Locata Positioning Used for World's First Fully-autonomous Robotic Testing in Vehicle Collision Avoidance Systems

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INTRODUCTION

America's influential Insurance Institute for Highway Safety (IIHS) is currently working with Perrone Robotics, Inc. (PRI) and Locata Corporation to implement a $30 million upgrade at their world-famous Vehicle Research Center (VRC) in Ruckersville, VA.

Figure 1: Vehicle Research Center near Washington DC

PRI's innovative robotics delivers an enhanced capability suitable for automated testing of next-generation vehicle safety technologies, and Locata's non-GPS-based positioning system provides the vitally important high-precision positioning required by the VRC to perform rigorous, consistent and repeatable automated testing. Together, these innovations promise to revolutionize the evaluation of new vehicle crash avoidance systems. VRC crash tests have historically produced the automobile industry's well-known TOP SAFETY PICK ratings, which have helped consumers make informed decisions about buying safer cars for years. Now, research into new technology systems which allow cars to "avoid" crashes in the first place will elevate the value of the Institute's safety ratings to new levels.

Carrying out these new tests is not a trivial exercise. The robotics used for crash-avoidance testing need to operate at realistic speed and acceleration dynamics while also being able to survive an actual crash. Additionally, the newly expanded VRC facility includes a continuous vehicle test track that transverses not only open-air roadway areas, but also a vast 300 foot by 700 foot (almost 5 acre) fully covered "indoor" testing area where GPS is unreliable. To meet the VRC's testing requirements, PRI applied their automation expertise to develop improved robotics, and a Locata positioning network is being installed in stages over the entire VRC test area. Locata's unique ability to provide seamless locally controlled centimeter-accurate positioning across both the outdoor and indoor environments gives the IIHS the flexibility to design a test system to meet their vital safety-of-life requirements, while also allowing easy upgrade and expansion in the future.

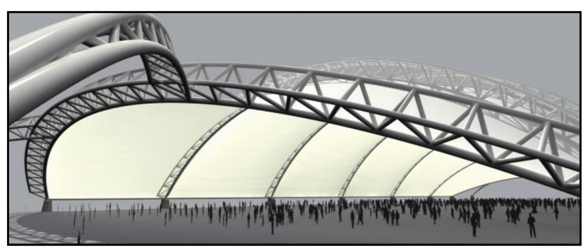

Figure 2: Artist Conception of the 5-acre VRC Indoor Test Area, now under construction

BACKGROUND

As automotive manufacturers and technology companies like Google inch closer to delivering the long-awaited driverless car, the safety systems and Advanced Driver Assistance Systems (ADAS) built into vehicles continue to exhibit more and more autonomy.

The Vehicle Research Center is a world-class center for research and testing, helping to drive life-saving improvements in vehicle designs. The Institute continues to innovate in its crash-test programs to advance vehicle safety amid rapidly changing technology.

When forward-thinking insurers launched the VRC in 1992, technology to help drivers avoid crashes was then in its infancy and automotive safety research mainly focused on protecting people inside vehicles during crashes. Most comparative testing of vehicles centered on brake stopping distances or lane-change maneuvers. Antilock brake systems (ABS) to help drivers steer in emergency situations were just beginning to gain a market foothold.

As such, the VRC was designed with a limited capability for crash avoidance evaluations. As originally constructed, the outdoor test track was large enough to accommodate straight-line braking for vehicles at speed. It allowed researchers to compare vehicle controllability under both normal and slippery conditions and demonstrate the potential (or lack of potential) for technologies like ABS and electronic stability control (ESC).

Clearly, as new crash avoidance systems became available, the IIHS needed the capability to conduct a much more varied range of tests to evaluate these emerging technologies and help push their development to new levels. After all, the passenger vehicle fleet looks much different today than it did 20 years ago, and computers are now embedded in myriad automotive systems. Technologies that warn drivers, and in some cases take control on their behalf, are quickly coming to market. As with ESC, the types of tests needed to evaluate such systems require larger testing areas than originally built at the VRC.

The tests the VRC has performed to assess new technologies over the last two decades demonstrate the need for testing under more controlled conditions than can be achieved with its legacy capability. Improved and more tightly controlled conditions will become increasingly important when comparing systems with different approaches to the same problem (for example, cameras versus radar for forward collision warning).

The IIHS recognized that testing today's collision avoidance systems safely, accurately and repeatably requires that the test system itself possess programmable, autonomous driving capability. Accordingly, in 2013 the Institute's Board of Directors authorized a $30 million expansion to the VRC to transform it into a world-class facility for crash avoidance testing. Thorough research and testing at this facility will encourage manufacturers to equip vehicles with advanced technologies that save lives and reduce both injuries and property damage on the nation's roads.

This expansion will once again show the world that US insurers "really mean it," as one automaker remarked upon seeing the VRC for the first time in 1992. Indeed, the expansion will maintain insurer leadership in driving vehicle safety improvements. Through crashworthiness testing at the VRC, insurers have greatly accelerated the introduction of life-saving technology and played a large role in educating the public about occupant protection in motor vehicle crashes. In return, US insurers have gained national and international prestige for independently funding this active role in protecting American motorists (and their own policyholders). The goal is to repeat this win-win outcome in the rapidly advancing world of electronic vehicle controls.

To support these initiatives and deliver a modern test capability for new crash-avoidance technologies, the IIHS contracted with Perrone Robotics, Incorporated (PRI) to develop the Autonomous Vehicle Test System (AVTS) as part of this facility expansion. Perrone Robotics has been a pioneer in autonomous ground vehicle technology since fielding an entry in the DARPA Grand Challenge in 2005, and has subsequently developed robotic platforms and systems to test automotive safety systems. Its AVTS is a combination of robotic subsystems that empowers safety test facilities, vehicle manufacturers and vehicle safety system suppliers to safely, accurately and repeatably test Advanced Driver Assistance Systems and autonomous collision avoidance systems in today's vehicles. Unlike previous test offerings, the AVTS supports testing and safe collisions at highway speeds and can be used in indoor labs and covered test tracks as well as outdoors. This was an attractive capability to the IIHS, since the VRC expansion will consist of both indoor and outdoor test areas.

The VRC expansion includes doubling the area of its legacy outdoor test track, an upgrade that has already been completed. The track's length has been extended by 175 feet and a portion of its width has been increased from 150 feet to 400 feet. This will provide sufficient space to safely conduct a variety of obstacle-avoidance maneuvers involving curved paths and multiple vehicles. With the existing turnaround loop, the expanded track is large enough for test vehicles to safely attain highway speeds for test maneuvers. The enlarged track is also suitable for human factors testing, allowing closed-loop courses to be established in order to observe volunteer driver reactions to system warnings and autonomous interventions.

Figure 3: VRC New Indoor Area Construction Underway

Many crash avoidance tests are now being conducted on the expanded outdoor track. However, outdoor tests are subject to changing environmental conditions. Variations in lighting, atmospheric conditions and surface wetness can affect the operation of crash avoidance systems. While it is desirable to evaluate systems under adverse environmental conditions, it is necessary to control as many conditions as possible when comparing the performance of different systems. Consequently, the Institute is also building an enclosed test facility covering approximately five acres. This size will limit the range of tests under controlled conditions, but it will allow a number of tests to be conducted on a year-round basis. A covered test track will also enable the Institute to continue to perform demonstrations on demand for the media regardless of prevailing weather conditions.

THE CHALLENGES

As one would expect, testing systems such as Crash Imminent Braking (CIB) or Dynamic Brake Support (DBS) requires putting the vehicle under test into real-world conditions where a crash is imminent to see how the crash avoidance systems perform. Unfortunately, doing this safely, accurately and repeatably poses a significant challenge.

Simply driving a car toward another car to see how the safety system performs runs the risk of injuring people and damaging property. For testing at low speeds with stationary hazards, it may be acceptable to have a human driver approach the obstacle. However, testing according to standards put forth by the organizations like National Highway Traffic Safety Administration (NHTSA) and European New Car Assessment Programme (Euro NCAP) requires not only higher speeds, but also with moving vehicle hazards in the test environments. Looking ahead, IIHS realized they needed a system that looked and moved like a car, which means traveling up to 55 mph as well as exhibiting car-like steering, acceleration and braking. And, of course, all this high-speed movement must be accurately controlled and repeatable to ensure that tests are performed the same for subsequent test runs and across different vehicles being tested. Another requirement IIHS had was the ability to operate on a covered track, that is, without dependence on GPS for location and heading information for navigation.

IIHS surveyed solutions for ADAS and crash avoidance testing in the marketplace. The initial work Perrone Robotics performed for the project involved researching how to adapt their existing robotic platforms to meet the stringent IIHS requirements, which proved to be difficult. The top speed of available targets were generally limited to under 40 mph, and the robotic driving options tended to be piecemeal offerings rather than fully integrated test systems. These existing options also didn't allow for the human driver to sit comfortably in the vehicle and regain control easily when needed. Furthermore, almost all systems evaluated for this project required GPS for autonomous navigation, which would not be available on the new covered track.

Finally, because most off-the-shelf hardware options were heavily tied to GPS, attempting to modify an existing system to meet maneuverability requirements (e.g. target speed, acceleration) while also developing a cost-effective adaptation to a non-GPS-based positioning system became extremely problematic. Thus, PRI had to simultaneously develop new robotic platforms, leverage cutting-edge positioning technology, update their automation software, and integrate these essential components into an automotive test system capable of meeting current and future crash-avoidance test requirements.

THE SOLUTION

In order to address these testing challenges, Perrone Robotics needed to develop a robotic test system to meet requirements for safety, accuracy and repeatability, as well as performance requirements set forth in NHTSA and Euro NCAP test profiles.

Additionally, the system needed to perform on the VRC's new covered track as well as on the outdoor track. This means that the test system could not rely on GPS for positioning and navigation.

To meet these crash avoidance test needs, Perrone Robotics developed the Automated Vehicle Test System (AVTS), an integrated system including an autonomous Target Robots and Drop-in Actuator Kit (DAK) systems of sensors and actuators to robotically drive the vehicle under test. The Target Robot accommodates one of several types of strike-able targets that are knocked off in the event that the collision avoidance system under test fails to prevent a collision. The vehicle simply runs over the target robot base, avoiding injury to drivers and damage to vehicles.

Both the target robot and test vehicle (under control of the DAK) drive autonomously according to programmed test plans to ensure repeatable testing of the test vehicle's safety systems. With this system, IIHS can repeatably put vehicles onto a collision course at highway speeds and effectively test the collision avoidance technology.

To achieve the necessary level of control precision, the IIHS and PRI enlisted Locata Corporation's expertise to install a network of ground-based beacons. These can provide the same as or better positioning information than high-precision GPS and have the advantage that they are wholly within the control of the researchers and technicians at the VRC. Thus, interruptions of the GPS position signals associated with obstructions, changing satellite constellation geometry and other interfering elements should not disrupt IIHS testing plans. Furthermore, it was determined that high-precision GPS likely would not be available on the covered test track because its roof would block satellite signals necessary for the precision which is essential for the facility. The Locata technology platform provides a single solution that can deliver the required precision over all of the newly expanded test areas.

SYSTEM DESCRIPTION

Many crash avoidance systems are designed to mitigate crashes with other vehicles or people. Consequently, "soft" vehicle targets representing vehicles and pedestrians are needed for many of the next-generation tests. These vehicle and pedestrian targets are typically balloons or made from foam, but they can be more elaborate when various elements are added to improve their fidelity to the real object from the perspective of the sensors used to support crash avoidance systems (e.g. radar, laser, cameras).

As part of the VRC expansion, the Institute's crash avoidance research will now also involve systems to make the dummies move on the test track. Perrone Robotics' AVTS includes "strike-able carrier systems" that are self-propelled and robotically controlled. This allows researchers to conduct more realistic tests than would be possible with just stationary dummies.

In addition, the AVTS vehicle control system helps drivers more precisely control test vehicle position, speed and acceleration than they would be able to alone. The high level of precision in carrying out crash avoidance maneuvers is necessary in order to detect differences in the performance of competing systems that provide the same basic function.

The AVTS consists of four key elements: The Test Vehicle Drop-In Actuator Kit (DAK), Target Robots, a Locata non-GPS-based Positioning System, and AVTS Software.

Figure 4: The Test Vehicle Drop-In Actuator Kit can convert any vehicle into an automated system within 30 minutes

Test Vehicle Drop-In Actuator Kit: Properly testing automated vehicle safety systems requires reliable and repeatable execution of test maneuvers. To accomplish this, a DAK can be installed in any vehicle in under 30 minutes to robotically drive the vehicle under test. The DAK precisely controls the vehicle's steering, brake, and throttle to repeatably execute all test maneuvers, either completely autonomously or—since it allows for a human driver to sit comfortably in the driver's seat during operation—human-operated without interference. The kit includes an e-box with all electronics for navigation and for interfacing with sensors and actuators.

Figure 5: The Target Robot is designed to sustain a run-over by SUVs and tractor trailers

Target Robot: The Target Robot, which also performs precise, repeatable maneuvers, carries multiple soft, crashable targets and supports collisions up to 55 mph. Through Teleop remote control or autonomous navigation, the Target Robot can travel with acceleration, steering and braking dynamics similar to a passenger car. Its mounted crashable targets are configured to represent passenger cars, trucks, cyclists and pedestrians. Its base, a mere four inches high, is designed to sustain a run-over by SUVs or, in some configurations, a run-over by tractor trailers. If the safety system of the vehicle under test fails to prevent a collision, the test vehicle runs over the base and collides with the soft target, which can be quickly retrieved and reassembled on top of the target robot base.

Locata Non-GPS-based Positioning System: The AVTS Positioning System provided by a Locata network is, by design, not tied to GPS. Both the DAK and Target Robot must operate under precise, autonomous navigation inside or outside, which is necessary to meet repeatable test objectives on a covered track or inside a building. Perrone Robotics understood early on that GPS can introduce reliability and repeatability issues on outdoor tracks and,

Figure 6: A Locata Receiver, installed as an integral part of the DAK, provides position accuracy to <10cm

because GPS is not designed to deliver accurate positioning in areas where its satellite signals are obstructed, is completely unsuitable for centimeter-level positioning in a covered or indoor environment. Fortunately, Locata Corporation provides non-GPS-based positioning system that overcomes the limitations of GPS or any other Global Navigation Satellite System (GNSS). Locata's positioning system uses a constellation of LocataLite units that can be placed to ensure that consistent and accurate position, navigation, and timing (PNT) data is available everywhere it is required. Properly configured, a Locata network can therefore provide centimeter level positioning capabilities in areas where GNSS systems cannot provide coverage. Armed with Locata, the AVTS is designed to be accurate to <10 cm indoors or outdoors, rain or shine, 24/7.

Integrating Locata into the AVTS was no more difficult than integrating GPS hardware, but mounting the Locata antenna on the Target Robot required some careful thought. Since the target is a "soft" vehicle that can be impacted and even run completely over by the test car, the Locata antenna needed to be in a good location to be able to see the LocataLites, but also had to be inexpensive since it might be destroyed in the collision. Additionally, the antenna also required a system to allow it to pull out of the Target Robot without pulling out any other RF cables or destroying the resident Locata receiver. To solve this problem, PRI found and deployed a quick disconnect RF connector, which proved to work well. Although such connectors are typically high loss when compared to standard connectors, Locata operates at a relatively high power level, so the additional loss imposed by the new RF connector does not impact system performance at all.

AVTS Software: The AVTS includes software for defining and controlling all tests, as well as transferring and reviewing data. Each Target Robot and DAK includes an embedded computer that runs the software for autonomous self-navigation, bot-to-bot communication for precise coordination of relative positioning and logging data. Based on IIHS requirements, the AVTS Software features software for performing tests including NHTSA Crash-Imminent Braking (CIB), NHTSA Dynamic Brake Support (DBS), Euro NCAP Autonomous Emergency Braking (AEB) and others.

TEST RESULTS

Since both both the DAK and Target Robot rely on precise positioning information from the Locata system to operate and thus enable the entire AVTS capability, great care was taken to install the LocataLite ground infrastructure, as well as to verify and validate its performance.

Figure 7: Temporary LocataLite Site

Locata installed an initial temporary network in June 2013 to allow development of the robot software. This network served as the development platform for the robots with temporary locations for the LocataLites. Temporary locations were used because of construction on the track that prevented occupying final locations. Also, using the temporary installations allowed testing of the final LocataLite installations prior to pouring concrete and erecting permanent towers.

The LocataNet was moved in the first quarter of 2014 to occupy four permanent towers on the outdoor track and new temporary locations on top of the buildings to support initial deployment into the covered area. This semi-permanent LocataNet has been used for the performance testing to date.

To verify the installation of the LocataNet and subsequent Locata receiver (also known as a Locata "rover") positioning performance, many tests have been conducted at the VRC test track. Given that there is no GPS used in the vehicles which can be employed as a truth reference, one of the conducted tests was to install two Locata rover antennas on the roof of a vehicle on a fixed baseline of known length (1.77 meters). With the two Locata rovers independently computing an autonomous position in real-time, the vehicle drove circuits around the test track.

Figure 8 shows the real-time horizontal position of one of the rovers. The baseline distance between the two Locata rover antennas was computed epoch-by-epoch and compared against the known baseline length of 1.77 meters.

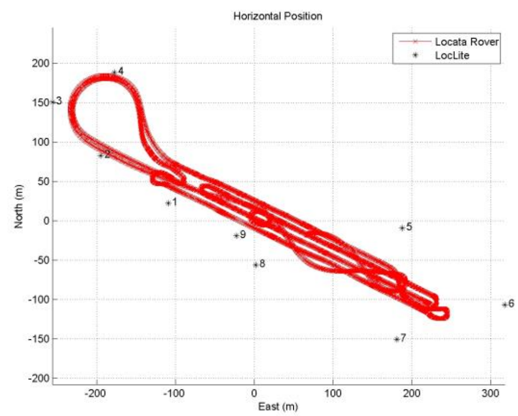

Figure 8: Horizontal positioning trajectory of fixed baseline test

Figure 9 shows the relative position error between the two Locata receivers as a percentage distribution. The graph in Figure 2 shows the error in 67% of the baselines computed is better than approximately 3.2cm and 95% better than approximately 6.1cm. These statistics relate to two receivers, so for individual receivers this equates to a horizontal positioning error of better than 2.1cm (67%) and 4.2cm (95%), thus demonstrating the required 10-centimeter relative positioning performance needed on the existing track area.

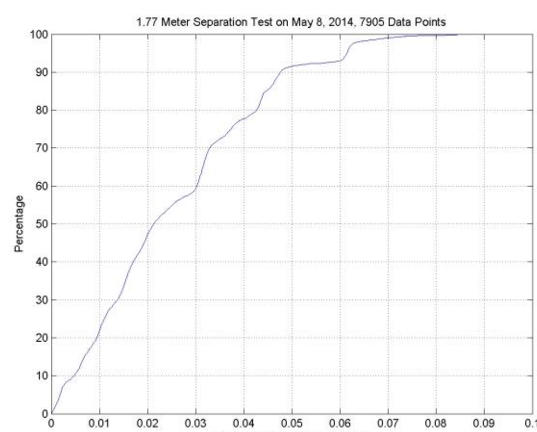

Figure 9: Percentage distribution of relative error between two Locata receivers in fixed baseline test

Locata's independently validated position accuracy enabled the fully integrated AVTS to meet the VRC's Acceptance Testing of DAK and Target Robot speed and precision requirements. Acceptance included running specific NHTSA and Euro NCAP tests including NHTSA Crash-Imminent Braking (CIB), NHTSA Dynamic Brake Support (DBS), and Euro NCAP Autonomous Emergency Braking (AEB).

FUTURE PLANS

The first phase of the project was essentially focused on developing version 1.0 of the system including one target robot, one DAK, and the required hardware and software infrastructure for operation on the outdoor track at the VRC. This infrastructure included an initial Locatalite constellation, wireless communications networking, and a safety system including a local Emergency Stop (E-stop) for the DAK and remote E-stop for the target robot.

The next phase of the VRC expansion involves building more robotic units and extending the safety system as well as software for test configuration, test control and data management. During this phase, PRI will install and configure the respective centralized planning and data collection servers and software for the outdoor and covered track sites. This includes a new Human-Machine Interface for test configuration and control that will provide a more user-friendly and comprehensive method for operation of the individual robots and overall systems. This interface will allow users to intuitively configure all elements of a complete test profile, including vehicle/robotic unit routes, parameterized condition triggers for actions and E-stop behavior. Examples of parameterized triggers include achieving target speed, achieving target following distance, achieving target deceleration rate and detection of audible, visual or haptic warnings. These conditions can trigger independently and immediately, or in combinations with each other according to defined wait states for duration of conditions. Actions taken in response to triggers include effecting motion parameters, maintaining or changing actuator positions, generating digital or analog output values and logging event messages.

The covered area of the track will be instrumented with LocataLites as soon as construction is complete, which is anticipated before the end of 2014.

Figure 10: Permanent LocataLite Site

CONCLUSION

The IIHS expansion project is a first of its kind for automated vehicle testing, breaking new ground for target positioning and control, and providing the first indoor test track for this purpose. Data from these tests will be used to improve safety of on road semi- and fully-automated vehicles and help save many thousands of lives, setting a high bar for capability and performance of all automated vehicle functions. Requirements for safety, repeatability, and seamless handoff between driver and autonomous control of the test vehicles, as well as the speeds at which the robots must travel and survive collisions, are met with Perrone Robotics' high-tech AVTS.

Each of the main components in the AVTS system represents a first-of-its kind achievement. The drop-in kit that quickly adapts to any vehicle and allows the human driver to ride comfortably and regain control is a novel achievement. The 4" high target robot platform with its improved capability for speed, acceleration and autonomous navigation is also an industry first. And the Locata localization and positioning system accurately positions both the DAK and the Target Robot, its first use for a robotic or autonomous vehicle application.

With the new kind of test system, the IIHS is well-positioned to test new and emerging vehicle safety systems and to continue to deliver the cutting edge technology required to fulfill its mission of improving the safety of all automobiles - standard *or* autonomous - on American roads.