Autonomous trenching robot with intelligent obstacle detection and path optimization for precision cable installation

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Article Info

Article history:

Received Nov 9, 2024
Revised May 28, 2026
Accepted Jun 28, 2026

Keywords:

Automation
IoT
Obstacle detection
Path optimization
Trenching

ABSTRACT

Trenching for underground cable and pipeline installation is typically labor-intensive, time-consuming, and potentially hazardous, particularly in environments with buried obstacles. This paper presents a low-cost autonomous trenching robot with intelligent obstacle detection and path optimization to improve excavation efficiency, safety, and accuracy. The proposed system integrates ultrasonic and infrared sensors with an embedded controller for real-time obstacle detection and autonomous navigation. A path optimization algorithm automatically adjusts the trenching route whenever an obstacle is detected, allowing continuous operation while reducing unnecessary movement and energy consumption. The robot employs a tracked mobile platform and an automated trenching mechanism capable of maintaining consistent trench depth and width under different terrain conditions. Experimental results demonstrate that the proposed system accurately detects obstacles, successfully replans its path in real time, and performs reliable autonomous trenching with minimal human intervention. Compared with conventional manual trenching methods, the developed robot improves operational efficiency, enhances excavation accuracy, and reduces safety risks for workers. The proposed system provides a practical and scalable solution for underground cable and pipeline installation and has strong potential for future applications in intelligent construction, infrastructure development, and autonomous civil engineering.

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1. INTRODUCTION

Automation of construction equipment has been investigated for more than five decades with the objective of improving productivity, safety, and operational efficiency. Despite significant technological advances in robotics, artificial intelligence (AI), and autonomous control, the adoption of robotic construction equipment remains limited, with most developments still confined to laboratory prototypes or experimental demonstrations [1], [2]. Consequently, many construction activities, particularly excavation and trenching, continue to rely heavily on manual operation.

The construction industry plays a fundamental role in achieving the United Nations Sustainable Development Goals (UNSDGs), particularly those related to resilient infrastructure and sustainable urban development [3]. Integrating advanced technologies into construction processes has the potential to improve operational efficiency, reduce project costs, enhance work quality, and minimize occupational hazards [4]–[6]. Nevertheless, compared with other industrial sectors, the construction industry has been relatively slow in adopting automation technologies due to high implementation costs, complex operating environments, and the fragmented nature of construction projects [7]. As infrastructure demand continues to increase worldwide, there is an urgent need for intelligent and autonomous construction equipment capable of operating safely and efficiently under dynamic field conditions.

AI, robotics, machine learning, computer vision, and internet of things (IoT) technologies have recently emerged as promising solutions for modernizing construction operations [8]. Numerous studies have focused on increasing the level of automation by improving perception, localization, navigation, and decision-making capabilities of construction machinery [9]–[11]. Among these capabilities, path planning and obstacle avoidance are particularly important because construction sites are highly unstructured and continuously changing environments [12]–[17]. Comprehensive surveys have demonstrated that reliable obstacle detection, localization, and motion planning remain fundamental challenges for achieving fully autonomous construction robots [18].

Several researchers have investigated the automation of trenching operations using different machine configurations. A modified walking excavator capable of generating free-form trenches was presented in [19], where autonomous mapping and excavation techniques improved trenching flexibility. However, the complexity of controlling the walking mechanism reduced the overall operational efficiency. A hierarchical software architecture based on behavior-driven control was proposed for autonomous excavation [20]. Although the system demonstrated adaptability to changing environments, its performance was limited when executing more complex excavation tasks. Reinforcement learning was employed in [21] to enable an excavator to adjust its operating parameters according to varying soil characteristics, thereby improving excavation efficiency. Nevertheless, the approach required extensive training data and significant computational resources for real-time implementation. An autonomous trencher equipped with terrain traversability mapping using RGB images and 3D point clouds was introduced in [22]. While the proposed system improved navigation in unstructured environments, further improvements were needed in obstacle detection accuracy, computational efficiency, and real-time path optimization.

Although considerable progress has been achieved, several important limitations remain. Most existing autonomous trenching systems employ expensive sensing hardware, require high computational resources, or focus primarily on either navigation or excavation without integrating intelligent obstacle detection, adaptive path optimization, and practical field deployment into a single low-cost platform. Furthermore, many reported systems remain experimental and have not sufficiently addressed the requirements of affordability, robustness, and scalability needed for practical construction applications.

To address these challenges, this paper proposes an autonomous trenching robot that integrates intelligent obstacle detection, adaptive path optimization, and IoT-enabled monitoring into a compact and cost-effective platform. The proposed system combines real-time environmental sensing with autonomous navigation algorithms to detect obstacles, optimize excavation trajectories, and maintain continuous trenching operations while minimizing operator intervention. Compared with existing approaches, the proposed system offers a practical balance between autonomy, computational efficiency, implementation cost, and operational robustness, making it more suitable for real-world construction environments.

The major contributions of this work are summarized as follows:

- A low-cost autonomous trenching robot is developed by integrating intelligent navigation, obstacle detection, and trench excavation into a single compact platform.
- A real-time obstacle detection and adaptive path optimization strategy is proposed to enable safe navigation and continuous trenching in dynamic construction environments.
- An IoT-enabled monitoring architecture is incorporated to provide remote supervision, operational monitoring, and improved system reliability.
- Comprehensive prototype experiments are conducted to validate the effectiveness of the proposed system in terms of autonomous navigation, obstacle avoidance, and trenching performance.

The remainder of this paper is organized as follows. In section 2 reviews existing automation techniques for autonomous trenching systems. In section 3 presents the proposed methodology and system architecture. Section 4 describes the experimental setup and prototype implementation. Section 5 discusses the experimental results and performance evaluation, while section 6 concludes the paper and outlines future research directions.

2. METHOD

2.1. Proposed system

The overall architecture of the proposed autonomous trenching system is illustrated in Figure 1. The system integrates sensing, intelligent control, autonomous navigation, obstacle avoidance, trenching, and remote monitoring into a unified platform. Real-time image data captured by the onboard camera and distance information obtained from the obstacle detection sensors are transmitted to the digital signal processor (DSP), which serves as the central processing unit. The DSP performs image processing and sensor fusion to accurately identify obstacles and evaluate the surrounding environment. Based on the processed information, the controller generates navigation commands that enable autonomous movement while maintaining the desired trenching path. When an obstacle is detected, the DSP executes the obstacle avoidance and path optimization algorithm to determine an alternative route with minimum deviation from the planned trajectory. The optimized path is then sent to the motor control unit, which actuates the tracked drive system and trenching mechanism to continue excavation safely and efficiently. This closed-loop control strategy ensures continuous operation while minimizing unnecessary movements and maintaining trench quality.

For monitoring purposes, the DSP simultaneously transmits live video and operational data to a web server through a wireless communication module. These data are accessed by an Android-based mobile application, allowing operators to remotely monitor the robot's status, viewing angle, and trenching progress in real time. A global positioning system (GPS) module provides the robot's geographical coordinates for navigation and position tracking, while an onboard gyroscope continuously measures the robot's orientation and inclination. The inclination information is used to improve motion stability and maintain safe operation when the robot traverses uneven or sloped terrain. The integration of real-time sensing, intelligent path planning, autonomous control, and remote monitoring enables the proposed system to perform trench excavation with minimal human intervention while improving operational safety, accuracy, and efficiency.

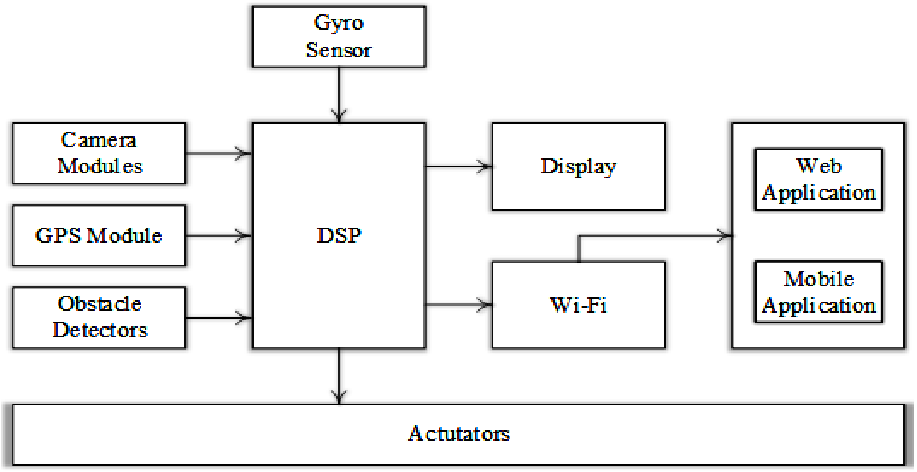


Figure 1. System block diagram

2.2. Prototype development

The proposed autonomous trencher was developed through two iterative stages, namely Proto-1 and Proto-2, to facilitate systematic hardware integration, software verification, and performance optimization. The first stage focused on validating the fundamental operation of the autonomous trenching system, including sensor integration, obstacle detection, navigation control, and remote communication. Based on the findings obtained from the initial prototype, a second prototype was subsequently developed with improved mechanical design, enhanced sensing capability, and refined control algorithms to achieve greater operational reliability and field performance. This staged development approach enabled progressive improvements while minimizing implementation risks and simplifying troubleshooting during system integration.

2.2.1. Proto-1 phase

The Proto-1 phase served as the proof-of-concept implementation of the proposed autonomous trenching system. During this stage, the mechanical structure, electronic hardware, sensing modules, and embedded control system were assembled to establish a functional prototype capable of autonomous navigation and trenching. The software development concentrated on implementing the core algorithms for obstacle detection, autonomous navigation, path optimization, trenching operation, and wireless remote monitoring. Individual modules were initially verified independently before being integrated into the complete control system to ensure reliable operation.

The prototype employed multiple sensors to obtain environmental and operational information, including obstacle distance, robot orientation, geographical location, and real-time visual feedback. The collected data were processed by the DSP to support autonomous decision-making and control of the trenching mechanism. The hardware components and sensing modules used in the development of Proto-1 are summarized in Table 1. Their specifications and functions are selected to provide reliable sensing, accurate navigation, and stable operation while maintaining a cost-effective system design suitable for practical deployment.

Table I. List of components for assembly of Proto-1

Sr.	Component description
1	Training kit (4 motor-driven wheels and chassis set).
2	L298N motor drivers for actuating DC motors.
3	4.5 V, 125 rpm DC motors for driving prototype wheels.
4	HC-SR04 ultrasonic distance sensor for obstacle detection.
5	HC-05 Bluetooth Module for remote control of prototype.
6	ESP32-CAM Wi-Fi + Bluetooth module for video processing.
7	GPS module based on the Ublox NEO-6M for positioning.

The fabricated prototype at the end of the Proto-1 phase of the project is shown in Figure 2. Algorithms were written for the controller to regulate various prototype functionalities and features. After connecting to a Wi-Fi access point, the system was capable of live video streaming via a web server. A two-step identification process of object contouring and identification implemented obstacle avoidance.

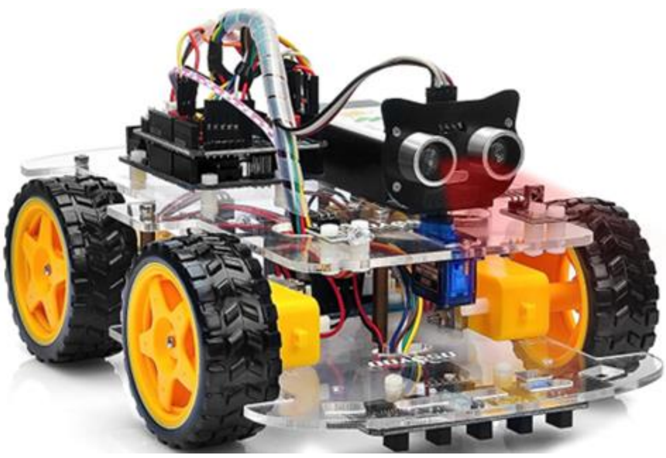


Figure 2. Assembled prototype at Proto-1 phase

Various algorithmic approaches for path planning and navigation are discussed in [23]. These are classified as grid-based, sampling-based and potential field techniques. The grid-based A* algorithm was selected for this project to determine optimal path during navigation. Additionally, two modes of operation were programmed: automatic and manual remote control. A flow chart for the obstacle detection algorithm is shown in Figure 3.

Region-based convolutional neural network (R-CNN) was used for obstacle detection. In R-CNN models, the most essential features were extracted using selective features. The process of selecting the most significant extractions was computed with the help of a selective search algorithm that achieved the most important regional proposals. After some initial testing of the prototype, it was determined that several changes were required to enhance its different performance parameters. These changes were made during the Proto-2 phase of the project, as discussed below.

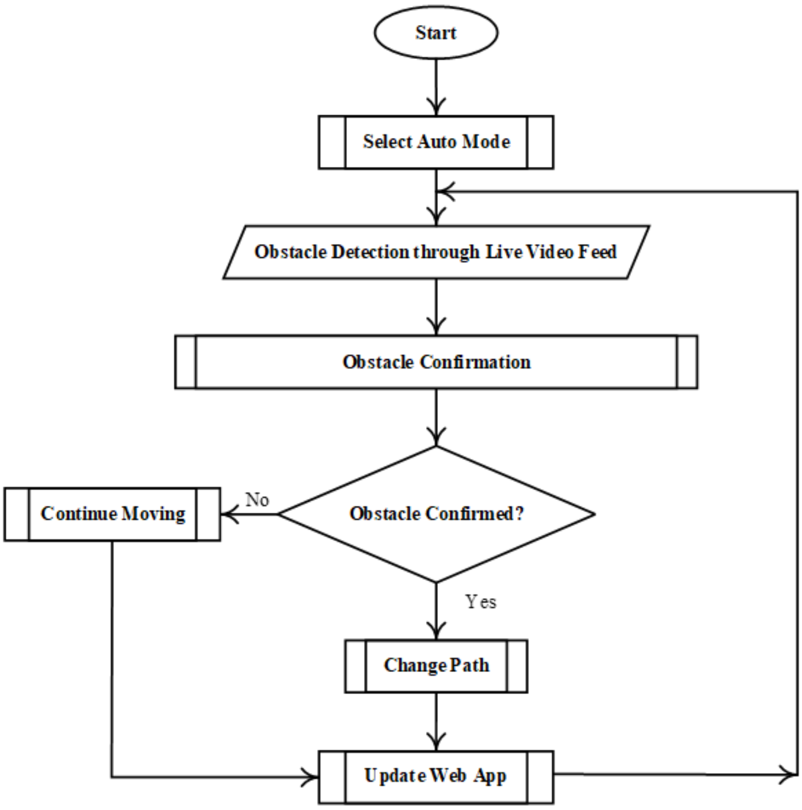


Figure 3. Flowchart for obstacle detection

2.2.2. Proto-2 Phase

Several changes were made to the system design, as listed in Table 2, to improve system performance. The new design required modifications to both the hardware and software end of the project. After the completion of the Proto-2 phase, the project moved on to the detailed testing and optimization phase.

Table 2. List of changes for Proto-2 phase

Sr.	Change made to prototype
1	Change of camera modules to 360˚ cameras.
2	Addition of gyroscope sensor for terrain slope detection capabilities.
3	Revision of positioning of ultrasonic sensors for better sensing.
4	Optimization of path planning and obstacle avoidance algorithms.
5	Several hardware design revisions for better visualization of the trencher.

The change of camera modules allowed better visualization of the prototype's surroundings, increasing the field of view and permitting better obstacle detection. The gyroscope sensor provided information about the inclination of the prototype, thereby determining the slope of the terrain where the machine was operating. This information is necessary to control various aspects of the trencher machine, such as wheel motor control, and the angle of the trencher blade for excavation. For an inclination beyond a threshold value, the prototype rerouted itself and found a more appropriate path for trenching.

Tabassum *et al.* [24], three ultrasonic sensors were used to detect and circumnavigate obstacles along the path of an autonomous robot. Initially, the designed prototype also utilized three sensors The sensors were positioned to provide proximity data, accurately distancing obstacles in the prototype's vicinity. The number of sensors needed to be optimized, for which extensive testing was carried out.

The prototype was moved between two points, 'A' and 'O'. It was observed that the trencher did not reroute to the shortest available path and chose a different route on each iteration. The number of sensors was increased incrementally, and tests were repeated for the same setup. It was determined that the optimal number of ultrasonic sensors was seven, and there was no appreciable improvement for a greater number of sensors on the prototype. A visualization of the test results is given in Figure 4. In the final design, the prototype was equipped with three camera modules (front, back, bottom) and seven ultrasonic sensors (3x front, 4x sides) along with other sensors and processors.

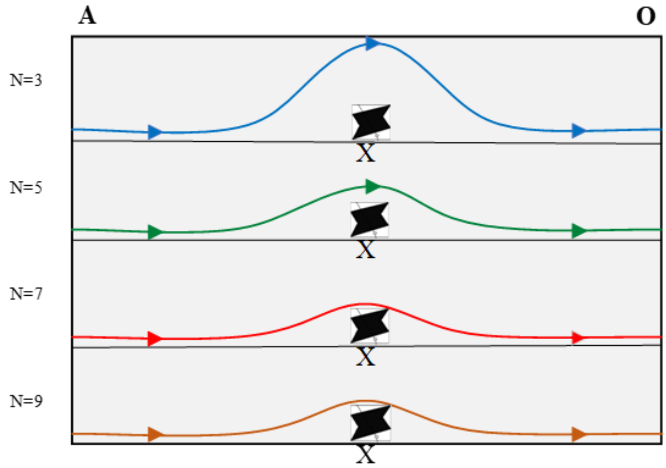


Figure 4. Detection and circumnavigation accuracy map for different number of ultrasonic sensors

There was a revision to the path planning and obstacle avoidance algorithms to improve overall system performance. The prototype was designed with a monocular vision technique, using a camera and ultrasonic sensors for contouring and detection of obstacles to determine the shortest possible path during circumnavigation. This ensured trenching efficiency by minimizing time of operation and fuel consumption.

Lastly, the prototype hardware was changed to better represent a trencher machine. A motor-controlled blade on the front was added, and off-road tyres were used for better traction. The final trencher prototype is shown in Figure 5.

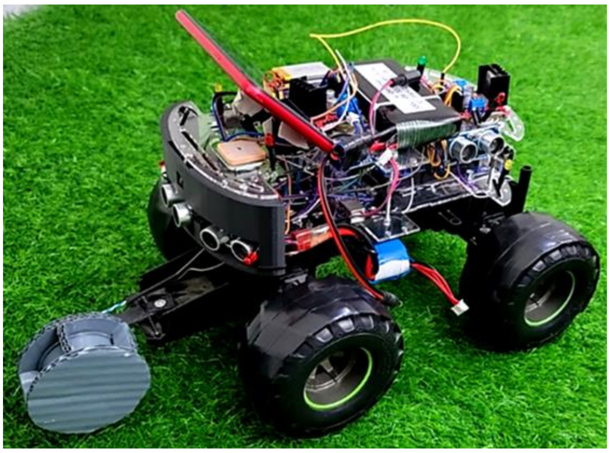
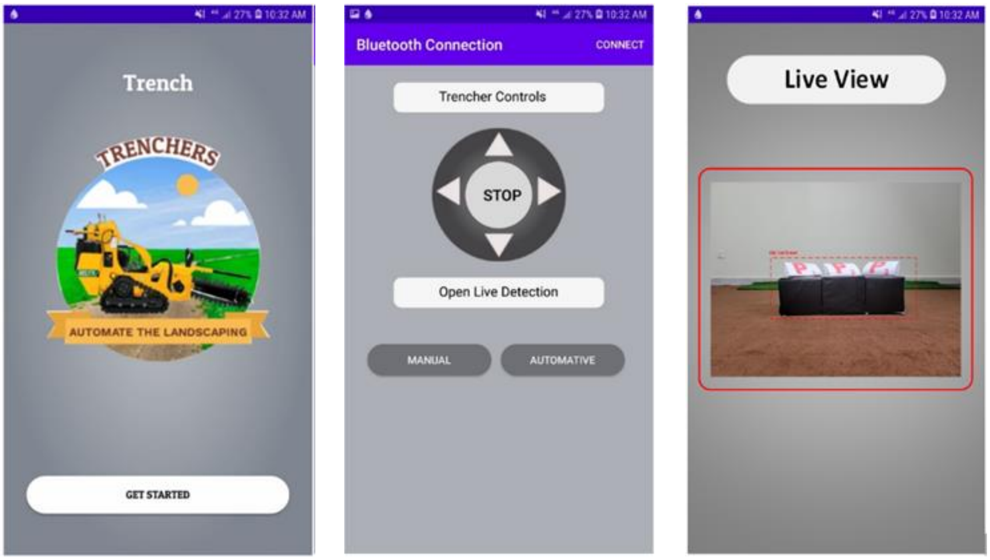


Figure 5. Trencher prototype after Proto-2 changes

2.2.3. Mobile application

A mobile application was developed for remote monitoring and control of the prototype. The mobile application communicated with the prototype via Bluetooth. The user could access a video feed from any of the cameras installed on the prototype. The user also had information about the trencher's location and planned path for trenching. The application also allowed the user to control the trencher remotely. The mobile application is shown in Figure 6. Figure 6(a) is application home screen, Figure 6(b) is screen for switching mode of operation and accessing live video feed, and Figure 6(c) is live stream from trencher camera.



(a) (b) (c)

Figure 6. Mobile application for controlling trencher; (a) application home screen, (b) screen for switching mode of operation and accessing live video feed, and (c) live stream from trencher camera

3. RESULTS AND DISCUSSION

The performance of the developed autonomous trencher was evaluated through a series of laboratory and field experiments conducted during the Proto-2 development phase. The evaluation focused on the effectiveness of the proposed autonomous navigation, obstacle detection, path optimization, and terrain adaptability mechanisms. Experimental results demonstrate that the developed system can reliably detect obstacles, generate alternative navigation paths, and continue trenching operations with minimal human intervention. The proposed system integrates multiple sensing technologies with an AI-based obstacle mapping algorithm to construct a real-time representation of the surrounding environment. Sensor fusion enables accurate obstacle localization while reducing false detections caused by environmental noise. Based on the generated environmental map, the path planning algorithm continuously determines the shortest collision-free trajectory, allowing the robot to avoid obstacles while maintaining the desired trenching direction.

Experimental observations indicate that the prototype successfully detected both static and unexpected obstacles and dynamically modified its trajectory according to obstacle dimensions and terrain conditions. The integration of GPS and gyroscope measurements further improved navigation accuracy by maintaining heading stability and compensating for terrain inclination during operation. Consequently, the robot maintained consistent trenching performance even when operating on uneven surfaces. Compared with the initial Proto-1 implementation, the Proto-2 prototype exhibited noticeable improvements in obstacle detection reliability, navigation accuracy, and overall operational stability. The optimized control algorithm reduced unnecessary steering corrections, resulting in smoother motion, lower energy consumption, and more efficient trenching operations. These improvements demonstrate the effectiveness of the proposed autonomous control strategy and highlight its potential for implementation in full-scale trenching equipment used for underground cable and pipeline installation.

Following the hardware and software enhancements introduced during the Proto-2 phase, the prototype underwent a comprehensive performance evaluation under controlled experimental conditions. An obstacle-laden test course was constructed to simulate practical construction environments containing fixed obstacles and varying terrain profiles. During each experiment, the robot was required to follow a predefined trenching route while autonomously detecting obstacles, selecting an alternative path, and returning to the original route after successfully bypassing the obstruction. The primary performance indicators included obstacle detection accuracy, path optimization capability, navigation stability, and autonomous trenching continuity. The experimental setup used for performance evaluation is illustrated in Figure 7. This experimental validation confirms that the proposed autonomous trencher provides a practical and reliable solution for intelligent trench excavation, offering significant potential to improve construction safety, reduce labor requirements, minimize fuel consumption, and increase operational efficiency in future smart construction and infrastructure projects.

Figure 7. Experimental setup for testing of trencher prototype

A number of obstacles (P1 – P10) were placed along the trencher's path. The prototype navigated through the obstacles using obstacle mapping, which was enabled using advanced AI algorithms. With the help of location and distance information for the obstacles from the camera and ultrasonic sensors, the prototype generated a real-time map of its surroundings. The map generated by the trencher while navigating through the obstacles is shown in Figure 8. Figures 8(a)–(h) illustrate the progressive obstacle detection and map generation process, from the initial detection of obstacles to the final stage where all obstacles are successfully identified.

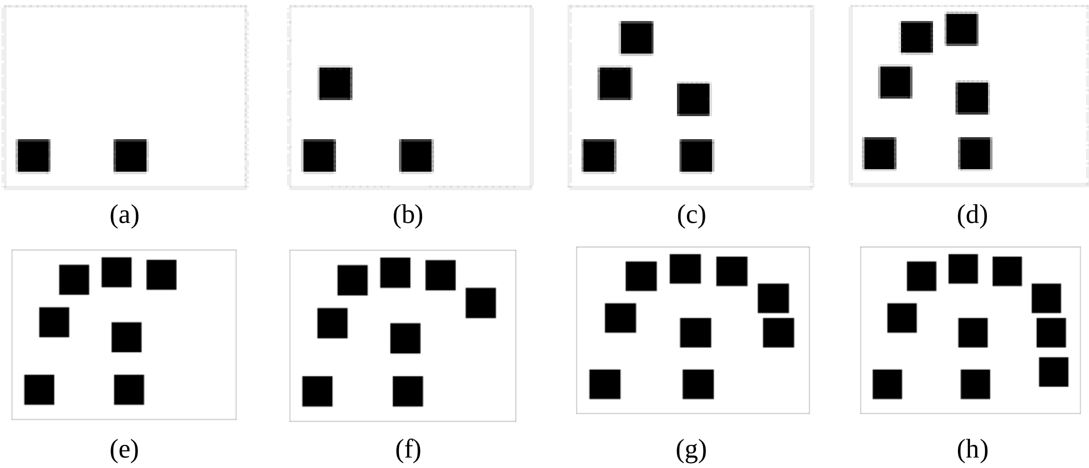


Figure 8. Obstacle mapping at various stages of the trencher's progress; (a) P1 and P2 detected, (b) P1, P2 and P4 detected, (c) P1, P2, P3, P4 and P5 detected, (d) P1, P2, P3, P4, P5 and P6 detected, (e) P1, P2, P3, P4, P5, P6 and P7 detected, (f) P1, P2, P3, P4, P5, P6, P7 and P8 detected, (g) P1, P2, P3, P4, P5, P6, P7, P8 and P9 detected, and (h) all obstacles detected

The prototype was further evaluated on terrains with different inclination angles to assess the accuracy of the terrain slope estimation and the effectiveness of the obstacle avoidance strategy. Prior to testing, the gyroscope sensor was calibrated to ensure accurate measurement of the robot's orientation and ground inclination. Experimental results showed that the calibrated gyroscope provided reliable real-time inclination data, enabling the controller to distinguish between traversable terrain variations and non-traversable obstacles. To improve navigation intelligence, the proposed system combined data from the onboard camera and ultrasonic sensor to estimate both the position and height of detected obstacles. The obstacle height was then compared with a predefined inclination threshold obtained from the gyroscope measurements. When the estimated obstacle height corresponded to an inclination angle below the threshold, the controller classified the obstacle as traversable, allowing the trencher to continue excavation without altering its planned path. Conversely, when the estimated obstacle exceeded the threshold, the obstacle was classified as non-traversable, triggering the path optimization algorithm to generate an alternative route around the obstacle.

For the experimental validation, the inclination threshold was set to 20°, representing the maximum terrain slope that the prototype could safely traverse while maintaining trenching stability. As illustrated in Figure 9, the prototype initially followed the planned route from Point O to Point A. During its movement, obstacle X was intentionally positioned along the trenching path. The sensing system successfully detected the obstacle and calculated its dimensions. Since the computed obstacle height exceeded the predefined threshold, the autonomous controller activated the obstacle avoidance routine. The prototype smoothly deviated from its original trajectory, navigated around the obstacle using the optimized path, and subsequently returned to the planned trenching route after safely bypassing the obstruction.

The experimental results demonstrate the effectiveness of the proposed sensor fusion and decision-making algorithm in accurately distinguishing between traversable and non-traversable obstacles. This capability significantly improves the autonomy, operational safety, and reliability of the trenching system, enabling continuous excavation with minimal interruption under varying terrain conditions. The successful integration of gyroscope-based terrain assessment, camera vision, and ultrasonic sensing further validates the proposed intelligent navigation framework for autonomous trenching applications.

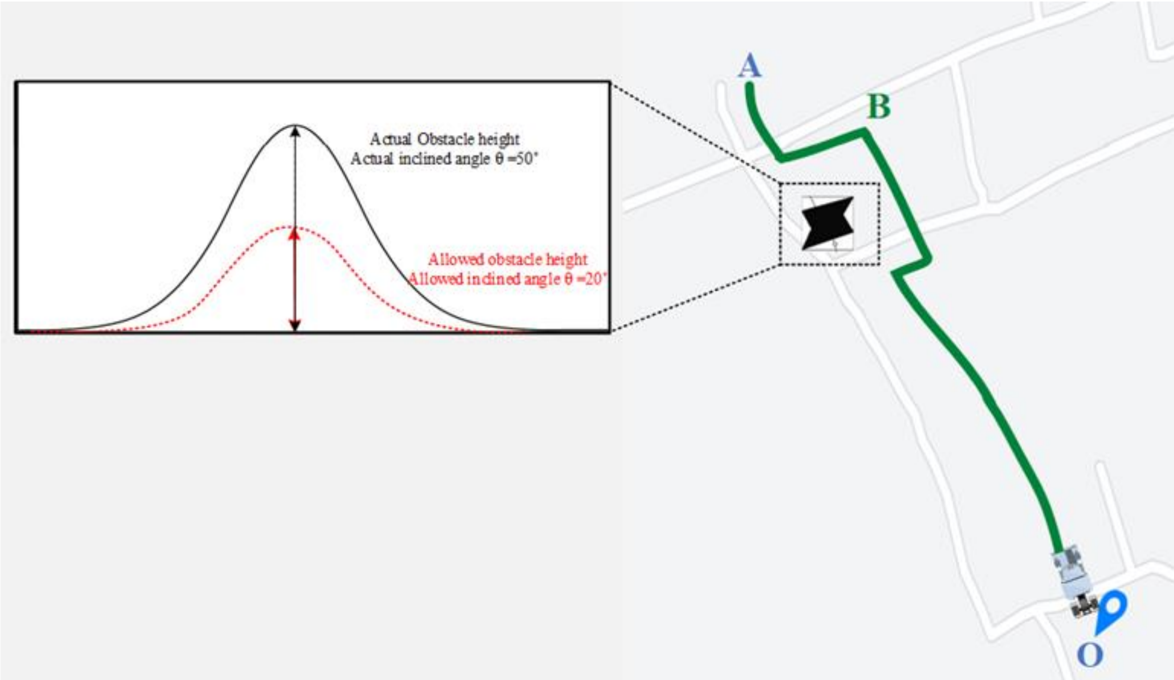


Figure 9. Obstacle avoidance based on obstacle height

After extensive testing in the laboratory, the experiments were also conducted in real-world environments. The prototype was trained to identify different types of obstacles and take appropriate action accordingly. The prototype was also tested for various topography and trenching operations.

To integrate the proposed control system with practical trenchers, the sensors to collect data need to be scaled to provide the same level of detection range and accuracy. A proposed layout for sensors and cameras on a large-scale trencher is shown in Figure 10.

Experimental results indicated that the proposed trencher automation and control system can be applied to practical machines. The obstacle detection algorithm successfully generated an accurate real-time obstacle map during operation. The obstacle avoidance algorithm allowed efficient rerouting during navigation to minimize time and fuel costs.

The findings of this study are significant as they offer a practical solution to one of the key challenges in trenching operations—automated obstacle detection and efficient navigation. By combining AI-based mapping algorithms with sensor fusion techniques, the prototype demonstrated reliable real-time decision-making, a feature not extensively addressed in previous literature (Table 3). The ability to compute obstacle height and terrain slope adds another layer of safety and efficiency, potentially reducing operational delays and fuel costs. However, while the controlled and real-world tests confirmed the system's effectiveness, a limitation lies in the need for further validation over extended periods and under varying environmental conditions such as extreme weather or highly uneven terrain. Additionally, scalability to industrial-scale trenchers will require more robust hardware and redundancy in sensor systems to ensure long-term reliability. Despite these limitations, the study provides a strong foundation for future research and development in fully autonomous trenching systems.

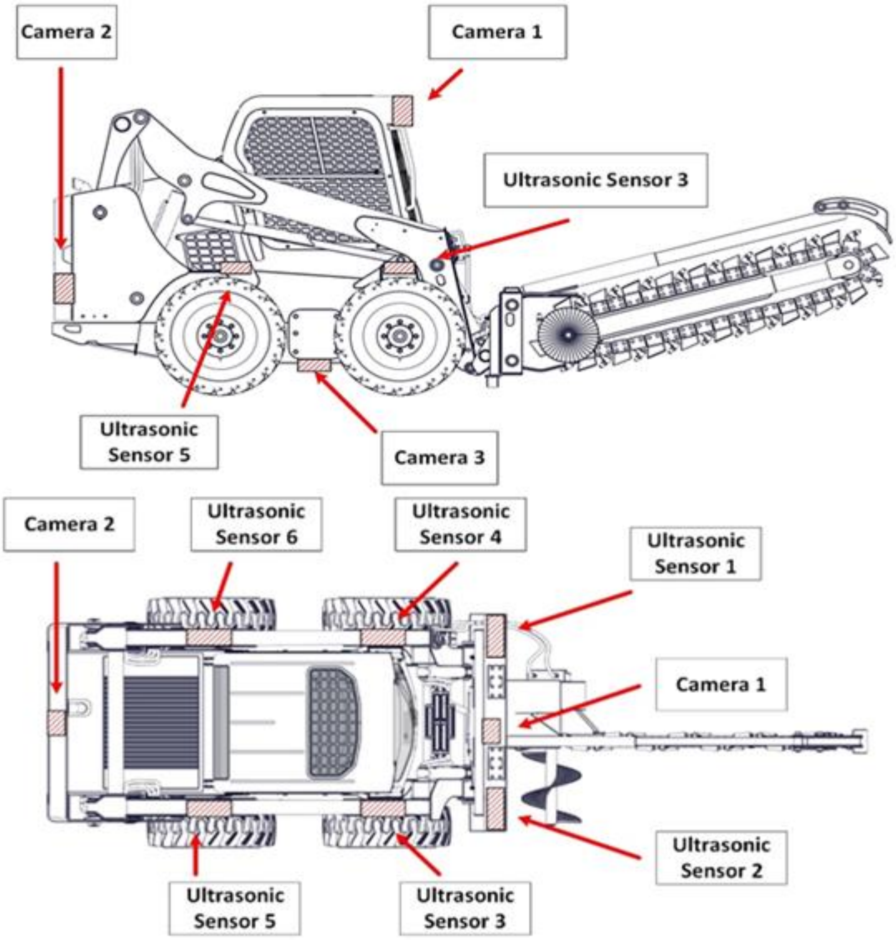


Figure 10. Proposed layout of sensors for integration with large-scale trenchers

Table 3. Comparison of proposed method with previous studies

Literature	Path planning technique	Obstacle detection
Das *et al.* [25]	CriticalPointBug algorithm	Ultrasonic sensing
Ling *et al.* [26]	HSTOR-9P	Computation by harmonic functions
Kim *et al.* [27]	Output Constrained model predictive control	Camera/sensor based
Proposed method	A* algorithm	Ultrasonic sensing, optical sensing

The findings support the initial hypothesis that automation and integration of AI-based algorithms for obstacle detection will increase efficiency of trenching operations. The prototype successfully demonstrated the ability to detect obstacles, compute their height, assess terrain slope, and adaptively reroute to maintain operational efficiency. The real-time obstacle mapping and avoidance system consistently generated accurate environmental data, allowing the trencher to navigate through both controlled and real-world environments without significant manual intervention.

This study opens new avenues for expanding the capabilities of automated trenching systems beyond basic obstacle detection and avoidance. A valuable perspective for future research is to explore the integration of machine learning models capable of classifying obstacle types (e.g., rocks, vegetation, infrastructure) and adapting trenching strategies accordingly, enhancing situational awareness and decision-making. Additionally, incorporating sensor redundancy, such as LiDAR or radar, alongside existing cameras and ultrasonic sensors, can improve performance under adverse weather or lighting conditions, addressing one of the key limitations identified. Another promising direction is the implementation of collaborative swarm systems, where multiple autonomous trenchers communicate and coordinate to optimize large-scale trenching operations. To address unanswered questions, long-term field trials across diverse terrains and environmental conditions should be conducted to evaluate the durability and scalability of the system. Further research could also focus on minimizing the computational load of real-time obstacle mapping to ensure energy efficiency without compromising accuracy. These steps will provide a more comprehensive understanding of the system's robustness and practical viability in large-scale, real-world applications.

Avoiding the automation of trenching operations can result in several negative consequences, which emphasize the critical importance of the proposed solution. Manual or semi-automated trenchers often face delays due to unanticipated obstacles, leading to increased project timelines and higher labor and fuel costs. Failure to detect and properly navigate obstacles may also result in equipment damage, posing safety risks to operators and nearby personnel. Additionally, inefficient rerouting or trenching over unsuitable terrain can compromise the quality and precision of the trenching process, affecting subsequent infrastructure installation. Over time, these inefficiencies can accumulate into significant financial losses and resource wastage. The proposed solution mitigates these risks, thereby ensuring safer, reliable, and cost-effective trenching operations.

4. CONCLUSION

This paper presented the design, implementation, and experimental validation of an autonomous trencher equipped with intelligent obstacle detection, path optimization, and IoT-based remote monitoring capabilities. The proposed system integrates camera vision, ultrasonic sensing, GPS, and gyroscope measurements with an embedded control system to achieve autonomous navigation and real-time decision-making during trenching operations. Experimental evaluations demonstrated that the developed prototype successfully detected obstacles, estimated terrain inclination, generated alternative navigation paths, and resumed the planned trenching route with minimal human intervention. The sensor fusion and path optimization algorithms enabled reliable operation across different terrain conditions while maintaining excavation continuity and operational stability. Compared with conventional manual trenching, the proposed system improves excavation accuracy, enhances worker safety, reduces operator workload, and increases operational efficiency. Furthermore, the modular hardware architecture and low-cost implementation make the system suitable for future deployment in infrastructure construction, utility installation, and smart civil engineering applications. Although the prototype demonstrated promising performance under controlled experimental conditions, further research is required before large-scale deployment.

Future work will focus on integrating advanced AI techniques, such as deep learning-based object recognition and simultaneous localization and mapping (SLAM), to improve navigation accuracy in unstructured environments. Additional studies will investigate adaptive path planning for dynamic obstacles, energy-efficient motion control, and autonomous trench depth regulation under varying soil conditions. Finally, full-scale field validation on commercial trenching equipment will be conducted to evaluate long-term reliability, scalability, and operational performance in real construction environments.

ACKNOWLEDGMENTS

The authors sincerely appreciation to the management and technical team of CMG for their invaluable guidance, technical expertise, and continuous support throughout the design, development, and evaluation of the autonomous trenching system. Their contributions have been instrumental in the successful completion of this research.

FUNDING INFORMATION

The work was done under project code CMG012, funded by Champion Mobile Global Limited, UK.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
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D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest in the submitted article, acknowledged by all authors.

DATA AVAILABILITY

All data generated or analyzed during this study are included in this published article.

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