**Adjunct Proceedings of the 10th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '18), September 23–25, 2018, Toronto, Canada.**

# Interface Concepts for Intent Communication from Autonomous Vehicles to Vulnerable Road Users

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*AutomotiveUI '18 Adjunct,* September 23–25, 2018, Toronto, ON, Canada © 2018 Association for Computing Machinery.
ACM ISBN 978-1-4503-5947-4/18/09…$15.00
https://doi.org/10.1145/3239092.3265946

## Abstract

This paper presents six interface concepts for Autonomous Vehicles to communicate their intention to Vulnerable Road Users. The concepts were designed to be scalable and versatile, and attempt to address some of the limitations of existing concepts towards an unambiguous communication. The interfaces exist currently as initial concepts generated from brainstorming sessions and are in the process of being validated through prototype development and controlled studies.

## Author Keywords

Autonomous vehicles; Vulnerable Road Users; Pedestrians; Cyclists; Interaction; Communication.

## ACM Classification Keywords

Human-centered computing ~ Interaction design.

## Introduction

Numerous concepts of Autonomous Vehicle (AV) – Vulnerable Road User (VRU) intent communication already exist [1,2,3,6,7,8,10]. However, there are certain limitations to the scalability and versatility of the existing concepts. Some concepts convey the various states of an AV's driving cycle with a segment of light on the windshield [6,7]. However, in a busy, urban environment, the information of the exact location or moment of the vehicle's stopping point may become crucial in answering questions of whether it is safe for a pedestrian

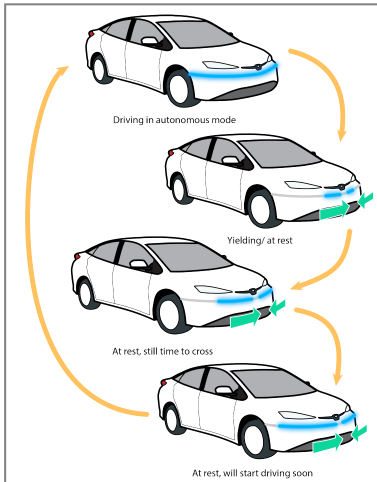


Figure 1

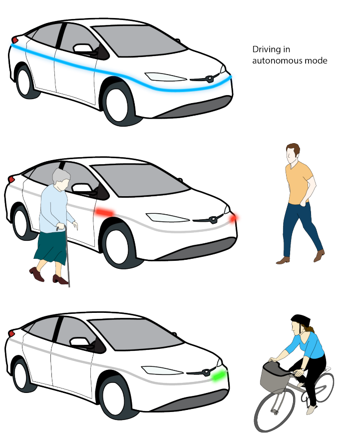


Figure 2

to step on the road. Other concepts involve projections of the street ahead [3], which may work well in low-light conditions (e.g. evening or nighttime) and in clear weather but might not prove as effective in broad daylight and in poor weather conditions. Additionally, while some designs work well for one-to-one communication, they are difficult to scale up when multiple VRUs – who are not at close proximity to each other – are involved. Thus, there is a need for designing a scalable, versatile interface that can effectively communicate the intention of an AV to surrounding VRUs unambiguously. We designed six concepts of interfaces for AV-VRU intent communication addressing the current limitations.

The concepts emerged out of brainstorming with 3 independent focus groups that included PhD students and faculty (total 7 individuals) involved in the fields of cognitive psychology and design. In coming up with the concepts, some ground rules were laid to direct and focus the design process. The concepts fundamentally addressed three states of an autonomous vehicle's driving cycle: 1) The vehicle is cruising, 2) The vehicle is yielding (stopping/at rest), 3) The vehicle is starting to drive. Another constraint we placed on ourselves in designing the concepts was that they cannot be language or culture specific, which prohibited the use of text or culture-specific symbols. Importance was given to intuitiveness and metaphors of natural interactions and associations, as well as to reduce the need for learning a new 'language' as much as possible, although this could not be entirely avoided. Furthermore, the research community sees a recurring discussion on the nature and color of lights used in interfaces for communication in autonomous vehicles. Laws and policies in several countries ban the use of red, yellow, or green lights (the colors used in traffic signals) in the front of a non-emergency vehicle [7]. Thus, aqua or white are emerging as preferred candidates of neutral colors for AV communication purposes. However, within the current scope, in the search of what serves as the most effective interface from a user-centered design perspective, the legal constraints have purposefully been given less importance.

## Concepts

*Concept 1: The Lightsaber (Figure 1)*

This concept takes inspiration from existing light-based interfaces on vehicle windshields to communicate the state of the vehicle [6,7], but attempts to make the communication more intuitive by adding a temporal component to the vehicle's change of driving state (i.e. driving to yielding, or from rest to starting to drive). The front bumper of the vehicle is equipped with a light strip that functions as an interface for communicating intention. The interface lights up and animates with different patterns based on the intent of the car. The vehicle indicates its status of cruising in autonomous mode with the entire strip steadily glowing, fully lit. As the car yields, two small segments of light animate inwards from the edge towards the center of the bumper. This animation continues repeatedly as long as the car is at rest and continues to yield to VRUs as an offer to cross in front of the vehicle. Thus, even at rest, the interface gives a clear feedback of the status and intention of the vehicle. The size and speed of the animated segments increase in inverse proportion to the amount of time remaining before the car begins to drive, until the point that just as the car is ready to start driving, the animated segments are large enough to cover the entire dimension of the interface and appears once again to be fully lit at a steady glow – the status indicator for "cruising".

*Concept 2: The Tracker (Figure 2)*

This concept takes inspiration from the Nissan IDS concept [8] and attempts to improve upon it. It fuses the communication of situational awareness with the vehicle's intent. The interface is essentially a band of light that surrounds the

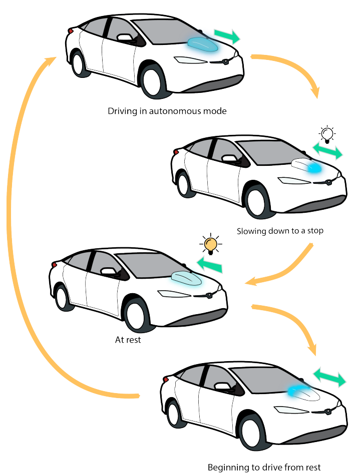


Figure 3

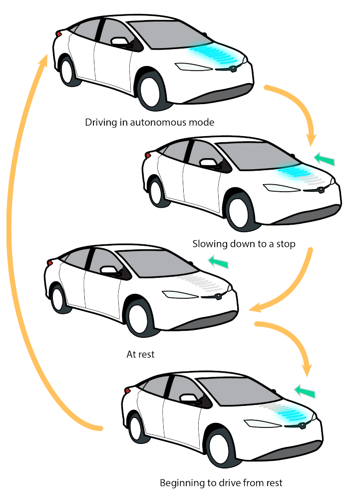


Figure 4

entire vehicle. The entire band glows steadily when the vehicle is cruising in autonomous mode. In dense, urban situations where negotiations and interactions are necessary, as the vehicle's sensors detect VRUs around itself and on its path, it illuminates a small segment of light on the part of the interface that is in spatial proximity to the position of the detected VRU. In addition, the segment of light corresponding to a detected VRU glows in a specific manner depending on the vehicle's intent – if the vehicle intends to yield to a VRU, the corresponding light segment glows green. Contrarily, if the vehicle needs to call attention of a VRU that it has "seen" them, but is not yielding to them, the corresponding segment of light on the interface pulses in a red color.

*Concept 3: The Water Dome (Figure 3)*

This concept uses a 'moving liquid' metaphor to convey the impending motion of the vehicle. The interface is a 3-dimensional dome of light on the hood of the vehicle, that is illuminated uniformly at a constant, moderately high intensity when the vehicle is cruising in autonomous mode. When the vehicle slows down with an intention to yield, the light within the dome moves and concentrates in the front of the dome (glowing with a very high intensity), just as a liquid would 'slosh forwards' by the inertia of motion if the vehicle was decelerating hard. When at rest after the braking, the concentrated light at the front of the dome dissipates leading to a uniformly lit dome glowing at a low intensity. Before the vehicle starts to drive again, the light within the dome moves and concentrates towards the back of the dome (again glowing with a very high intensity) as a liquid would 'slosh backwards' within its container if a vehicle accelerates forwards. As the vehicle stabilizes in its autonomous cruise, the concentrated light at the back of the dome dissipates once again to a uniform distribution within the dome illuminated in the moderately high intensity indicating the vehicle's current status. Given the dependence of this design on the ability of VRUs to identify the concentration of light in the dome – near the front, back, or uniformly within the dome, the shape of the dome need to be narrow and low at the front, and wide and relatively high at the back.

*Concept 4: The Timeline (Figure 4)*

The interface in this concept is a series of light segments on the hood of the vehicle arranged longitudinally. A lit segment corresponds to the vehicle's driving state, while an unlit segment corresponds to a stopped state. The segment at the very back of the interface (nearest to the windshield) corresponds to the current vehicle state, and each segment situated progressively forward correspond to a future vehicle state (the segment at the very front corresponds to the moment in time the farthest in the future within the time frame the interface is designed to communicate within). If all the segments in the interface are lit, it denotes that the vehicle is currently driving, and will be continuing to drive in the future (within the time frame of the interface). As the vehicle starts slowing down with the intention to stop, the segments start to dim progressively from the front to the back. This essentially indicates that the moment that the car will stop is approaching. If the car is at rest, the entire interface is unlit. As the car prepares to start driving again, the interface lights up progressively from the front towards the back (denoting that the moment in time when the car will be driving is approaching). Essentially, the entire interface is a moving light stream that animates from the front towards the back denoting various points in time when the vehicle will be driving or stopping. As in concept 3, this interface depends on the ability of the VRUs to see the length of the hood, so the light segments are arranged on a surface so that the segments near the back are positioned higher than the ones in the front to aid visibility from the front.

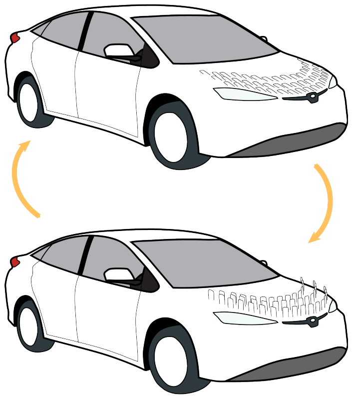

Figure 5

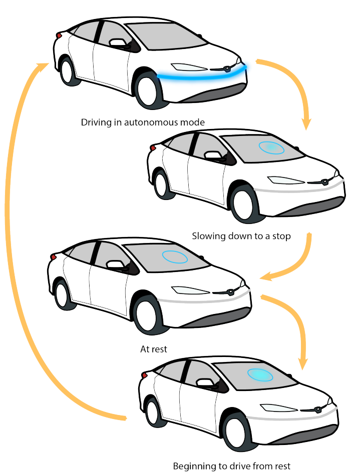


Figure 6

*Concept 5: The Hedgehog (Figure 5)*

Many existing researches call out the effectiveness of movement patterns and the 'body language' of a vehicle in implicitly communicating its intent [4,5,9,11]. While movement patterns are a direct consequence of the physics of the vehicle's drive, this concept attempts to use shape changing interfaces to augment a vehicle's implicit communication. This takes inspiration from the animal kingdom – many animals make themselves bigger (deimatic behavior) to appear assertive and ward off enemies; or exhibit demure characteristics to imply compliance or yielding behavior. Similarly, this concept uses an interface which is essentially made up of tiny 'feathers' on the hood of the vehicle which either lie flat, flush with the hood surface to simulate yielding behavior, or flare out and draw more attention to itself when it is beginning to drive from rest (assertive behavior). Shape changing interfaces have been used in concept vehicles in the past [1] for aerodynamics purposes. This concept takes inspiration from that and attempts to use them as an interface to provide an intuitive feedback of the vehicle's behavior drawing parallels to animal behaviors.

*Concept 6: The Countdown Timer (Figure 6)*

Anecdotal evidence suggests that while making road-crossing decisions in the presence of an approaching car, we look at the appearance of the car in general when it is far away but may seek to look more towards the windshield as the vehicle comes closer in search for additional evidences that the driver has recognized us and yielding to us. Thus, the place on a vehicle where pedestrians search for information changes with the distance of the vehicle. From this follows the hypothesis that the distance of the vehicle from its stopping point plays a role in the kind of information expected from it, as well as where that information is presented. Concept 6 leverages this hypothesis with a two-part interface, one part on the bumper, and the other on the windshield of the vehicle. When the vehicle is cruising in autonomous mode, the interface communicates this information through a band of light that glows uniformly on the front bumper of the vehicle. As the vehicle prepares to yield to a stop, the communication moves from the bumper to the windshield, showing a ring with a glowing light element. As the vehicle slows down, the glowing element within the ring diminishes gradually in size in relation to the vehicle speed. When the vehicle is stopped, the ring is visible and pulsates while the light element within the ring disappears. As the vehicle is ready to start driving again, the light element within the ring starts glowing again and progressively increases in size until it fills the ring. At this point, the vehicle starts driving, and the communication moves from the windshield interface to the bumper interface.

## Future Work & Conclusion

This paper describes six concepts that communicate AV intent to VRUs in dynamic, urban situations. Two of these concepts (1, 2) are improvements of existing designs, and the other four (3, 4, 5, and 6) are entirely novel to our knowledge. Each of the concepts described attempts to communicate the intent of the vehicle in a manner that scales to multiple VRUs in its environment, with the aim to be unambiguous regarding what is safe for the VRUs. In concept 2, it achieves this by pointedly conveying to each VRU in its space whether it is safe for them to proceed. In the other concepts, it achieves this by conveying a time frame of when the vehicle intends to stop. The concepts are initial designs from three brainstorming sessions from focus groups and have not been tested in real life. We expect that not every concept described in this paper will have equal effectiveness in achieving their goal. Currently, work is in progress to validate the hypothesis behind concept 6, and build tangible prototypes of Concepts 1, 2, and 5. Insights from the studies and user tests with these prototypes will help uncover the viability of the concepts.

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