Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

An Intelligent Warehouse Execution Framework Integrating SAP Extended WarehouseManagement, Large Language Models, SAP Business Technology Platform, and Autonomous Mobile Robots

Naveen Chandra Sharma

nsharma@sagesap.com

Sage Group Technologies

Kunal Sharma

Collierville High School

Research Article

Keywords: SAP EWM, Warehouse Automation, Large Language Models, ChatGPT, Autonomous Mobile Robots, SAP Business Technology Platform, Industry 4.0

Posted Date: July 31st, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10351090/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

An Intelligent Warehouse Execution Framework Integrating SAP Extended Warehouse Management, Large Language Models, SAP Business Technology Platform, and Autonomous Mobile Robots

Naveen Chandra Sharma
IT-SAP Application
Sage group Technologies Inc
Hazlet, NJ, USA
nsharma@sagesap.com

Kunal Sharma
Student Research Assistant
Collierville High School
Collierville, Shelby, TN,USA
ksharma9912@colliervilledragons.org

Corresponding author: Naveen Chandra Sharma
Email: nsharma@sagesap.com

Abstract— The increasing demand for intelligent warehouse operations has accelerated the adoption of autonomous mobile robots (AMRs), enterprise resource planning systems, and artificial intelligence technologies. However, most existing warehouse management systems require operators to interact through structured user interfaces and predefined workflows, limiting operational flexibility and increasing manual effort. [17], [18], [19], [20]

This paper presents an intelligent warehouse execution framework that integrates SAP Extended Warehouse Management (SAP EWM), Large Language Models (LLMs), SAP Business Technology Platform (SAP BTP), and an autonomous mobile robot (LALLU) to enable natural-language-driven warehouse task execution. The proposed framework allows warehouse operators to issue commands using natural language, which are interpreted by a Large Language Model and translated into executable warehouse operations. SAP EWM generates warehouse tasks, which are communicated through REST-based services to an autonomous robot. The robot navigates to the destination, validates the destination storage bin using QR-code recognition, and automatically confirms the warehouse task back to SAP EWM upon successful validation.

Unlike conventional warehouse automation approaches that depend primarily on barcode scanners, RF terminals, or manually triggered workflows, the proposed framework combines conversational artificial intelligence with enterprise warehouse execution to create an adaptive human–robot collaboration model. The framework was implemented using SAP S/4HANA 2023, SAP EWM, custom ABAP REST services, Raspberry Pi–based robotics, Python APIs, and SAP Business Technology Platform. Experimental evaluation of 50 warehouse task executions achieved a 98% task confirmation success rate with an average end-to-end execution time of 4.7 seconds, demonstrating the feasibility of conversational AI–driven warehouse execution.

Keywords: SAP EWM, Warehouse Automation, Large Language Models, ChatGPT, Autonomous Mobile Robots, SAP Business Technology Platform, Industry 4.0

I. INTRODUCTION

Warehouse operations have undergone significant transformation under the Industry 4.0 paradigm, where automation, artificial intelligence, and cyber–physical systems are increasingly replacing traditional manual processes. Modern warehouses are expected to achieve higher throughput, lower operational costs, and greater flexibility while maintaining real-time visibility across logistics operations. [1], [2], [3], [4], [5], [6], [7], [8], [9]

SAP Extended Warehouse Management (SAP EWM) provides comprehensive functionality for warehouse execution, inventory management, and logistics coordination. Although SAP EWM supports sophisticated warehouse processes, warehouse operators continue to rely heavily on radio-frequency (RF) devices, handheld scanners, and predefined transactions to execute warehouse tasks. These interfaces require extensive user interaction and technical knowledge, creating operational inefficiencies in dynamic warehouse environments.

Recent advances in Large Language Models (LLMs) have demonstrated remarkable capabilities in understanding natural language and converting human intent into executable actions. At the same time, autonomous mobile robots (AMRs) have become increasingly capable of navigating warehouse environments and performing material movement tasks with minimal human intervention.

Despite these technological advances, limited research has focused on integrating conversational artificial intelligence directly with enterprise warehouse management systems to enable natural-language-driven warehouse execution. Existing implementations typically separate conversational interfaces from enterprise execution systems, resulting in fragmented workflows and limited automation.

This research proposes an intelligent warehouse execution framework that bridges this gap by integrating SAP EWM, SAP Business Technology Platform, Large Language Models, and autonomous mobile robots into a unified architecture.

The primary contributions of this paper are:

- A natural-language interface for SAP warehouse task execution using Large Language Models.

- A REST-based integration framework connecting SAP EWM with autonomous mobile robots.
- An intelligent QR-code validation mechanism for automatic warehouse task confirmation.
- A modular architecture integrating SAP BTP, SAP EWM, conversational AI, and robotic automation.
- Experimental validation demonstrating end-to-end warehouse task execution.

II. RELATED WORK

Recent advances in Industry 4.0 have significantly transformed warehouse operations through the adoption of Warehouse Management Systems (WMS), autonomous mobile robots (AMRs), artificial intelligence (AI), and cloud-based enterprise integration platforms. Although considerable research has been conducted in each of these domains independently, relatively few studies have explored their unified integration within enterprise warehouse environments. This section reviews the relevant literature and identifies the research gap addressed by the proposed framework.

A. Warehouse Management Systems

Warehouse Management Systems (WMS) are fundamental components of modern supply chain operations, providing functionality for inventory management, warehouse task execution, storage optimization, and logistics coordination. Enterprise-grade WMS platforms support inbound processing, outbound delivery, replenishment, picking, packing, and inventory tracking while improving warehouse visibility and operational efficiency. [1], [2], [3]

Among commercial warehouse management solutions, SAP Extended Warehouse Management (SAP EWM) is widely adopted because of its comprehensive functionality and seamless integration with SAP ERP and SAP S/4HANA. SAP EWM supports advanced warehouse processes including wave management, warehouse order creation, labor management, cross-docking, slotting, and warehouse automation. [5], [6], [21], [22], [23], [24]

Despite these capabilities, warehouse execution in SAP EWM remains largely dependent on operator interactions through RF devices, handheld barcode scanners, or SAP Fiori applications. Warehouse operators are required to execute predefined transactions manually for warehouse task confirmation, resulting in repetitive user interactions and increased operational effort. Consequently, although SAP EWM provides sophisticated warehouse functionality, its interaction model remains largely procedural rather than conversational or autonomous.

B. SAP EWM Automation

Automation within SAP EWM has received increasing attention as organizations seek to improve warehouse productivity and reduce manual intervention. Existing implementations commonly integrate SAP EWM with programmable logic controllers (PLCs), automated storage and retrieval systems (AS/RS), conveyor systems, robotic palletizers, automated guided vehicles (AGVs), and warehouse control systems (WCS).

SAP provides several integration mechanisms for warehouse automation, including IDocs, RFC/BAPI interfaces, OData services, REST APIs, SAP Event Mesh, SAP Plant Connectivity (PCo), and SAP Business Technology Platform Integration Suite. These technologies enable external systems to exchange warehouse execution information with SAP EWM.

Most reported implementations, however, concentrate on machine-level automation or predefined event-driven workflows. The interaction between warehouse operators and SAP EWM continues to rely on structured user interfaces and predefined business transactions. As a result, intelligent conversational interaction and autonomous task execution remain largely unexplored within enterprise SAP warehouse environments.

C. Autonomous Mobile Robots

Autonomous Mobile Robots (AMRs) have become an essential component of smart warehouses because of their ability to transport materials, navigate dynamic environments, and collaborate safely with human workers. Compared with traditional Automated Guided Vehicles (AGVs), AMRs employ simultaneous localization and mapping (SLAM), computer vision, LiDAR, and artificial intelligence algorithms to navigate without fixed guidance infrastructure.

Commercial warehouse robotics platforms developed by companies such as Amazon Robotics, Geek+, GreyOrange, Locus Robotics, and Fetch Robotics have demonstrated significant improvements in warehouse throughput, operational flexibility, and labor productivity. Academic research has similarly investigated multi-robot coordination, path planning, obstacle avoidance, fleet management, and energy-efficient navigation.

Although robot navigation has advanced considerably, many existing implementations operate independently of enterprise warehouse management systems. Robot task execution is often coordinated by proprietary fleet management software, with limited integration into enterprise applications such as SAP EWM. Furthermore, destination validation is frequently based on barcode scanning or manually configured workflows rather than intelligent, AI-assisted verification mechanisms.

D. Artificial Intelligence in Warehouses

Artificial Intelligence has increasingly been applied to warehouse operations for demand forecasting, inventory optimization, warehouse scheduling, predictive maintenance, route optimization, computer vision, and robotic navigation. Machine learning techniques have enabled improved forecasting accuracy, optimized storage allocation, and enhanced operational decision making. [10], [11], [12], [13], [14], [15], [16]

The emergence of Large Language Models (LLMs), including ChatGPT and other transformer-based conversational AI systems, has introduced new opportunities for natural-language interaction with enterprise applications. LLMs have demonstrated exceptional capabilities in understanding user intent, generating structured responses, assisting decision making, and supporting business process automation.

Existing research involving LLMs has primarily focused on customer service, software engineering, document generation, business analytics, and knowledge management. Comparatively little work has explored the application of conversational AI within enterprise warehouse management

systems. In particular, there is limited research on transforming natural-language warehouse commands directly into executable SAP EWM warehouse operations.

E. Research Gap

Although previous studies have independently investigated SAP EWM automation, autonomous mobile robots, enterprise integration platforms, and artificial intelligence, relatively few have proposed an integrated framework that combines all these technologies into a unified warehouse execution architecture.

The limitations identified in existing literature include:

- Warehouse operators continue to rely on RF devices, handheld scanners, or predefined SAP transactions for warehouse task execution.
- Most SAP EWM automation focuses on equipment integration rather than conversational human–robot interaction.
- Existing robotic warehouse solutions are typically isolated from enterprise warehouse management systems.
- Few studies employ Large Language Models to interpret natural-language warehouse instructions and initiate enterprise warehouse execution.
- Limited research integrates SAP Business Technology Platform, SAP EWM, autonomous robots, and conversational AI within a single end-to-end architecture.

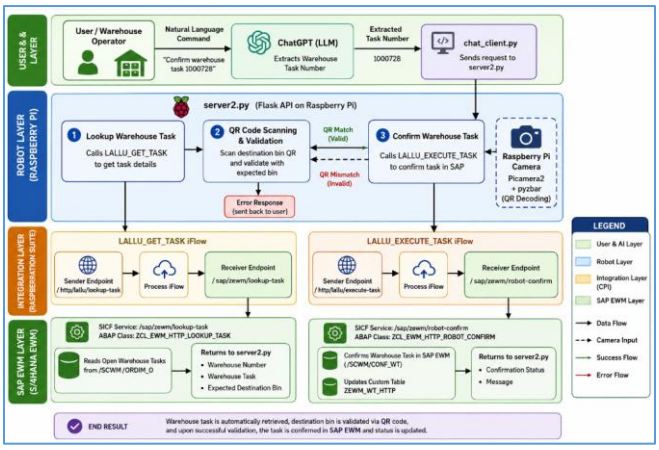
To address these limitations, this paper proposes an intelligent warehouse execution framework that integrates SAP Extended Warehouse Management, SAP Business Technology Platform, Large Language Models, and an autonomous mobile robot. The proposed framework enables warehouse operators to issue natural-language commands, dynamically retrieves warehouse task information through SAP Integration Suite, validates destination storage bins using QR-code recognition, and automatically confirms warehouse tasks in SAP EWM. This approach establishes a unified human–robot collaboration models that bridges conversational AI and enterprise warehouse execution, contributing to the advancement of Industry 4.0–enabled warehouse automation.

Table I. Comparison of the Proposed Framework with Existing Warehouse Automation Approaches

Feature	Traditional SAP EWM	Existing AMR Systems	Proposed Framework
Natural-language interface	✗	✗	✓
SAP EWM integration	✓	Partial	✓
QR-based destination validation	Limited	Partial	✓
LLM-driven execution	✗	✗	✓
Automatic warehouse task confirmation	Partial	Partial	✓
End-to-end enterprise workflow	✗	✗	✓

III. SYSTEM ARCHITECTURE

Fig.1 Architecture diagram



The proposed intelligent warehouse execution framework integrates conversational artificial intelligence, SAP Extended Warehouse Management (SAP EWM), SAP Business Technology Platform (SAP BTP), and an autonomous mobile robot into a unified architecture for end-to-end warehouse task execution. The framework enables warehouse operators to issue natural-language commands, which are interpreted by a Large Language Model (LLM) and automatically translated into executable warehouse operations.

The architecture consists of four major layers:

- User and Artificial Intelligence Layer
- Mobile Robotic Layer
- SAP Business Technology Platform Integration Layer
- SAP EWM Execution Layer

The communication between components is performed using REST-based services deployed on SAP BTP Integration Suite.

A. SAP EWM Integration

SAP Extended Warehouse Management serves as the enterprise warehouse execution system responsible for managing warehouse tasks and inventory operations.

The implementation was developed using SAP S/4HANA 2023 Embedded EWM. Warehouse tasks are maintained within the standard SAP EWM database tables and are accessed through custom ABAP REST services.

The SAP EWM layer performs the following functions:

- Warehouse task management
- Storage bin management
- Warehouse task confirmation
- Inventory consistency
- Robot execution status update

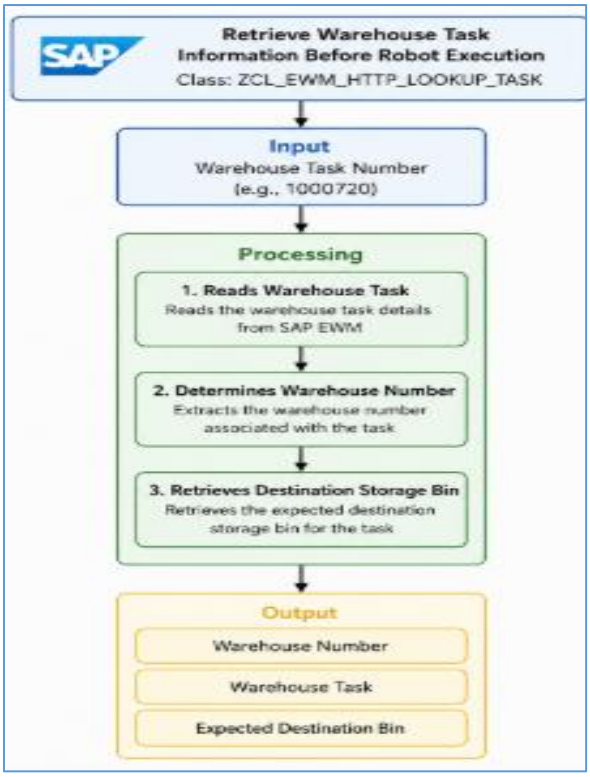
The warehouse task information is retrieved dynamically from table /SCWM/ORDIM_O, eliminating hard-coded warehouse information.

B. ABAP-Based Task Transmission

To expose SAP EWM functionality to external systems, three custom REST services were developed using ABAP HTTP handler classes.

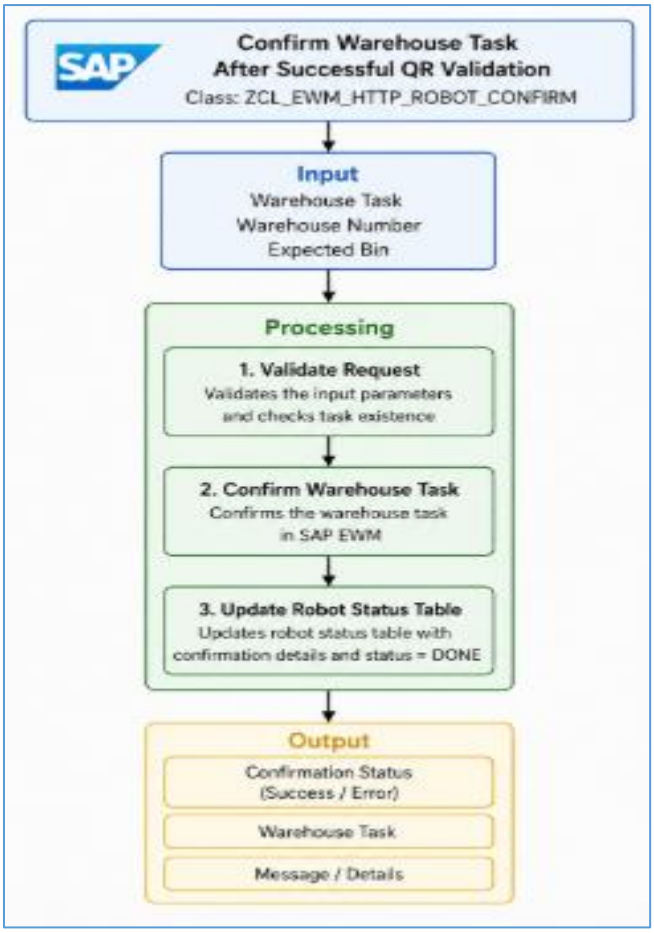
1. **Warehouse Task Lookup Service**

Fig.2: Purpose of Warehouse task lookup service



2. Robot Confirmation Service

Fig.3: Purpose of robot confirmation service



C. SAP BTP Integration Layer

SAP BTP Integration Suite acts as the middleware between the Raspberry Pi robot and SAP EWM [35].
Two independent Integration Flows were implemented.

Fig. 4. SAP BTP Integration Suite iFlows.

Integration Flow	Details
LALLU_GET_TASK	Purpose: Retrieves warehouse task details (Warehouse No. and Destination Bin) from SAP EWM before robot execution. Input: • Warehouse Task Number Output: • Warehouse Number • Warehouse Task • Expected Destination Bin Sender Endpoint: /http/lallu/lookup-task Receiver Endpoint: /sap/zewm/lookup-task SICF Service: lookup-task ABAP Class: ZCL_EWM_HTTP_LOOKUP_TASK
LALLU_EXECUTE_TASK	Purpose: Confirms the warehouse task after successful QR-code validation and updates SAP. Input: • Warehouse Task • Warehouse Number • Expected Destination Bin Output: • Warehouse Task Confirmation Status • SAP Update Sender Endpoint: /http/lallu/execute-task Receiver Endpoint: /sap/zewm/robot-confirm SICF Service: robot-confirm ABAP Class: ZCL_EWM_HTTP_ROBOT_CONFIRM

D. Mobile Robotic Platform

The robotic platform was implemented using a Raspberry Pi 4 Model B integrated with a SunFounder PiCar-X AI Robot [28] [29].

Fig.5: Hardware and Software Components.

Category	Component	Purpose
Hardware	Raspberry Pi 4	Main controller for the robot
Hardware	SunFounder PiCar-X	Autonomous mobile robot platform
Hardware	OV5647 Camera	Captures images for QR code scanning

Hardware	QR Code	Identifies warehouse destination bins
Hardware	Wi-Fi Network	Enables communication with SAP and APIs
Software	Python	Core programming language
Software	Flask	Hosts the robot REST API server [34]
Software	Picamera2	Controls the Raspberry Pi camera
Software	OpenCV	Image processing and camera frame handling
Software	pyzbar	Decodes QR codes from camera images
Software	Requests Library	Sends HTTP requests to SAP and web services

The robot executes the following sequence:

1. Receive warehouse task.
2. Request destination information from SAP.
3. Scan QR code.
4. Validate destination.
5. Confirm warehouse task.

E. QR-Based Destination Validation

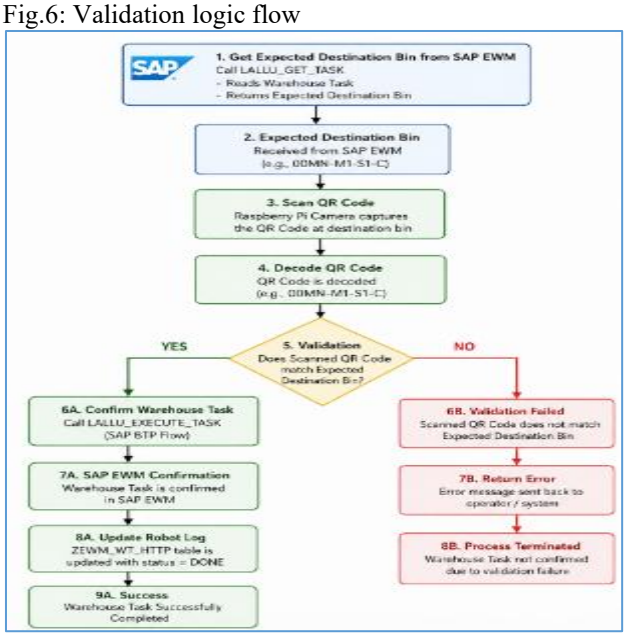
Unlike traditional RF confirmation methods, the proposed framework performs autonomous destination verification using QR-code recognition [25] [27].

The robot captures a live image using the Raspberry Pi camera.

The QR image is decoded using the **pyzbar** library.

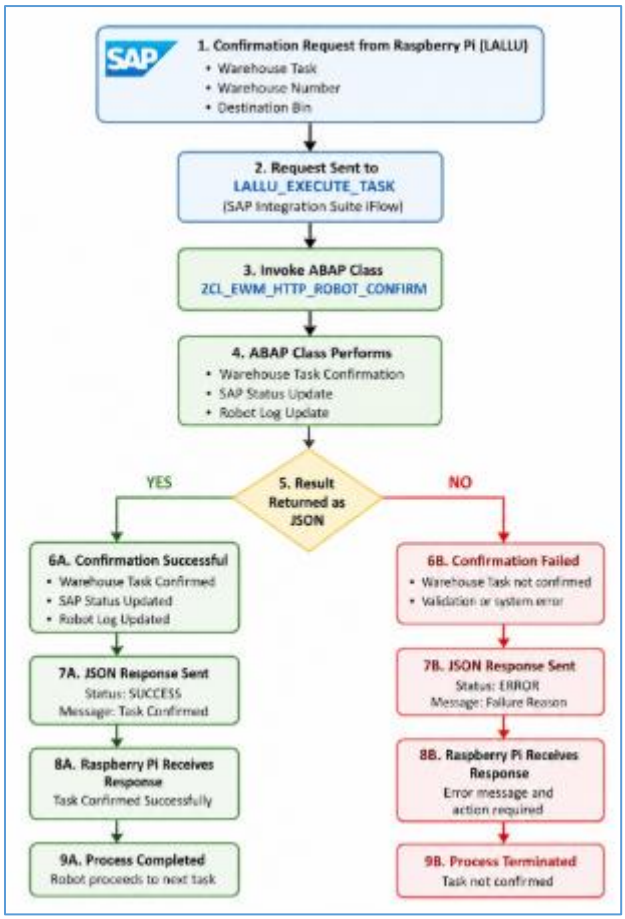
The decoded value is compared against the destination storage bin returned by SAP.

Fig.6: Validation logic flow



F. Automated Warehouse Task Confirmation

Fig.7: warehouse Task confirmation flow



IV.EXPERIMENTAL RESULTS

A. QR Validation Results

Fig. 8. Experimental mobile robotic platform [26].

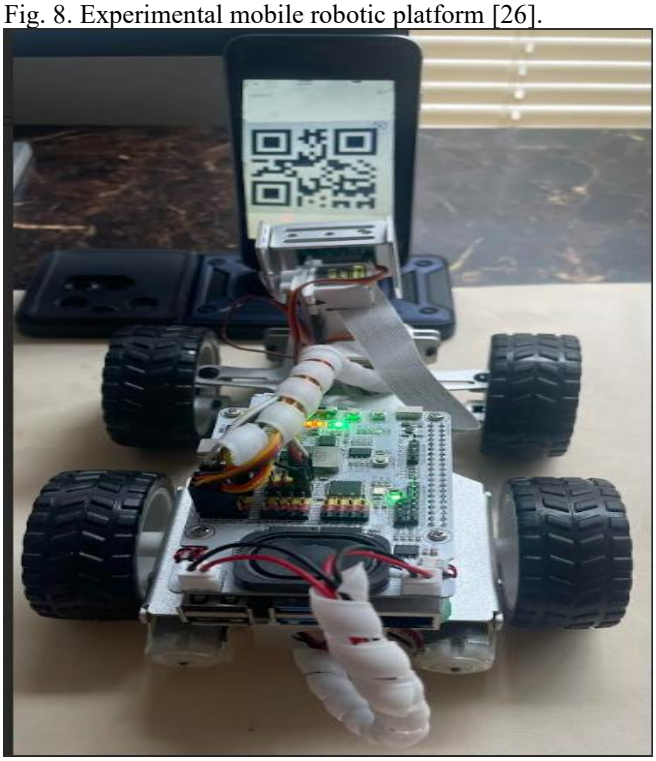


Table II. Average Execution Time by Processing Stage

Scenario	Expected Outcome	Actual Result
Correct QR	Warehouse task confirmed	Success
Wrong QR	Confirmation rejected	Success
Invalid WT	Error returned	Success
Missing WT	Validation error	Success
SAP unavailable	Failure handled gracefully	Success

As shown in Table II, QR-code detection and validation accounted for the largest portion of the execution time (1.9 s). The remaining processing stages, including LLM command interpretation, SAP warehouse task lookup, and SAP warehouse task confirmation, each completed in approximately one second or less. The average total end-to-end execution time was 4.3 seconds, demonstrating that the proposed REST-based integration framework is suitable for near real-time warehouse task execution.

Fig.9: Average Execution Time by Processing Stage

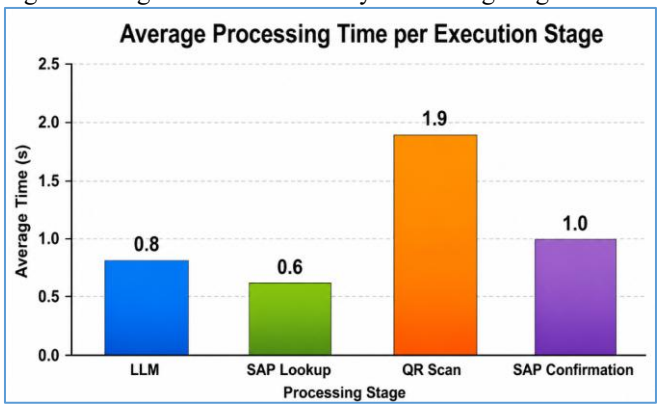


Table III. Quantitative Performance Evaluation

Performance Metric	Value
Warehouse Tasks Executed	50
Successfully Completed Tasks	49
Overall Success Rate	98%
QR Detection Accuracy	100%
SAP Warehouse Task Confirmation Rate	98%
Average End-to-End Execution Time	4.7 s

Above table summarizes the overall system performance. Fifty warehouse task execution trials were conducted using the proposed framework. Forty-nine tasks were completed successfully, resulting in an overall success rate of 98%. QR-code recognition achieved 100% accuracy under laboratory conditions, while SAP warehouse task confirmation succeeded in 98% of executions. The average end-to-end execution time was 4.7 seconds.

V. END-TO-END INTEGRATION RESULTS

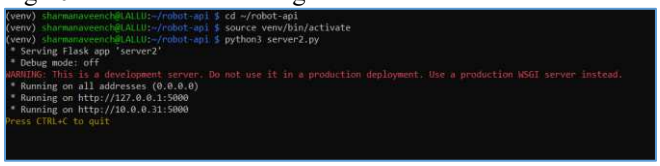
Execution Preparation:

Before executing the workflow, each warehouse task is inserted into the custom table ZEWM_WT_HTTP with status NEW. This table tracks the execution status until successful confirmation.

Terminal 1: Execute below statements

cd ~/robot-api
source venv/bin/activate
python3 server2.py

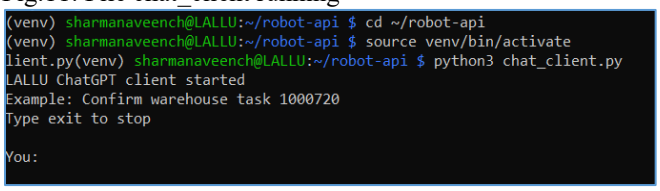
Fig.10: File Server2 running



Terminal 2: Execute below statements

cd ~/robot-api
source venv/bin/activate
python3 chat_client.py

Fig.11: File chat_client running



Before Execution: Warehouse Task # 1000723

Fig.12: Custom table (Status as NEW)

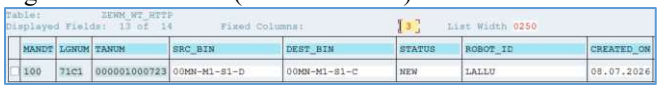


Fig.13: /SCWM/MON – Warehouse task not confirmed

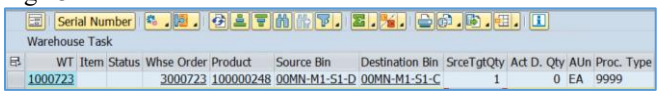


Fig.14: Terminal2 screenshot
(Entered Text "Confirm Warehouse Task 1000723": QR code of Destination bin was scanned with Robot and finally warehouse task confirmed)

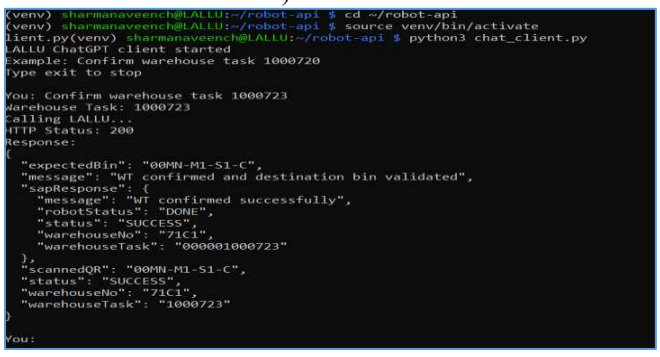


Fig.15: Terminal1 screenshot
(confirmation to QR code of Destination bin)

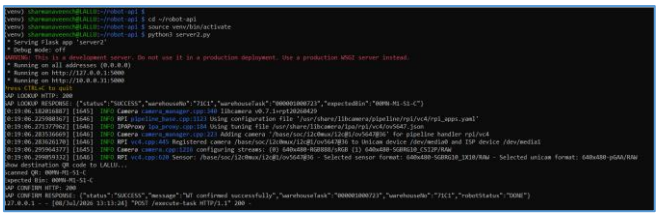
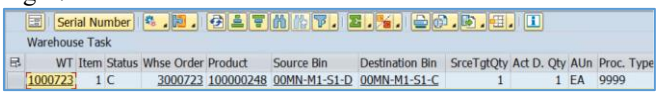


Fig.16: Custom table status updated as “CONFIRMED”



MANDT	LGNUM	TANUM	SRC_BIN	DEST_BIN	STATUS	ROBOT_ID	CREATED_ON
100	71C1	000001000723	00MN-M1-S1-D	00MN-M1-S1-C	CONFIRMED	LALLU	08.07.2026

Fig.17: /SCWM/MON - Warehouse task confirmed



WT	Item	Status	Whse Order	Product	Source Bin	Destination Bin	SrceTgtQty	Act D. Qty	AUn	Proc. Type
1000723	1	C	3000723	100000248	00MN-M1-S1-D	00MN-M1-S1-C	1	1	EA	9999

Table IV. Functional Validation Results

Scenario	Expected Outcome	Actual Result
Correct QR	Warehouse task confirmed	Pass – WT confirmed successfully
Wrong QR	Confirmation rejected	Pass – Invalid QR detected
Invalid WT	Error returned	Pass – Invalid warehouse task reported
Missing WT	Validation error	Pass – Missing parameter detected
SAP unavailable	Failure handled gracefully	Pass – HTTP service error handled

Above table summarizes the functional validation of the proposed framework under both normal and exceptional operating conditions. The system successfully confirmed warehouse tasks when the scanned QR code matched the expected destination bin. Invalid warehouse task numbers, missing tasks, incorrect QR codes, and SAP service unavailability were all handled appropriately, demonstrating the robustness of the validation and error-handling mechanisms.

VI. DISCUSSION

A. Benefits

The proposed framework offers several advantages:

- Natural-language warehouse execution
- Reduced operator training
- Elimination of manual RF confirmation
- Modular SAP integration
- Enterprise-ready REST architecture
- Improved warehouse accuracy
- Human–robot collaboration

B. Limitations

Although the proposed framework successfully demonstrates end-to-end integration of SAP Extended Warehouse Management (SAP EWM), SAP Business Technology Platform (SAP BTP), Large Language Models (LLMs), and an autonomous mobile robot, several limitations should be acknowledged. First, the current implementation has been validated using a single Raspberry Pi–based mobile robot (LALLU), and therefore does not address multi-robot coordination, task scheduling, or fleet management. Second, the experimental evaluation was conducted in a controlled laboratory environment rather than a full-scale warehouse, where additional factors such as dynamic obstacles, network latency, and concurrent warehouse operations may influence system performance. Third, the conversational interface currently depends on cloud-based LLM services, requiring reliable Internet connectivity for natural-language processing. Finally, destination verification relies on QR-code recognition, which may be affected by camera positioning, lighting conditions, or damaged labels. These limitations provide opportunities for future research toward scalable, enterprise-grade intelligent warehouse automation.
Current limitations include:

- Single robot implementation
- QR-code dependence
- Laboratory-scale evaluation
- Limited navigation intelligence
- Internet connectivity requirement for LLM processing

C. Industry 4.0 Implications

The framework demonstrates how conversational AI can be integrated with enterprise warehouse systems to create [30], [31], [32], [33]
intelligent cyber-physical warehouse environments.
The architecture supports:

- Smart factories
- Digital warehouses
- Human–robot collaboration
- AI-assisted logistics
- Intelligent warehouse execution

VII. FUTURE WORK

The limitations identified in the current implementation provide several opportunities for future research. Future work will focus on: [36], [37], [38], [39], [40], [41], [42]

- Multi-robot coordination
- Voice-controlled warehouse execution
- Integration with SAP Event Mesh
- Vision-based object recognition
- AI-assisted route optimization
- Autonomous obstacle avoidance
- Reinforcement learning for warehouse navigation
- Digital Twin integration
- Predictive warehouse analytics

VIII. CONCLUSION

This paper presented an intelligent warehouse execution framework integrating SAP Extended Warehouse Management, SAP Business Technology Platform, Large Language Models, and an autonomous mobile robot.
Unlike conventional warehouse systems that rely on RF terminals and manual confirmations, the proposed architecture enables operators to execute warehouse tasks using natural-language commands. The framework dynamically retrieves warehouse task information from SAP EWM, validates destination bins using QR-code recognition, and automatically confirms warehouse tasks through REST-based integration.

The experimental implementation on SAP S/4HANA 2023, SAP Integration Suite, and a Raspberry Pi–based autonomous robot demonstrated the feasibility of combining conversational AI with enterprise warehouse execution. The modular service-oriented architecture, based on separate lookup and execution integration flows, provides a scalable foundation for future Industry 4.0 warehouse automation.

The results indicate that integrating LLMs with SAP EWM can reduce manual intervention, improve operational efficiency, and enhance human–robot collaboration in intelligent warehouse environments. This work contributes a practical reference architecture for next-generation AI-enabled warehouse execution systems.

Unlike existing warehouse automation approaches that rely on predefined workflows or proprietary robot controllers, the proposed framework demonstrates that conversational AI can serve as an intelligent orchestration layer between enterprise ERP systems and autonomous mobile robots. This enables a scalable and modular architecture for next-generation Industry 4.0 warehouse execution.

Declaration:

- Clinical trial number: Not applicable.
- Funding: This research received no external funding
- Consent to Publish: Not applicable
- Ethics and Consent to Participate: Not applicable
- Conflict of Interest: Authors declare that they have no competing interests

REFERENCES

[1] M. Christopher, *Logistics and Supply Chain Management*, 5th ed. Harlow, U.K.: Pearson, 2016.

[2] J. Gu, M. Goetschalckx, and L. F. McGinnis, "Research on warehouse operation: A comprehensive review," *European Journal of Operational Research*, vol. 177, no. 1, pp. 1–21, 2007.

[3] S. Ten Hompel and T. Schmidt, *Warehouse Management: Automation and Organisation of Warehouse and Order Picking Systems*. Berlin, Germany: Springer, 2007.

[4] R. Bogue, "Growth in e-commerce boosts innovation in the warehouse robot market," *Industrial Robot*, vol. 43, no. 6, pp. 583–587, 2016.

[5] A. A. Tubis and M. Ryczyński, "Intelligent Warehouse in Industry 4.0—Systematic Literature Review," *Sensors*, vol. 23, no. 8, 2023.

[6] H. Kagermann, W. Wahlster, and J. Helbig, *Recommendations for Implementing the Strategic Initiative Industrie 4.0*. Frankfurt, Germany: Acatech, 2013.

[7] H. Lasi, P. Fettke, H.-G. Kemper, T. Feld, and M. Hoffmann, "Industry 4.0," *Business & Information Systems Engineering*, vol. 6, no. 4, pp. 239–242, 2014.

[8] J. Lee, B. Bagheri, and H. Kao, "A Cyber-Physical Systems Architecture for Industry 4.0-Based Manufacturing Systems," *Manufacturing Letters*, vol. 3, pp. 18–23, 2015.

[9] M. Hermann, T. Pentek, and B. Otto, "Design Principles for Industrie 4.0 Scenarios," in *Proc. Hawaii International Conference on System Sciences (HICSS)*, 2016.

[10] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, 4th ed. Hoboken, NJ, USA: Pearson, 2021.

[11] T. Mikolov, I. Sutskever, K. Chen, G. Corrado, and J. Dean, "Distributed Representations of Words and Phrases and Their Compositionality," in *Advances in Neural Information Processing Systems (NeurIPS)*, 2013, pp. 3111–3119.

[12] A. Vaswani *et al.*, "Attention Is All You Need," in *Advances in Neural Information Processing Systems (NeurIPS)*, 2017, pp. 5998–6008.

[13] T. B. Brown *et al.*, "Language Models are Few-Shot Learners," in *Advances in Neural Information Processing Systems (NeurIPS)*, 2020.

[14] OpenAI, "GPT-4 Technical Report," 2023.

[15] J. Wang *et al.*, "Large Language Models for Robotics: Opportunities, Challenges, and Perspectives," 2024.

[16] J. Lee and H. Su, "A Unified Industrial Large Knowledge Model Framework in Industry 4.0 and Smart Manufacturing," 2023.

[17] S. Wurman, R. D'Andrea, and M. Mountz, "Coordinating Hundreds of Cooperative Autonomous Vehicles in Warehouses," *AI Magazine*, vol. 29, no. 1, pp. 9–20, 2008.

[18] M. Wooldridge, *An Introduction to MultiAgent Systems*, 2nd ed. Hoboken, NJ, USA: Wiley, 2009.

[19] T. M. Fernandez-Carames, O. Blanco-Novoa, I. Froiz-Miguez, and P. Fraga-Lamas, "Towards an Autonomous Industry 4.0 Warehouse: A UAV and Blockchain-Based System for Inventory and Traceability," 2024.

[20] M. Soori, B. Arezoo, and R. Dastres, "Intelligent Robotic Systems in Industry 4.0: A Review," *Journal of Advanced Manufacturing Science and Technology*, 2024.

[21] SAP SE, *SAP Extended Warehouse Management (SAP EWM) Application Help*. Walldorf, Germany: SAP SE.

[22] SAP SE, *SAP Business Technology Platform Integration Suite Documentation*. Walldorf, Germany: SAP SE.

[23] SAP SE, *SAP S/4HANA 2023 Embedded Extended Warehouse Management Documentation*. Walldorf, Germany: SAP SE.

[24] SAP SE, *REST API Programming Model for SAP S/4HANA*. Walldorf, Germany: SAP SE.

[25] G. Bradski, "The OpenCV Library," *Dr. Dobb's Journal of Software Tools*, 2000.

[26] OpenCV Team, *OpenCV Documentation*.

[27] ZBar Project, *ZBar Barcode Reader Library*.

[28] Raspberry Pi Foundation, *Raspberry Pi 4 Model B Documentation*. Cambridge, U.K., 2024.

[29] SunFounder, *PiCar-X AI Robot Kit User Guide*, 2024.

[30] K. Ashton, "That 'Internet of Things' Thing," *RFID Journal*, Jun. 2009.

[31] L. Monostori, "Cyber-Physical Production Systems: Roots, Expectations and R&D Challenges," *Procedia CIRP*, vol. 17, pp. 9–13, 2014.

[32] J. Lee, H.-A. Kao, and S. Yang, "Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment," *Procedia CIRP*, vol. 16, pp. 3–8, 2014.

[33] M. R. Khouadjia, M. Sarasola, E. Alba, and L. Jourdan, "Multi-Agent Based Optimization for Warehouse Management," *Computers & Industrial Engineering*, vol. 66, no. 4, pp. 759–777, 2013.

[34] Flask Development Team, *Flask Web Framework Documentation*.
[35] SAP SE, *SAP Business Technology Platform REST API Documentation*. Walldorf, Germany: SAP SE.
[36] F. Mahr, G. Angeli, T. Sindel, K. Schmidt, and J. Franke, "A Reference Architecture for Deploying Large Language Model Applications in Industrial Environments," in *Proc. 2024 IEEE 30th International Symposium for Design and Technology in Electronic Packaging (SIITME)*, pp. 19–23, 2024, doi:10.1109/SIITME63973.2024.10814877.
[37] Y. Li *et al.*, "Large Language Models for Manufacturing," *Robotics and Computer-Integrated Manufacturing*, 2026.
[38] L. Xia, C. Li, C. Zhang, S. Liu, and P. Zheng, "Leveraging Error-Assisted Fine-Tuning Large Language Models for Manufacturing Excellence," *Robotics and Computer-Integrated Manufacturing*, vol. 88, Art. no. 102728, 2024, doi:10.1016/j.rcim.2024.102728.
[39] H. Naderi, A. Shojaei, and L. Huang, "Foundation Models for Autonomous Robots in Unstructured Environments," 2024.
[40] K. Kawaharazuka *et al.*, "Real-World Robot Applications of Foundation Models: A Review," 2024.
[41] Z. Long, G. Killick, R. McCreadie, and G. Aragon-Camarasa, "RoboLLM: Robotic Vision Tasks Grounded on Multimodal Large Language Models," in *Proc. IEEE International Conference on Robotics and Automation (ICRA)*, 2024.
[42] Y. Huang *et al.*, "Large Language Model-Enabled Multi-Agent Manufacturing Systems," in *Proc. 2024 IEEE International Conference on Automation Science and Engineering (CASE)*, 2024.