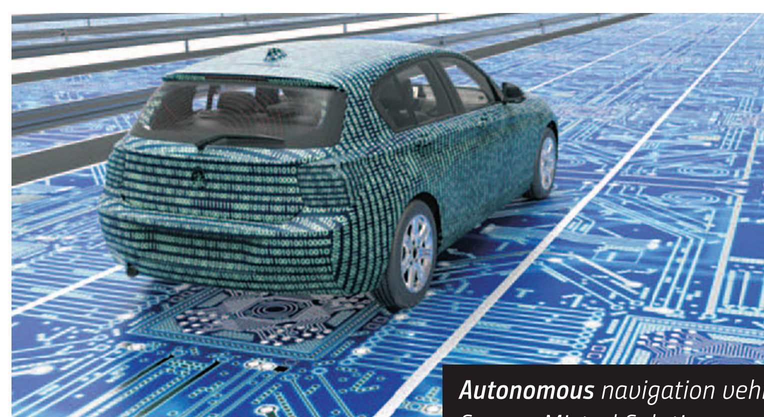
# How to get started

## with designing a cost-effective UGV for security and surveillance

***When building an autonomous vehicle,*** *start with mission requirements and basic components.*



***Autonomous** navigation vehicle. Source: Mistral Solutions*

By Raja Subramanian N and Pramod Ramachandra • Mistral Solutions

**Mobility is hot,** from the mobile robots in warehouses to the self-driving cars and trucks now being tested. By 2040, three out of every four vehicles will be autonomous, according to the Institute of Electrical and Electronics Engineers. The unmanned vehicle industry is becoming very competitive, making it difficult for startups to gain the necessary investment. However, there are ways to design and build an autonomous system for a commercial application without burning a hole in your pocket.

While most of the attention has been on semi-autonomous or fully autonomous passenger vehicles, there is a huge void in developing these technologies for security and surveillance applications.

What is an unmanned ground vehicle, or UGV? A simple definition is that it is a ground vehicle that can run independently of a human operator. It uses sensors and machine vision to perceive and comprehend its environment, while drive-by-wire actuators and motors perform operations.

Various open-source tools can come in handy when designing a cost-effective, safe, and reliable UGV based on an electric platform. Let's focus on building a multi-terrain vehicle rather than one just suited for roads. We will also discuss a surveillance payload that can be integrated into this vehicle.

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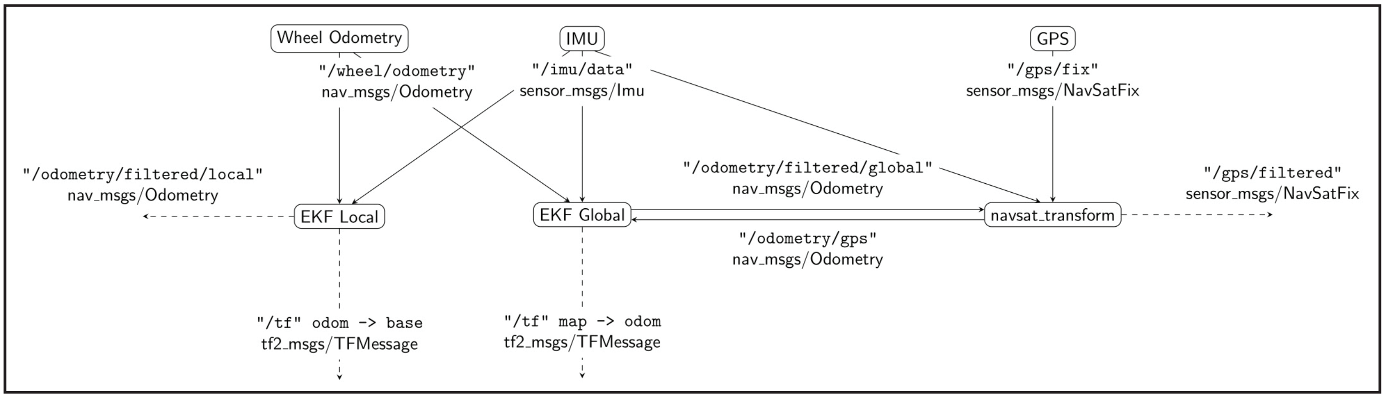



***Using navsat_transform_node** to integrate GPS data. Source: ROS.org*

**Software for UGVs ROS:** It is possible to build a high-quality software package with the open-source tools currently on the market. The Robot Operating System, or ROS, is a flexible, open-source platform for software development. ROS was developed to save the time spent on design and engineering and let product developers build on solved problems.

The ROS community provides several tools, as well as support for various sensors, algorithms, visualization and simulation to develop a robust software. ROS allows software nodes to run on distributed computational units, depending on the hardware architecture.

By choosing ROS, developers can reuse various modules and build application use cases on Python, C++, and Java. With minimum customization based on project requirements, they can optimize the modules for the autonomous vehicle's intended function.

**Maps and navigation:** Open-source maps and navigation tools can help developers incorporate a dynamic map in a Web application. These tools are completely free, and they offer developers with the ease and flexibility of a cutting-edge, mobile-ready solution. It is very easy to customize these platforms by accessing application programming interfaces (APIs) or using third-party libraries.

Developers can also build a Web-based geographic information system (GIS) and integrate it with ROS, along with various algorithms to identify and define the path of the vehicle and turn-by-turn navigation support. The edit support in Maps can be used when in-road networks are not available.

There are also a few open-source tools that provide free geospatial data and permit relevant modifications. These tools can help developers to generate and define a path for the vehicle. The geospatial data includes detailed information about streets, landmarks, railways, major institutions, and much more. It may also include the name, type, and width of the street and even the speed limits applicable. They support offline maps and allow for the addition of custom road networks.

**LAMP:** Standing for open-source components Linux, Apache, MySQL, and PHP/Python, LAMP is a reliable platform for developing UGV Web applications. LAMP makes the developer's life easy by minimizing the programming efforts that a complex autonomous platform or a robot ask for.

**Autonomous navigation algorithms:** UGVs rely on navigation technologies, sensors, and cameras to navigate across terrain. Now, consider an environment that is unknown or not updated in the navigation platform. This is where various autonomous navigation algorithms play a crucial role.

These algorithms help identify obstacles, avoid them, calculate best routes, and define a new path for the vehicle by understanding the surroundings based on the data from various sensors. There are three important algorithms in autonomous navigation: geolocalization, path planning, and navigation.

The system uses Global Positioning System/inertial navigation system (GPS/INS) for accurate vehicle positioning, Map to choose the best route, and navigation algorithms to provide steering angular profile commands to the vehicle.

**Hardware for UGVs**

Software is increasingly important, but the vehicle platform itself is still the basis of any UGV. An internal combustion (IC) engine poses several challenges such as noise, pollution, and complexity in integration, and most are not designed for autonomous mode.

By contrast, in electric vehicles, many of the mechanical customization challenges can be surmounted. Developers can also easily access vehicle network for obtaining data such as engine status, fuel status, gear level, clutch, and so on.

Drive by wire, also known as "X by wire," is transforming the way people drive or commute. Drive-by-wire systems rely on electronics and various sensor inputs to control operations such as steering, acceleration, and braking, while the conventional vehicles use mechanical and hydraulic technologies. Let's look at the various components such as the driving or AC motor, motor controllers, hub motors, and steering controls.

**AC motor:** Among the prime concerns of UGV designers while considering AC


***In-wheel motor.*** *Source: Elaphe*

motors are torque, power and efficiency of the motor. The motor and other motion systems should provide superior quality, reliability, and performance at the lowest possible cost. While choosing the motor and deciding on the power, the developer should consider the terrain where the UGV will be deployed.

Acceleration of the vehicle is controlled by sending electrical signals of defined voltage, directly to the motor controller. For this, one can use an existing AC motor controller available in open market. Building a custom AC motor controller may not be a viable decision because of expense and potential project delays.

**Wheel hub motor:** In electric vehicles, hub motors power each wheel. The more powerful the integrated hub motors are, the more capable the UGV will in demanding environments.

**Steering control:** Another crucial component of autonomous vehicles is the automatic lateral control. A specially designed electric power-assisted steering (EPAS) popularly used in modern vehicles has various advantages over the conventional steering system.

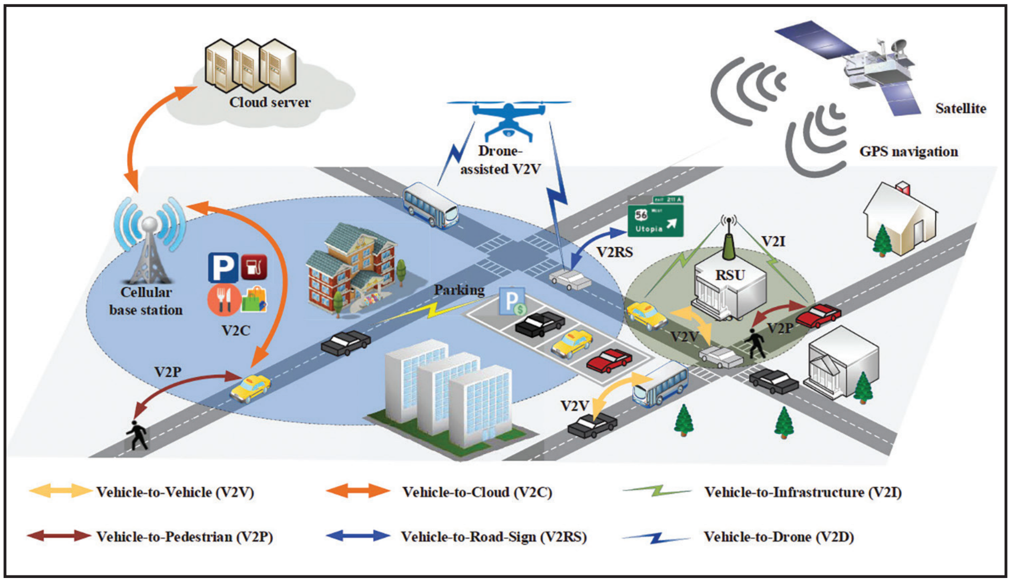
In an autonomous vehicle, EPAS consists of a controller integrated into the steering column in addition to the electric motor and a torque sensor. The EPAS controller unit receives inputs from the computer, which in turn controls the steering.

**Braking:** For service brakes, one can use a linear actuator-based control system. In an electric vehicle, regenerative or re-gen brakes could also be helpful because they use the kinetic energy generated while braking and convert it back to stored energy in the vehicle battery.

Designers can also consider ACME-based linear actuators for parking brakes. There are several off-the-shelf parking-brake systems that a developer can use, depending on the terrain and ruggedness the system demands.

**Vehicle communication networks:** The vehicle communication network connects the in-vehicle electronics and devices, as well as the vehicle itself to the external world using technologies such as Controller Area Network (CAN), Ethernet, Wi-Fi, and mesh networks.

The selection of a reliable and redundant network structure is key to avoiding any failures. The vehicle network must be able to handle the huge amount of high-speed data generated by various onboard sensors. The network should be fully capable of handling this data and supporting the sophisticated vehicle electronics.




***Vehicle communications network*** *with different V2X communication nodes. Source: "Vehicular Communication Networks in Automated Driving Era," by IEEE members Shan Zhang and Nan Cheng; IEEE student members Jiayin Chen, Feng Lyu, and Weisen Shi, and IEEE Fellow Xuemin (Sherman) Shen*


***An integrated, camera and mmWave radar sensor platform based on*** *Texas Instruments TDA3 SoC and AWR1443 FMCW RADAR sensor for ADAS applications. Source: Mistral Solutions*

A gigabit-speed network is recommended so that sensors and various processors can take advantage of its high-bandwidth, low-latency, high-reliability links, paving the way to real-time autonomous operations.

**Autonomous vehicle sensors**

An autonomous vehicle relies on GPS and inertial measurement units (IMUs) for localization and navigation, while it relies on sensors to perceive the environment, obstacles, and moving objects such as other vehicles or pedestrians. While the GPS and IMU provide vehicle position, speed, and direction, it is the cameras, radar, and lidar that facilitate safe decision making.

These sensors must work in extreme weather conditions, ranging from bright sunshine to dark, rainy, foggy, or dusty conditions, not to mention freezing or high temperatures. We recommend IP65 or IP67-grade sensors.

**Millimeter-wave radars** provide crucial data for autonomous vehicle and UGV functions, including obstacle detection, proximity warnings, collision avoidance, lane-departure warnings, and adaptive cruise control. One big advantage of radar over other sensors is that it works accurately in any weather condition.

Radar has evolved significantly over the past decade. Advancements in antenna design, signal transmission, processing power, digital signal processing, silicon technologies, and machine vision algorithms have transformed radar into a system on a chip (SoC).

In automotive applications, the range requirement is as low as few hundred meters, which is where mmWave radar comes into the picture. 77-GHz radar modules are gaining popularity, as they generate better object resolution and greater accuracy in velocity measurement. These modules come in ultra-compact form factors and provide superior processing power.

Off-the-shelf radar modules available include Texas Instruments' ultra-high resolution AWR sensors, which it says include high-accuracy and low-power 45nm RF CMOS build technology.

For advanced autonomous driving applications, developers can consider the Sensor Fusion Sensor Fusion Kit (camera vision + mmWave radar) from Mistral Solutions, powered by Texas Instruments' TDA3 SoC and AWR1443 FMCW RADAR sensor.

**Lidar** sensors can generate high-resolution 3-D maps with detailed information including road features, vehicles, and other obstacles in the terrain. Lidar can provide quick scans of objects and help an autonomous vehicle or UGV perceive its surroundings.

**Cameras** were among the first sensors deployed in vehicles for driver assistance applications. The technology is mature, and miniaturization has made cameras indispensable components in every modern-day vehicle.

With the introduction of advanced image-processing technologies and vision analytics, cameras have become one of the key sensors in advanced driver-assist systems (ADAS), self-driving cars, and mobile robots. In addition, cameras enable in-object identification and classification, as well as depth perception including the position, distance and speed of objects.

In an autonomous surveillance platform, two layers of cameras need to be implemented. The first set of camera sensors assists the vehicle in gathering data for autonomous , and second gathers intelligence. Surveillance camera specifications are addressed below.

**Ultrasonic sensors** have fallen incost, allowing autonomous systems developers to consider them for new applications. Ultrasonic sensors can play a major role in obstacle avoidance. The latest sensors can detect the distance to obstacles and assist in safe manoeuvring and automatic parking. Ultrasonic sensors are comparatively economical and work perfectly in bad weather.

**GPS-INS:** GPS aids in identifying the vehicle location accurately on the ground. Traditional GPS receivers may have position error in the range of meters, depending upon satellite visibility; signal strength; weather conditions; and surroundings such as buildings, trees, or hills.

The safety demands for autonomous vehicles require position errors within sub-centimeter or millimeter levels. Accuracy can be further improved by combining GPS with an INS -- a device that uses accelerometers, gyroscopes, GNSS receiver, microprocessor, and a data logger to continuously calculate the position, orientation, and velocity of the vehicle using dead reckoning.

The position errors can be further reduced by deploying Real-Time Kinematic (RTK) base station, which will send position correction messages to the GPS receivers periodically.

**Surveillance payloads**

For developers, identifying the surveillance needs is the first and most important step in building an application-specific UGV. Advanced electronics modules may be costly, so the developer needs to be clear on the system requirements.

Developers and integrators can consider infrared cameras, which use thermal imaging regardless of the lighting conditions; pan-tilt-zoom (PTZ) cameras for covering large areas and seeing small details; and a 360-degree camera, which provides a bird's-eye view of the surroundings.


*Command-and-control vehicles.* Source: Mistral Solutions

In addition, standard surveillance equipment including communications systems and control consoles are available on the market.

The communications network is another aspect to be considered. Video feeds from various cameras are streamed live to the teleoperator console or the command center. For this, one can either use an existing Wi-Fi network or a wireless mesh network. This can enable a wireless ad hoc network to communicate faster and safer in a demanding environment.

**Teleoperator console:** Building an autonomous surveillance vehicle does not mean that security is independent of human intelligence. There is always a human eye in the loop, monitoring the vehicle movement and keeping a check on the live feeds received. This is where the teleoperator console comes into picture.

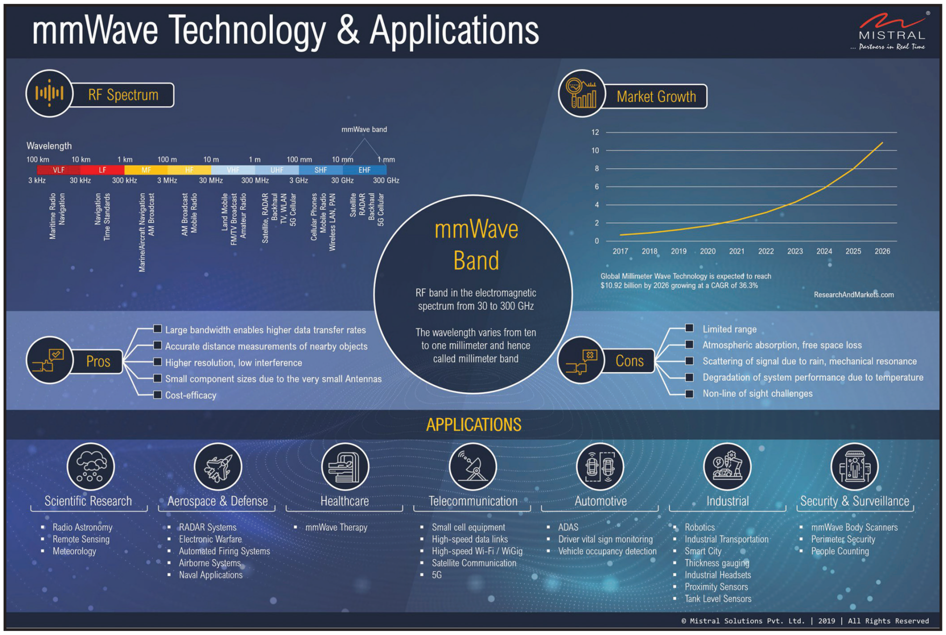
The operator console acts like a command center and facilitates the gathering of surveillance intelligence. The console should be equipped with reliable communication and control systems. The operator should be able to take remote control of a vehicle at any time, control the surveillance payload, make an emergency announcement, start or stop the vehicle, and so on.

Developers can integrate the teleoperator console into an existing central command-and-control center, or it can be designed as a portable kit. The portable console should be lightweight and easily deployable. A standard teleoperator console consists of a touch control panel that runs an intuitively designed Web app for configuring missions and teleoperating the vehicle.

You can consider a metro-style user interface like grid stack for teleoperator console, which will enable the user to define what to focus on in each mode of operation.

**e-Stop and telemetry data:** Consider a situation in which the user wants to stop the UGV immediately -- that's when emergency stop or e-Stop feature comes handy. With the press of a button, the vehicle and its surveillance systems shut down completely. This can help safeguard the vehicle from being tampered with or protect it from an unexpected malfunction.

In addition to the vehicle network, a dedicated wireless network is required for implementing the e-Stop functionality. There are third-party, off-the-shelf products available in ISM (Industrial, Scientific, and Medical) and non-ISM frequencies, but they are not cost-sensitive.




***mmWave technologies.*** *Source: Mistral Solutions*

As a cost-effective alternative, developers can consider wireless networks that support long range for e-Stop functionality.

**Security UGVs require multiple disciplines**

Using the technologies discussed above, developers can build a state-of-the-art autonomous surveillance vehicle. They will need a customized electric vehicle platform, drive-by-wire actuators and sensors, and ROS. Builders will also need a graphics processor that runs compute intensive navigational and visual algorithms, a surveillance payload, and Web-based GIS systems.

The resulting rugged, all-terrain UGV can be deployed for a wide range of applications such as perimeter surveillance, 24x7 patrolling of critical infrastructure , first-response to fires or other disasters, and more.

To realize a surveillance UGV, product developers need experience in mechanical design, development, and integration of electrical components, as well as power management, various sensors and actuators, and software. Select mechanical parts and components to ensure high protection from shock and vibration.

Knowledge of tools such as HTML5, CSS3, Python, MySQL, Bootstrap, jquery, ROS Kinetic, and Melodic support will help the developers kickstart such projects immediately. Knowledge on DBW Algorithms, navigation, obstacle avoidance, path planning, and visualization provides an added advantage. **RR**

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*Mistral is a certified product design and systems engineering company. It focuses on product engineering services, aerospace and defense, and homeland security.*