Real World Meets Virtual World:
Augmented Reality Makes Driverless Vehicle Testing Faster, Safer, and Cheaper

HENRY LIU, PhD
Professor of Civil and Environmental Engineering, U-M College of Engineering, and Research Professor,
U-M Transportation Research Institute

YIHENG FENG, PhD
Assistant Research Scientist,
U-M Transportation Research Institute

Contents

EXECUTIVE SUMMARY

Researchers affiliated with the University of Michigan's Mcity connected and automated vehicle research and testing center are combining the real-world feedback of on-the-road vehicle testing with the efficiency and speed of computer-generated environments to create augmented reality testing. This hybrid evaluation process combines simulated vehicles and traffic situations with real vehicles to create a faster, more efficient and economical approach to testing connected and automated vehicles.

By projecting the kinds of virtual traffic you might see in a video game into on-board wireless communication devices on Mcity's test-course vehicles, researchers can instantly generate the kinds of critical traffic safety situations that happen only once in millions of miles of real-world driving. Researchers are also able to adjust and replay those driving scenarios as often as they need to produce statistically valid results. The computer-generated cars, trucks, buses, trains, pedestrians and animals that confront self-driving vehicles in Mcity's augmented reality testing environment are not only less expensive to obtain than the real thing, but also won't show so much as a scratch when the research is finished.

SAFETY TESTING IS CRITICAL TO DEVELOPMENT

One of the biggest challenges facing the widespread adoption and success of driverless vehicles is guaranteeing the public, lawmakers, insurers and others that these "vehicles of tomorrow" are completely safe and trustworthy. Doing so requires a rigorous and extensive system of testing that comes with a significant stumbling block: Answering the question of whether a self-driving vehicle can safely avoid serious and potentially fatal crashes.

A critical element in testing fully automated vehicles is that, unlike conventional, driver-piloted vehicles, the evaluation process extends well beyond making sure these cars operate dependably in normal conditions while also protecting the occupants from injury and death in a collision. Instead, successful driverless vehicles must prevent and avoid crashes altogether. This means evaluators need to record the responses of self-driving vehicles to a huge number of potential crash situations – situations that are exceedingly rare. According to the National Highway Traffic Safety Administration (NHTSA), an accident serious enough to be reported to police – typically, one with at least $1,000 worth of vehicle damage – occurs once in just every 530,000 miles of driving. A crash that results in a fatality is even rarer – once in every 100 million miles of driving.

Accelerating the testing process to make it more efficient and comprehensive has been a focus of research at Mcity. Previous efforts include creating an accelerated evaluation model that can eliminate millions of miles of unnecessary and irrelevant test driving by combining elements of six separate evaluation approaches. Mcity also has a 32-acre state-of-the-art testing site on the U-M's North Campus in Ann Arbor, featuring more than 16 acres of roads and traffic infrastructure. The grounds include urban and suburban streets with intersections, including various lane configurations and sidewalks; traffic signs and signals; simulated buildings, street lights, and bike lanes; as well as obstacles such as construction barriers.

With the new augmented reality testing capability, Mcity combines the concrete reality of its highly advanced Mcity Test Facility with the safety and efficiency that computer-generated driving scenarios and virtual connected vehicles can provide. In these tests, the computer-generated virtual traffic elements are broadcast to Mcity test vehicles using a patent-pending, secure, wireless technology that allows both real and virtual vehicles to "talk" to each other and to the test-course infrastructure. Beyond cutting the time, risk and expense of testing, the augmented reality environment also allows researchers to efficiently fine-tune vehicle responses as part of the vehicle development process.

The patent-pending technology was developed by Professor Henry Liu and researcher Yiheng Feng. Liu is professor of civil and environmental engineering in the U-M College of Engineering, and research professor with the U-M Transportation Research Institute (UMTRI). Feng is an assistant research scientist at UMTRI.

OVERVIEW OF TESTING METHODS

For connected and driverless vehicles to succeed, these cars and trucks will need to be extensively tested before they can be responsibly put on the road – in tests that will be accepted and embraced by insurers, lawmakers and the driving public. Until this new effort by Mcity researchers, testing fully automated vehicles primarily has consisted of three different approaches: computer-generated simulations; testing vehicles or vehicle components on a closed test course, such as the Mcity Test Facility; and putting vehicles or individual components on public roads. Much of the debate about testing focuses on the legality, liability, and risk of putting test vehicles on public roads, and accidents involving test vehicles only serve to underscore the risk of trusting "robot cars" on public highways. Between September 2014 and January 2017, for example, 11 suppliers and manufacturers reported 26 crashes while testing self-driving technology on public roads in California. In 2018, a woman walking her bicycle across a street in Tempe, Arizona, was killed when she was hit by a driverless vehicle operated by Uber.

This is where Mcity's new augmented reality testing capability presents a solution. The researchers borrowed from the world of video-gaming and other virtual technologies to pioneer a way to combine the virtual and real worlds. Augmented reality testing offers the safety of a closed vehicle testing facility with real infrastructure and the added complexity of computer-generated vehicles and other elements that test vehicles can interact with in real time. The result is an infinitely adaptable testing environment where test vehicles interact and communicate with computer-generated virtual traffic in situations of all kinds with little to no risk and at far less cost than other testing approaches.

ELEMENTS OF AUGMENTED REALITY TESTING

Mcity's augmented reality testing works by combining two existing test environments: the real world and simulation.

Simulation tests, performed in labs, are useful for developing and early testing of sensors, controllers, software, and even, in some situations, complete vehicles. A closed test track is a good step up from computer-only simulations because it involves real roadways, infrastructure such as signals and signs and, to a limited extent, other vehicles. But to get a complete test environment, self-driving vehicles need to interact with background traffic and other elements encountered every day by drivers on public roadways. Unless the driverless test vehicle encounters and responds to real traffic, the test scenarios that can be created in simulation labs and on closed tracks are constrained in proving the reliability of driverless cars. The drawback to real traffic testing, however, is that while designers are perfecting driverless technologies, any mistakes a self-driving vehicle makes on public roads can be expensive, dangerous and even potentially fatal. This is where augmented reality testing provides an answer.

The real-world elements consist of the Mcity Test Facility, its connected infrastructure, and self-driving test vehicles, such as a Lincoln MKZ hybrid already in use at Mcity. The virtual environment is created using an array of computers, wireless communication, and mapping modules and other components that send and receive data and signals to and from the test vehicle. This test platform can generate a virtual vehicle that threatens the self-driving test vehicle, and can broadcast that information to the test vehicle's on-board communications device in real time using Dedicated Short-Range Communications, or DSRC.

As the test car travels the track, responding to real and virtual traffic and environments, researchers can measure how it responds, knowing that if it doesn't react in time or takes the wrong action, no actual collision will take place. An observer watching such a test would witness, for example, a test vehicle approaching a stoplight but stopping several yards short of the intersection, in order to avoid rear-ending the simulated vehicles already waiting at the same light.

With this approach, background vehicles created by the simulation computers are coordinated with the actual signals the test vehicle receives from its own sensors and the roadside signals on the test track. To the test vehicle, both sets of data inputs are equally "real" and require an equal and appropriate response. In turn, the test platform's data management component receives and collects data from the test vehicle's sensors and controllers, adjusting the simulated traffic and other components of the virtual traffic layer to respond in turn to the test vehicle's actions. This creates a sophisticated loop of events, responses, and reactions circulating between the test vehicle, physical test track components, and the simulated world of traffic and events that is layered over the real-world test car and track.

One technical challenge U-M researchers had to wrestle with was making sure that signals between the simulated testing platform and the test vehicles matched what driverless vehicles would encounter in the real world, when they interact with other self-driving cars and trucks as well as communications from traffic signals, mapping satellites and other infrastructure components.

The researchers found that if a message can be received and processed before the next message is sent, any difference between the speed of a signal transmission in real-world driverless vehicle situations and augmented reality tests does not influence the test-vehicle reaction and the outcome of the tests. Scenarios with fewer than 100 vehicles could be processed in 90 percent of cases with no consequential lag. And, even in the very rare cases where a test would need to involve 100 vehicles, only about 30 percent of the data would be transmitted at less than the acceptable required speed for testing.

Because all of these events and interactions between the test vehicle, test track, and virtual environment are captured by the simulation platform, each scenario is easily recorded and preserved so it can be analyzed and exactly repeated in the future, or tweaked to add additional variables.

TESTING THE AUGMENTED REALITY APPROACH

Mcity researchers tested their new evaluation procedure using two high-risk scenarios created in the Mcity Test Facility – an approaching train at a railroad crossing and a virtual vehicle running a red light when the test car approaching the intersection has the green light.

Train-car collisions are far less frequent than the 6 million-plus crashes between vehicles each year – and are substantially reduced from several years ago, down to a projected 2,250 for 2016 versus more than 3,500 recorded in 2000. However, car-train accidents are far more dangerous. According to NHTSA, a driver is nearly 20 times more likely to die in a crash involving a train than in an accident that involves another motor vehicle.

The time, expense, and complications of repeatedly running a diesel train through a closed test course would make testing a self-driving car against an approaching train nearly impossible, as would the risks involved in sending a driverless test vehicle onto a public roadway to encounter a real freight train, not to mention the enormous amount of time to gather a statistically significant number of train-crossing interactions.

With augmented reality testing, U-M researchers were able to successfully measure the test vehicle's ability to stop at the crossing and wait for the train to pass. In addition to a virtually generated oncoming train, the scenario was further complicated by directing the simulation platform to generate three virtual vehicles stopped ahead of the testing vehicle at the crossing, which the test vehicle also had to sense and avoid.

The red-light running test scenario presents a serious traffic risk to drivers. During 2014 more than a quarter of all people killed in crashes at intersections controlled by signals were fatal. In the Mcity test, a west-bound test vehicle approaches an intersection where the test car has the green light as a simulated vehicle approaches the intersection from the south without slowing down. The test vehicle is required to project its own path, plus the path of the virtual vehicle, to avoid any potential collision. In one scenario, the test and simulated vehicles are close enough that the test vehicle needs to stop to successfully avoid a crash. In the second, the test car is far enough away from the intersection that it can simply slow down or continue on its way without being hit. The test vehicle needs to keep going so it does not create a hazard to other traffic by swerving or slamming on the brakes.

The researchers were able to time the approach of both vehicles with the traffic signals and run enough test scenarios to determine when the test vehicle needed to make a full stop and when it could safely continue. The researchers estimate that this new approach can accelerate the evaluation process by 1,000 to 100,000 times, depending on different testing scenarios.

Now consider the number of vehicles, drivers, and damaged sheet metal that would go into testing whether a self-driving car can avoid a vehicle running a red light on a closed test track with any kind of certainty. Then think about how many thousands – or even millions – of miles a driverless car would need to travel before it encounters even one other driver running a red light.

To find out just how reliable the augmented reality approach can be, the researchers also tested this red-light running scenario with a real vehicle on the Mcity track. The results? Exactly the same as data collected in the augmented reality tests.

CONCLUSION

Augmented reality testing shows great potential in speeding up and reducing the cost of testing self-driving vehicles. It can accelerate testing by an estimated 1,000 to 100,000 times, depending on different testing scenarios, and reduce costs beyond physical test vehicles to almost zero. Evaluators can create an unlimited virtual library of computer-generated traffic scenarios that can then be endlessly repeated with no risk, no damage, and no injuries to help developers refine hardware and software components. Augmented reality testing will help assure manufacturers, suppliers, and – most importantly – consumers, that the rapidly developing "cars of tomorrow" will be reliable, trustworthy and safe.

About Mcity

Mcity at the University of Michigan is leading the transition to connected and automated vehicles. Home to world-renowned researchers, a one-of-a-kind test facility, and on-road deployments, Mcity brings together industry, government, and academia to improve transportation safety, sustainability, and accessibility for the benefit of society.

UNIVERSITY OF MICHIGAN

RESOURCES

Mohd Zulkefli, M. A., P. Mukherjee, Z. Sun, J. Zheng, H. X. Liu, and P. Huang. Hardware-in-the-Loop Testbed for Evaluating Connected Vehicle Applications. *Transportation Research Part C: Emerging Technologies*, Vol. 78, 2017, pp. 50-62. https://doi.org/10.1016/j.trc.2017.02.019.

Sunkari, S. A Platform for Change: TTI Provides FHWA a New Way to Test CV/AV Technologies. *Texas Transportation Researcher*, Vol. 52, No. 4, 2016.

Wang, F. Y. Parallel Control and Management for Intelligent Transportation Systems: Concepts, Architectures, and Applications. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 11, No. 3, 2010, pp. 630–638. https://doi.org/10.1109/TITS.2010.2060218.

Li, L., and D. Wen. Parallel Systems for Traffic Control: A Rethinking. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 17, No. 4, 2016, pp. 1179–1182. https://doi.org/10.1109/TITS.2015.2494625.

Li, L., W. L. Huang, Y. Liu, N. N. Zheng, and F. Y. Wang. Intelligence Testing for Autonomous Vehicles: A New Approach. *IEEE Transactions on Intelligent Vehicles*, Vol. 1, No. 2, 2016, pp. 158–166. https://doi.org/10.1109/TIV.2016.2608003.

Fagnant, D. J., and K. Kockelman. Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations. *Transportation Research Part A: Policy and Practice*, Vol. 77, 2015, pp. 167–181. https://doi.org/10.1016/j.tra.2015.04.003.

Singhvi, A., and K. Russell. Inside the Self-Driving Tesla Fatal Accident. *The New York Times*, 2016.

PTV. VISSIM 6.0 *User Manual*. Karlsruhe, Germany, 2013.

Farrell, J., and M. Barth. *The Global Positioning System & Inertial Navigation*. McGraw Hill Professional, 1999.

Gipps, P. G. A Behavioural Car-Following Model for Computer Simulation. *Transportation Research Part B*: Methodological, Vol. 15, No. 2, 1981, pp. 105–111. https://doi.org/10.1016/0191-2615(81)90037-0.

Zhao, D., H. Lam, H. Peng, S. Bao, D. J. LeBlanc, K. Nobukawa, and C. S. Pan. Accelerated Evaluation of Automated Vehicles Safety in Lane-Change Scenarios Based on Importance Sampling Techniques. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 18, No. 3, 2017, pp. 595–607. https://doi.org/10.1109/TITS.2016.2582208.

Zhao, D., X. Huang, H. Peng, H. Lam, and D. J. LeBlanc. Accelerated Evaluation of Automated Vehicles in Car-Following Maneuvers. *IEEE Transactions on Intelligent Transportation Systems*, Vol. PP, No. 99, 2017, pp. 1-12. https://doi.org/10.1109/TITS.2017.2701846.