Design and Development of an Intelligent Autonomous Robot for Elderly Nursing Care Applications

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Abstract

In recent years, Malaysia has experienced a steady increase in its elderly population, with adults aged 65 and above rising from 7.2% in 2022 to 7.4% in 2023, as reported by the Department of Statistics Malaysia (DOSM). By 2024, this number of senior citizens is projected to exceed six million, leading to a growing demand for elderly care services and applications. This demographic shift poses significant challenges, particularly due to a shortage of caregiving personnel and limited availability of family members to provide full-time support. To address this issue, an Intelligent Autonomous Robot (IAR) for elderly nursing care applications was designed and developed to assist with routine care tasks and reduce dependency on human resources. In this study, the IAR is equipped to autonomously deliver food, water, and medication to elderly individuals within care facilities. The system utilises an ESP32 microcontroller with built-in Wi-Fi and Bluetooth for remote monitoring and control, supported by infrared sensors for line detection, ultrasonic sensors for obstacle and checkpoint identification, and direct current (DC) motors driven by motor drivers for navigation. Upon reaching each checkpoint, the robot halts for a predetermined duration before continuing its route and notifies nursing staff via Telegram upon successful medication delivery. Initial testing in a simulated care environment demonstrated the robot's functionality and consistency in completing delivery cycles without human intervention. This innovation highlights the potential of autonomous robotic systems to enhance the efficiency and sustainability of elderly care applications, particularly in the context of limited manpower and increasing care demands.

Keywords: Autonomous Robot, Elderly Care, ESP32 Microcontroller, Healthcare Automation, Sensor-Based Navigation

1.0 Introduction

Malaysia is experiencing a significant demographic transition towards an ageing society. According to the Department of Statistics Malaysia (DOSM), the proportion of individuals aged 65 and above increased from 7.2% in 2022 to 7.4% in 2023, translating to approximately 2.5 million older adults [1], [2],

[3]. This trend is expected to intensify, with projections indicating that by 2040, the proportion of the elderly population of 14.5% will approach that of the younger population, which is 18.6% [4], [5]. By the same year, the number of senior citizens is anticipated to exceed six million, signifying Malaysia's shift towards becoming an aged nation [6], [7].

This demographic shift presents substantial challenges for the healthcare sector, particularly in elderly care applications. A prominent concern is the declining number of experienced nurses, leading to staff shortages, increased workloads, and a potential rise in patient mortality [8], [9], [10], [11]. Contributing factors include workforce retirement, occupational fatigue, and a perceived lack of professional recognition. Nurses play a vital role in delivering comprehensive care, which encompasses medical administration, vital sign monitoring, emotional support, and patient advocacy. However, the increasing demands placed on healthcare institutions, particularly nursing homes, have made it increasingly difficult to meet the complex needs of the elderly, exacerbated by a shortage of trained specialists in geriatric care [12], [13]. Without timely intervention, the existing human resource constraints may undermine the quality of care provided to this vulnerable population [14].

In response to these challenges, the integration of robotic technology into elderly care has gained considerable attention [15], [16], [17], [18]. Care robots have demonstrated potential in supporting various aspects of elderly care, including physical assistance, cognitive support, and psychosocial engagement. Their ability to reduce the workload of nursing staff by undertaking repetitive and non-value-added tasks such as routine monitoring, safety checks, and basic service delivery [19]. Furthermore, robotic systems can facilitate social interaction, improve mobility, assist with rehabilitation, and enhance overall quality of life for elderly individuals [20], [21], [22], [23].

Therefore, to contribute towards a sustainable solution in addressing the increasing demand for elderly care, this study presents the design and development of an Intelligent Autonomous Robot (IAR) intended to support caregiving tasks within nursing home environments. The IAR is engineered to enhance safety, comfort, and operational efficiency by autonomously navigating the facility, avoiding obstacles, and delivering essential items such as food, water, and medication to elderly residents. It also integrates real-time communication via Telegram to provide timely alerts and coordination with nursing staff. The key contribution of this study lies in the development of a low-cost, sensor-based intelligent autonomous robot tailored to the Malaysian elderly care context. Unlike existing systems, the proposed IAR combines autonomous navigation, real-time communication, and multi-service delivery in a single integrated platform. This work contributes to the field of assistive robotics by offering a scalable and context-sensitive solution for improving care quality in resource-constrained environments [22], [23].

2.0 Methodology

This section outlines the methodology adopted for the development of the IAR, which includes system design, software implementation, and hardware integration. The methodology is structured into three main parts: the block diagram of the system, the software development process, and the hardware development details.

2.1 Block Diagram

Figure 1 presents the system block diagram of the IAR developed for elderly nursing care applications. The system integrates multiple sensors, a microcontroller, motor drivers, and communication modules to enable autonomous navigation and effective interaction with the environment. The robot is equipped with two Miniature Hybrid (MH) infrared sensors mounted beneath the chassis to detect black lines along the navigation path. These sensors continuously transmit real-time feedback to the ESP32 microcontroller. This feature enables the robot to accurately determine its directional movement, whether to move forward, turn left, or turn right, based on the position of the detected line.

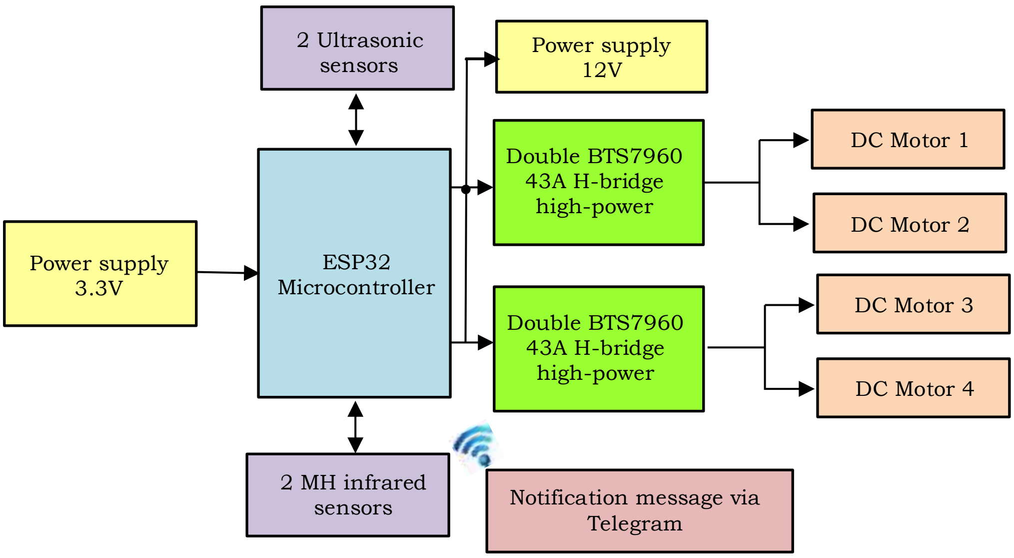

Figure 1: System block diagram of the IAR for elderly nursing care applications

For obstacle detection and checkpoint recognition, the IAR employs two ultrasonic sensors positioned at the front of the robot. These sensors measure distances to nearby objects or predefined checkpoints, sending this information to the microcontroller. When an obstacle is detected within a predefined range, the ESP32 immediately commands the motor drivers to stop the robot, which prevents collisions. The robot's movement is controlled by a Double BTS7960 43A high-power motor driver, which provides efficient and reliable power management for the DC motors. This motor is connected directly to the ESP32 microcontroller and is responsible for translating control signals into precise motor operations, such as speed regulation and directional changes. Together, the line tracking sensors, ultrasonic sensors, ESP32 microcontroller, and high-power motor driver form a robust autonomous navigation system that is capable of safely transporting items within an elderly care environment, as illustrated in Figure 1.

2.2 Software Development

Figure 2 illustrates the development environment used for programming the IAR, which is based on the Arduino Integrated Development Environment (IDE). The Arduino IDE is a cross-platform application compatible with Windows, Linux, and macOS operating systems. Arduino IDE functions as a versatile code editor that allows users to write, compile, and upload code to microcontrollers such as the ESP32 [24].

The IDE supports programming in C and C++, and its open-source nature enables users to customise software features and develop additional modules to suit specific application requirements. It also supports a wide range of Arduino boards, including the Ethernet, Mega, Leonardo, and other commercially available models.

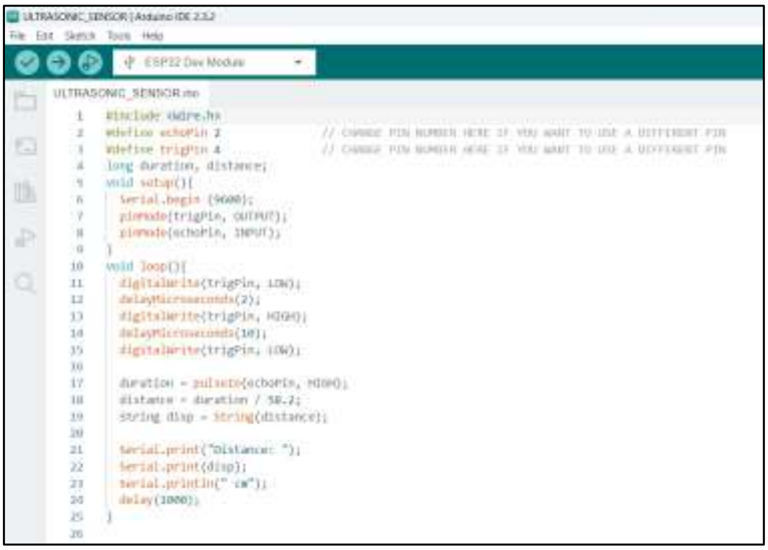

Figure 2: Development environment for Arduino-based programming

Figure 3 presents the programming flowchart for the IAR. For the communication module, the project utilises the Telegram messaging application, available on the Google Play Store. To configure the bot, users must search for "BotFather" within the Telegram application, initiate the setup by typing /start, and select the **New Bot** option. A unique name is then assigned to the bot, after which an access token is generated and displayed.

To obtain the user ID, users must search for **GetMyIDBot** in Telegram and click **Start**. Both the bot token and user ID are then inserted into the source code to enable the notification function. Additionally, the SSID and password of the mobile hotspot used for Wi-Fi connectivity must be included in the code to enable communication with the Telegram server.

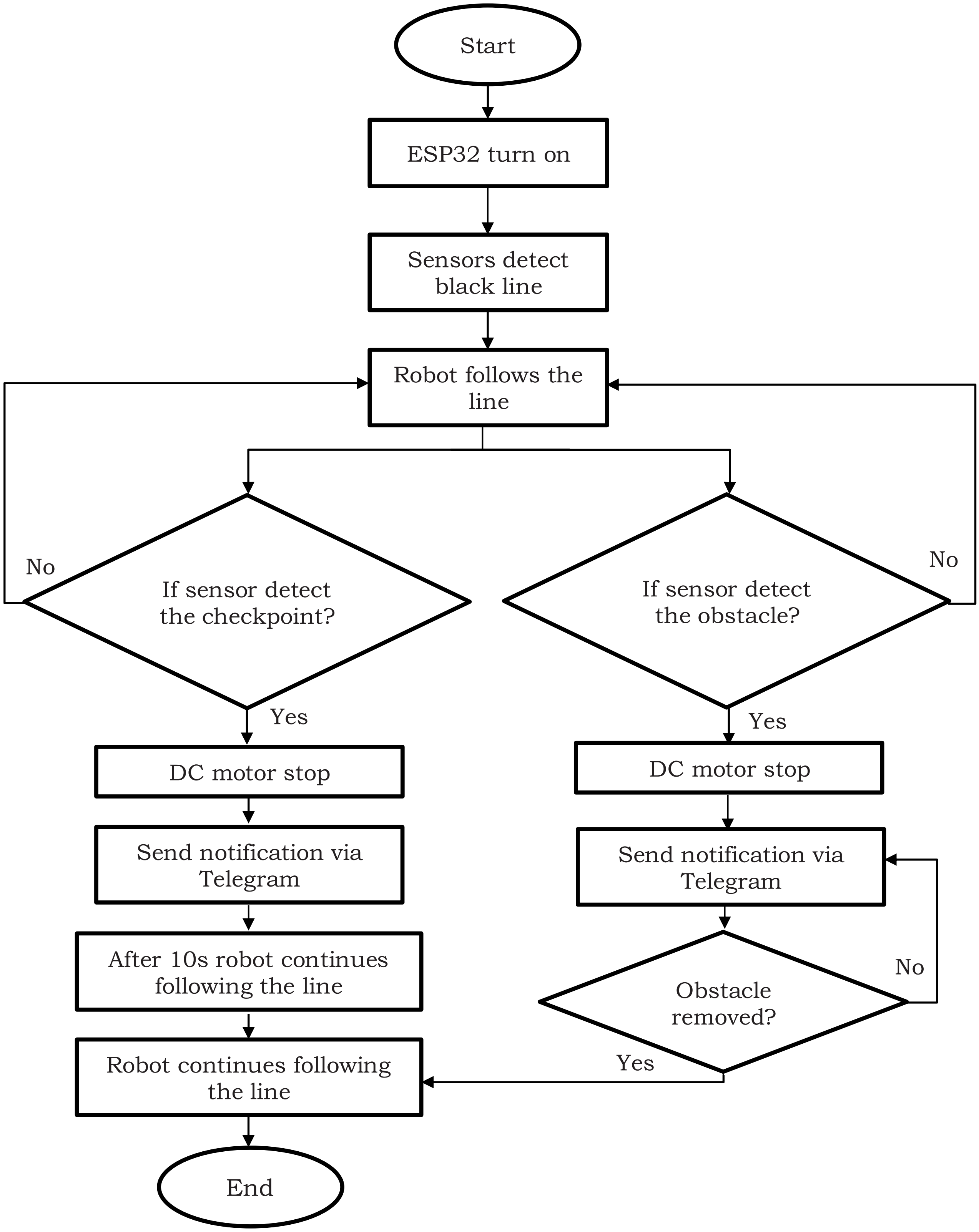

Figure 3: Programming flowchart for the IAR

2.3 Hardware Development

Figure 4 shows the schematic diagram of the IAR. Both MH infrared sensors are directly interfaced with the ESP32 microcontroller [25]. An ultrasonic sensor is employed for both obstacle detection and checkpoint recognition along the navigation path. The motor control system utilises Random Pulse-Width Modulation (RPWM) and Low-Power Pulse Width Modulation (LPWM) signals. For the left motor driver, RPWM and LPWM are connected to GPIO pins 12 and 13 of the ESP32, respectively. The right motor driver is connected to GPIO pins 25 and 26. The positive terminals of the 12V DC geared motors are connected to the M terminals of the motor drivers, while the negative terminals are connected to the M– outputs. The entire system is powered by 12V batteries, which supply the necessary voltage to the motors and the control circuitry.

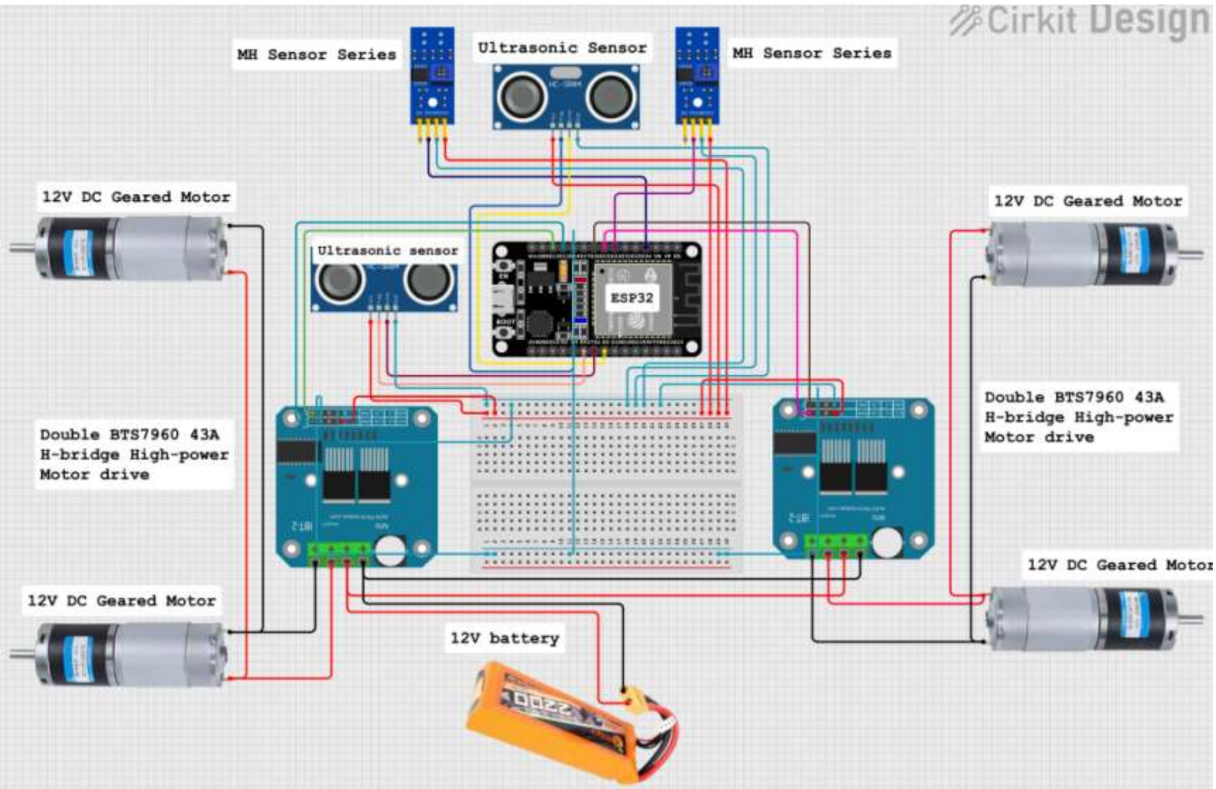

Figure 4: Schematic diagram of the IAR

Figure 5 shows the materials used to construct the casing of the IAR. The chassis is made from aluminium angle bars, plywood, and plastic cardboard. The overall dimensions of the robot are 19 inches in height and 16 inches in width. The 1/2" x 1/2" aluminium angle bar was selected for its strength and light weight, and rivets were used to assemble the frame. The robot consists of two main storage rows: the top row is designated for food delivery, while the bottom row is used to carry clothing, towels, or other essential items. Additionally, a side pocket is included to hold items such as bottled water, medications, and medical measuring devices. Figure 6 presents the side, front, and top views of the final IAR design.

Figure 5: Materials used to construct the IAR casing

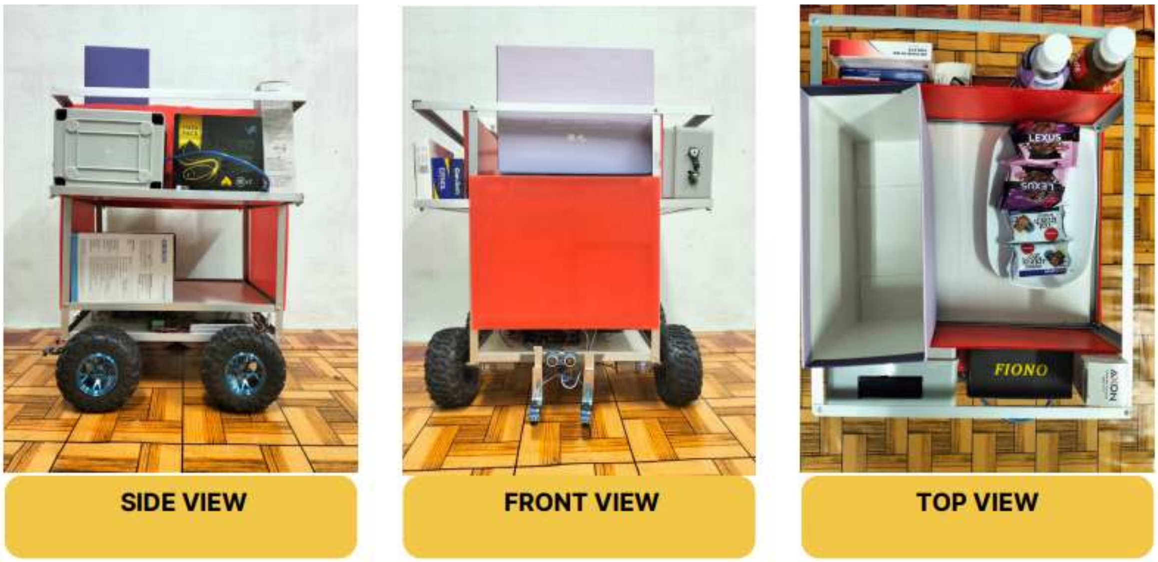

Figure 6: The side, front, and top views of the IAR

3.0 Results and Discussion

This section presents the performance evaluation of the IAR for elderly nursing care applications. The results are divided into functional validations through real-world testing, video monitoring capabilities, and a comparative performance analysis with existing robotic systems.

3.1 Functional Testing and Real-Time Notifications

Figures 7 and 8 illustrate the robot's ability to detect both obstacles and predefined checkpoints during its navigation. Upon detecting an obstacle or reaching a checkpoint, the robot autonomously halts and sends a real-time notification to the user via the Telegram messaging platform. This notification system enhances situational awareness, allowing caregivers to remotely monitor the robot's status and intervene if necessary. Such automation is particularly valuable in healthcare environments, where timely responses are critical.

Figure 7: Robot detecting an obstacle

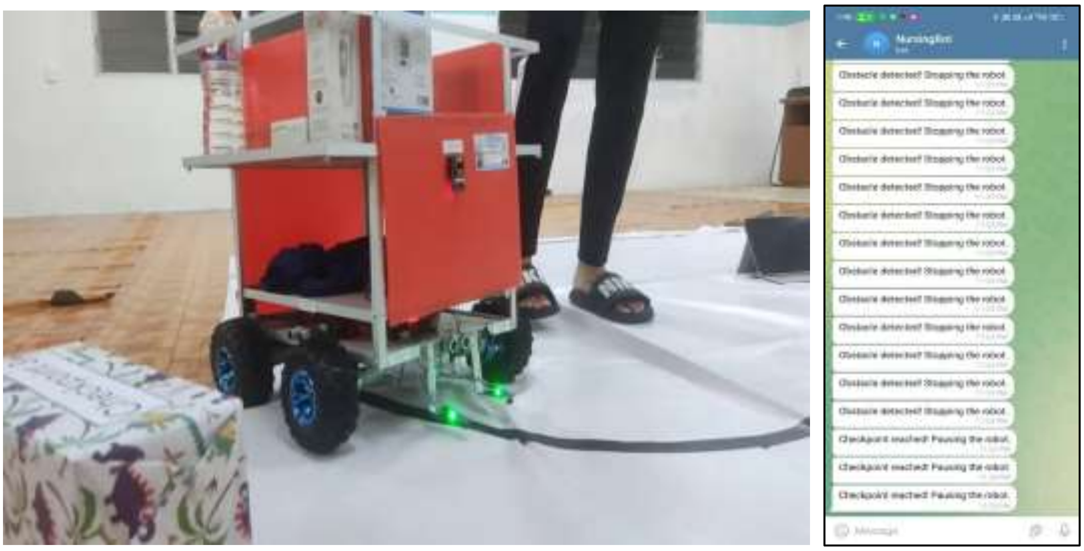

Figure 8: Robot detecting a checkpoint

To further improve monitoring, the system integrates a live video feed via the ESP32-CAM module, as shown in Figure 9. The ESP32-CAM is a compact and cost-effective camera module with built-in microcontroller functionality and a microSD card slot. This project provides visual feedback of the robot's surroundings in real time, enabling caregivers to observe the navigation environment and ensure operational safety. This feature enhances the IAR's usability in dynamic and unpredictable care settings.

Figure 9: Camera view from the ESP32-CAM module

3.2 Comparative Performance Analysis

A performance comparison was conducted between the proposed IAR and two existing robotic systems: the Food Delivery Robot [26] and the Infrared Sensor Line Follower [27]. Table 1 summarises the comparison across various parameters, including microcontroller capability, navigation mechanism, sensor configuration, motor drivers, and motor performance.

The IAR incorporates an ESP32 microcontroller, which offers higher processing speed and integrated Wi-Fi connectivity, providing a significant advantage over the Arduino Uno and Nano used in [26] and [27], respectively. In terms of navigation, the IAR combines line-following with ultrasonic obstacle detection, unlike the basic line-following approach used in [26] or the PID-controlled line-following in [27], which lacks environmental awareness.

The use of two BTS7960 43A H-bridge motor drivers ensures reliable power handling and higher current capacity, in contrast to the L298 drivers used in [26], [27]. Moreover, the IAR employs four 12V 20RPM DC geared motors, offering better torque and movement stability across different surfaces. These design improvements collectively contribute to the robot's superior adaptability and performance in healthcare environments. Overall, the comparative analysis highlights the technical advantages of the IAR, supporting its potential as an effective solution to enhance the quality of elderly patient care.

3.3 Implications and Market Potential

From a technological perspective, the proposed IAR demonstrates strong potential to enhance the quality, efficiency, and consistency of elderly care services. Its autonomous operation reduces the need for continuous human supervision, enabling reliable task execution while improving the workload on caregivers. Unlike human personnel, robotic systems are not subject to fatigue and can operate continuously with minimal performance degradation, making them well-suited for repetitive and time-sensitive tasks in healthcare environments [23].

Table 1: Comparative analysis between the proposed IAR and existing robot systems

Function and Specification	The proposed IAR for elderly nursing care applications	Food Delivery Robot [26]	Infrared Sensor Line Follower [27]
Microcontroller	ESP32 (Wi-Fi enabled)	Arduino Uno (basic)	Arduino Nano (compact)
Navigation	Use line-following with obstacle detection	Use basic line-following	Use PID-controlled line-following
Sensors	Use 2 infrared sensors (line tracking) and 2 ultrasonic sensors (obstacle detection)	Use 2 IR sensors to detect the line	Use photodiodes and LEDs for line detection
Motor Drivers	Use 2 BTS7960 43A H-bridge motor drivers (high current)	Use L298 motor driver (low power)	Use L298 motor driver (low power)
Motors	Use a 4 x 12V 20RPM DC geared motor, offering better torque	Use 4 DC geared motors, but without enhanced power management	2 DC motors provide less stability

To facilitate broader adoption and ensure long-term impact, future developments of the IAR should aim to incorporate advanced technologies such as artificial intelligence (AI)-driven path planning, energy-efficient hardware components, and sustainable manufacturing methods. These enhancements would further align the system with emerging technologies in smart healthcare and support compliance with environmental and industry standards.

The integration of BTS7960 high-current motor drivers and 12V geared motors provides superior torque and operational stability, particularly on variable surfaces commonly encountered in real-world settings. These hardware choices contribute to the robot's robustness and reliability, reinforcing its suitability for deployment in healthcare facilities.

In terms of commercial potential, the IAR is strategically positioned to address the rising demand for intelligent support systems, particularly in elderly care. Key factors driving this demand include a rapidly ageing population, rising healthcare costs, workforce shortages in the caregiving sector, and growing acceptance of automation and robotics in clinical settings. As these challenges continue to intensify, the IAR offers a timely and promising solution that can contribute to improving the accessibility, efficiency, and sustainability of elderly care services [22], [23].

4.0 Conclusion

This study presented the development of an IAR designed to support nursing care for the elderly through autonomous delivery of essential items such as food, water, and medication. The proposed system would enhance care efficiency by automating routine tasks, reducing caregiver workload, and enabling real-time monitoring, thereby improving safety and support for older adults in both residential and healthcare settings. The developed IAR demonstrates strong applicability and commercial potential in sectors including home-based healthcare, assisted living facilities, and medical service automation. Its implementation could contribute to reduced operational costs, improved care quality, and more sustainable healthcare delivery. Future enhancements may include the incorporation of Bluetooth functionality to enable remote control via mobile devices, as well as implementing a wireless charging system to facilitate autonomous recharging. These enhancements aim to increase the robot's autonomy, adaptability, and overall utility as an innovative solution to address the growing challenges in elderly care.

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Author Contributions

Bong Siaw Wee: Conceptualisation, Hardware and Software Design, Data Curation, Analysis, Validation, Writing – Original Draft;
Gilbert Clay Abeng: Initial Study, Methodology, Hardware and Software Design, Data Curation and Analysis;
Chen Wong Keong: Software, Writing – Review & Editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by any other journal. All authors have reviewed and approved the manuscript, consent to its submission, and declare that there are no conflicts of interest.

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