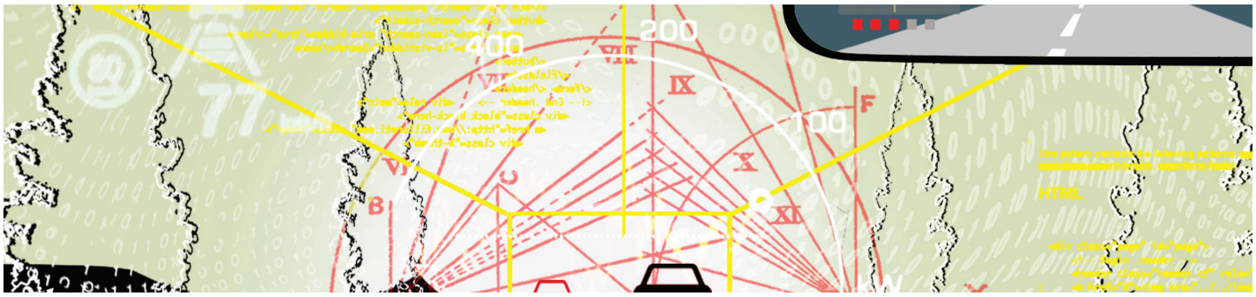

Smart Vehicle Spaces

K. Venkatesh Prasad
Ford Motor Company

Steve Hodges
Microsoft Research

Brian Noble
University of Michigan

Generally speaking, vehicles are land, airborne, and maritime transportation systems—in both motorized and nonmotorized form—that safely move people and goods and deliver related services. In the past few years, significant advancements in the form and function of computing technologies have made such vehicles "smart" spaces. Furthermore, as computing capabilities have increased, the underlying computers themselves have largely "disappeared." These invisible, pervasive computing technologies underpin and augment virtually all modes of transportation through a combination of embedded computers "built-in" to the vehicles, mobile devices "brought-in," and cloud services that are "beamed-in."

This is what makes this special issue on smart vehicle spaces so interesting and timely. These vehicle spaces have a growing intelligence and thus are increasingly able to respond to the needs of vehicle users, despite the challenges presented by the physical environments in which they operate. This growing intelligence will also help improve the safety of the people involved—those within and around the vehicles—and increase environmental sustainability, all while offering increased comforts and conveniences and improved system performance.

Computing in Cars

In our everyday experience of traveling for work or pleasure, or driving to a grocery store, or even just express-mailing a packet across the world, we often lose sight of the many technical challenges of safely taking us from "A to B" or delivering goods and services day and night. Passenger cars—a special case of motorized vehicles—are particularly interesting in this day and age, as we begin to experience "tectonic" shifts in car-related experiences. These shifts range from ride services, such as Uber and Lyft, to autonomous vehicles.

Cars contain, and are often further connected to, the essential ingredients of smart systems—they have built-in sensors and actuators, and computational and communication resources can be built-in, brought-in, or beamed-in. In *Rethinking a Lot*, Eran Ben-Joseph notes that as of 2009, there were "over 600,000,000 cars traveling on the streets and roads... and ultimately searching for parking."[1] Though Ben-Joseph didn't necessarily imply autonomously searching for parking, vehicles today are smart enough to find parking spaces and help drivers parallel-park, and they are getting smarter as autonomous driving capabilities advance.

While the number of computing elements in cars has grown linearly (from a single processor 40 years ago to 40 or more processors today), the number of interactions between the computing elements has grown dramatically—especially when you include mobile devices that interact or "pair" with cars and the embedded modems that connect to the cloud. During the past few decades, cars have transformed from being mostly mechanical platforms with isolated computing modules to networked, computing platforms, working in concert with mechanical counterparts to deliver all the attributes we expect today—safety, environmental sustainability, comfort and convenience, and entertainment!

From a societal standpoint, we're continually raising the bar for safety requirements and tailpipe emissions. From a consumer standpoint, there's a constant demand for new capabilities at affordable prices. Many car manufacturers have taken a platform approach to computing in cars, where an upfront investment in computational and communication infrastructure enables future expansion of the car's capabilities and functionality. For example, APIs for certain systems, such as the infotainment system, let us add new navigation or streaming music applications to cars. Having a mechanism for directly and securely communicating with the cloud (say, via an embedded modem or a wireless local area network such as Wi-Fi) enables a conduit through which new features can be added remotely. A recent case in point is how the carmaker Tesla remotely added and turned on an "autopilot" capability for existing owners of their product.[2]

It was with this background that we assembled this special issue on smart vehicle spaces with two articles, an interview with a technical leader, and a department on smart sensing systems for drivers. Collectively, this gives us a sampling of the advancements at the frontiers of vehicular smart spaces.

In this Issue

The first article, "RtVMF: A Secure Real-Time Vehicle Management Framework," by Konstantinos Fysarakis, George Hatzivasilis, Charalampos Manifavas, and Ioannis Papaefstathiou, describes how sets of smart vehicles could be managed by measuring key system operating parameters, thereby allowing the stakeholders to detect, enforce, and control usage and preempt security vulnerabilities. This solution includes the automated enforcement of customized fair-usage policies, such as speed limits and, in special cases, aspects of driver behavior to ensure that occupant or road safety isn't compromised.

Cars have, until now, been built on the tacit assumption that the driver will always have his or her hands on the wheel and eyes on the road! This assumption was interestingly not always valid in the horse-driven carriage era; the intelligence of the horses was forgiving of the distractions that the human carriage driver might succumb to. More than a century later, with the progress of artificial intelligence and its application in cars, we're in a position to go back to the future. In "Shifting Gears: User Interfaces in the Age of Autonomous Driving," Andrew Kun, Susanne Boll, and Albrecht Schmidt describe the need to rethink and redesign human-machine interfaces, as we embark on a journey to redefine the horseless carriage with autonomous driving capabilities. What interfaces might be relevant to the standby-human driver, when the primary driver is the machine? How might such interfaces inform the driver and, when needed, alert or "wake up" the driver? This is a very germane discussion at this point in time.

To share some perspectives on how far the industry has come with respect to the development of enabling technologies for smart vehicle spaces and the wireless communications between such spaces, we include an interview with an industry thought leader—Toyota's Ken Laberteaux. His 23-year industry experience helps pave the road ahead, as we advance to a future of a safer, greener, and more entertaining smart vehicle spaces.

Yet the true and sustaining value of a smart space is that it can also improve or alleviate other related spaces. Might smart vehicles reduce congestion, reduce tailpipe emissions, make roadways safer, and perhaps even reduce the demand for car ownership through car and ride sharing? Might smart vehicle spaces interact with smart healthcare spaces to provide improved outcomes to emergency responses? As we think of the possibilities, it's hard not to reflect on Mark Weiser's vision of computing in the 21st century[3]—the very foundation of pervasive computing. With many enabling technologies ripe for application development, and even more emerging technologies being developed in university labs, research centers, and the "garages" of startups, the time couldn't be better for us to further research and build this future of harmoniously integrated smart spaces. Sarfraz Nawaz, Christos Efstratiou, and Cecilia Mascolo describe one relevant and important example of working across smart spaces in this issue's Spotlight department, "Smart Sensing Systems for the Daily Drive." They use brought-in and beamed-in resources to help a driver finding parking, and their application builds on smart mobile devices and smart vehicles to create sensing systems for the daily commute.

As the writer and artist J.B. Jackson once said, "the parking lot symbolizes a closer, more immediate relationship between various elements in our society: consumer and producer, public and private, the street and the dwelling."[4] As computing enables smart spaces in vehicles, we see endless possibilities for individual human users and society at large to interact with and benefit from these spaces.

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the AUTHORS

K. Venkatesh Prasad is a Senior Technical Leader for Open Innovation at Ford Motor Company. His research interests include open source systems. Prasad received his PhD in electrical engineering from Rutgers University. Contact him at kprasad@ford.com.

Steve Hodges leads the Sensors and Devices research group at Microsoft Research, Cambridge UK and is a Visiting Professor at the School of Computing Science, Newcastle University. His interests broadly fall into two categories: novel electronic devices and new technologies and techniques for interaction. He has a PhD in robotics and computer vision from Cambridge University. Contact him at steve.hodges@microsoft.com.

Brian Noble is a professor of computer science and engineering at the University of Michigan. His research interests include software that supports mobile computing systems, including networking, infrastructure, and end-system concerns. Contact him at bnoble@umich.edu.