Whitepaper | Automation for agricultural machinery

From assistance systems to autonomous field robots

Invented for life

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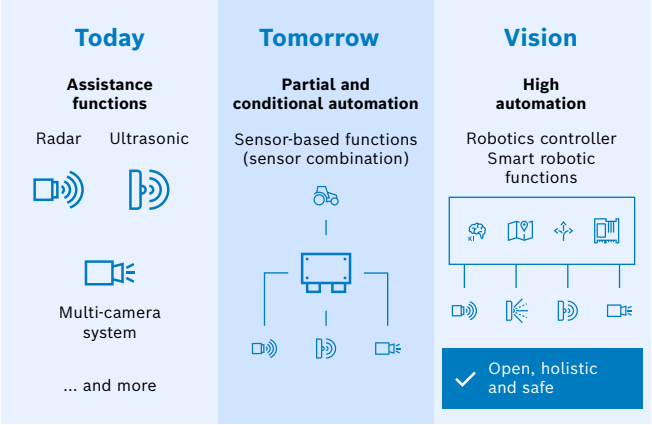
The challenges the agricultural industry faces are constantly increasing, as rising costs are often contrasted with too low product prices; add to this the shortage of workers, crop failures due to larger numbers of extreme weather events, ever more stringent environmental requirements, and a growing global population. Innovative technologies play a major part in making agriculture more efficient and sustainable, and therefore solve many of the above-mentioned problems, or at least mitigate their consequences. This is particularly true for assistance functions for agricultural machinery and equipment – right up to autonomous field robots. To facilitate automation in the various business sectors and stages, Bosch Engineering has created a toolbox of different sensor technologies, which can be used to devise the optimum solution for each individual scenario. In this toolbox, the sensors form the “eyes”, the control system takes charge of data processing, and the surround sensing system serves as its “brain.” Bosch Engineering also offers hardware and software solutions which can be used to make the vision of fully automated agricultural machinery a reality step-by-step.

By developing new assistance systems which are specially designed for the particular requirements placed on agricultural machinery, Bosch Engineering is a significant driver of machinery and equipment automation in the agricultural sector. On the path to autonomous agricultural machinery and the field robots of tomorrow, Bosch Engineering is employing a three-stage launch scenario, in which the level of automation increases with each successive step. The first stage is the assistance systems and the initial partially autonomous functions which are already available ("Today"). Market-ready partially automated machinery and equipment with new and significantly larger ranges of functions will be available over the next few years ("Tomorrow"). This is made possible by the expanded use of surround sensing. The sensor-based functions are an important, logical next step toward full automation. By specifically focusing on individual core applications and using the cascaded approach, experience in applying sensor technologies can be gained and end users can be convinced of the new systems' efficiency and performance. The third, long-term stage includes the full automation of all machinery in the agricultural sector ("Vision").



"Today," "Tomorrow," and "Vision" – the three stages of agricultural machinery automation at Bosch Engineering

With Bosch's approach, manufacturers of agricultural machinery and equipment are already able to take their first steps toward automation thanks to the "Today" technologies. They are then able to gradually develop systems for the next stages ("Tomorrow" and "Vision") based on this. This in turn creates an ideal foundation for the later introduction of advanced automation functions up to full automation.

"Today"

Assistance systems that help farmers when operating tractors or other machinery and therefore enable them to work quickly, precisely and safe are already available today. These also include surround sensing systems. The functions ensure increased safety, boost efficiency when working, and reduce the mental and physical strain on the machine operator. Such systems take the form of acoustic and/or visual warnings and information on the display in the vehicle cabin, which provide advice or even control the machine using partially automated functions. An example of the first case are safety functions such as collision warning systems for safeguarding tractors' or combine harvesters' front or rear areas. When the systems identify persons or objects within the detection area, they issue corresponding warnings and show the exact position on the display, thus allowing the farmer to keep a close eye on any blind spots.

If partial automation is used, the electronics employ radar or ultrasonic sensors to take on selected tasks such as track guidance, while the other control tasks are performed manually as before. An example of an application is machinery used in wine-growing. If operating it manually, the driver has to maintain the same track and monitor operation (for example at a mowing unit) at the same time. Things are different if automatic track monitoring is used, as the system measures the distance of the machine from the rows of grape vines on the left and right and keeps the equipment precisely in the track between them, meaning the driver can focus on other operations. This reduces complexity when carrying out tasks, meaning that the working speed and therefore also productivity can be increased.

"Tomorrow"

Automated systems will take on ever increasing numbers of agricultural tasks over the next few years and establish themselves in all segments and size/performance classes. Furthermore, the systems are designed such that they assist the machine operator in their work in some areas, but also offer new and/or expanded functionalities. When looking at the above-mentioned example of machinery in wine-growing, the electronics don't only take over steering and lateral guidance, but also control the accelerator and brake, meaning that the farmer's role is simply to monitor the machine. As before, the operator is still on board, retains responsibility for anything that may occur, and can intervene at any time.

As the number of applications and market penetration increase, the requirements placed on the automation software and hardware are rising as well. End users have to be convinced of the automation systems' robustness and performance over the long term. That's why the solutions need to be easy to operate, offer a high level of precision and functional reliability, provide maximum protection against errors in all weather and operation conditions as well as a long service life, and also be economically viable. From the perspective

of machine manufacturers, it must also be possible to apply the system components flexibly in order to cover a wide range of use cases and the sometimes conflicting requirements of the various applications. Bosch Engineering's new generation of automation tool kits is specifically designed to meet these increasing requirements and forms a sound technical basis for the "Tomorrow" and "Vision" automation stages thanks to its high degree of flexibility and scalability.

"Vision"

In the long term, fully automated agricultural machinery will be able to work without any machine operator at all. It will automatically travel from the farm to the field, carry out its work there, and then autonomously return to the depot. An intelligent fleet control system will coordinate machinery and equipment deployment, meaning that unwanted downtimes can be minimized. The machines themselves will also receive a certain level of intelligence in order to be able to make the right decisions to ensure their tasks are carried out safely in all expected and unexpected operation environments and scenarios. The software and hardware modules from Bosch Engineering will form the basis for the automation system required for this. The intelligence implemented in the machinery and equipment will mean that they are much easier to use. Since only a small number of specialist personnel are required to monitor the machine functions when working, the machinery and equipment can be used 24 hours a day – something which will also boost utilization. The elimination of the traditional operator's cabin will pave the way for entirely new vehicle design concepts, which are further optimized to suit the specific requirements of the individual applications. Bosch Engineering is already working together with partners to develop fully automated off-highway systems as part of multiple research and development projects.

Automation system

To enable automation, the machine must be able to sense the surroundings – i.e., it must essentially have "eyes" and be able to correctly interpret the surroundings using its own "brain".

The following building blocks are among those required for full automation ("Vision" automation stage):

- Comprehensive safety concept
- Sensing of surroundings to create a 360° model of the environment
- Planning of the machine trajectory based on the terrain profile
- Work and fleet management via a reliable backend
- Precise localization of the machine position
- Situational analysis to enable correct decision-making
- Safe, fast, and precise motion control including actuators
- State-of-the-art system architecture and security concept

Depending on the degree of automation and application, only parts of the above-mentioned technology package are required in "Tomorrow" systems. However, the basic surround sensing function using high-performance sensors and data interpretation with a smart control system must always be integrated. The developments from Bosch Engineering include many components that are required for current and future automation. Machine manufacturers therefore benefit from a coordinated system in which all components are compatible and which "grows" along with the degree of automation. Thanks to the flexible tool kit concept, it is possible to optionally integrate individual components from Bosch Engineering's overall package into an existing in-house automation system as hardware and/or software.

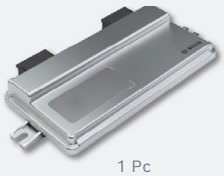
Automation control is available using a dedicated controller developed together with Bosch Rexroth. Alternatively, machine manufacturers can simply source individual software modules from Bosch Engineering and integrate them on their own controller. An example of this is the radar sensor toolbox – a software package which pre-processes the raw data from the various system sensors. New automation functions can be developed quickly and efficiently based on this.

The system components provided by Bosch Engineering comply with the applicable standards such as ISO13849 or ISO25119, meaning that they meet all requirements for ensuring safe operation. Software drivers for the open source operating system ROS2 (Robotic Operation System 2) – which is established and tried-and-tested in the world of automation – provide a high degree of flexibility during integration and make the individual components and the system future-proof. The automation hardware and software can be seamlessly integrated into the BODAS (Bosch Rexroth Digital Application Solutions) digital ecosystem from Bosch Rexroth. BODAS provides users with a bundle of IT solutions that raise productivity and efficiency while also facilitating the automation process.

Current automation projects implemented by Bosch Engineering together with machine manufacturers cover all agricultural technology applications:

- Autonomous tractors
- Special machines (self-propelled) such as sprayers or combine harvesters
- Implements (attachments)
- Field robots (full automation with central monitoring via control center)

Bosch retrofit kit components



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Sensor systems

Bosch Engineering is constantly further developing its sensor system tool kit particularly for the requirements of agricultural machinery automation. It can be used to ensure reliable and robust automation. In developing the software that processes and interprets the sensor signals, Bosch Engineering is using development methods that are already well established in the passenger car and commercial vehicle sectors. Differences primarily result from the differing surrounding and application conditions (such as sensor mounting position) and the objects to be detected which the software is specially trained for.

The sensor tool kit from Bosch Engineering includes various ultrasonic and radar systems as well as a camera system. All components can be flexibly configured, meaning that the system can be tailored to the individual requirements of the specific application and assistance function. When it comes to the optical output of the camera, radar, and ultrasonic information in a central display, Bosch Engineering combines all signals in the off-highway vision system. For challenging assistance functions and automation tasks, the data from the individual sensors is centrally merged into an overall scene, which ensures that the control electronics receive a precise overview of the surroundings. The systems combine a high level of functional safety with exceptional robustness, even under the toughest of operating conditions.

Multicamera system

The multicamera system from Bosch Engineering consists of an electronic control unit and four digital near-range cameras. It offers a high resolution (1280 x 800 pixels) and a 360° panoramic view all the way around the vehicle. The various views can be displayed on a monitor in full-screen or split-screen mode. The original equipment version (sight assist) is designed for integration in new or future vehicle concepts. For example, the system functions include a camera zoom feature linked to the vehicle speed for a top view and a steering-angle-dependent lane display. Since agricultural vehicles are often used for many years and integrating a camera system during vehicle development is not always possible, Bosch Engineering also offers a retrofit kit which comprises all components including the wiring harness and camera holder. This solution is characterized by an intuitively used display and easy commissioning – including in existing vehicles.

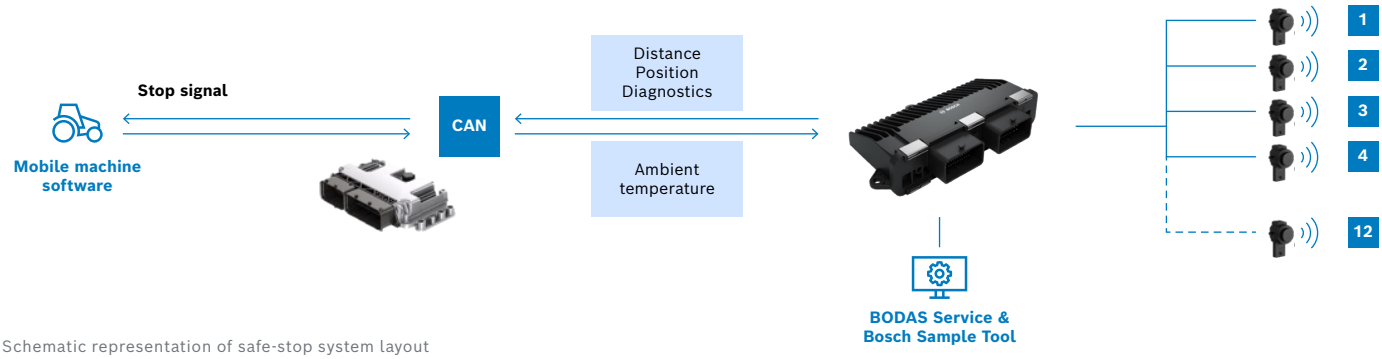
Ultrasonic sensors

Ultrasonic systems for agricultural applications from Bosch Engineering cover a wide detection range (up to 360° panoramic view) with up to twelve ultrasonic sensors. Depending on the configuration, the sensors simply measure the distance or also offer object localization. For this purpose, an algorithm determines the position of the object within the detection area using the triangulation method. It is based on angle measurement of the signals from two sensors with an overlapping field of view which have detected the same object.

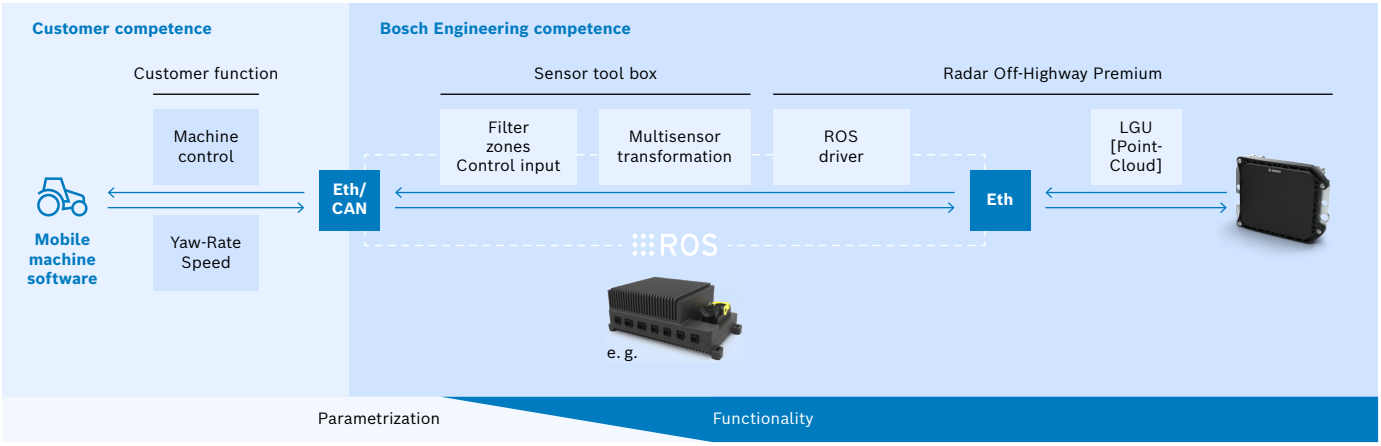
Thanks to its safety certification according to ISO25119, the ultrasonic system can be easily integrated into the sensor cluster of a surround sensing system which has to meet functional safety requirements. For example, this includes move-off control or emergency braking functions for slow-moving machines. Bosch Engineering is working on a safe-stop system in order to establish the link between objects detected by the sensor system and the machine stopping.

Example application of the safe-stop system

The goal of the concept is to trigger a stop signal for the vehicle control system when obstacles are detected in the trajectory. Machine manufacturers are therefore able to integrate the demanding emergency braking assistance function into their application as a secure and reliable “plug and play” solution, without having to tie up their own development capacities.



Schematic representation of safe-stop system layout



Schematic radar representation

Radar system

The benefit of radar technology compared to other sensor concepts such as LiDAR is its exceptional robustness against adverse weather and environmental influences such as rain, fog, or dust, and therefore high functional reliability with comparatively low overall costs. Bosch Engineering is further boosting these benefits in the radar generation available from 2024 onward. The completely newly developed high-imaging radar system (“4D radar”) is based on the latest automotive technology and offers a point cloud with a ten times higher resolution compared to previous system generations, meaning that objects in the detection area (x, y, and z coordinates) which are very close to one another can be distinguished even more reliably. In specific, objects that are just one degree from one another from the perspective of the radar sensor are still detected as separate obstacles. Among other things, this enables very precise height measurement for precise readjustment of the device’s working height from the ground during travel over uneven terrain.

In order to simplify development of automation functions based on the 4D radar, Bosch Engineering is further developing the software package for radar applications, the so-called radar sensor toolbox, with each application. The radar sensor toolbox is based on ROS2 and specifically filters out only the information from the huge quantity of sensor data available which is relevant for the respective automation function. This includes, among other things, measuring the height of an implement and determining the machine’s track center for applications in orchards. When configuring a new application, the developers simply have to enter the parameters they are looking for to define the requirements for the sensor system and the software then automatically integrates the required sensor data. This reduces the requirements regarding the use of radar technology on the part of the machine manufacturers.

Off-highway robotics controller 2 control unit

Powerful hardware is available for partial and full automation concepts thanks to the 2nd generation of Bosch’s off-highway robotic controller (ORC2). The system offers a high level of computing and storage capability which also has sufficient capacity for demanding automation functions. It can be integrated quickly and easily in the vehicle electronics using standardized interfaces; the sensors from Bosch Engineering are also easy to integrate using preinstalled drivers. The hardware is designed for functions of “Performance Level D” (a measure for determining the reliability of a technical safety function) according to ISO25119 and ISO13849 and meets all current safety and security requirements. In terms of software, Bosch Engineering offers various functionalities and modules for automation. If required, these can be combined to form a dedicated assistance system. These range from surround sensing algorithms and localization to path planning algorithms. Such applications give machine manufacturers the opportunity to integrate the complete automation set-up into the machine as a coordinated and flexibly expandable system and to be able to provide their customers, i.e., farmers, with an attractive, safe, and robust system.

Summary and outlook

Automation in the agricultural sector is in full swing and will significantly change agricultural technology over the next few years. The path to full automation is evolutionary and includes various stages of partial automation. In order to reduce challenges for machine manufacturers when implementing new types of systems, Bosch Engineering offers a completely coordinated, scalable, and flexibly expandable hardware and software system. Development services in the field of agricultural machinery automation include the entire spectrum from demand analysis, concept design, development, validation, and verification to the final release of a function. This full-service package makes Bosch Engineering one of the leading pioneers when it comes to automating machinery and equipment in the agricultural sector – right from the initial prototype through to the market-ready production solution.

Further information
www.bosch-mobility-solutions.com

Bosch Engineering GmbH is a wholly owned subsidiary of Robert Bosch GmbH and is head-quartered in Abstatt, Germany. As a systems development partner to the automotive industry since 1999, the company with its more than 3,300 associates offers development services for powertrains, safety and convenience systems, and electrical and electronic systems – from the original concept to series production. Specialized in electronics and software, it draws on Bosch's proven large-scale series production technology to develop tailored solutions for a wide variety of applications in passenger cars, commercial vehicles, off-highway and in rail applications, marine, and smart robotic functions. Bosch Engineering GmbH also coordinates all the Bosch Group's motorsports activities.

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