Executive Summary

To Win Consumers, First Earn Trust

It's an exciting time to be on the road. The industry is making huge strides with the technology that enables fully automated vehicles (AVs) to drive themselves. However, designing automated vehicles that people trust is just as important as the technology required to make them work.

Trust interactions will promote confidence, control, and a sense of safety for the people operating AVs. At the heart of these interactions are four capabilities: comprehensive sensing, clear communication, response to changes, and multiple modes of interaction. To support these capabilities, active safety and infotainment systems must converge into a unified system architecture. This new system architecture will link self-driving functionality with visual, audible, and other communication with passengers.

Introduction

Cars Are Evolving . . . But Are Drivers?

In the last few years, we've seen a steady rise in AV features on the market—and a lot of talk around AVs in general. Most efforts today focus on advanced driver assistance systems (ADASs), which include features like automatic braking and lane assist. These are designed to prevent driver distraction and improve driving safety.

At the same time, there is an increasing focus on highly or fully automated vehicles. In fully automated vehicles, the automated system is the driver. Automakers and researchers are experimenting with driverless AVs on test tracks and even public streets. Conversations about these AVs often focus on societal benefits—how they might ease urban congestion and reduce fuel consumption. Analysts talk about emerging business models and which companies are most likely to succeed first. Still others ponder the ramifications of an AV making ethical decisions in emergency situations. But whether focused on ADASs or driverless AVs, one crucial issue underlies every effort: will people trust AVs?

Over the years, many tech companies have struggled with the issue of trust. Too often, the industry focuses more on creating “trusted technologies” (like trusted execution environments or trusted modules) than on how those technologies might be received by people. Confusing designs and interactions can make embracing new technologies difficult. Many products and services have claimed to make our lives better, easier, or less stressful . . . only for the opposite to be true.

When it comes to AVs, the need for trust is even more critical simply because the stakes are much higher. If a mobile app doesn't work well, we can simply uninstall it. If an AV doesn't work well, we can face serious injury or even death.
So for AVs to be successful, we must first understand how people learn to trust them—and create designs that build that confidence. We know that trust is hard to gain and easy to lose, and that distrust of one product can easily be transferred to related products. We also know that trust is established when a person's concerns, questions, or confusions are addressed quickly and simply, and that it is nurtured when a person feels understood. Trust is a human feeling, not a technical capability. If AVs are to be accepted, we must create platforms in service of establishing trust—ones that help people feel safe, confident, and in control of AVs.

Background

Embracing the Unfamiliar

The harsh truth is that in the current landscape of ADAS technologies, some approaches are seeding distrust in AVs. The actual technology behind these features is often not the issue. Instead, it is the implementation that leads to problems with how people understand and interact with AVs.

In some cases, people simply don’t use ADAS features because they don’t understand how they work. Some features are confusing or difficult to use. As recent high-profile accidents have shown, drivers have misunderstood the limitations of an ADAS feature or have disengaged it by mistake, while believing it was still working. Missing or confusing indicators (such as lights, icons, and audible cues) can make these problems worse.

All of this leads to perceptions of ADAS technologies that are exactly the opposite of what was intended. Instead of feeling safe, confident, and more comfortable when driving, drivers may feel a sense of anxious vigilance. Because they are unsure of how the vehicle will behave, they must pay attention to their driving and make sure the feature is working correctly. Some may be so hesitant that they choose not to use the features at all.

Early efforts in driverless AVs have focused on the technology required to make them autonomous—cameras, sensors, vision computing—and far less on how people engage with the AV system and understand what it is doing. Early on-road testing has revealed situations in which other drivers are confused or frustrated by the behavior of driverless AVs, such as how they handle taking turns at a four-way stop. This leads to an overall uncertainty that driverless AVs can handle themselves amid numerous traffic laws and customs, as well as doubts that they can function safely with other vehicles on the road.

Furthermore, little testing has been done on the passengers inside the AV. For the most part, the only passengers in many driverless AV prototypes have been the scientists and technologists tasked with making them work. Naturally, these passengers control and react to the AV system in highly technical ways. But how would a nonexpert passenger understand and interact with these systems?

While the technical work behind driverless AVs rushes ahead, and automakers and ride-hailing services push to get to market first, there remains much work to be done before people will trust AVs enough to use them.

Recommendations

The Four Capabilities That Build Trust

Note: While many ADASs on the market today could benefit from some of the ideas proposed here, our focus is on driverless AV systems. The challenges with driverless AVs are more complicated and widespread, and must be tackled effectively before driverless AVs can come to market. We’re also concentrating on fleet AVs. These are vehicles a person can hire, like a taxi, and are not personally owned. Fleet AVs present unique challenges that, when resolved, will likely apply to consumer-purchased vehicles.

Before driverless AVs can be widely accepted, people must be willing to trust them with the most precious thing we have: our own lives, and sometimes the lives of those we care about. AVs must behave, react, and communicate in ways that make it easy for people to trust them—not only the passengers inside, but also pedestrians and the other drivers who encounter them on the road.
We believe AVs must address a core set of **trust interactions**. These are interactions that engender confidence, control, and a sense of safety when operating the AV. To be sure, there are many important interactions involved when using an AV. But these core trust interactions are the most significant. Together, they shape the passenger’s fundamental engagement with an AV.

**The following are the six key use cases we believe will be crucial to the success of driverless AVs:**

1. Requesting an AV
2. Entering an AV and initiating a trip
3. Making trip changes (intended or unintended) in an AV
4. Responding to errors or emergencies in an AV
5. Safely pulling over and exiting an AV
6. Using the road in proximity to an AV

To create trust, the AV system must provide clear, simple, and understandable controls and feedback for passengers. Intel has conducted initial end user testing of trust interactions in our AV prototyping environment. While we’ve only just begun our prototyping and testing efforts, a few key findings have surfaced and are likely to be paramount to the adoption of AVs. The following are four key capabilities we believe must be at the heart of trust interactions for them to be truly effective:

**Comprehensive sensing**

An AV system must be able to sense pervasively: as close to 360 degrees around the vehicle as possible, and in a variety of challenging conditions (for example, night, dusk, rainstorms, and alternating bright sun and shade). This is essential for safe driving. But an AV must also share with passengers not just **that** it is sensing, but **what** it is sensing. This gives passengers confidence that the AV is constantly aware of its surroundings.

Sensing helps passengers feel safe while entering and exiting an AV, when pedestrians cross the road in front of the AV, and when other cars approach the AV. Passengers must be able to see what the AV is sensing; our research found that this is a key aspect of establishing trust. For example, many participants felt more confident with the AV system when it included a visual display of a pedestrian crossing the street, which corresponded to the pedestrian they actually saw through the window.

Sensing is important inside the AV as well. When an AV system recognizes the number of passengers, their locations within the AV, and possessions (such as mobile devices), it can do a better job displaying trip information or alerting a passenger if an item is left behind. Sensing can also provide passengers with an overall sense of safety and security (for example, when riding alone late at night) and help detect and respond to problems or emergencies that might arise during a trip.

**Clear, bidirectional communication**

An AV system must communicate simply and clearly with passengers. This is the most important way to avoid ambiguity and confusion. Whether alerting passengers to an emergency, requesting details for a route, or acknowledging passenger inputs, clear communication is about providing the information necessary for passengers to feel confident and in control of the trip. Reliable communication also reassures passengers that the AV will address problems if they arise.

Communication is a balancing act. It must be flexible, providing more or less information based on preferences and context. Our research found that in certain situations, participants responded positively to more information—for example, when encountering road construction and choosing an alternate route. In other situations, participants wanted far less communication. For example, when the AV stopped at a traffic light, some participants responded, “Don’t show or tell me every little thing.”
Offering a variety of communication methods is very important. Voice interactions, large displays, smaller touchscreens, and the passengers’ own mobile devices can all work in different ways to help passengers notice and understand information. This is particularly meaningful because passenger attention is likely to be focused on other activities when driving is no longer necessary. Multiple communication methods can also help AVs accommodate disabled passengers who may struggle with, or be unable to use, standard interfaces such as touchscreens.

Response to changes

An AV system must respond quickly and effectively to a variety of passenger inputs. If a system has slow, complicated, or imprecise responses, passengers will think it has made an error or that there is something generally unreliable or “wrong” with the system. For comparison, when a computer loads a web page slowly, it may be seen as not working right. Quick, precise, and predictable responses will help passengers feel comfortable that the AV system is completing an interaction, and reinforce the idea that the system understands and is capable of carrying out what has been asked of it.

In emergency situations, or when the AV needs to react suddenly (for example, braking to avoid a vehicle running a red light), the system should provide context for what just happened. If needed, the system should provide additional instructions for what should or will be happening next. For example, if there is a problem with the AV’s operation that requires it to pull over to the side of the road, the system should communicate why it has pulled over and explain what other actions are being taken (e.g., emergency road services are being contacted) and what the passenger should do next (e.g., exit the vehicle, stay away at a safe distance, and wait for a replacement AV to arrive).

Multiple modes of interaction

An AV system must have multiple ways in which passengers can interact with it and understand information. Voice interactions, touchscreens, and mobile devices can help passengers interact with the system in the right way at the right time.

In our research, we often observed participants starting a trip in one way (speaking the destination of where he or she wanted to go), and then shifting to other modes during the trip (using the touchscreen to find and select an additional stop along the route). This happens because the level of attention a passenger must give the AV system fluctuates during a trip. For system acknowledgments, a quick voice response may be enough. However, deciding exactly where the AV should pull over at the end of the trip may require multiple modes of input and review.

Another reason to provide multiple modes of interaction is that one or more modes may already be in use when interaction is required. For example, a passenger may request a trip using his or her mobile device. But once the trip begins, the mobile device may be used to make a phone call, and the passenger will need to use a touchscreen for further inputs. Multiple interaction modes will also be important when several passengers are in the vehicle. A voice interface may be the best way to interact with a single passenger, but might be less effective when four passengers are sharing a vehicle.

Platform Implications

A Unified System Architecture

Ironically, supporting trust interactions requires breaking down the “trust barriers” that exist between traditionally disparate systems within the vehicle. Historically, the infotainment and active safety systems have been strictly separated, and often developed by entirely different engineering teams. However, in a highly or fully automated vehicle, the active safety systems required for self-driving must include user interactions. Sensor processing, fusion, and decision-making must include visual or audio mechanisms for communicating with the passengers.

So how, technically, does an AV establish and perform these trust interactions with passengers? In a word: convergence. Simply put, highly and fully automated vehicles must converge their active safety and infotainment systems into a unified system architecture that is capable of linking self-driving functionality with visual, audio, and other forms of communication with passengers.
Hardware Requirements

Convergence Is Key

Architectural convergence can take many forms. Whether the active safety and infotainment systems are physically converged onto a single, high-performance compute cluster or remain separate, systems engineers will have a new challenge: how to safely and securely link two very different systems in a way that can deliver a cohesive experience to passengers.

Clearly, single-platform convergence is the most elegant solution. One system that delivers both infotainment and human-vehicle interactions, while also performing active safety functions, affords exciting new opportunities for tight integration. However, it requires specialized hardware separation to ensure that safety systems with high Automotive Safety Integrity Levels (ASIL) are protected and take priority over non-critical safety functions. Process and memory isolation delivered by Intel® Virtualization Technology (Intel® VT) is an excellent example of the kind of technology needed to deliver a converged system.

Even if active safety and infotainment systems aren't physically converged, they still must achieve convergence at a system level, with highly secure and deterministic mechanisms to communicate with each other. For example, if the active safety system encounters a situation in which the AV’s passengers must be immediately notified, it must have a highly secure, isolated, and deterministic communication channel to the infotainment system. Furthermore, whatever had been taking place on the infotainment system must be interrupted at once to deliver the safety message to passengers. Contrary to the traditional design, these mechanisms will now likely require conformance to an ASIL for the very first time.

This challenge may not be as difficult as it seems. One opportunity comes with the recent industry trend to converge the infotainment and digital instrument clusters, leveraging hardware virtualization technologies such as Intel VT. The hardware between instruments and infotainment can be used to provide an isolated extension of the active safety system. This would provide the necessary safety and security isolation to support a converged active safety and infotainment system, better positioning the AV to deliver the trust interactions outlined in this paper.

Conclusion

Accelerating Adoption of AVs

These are early days for AVs. But if self-driving vehicles are to truly succeed in the market, it will be critical to design trust interactions that make drivers and passengers feel safe, comfortable, confident, and in control. Four key capabilities are required to achieve these trust interactions: comprehensive sensing, clear communication, response to changes, and multiple modes of interaction. In short, we'll need to see what AVs see, understand what they're doing, and be able to tell them what we want.

To reach this goal, active safety and infotainment systems must converge into a unified system architecture that links self-driving functionality with visual, audio, and other kinds of communication with passengers. Without this kind of rapport between the next-generation vehicle and its human passengers, people will find it hard to believe in the promise of AVs and all they can offer to society.

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