White Paper ▶

e-con Systems®

Think Vision. Think e-con.

How Embedded Vision Helps AMRs Make the World Safer and Smarter

Explore the impact of embedded vision technology on Autonomous Mobile Robots across various industries, such as retail, healthcare, industrial operations, and beyond. Discover how the integration of camera systems has enabled AMRs to fool-proof and future-proof the world.

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1. INTRODUCTION

Autonomous Mobile Robots (AMRs) are shaking things up across global industries, from large warehouses to retail and healthcare to factories, smart cities, and even farms. These robots are changing how tasks get done by automating everything from simple chores to more complicated jobs.

The better the camera system, the more accurately these robots can do their jobs all on their own. But here's the thing: every robot has different needs depending on what it's supposed to do and where it's working. For instance, a robot designed for warehouse use will have different imaging requirements than one used in an airport. Factors like lighting conditions, types of obstacles, speed of the robot and the need for object recognition or depth perception can vary greatly between use cases.

That's why there's no one-size-fits-all solution for camera integration. This means selecting the right type of camera, configuring it correctly, and ensuring it works seamlessly with the robot's software. Important considerations include the camera's resolution, frame rate, field of view, and performance under different lighting conditions.

Putting all this together can be tricky. Any misalignment or improper configuration can cause significant issues, such as failing to detect obstacles accurately or recognizing objects.

That's why it's highly recommended to seek help from camera experts before embarking on the integration journey.

2. Market Size and Growth of AMRs

The global market demand for Autonomous Mobile Robots is experiencing rapid growth. In 2023, the global market value for AMRs stood at USD 1.8 billion. This market is projected to reach USD 4.1 billion by 2028, reflecting a CAGR of 17.5% from 2023 to 2028. Moreover, the market is expected to expand, reaching an impressive USD 18.9 billion by 2032.

One of the primary factors contributing to this growth is the adoption of AMRs in the manufacturing sector, particularly in warehouses and factories.

2023	USD 1.6 billion
2028	USD 4.1 billion
2032	USD 18.9 billion

Global market value for AMRs

Leading adopters

The leading category within the AMR market is "goods-to-person" picking robots, which streamline the process of retrieving items from storage and delivering them to workers.

> *"Goods-to-person picking robots represented 11.5% of the market, valued at USD 478.4 million, and are expected to grow at a CAGR of 6.99%."*
>
> ***Statzon***

Within the broader AMR market, the "pick and place" segment holds the leading position. These robots handle products of different shapes and sizes, making them a force to reckon with in assembly lines and packaging processes.

Naturally, manufacturing remains the dominant industry.

CATEGORY	“Goods-to-person" picking robots
SEGMENT	Pick and place
INDUSTRY	Manufacturing

Leading adopters

3. Factors Driving AMR Adoption

Spurt of technological advancements

One of the main catalysts behind the rapid progress in AMR technology, especially indoor robots, is how quickly Artificial Intelligence (AI) and Machine Learning (ML) are advancing. These technologies have enabled the development of robots that can perform tasks autonomously.

Need for automation

Another major factor fueling the growth of AMRs is the increasing need for automation and labor optimization in warehouses. As e-commerce continues to grow at a startling rate, the need for accelerated warehouse operations has also surged. AMRs address this need by automating labor-intensive tasks, such as picking, packing, and transporting goods.

Supply chain optimization

The rising demand for supply chain optimization is also a driver of AMR adoption. Companies are keen to streamline their supply chains to reduce costs and improve delivery times. AMRs contribute to this goal by enhancing the accuracy and speed of order fulfillment processes.

“Supply chain adoption of mobile robots will far outpace drones over next three years.”

Statzon

Safety and risk management

Incorporating AMRs into various industries enhances safety and risk management. AMRs operate in environments that may be hazardous to human workers, such as areas with heavy machinery, extreme temperatures, or exposure to harmful substances. By taking over tasks in these high-risk areas, AMRs help reduce workplace injuries and accidents

Demand for scalability

AMRs offer unmatched scalability and flexibility. As companies grow, the demand for optimal operations increases. AMRs can be easily scaled to meet this demand without huge additional investment.

4. Challenges Faced by AMRs

Integration complexities

One of the primary challenges in AMR development is integrating these robots into existing workflows and systems. Many businesses operate with established processes and legacy systems that may not be compatible with new robotic technologies. The introduction of AMRs requires a thorough assessment of current operations to identify how these robots can be incorporated without disrupting productivity.

High costs

Another barrier to AMR development is the high cost associated with implementation and integration. The initial investment in AMR technology can be substantial, covering the cost of the robots themselves, as well as the infrastructure upgrades and software integration. Additionally, ongoing maintenance and support costs must be considered.

Security concerns

Security is a critical concern in the deployment of AMRs, especially as indoor robots become more interconnected with other systems through IoT (Internet of Things) technologies. Ensuring that AMRs are secure from cyber threats is essential to prevent potential breaches that could disrupt operations or compromise sensitive data.

Workforce-related issues

Adapting the workforce to work alongside AMRs presents another challenge. Employees may have concerns about job security and how their roles are likely to changed, considering the growing need for automation. Therefore, timely change management strategies are required to address such concerns and drive hassle-free transition.

It includes providing training programs to upskill employees and clearly communicating the benefits of AMRs to the workforce.

> *"The primary industry concern continued to be the difficulty in attracting and retaining a qualified hourly workforce, cited by 50% of respondents."*
>
> ***Warehouse/DC Operations Survey***

5. Recent Developments in the AMR World

2022

- Locus Robotics, a manufacturer of autonomous mobile robots for fulfillment warehouses, launched the Locus Vector and Locus Max.
- Geek+ announced a partnership with Systemex Automation, a prominent Canadian systems integrator, to increase AMR installations in North America.
- Boston Dynamics and NFI signed a USD 10 million agreement to deploy their newest robot, Stretch, across NFI's U.S. warehousing operations.
- Forklift manufacturer Linde adopted IDEALworks' autonomous logistics technology and offered the iw.hub mobile robot through Anyfleet, the leading cloud platform.

2023	• Geek+ launched RoboDShuttle Plus, combining its storage Roboshuttle robot with both the tote-carrying P40 and flagship rack-to-person P800 robots. • Locus Robotics introduced LocusONE, a data-science-driven warehouse platform to manage large quantities of multiple AMR form factors as a single, coordinated fleet. • Barcodes Group launched its new autonomous mobile robotics portfolio with Plug-and-Play Integration Software. • OTTO Motors launched its AMR, the OTTO 600, which can handle payloads up to 600kgs.
2024	• Cyngn announced commercial and technological advancements in autonomous mobile robots, marked by the expansion of its distribution network. • LG Business Solutions USA collaborates with SVT Robotics to deploy LG's new CLOi CarryBot AMRs in U.S. warehouse environments.

6. Where AMRs Can Be Deployed

Warehouse operations

> *"By 2027, over 75% of companies will have adopted some form of cyber-physical automation within their warehouse operations."*
>
> ***Gartner***

In modern warehouses, automation plays a crucial role in streamlining operations and increasing productivity. AMRs, equipped with advanced vision technologies, perform essential tasks with minimal human intervention, demonstrating human-robot collaboration

Automated forklifts: Indoor AMRs are equipped with advanced sensors and vision systems that help them map the warehouse layout, avoid obstacles, and optimize their routes. These systems help forklifts automate the movement of heavy loads, thereby reducing the risk of injury to human workers and enhancing productivity.

"Self-driving forklifts had the largest share, making up about 37.5% of the market with a valuation of USD 1.559 billion, projected to grow at a CAGR of 8.01% to reach USD 3.351 billion by 2033."

Statzon

Inventory tracking robots: Inventory tracking robots leverage embedded vision technology to monitor inventory levels, track item locations, and conduct stock checks. They scan barcodes, RFID tags, and other identifiers to keep real-time records of inventory while ensuring that stock levels are accurately maintained.

"Autonomous inventory robots, occupying the second-largest segment with an 18% market share and a 2023 valuation of USD 750 million, are anticipated to grow at a rate of 7.56%, achieving a value of USD 1.5 billion by 2033."

Statzon

Cleaning/disinfection robots: Cleaning and disinfection robots can navigate autonomously, using their vision systems to detect areas that need cleaning while avoiding obstacles. They are capable of performing tasks such as vacuuming, mopping, and disinfecting surfaces.

"Professional cleaning robots, with a usage rate of 41%, are revolutionizing the cleaning industry by offering automated and efficient solutions."

International Federation of Robotics

Patrolling and surveillance

Indoor patrol robots equipped with camera technology are increasingly used in environments requiring high security and constant monitoring. They are integrated with advanced vision systems to perform tasks such as:

- **Chemical plants**: Chemical plants are environments where safety is hugely important due to the presence of hazardous materials. So, indoor AMRs are equipped with sensors for detecting gas leaks, temperature anomalies, and other hazardous conditions.
- **Airports**: Patrol robots can navigate these complex spaces at airports, providing continuous surveillance and ensuring passenger safety. They can detect unattended luggage, monitor crowd movements, and identify potential security threats.
- **Distribution centers**: In distribution centers, patrol robots help maintain security and undisturbed operations. Such locations often store valuable goods, making them targets for theft and vandalism. Hence, indoor AMRs monitor the premises 24/7, detecting and reporting any unauthorized activities.

Telepresence

As digital interactions become more prevalent, telepresence robots have emerged as a dynamic solution for remote communication across various sectors. It enhances connectivity beyond traditional video conferencing systems, providing support for functions such as:

- **Remote offices:** In modern office environments, indoor AMRs enable remote employees to virtually "walk" through office spaces, attend meetings, and interact with colleagues in real time. Hence, remote workers can engage in spontaneous discussions, participate in team-building activities, and attend important meetings without the need for physical travel.
- **Virtual classrooms**: Telepresence robots empower remote students and educators to interact within the classroom. Students unable to show up in person because of health issues, geographical constraints, or other reasons can use indoor AMRs to attend classes virtually.

"Social interaction and education robots are the second largest consumer application group with 157,000 units sold in 2022."

International Federation of Robotics (IFR)

- **Remote tours and inspections**: In industrial and commercial locations, these indoor AMRs are enabling remote tours and inspections. Managers, clients, and stakeholders who are unable to visit a site in person can use these robots to conduct detailed tours and inspections of the facility.

Service robots are developed to assist humans by performing tasks that range from simple chores to more complex functions. They can be used in:

- **Hotels and restaurants:** Indoor AMRs can handle a variety of tasks, including greeting guests at the entrance, guiding them to their tables, and serving food and beverages. They can also provide information about the menu, take orders, and even deliver room service.
- **Office buildings**: In office buildings, indoor AMRs help support day-to-day operations. They assist with reception services by greeting visitors, providing directions, and managing appointment schedules. They can also handle mail delivery within the building.

- **Retail stores**: Indoor AMRs assist with inventory management by scanning shelves, checking stock levels, and notifying staff when items need to be restocked. They enhance the shopping experience by providing customer service, answering questions, and guiding customers.

WAREHOUSE OPERATIONS	• Automated forklifts • Inventory tracking robots • Cleaning/disinfection robots
PATROLLING AND SURVEILLANCE	• Chemical plants • Airports • Distribution centers
TELEPRESENCE	• Remote offices • Virtual classroomRemote tours and inspections
SERVICE/ COMPANION	• Hotels and restaurants • Office buildings • Retail stores

Indoor use cases of AMRs

7. Role of Embedded Vision in AMRs and How It Can Help

Embedded vision equips AMRs to enhance navigation and mapping. It provides detailed and continuous data, allowing AMRs to create precise maps and better understand their environment. This is helpful in use cases such as warehouse automation, where the layout can change frequently, and accurate navigation is needed to maintain operational flow.

Moreover, embedded vision enhances the safety and efficiency of AMRs in industrial and commercial applications. By enabling better object recognition and situational awareness, these systems help AMRs to interact more seamlessly with humans and other machines. It minimizes risks and drives smoother operations, ultimately contributing to higher productivity and operational safety.

What can AMRs do with embedded vision?

- **Navigation and mapping**: Embedded vision helps capture detailed visual data by constructing accurate maps of the AMR surroundings. It enables accurate path planning and movement through complex environments.
- **Obstacle detection and avoidance**: With embedded vision, AMRs can detect and avoid obstacles to identify potential hazards in their path and navigate around them safely. This makes it easy to maintain uninterrupted operation and prevent collisions in dynamic scenarios.
- **Real-time environmental perception**: Embedded vision systems provide AMRs with real-time environmental perception, allowing them to respond quickly to changes in their surroundings. Such feedback is pertinent in locations where quick adjustments are necessary, such as crowded industrial floors.
- **Object recognition and situational awareness**: Thanks to embedded vision, AMRs can accurately identify and classify objects. So, they interact more intelligently with their environment and perform tasks like picking and placing items.

Need for multi-camera systems

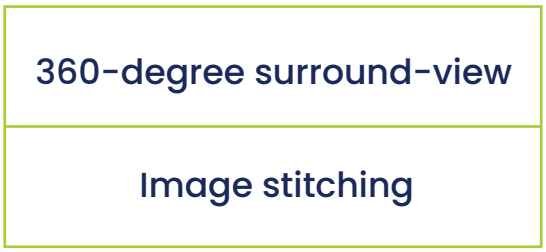
Synchronization in multi-camera systems ensures that all cameras capture images simultaneously – through hardware and software mechanisms. Hardware synchronization uses a common clock signal to trigger image capture at the same time, while software synchronization involves time-stamping each frame and aligning them in post-processing.

Cameras are strategically installed at predetermined points around the AMR, chosen based on design and intended use, to ensure comprehensive coverage.

The setup lets the system capture data from all angles and offer a unified 360-degree view. The placement also considers each camera's field of view, aiming for minimal overlap and maximum coverage.

Here's how multi-camera synchronization works in AMRs.

- **Creating a 360-degree surround-view**: Multi-camera synchronization enables a 360-degree surround view, enhancing AMR awareness. It combines images from multiple cameras to create a bird's-eye view of the surroundings.
- **Enabling image stitching**: Image stitching combines images from different cameras to form a single, coherent visual. The extended view is required for tasks like safe lane changes and merging. First, the synchronized camera setup captures the overlapping fields of view. Then, these images are digitally stitched together for proper transitions.



how multi-camera synchronization works in AMRs

8. What Are the Types of Imaging Used in AMRs?

2D vision

2D vision involves capturing flat images that can be used for various applications, such as reading barcodes, monitoring surroundings, and identifying objects. This type of imaging is essential for tasks that require recognition and analysis of visual patterns. For instance, in warehouses, 2D vision-based indoor robots are used to scan barcodes on packages, ensuring accurate inventory management and tracking.

Additionally, 2D cameras monitor the robot's immediate environment, providing visual feedback that aids in real-time decision-making and task execution.

3D vision

3D vision technology harnesses depth-based imaging to provide a three-dimensional view of the environment. This type of imaging makes it possible to execute tasks such as mapping, localization, and navigation. By capturing detailed depth information, 3D vision systems enable AMRs to create accurate maps of their surroundings and navigate complex environments with high accuracy.

This is key for obstacle avoidance, path planning, and dynamic interaction with objects and structures within the robot's operating area. For example, technologies such as LiDAR and stereo cameras are commonly used to achieve 3D vision, providing the necessary depth information for indoor AMRs to help achieve new levels of warehouse automation.

AMRs require depth cameras for effective 3D vision. The three primary cameras used for depth mapping are:

- **Stereo cameras**: Utilizes stereo disparity by processing images from multiple cameras to measure the target object's depth.
- **Time-of-Flight cameras**: Employs light detection, calculating the time light takes to travel to and from the target object to determine depth.
- **Structured light cameras**: Projects a pattern onto the target object and measure depth by analyzing deformations in the reflected pattern.

Stereo cameras
Time-of-Flight cameras
Structured light cameras

Primary depth cameras for AMRs

9. How to Choose the Right Camera for AMRs

Both 3D and 2D vision play major roles in AMRs, enhancing the robot's performance in various tasks. That's why knowing the considerations for selection is extremely important.

Selection criteria for the right camera for AMRs - 2D vision

Lighting

Often, lighting conditions are the first criterion, as cameras must be capable of capturing clear images even in low-light environments. High Dynamic Range (HDR) cameras are often recommended for their ability to produce low-noise images under limited lighting conditions.

Target

The type of target also influences the choice of camera shutter type. For stationary or slow-moving objects, rolling shutter cameras are generally sufficient. However, if the object moves quickly, two potential issues can arise - motion blur and rolling shutter artifacts. To address motion blur, a rolling shutter camera with a high frame rate may be used while avoiding rolling shutter artifacts requires a global shutter camera.

Detail

Another important consideration is the level of detail needed in the output image. High-resolution cameras, such as those capable of 4K imaging, are ideal for capturing high-quality images. Additionally, if the object is static and more light collection is desired, selecting a camera with a lower frame rate or longer exposure time is beneficial.

Interface

The camera's interface must be able to handle the bandwidth required for transmitting high-resolution images at high frame rates. Interfaces like MIPI, GMSL2, or FPD Link-III are suitable for applications with high data throughput needs, with the choice depending on the transmission distance and specific requirements.

Lens and sensor

The area to be captured and the optics of the camera are also major factors. Ensuring that the vision system covers the desired field of view requires selecting the appropriate lens and sensor. This decision will determine whether a single-camera or multi-camera system is necessary. For multi-camera setups, choosing the method of synchronization, either hardware-level or software-level, is a moment of truth.

HDR

Often, lighting conditions are the first criterion, as cameras must be capable of capturing clear images even in low-light environments. High Dynamic Range (HDR) cameras are often recommended for their ability to produce low-noise images under limited lighting conditions.

ROS compatibility

Compatibility with the Robotic Operating System (ROS) is critical for 2D vision in AMRs. Ensuring that the cameras can seamlessly integrate with ROS supports seamless operation and enhances the robot's capabilities in performing its tasks.

Lighting	Interface
Target	Lens and sensor
Detail	ROS compatibility

Selection criteria for 2D vision-based AMRs

Selection criteria for the right camera for AMRs - 3D Vision

Platform's processing capability

The host platform's processing power is vital, especially when using stereo cameras. Stereo cameras require a stereo algorithm to run on the host platform to calculate the depth of objects in the scene. It calls for sufficient processing capability to handle these computations.

Platforms like the NVIDIA Jetson series are popular choices due to their robust performance and the extensive software development kits (SDKs) they offer. Conversely, Time-of-Flight and structured light cameras provide depth data directly, reducing the processing burden on the host platform.

Lighting and sensitivity

Accurate depth information capture heavily depends on ambient lighting and the camera's lighting mechanism. Passive stereo cameras are suitable for environments with ample ambient light. However, in settings with limited light, active stereo cameras, Time-of-Flight cameras, or structured light cameras are recommended. These cameras have built-in lighting mechanisms that make them function accurately in low-light conditions.

Support for ROS

Given that most robotic systems utilize the Robotic Operating System (ROS), the selected camera must support ROS. This compatibility enables smoother integration, enabling product developers and engineers to shorten development cycles and expedite the time to market for their robots.

Other considerations

Furthermore, similar to 2D vision, a few generic considerations must be kept in mind, as well. These include:

- Cameras with high resolution and frame rate must be selected for high-quality imaging. An interface like GMSL2 or FPD Link can handle the required data transmission over long distances.
- The appropriate field of view must be determined to decide on the number of cameras needed. For multi-camera systems, the type of synchronization, hardware or software, is important to ensure coordinated operation.
- Also, the aperture, depth of field, and focal length must be carefully considered when selecting a lens.

Platform processing	Field of view
Lighting and sensitivity	Synchronization type
Support for ROS	Aperture
High resolution and frame rate	Depth of field and focal length

Selection criteria for 3D vision-based AMRs

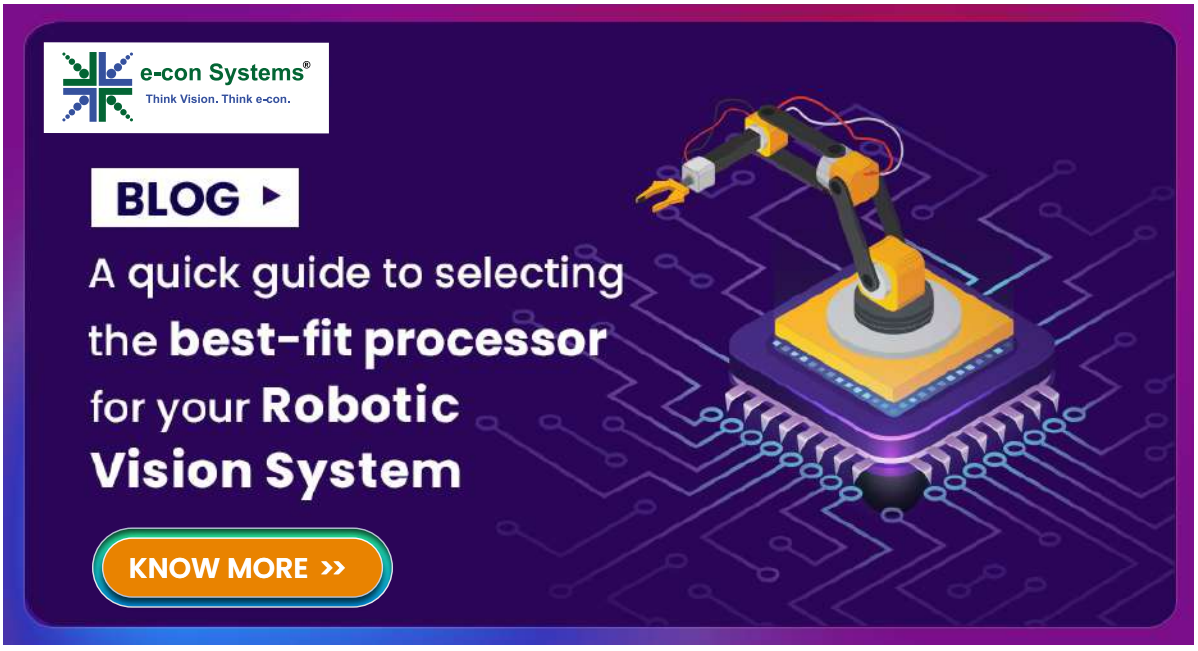
10. Popular Processors Available in the Market for AMRs

High-quality camera solutions are crucial for robotic vision systems, but the processors that handle the images are just as important. Selecting the best processor requires understanding its capabilities and how it can enhance AMR performance.

Several top-tier companies offer advanced processors for robotic applications:

- ***NVIDIA*** - Jetson family (from Jetson Nano to AGX Xavier)
- ***Intel*** - Atom (processor) and FPGAs
- ***Xilinx FPGAs and MPSoCs*** - Zynq UltraScale+ MPSoCs and Kria K26 SOMs
- ***Qualcomm*** - QCS8550, QRB5165, QCS5430, etc.
- ***Renesas*** - RA8 Series MCUs, RZ/V2H microprocessors, etc.

Furthermore, Ambarella and SIMA are also set to offer upcoming processors for autonomous systems like AMRs.



11. e-con Systems' Expertise in Camera Solutions for AMRs

e-con Systems has been at the forefront of designing, developing, and manufacturing OEM cameras for over 20 years. We have established an unparalleled track record in enabling camera integration in various AMRs.

We leverage our strategic partnerships with leading sensor manufacturers like Sony, onsemi, and OmniVision, along with our status as an Elite Partner of NVIDIA. Our cameras are also built to withstand diverse environmental conditions and meet the unique operational requirements of different AMR applications, from navigating warehouse aisles to monitoring airports.

Our in-depth customization capabilities ensure that our camera systems meet the specific needs of these AMRs, whether for object detection, obstacle avoidance, or detailed environmental mapping.

Visit our Autonomous Mobile Robots Page to learn more about our expertise.

Use our Camera Selector to explore our comprehensive portfolio.

12. Wrapping Up

These days, the phrase "game-changer" is used rather loosely, no matter the type of technology. However, in the case of the role of embedded vision in Autonomous Mobile Robots, it rings true. Of course, the level of customization of imaging systems to meet the demands of several applications and environments can't be overlooked.

In many cases, understanding and addressing the challenges of camera integration is the first step. This is where imaging specialists like e-con Systems come in, providing valuable insights to ensure that AMRs reach their full potential.

As technology continues to take quantum leaps, the capabilities of embedded vision-based AMRs will expand further to create an even more futuristic world for humans.

Thank you for taking the time to read our white paper. We hope it provided some much-needed insights into the role of embedded vision in Autonomous Mobile Robots.

If you have any questions or feedback, please feel free to contact us at camerasolutions@e-consystems.com.

About the Author

Suresh Madhu is the Head of Industrial Business Unit at e-con Systems, overseeing Autonomous Mobility and Industrial Vision Solutions. With 18+ years of experience in embedded product design, technical architecture, SOM product development, and camera solutions, he has been instrumental in helping customers integrate the right vision technology into their products.

Dilip Kumar is a Product Manager, specializing in embedded vision solutions. With over 10 years of experience in camera solutions development and edge computing, he has led research and development efforts in computer vision and AI for the evolving edge AI industry. He has been at the forefront of building multiple vision based products using embedded SoCs for industrial use cases such as Autonomous Mobile Robots, AI based video analytics systems, Drone based inspection & surveillance systems.

About e-con Systems

e-con Systems® designs, develops, and manufactures OEM cameras. With 20+ years of experience and expertise in embedded vision, it focuses on delivering vision and camera solutions to industries such as retail, medical, industrial, agriculture, smart city, etc.

Our wide portfolio of products includes Time-of-Flight cameras, MIPI camera modules, GMSL cameras, USB 3.1 Gen 1 cameras, stereo cameras, GigE cameras, low light cameras, etc. Our cameras are currently embedded in over 350+ customer products.

So far, we have shipped over 2 million cameras to the United States, Europe, Japan, South Korea, and many more countries.

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