NATIONAL CENTER FOR MANUFACTURING SCIENCES

Progress in Ground Vehicle Automation Points to Bright Future for Driverless Transportation

Industry 4.0 technologies, including automation, are rapidly improving operations in many sectors, including manufacturing, healthcare, agriculture, food processing, and logistics. Automation has been widely accepted in industrial settings because it generates increased productivity, more efficient material usage, improved product quality, better worker safety, and lower labor costs. These advantages have led to steady growth in use of automation technologies: the industrial automation market is projected to expand from $147.06 billion in 2019 to $264.69 billion by 2026.

While automation has been welcomed throughout manufacturing for decades, its growth might be most noticeable in a setting where it has not gained full acceptance: the commercial and consumer transportation industries. Autonomous vehicles (AVs) have been developed by combining sensors, cameras, radar, and artificial intelligence (AI), allowing them to travel between destinations without a human operator. When the technology matures sufficiently, privately owned AVs are expected to reduce traffic deaths, lower emissions, improve traffic flows, increase lane capacity, lessen travel time, and save consumer insurance costs.

Commercial AVs are likewise projected to help improve supply chain operations by more efficiently moving goods from factories, retail locations, and distribution centers to their destinations. The advanced sensors and AI built into AVs are expected to allow better data-sharing about the location and availability of everything from raw materials to finished components, enabling improvements to just-in-time manufacturing.

The National Center for Manufacturing Sciences (NCMS) has for several years been teaming up with researchers, industry innovators, and the Department of Defense to fuel the development of more capable autonomous vehicles. More recently, NCMS has been working with the US Air Force and Federal Aviation Administration (FAA) to help advance automation for the tasks of lawn mowing, Foreign Object/Debris (FOD) detection, and perimeter patrols in commercial and military airports across the country.

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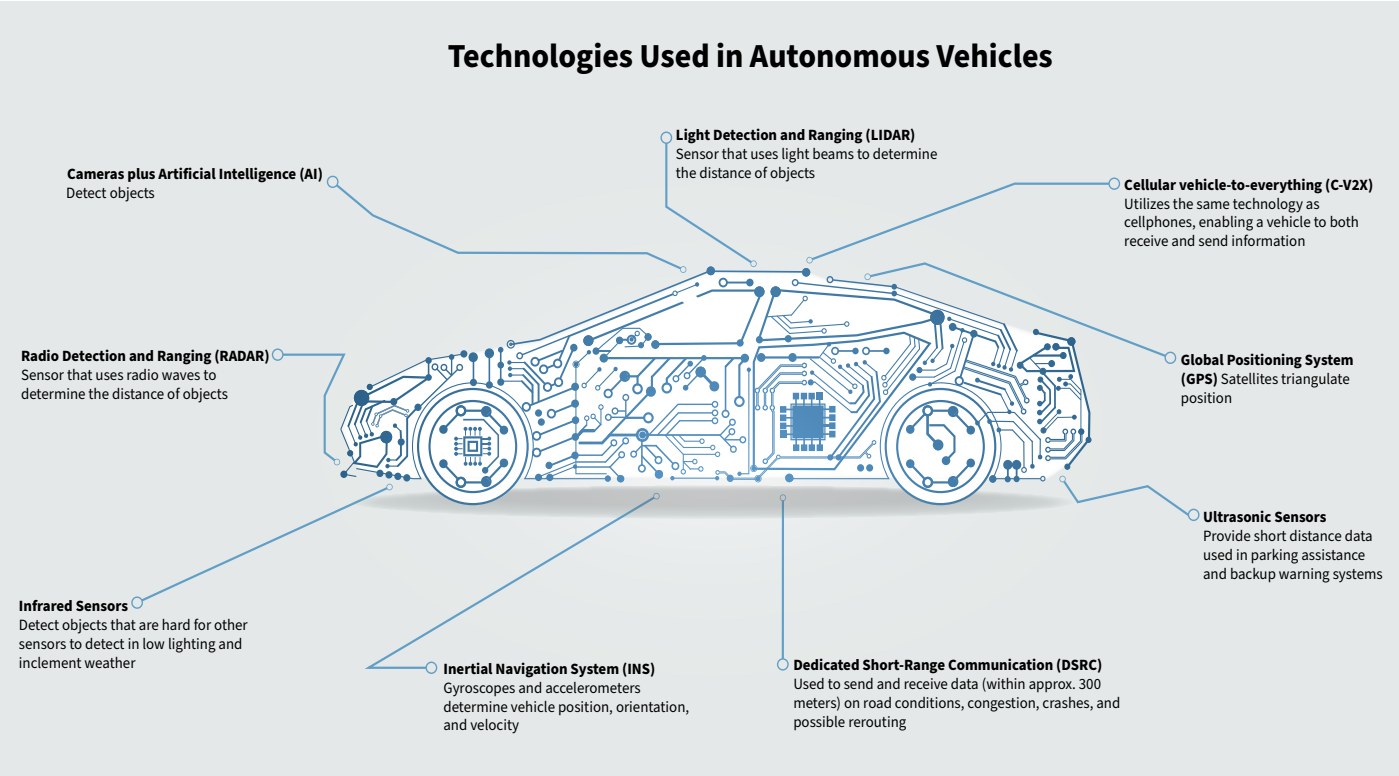
The first autonomous vehicles were developed in 1984, when Carnegie Mellon University's Navigation Laboratory (NavLab) and ALV (autonomous land vehicles) projects produced computer-controlled vehicles for automated and assisted driving. In 1995, NavLab 5 completed



the first autonomous coast-to-coast drive of the US, with 98.2% of the driving fully autonomous, at an average speed of 53.8 miles per hour. Starting in 2004, the US Defense Advanced Research Projects Agency (DARPA) began holding Grand Challenges to accelerate the development of autonomous vehicle technologies. While no team won the first Grand Challenge, in 2005, five vehicles out of the 195 entered successfully completed the 132-mile course.

Since then, developments in sensors, cameras, computers, and software have improved the ability of AVs to create and maintain a map of their surroundings and to maneuver around variables that might impede a vehicle's forward motion. This is no small feat. The sensors and cameras on AVs generate a massive amount of data—an estimated 434 TB for lower-level autonomy or up to 5,894 TB of data for higher-level autonomy, per car, each year. This data is fed into the central onboard computer running software with AI, machine learning (ML), neural networks, and deep learning. These algorithms combine the raw data from various sensor modalities to classify objects, make decisions, and send instructions to the AV's actuators, which control its movement.

One initiative that made significant progress in the development of autonomous vehicles—the Applied Robotics for Installations and Base Operations (ARIBO) program—launched in 2015 as a public-private partnership between industry partner Robotic Research, the Army Research Laboratory (ARL), and the US Army Combat Capability Development Center (CCDC) Ground Vehicle Systems Center (GVSC).

In 2015, ARIBO conducted one of the first projects in America that provided an on-demand autonomous transport system for soldiers and medical staff. At Fort Bragg in North Carolina, the ARIBO team developed and operated two, six-passenger, fully autonomous, electric shuttles to transport soldiers between the Warrior Transition Battalion barracks and Womack Army Medical Center. The autonomous vehicle

successfully maneuvered between five stops, navigating roads, intersections, traffic circles, and pedestrian walkways. Passengers received mobile updates about reservations and vehicle status.

Given that user socialization was one goal of the project, one measure of its success lay in findings that the majority of users had positive trust-related ratings of ARIBO. In 2016, NCMS joined the collaboration to bring a much larger ARIBO project to Fort Leonard Wood in Missouri. Originally this initiative planned to develop autonomous buses to transport company-sized units from their barracks to a centralized dining facility (DFAC), enabling the base to shut down under-utilized DFACs, thereby significantly reducing operational costs. However, the project team decided to shift their focus to producing upgrades to the nSight™ platform developed by Robotic Research.

This platform provides a comprehensive suite for studying the safety of an autonomous system through data collection and automated performance analysis. The platform pinpoints autonomy issues that autonomous vehicles may encounter during testing. The nSight™ platform saves costs, as it can verify if a $1K sensor can replace a $10K sensor. Overall, the nSight™ upgrades lowered the cost per unit, such that mass production of the system cost approximately $3K, a cost savings of $15K per unit.

The project's industry partner, Robotic Research, has continued to accelerate the transition of advanced unmanned technology to the military and government. Since 2015, Robotic Research has worked on a vehicle-agnostic applique kit that equips legacy military ground vehicles with scalable autonomy, enabling vehicles to successfully complete unmanned follower missions at high speeds in a variety of difficult terrains. Additionally, Robotic Research is implementing its proprietary AutoDrive® advanced driver assistance system to facilitate the automation of three 40-foot electric buses running on the CTfastrak corridor in Connecticut.

Currently, most new vehicles have semi-autonomous driving systems including adaptive cruise control and lane-centering assist. As of 2022, most commercially available AVs have reached level 2 of the six levels of autonomy defined by the Society of Automotive Engineering (SAE), which range from Level 0 (no driving automation) to Level 5 (full self-driving capabilities under all conditions). Progress still needs to be made in several areas: software that can accurately analyze an enormous amount of data to make correct decisions, (especially for object analysis and detection at nighttime and in inclement weather), safety and operational testing, cybersecurity, networking infrastructure, and laws to regulate fully autonomous systems, among other challenges. Leading automakers aim to launch fully autonomous commercial vehicles by 2025.

In the meantime, a new initiative is progressing automation in commercial and military airports across the country by using the Air Force as the test bed. In 2022, NCMS announced the Airfield Autonomy Initiative (AAI), hosted by the US Air Force Mobility Command (AMC). AAI aims to advance airfield automation and command and control (C2) systems. Airfields require a broad span of routine but critical functions: foreign object debris (FOD) control, runway surveillance, and ground power cart operation. While many of these tasks are being demonstrated for and converted for use on automated vehicles, there is currently no robust command, control, communications, coordination, navigation, and collision avoidance system. AMC launched the AAI to inexpensively and rapidly learn the requirements of a viable airfield automation C2 system that can enable the development of more airfield automation.

The AAI initiative focuses on automation for the simple tasks of lawn mowing, Foreign Object/Debris (FOD) detection, and perimeter patrols (for both security and wildlife management). The 8- to 12-month development, integration, and test period will enable successful applicants to participate in a series of test demonstration exercises at Joint Base McGuire-Dix-Lakehurst (JB MDL) in Burlington County, NJ. Additionally, the FAA William J Hughes Technical Center (WJHTC) has coordinated with the National Aerospace Research and Technology Park (NARTP) to provide two weeks of test/development time at Atlantic City Airport (ACY), a smart airport test bed.

The initiative aims to develop specific technology areas including:

- C2 systems that operate in airfields, flight lines facilities, and/or environments not initially designed for autonomy while increasing human safety without reducing performance
- Interoperable multiple agent C2 that enables scale up through heterogeneous integration of other Airfield Autonomy vehicles from a wide range of current and future technology providers
- C2 fleet manager that coordinates assets, human-robot teaming, robot-robot teaming, reduced downtime, and tasks allocation based on workload.

About NCMS

The National Center for Manufacturing Sciences (NCMS) is a cross-industry technology development consortium, dedicated to improving the competitiveness and strength of the U.S. industrial base. As a member-based organization, it leverages its network of industry, government, and academia partners to develop, demonstrate, and transition innovative technologies efficiently, with less risk and lower cost.

NCMS enables world-class member companies to work effectively with other members on new opportunities – bringing together highly capable companies with providers and end users who need their innovations and technology solutions. NCMS members benefit from an accelerated progression of idea creation through execution.