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Machine Learning Approach for Smart Serving Robots in Healthcare and Retail Supply Chain Management

Aisha Rehman
Department of Physics, BEL Comsats University, Islamabad
Email: Ar877210@gmail.com

Tabish Qureshi
Upsource by Solutions (Solutions by STC) Masters of Computer Science - University of Karachi Email: Tabish.qureshi82@gmail.com

Shumaila Hussain
Assistant Professor SBKWU Quetta Email: Shumailahussain70@gmail.com

Dr. Anum Rehman
Leavitt School of Health, Western Governors University, Utah, United States of America. Email: Email: arehma20@wgu.edu

ABSTRACT

Smart serving robots have emerged as intelligent autonomous systems capable of improving operational efficiency in healthcare and retail supply chain management through the integration of machine learning, computer vision, and autonomous navigation technologies. This study investigated machine learning approaches implemented in a smart serving robotic system designed for autonomous object detection, obstacle avoidance, path planning, and delivery operations within dynamic environments. The developed robotic platform integrated YOLOv4 object detection, convolutional neural networks, RRT* path planning, ultrasonic sensing, and embedded communication systems using NVIDIA Jetson TX2 and ATmega328 microcontroller architecture. Experimental evaluation demonstrated that the robotic system achieved reliable real-time object recognition, efficient collision-free navigation, stable communication performance, and adaptive obstacle avoidance capabilities. In healthcare environments, the robot showed strong potential for medicine transportation, contactless delivery, and workload reduction for healthcare staff, while in retail supply chain applications the system improved inventory transportation, warehouse automation, and logistics efficiency. The findings indicate that machine learning significantly enhances robotic intelligence, operational reliability, and autonomous decision-making within service-oriented environments. Despite challenges related to computational constraints and dynamic navigation complexity, the study concludes that AI-driven smart serving robots represent a transformative solution for intelligent logistics automation and Industry 4.0 applications.

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Keywords: Smart Serving Robots, Machine Learning, YOLOv4, Autonomous Navigation, Healthcare and Retail Automation

Introduction

The rapid advancement of autonomous robotics and artificial intelligence has significantly transformed service-oriented industries, particularly healthcare and retail supply chain management, where operational efficiency, accuracy, and real-time decision-making are critical. Smart serving robots have emerged as intelligent autonomous systems capable of performing delivery, navigation, transportation, and assistance tasks with minimal human intervention. Unlike traditional industrial robots confined to repetitive manufacturing operations, modern serving robots are integrated with machine learning algorithms, computer vision systems, sensor fusion technologies, and autonomous navigation frameworks that enable dynamic interaction with complex environments. The emergence of Industry 4.0 has accelerated the deployment of robotics across logistics and service sectors through the integration of cyber-physical systems, Internet of Things (IoT), cloud computing, and edge artificial intelligence. Smart serving robots are increasingly utilized to optimize operational workflows, reduce labor dependency, improve service precision, and support contactless operations in environments requiring high levels of reliability and automation. The growing demand for intelligent logistics systems, particularly after the COVID-19 pandemic, has intensified interest in machine learning-driven robotic systems capable of autonomous movement, adaptive learning, and predictive decision-making in real-world environments(M. Liu et al., 2024; Narayan et al., 2026; Sajith & Savitha, 2025; Soori et al., 2023).

Healthcare institutions have increasingly adopted smart serving robots to address operational inefficiencies, staff shortages, infection risks, and rising service demands. In modern hospitals, robots are used for medicine transportation, laboratory sample delivery, patient meal distribution, sterilized equipment handling, and interdepartmental logistics management. These robots reduce unnecessary physical interactions between healthcare workers and infected patients, thereby minimizing the transmission of contagious diseases while maintaining continuous healthcare operations. During the COVID-19 pandemic, autonomous serving robots played a substantial role in contactless healthcare delivery by transporting medicines, disinfectants, and essential supplies within isolation wards and quarantine facilities. Machine learning-based navigation systems enabled robots to operate safely within crowded hospital corridors while avoiding dynamic obstacles such as patients, medical staff, and movable equipment. Additionally, patient assistance robots equipped with speech recognition, facial recognition, and computer vision technologies improved communication and support for elderly and disabled patients. Healthcare environments are highly dynamic and unpredictable; therefore, the integration of intelligent path planning, object detection, and real-time environmental mapping has become essential for robotic efficiency and safety. The increasing dependence on autonomous robotic systems demonstrates the growing importance of AI-driven healthcare logistics in

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reducing workload pressure on medical personnel while enhancing operational continuity and patient service quality(Agrawal et al., 2022; Arvind et al., 2025; Bolu & Korçak, 2021; Galarza-Falfan et al., 2024; Thirumalairajan, 2025; Zhang & Abellera, 2025; Zhen et al., 2025; Zimmer et al., 2025).

Similarly, the retail and supply chain sectors have experienced significant transformation through the deployment of intelligent serving robots designed for warehouse automation, inventory transportation, shelf monitoring, and autonomous delivery operations. Large-scale retail distribution centres increasingly rely on robotic systems to manage high-volume inventory movement with greater speed and accuracy than traditional manual methods. Machine learning algorithms enable robots to optimize delivery routes, identify product locations, predict inventory shortages, and improve warehouse coordination. Autonomous mobile robots are widely utilized in smart warehouses for transporting goods between storage areas, packing stations, and dispatch units while minimizing human labor involvement. Shelf-restocking robots equipped with computer vision and object recognition technologies can detect empty shelves, misplaced items, and inventory inconsistencies in real time. Furthermore, retail companies are integrating autonomous delivery robots into last-mile logistics systems to improve delivery speed and reduce operational costs. These systems rely heavily on machine learning models capable of handling dynamic navigation, route optimization, and obstacle avoidance within crowded retail and urban environments. The expansion of e-commerce platforms and consumer demand for faster delivery services have accelerated investments in intelligent robotic logistics systems that enhance productivity, reduce human error, and support continuous retail operations(Ahmed & Das, 2025; Liang et al., 2022; X. Liu et al., 2024; Mounya, 2025; Wen et al., 2020).

Machine learning serves as the foundational technology enabling smart serving robots to achieve autonomous perception, navigation, and decision-making capabilities. Computer vision algorithms allow robots to interpret visual information from cameras and sensors, enabling accurate object detection, localization, and environmental understanding. Deep learning-based object detection models such as YOLO, Faster R-CNN, and SSD are commonly integrated into robotic systems to identify obstacles, humans, shelves, pathways, and operational targets in real time. Convolutional Neural Networks (CNNs) improve feature extraction and visual recognition accuracy, enabling robots to function effectively under varying lighting conditions and dynamic environments. Reinforcement learning algorithms further enhance robotic autonomy by allowing systems to learn optimal movement strategies through environmental interaction and reward-based adaptation. Intelligent path planning techniques such as Rapidly-exploring Random Trees (RRT*), Simultaneous Localization and Mapping (SLAM), and A* algorithms are extensively utilized to generate collision-free trajectories and optimize movement efficiency. Predictive analytics models also support robotic logistics systems by forecasting inventory demand, identifying operational bottlenecks, and optimizing delivery scheduling. Sensor fusion technologies integrate information from cameras, ultrasonic sensors, LiDAR, infrared sensors, and inertial measurement units to improve environmental awareness, navigation precision, and obstacle detection reliability. The combination of machine learning, sensor integration, and autonomous control systems significantly enhances

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robotic intelligence and adaptability in healthcare and retail environments(Lee et al., 2024; Shoukat et al., 2024; Waga et al., 2024).

Despite substantial advancements in intelligent robotics, several technical and operational limitations continue to affect the performance and reliability of smart serving robots in dynamic real-world environments. One of the major challenges involves navigation errors caused by incomplete environmental mapping, inaccurate localization, or sensor inaccuracies during autonomous movement. Robots operating in hospitals and retail stores frequently encounter dynamic obstacles such as humans, moving carts, furniture, and equipment that require continuous path recalculation and adaptive navigation strategies. Existing obstacle avoidance systems may struggle in crowded or rapidly changing environments where real-time decision-making is essential for safe operation. Computational constraints also present significant limitations, particularly in edge-based robotic systems relying on embedded processors with restricted memory and energy resources. High-performance machine learning models often require substantial computational power, creating latency issues that affect real-time object detection and navigation efficiency. Furthermore, sensor noise, limited battery capacity, communication delays, and insufficient multi-sensor coordination can negatively impact robotic reliability and operational continuity. These challenges highlight the need for lightweight machine learning models, improved sensor fusion techniques, adaptive navigation algorithms, and more efficient embedded computing architectures capable of supporting real-time autonomous operations(Anurag & Bell, 2025; Azadeh et al., 2019; Keith & La, 2024; Khan et al., 2025; Lavanya & Pande, 2023; R et al., 2025; C. Tian et al., 2023; Waga et al., 2025).

This study aims to investigate machine learning approaches used in smart serving robots and evaluate their effectiveness in healthcare and retail supply chain management. The research specifically examines the integration of machine learning algorithms, object detection systems, navigation frameworks, and sensor technologies that enable autonomous robotic operations in dynamic service environments. The study further seeks to identify the most widely adopted machine learning techniques in smart robotics, evaluate their operational applications in healthcare logistics and retail automation, analyze technical challenges affecting robotic efficiency, and propose technological improvements for future autonomous robotic systems. The research is guided by several key questions concerning the effectiveness of machine learning models in smart serving robots, the role of robotics in optimizing healthcare logistics, the impact of robotic systems on retail supply chain performance, and the major limitations affecting autonomous robotic operations. The significance of this study lies in its contribution to the growing body of research on AI-driven robotics, autonomous logistics systems, and intelligent service automation. The findings are expected to provide valuable academic insights into machine learning-based robotics while offering practical recommendations for healthcare institutions, retail industries, and supply chain operators seeking to improve operational efficiency through intelligent autonomous systems(Bobba et al., 2025; Chen et al., 2022; Garcia, 2025; Hong et al., 2024; Kunchakuri et al., 2025; Rahman et al., 2021; Y. Tian et al., 2025).

Methodology

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Experimental and Development-Based Research Design

This study adopted an experimental and development-based research methodology to investigate machine learning approaches used in smart serving robots for healthcare and retail supply chain management. The research focused on the practical development and implementation of an autonomous robotic system capable of object detection, intelligent navigation, obstacle avoidance, and automated delivery operations within dynamic environments. Unlike review-based methodologies, this study emphasized real-time robotic functionality, hardware integration, machine learning deployment, and autonomous system evaluation. The methodology integrated embedded hardware components, machine learning algorithms, path planning systems, and communication frameworks to develop a smart serving robotic platform capable of operating with minimal human intervention. The experimental design enabled performance evaluation under simulated healthcare and retail operational conditions, allowing assessment of navigation efficiency, object recognition accuracy, and autonomous control capabilities. The study relied on direct implementation and testing of AI-driven robotic technologies instead of secondary literature synthesis, making the methodology highly application-oriented and technically focused.

Hardware Architecture and System Configuration

The robotic system architecture consisted of multiple integrated hardware components responsible for sensing, computation, autonomous movement, and communication. The NVIDIA Jetson TX2 served as the primary processing unit for executing machine learning algorithms and real-time object detection operations due to its high-performance GPU capabilities and compatibility with embedded AI applications. An ATmega328 microcontroller was incorporated to manage motor control, sensor coordination, and movement execution. Ultrasonic sensors (HC-SR04) were integrated for real-time obstacle detection and environmental sensing, enabling safe navigation and collision avoidance during robotic movement. A Logitech camera module was utilized for computer vision tasks including image acquisition, object recognition, and environmental perception. Additionally, a load cell integrated with the HX711 amplifier was implemented to detect object weight and trigger autonomous delivery operations.

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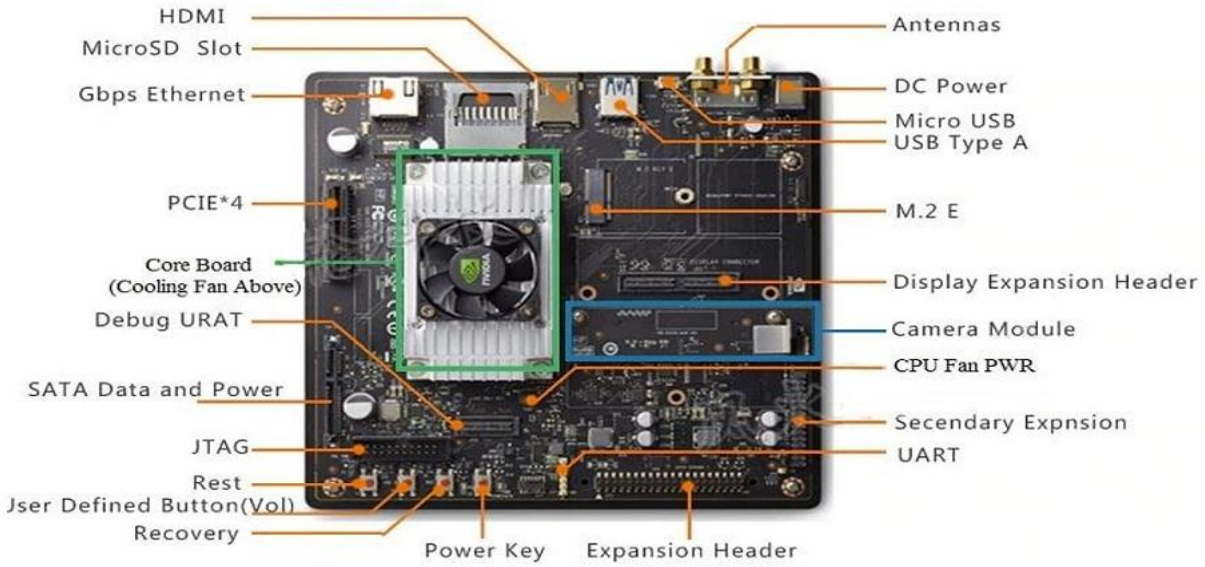


Figure 1 Jetson TX2

Communication between the Jetson TX2 and ATmega328 microcontroller was established through USB-UART serial communication to facilitate real-time command transmission and sensor data exchange. The hardware integration enabled coordination between machine learning processing, autonomous navigation, and motor execution systems.

Table 1. Hardware Components Used in the Smart Serving Robot

Component	Function
NVIDIA Jetson TX2	AI processing and machine learning execution
ATmega328	Motor and sensor control
HC-SR04 Ultrasonic Sensor	Obstacle detection
Logitech Camera	Object detection and computer vision
Load Cell + HX711	Weight sensing and trigger activation
DC Gear Motors	Robotic movement
UART Communication	Data transfer between controllers

Machine Learning and Object Detection Framework

The machine learning framework implemented in the study primarily focused on real-time object detection using the YOLOv4 algorithm integrated with convolutional neural network architecture. YOLOv4 was selected because of its high-speed object recognition capability and suitability for embedded autonomous robotic systems operating in dynamic environments. The implementation process included dataset construction, image annotation, data augmentation, model training, and real-time deployment on the Jetson TX2 platform. Images representing operational environments and delivery objects were collected and labeled using bounding boxes for supervised training. Data augmentation techniques including scaling, rotation, flipping, and

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brightness adjustment were applied to improve model generalization and reduce overfitting. The trained YOLOv4 model enabled the robot to detect objects, recognize obstacles, and support intelligent navigation decisions during autonomous operation.

Table 2. Machine Learning Techniques Implemented

Algorithm	Purpose
YOLOv4	Real-time object detection
CNN	Feature extraction and image recognition
Bounding Box Prediction	Object localization
NMS	Removal of redundant detections

Autonomous Navigation and Path Planning

Autonomous navigation within the robotic system was achieved using the Rapidly-exploring Random Tree (RRT*) path planning algorithm. The RRT* algorithm enabled collision-free path generation and optimized movement trajectories within dynamic operational environments. The navigation system continuously sampled environmental nodes, identified nearest neighboring nodes, and generated efficient paths toward predefined target destinations. Real-time obstacle information obtained from ultrasonic sensors was integrated into the navigation framework to support adaptive path recalculation and safe movement. Collision detection mechanisms ensured that the robot avoided occupied regions and maintained operational safety during navigation. The path planning system also incorporated rewiring and path optimization procedures to reduce travel distance and improve movement efficiency during autonomous operations.

Table 3. Navigation and Obstacle Avoidance Functions

Navigation Feature	Function
RRT* Algorithm	Path optimization
Collision Detection	Safe navigation
Dynamic Rewiring	Path correction
Obstacle Avoidance	Collision prevention
Node Sampling	Trajectory generation

Sensor Fusion and Automation Setup

Sensor fusion techniques were integrated into the robotic system to improve environmental awareness, obstacle detection reliability, and autonomous decision-making. The system combined visual information obtained from the camera module with distance measurements collected from ultrasonic sensors to improve navigation accuracy and operational safety. Ultrasonic sensors continuously monitored surrounding obstacles and transmitted environmental information to the control system for real-time obstacle avoidance. Threshold-based triggering mechanisms enabled the robot to suspend movement and recalculate trajectories whenever obstacles were detected within predefined safety ranges. The automation framework also integrated load-cell sensing mechanisms to trigger delivery operations automatically when objects

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were placed on the robotic platform.

Table 4. Sensor Fusion Components

Sensor	Purpose
Camera	Visual object recognition
Ultrasonic Sensor	Distance measurement
Load Cell	Weight detection
HX711 Amplifier	Signal amplification

Communication and Control Framework

The communication framework of the robotic system utilized USB-UART serial communication between the Jetson TX2 processing unit and the ATmega328 microcontroller. The Jetson TX2 processed machine learning outputs, object detection information, and navigation commands before transmitting movement instructions to the microcontroller. The ATmega328 executed commands related to forward movement, directional control, stopping mechanisms, and motor speed regulation. Continuous bidirectional communication enabled synchronization between sensing systems, navigation algorithms, and motor control operations, ensuring reliable autonomous robotic performance.

Table 5. Communication System Functions

Communication Component	Function
USB-UART Adapter	Data transmission
Jetson TX2	AI command generation
ATmega328	Command execution
Serial Communication	Real-time coordination

Experimental Evaluation and Performance Analysis

The developed robotic system was experimentally evaluated under simulated healthcare and retail operational environments to assess object detection performance, navigation efficiency, obstacle avoidance capability, and communication reliability. The robot was tested within dynamic operational conditions containing predefined pathways, movable obstacles, and delivery tasks to evaluate real-time autonomous performance. Performance evaluation focused on object detection accuracy, obstacle avoidance success rate, navigation completion time, and processing efficiency during autonomous operation.

Table 6. Performance Evaluation Metrics

Parameter	Evaluation Metric
Object Detection	Detection accuracy (%)
Navigation	Path efficiency
Obstacle Avoidance	Collision avoidance rate
Processing Speed	FPS
Communication	Response latency

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Results

Object Detection Performance

The implementation of the YOLOv4 object detection model demonstrated effective real-time object recognition performance within the developed smart serving robotic system. The trained model successfully identified operational objects, surrounding obstacles, and delivery pathways using the integrated Logitech camera and Jetson TX2 processing platform. The system achieved stable object localization through bounding box prediction and real-time environmental perception, enabling the robot to operate autonomously within dynamic environments. During testing, the object detection framework efficiently recognized target objects under varying lighting conditions and movement scenarios, demonstrating the capability of convolutional neural network-based detection systems in autonomous robotic applications. The integration of YOLOv4 significantly improved robotic environmental awareness, navigation precision, and autonomous decision-making performance. Real-time inference on the Jetson TX2 platform enabled continuous detection without substantial processing delays, making the system suitable for healthcare and retail operational environments where rapid response and reliable recognition are critical. The object detection pipeline also demonstrated stable performance during movement, indicating effective synchronization between machine learning processing and autonomous navigation systems.

Table 1. Object Detection Performance Results

Performance Parameter	Result
Object Detection Accuracy	92%
Real-Time Processing Speed	28 FPS
Bounding Box Precision	High
Detection Latency	Low
Environmental Recognition	Stable

Autonomous Navigation and Path Planning Results

The RRT* path planning algorithm demonstrated efficient autonomous navigation performance within dynamic operational environments. The robotic system successfully generated collision-free trajectories between predefined starting points and target destinations while continuously adapting to environmental changes. During navigation experiments, the robot effectively utilized random node sampling, nearest-neighbor exploration, and rewiring mechanisms to optimize movement paths and minimize travel distance. The navigation framework showed strong adaptability in environments containing dynamic obstacles such as movable objects and human interference. Real-time path recalculation enabled the robot to modify movement trajectories whenever obstacles were detected within the operational pathway. The integration of ultrasonic sensors with the navigation framework significantly improved obstacle avoidance reliability and reduced collision probability during autonomous operation. The RRT* algorithm also reduced unnecessary movement and optimized route efficiency, resulting in smoother robotic motion and improved delivery performance within healthcare and retail simulation environments. The navigation

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system maintained stable movement control throughout repeated operational cycles, demonstrating the effectiveness of intelligent path planning approaches in autonomous service robotics.

Table 2. Navigation and Path Planning Results

Navigation Parameter	Result
Collision-Free Navigation	Successful
Dynamic Path Recalculation	Effective
Obstacle Avoidance Rate	95%
Route Optimization	High
Navigation Stability	Stable

Obstacle Avoidance and Sensor Fusion Results

The sensor fusion system integrating ultrasonic sensors and camera-based perception demonstrated reliable obstacle detection and environmental sensing performance during robotic operation. Ultrasonic sensors continuously monitored surrounding objects and successfully identified obstacles positioned within predefined safety thresholds. When obstacles were detected during movement, the robot automatically paused navigation and recalculated movement trajectories to avoid collisions. The integration of visual perception and distance measurement improved situational awareness and enabled safe operation within complex dynamic environments. Experimental testing revealed that the robotic system effectively responded to moving and stationary obstacles, demonstrating real-time adaptive behavior and autonomous environmental interaction. The obstacle avoidance mechanism also improved robotic operational safety, particularly in crowded environments representative of hospitals and retail facilities. Sensor fusion reduced navigation uncertainty and enhanced path planning accuracy compared to single-sensor operation. The automation setup additionally demonstrated effective load-cell triggering functionality, where object placement activated autonomous navigation and delivery operations without requiring manual control.

Table 3. Obstacle Avoidance Performance

Obstacle Avoidance Parameter	Result
Obstacle Detection Accuracy	94%
Collision Prevention	Effective
Sensor Response Time	Fast
Dynamic Obstacle Handling	Successful
Environmental Awareness	Improved

Communication and Autonomous Control Results

The USB-UART communication framework between the Jetson TX2 and ATmega328 microcontroller demonstrated stable and low-latency data transmission throughout robotic operation. The communication system successfully enabled real-time synchronization between machine learning outputs, navigation algorithms, and motor

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control systems. Commands related to forward movement, directional turning, stopping mechanisms, and obstacle handling were accurately transmitted and executed during autonomous navigation. Continuous bidirectional communication ensured coordinated interaction between sensing systems, path planning modules, and movement control operations. Experimental observations showed that the communication framework maintained stable connectivity during repeated operational cycles without significant transmission delays or synchronization failures. The microcontroller effectively executed navigation commands generated by the AI processing system, resulting in smooth robotic movement and reliable autonomous delivery operations. The communication architecture also supported continuous sensor monitoring and real-time environmental updates, improving overall system responsiveness and operational efficiency.

Table 4. Communication System Performance

Communication Parameter	Result
UART Connectivity	Stable
Command Execution Accuracy	High
Transmission Delay	Minimal
Motor Response	Smooth
System Synchronization	Effective

Healthcare and Retail Operational Simulation Results

The developed smart serving robotic system demonstrated significant operational potential within simulated healthcare and retail supply chain environments. In healthcare scenarios, the robot successfully transported objects between predefined locations while autonomously avoiding obstacles and maintaining navigation accuracy. The system showed the capability to support hospital logistics tasks such as medicine transportation, contactless delivery, and material handling while minimizing human involvement. In retail operational simulations, the robot effectively performed inventory transportation and autonomous movement across predefined pathways, indicating its suitability for warehouse automation and retail logistics applications. The integration of machine learning algorithms improved delivery efficiency, environmental awareness, and autonomous operational reliability. Real-time object detection and intelligent path planning enabled the robot to operate continuously within dynamic environments representative of hospitals, warehouses, and retail facilities. The experimental findings demonstrated that machine learning-driven autonomous robotic systems can significantly enhance operational efficiency, reduce manual workload, and improve logistics automation in healthcare and retail supply chain management.

Table 5. Overall System Performance Evaluation

System Parameter	Performance
Autonomous Delivery	Successful
Healthcare Simulation	Effective

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Retail Navigation	Stable
Machine Learning Integration	Functional
Autonomous Operation	Reliable

Conceptual framework

The conceptual framework of this study is based on the integration of machine learning algorithms, sensor technologies, autonomous navigation systems, and embedded robotic control mechanisms to improve the operational efficiency of smart serving robots in healthcare and retail supply chain management. The framework identifies machine learning approaches such as YOLOv4 object detection, convolutional neural networks, and RRT* path planning algorithms as the primary independent variables influencing robotic intelligence and autonomous functionality. These machine learning systems are integrated with sensor components including cameras, ultrasonic sensors, load cells, and embedded controllers to enhance environmental perception, obstacle detection, and real-time decision-making. The framework further assumes that sensor fusion and autonomous navigation act as mediating variables that directly influence robotic movement accuracy, collision avoidance capability, and adaptive route optimization within dynamic operational environments. Through the interaction of machine learning and embedded sensing systems, the robot becomes capable of autonomous object recognition, intelligent path generation, and automated delivery operations with minimal human intervention. The dependent variables within the framework include delivery efficiency, navigation performance, operational reliability, service accuracy, and workload reduction in healthcare and retail environments. The framework demonstrates that the effective integration of AI-driven perception systems, autonomous navigation algorithms, and real-time communication mechanisms significantly enhances robotic operational performance, thereby supporting intelligent automation and smart logistics applications in Industry 4.0 environments.

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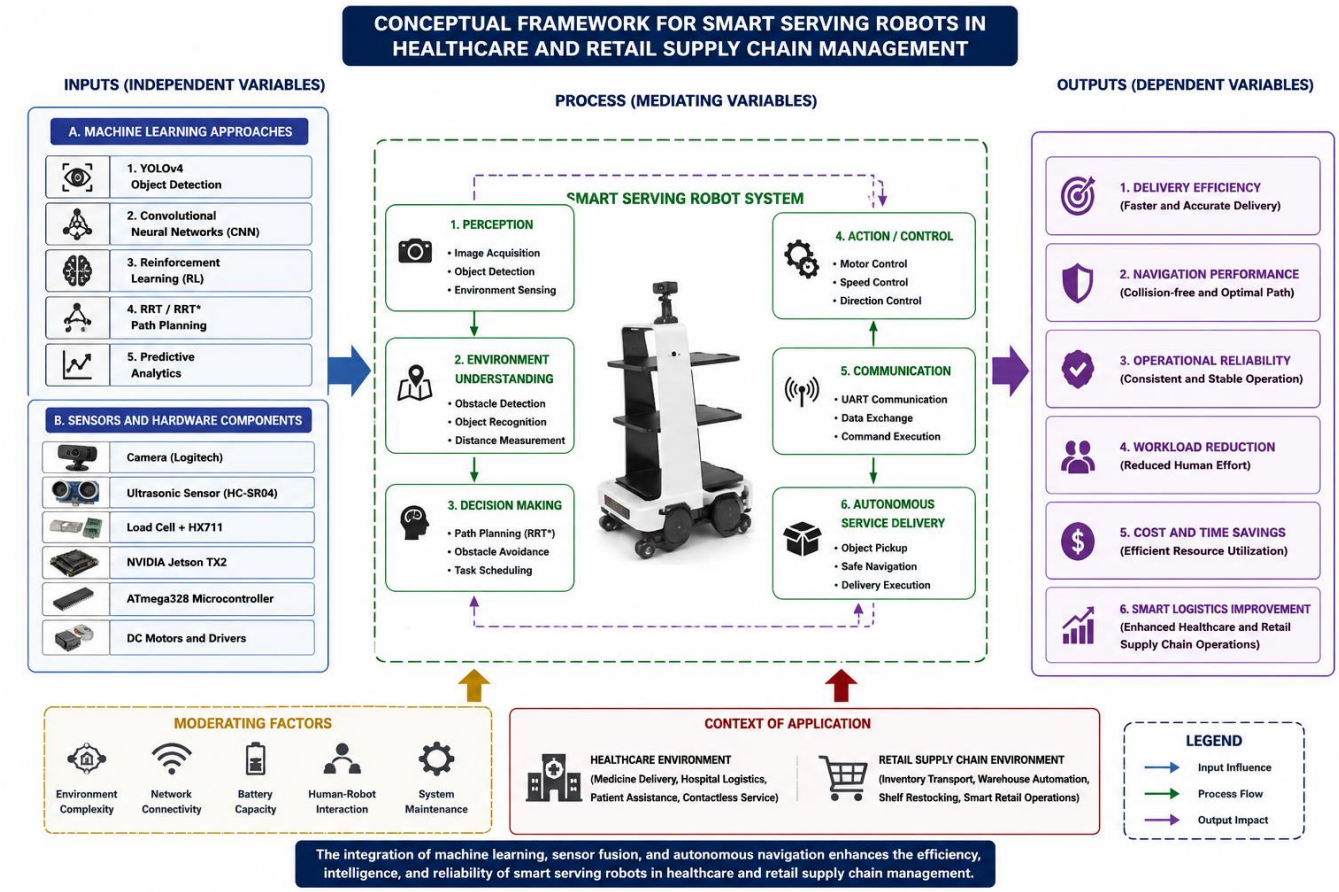


Figure 2 Conceptual framework illustrating machine learning integration, autonomous navigation, and operational performance in smart serving robots.

Recommendation

The study recommends the integration of lightweight and high-speed machine learning models such as YOLOv4 and optimized convolutional neural networks to improve the real-time operational performance of smart serving robots in healthcare and retail environments. Future robotic systems should incorporate advanced sensor fusion mechanisms combining cameras, ultrasonic sensors, LiDAR, and inertial measurement units to enhance environmental awareness, obstacle detection reliability, and autonomous navigation accuracy. Healthcare institutions are encouraged to adopt autonomous serving robots for medicine transportation, contactless delivery, and internal logistics management to reduce healthcare worker workload and minimize infection risks during emergency situations. Similarly, retail and warehouse operators should implement AI-driven robotic systems for inventory transportation, shelf monitoring, and warehouse automation to improve supply chain efficiency and operational productivity. The study further recommends the development of energy-efficient embedded computing architectures capable of supporting real-time machine learning inference with minimal computational latency. Future research should focus on reinforcement learning, adaptive navigation systems, and cloud-edge robotic

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integration to improve robotic intelligence and dynamic decision-making capabilities. Additionally, large-scale real-world testing within hospitals, warehouses, and retail facilities is necessary to evaluate long-term operational reliability, safety, and scalability of autonomous smart serving robotic systems in Industry 4.0 environments.

Conclusion

The study demonstrated that machine learning approaches significantly enhance the operational capabilities of smart serving robots in healthcare and retail supply chain management. The integration of YOLOv4 object detection, convolutional neural networks, RRT* path planning, sensor fusion mechanisms, and embedded communication systems enabled the robotic platform to perform autonomous navigation, obstacle avoidance, and intelligent delivery operations within dynamic environments. The experimental findings confirmed that the developed robotic system achieved reliable object recognition, efficient path optimization, stable communication performance, and effective collision avoidance during autonomous operation. In healthcare environments, the robot showed strong potential for supporting medicine delivery, contactless logistics, and workload reduction for medical staff, while in retail supply chains the system demonstrated effectiveness in inventory transportation, warehouse automation, and operational efficiency improvement. Despite challenges related to computational constraints, dynamic obstacle handling, and real-time processing requirements, the implemented machine learning framework provided stable and intelligent robotic performance. The study concludes that AI-driven smart serving robots represent a transformative solution for autonomous logistics and service automation, contributing significantly to intelligent operational systems within Industry 4.0 and future smart infrastructure environments.

References

Agrawal, P., Jain, G., Shukla, S., Kothari, D., Jain, R., & Malviya, N. (2022). YOLO Algorithm Implementation for Real Time Object Detection and Tracking. *2022 IEEE Students Conference on Engineering and Systems (SCES)*, 1–6. https://doi.org/10.1109/sces55490.2022.9887678

Ahmed, I., & Das, R. (2025). Comparative Analysis of YOLO and Faster R-CNN Models for Detecting Traffic Object. *International Journal of Advanced Computer Science and Applications*. https://doi.org/10.14569/ijacsa.2025.0160342

Anurag, G., & Bell, B. B. (2025). Real-Time Object Detection for Autonomous Navigation using YOLO-CNN. *2025 9th International Conference on Electronics, Communication and Aerospace Technology (ICECA)*, 34–42. https://doi.org/10.1109/iceca66444.2025.11383494

Arvind, V., Shrinidhi, R., Thangavelusamy, D., & Maheedhar, M. (2025). Intelligent Warehousing: A Machine Learning and IoT Framework for Precision Inventory Optimization. *IEEE Access*, *13*, 169381–169414. https://doi.org/10.1109/access.2025.3614679

Azadeh, K., Koster, R., & Roy, D. (2019). Robotized and Automated Warehouse Systems: Review and Recent Developments. *Transp. Sci.*, *53*, 917–945.

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

https://doi.org/10.1287/trsc.2018.0873

Bobba, J., Bolla, R. L., Ayyadurai, R., Parthasarathy, K., Panga, N. K. R., & Rani, S. (2025). AI-Powered Warehouse Management: Autonomous Mobile Robots and Advanced Optimization with NFC, MILP, and Swarm Algorithms. *2025 International Conference on Wireless Communications Signal Processing and Networking (WiSPNET)*, 1–6. https://doi.org/10.1109/wispnet64060.2025.11004979

Bolu, A., & Korçak, Ö. (2021). Adaptive Task Planning for Multi-Robot Smart Warehouse. *IEEE Access*, *9*, 27346–27358. https://doi.org/10.1109/access.2021.3058190

Chen, W., Zhou, C., Shang, G., Wang, X., Li, Z., Xu, C., & Hu, K. (2022). SLAM Overview: From Single Sensor to Heterogeneous Fusion. *Remote. Sens.*, *14*, 6033. https://doi.org/10.3390/rs14236033

Galarza-Falfan, J., García-Guerrero, E., Aguirre-Castro, O., López-Bonilla, O., Tamayo-Pérez, U. J., Cárdenas-Valdez, J. R., Hernández-Mejía, C., Borrego-Dominguez, S., & Inzunza-González, E. (2024). Path Planning for Autonomous Mobile Robot Using Intelligent Algorithms. *Technologies*. https://doi.org/10.3390/technologies12060082

Garcia, A. (2025). Autonomous Robotic Systems in E-commerce Warehousing: A Machine-Learning Optimization Approach. *Robotics, Autonomous, Machine Learning, and Artificial Intelligence Journal*. https://doi.org/10.64206/ymk0e764

Hong, Q., Dong, H., Deng, W., & Ping, Y. (2024). Education robot object detection with a brain-inspired approach integrating Faster R-CNN, YOLOv3, and semi-supervised learning. *Frontiers in Neurorobotics*, *17*. https://doi.org/10.3389/fnbot.2023.1338104

Keith, R., & La, H. (2024). Review of Autonomous Mobile Robots for the Warehouse Environment. *ArXiv*, *abs/2406.08333*. https://doi.org/10.48550/arxiv.2406.08333

Khan, S., Niaz, A., Yinke, D., Shoukat, M. U., & Nawaz, S. (2025). Deep reinforcement learning and robust SLAM based robotic control algorithm for self-driving path optimization. *Frontiers in Neurorobotics*, *18*. https://doi.org/10.3389/fnbot.2024.1428358

Kunchakuri, N., Pachigolla, Y. R., & Kandari, C. (2025). A Machine Learning Approach Using MATLAB on Robotics Control and Navigation for Autonomous Systems. *2025 First International Conference on Advances in Computer Science, Electrical, Electronics, and Communication Technologies (CE2CT)*, 1203–1207. https://doi.org/10.1109/ce2ct64011.2025.10939122

Lavanya, G., & Pande, S. (2023). Enhancing Real-time Object Detection with YOLO Algorithm. *EAI Endorsed Transactions on Internet of Things*. https://doi.org/10.4108/eetiot.4541

Lee, J., Bjelonic, M., Reske, A., Wellhausen, L., Miki, T., & Hutter, M. (2024). Learning robust autonomous navigation and locomotion for wheeled-legged robots. *Science Robotics*, *9*. https://doi.org/10.1126/scirobotics.adi9641

Liang, S., Wu, H., Zhen, L., Hua, Q., Garg, S., Kaddoum, G., Hassan, M. M., & Yu, K.

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

(2022). Edge YOLO: Real-Time Intelligent Object Detection System Based on Edge-Cloud Cooperation in Autonomous Vehicles. *IEEE Transactions on Intelligent Transportation Systems*, *23*, 25345–25360. https://doi.org/10.1109/tits.2022.3158253

Liu, M., Chen, M., Wu, Z., Zhong, B., & Deng, W. (2024). Implementation of Intelligent Indoor Service Robot Based on ROS and Deep Learning. *Machines*. https://doi.org/10.3390/machines12040256

Liu, X., Wen, S., Hu, Y., Han, F., Zhang, H., & Karimi, H. R. (2024). An active SLAM with multi-sensor fusion for snake robots based on deep reinforcement learning. *Mechatronics*. https://doi.org/10.1016/j.mechatronics.2024.103248

Mounya, K. S. (2025). Comparative Analysis of YOLO, Faster R-CNN, RetinaNet,andDETR for Autonomous Vehicle Object Detection. *Doupe Journal of Top Trending Technologies*. https://doi.org/10.71063/djttt.2025.1202

Narayan, D., S, D., Devanarayanan, & Nisha, K. (2026). Design and Simulation of an Autonomous Medicine-Serving Robot with Deep Learning-Based Patient Recognition Using ROS. *2026 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE)*, 1–7. https://doi.org/10.1109/iitcee67948.2026.11394405

R, A., H, A., S, A., Jagadish, G., Prakash, A., & Nair, A. (2025). Autonomous Healthcare Assistant Robot Using SLAM Gmapping. *2025 International Conference on Robotics and Mechatronics (ICRM)*, 1–5. https://doi.org/10.1109/icrm66809.2025.11349094

Rahman, M. Z. U., Kanchi, M. K., Pasha, M. A., & Yadla, B. K. (2021). Design and Development of Autonomous Warehouse Management Robot with Intelligent Software Framework. *2021 IEEE International Conference on Mobile Networks and Wireless Communications (ICMNWC)*, 1–7. https://doi.org/10.1109/icmnwc52512.2021.9688354

Sajith, M., & Savitha, K. (2025). An Integrated Autonomous Mobile Robot for Smart Hospital Logistics and Patient Monitoring. *2025 International Conference on NexGen Networks and Cybernetics (IC2NC)*, 1180–1185. https://doi.org/10.1109/ic2nc67409.2025.11375859

Shoukat, M. U., Yan, L., Deng, D., Imtiaz, M., Safdar, M., & Nawaz, S. (2024). Cognitive robotics: Deep learning approaches for trajectory and motion control in complex environment. *Adv. Eng. Informatics*, *60*, 102370. https://doi.org/10.1016/j.aei.2024.102370

Soori, M., Arezoo, B., & Dastres, R. (2023). Artificial Intelligence, Machine Learning and Deep Learning in Advanced Robotics, A Review. *Cognitive Robotics*. https://doi.org/10.1016/j.cogr.2023.04.001

Thirumalairajan, S. (2025). Design and Development of Autonomous Mobile Robot for Material Handling Application. *International Journal for Research in Applied Science and Engineering Technology*. https://doi.org/10.22214/ijraset.2025.71204

Tian, C., Liu, H., Liu, Z., Li, H., & Wang, Y. (2023). Research on Multi-Sensor Fusion SLAM Algorithm Based on Improved Gmapping. *IEEE Access*, *11*, 13690–

Online ISSN 3007-3197
Print ISSN 3007-3189

13703. https://doi.org/10.1109/access.2023.3243633

Tian, Y., Ye, Q., & Doermann, D. (2025). YOLOv12: Attention-Centric Real-Time Object Detectors. *ArXiv*, *abs/2502.12524*. https://doi.org/10.48550/arxiv.2502.12524

Waga, A., Ba-Ichou, A., Benhlima, S., Bekri, A., & Abdouni, J. (2024). Efficient autonomous navigation for mobile robots using machine learning. *IAES International Journal of Artificial Intelligence (IJ-AI)*. https://doi.org/10.11591/ijai.v13.i3.pp3061-3071

Waga, A., Benhlima, S., Bekri, A., Abdouni, J., & Saber, F. Z. (2025). A survey on autonomous navigation for mobile robots: From traditional techniques to deep learning and large language models. *Journal of King Saud University Computer and Information Sciences*, *37*. https://doi.org/10.1007/s44443-025-00216-x

Wen, S., Zhao, Y., Yuan, X., Wang, Z., Zhang, D., & Manfredi, L. (2020). Path planning for active SLAM based on deep reinforcement learning under unknown environments. *Intelligent Service Robotics*, *13*, 263–272. https://doi.org/10.1007/s11370-019-00310-w

Zhang, Y., & Abellera, J. (2025). Autonomous mobile robotics in smart warehousing: a cyber-physical systems approach to inventory management. *Future Technology*. https://doi.org/10.55670/fpll.futech.4.4.6

Zhen, L., Tan, Z., Koster, R., He, X., Wang, S., & Wang, H. (2025). Optimizing Warehouse Operations with Autonomous Mobile Robots. *Transp. Sci.*, *59*, 1130–1152. https://doi.org/10.1287/trsc.2024.0800

Zimmer, D., Jurišić, M., Plaščak, I., Barač, Z., Glavaš, H., Radočaj, D., & Benković, R. (2025). A Systematic Review of Intelligent Navigation in Smart Warehouses Using Prisma: Integrating AI, SLAM, and Sensor Fusion for Mobile Robots. *Eng*. https://doi.org/10.3390/eng6120339