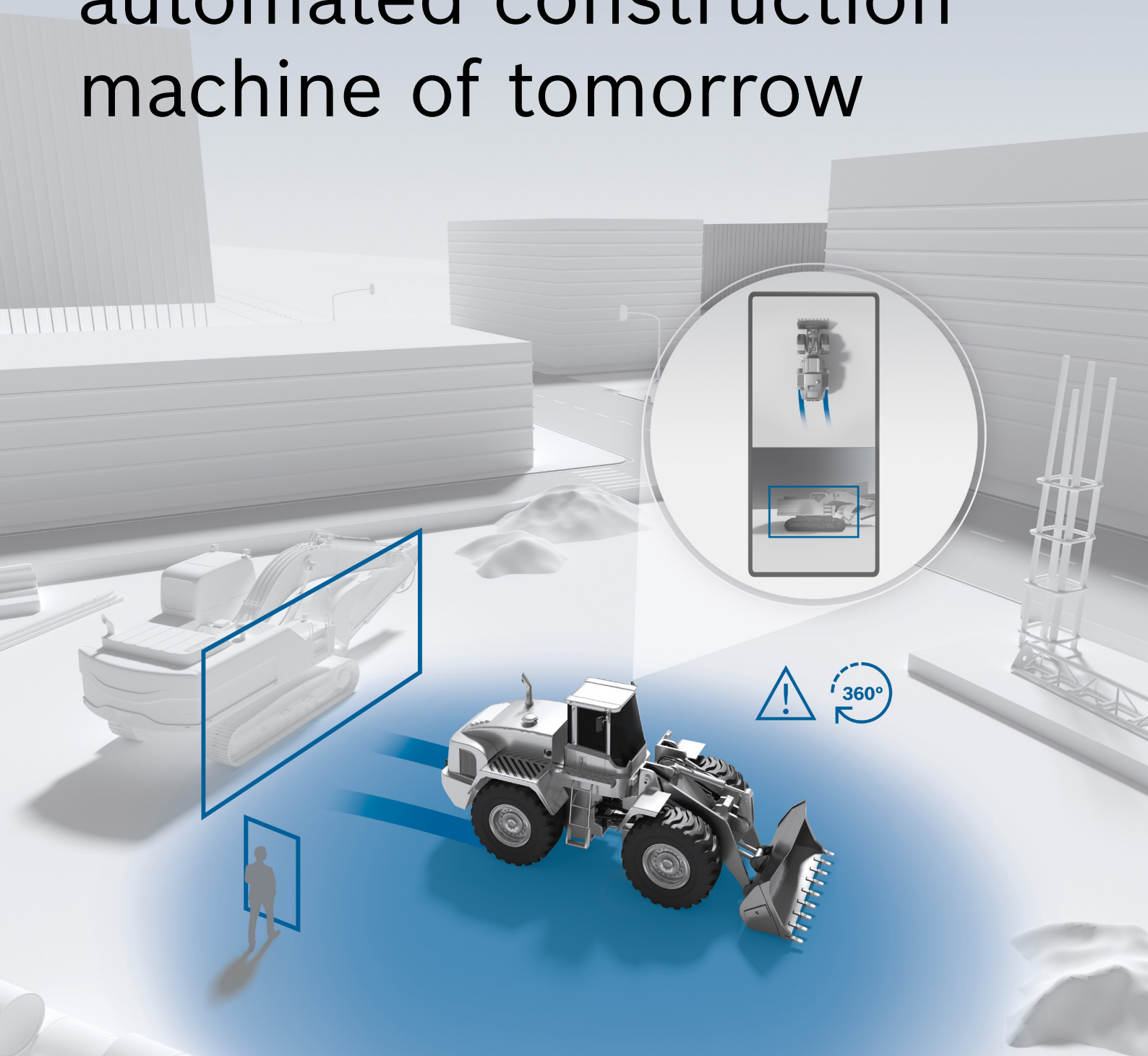


Bosch Engineering is making the vision a reality: on the road to the fully automated construction machine of tomorrow



Lower manufacturing costs, more efficient project implementation, and faster completion: The automation of future construction machinery benefits both construction companies and their clients. In bringing the vision of a fully automated construction site to life, Bosch Engineering supports the customer from the very beginning with the development of market-relevant solutions that ensure sustainable, needs-based automation. In doing so, Bosch Engineering employs an incremental approach encompassing everything from warning assistance functions and partially automated systems that assist the machine operator with specific activities right up to fully automated machinery.

The construction site of the future is automated and connected: Thanks to advanced electronic control systems, the construction machines perform their work fully automatically without any manual intervention required on the part of the machine operator. Just a handful of specially trained experts coordinate and monitor the machine operation from a central control center. Automated machines are particularly well suited to monotonous workflows or for use under extreme conditions, which would otherwise place a great physical strain on human operators or potentially endanger their health. Due to their high working precision, autonomous machines can also complete complex tasks with utmost speed and efficiency. Moreover, their ability to work at high capacity – even “round the clock” if necessary – offers considerable potential for raising efficiency and productivity. Particularly against the backdrop of the ever-increasing shortage of skilled workers, this is a crucial factor when it comes to safeguarding long-term competitiveness. In short, automation results in lower manufacturing costs and faster completion of even the most demanding construction projects.

Bosch Engineering is driving the introduction of automated construction machinery with the development of advanced assistance systems and automation functions tailored to the specific requirements of this sector. Along with construction machinery, applications in areas such as the agricultural, logistics, and municipal sectors are also being explored by Bosch Engineering. On the road to the fully automated construction machine of tomorrow, Bosch Engineering is employing a three-stage launch scenario, in which the level of automation increases with each successive step. Depending on the functional scope and the expected time of launch, a distinction is made between assistance functions that are already available today (“Today”), partially automated systems that will reach market maturity in the medium term (“Tomorrow”), and long-term, fully automated solutions (“Vision”). This provides construction companies with a direct entry point into the world of automation, allowing them to benefit from the technological advances offered by the solutions available on the market. This in turn creates an ideal foundation for the later conversion of the machinery to full “Vision” automation.

“Today”

Assistance functions that support the demanding activities of machine operators are already available today. The systems usually take the form of acoustic and/or visual warnings and information on the display in the vehicle cockpit, which provide valuable advice to assist in machine operation. One example is the load

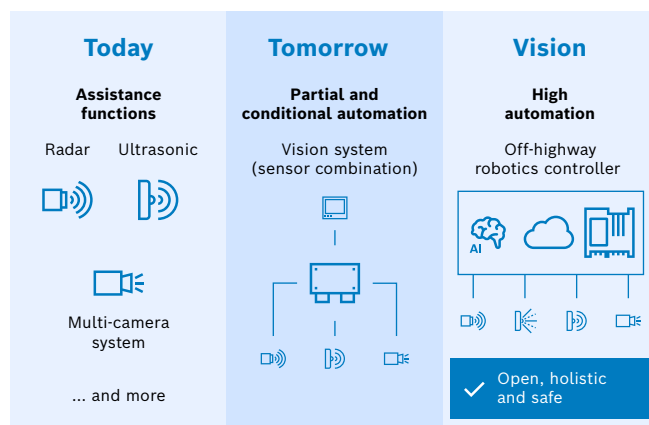
sensors for excavator buckets. These are supplemented with safety functions such as collision warning systems to secure the front and rear of the machine. When the systems identify persons or objects within the detection area, they issue corresponding warnings and show the exact position on the display, thus allowing the machine operator to keep a close eye on any blind spots.

“Tomorrow”

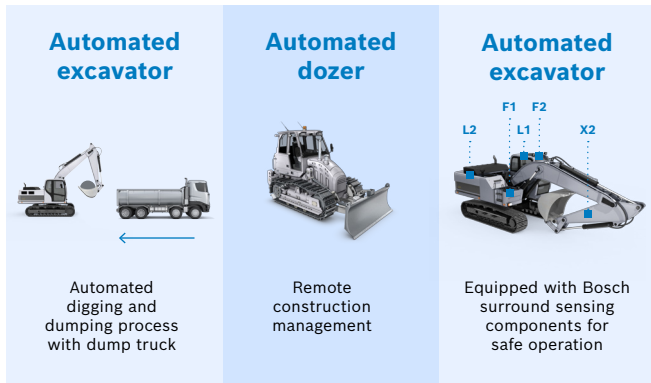
In the medium term, partially automated machines will establish themselves in the construction sector. In this case, the machine will perform individual activities or processes autonomously in order to assist the operator. However, the latter is always onboard and can intervene at any time to retain full control of the system. Application examples include maneuver assistance systems for hitching trailers or semitrailers to a truck as well as guidance functions with automatic tracking and braking in challenging terrain with poor visibility. Since no data communication with a control center is required to perform partially automated operations, “Tomorrow” functions ensure utmost flexibility and availability, thus enabling universal use of the construction machinery.

“Vision”

The fully automated construction machinery of the future will require no human operators at all. The elimination of the traditional operator’s cabin will pave the way for entirely new vehicle concepts, which are further optimized to suit the specific requirements of the individual applications. Multiple research and development projects are currently underway in which Bosch is working with its partners to create machines such as fully automated excavators and bulldozers.



“Today”, “Tomorrow”, and “Vision” – the three stages of construction machinery automation at Bosch Engineering

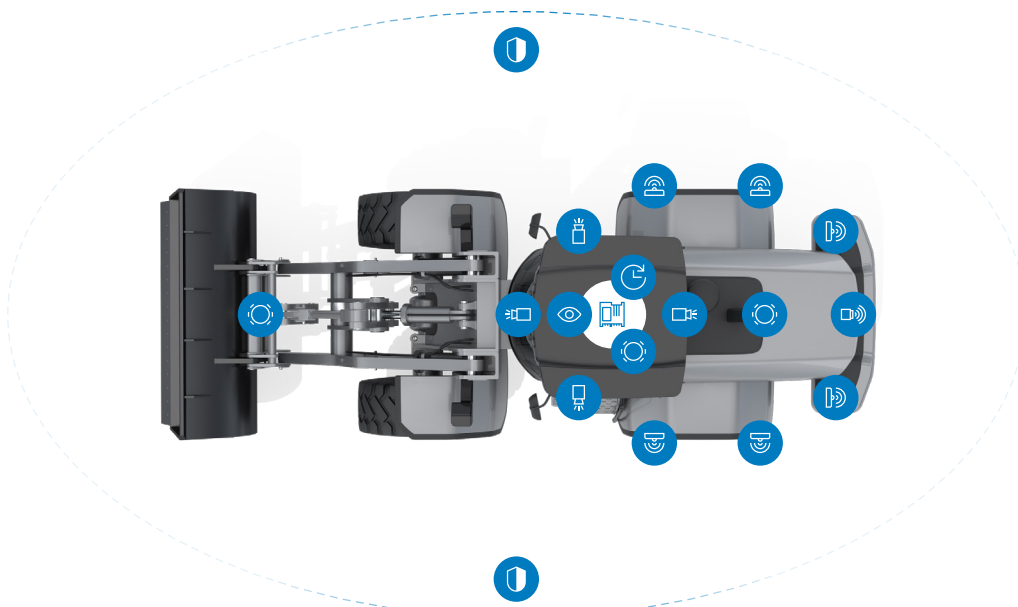


Examples of future, fully automated construction machinery applications

To enable full automation, the machine must have its own sensory system – i.e., it must essentially have “eyes” and be able to interpret the surroundings using its own “brain”. While the same is also true of the “Today” and “Tomorrow” functions, these solutions merely require subsystems, the selection of which depends on the functional scope of the automation. Full automation, on the other hand, requires a complete system comprising the following elements:

- ▶ Comprehensive safety concept
- ▶ Sensing of surroundings to create a 360° model of the environment
- ▶ Accurate and up-to-date map data
- ▶ Planning of the machine trajectory based on the terrain profile
- ▶ Job and fleet management via a reliable back end
- ▶ Precise localization of the machine position
- ▶ Situational analysis to enable correct decision-making
- ▶ Safe, fast, and accurate motion control
- ▶ State-of-the-art electronic architecture and security concept.

- Off-highway robotics control unit
- Perception system
- Functional safety
- Multi-camera system
- Ultrasonic sensor system
- Radar sensor
- Inertial sensor
- Future sensor technologies
 - ▶ LiDAR
 - ▶ Cameras
 - ▶ Global navigation satellite system (GNSS)



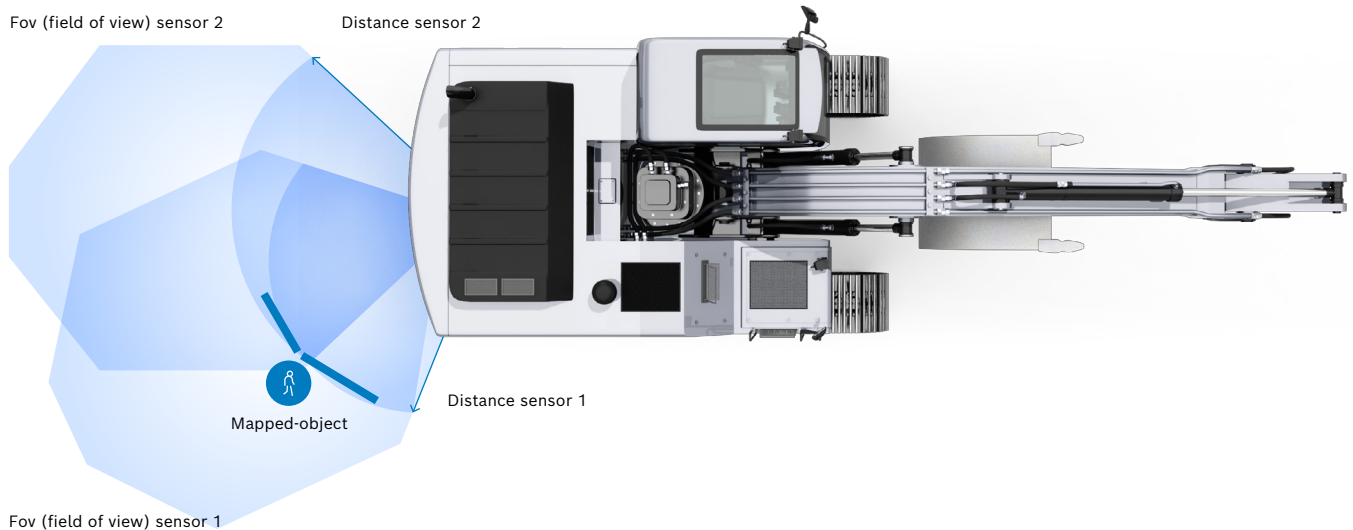
Elements in the E/E network for full automation

Bosch Engineering’s development efforts encompass all system components that are necessary for full automation. Customers thus benefit from a well-coordinated system in which all elements work in perfect harmony. This applies not only to the vehicle’s software and hardware but also to the communication and data exchange with the central control center as well as the connectivity to other automated machines on the construction site, for which Bosch Engineering is working on sophisticated 5G communication solutions.

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. The main distinctions lie in the different environmental and application conditions as well as the objects for which the software’s artificial intelligence receives special training by means of deep learning.

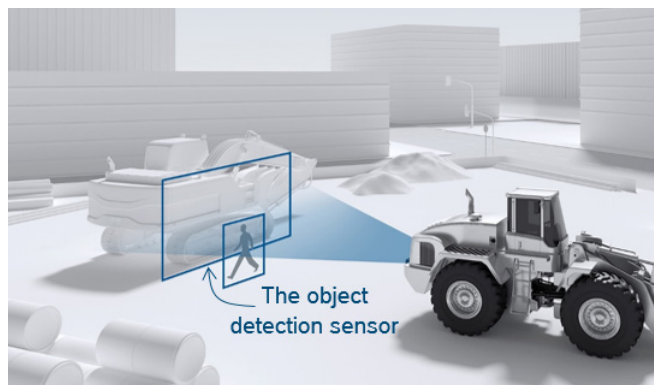
Sensors

All three stages of the assistance and automation functions require sensors to read and observe the machine’s surroundings. For systems of the “Today” stage, the sensor signals are used to provide acoustic and/or visual warnings or to display information on a monitor in the vehicle cabin. In the automation, the sensor information serves – in addition or exclusively – as input signals for the electronic vehicle control system. Bosch Engineering has developed a modular sensor system comprising individual ultrasonic, radar, and camera systems, which can either be adopted unchanged (“component-off-the-shelf”) or tailored to suit the wide range applications in the off-highway sector. With this approach, Bosch draws on its profound expertise along with tried-and-tested basic technologies from the automotive sector and



Safety at the rear of the construction machine by means of ultrasonic sensors

enhances these on a continuous basis for use in the off-highway segment. This includes, for instance, adaptation to the 24V vehicle electrical system and modifications to ensure IP69K protection. As a result, the systems combine high levels of functional safety with exceptional robustness, even under the toughest operating conditions. Since the Bosch sensors are developed in accordance with the relevant ISO standards, they can be used in certified systems without the need for elaborate additional testing.

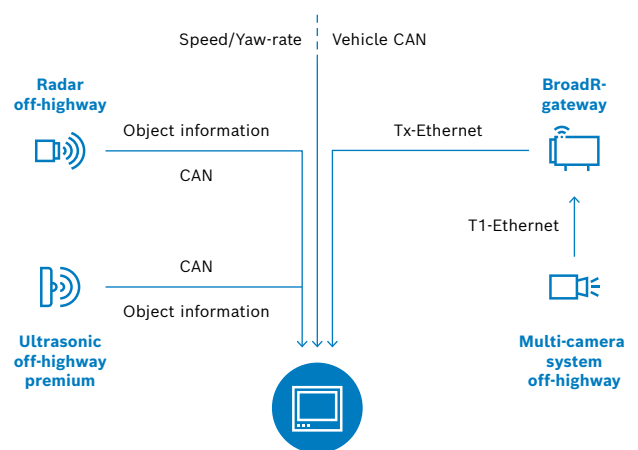


Object recognition using radar sensors

Thanks to an electronic fusion of the sensor data, the benefits of the different sensor technologies are combined to optimum effect, thereby enhancing the automation performance capability. Radar sensors, for example, can accurately measure longitudinal distances and speeds irrespective of the environmental conditions, while the multicamera system ensures maximum precision when it comes to lateral measurements. This fusion provides access to information that would not be obtainable with individual sensors working in isolation. Moreover, the measuring range is increased along with the reliability and accuracy of measurements.

Off-highway vision system

To provide a simple visual representation of the sensor information, Bosch Engineering has developed the off-highway vision system. It displays the video stream from the multicamera system and adds an overlay that visually emphasizes the objects identified within the detection area of the radar and ultrasonic sensors. The information is transferred into a standardized coordinate system so that localization of the objects within the detection area is ensured regardless of the sensor concept. The off-highway vision system has been designed as a prototype system. Bosch Engineering thus provides manufactures of mobile machinery with a validated, functional basic construction kit, allowing them to easily design and develop their own assistance systems based on the plug-and-play principle.



Functional diagram of the off-highway vision system

Off-highway robotics controller

Full automation is particularly demanding in terms of the applicable safety standards. During system and function development, for instance, automatic shut-off devices must be implemented along with different fallback levels for potential defects. This not only ensures permanent system availability but also maximizes safety levels on the construction site. In addition, the data processing and fusion as well as the surround sensing must satisfy the latest standards relating to functional safety and system security. Bosch Engineering assists manufacturers of construction machinery in making the move towards machine automation by means of a coordinated, intrinsically tested and verified complete system, which comprises both the sensor systems described above and the electronic control unit. This new off-highway robotics controller serves as the link between the sensor control units and the machine's electronics. As a central unit, it can also control the full scope of automation functions. In addition to the computing capacity reserved for the surround sensing and perception, the electronic system features additional processing and storage capacity for the application-specific automation software. Data is exchanged entirely within the device to guarantee the shortest possible communication paths, reduce system and wiring requirements, and minimize error sources in the vehicle. The system meets the requirements for safety-related machine controllers pursuant to ISO 13849 and is thus suitable for ISO-1904-certified applications. The interfaces of the off-highway robotics controller comply with the latest standards, thus making the device compatible with systems from other manufacturers. This allows manufacturers of construction machinery to integrate their own sensors or third-party products in the overall system.

The proven open-source operating system ROS2 (robotic operation system 2) is well established in the world of robotics and ensures maximum flexibility in the creation of the application software since individual program modules can be easily combined, replaced, and reused. Bosch Engineering is currently developing its own ROS2-compatible program modules specifically for the off-highway robotics controller, and these can be integrated in the application software. To allow the application to communicate with the control center and other machines on the construction site as well as to facilitate software updates over the air (OTA), Bosch Engineering is also developing a robust, high-performance 5G data connection, which is currently being tested on a pilot construction site.

Bosch Rexroth digital application solutions

The automation software and hardware from Bosch can be seamlessly integrated in the digital ecosystem of BODAS (Bosch Rexroth digital application solutions). BODAS provides users with a bundle of Mobile Electronics that support the digital transformation and thus raise productivity and efficiency while also facilitating the automation process. The scope of services includes a scalable and modular end-to-end connectivity solution for transmitting data from and to the mobile machinery, standard application software for machine functions based on BODAS hardware, as well as an open, scalable, and freely and easily accessible mobile electronics hardware platform. The latter comprises control units, connectivity devices, sensors, and human-machine interfaces (joysticks, displays, pedals), as well as the actuators (hydraulic cylinders and travel drives) for mobile machinery.

Summary and outlook

Much like electrification, automation is one of the main development trends in the world of construction machinery. Bosch is a pioneer in both areas and, using synergies gained from the combination of automotive and off-highway technology, develops cost-effective, powerful, and durable systems for construction machinery of the future. To facilitate automation in the various sectors, Bosch Engineering has created a modular system of different sensor technologies, which can be used to devise the optimum solution for each individual scenario. If the sensors are the “eyes” of the application, the control system, data processing, and associated surround sensing serve as its “brain”. In this area, Bosch is also working on software and hardware solutions to allow manufacturers of construction machinery to implement a well-coordinated, intrinsically tested complete system within their application. A graduated launch scenario, ranging from warning assistance systems to partial automation and completely autonomous construction sites, assists machine manufacturers in taking their first steps towards this forward-thinking technology. As a result, the vision of tomorrow’s fully automated construction site is already within reach.

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 3,000 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 recreational vehicles, and in rail applications, ships, and industry. Bosch Engineering GmbH also coordinates all the Bosch Group’s motorsports activities.



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