© MAR 2026 | IRE Journals | Volume 9 Issue 9 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I9-1715450

Magneto Lock: Secure & Automatic Train Coupling

SOUVIK PODDAR[1], ADITYA MAJHI[2], ZHEERUDDIN SHAH[3], GURUPADA PAL[4]
[1,2]*Department of Electrical Engineering, Camellia Institute of Engineering and Technology*
[3] *Department of Computer Science and Engineering, Camellia Institute of Engineering and Technology*
[4] *Department of Mechanical Engineering, Camellia Institute of Engineering and Technology*

Abstract- The process of train coupling is a critical operation in railway systems, traditionally dependent on manual or semi-mechanical methods that pose safety risks, increase operational time, and reduce efficiency. This research presents the design and development of an electromagnetic-based automatic train coupling system, termed Magneto Lock, aimed at enhancing automation, safety, and reliability in railway operations. The proposed system utilizes electromagnets for contactless coupling and decoupling, integrated with sensors such as ultrasonic, Hall effect, and infrared sensors to ensure precise alignment, obstacle detection, and magnetic field verification. A microcontroller-based control unit enables intelligent decision-making and supports remote operation through wireless communication modules. Additionally, a secure locking mechanism ensures stable mechanical connectivity, while provisions for power and data transfer between train units are incorporated. The system also includes monitoring features such as short-circuit detection and visual indicators to enhance operational safety. Experimental demonstration of the prototype validates its effectiveness in achieving faster, safer, and more reliable coupling compared to conventional methods. The proposed solution significantly reduces human intervention, minimizes accident risks, and aligns with the growing demand for smart and automated railway infrastructure. Moreover, the system employs an ESP32-CAM-based camera module for real-time visual monitoring of the coupling process. This functionality allows for verification of precise alignment between train units, thereby improving accuracy and providing an extra layer of safety and oversight, particularly in remote or automated contexts.

Index Terms- Automatic Train Coupling, Electromagnetic System, Railway Automation, Sensor Integration, Smart Transportation

I. INTRODUCTION

Train coupling is a basic operation in railway systems. It allows multiple railcars or locomotives to connect and function as a single unit. Traditional methods, mainly mechanical and pneumatic, rely on manual intervention. This leads to inefficiencies, longer coupling times, and significant safety risks for workers. These issues highlight the need for reliable, automatic coupling mechanisms in modern rail transport. [1]

This paper explores a new method that uses electromagnetic forces for automatic train coupling, along with a servo-motor-driven mechanical safety mechanism. This combination aims to reduce operational hazards and improve efficiency.

With the rapid advancement of automation and smart transport technologies, electromagnetic coupling systems are becoming a strong alternative to traditional methods. These systems use precisely controlled magnetic forces to ensure accurate alignment, secure connections, and simplified decoupling without needing human help. This method not only increases operational efficiency but also significantly reduces the risk of accidents during coupling and decoupling.

The proposed research, *Magneto Lock: Secure & Automatic Train Coupling*, aims to create an electromagnetic automatic coupling system. It combines electromagnets, sensors, and microcontroller-based control units to allow for intelligent, contactless, and remote-controlled coupling. The system also enables seamless power and data transfer between connected units to meet modern railway automation needs.

Additionally, the system uses an ESP32-CAM-based camera module for real-time visual monitoring of the coupling process. This feature checks the precise alignment between train units, improving accuracy and adding an extra layer of safety, especially in remote or automated settings. This research seeks to demonstrate the working principles, design considerations, and practical implementation of an electromagnetic coupling mechanism. It contributes to safer, faster, and more efficient railway operations. [2]

II. LITERATURE REVIEW

The modernization of railway infrastructure has driven significant research into automated train coupling technologies. The goal is to improve safety and operational efficiency. Traditional systems, like screw and knuckle couplers, require manual intervention. This leads to delays and increased safety risks.

These issues have pushed the development of automated and smart coupling mechanisms. For example, recent events, such as the train accident at Baruni Junction, Bihar, on November 9, 2024, show the urgent need for automated solutions to avoid human error during coupling and decoupling.

To tackle these challenges, several innovative systems have been suggested. Some use electromagnetic principles for contactless torque transmission and precise alignment. These systems can reduce the risks of collisions and improve the reliability of disconnections.[3]

Recent advancements in railway control systems also include the concept of virtual coupling, wherein a group of trains can run together with coordination through advanced control algorithms [4].

Research indicates that these types of railway control systems can enhance efficiency and security through predictive control. However, these types of railway control systems are more centered on control strategies rather than physical coupling mechanisms. Electromagnetism has been extensively studied in modern railway and industrial systems. In the study of Electromagnetic coupling and interference, the significance of Electromagnetic coupling in the railway environment has been emphasized. It has been noticed that the reliability of the systems is influenced by Electromagnetic coupling and needs to be managed. In addition, the study of magnetic coupling, which includes resonant inductive coupling, has been carried out for efficient energy transfer.

Therefore, it is evident that Electromagnetic coupling is a promising method for train coupling systems. The integration of wireless communication technologies is also enhancing the automation of railway systems. Research on the use of Wi-Fi technology to implement train communication systems shows the efficiency of the system in the transmission of information between the train units [5]. The use of such systems is necessary to implement the remote coupling system.

Sensor-based automation is also a crucial aspect of the implementation of intelligent railway systems. Ultrasonic sensors, infrared sensors, Hall effect sensors, etc., are commonly used to implement railway systems. Research shows the efficiency of the use of multiple sensors to ensure the accuracy of the system in railway safety systems [6] In recent years, vision-based monitoring systems have gained significant attention. The ESP32-CAM module has been successfully used in railway safety applications for real-time monitoring and cloud-based alert systems. [7]. Furthermore, image processing techniques using embedded vision systems enable real-time object detection and monitoring in industrial environments.

Moreover, the ongoing development of digital automatic couplers in Europe underscores the industry's shift towards advanced coupling solutions, prioritizing enhanced monitoring and integrity verification through technologies like inclination angle detection and wireless sensor networks for robust communication between train units.

The broader trend towards autonomous railway systems, often incorporating computer vision and machine learning, further emphasizes the necessity of automated coupling mechanisms that seamlessly integrate with these advanced operational paradigms.

Despite these advancements, existing research primarily focuses on individual aspects such as control systems, communication, or sensing. The integration of electromagnetic coupling with embedded control systems, wireless communication, multi-sensor feedback, and camera-based alignment verification remains relatively unexplored. [8]

This gap highlights the need for a comprehensive system that combines these technologies to achieve a safe, efficient, and fully automated train coupling mechanism.

III. METHODOLOGY

The proposed system is designed to implement an automated and secure train coupling mechanism using electromagnetic principles, embedded control, sensor integration, and vision-based monitoring. The methodology consists of system design, hardware integration, control logic, and operational workflow.

1. System Architecture

The overall system is divided into four major subsystems:
(I)Electromagnetic Coupling Unit
(II)Sensor and Detection Unit
(III)Control and Processing Unit
(IV) Monitoring and Communication Unit

These subsystems work together to achieve automatic alignment, coupling, locking, and verification. This integrated approach enhances the reliability and safety of the coupling process by minimizing human intervention and maximizing precision.

2. Electromagnetic Coupling Mechanism

When powered on, these electromagnets create a magnetic field that attracts the ferromagnetic coupling plates of adjacent units.

Once the units are properly aligned, a solenoid-based locking mechanism is activated to secure the mechanical connection.

This electromagnetic attraction facilitates a controlled, contactless preliminary alignment, crucial before the engagement of mechanical interlocks.

3. Sensor-Based Detection and Alignment

To ensure accurate and safe coupling, multiple sensors are used:

- Ultrasonic Sensor (HC-SR04): Measures the distance between train units. When the distance reaches a predefined threshold, the system initiates the coupling process
- Hall Effect Sensor: Detects the presence of a magnetic field to confirm that the electromagnets are active and properly aligned.
- Infrared (IR) Sensor: Identifies obstacles or objects on the track, improving safety, especially in low-light conditions.

The combination of these sensors provides reliable and precise detection, minimizing alignment errors.

4. Control System Implementation

An Arduino UNO microcontroller serves as the central control unit. It processes sensor inputs and executes control algorithms to manage the coupling sequence.

The logic includes:

1. Continuously monitor distance using the ultrasonic sensor.
2. Trigger an alert (buzzer/LED) when the threshold distance is reached.
3. Activate electromagnets for initial attraction.
4. Verify magnetic alignment using the Hall sensor.
5. Engage the locking mechanism for secure coupling.

The control system ensures synchronized and automated operation without human intervention.

5. Vision-Based Monitoring (ESP32-CAM Integration)

An ESP32-CAM module is integrated into the system to provide real-time visual monitoring of the coupling process. The camera captures live video or images, which can be transmitted wirelessly to a remote device. [9]

This module is used to:

- Verify proper alignment between train units
- Monitor the coupling process remotely
- Provide an additional safety layer beyond sensor-based detection

The visual feedback helps in identifying misalignment or system errors, thereby improving reliability.

6. Wireless Communication and Remote Operation

Wireless modules (Wi-Fi/Bluetooth) enable remote monitoring and control. The ESP32-CAM and microcontroller can transmit data to a user interface, allowing operators to observe system status and control coupling/decoupling operations if required.

7. Operational Workflow

The step-by-step operation of the system is as follows:

1. Train units approach each other.
2. Ultrasonic sensor measures decreasing distance.
3. At threshold distance, system triggers alert and activates electromagnets.
4. Magnetic attraction aligns the units automatically.
5. Hall sensor confirms magnetic field presence.
6. Locking mechanism secures the connection.
7. ESP32-CAM verifies alignment visually.
8. System indicates successful coupling via LED/buzzer. This comprehensive operational workflow ensures a robust and verifiable coupling process, minimizing human error and enhancing overall railway safety.

8. Testing and Validation

The system is tested under controlled conditions using a prototype model. Parameters such as alignment accuracy, coupling time, sensor response, and reliability of wireless communication are evaluated. The performance is analysed to ensure safety, efficiency, and robustness of the system. This rigorous validation process ensures that the proposed automated coupling mechanism meets stringent industry standards and effectively mitigates potential risks associated with traditional coupling procedures. Furthermore, the development of a scaled-down prototype or mini model train will facilitate the showcasing of the safety features, involving the assembly of hardware components and the testing of software algorithms for real-time data processing and decision-making.

IV. RESULTS

The developed prototype of the electromagnetic automatic train coupling system was tested under controlled conditions to evaluate its performance. The ultrasonic sensor accurately detected the distance between train units and reliably triggered the coupling process at the predefined threshold (~6 cm).

The electromagnetic mechanism successfully achieved smooth alignment and secure attraction between units, while the Hall effect sensor confirmed proper magnetic engagement. The solenoid-based locking system ensured a stable and reliable connection without unintended decoupling during repeated trials.

The integration of infrared sensors enhanced safety by detecting obstacles and preventing unsafe coupling operations. Additionally, the ESP32-CAM module provided real-time visual monitoring, enabling effective verification of alignment and improving overall system reliability.

The system demonstrated high accuracy, reduced coupling time, and consistent performance, validating its effectiveness as a safe and efficient solution for automated train coupling. These experimental results, derived from a replica rail environment with 60 trips, corroborate the efficacy of the proposed method in mitigating metro rail accidents and incidents during coupling. This empirical validation supports the potential for real-world implementation, particularly in enhancing safety protocols in urban rail transit systems.

© MAR 2026 | IRE Journals | Volume 9 Issue 9 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I9-1715450

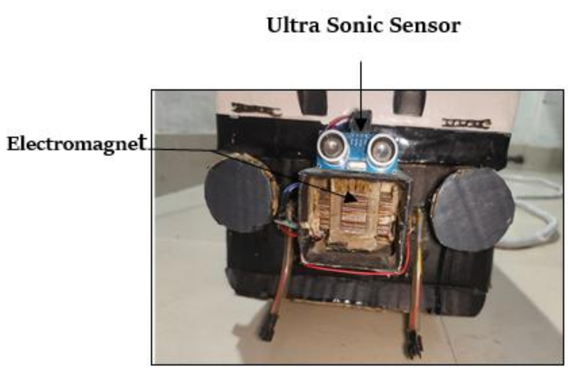
Before Coupling

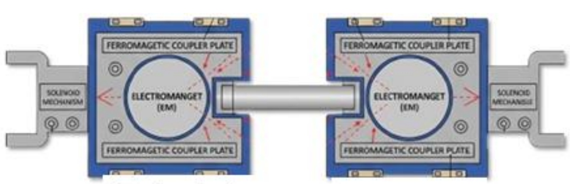
After Coupling

Video Link:

https://youtu.be/kDu_mxlR1rE?si=jCkAUKuccsin5vyB&t=8

SOLUTION





Train unit A Train unit B

This model we use of electromagnets for automatic train coupling, showing how train units can connect and disconnect without manual effort. The system will demonstrate magnetic attraction, alignment, auto-locking, and decoupling mechanisms, time efficient & making train operations more efficient and safer.

V. DISCUSSION

This study demonstrates that the proposed electromagnetic automatic train coupling system (*Magneto Lock*) provides a viable and efficient alternative to conventional manual and mechanical coupling methods. The implementation of electromagnets combined with sensor-based detection and microcontroller control enables precise alignment, secure locking, and reliable coupling without the need for direct human intervention. The results indicate a significant improvement in operational safety and time efficiency, addressing key limitations associated with traditional coupling techniques.

The integration of ultrasonic sensors for distance measurement and Hall effect sensors for magnetic field detection ensures accurate positioning and confirmation of successful coupling. Additionally, the incorporation of infrared sensors for obstacle detection enhances safety by preventing unintended collisions, particularly under low-visibility conditions. These features collectively contribute to a more intelligent and responsive system capable of minimizing human error and reducing accident risks.

The inclusion of remote operation and wireless communication further strengthens the system’s applicability in modern railway environments, where automation and real-time monitoring are essential. The ability to facilitate seamless power and data transfer between coupled units highlights the system’s potential for integration with advanced railway networks. Moreover, the implementation of a locking mechanism ensures mechanical stability, addressing concerns regarding the strength and reliability of magnetic coupling.

However, certain limitations must be considered. The performance of the electromagnetic system is dependent on consistent power supply and optimal environmental conditions. Variations in load, alignment accuracy, or external disturbances may affect coupling efficiency. Additionally, large-scale implementation would require further validation in real-world railway scenarios, along with considerations of cost, scalability, and maintenance.

Overall, the findings emphasize the potential of electromagnetic coupling systems in transforming railway operations by enhancing safety, reducing manual dependency, and improving efficiency. The study underscores the need for further research and development to optimize system performance and support the transition toward fully automated and smart railway infrastructures.

VI. CONCLUSION

This study presents the *Magneto Lock system* as an effective electromagnetic solution for automatic train coupling. The proposed model improves safety, reduces human intervention, and enhances operational efficiency through the use of sensors and microcontroller-based control. The results validate its reliability and potential for modern railway automation. Future work is required for large-scale implementation and system optimization.

VII. RECOMMENDATION

On the basis of the results obtained from this research, some recommendations are proposed to improve the performance and practicality of the proposed system. Optimization of the electromagnetic coupling mechanism needs to be carried out to improve the performance of the system under different operating conditions. Testing the system under practical conditions needs to be conducted to evaluate the reliability, durability, and safety of the proposed system for use in large-scale railway environments.

In addition, the inclusion of advanced control techniques and smart monitoring technologies is recommended to improve the performance and responsiveness of the proposed system. The inclusion of advanced safety features, as well as fault detection and override mechanisms, would improve the reliability of the system. Moreover, a detailed analysis of the practicality, costs, and compatibility of the proposed system with the existing railway infrastructure needs to be conducted. The proposed system needs to be aligned with the development of smart railway technologies, which includes IoT-based communication technologies, to develop efficient railway infrastructure.

REFERENCES

[1] Digital Automatic Coupling as an Enabler for Rail Freight Innovations| Patrick Seeßle, Daniel Wolfram, Andreas Haller, Florian Einsele, Victoria Jäger & Simon Funke

[2] Research on railroad locomotive driving safety assistance technology based on electromechanical coupling analysis| Published/Copyright: November 21, 2023

[3] *Article:* Train Collision Prevention using RF| International Journal for Research in Applied Science & Engineering Technology (IJRASET) ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538 Volume 11

[4] *Article:* Distributed Robust Model Predictive Control for Virtual Coupling Under Structural and External Uncertainty| University of Glasgow

[5] *Article:* Distributed model predictive control strategy for constrained high-speed virtually coupled trains |University of LEEDS

[6] "Railway safety system using ESP32-CAM and sensors," *IJRAR*, 2023.

[7] "X. Mou and H. Sun, "Wireless Power Transfer: Survey and Roadmap," 2015.

[8] Abba, S., Wadumi Namkusong, J., Lee, J. A., & Liz Crespo, M. (2019). Design and performance evaluation of a low-cost autonomous sensor interface for a smart IOT-based irrigation monitoring and control system. Sensors.

[9] "Real-time image processing using ESP32-CAM and YOLO algorithm," *IJARSCT*, 2025.