Rethinking Touch HMI Controls for Automotive Displays and Smart Surfaces

Solid-state haptic technology enables novel HMI interactions while delivering safety benefits, cost savings, and multisensory brand differentiation.

by **Kevin Klein**

CONSUMERS NOW LIVE IN TWO WORLDS—THE PHYSICAL and the digital. They expect their cars to understand this dual reality and operate as seamlessly as their mobile phones and other smart devices. This preference for connectivity is one of the key drivers behind major changes to automotive interiors, touch displays, and the underlying technology powering connected experiences.

Automotive Connectivity and Display Trends

The industry is moving toward a more connected—and eventually software-defined—car, where links to the cloud and other wireless destinations are the industry standard. According to forecasts from SBD Automotive cited in the Experiences Per Mile 2030 report, built-in vehicle connectivity will grow sharply from 48 percent of all new global vehicles in 2020 to nearly 96 percent by 2030.[1]

To support the driver's and passenger's connectivity demands, automotive displays in newer models are increasing in size (15 inches and up, even stretching pillar to pillar) while also becoming thinner. Step into any modern vehicle, and you may see multiple screens as well as curved displays along the center console and elsewhere throughout the interior (**Fig. 1**).

According to research from McKinsey & Company,[2] the year 2030 could see these touchscreens either fully integrated into existing interior surfaces or foldable and retractable to make them even less obtrusive. Automakers are experimenting with new designs and locations for both driver and passenger screens, showcasing interactive surfaces in new ways, and readying consumers for a future where electrification, shared, and autonomous vehicles redefine mobility as we know it today.

Yet, despite all the innovation in size, shape, position, and connectivity, the topic of touchscreens in cars is often a polarizing one. Connectivity is just one source of frustration for drivers and passengers when their lived experience inside the car doesn't match the ease and familiarity of interacting with their everyday digital devices. Some drivers lament the loss of familiar physical controls and having to learn new digital interfaces. Other sources of pushback can be seen in automotive magazines headlines that discuss road safety and driver distraction related to vision-based displays. Mazda even made the decision to remove touchscreens based on their research that drivers reaching for screens unintentionally applied torque to the steering wheel, causing a drift in lane position.[3]

While it's true that audio, chatbots, and AI virtual assistants are available to make technology in general more accessible, the multiple applications, colorful icons, and various gestures used in today's smartphones rely primarily on vision as the means of operation. Given the ubiquity and success of the smartphone interface, it is unsurprising to see many of the same approaches and visual language transferred to vehicle display designs. This leads us to the second—and perhaps more immediate issue—safety.

Fig. 1.

Exclusive to the 2022 EQS, this 56-inch curved glass instrument panel stretches from door to door to seamlessly merge three screens.

Fig. 1: Source: Mercedes-Benz.

Minimizing Driver Distraction

For many drivers, all that is required to adjust the radio level is reaching out, feeling for a physical dial or steering wheel control, and turning down the volume without having to look away from the road. But in the move to smooth, featureless displays and vision-based controls, we lose the control's familiar physical sensation. Button elimination or replacement creates a void of haptic feedback, where once there was tactile feeling and eyes-free control.

The driver's task becomes more complex if the human-machine interface (HMI) demands additional eye-hand coordination to locate and operate controls. Infotainment systems using visual, multilayer menus add to the driver's cognitive load, which also can increase risk.

According to the US National Highway Traffic Safety Association,[4] 36,096 people were killed in motor vehicle crashes on US roadways in 2019, a 2 percent decrease from 2018. However, fatalities in distraction-affected crashes increased by 9.9 percent during that same period. Audio cues can certainly help here, particularly when they work as desired. But the lack of standardization and pace of technology change often results in an inconsistent and less than ideal experience for the driver. Enter haptics.

From Buzz to Surface Textures

When most people think about haptic technology, the buzz of their smartphone or the rumble of a gaming console may come to mind. This shaking sensation is created by physically moving mass using different types of motors, such as eccentric rotating mass (ERM) or linear resonant actuator (LRA) vibration motors. Every form of vibrotactile haptics on the market today can trace its roots back to the vibration motor. That is, until surface haptics—a new branch of haptic technology—was invented.

Surface haptics are programmable haptic textures and effects on physical surfaces. In lieu of traditional vibration actuators, surface haptics work through a phenomenon called electroadhesion (**Fig. 2**). By creating an electric field on the surface of the touchscreen, the amount of friction the finger feels as it moves across the surface can be varied.

As the finger moves through this friction, programmable software creates the sensation of bumps, ridges, and textures—the types of things people are accustomed to feeling on physical objects. Surface haptics are experienced using bare fingers directly exploring the surface, and therefore tap controls would not be felt without finger movement.

Both conceptually and practically, electroadhesion-based surface haptic technology is unlike traditional vibrotactile haptics in the following ways:

- **How it is built:** No piezos, motors, or other moving parts; the solution is entirely solid state.
- **How it is programmed:** Software-defined, high-resolution effects can be designed in localized zones.
- **How it is experienced:** Effects are felt as the finger

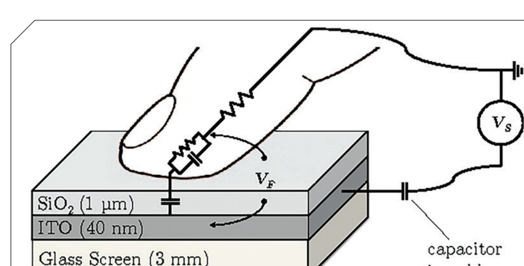


Fig. 2.

Illustration of electroadhesion:[5] An electric field acting across the skin's surface creates additional normal force, increasing adhesion. V, applied voltage; F, electrostatic force.

slides or swipes across, up, down, and around the surface.

Key Considerations for Automotive Haptics

There are a few key areas for automakers to consider when specifying and designing haptics inside the vehicle. Safety concerns can be addressed by designing controls that are easy for the driver to locate and operate using a short glance or without taking their eyes off the road. Northwestern University-based research performed in a full vehicle driving simulator demonstrated a 30 percent improvement in eyes-on-road time with the addition of surface haptics.[6] Designers also should seek to minimize the number of menus needed to access controls, as this contributes to cognitive load.

On the cost side, there are many short- and long-term factors to examine, including the number of moving parts, weight, and impact of using vibration-based haptics. As in-vehicle screens get larger, the physics are more challenging, where it becomes difficult to move the mass to create vibration-based haptics. At some point, it is no longer practical or cost-effective to vibrate large masses and isolate them from the rest of the vehicle without compromising the haptic effect. For curved, flexible, and rollable screens, vibration may not even be an option.

A solid-state surface haptic solution eliminates much of the cost and complexity introduced by vibration. Because surface haptic technologies do not vibrate the screen, they avoid large actuators and mechanical mounting and can be scaled to larger screens. Further, the tactile experience is not affected by any additional vibration created by the motion of the vehicle.

It is also important for automakers to consider how the haptic technology will integrate into existing supply chains and weigh the associated costs of different solutions. For example, a typical automotive switch pack may have expenditures beyond the module itself (e.g., costly wire assemblies, labor), and there may be reliability concerns because of air gaps, mechanical failure, moisture, and spills.

Some car manufacturers are replacing traditional switch packs with a single smart surface reusable across multiple car platforms and option packages (**Fig. 3**). Adding haptic feedback to window control locations, or front and rear controls, can give the driver or passenger confidence that the action they initiated occurred. Software programmability also means a single hardware design can be reused, updated, and upgraded in the field, allowing the addition of a new feature after purchase or at the dealership. These over-the-air (OTA) updates are a high-value investment addressing cost, design, and customer experience.

Fig. 3.

Smart surfaces, such as these digital door controls from Yanfeng, are appearing in many modern interiors.

Fig. 3: Source: Yanfeng Global Automotive Interiors.

To take advantage of long-term savings, automakers also must consider the type of haptic technology to specify, where to place haptic effects (both now and in the future), what surfaces the technology can support, and whether the technology needs to work in harmony across multiple surfaces in the vehicle. Integration considerations also must include how the technology will integrate with audio, force sensing, and other complementary technologies.

Lastly, when it comes to specifying haptic technology, it is important to think about the quality and range of haptic effects that are possible. Infotainment systems offer automakers an enormous opportunity to differentiate their brands. Those original equipment manufacturers (OEMs) that learn the ins and outs of haptic technology, how it is programmed, as well as their customers' preferences will be best positioned to compete in the fast-moving connected future.

More Sliding, Less Tapping, and Multiple Zones

The way we interact with the digital world is constantly evolving. When you want to feel something in real life, you rarely walk up to it and poke it. The natural tendency is to take it into your hands or slide your finger across it to evaluate the texture or feel. Surface haptics allow the system designer to take advantage of this natural approach.

Today, the act of tapping on digital controls is mediated mostly through the sense of vision. We look at the screen, identify where to tap, and confirm the validity of the action. In this instance, there is brief contact between the finger and surface, and therefore, limited opportunity for haptic feedback, save the occasional buzz.

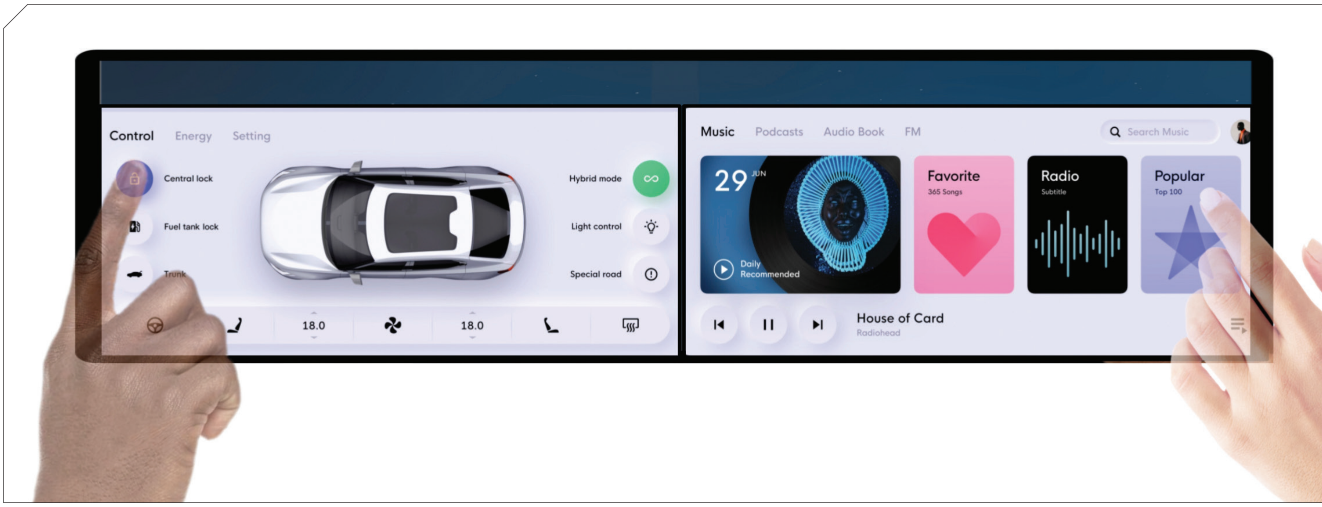


Fig. 4.

With multizone haptics capability, a single screen can be divided into dual zones—one for the driver and another for the passenger.

Fig. 4: Sources: Ran Mingwei, Car UI Concept, Behance, with additional rendering by Tanvas, Inc.

Unlike discrete taps, slide or swipe controls are mediated mostly through touch using dynamic movements. This sustained contact with the surface presents an opportunity to make haptics present during the entirety of the movement. By adding both textures and movement, more surface effects are possible. Sliding and gesture-based interactions are becoming more common in smartphones and tablets, which makes the learning curve faster and more intuitive, even in unfamiliar environments.

Because of the nature of how vibration-based haptics move mass, the range of haptic effects often is limited to one person across the whole screen. The solid-state nature of surface haptic technology gives the designer more freedom to create different effects and experiences in different zones on the same piece of glass—allowing multiple users to get a unique experience.

For instance, when multizone haptics are activated with surface haptics, the digital surface is divided into two or more zones. Both the driver and passenger can operate and experience different tactile effects on the same smart surface at the same time. For example, in **Fig. 4**, the driver might be selecting the lock at the same time the passenger is searching for music. Each person is simultaneously experiencing different haptic feedback on the same screen.

Generating High-Resolution Haptic Effects

The ability to generate dynamic tactile effects across large surfaces means a new level of haptic interaction is possible. For automakers and HMI designers creating the next generation of interfaces, the method by which haptic effects are created also must be evaluated.

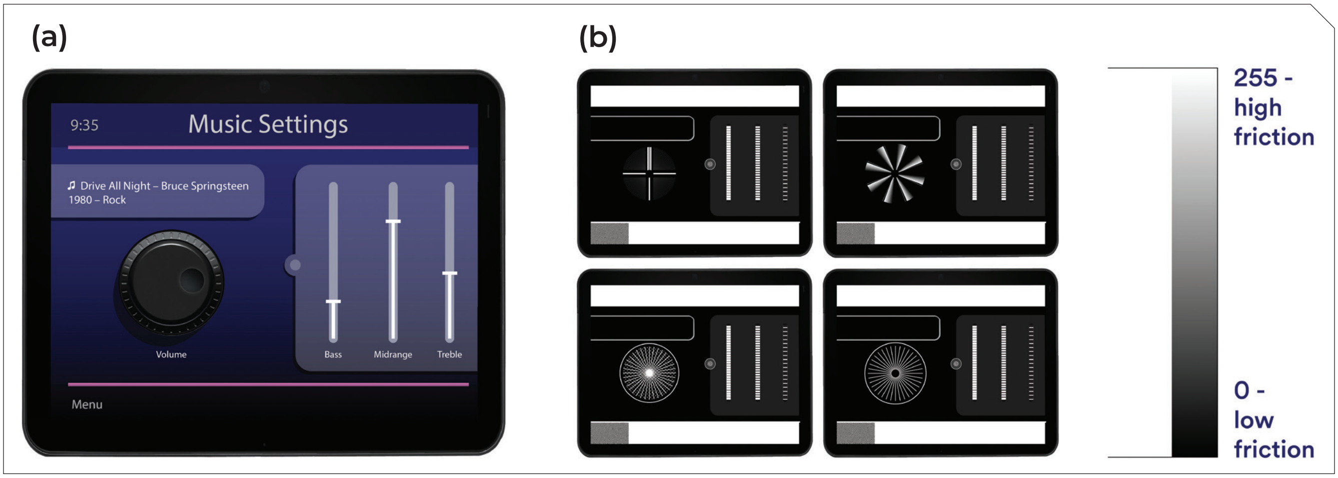
Traditional vibration-based haptic solutions can generate a range of effects, but that range may be limited. Generating effects involves complex motor control and mechanical tuning because the entire surface moves, and the effect is felt everywhere on the device at once.

Electroadhesion-based surface haptics allow for a wider range of textures because the effects are experienced only when and where the finger moves across the surface. Software programmability not only expedites the haptic generation process, but also allows for novel high-resolution effects. The click of a digital dial, flip of a toggle switch, and any range of texture from grainy to fine can be designed intentionally.

Surface haptic effects are programmed using grayscale bitmapped images, where haptic effects vary in strength from zero (none, darkest) to 255 (full, brightest), with varying strength along the spectrum (every gray in between). There are many benefits associated with using a simple image metaphor to determine where to place the haptic effects and how they will feel. Textures, detents, ridges, virtual ticks, and edges can all be programmed using software and a simple image-based metaphor (**Fig. 5**). These features and effects are infinitely flexible and can be moved anywhere on the display at any time or replaced by entirely different visuals and haptics; they are not fixed in place like electromechanical haptics. The visuals and effects also can be updated OTA, even in the field after the system is sold to the customer.

Unlike motor control waveforms used in vibration-based haptics, surface haptic assets are images that are understood easily and manipulated in familiar ways; no special knowledge or tools are necessary. The haptic images are created like any other graphic asset using industry-standard applications, such as Photoshop, Illustrator, Paint, or software programming languages, such as OpenCV and graphics drawing libraries. Haptic images match the graphic image pixel by pixel, providing high-resolution effects that can change in real time with the graphics and can be varied based on the speed and direction the finger is moving.

In the context of automotive, this high pixel-level resolution gives HMI designers a vast gamut of options with which to create new sensory experiences. Coupled with sound, these controls can begin to mimic a lifelike experience, while giving the automaker flexibility to adjust the look and feel as trends change and connectivity offerings advance.



The Art and Science of Designing Haptic Interfaces

User interface design is a mixture of both art and science, including all of the interactions the driver or passenger will have with the car interface. Designers must consider the layout of various controls, the look and feel of the overall design, and even the response time for selecting and completing actions. Textures can be designed and painted to the screen, and graphical objects can be massive, heavy, or stretchy. The only limitations are the designer's imagination and command of the tools.

Just as HMI technology constantly is evolving, so are visual design standards. Over the years, preferences have shifted back and forth along the spectrum of graphic styles. For example, in the early 2010s, flat icons gained popularity as many of the Internet giants rebranded their familiar icons. Flat icons follow the "less is more" approach for a simple way to convey a message or promote a product, whereas embossed and 3D images use more gradients and drop shadows to add depth to the icon, often giving it a more realistic appearance (**Fig. 6**).

Skeuomorphism, as defined by the Interaction Design Foundation, is when interface objects imitate their real-world counterparts, either in their appearance or how users can interact with them. User-experience designers have moved away from skeuomorphic icons toward flat designs to simplify visual interfaces on smartphones.

Neumorphism is a new take on the skeuomorphic style, where the focus is not necessarily on the contrast or similarity between the real and digital worlds, but instead the color palette. In neomorphism, there is a focus on how light moves in three-dimensional space.[7] Sometimes these effects are referred to as "soft design," and various tools help create them.

These design trends will continue to shift as HMI technology advances. Electroadhesion-based haptics that have both graphical (visual) and haptic (textural) depth may shift designs back to more realistic-looking controls. The combined tactile and visual effect also may shorten the learning curve and adoption of new technologies.

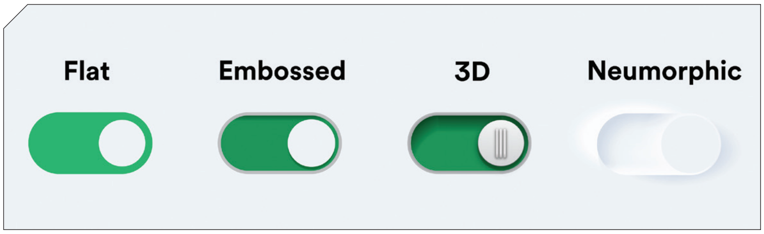


Fig. 5.

Programming display surface haptics effects. (a) A graphic image is sent to the display and viewed by the driver or passenger. These visuals are easily updated using standard graphics or programming software. (b) These four images represent examples of corresponding haptic images created using the same software as the visible graphic image. Changes to the underlying haptic texture for the volume knob alter what is felt when a finger moves across the display's surface.

Future Cabin Designs and the Role of Haptic Technology

Considering all the latest concept cars being shown, there is little doubt that automakers will continue to innovate. Understanding where to focus efforts may be the defining factor between winners and losers in a highly connected automotive future.

Research from McKinsey[2] identifies several strategic imperatives for OEMs and suppliers focused on interior differentiation. At the top of the list is building substantial new knowledge on HMI technology, OTA, and future materials followed by reducing complexity to optimize costs and make customers' lives easier. Haptic technology can play a leading role in many of these efforts.

As creativity and design freedom shift to the HMI layer, automakers can explore haptic technology as an innovative feature to make their interiors stand out during this mobility era in transition, along with providing future-proof technology to support connectivity, autonomous, shared, and electrification demands to come. In the context of broader strategic guidelines for haptic technology's wide implementation, OEMs and suppliers must keep in mind the following requirements:

Fig. 6.

Variety of graphic styles used in digital applications and interfaces.

Figs. 5-6: Source: Tanvas, Inc.

- intuitive and easily discoverable;
- low latency;
- harmonious;
- size, shape, and materials;
- noiseless;
- no moving parts;
- high bandwidth and resolution; and
- cost and ease of integration.

Current automotive trends require a holistic assessment of fundamental aspects of the car. The vehicle interior offers an untapped playground for the designer's imagination. Automotive and HMI designers are the artisans of the future, deciding both where to place smart surfaces and controls and how they should work and feel. The ability to design high-resolution haptics with pixel-point accuracy may open the door to a new creative chapter in automotive history.

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