions that the cars need to do. For example, if there is a slight bend in the road, the sensors send the data of the road and objects around it to the artificial intelligence model or algorithm that is used in the vehicle. This model or algorithm would determine if there needs to be a change in speed or direction and enact the change. Therefore, artificial intelligence-related technologies are the backbone of autonomous vehicles, and improving these technologies even further could improve autonomous vehicles to level 5, which hasn’t been achieved commercially so far.

CONCLUSION

The method I used to conduct my research had both successes and limitations. It is important to analyze both of these before creating a conclusion based on my results. My method tried to limit bias as much as possible. I created seven original questions and seven more questions which were the same as the original questions with slightly different wording. This prevented the bias that could originate from posing a question in a specific way. I also prompted Gemini three times per question, which would prevent my sentiment analysis algorithm from considering only the wording of answers as a determiner of the score for the question. Adding 14 questions allowed me to minimize bias by giving Gemini different aspects of the technologies to consider when writing its responses. The sentiment dictionary that was used in my sentiment analysis was created by a natural language processing research group which is a part of a renowned research institution. This group of researchers is qualified as they have PhDs and are professors at various universities around the world. This reduces the bias that might arise from using this dictionary as a sole indicator of whether the words are negative or positive and their magnitude.

However, Gemini is just a conversational artificial intelligence, which means it has its limitations. One of the biggest is that it isn’t the most qualified to give input on my topic, rather an industry professional, automotive engineer, or computer scientist who



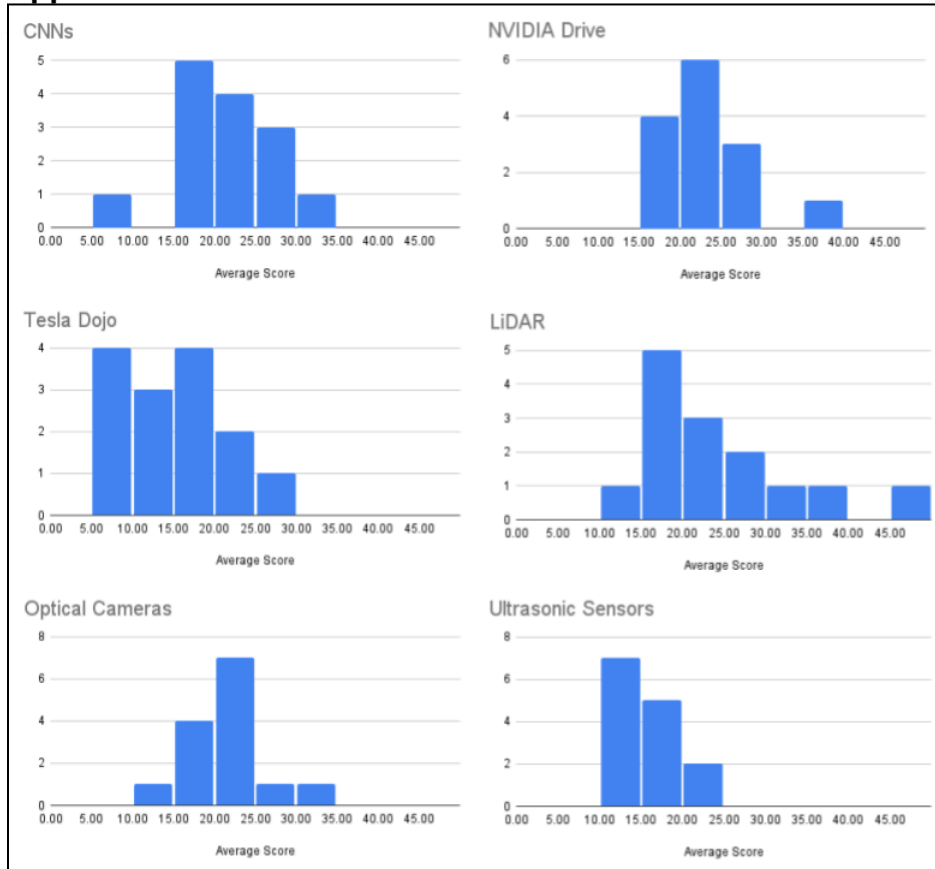
works on artificial intelligence and its integration into vehicles would be a better source of answers to these questions. Conversational artificial intelligence isn't able to do logical thinking very accurately compared to most humans, which could skew some of my data. Furthermore, conversational artificial intelligence uses online sources that might not be the most academically accurate, which poses some questions on the accuracy of the answers to the questions that were given by Gemini. The next step with this research would be to collaborate with an industry professional, like one of the ones listed above, and create more sound and accurate responses to the questions. This would decrease the bias, which would make the sentiment scores more accurate and enable us to better predict the most impactful safety technology that has contributed to the rise of autonomous vehicles in the past ten years.

The responses given by Gemini had several trends that were apparent in multiple responses. The word count for responses as the method was conducted appeared to generally increase as more prompts were fed into Gemini. This wouldn't be a big issue if the difference in the words per response was around the same, but there is a difference of as large as 300 words between several responses. This can be a confounding factor in determining the sentiment score and also determining the technology that has had the largest impact on safety in autonomous vehicles in the past ten years because the algorithm that is used finds the sentiment of each word in the response and sums it up. Therefore, having more words, with even slightly higher than 0 sentiment scores can drastically change the tone and sentiment of the text, especially with a difference of 300 words. This issue was limited as much as possible by having multiple different questions and querying Gemini three times for each question. In the future, we could divide the score by the number of words in the response to get a more accurate score. This would rely less on the number of words and more on the overall tone of the response, making my analysis more accurate.

We can conclude that spatial mapping and positioning technologies were the most impactful in improving safety in the past ten years in autonomous vehicles through my method. Specifically, LiDAR sensors are the technology that had the greatest impact in improving safety in the past ten years in autonomous vehicles. Vehicle manufacturers and engineers can use this information to improve their autonomous vehicles by focusing on these components and improving them. This would improve safety on the road for all vehicles, including non-autonomous vehicles, as drivers can better predict how autonomous vehicles are driving and what they are going to do next. Furthermore, vehicle manufacturers can focus on improving specifically LiDAR sensors and similar technologies to make these vehicles safer, which will reduce their costs and enable them to use that money to improve other areas and create more innovative technology.

APPENDIX

Appendix A



Appendix A: Set of histograms that showcase the average question scores of each technology.



Appendix B

Ultrasonic Sensor				
Question #	Score 1	Score 2	Score 3	Average Score
1	13.08461	12.74769	11.60679	12.47969667
2	12.529	18.37041	17.70165	16.20035333
3	10.60236	10.50655	13.10903	11.40598
4	14.79871	14.30456	14.10345	14.40224
5	7.84057	9.21374	15.01737	10.69056
6	13.87663	17.14428	16.0663	15.69573667
7	18.60221	17.40009	18.13625	18.04618333
8	22.46266	24.75397	23.1616	23.45941
9	17.16826	16.1567	17.33435	16.88643667
10	19.7328	17.61769	17.4436	18.26469667
11	13.19571	16.41741	8.15121	12.58811
12	21.19906	18.40939	21.20043	20.26962667
13	13.34242	12.34963	12.0702	12.58741667
14	14.14258	11.55428	18.63937	14.77874333

Appendix B: Table that displays the scores that were generated from prompting Gemini about ultrasonic sensors.



Appendix C

Optical Camera				
Question #	Score 1	Score 2	Score 3	Average Score
1	5.91355	6.88137	26.16134	12.98542
2	30.62443	30.59054	31.54138	30.91878333
3	15.4336	21.10177	21.06186	19.19907667
4	21.27889	18.65134	21.97582	20.63535
5	16.75276	14.80847	20.83664	17.46595667
6	19.19483	19.37053	19.37053	19.31196333
7	18.80893	20.65197	20.41004	19.95698
8	27.4079	22.86951	21.09435	23.79058667
9	22.05651	22.3973	29.02337	24.49239333
10	22.67736	25.37393	24.76893	24.27340667
11	18.48193	25.43016	27.02502	23.64570333
12	26.20085	27.62358	27.45721	27.09388
13	18.9557	23.25215	19.71026	20.63937
14	24.28709	22.09293	26.63075	24.33692333

Appendix C: Table that displays the scores that were generated from prompting Gemini about optical sensors.



Appendix D

NVIDIA DRIVE				
Question #	Score 1	Score 2	Score 3	Average Score
1	11.06444	17.18102	22.02151	16.75565667
2	16.83156	19.76933	23.61604	20.07231
3	15.55347	17.19072	17.42683	16.72367333
4	19.01442	16.15454	17.15275	17.44057
5	14.99662	21.58367	20.34663	18.97564
6	20.12115	21.16054	24.42195	21.90121333
7	23.28434	20.90831	21.01747	21.73670667
8	20.58072	18.89927	20.68543	20.05514
9	20.68543	22.07362	26.25319	23.00408
10	26.2301	25.73246	28.14068	26.70108
11	20.39179	27.47849	25.00562	24.29196667
12	26.71997	31.50967	29.50641	29.24535
13	21.9888	21.79254	38.64202	27.47445333
14	38.05501	36.29236	39.97115	38.10617333

Appendix D: Table that displays the scores that were generated from prompting Gemini about NVIDIA Drive.



Appendix E

Tesla Dojo System				
Question #	Score 1	Score 2	Score 3	Average Score
1	14.31308	14.13035	14.32394	14.25579
2	23.21411	23.02233	22.77036	23.00226667
3	18.66964	27.48568	24.52756	23.56096
4	24.16771	29.70859	30.88264	28.25298
5	14.63432	18.14626	16.23133	16.33730333
6	16.62174	13.00471	15.398	15.00815
7	9.77433	7.80492	10.27109	9.283446667
8	10.5184	14.15674	12.38228	12.35247333
9	15.87833	17.4378	16.29443	16.53685333
10	17.79718	17.00891	18.99196	17.93268333
11	9.0871	11.80833	12.07966	10.99169667
12	7.3432	3.11056	11.79712	7.41696
13	8.00733	6.01028	7.89261	7.303406667
14	8.03422	8.26784	6.98087	7.760976667

Appendix E: Table that displays the scores that were generated from prompting Gemini about the Tesla Dojo System.



Appendix F

Convolutional Neural Network				
Question #	Score 1	Score 2	Score 3	Average Score
1	15.35775	15.74146	18.72672	16.60864333
2	23.33733	26.09894	24.53067	24.65564667
3	14.86921	16.28951	14.0323	15.06367333
4	6.03491	7.37312	3.81994	5.742656667
5	21.71358	15.93367	21.13484	19.59403
6	18.02512	18.15335	17.84061	18.00636
7	24.07015	31.13392	31.14515	28.78307333
8	32.57778	34.95272	32.07868	33.20306
9	30.02142	26.11672	30.64657	28.92823667
10	15.61381	14.68983	19.94563	16.74975667
11	23.55284	20.62695	26.07452	23.41810333
12	26.98385	28.09	29.20353	28.09246
13	20.91957	20.22387	22.23434	21.12592667
14	23.66959	23.34678	20.47678	22.49771667

Appendix F: Table that displays the scores that were generated from prompting Gemini about convolutional neural networks.



Appendix G

LiDAR Sensor				
Question #	Score 1	Score 2	Score 3	Average Score
1	22.49585	23.95864	23.91165	23.45538
2	28.39483	27.17328	26.3696	27.31257
3	13.1083	12.92282	12.4525	12.82787333
4	17.00619	20.68316	18.01253	18.56729333
5	20.26157	20.26157	22.46186	20.995
6	21.59639	22.85098	23.54551	22.66429333
7	23.58323	27.13633	30.76267	27.16074333
8	32.24211	27.6512	32.79426	30.89585667
9	42.20935	34.4635	33.77827	36.81704
10	43.21196	49.7291	45.7821	46.24105333
11	16.27007	16.15741	16.90278	16.44342
12	15.41749	16.75756	16.6433	16.27278333
13	14.81158	19.36885	17.50036	17.22693
14	19.80088	17.52796	22.56199	19.96361

Appendix G: Table that displays the scores that were generated from prompting Gemini about LiDAR sensors.



Appendix H

While not the sole player on the field, ultrasonic sensors do play a specific role in the realm of self-driving cars. Here's how they contribute: **Short-range specialists:** Unlike LiDAR and radar, which excel at long-range detection, ultrasonic sensors shine in close-quarters. They are adept at pinpointing objects immediately surrounding the vehicle, making them ideal for low-speed maneuvers like: **Parking:** They help self-driving cars navigate tight spaces during parking by detecting nearby obstacles like walls, curbs, and other vehicles. **Docking:** Similar to parking, they can be used for precise docking maneuvers in situations like self-driving car pick-up and drop-off zones. **Complementing the team:** Ultrasonic sensors work best in conjunction with other sensors like LiDAR and cameras. They provide additional data, particularly in low-visibility conditions like fog, rain, or even darkness. These conditions can hinder the effectiveness of cameras and LiDAR, but ultrasonic sensors, using sound waves, are largely unaffected. **Cost-effective solution:** Compared to other sensors, ultrasonics are relatively inexpensive. This makes them an attractive option for automakers, especially for incorporating them in specific functionalities like parking assistance. Overall, while not the primary sensor for long-range perception in self-driving cars, ultrasonic sensors play a crucial role in low-speed maneuvers, harsh weather conditions, and cost-effectiveness. They contribute to the overall sensor suite, working alongside other technologies to create a more comprehensive picture of the environment for self-driving vehicles.

Appendix H: Gemini's first response to the first question for ultrasonic sensors.



Appendix I

In the world of self-driving cars, ultrasonic sensors act like the close-up specialists, complementing other sensors to provide a complete picture of the immediate surroundings. Here's a breakdown of their role: **Short-range masters:** Unlike LiDAR and radar, which excel at detecting objects far away, ultrasonic sensors are the go-to for short-range detection. They can pinpoint objects right next to the car, making them perfect for low-speed situations like: **Parking:** During parking maneuvers, they help self-driving cars navigate tight spaces by precisely detecting nearby obstacles like walls, curbs, and other vehicles. **Docking:** Similar to parking, they can be used for accurate docking in scenarios like designated self-driving car pick-up and drop-off zones. **Teaming up for success:** Ultrasonic sensors work best when they're part of a team. They provide additional data, especially in low-visibility conditions like fog, rain, or darkness. While cameras and LiDAR might struggle in such conditions, ultrasonic sensors, using sound waves, are largely unaffected. **Budget-friendly option:** Compared to other sensors, ultrasonics are relatively cheap. This makes them an attractive choice for automakers, especially for incorporating them in specific functionalities like parking assistance. In essence, while not the primary long-range perception tool, ultrasonic sensors are crucial for low-speed maneuvers, harsh weather conditions, and keeping costs down. They contribute to the overall sensor suite, working alongside other technologies to give self-driving vehicles a comprehensive understanding of their immediate environment.

Appendix I: Gemini's second response to the first question for ultrasonic sensors.



Appendix J

Self-driving cars rely on a multitude of sensors to navigate the environment, and ultrasonic sensors play a specific and valuable role in this complex system. Here's how: Short-range specialists: Unlike LiDAR and radar, which excel at detecting objects far away, ultrasonic sensors are short-range experts. They can precisely identify objects in the immediate vicinity of the vehicle, making them ideal for low-speed situations such as: Parking: During parking maneuvers, they help self-driving cars navigate tight spaces by accurately detecting nearby obstacles like walls, curbs, and other vehicles. Docking: Similar to parking, they can be used for precise docking in scenarios like designated self-driving car pick-up and drop-off zones. Complementing the team: Ultrasonic sensors don't operate in isolation. They work best when combined with other sensors like LiDAR and cameras, providing complementary data. This becomes particularly important in low-visibility conditions like fog, rain, or darkness. While cameras and LiDAR might struggle in such situations, ultrasonic sensors, using sound waves, are largely unaffected by these conditions. Cost-effective solution: Compared to other sensors used in self-driving technology, ultrasonics are relatively inexpensive. This makes them an attractive option for automakers, especially for incorporating them in specific functionalities like parking assistance, where cost-efficiency is a factor. In summary, while not the primary sensor for long-range perception, ultrasonic sensors play a crucial role in short-range detection, low-speed maneuvers, harsh weather conditions, and cost-effectiveness. They contribute to the overall sensor suite, working alongside other technologies to give self-driving vehicles a comprehensive understanding of their immediate surroundings.

Appendix J: Gemini's third response to the first question for ultrasonic sensors.

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