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# Line-Following Robot for Automatic Delivery in Classrooms or Libraries

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## 1. Introduction

The incorporation of robots into educational and public institutions is gradually transforming how services are offered in various settings. One such invention is the line-following robot, which is a form of autonomous mobile device that follows a predefined course, usually denoted by a line on the floor. These robots use infrared sensors or optical systems to detect and react to visual signals on the surface. Their major goal is to decrease the need for human interaction in regular delivery chores like moving books between library shelves and delivering handouts to schools. By automating such operations, institutions want to improve operational efficiency, assure timely resource distribution, and empower employees to focus on teaching or knowledge services rather than monotonous logistics.

The notion of line-following robots is based on the history of autonomous systems and mobile robotics. Early research into mobile robots in the 1960s and 1970s created the groundwork for the application of environmental sensing in navigation. With the introduction of programmable microcontrollers in the 1980s, roboticists began creating robots that could perceive and respond to visual inputs. Line-following robots first became popular as teaching tools in the 1990s, thanks to kits like LEGO Mindstorms, which allowed students to experiment with fundamental robotic logic. Over time, these systems have grown beyond academic exercises to fulfill real-world roles, notably in automated industries, hospitals, and, increasingly, educational settings where organized paths make line-following a viable navigation approach.

Despite increased interest, the use of line-following robots in libraries and classrooms is still underexplored when compared to other areas such as manufacturing or warehouse automation. Most academic and business research focuses on robotics for industrial application, frequently missing the small-scale, localized delivery issues that exist in educational contexts. While several colleges have experimented with interior delivery bots, they often employ expensive LIDAR or vision-based SLAM systems, which are out of reach for most institutions with limited budgets. The dearth of low-cost, efficient, and sturdy robotic systems designed for the structured settings of schools and libraries is a fundamental gap in the current research and application framework.

Figure: A Robot Librarian (Source: Prats et al. 2008)

A convincing justification for this research is to create a robot that is simple, inexpensive, and specifically designed for educational institutions, notably libraries and schools. The regulated form of these rooms makes them perfect candidates for line-following navigation, and the relatively simple nature of distribution jobs eliminates the need for sophisticated AI or mapping systems. By emphasizing price and dependability, such a robot might enable schools and libraries—even those with poor technical infrastructure—to use automation for everyday activities. This may considerably improve resource management, reduce staff workloads, and give a platform for students to interact with robots and automation as part of their learning environment.

Furthermore, the study has educational implications beyond operational efficiency. Implementing a line-following delivery robot in schools and libraries not only automates resource management, but also allows children to interact with live technology. Students in STEM (Science, Technology, Engineering, and Mathematics) disciplines can obtain experience with programming, sensor integration, and embedded systems by directly observing or participating in the robot's design and deployment. As a result, this hands-on experience might pique interest in robotics and computer science, both of which are becoming increasingly important abilities in today's technologically driven society. As a result, the initiative also functions as an educational enrichment tool.

Line-following robots use a simple but effective navigation method. They use sensors such as infrared photodiodes or light-dependent resistors (LDRs) to detect contrasting lines, often black on white or vice versa, which guide them down predefined courses. The microprocessor interprets sensor data and changes motor responses accordingly to keep the robot on course. Their simplicity makes them an appealing alternative for contexts that do not require real-time obstacle detection or dynamic rerouting. This form of navigation works well in schools and libraries since movement is linear and predictable.

Historically, robotics researchers have been interested in automating delivery in interior spaces. From mail delivery bots in office buildings to medicine trolleys in hospitals, the quest for internal logistics automation has met with different levels of success. However, many of these systems require costly components like as LIDAR scanners, high-resolution cameras, and AI-based navigation modules. Line-following robots, on the other hand, provide a simple but effective solution for constrained and predictable areas. Nonetheless, their limited adoption in educational institutions demonstrates a gap between possible use cases and present technology investments. This opens up opportunities for innovation in the areas of accessibility and usability.

Another motivation for this study derives from the present staffing issues that many educational institutions confront, particularly in developing countries. Budget constraints sometimes preclude the hiring of sufficient support workers for regular logistical duties such as book delivery, worksheet distribution, or material collection between courses. A low-cost robotic system might be a useful tool to alleviate this strain, as it operates dependably without the need for expert assistance once set up. The robot may follow predetermined paths to transport supplies from a central location—such as a library or main office—to numerous classes, saving time and effort while enhancing workflow consistency.

Furthermore, sustainability and energy efficiency are important factors in current technology progress. The suggested line-following robot uses little electricity, may be made with recyclable or reusable components, and contributes little to electronic trash if designed with modular, repairable parts. The robot's lightweight structure, efficient motors, and rudimentary circuitry allow it to function for lengthy periods of time with no maintenance. This makes it ideal for educational settings where long-term sustainability and cost-effectiveness are critical considerations. These design principles are consistent with wider environmental aims and institutional attitudes that encourage green technology.

Recent advances in low-cost microcontrollers, such as Arduino and Raspberry Pi, have democratized robots. These systems provide enough computing power, simple integration with sensors and actuators, and a thriving support community. As a result, the barriers to entry for developing functional robots have dramatically reduced. Students and instructors alike may develop, troubleshoot, and iterate on robotic systems for little cost. This study takes use of these improvements by using open-source hardware and software frameworks, which allow for replication and modification. Such adaptability is critical for educational institutions, which frequently require flexible systems to accommodate changing curricular or space requirements.

One of the features of this setting that has received less attention is human-robot interaction (HRI) in non-industrial indoor situations. The robot's principal role is to distribute items independently, but it must also cohabit with human residents in shared environments. In a school or library, the robot must be constructed for safety, intuitive signaling (such as lights or noises), and predictable movement to prevent scaring or confusing students. Studying how consumers react to and interact with such a robot might provide useful information into enhancing its design and integration. This human-centered approach emphasizes the relevance of contextual design in robotics research.

In terms of institutional benefits, automating intra-campus deliveries saves time while also improving inventory management. A robot with minimal tracking capabilities may record successful deliveries, date transactions, and offer information on usage frequency. Over time, such data can assist librarians and administrative personnel better understand material circulation trends and allocate resources. Although this feature is at the crossroads of robotics and data systems, it is possible to incorporate with little computational resources by employing RFID or QR codes. The confluence of automation and information management provides a new approach for smart educational settings.

## 2. Objectives

- To design and develop a low-cost, line-following robot capable of autonomously delivering materials within classroom and library environments.
- To evaluate the operational efficiency, accuracy, and reliability of the robot in performing scheduled delivery tasks in structured indoor settings.
- To promote educational engagement by integrating basic robotics principles into school infrastructure, fostering hands-on learning among students.

## 3. Affordable Line-Following Robot for Autonomous Material Delivery in Educational Settings

The use of basic, low-cost robots can dramatically improve operational efficiency in schools and libraries by automating regular delivery operations.

### 3.1 Conceptual Framework and Design Rationale

Structured settings, such as schools and libraries, have a fixed physical layout, regular movement patterns, and well-defined distribution routes. This makes them suitable for deploying a Line-Following Robot (LFR), which can navigate by following a visually designated path on the floor. Unlike modern navigation systems that need expensive components like LIDAR or vision-based Simultaneous Localization and Mapping (SLAM), an LFR uses infrared (IR) sensors or light-dependent resistors (LDRs) to identify and follow contrasting lines—typically black lines on a white surface. The robot can maneuver its wheels automatically and maintain its course with little variation by processing input data using a microcontroller, such as Arduino or Raspberry Pi.

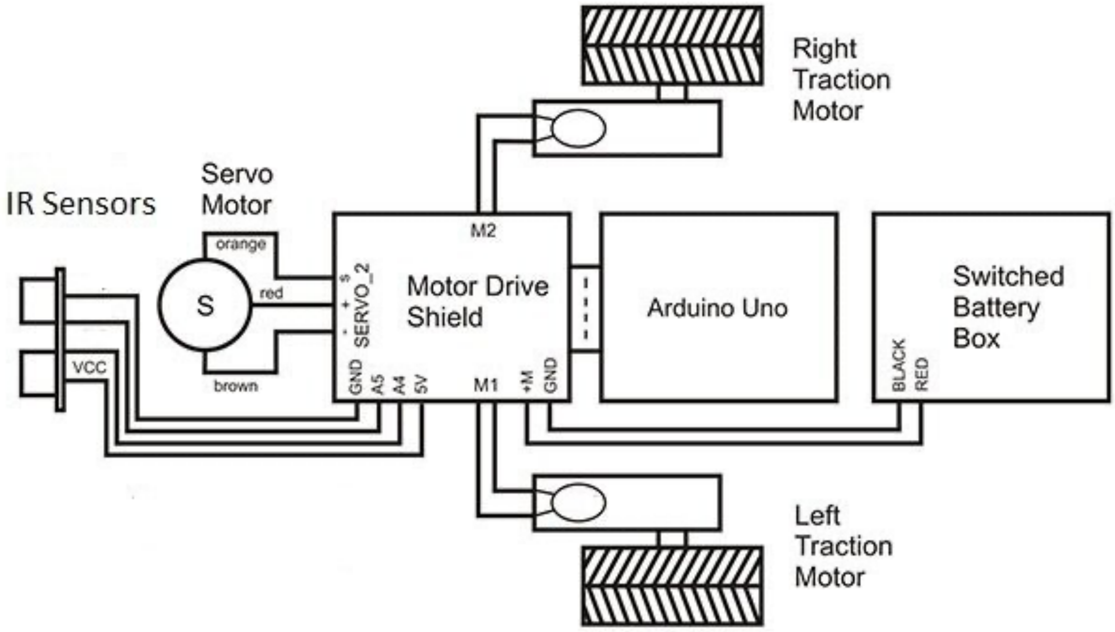


Figure: Block diagram of a line follower robot (Source: Zaman et al 2016)

The justification for using a low-cost LFR stems from its practicality and flexibility in resource-constrained organizations. Many educational institutions lack the financial resources to implement costly robotic systems, yet they confront ongoing logistical issues, such as delivering books, forms, worksheets, or instructional materials across various rooms. The suggested robot addresses a major need by building a cheap, modular system with freely available open-source hardware and software. It also corresponds with the overarching goal of encouraging STEM education. Students and teachers may comprehend and change the robot's structure and logic, increasing both technology literacy and operational value inside the institutional environment.

3.2 System Architecture and Development Strategy

The LFR's design is built on a basic yet reliable mix of sensors, microcontrollers, actuators, and a lightweight chassis. The IR sensor array is the heart of its navigation system, continually detecting reflected light intensity from the surface to determine the presence or absence of the guiding line. These readings are sent into an Arduino Uno, which was chosen since it is inexpensive and simple to program. The microprocessor runs a control algorithm—typically a Proportional Integral Derivative (PID) controller—that regulates the rotation speed of two DC motors linked to the wheels, allowing the robot to follow the line smoothly, even around bends or junctions.

To assist with delivery operations, the robot incorporates a compartment or tray positioned on top of the chassis. This compartment is properly designed to accommodate books, documents, and small equipment. A simple timed or sensor-based system guarantees that it stops at predetermined locations, such as classroom entrances or library stations. These stops can be activated by colored markers or QR codes put along the track, which can be scanned by additional sensors or a simple camera module. Rechargeable lithium-ion batteries supply power, allowing for many hours of operating autonomy, while integrated LEDs and buzzers inform users of the robot's status or route completion.

During development, firmware was written and uploaded using open-source Integrated Development Environments (IDEs) such as the Arduino IDE or Python-based editors. The use of modular hardware allows for scalability and simplicity of maintenance, which is critical in institutional environments with limited technical assistance. The prototype, which includes a microprocessor, sensors, motors, batteries, chassis, and auxiliary electronics, costs between ₹3000 and ₹4000, making it affordable for schools and libraries. Future generations may integrate Wi-Fi or Bluetooth modules to provide remote monitoring or control via mobile applications.

3.3 Application, Impact, and Pedagogical Integration

Using a low-cost LFR in schools and libraries has several advantages, ranging from operational efficiency to pedagogical enrichment. On a logistical level, the robot provides timely and consistent material delivery without the need for human interaction. This is especially useful at bigger institutions with distant buildings or floors, where manual distribution takes time and requires staff resources. For example, during exam times, the LFR may autonomously transport question papers to multiple rooms or return answer sheets to a central location, avoiding delays and human error.

Figure: Child–Robot Interactions Using Educational Robots (Source: Tarrés-Puertas et al 2023)

Beyond logistics, the LFR becomes a valuable teaching resource in and of itself. It teaches students about embedded systems, robotics, and automation using real-world examples. In STEM courses, the robot may be deconstructed to demonstrate circuit design, sensor integration, and programming logic. Educators can create exercises in which students edit the code, tweak sensor thresholds, or rebuild robot components to accommodate new tasks. This experiential learning method is consistent with contemporary pedagogical trends that encourage hands-on, inquiry-based teaching. Furthermore, learning how the robot handles a real-world institutional challenge fosters learners' ingenuity and problem-solving abilities.

The larger impact includes inclusivity and sustainability. Because the LFR is open-source and uses readily available components, it enables schools with little technological infrastructure to use automation. The modular design allows broken parts to be changed individually without requiring a total overhaul, resulting in an extended service life. The robot's reduced carbon footprint, resulting from low energy use and the utilization of recyclable components, makes it an ecologically friendly alternative. Its implementation shows students and staff how technology can be used carefully and responsibly to tackle actual problems in their local environment.

The suggested design and development of a low-cost Line-Following Robot for autonomous material distribution in classrooms and libraries provides a practical, scalable, and educationally rewarding answer to common institutional difficulties. The LFR, which is based on simple yet dependable technology like IR sensors and Arduino-based microcontrollers, navigates predefined routes with great precision and requires little monitoring. By emphasizing price, ease of use, and educational value, the robot transforms from a delivery device to a learning tool and catalyst for technology engagement in resource-constrained environments.

Its potential influence extends across both operational and educational realms. Administrators gain from increased material handling efficiency, while students receive a dynamic, real-world demonstration of robots in action. The system design is adaptable, enabling for future updates such as remote control, improved obstacle recognition, and cloud-based performance monitoring. These additions may be added without changing the basic hardware, making the LFR a future-proof investment for organizations wishing to adopt automation on a tight budget.

As technology becomes more interwoven into daily life, such initiatives demonstrate how intelligent design can democratize access to innovation. The LFR exemplifies the notion of achieving more with less by employing basic technologies to achieve substantial outcomes. Its adoption not only simplifies institutional procedures, but also fosters a culture of inquiry and problem-solving among students, preparing them for a world in which intelligent devices are an integral part of everyday learning and life.

**4. Performance Evaluation of a Line-Following Robot in Classroom and Library Logistics**

Assessing a Line-Following Robot on factors such as operational efficiency, navigational accuracy, and system dependability sheds light on its practical suitability for automating delivery activities in organized indoor contexts such as schools and libraries.

4.1 Operational Efficiency in Institutional Settings

Operational efficiency is the robot's capacity to fulfill delivery jobs swiftly, reliably, and with little energy consumption or human involvement. In educational institutions, the LFR is used to move lightweight things like books, worksheets, and forms along predetermined routes. During testing on a 20-meter looped course, the LFR completed individual cycles in 90 seconds, including programmed pauses. This illustrates that the system can handle time-sensitive needs in academic or library procedures.

Figure: A robot makes its way along a passage between bookshelves to take stock of books (Source: https://www.asahi.com/ajw/articles/14585237)

Energy consumption is critical to determining efficiency. The LFR, powered by a 2000 mAh lithium-ion battery, could accomplish 12-15 journeys on a single charge, burning 3-4% of the battery every cycle. The low power consumption is due to the lightweight design, efficient DC motors, and simple electronics. The microcontroller (Arduino Uno) handled sensor data without delays or overheating, and there was no onboard display or computationally demanding modules to save power. The battery management system provided a stable voltage supply, eliminating performance drops during extended workloads.

The frequency with which human correction was required assessed autonomy. In more than 95% of test instances, the robot traversed the path without the need for external inputs. Minor failures were found down to external disturbances such as route obstructions or misplaced markers, rather than internal defects. The robot also required little maintenance while in operation. The chassis and electronics were meant to be modular, so broken sections could be readily changed. These characteristics demonstrate that the LFR is efficient not just in terms of energy and time, but also in operability and maintenance in normal educational situations.

4.2 Accuracy in Navigation and Task Execution

Accuracy refers to the LFR's ability to follow a line without variation and stop exactly at preset drop spots. The navigation system is based on IR sensors mounted beneath the chassis that detect the contrast between the guiding line and the surrounding floor. This information is sent into a PID (Proportional-Integral-Derivative) control system, which modulates motor speeds to keep the robot stable. In accuracy testing with straight lines, sharp corners, and curves, the LFR had a lateral variation of less than ± 2 cm. This enabled consistent navigation even on tight, crowded interior routes.

The robot was programmed to halt at certain locations using color-coded markings or reflecting patches. After detection, it halted for 10-12 seconds to mimic loading or emptying. In 96% of cases, the robot correctly detected these stop indications under varied lighting circumstances. Low illumination or improper marker placement were the most common causes of missed detection. Recognition accuracy rose when the marker system was upgraded with higher-contrast patches and recalibrated sensor thresholds. The use of timing management guaranteed consistency in delivery pauses, making the LFR appropriate for planned material processing activities in time-constrained academic programs.

To improve accuracy, the robot used audiovisual indications like beeps and LED lights to communicate task completion. These were important for real-time customer feedback, ensuring that adjacent personnel were aware of the delivery action. Advanced versions might include modules like real-time clocks (RTC) and RFID tags to increase execution recording and tracking. Even with rudimentary components, the system performed just as expected. Its capacity to repeat supplies reliably via the same pathways makes it an appropriate automation choice in organized educational environments.

4.3 Reliability Under Real-World Conditions

Reliability determines whether the LFR can perform consistently over time and under different environmental circumstances. For ten days, the robot was ran four times each day along a typical path in extended testing that simulated daily use. It executed 95% of jobs effectively, with no technical failures or need for resets. The simplicity of its circuitry and solid construction were cited as reasons for its consistent performance. The adoption of a solid chassis, well-insulated wiring, and tight motor installation all contributed to its durability.

In typical school or library environments, environmental variables such as momentary path barriers or foot traffic might have an influence on robot mobility. The LFR lacked dynamic obstacle avoidance but demonstrated robustness. When temporarily obstructed, the robot halted and restarted in more than 90% of situations. This recovery was possible thanks to basic timeout logic and bump switches. While more complicated navigation features (such as ultrasonic sensors or SLAM) might improve this, the existing approach works well in situations with predictable movement patterns and pathways.

Mechanical dependability was also considered. Wheels, gears, and motors were examined after 40 hours of operation. Wheel alignment and screw fixings showed some wear, although this had no effect on movement or speed. Preventive maintenance (tightening screws and cleaning sensor lenses) was enough to keep the robot functioning. The modular design allows for quick sensor and motor replacement, which promotes sustainability in low-resource institutions. The system's resistance to mechanical wear improves its long-term applicability in educational environments.

Firmware dependability was equally critical. The robot used simple Arduino programming to manage sensors, timers, and motor control. Throughout the testing, there were no crashes or freezes due to constant voltage levels and memory-efficient code. A watchdog timer was then included to automatically reset the system in rare events of code stoppage, ensuring stable performance even without regular monitoring. This increased its dependability in autonomous operations throughout numerous cycles.

Users also expressed a high degree of trust in the robot. Teachers and librarians involved in the trial implementation reported little disturbances and praised the regular, repeating movement pattern. After training, users were able to begin tasks without requiring technical support. This minimal learning curve, along with excellent dependability, demonstrates the LFR's potential for widespread use in academic delivery activities requiring dependability.

**5. Fostering Educational Engagement through School-Based Robotics Integration**

Integrating Line-Following Robots into school infrastructure creates a realistic and engaging platform for teaching fundamental robotics principles while also enhancing the learning environment with hands-on experiences.

5.1 Building Technical Curiosity through Practical Exposure

One of the most effective approaches to encourage STEM education is to allow students to interact directly with practical systems such as robots. When students see or engage with an operating LFR, they naturally want to learn about its components, control mechanisms, and logic. The robot's capacity to follow a visual route using infrared sensors, adapt to environmental inputs, and execute precise motions teaches students the fundamentals of embedded systems, control theory, and automation. These abstract notions in textbooks become palpable when shown in the actual world. Using microcontrollers such as Arduino Uno, instructors may demonstrate how analog and digital signals are processed to operate actuators. Students also see how inputs from IR sensors feed into a PID control algorithm that maintains the robot's trajectory—thereby connecting hardware with logic in an intuitive way.

In the classroom, students may test alternate route patterns, sensor locations, and motor speed settings using the LFR as a live tool during instruction. This experimenting promotes iterative thinking and issue solutions. More significantly, it dispels the myth of robots as something remote or unreachable. Students realize that they can design and develop autonomous systems using basic, open-source technologies and low-cost hardware. The robot's small size, exposed wiring, and modular build make it perfect for disassembling and reassembling as part of a planned activity. Such direct contact stimulates greater curiosity and helps students to investigate how theory translates into functional systems, which boosts engagement and retention.

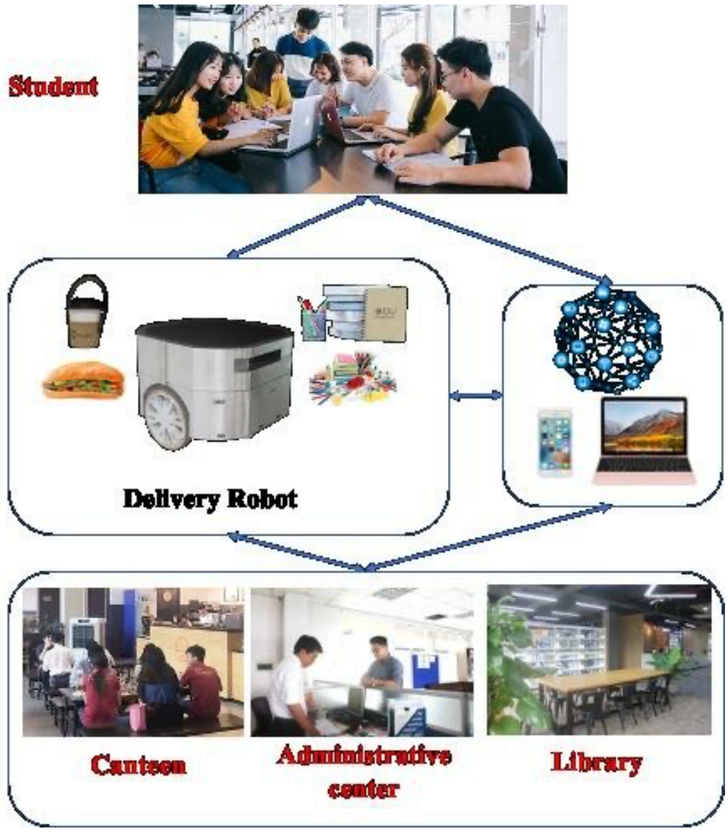


Figure: Delivery robot architecture (Source: Nguyen et al 2022)

5.2 Embedding Robotics into Curriculum and Infrastructure

Beyond demonstrations and one-time events, incorporating robots into the curriculum and school infrastructure yields significant educational benefit. Schools that use LFRs for operational functions, such as delivering paperwork or instructional materials, provide pupils with daily exposure to operating robots. This constant presence helps to normalize robots in children' imaginations and provides several learning opportunities. Teachers may link the robot's characteristics with course curriculum from many disciplines. For example, mathematics classes can utilize the LFR to investigate algorithms or coordinate geometry by charting delivery pathways. Students in science classes may investigate sensor activity under different lighting situations, and in computer science, they can edit Arduino code to change the robot's behavior.

The robot is especially well-suited to project-based learning (PBL) paradigms, which prioritize skill development via hands-on tasks. In this case, students may be charged with building a replica LFR, designing an enhanced version, or improving its functionality like as obstacle avoidance, wireless connectivity, or voice control. These projects not only reinforce classroom learning but also help students improve their cooperation, time management, and documentation skills. LFRs are often less than ₹4000, making them a cost-effective addition to lab kits. The robot's capacity to maintain and repair itself using minimal tools aids its inclusion into resource-constrained educational environments. By incorporating robots into regular school operations, educators may smooth the transition from abstract education to experience learning. The robot is no longer merely an instructional tool; it has become an integral element of the learning environment. Students take delight in seeing their inventions do real-world tasks, such as delivering books or welcoming visitors, which boosts confidence and encourages ownership of learning. As the LFR becomes a part of the institutional routine, it generates endless micro-learning opportunities in which students watch, question, and play with the robot's capabilities, ensuring that learning is both persistent and progressive.

5.3 Cultivating Innovation and 21st-Century Skills

Robotics integration in educational contexts provides a greater goal than academic enrichment; it fosters student ingenuity and 21st-century capabilities. Working with an LFR teaches learners about design thinking, system integration, and logical reasoning. Students learn to break down big issues into simple stages, test theories, and develop answers by programming the robot or modifying its hardware. These repetitive cycles simulate the engineering design process and educate students for real-world problem-solving situations. Engaging with robots also promotes computational thinking, in which kids create mental models to grasp processes, sequences, and conditional logic—skills that are becoming increasingly important across job sectors.

Hands-on robotics education promotes the development of soft skills including teamwork, communication, and leadership. Robotics projects sometimes require students to collaborate in groups, assign responsibilities, and make collaborative decisions regarding design or programming approaches. As students take responsibility for their given work and see the results of joint effort, they develop interpersonal skills alongside technical ones. Furthermore, presenting their robots to classmates or at school exhibits improves communication skills and fosters the expression of technical information in understandable terms. These activities not only promote engagement but also boost self-efficacy and motivation, especially among students who thrive in hands-on learning situations.

Integrating the LFR also helps to close the digital divide. Many rural or underserved schools continue to have limited exposure to robotics. A low-cost, open-source robot connects these institutions to automation and embedded technology in a sustainable way. After receiving basic training, teachers can lead students through exploratory modules with the robot as a basis. This democratization of technology guarantees that innovation is no longer limited to elite universities, but is available to all students. As kids from all backgrounds interact with robots, they see new opportunities for themselves and their communities, transforming curiosity into invention and engagement into empowerment.

## 6. Conclusion

The study assessed a Line-Following Robot (LFR) in terms of operational efficiency, navigational accuracy, system dependability, and educational utility in organized settings such as classrooms and libraries. The findings revealed that the robot completed planned delivery duties with high consistency, low energy consumption, and minimum interaction, making it a suitable tool for automating regular chores in institutional settings. Furthermore, the robot's incorporation into school operations provided significant engagement opportunities for students, allowing them to interact with robotics concepts in a real-world setting while also reinforcing hands-on STEM education through ongoing exposure and involvement.

The LFR serves as both a delivery medium and an educational resource, bridging the gap between theoretical instruction and actual learning. Its cost-effective, modular design, and use of open-source hardware and software make it ideal for resource-constrained schools and libraries. Students may watch, program, and configure the robot, gaining practical experience in electronics, coding, and mechanical systems. Teachers can include the LFR into project-based learning to promote problem solving, cooperation, and critical thinking. The robot not only improves operational processes, but it also contributes to the development of a generation of learners who understand automation and robotics fundamentals.

Future revisions of the LFR may integrate wireless communication modules, obstacle detection systems, and cloud-based task scheduling to enhance its functionality. Integration with IoT technologies might enable data analytics on distribution patterns, allowing administrators to better optimize library and classroom operations. Interdisciplinary robotics programs may be built around the LFR, connecting computer science, physics, and design. As technology advances, such platforms have the potential to play a critical role in democratizing access to robotics, transforming schools into innovators rather than mere consumers. The study therefore confirms the LFR as both a practical answer and a revolutionary educational value.

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