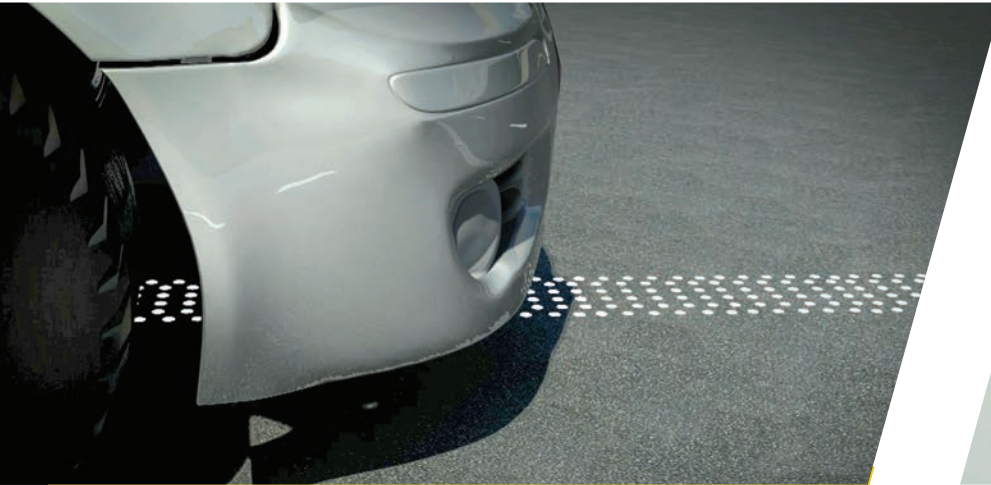# Autonomy on Roadways and Railways

RPS reads coded paint drop bit patterns on road.

The success of autonomous vehicles depends on both changes in the vehicles themselves and the transportation infrastructure. Autodrive is developing technology that uses plastic code markers on roads and rail tracks to precisely locate a vehicle. Such precision can increase the safety and the traffic capacity of infrastructures and reduce energy consumption on railways. It can also help to avoid automobile collisions and provide a powerful tool to achieve Level 5 autonomous driving. Simulation and model-based development code is critical in creating the certified embedded software that controls the hardware in these systems.

By **Alejandro Badolato**,
Founder and CEO,
Autodrive Solutions,
Madrid, Spain

Roadway Applications

Many of the autonomous vehicle solutions being developed today focus on the sensors and embedded software in individual vehicles making the right decision for that vehicle. Slowing down, braking, turning, speeding up — all depend on information being continuously gathered by sensors in the vehicle. Some additional information can be obtained from communications with other vehicles in the area.

Autodrive Solutions believes that safe, autonomous transportation relies on a coordinated societal solution. For roadways, the cooperation of the transportation departments in cities and states is necessary to establish central host data centers that will act like air traffic control systems. The central host computers will collect data from vehicles on the roads and synchronize traffic flows. This could go as far as eliminating the need for traffic lights.

To make this possible, every centimeter of every road must be mapped using a unique series of circular, 6-mm-thick plastic paint spots. The paint spots will run down the center of each lane in 64 rows of four spots each to produce a 64-bit digital code that tells the vehicle its location with
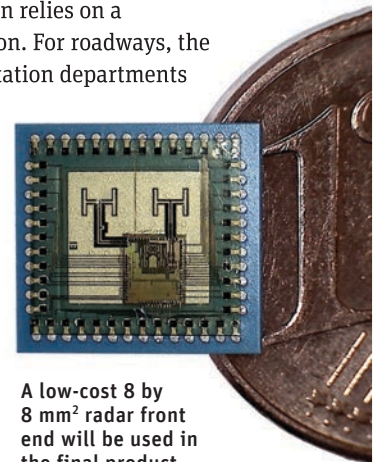
A low-cost 8 by 8 mm² radar front end will be used in the final product.

> ## "ANSYS SCADE proved to be absolutely critical to Autodrive engineers, saving the company 80 percent in development time in getting RPS to market."
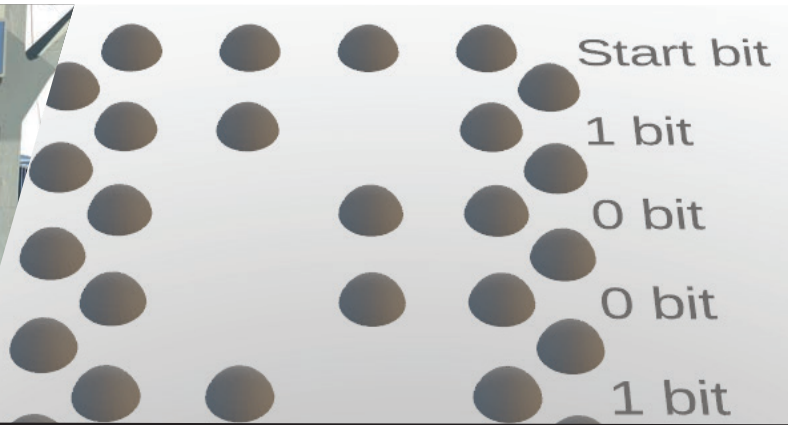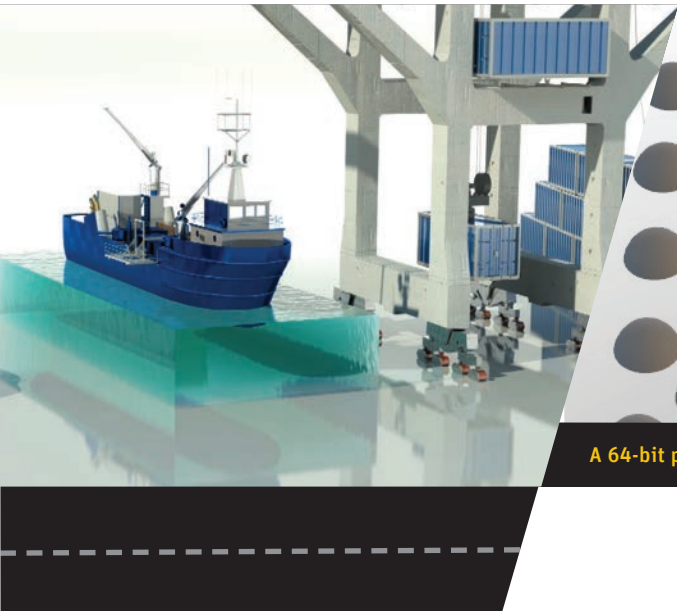
A 64-bit paint drop code provides precise roadway mapping used by RPS.

centimeter precision. This valuable data can be shared with the central host.

A mapping vehicle will drive on every lane of the city when the paint drops are completed. It will log every 64-bit pattern and create a map of each centimeter of the roadway to serve as a reference map. While such precise mapping of every road may seem prohibitively complex and expensive, existing automated line painting trucks could be easily modified to deposit paint drops instead of lines. Autodrive engineers, taking into account data provided by the Los Angeles Department of Transportation, have determined that the entire 44,900 km of driving lanes in Los Angeles could be coded with paint drops in two months by 50 trucks painting at a rate of 6 km/h.

In everyday operation, a radar unit containing four separate millimeter-wave (mm-wave) radar detectors located under an autonomous car will read the four paint spots in each row as the automobile passes over them. This reading is achieved through the mm-wave radar's ability to measure the distance to the ground with 0.1 mm accuracy every 50 μs. In this way, each radar is able to obtain a high-detail profile of the ground while the vehicle is running, detecting the presence or absence of a paint-drop due to its thickness.

After reading the entire 64-bit code, the vehicle is located with 1 centimeter accuracy. The road map stored in the memory of the vehicle will anticipate the road

shape ahead and update the position by reading row by row instead of waiting for a complete 64-bit-code read. This is possible because the next 64-bit-code sequence is already known. Therefore, the vehicle can set the optimum trajectory for driving safely using the road shape embedded in the road map.

The extreme accuracy of RPS enables data sharing between vehicles by transferring the vector of each target from one car to another. In this way, the autonomous car can use the information gathered not only by its own sensors but from a vehicle that is driving 100 m ahead, improving the vehicle's perception. It will also transmit its location to the central host traffic controller, which will use the information from all vehicles to control the flow of traffic in that region.

The Radar Position System

Autodrive's Radar Position System (RPS) uses the miniaturized, low-cost, high-resolution mm-wave radar sensor developed by the European Union's SUCCESS consortium in its radar units. The surface-mountable package of this fully integrated 122 GHz radar sensor is 8 mm by 8 mm and includes an SiGe chip along with transmitting and receiving antennas. Four of these sensors are housed in sealed, weatherproof plastic units connected to the chassis under an autonomous vehicle. The system is absolutely secure — it is

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> **Continual speed adjustments could result in a *savings of 20 percent* of the *8 billion* euro energy cost of the European train fleet each year.**

impossible to jam the radar because it has a very high frequency of 122 GHz and a huge bandwidth of more than 15 GHz. Any manipulation of the track is easily detected as it will generate a mismatch with the recorded road map.

A customized plastic lens had to be developed to focus the radar waves into a 1-cm circle over the ground to achieve the 1-cm positioning accuracy of the RPS. Autodrive engineers used ANSYS HFSS SBR+ — the industry-leading tool for simulating installed antenna performance on electrically large platforms, including the applications of predicting installed radiation patterns, field distributions and antenna-to-antenna coupling — to successfully design the lens.

Four-radar RPS reading paint dot bit pattern on road

Due to a small wavelength (lambda less than 3 mm) and a big simulation volume (100 lambda by 100 lambda by 400 lambda), the problem has to be divided for optimizing computing requirements. A first simulation of the patch antennas is obtained using the finite element method solver from ANSYS HFSS. Then the simulation results are used to excite the radiating source in HFSS SBR+, which leverages the asymptotic Shooting and Bouncing Ray Plus (SBR+) technique to efficiently compute accurate solutions.

The lens was essential to the operation of the RPS, but perhaps even more critical was the development of the embedded software that must control the hardware flawlessly to meet the EU's rigid certification standards. While Autodrive Solutions had a lot of experience with radar systems, they had little with critical real-time embedded software. So they turned to ANSYS SCADE to generate, validate and obtain certification for their software. SCADE proved to be absolutely critical to Autodrive engineers working on this application, saving the company 80 percent in development time in getting RPS to market. The engineers focused on the model, on solving the problem, and let SCADE develop certifiable software to control the hardware they developed. If they found after testing that there was a problem with the model, they simply had to modify the model to solve the problem. SCADE then took this model to generate the code with the certified KCG compiler to provide the traceability and the documentation required by the certification authorities in a few minutes. SCADE-generated software met the certification standards for embedded software in critical safety applications every time.

Railway Applications

Though it seems less obvious, the railway industry also has challenges that can be solved using autonomous systems. Determining the precise location of a train on a track is not as easy as it might seem. Because of this, the cost of stopping a train accurately, which is required for deploying platform screen doors (to prevent people from falling or jumping onto the tracks), is 0.5 million euros per train station. With the current technology, when a train passes an RFID unit, a preprogrammed braking process is automatically initialized. This process can estimate where the train will stop. The high cost of stopping a train accurately is due to the continuous calibrations required for each train because the braking

process depends on multiples variables such as the number of coaches, the load, the wear of the wheels and so on.

Autodrive Solutions developed a solution similar to the one they created for roadways. In this case, instead of dots of paint, they install bars of plastic either 1-cm or 2-cm high in a cluster at multiple points along the train tracks. A 1-cm-high bar represents a digital 0, and a 2-cm-high bar represents a digital 1. A cluster of these bars can therefore encode the location of the train on the track in a series of digital bits that can be read by a single RPS unit attached to the bottom of the train's engine car. By measuring the time it takes for the train to travel between specific locations, they can determine precisely how fast the train is traveling at each point and apply a customized braking process tailored to the load of the train. The adaptive braking system gives operators precise control over where the train will come to a stop.

RPS can also increase the amount of traffic that can be safely handled on a given railway by reducing the headway — the distance separating two consecutive trains. In Europe today, a track is divided into segments called "block sections" that have a minimum length of 400 meters; if one train is in a segment, no other train can enter that segment. This 400-meter separation, which is designed for safety, produces bottlenecks that limit the number of trains traveling through an area. The bottlenecks occur most frequently near train stations and cities, where trains run at slow speeds.

Autodrive's accurate positioning RPS can reduce the headway by reducing the block section length to only 50 meters, significantly reducing bottlenecks. Finally, Autodrive's RPS can also increase the energy efficiency of train systems. Today, European trains travel between two consecutive RFID beacons at a fixed speed. When the train detects a signal indicating it can speed up or slow down in the next segment, it does so. The RPS can detect when track conditions change at smaller intervals. It can tell if the slope is uphill or downhill and adjust the speed for these conditions immediately, without waiting for a signal in the next Eurobalise (European Standard RFID signaling device). Continual speed adjustments could result in a savings of
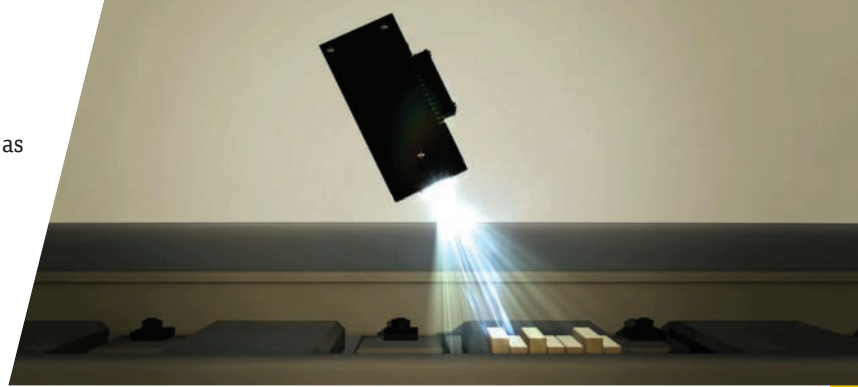
Single RPS railway unit reading height of plastic bars on train tracks

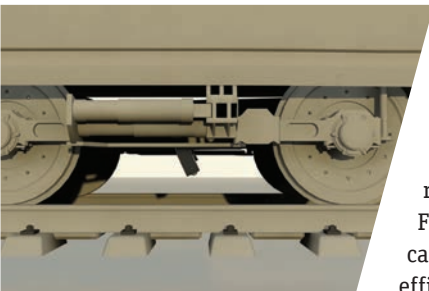**Single RPS unit under train**

20 percent of the 8 billion euro energy cost of the European fleet each year.

Autodrive has successfully tested a prototype of the RPS in Metro de Madrid. They have also tested the measuring capabilities of the radar in a high-speed train traveling at 330 km per hour.

Using embedded software generated by ANSYS SCADE, Autodrive expects to achieve the SIL4 (Safety Integrity Level 4) certification as specified in standard EN 50128 during 2018, which will allow them to sell their technology on the European railway market soon.

Future Plans

Autodrive Solutions' RPS has possible future applications for aircraft that are taxiing on a runway and for optimizing the speed and braking of the Hyperloop. They are collaborating with departments of transportation, as well as metro and train authorities, in various cities around the world to explore the possibility of using the RPS to improve roadway and railway transportation safety and efficiency. ANSYS SCADE and ANSYS HFSS SBR+ simulations will be part of every solution they develop throughout the world. ∧