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Research Article

Design and Implementation of an Automated Shopping Companion for Elderly Support and Mobility Enhancement

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ABSTRACT

The proposed system utilizes facial recognition technology to detect and track the user, eliminating the need for physical effort in pushing a shopping cart. Additionally, the robotic trolley is equipped with an ultrasonic sensor that estimates the distance walked by the user, providing them with valuable information about their physical activity levels during the shopping trip. The implementation of this system leverages the OpenCV computer vision library within the Python programming framework, enabling the integration of the facial recognition and distance estimation capabilities. Evaluation of the developed prototype has demonstrated significant improvements in the quality of life and independence of elderly individuals, as they can now navigate the shopping environment with greater comfort and ease. This innovative robotic shopping companion represents a promising solution to enhance the shopping experience for the aging population, addressing their unique needs and empowering them to maintain their autonomy, well-being, and public health during their daily activities.

1. Introduction

According to Ng, people occasionally come up with new ideas to update or improve particular technologies because of how quickly technology is evolving [1]. Shopping trolleys are a technology commonly found in supermarkets, designed to simplify the shopping experience by aiding customers in selecting and storing products. In the traditional retail shopping paradigm, prior to moving forward to the checkout counter, customers must first choose the items they want to buy. Customers usually have to select a shopping cart or trolley when they enter a grocery store or mall, gather the desired items, and then place them inside the cart for transport to the point of sale. This conventional approach can pose significant challenges, particularly for senior citizens, who may struggle with the physical demands of manoeuvring heavy shopping carts and loading the items into them. The difficulties encountered by the aging population in conventional shopping scenarios have been well-documented. The physical strain associated with pushing and navigating steel shopping trolleys can be taxing, hindering the overall shopping experience and potentially discouraging elderly individuals from engaging in these routine activities. This issue underscores the need for innovative solutions that can address the unique requirements and limitations faced by senior customers in retail environments. To enable the robotic shopping companion to navigate and follow the user, a central control system, akin to a "brain," must be developed. This brain will orchestrate the movement and coordination of the various components selected by the engineer or designer. The brain will issue commands to the respective subsystems in a specific sequence, and crucially, it will also have the ability to dynamically adjust this sequence as needed, based on the prevailing conditions and requirements. The functionality of this brain is underpinned by the algorithmic software, which serves as the language of communication between the human user and the automated trolley system. This software-driven algorithm is responsible for integrating the individual components, interpreting the user's actions and intentions, and translating them into the appropriate

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control signals to drive the robotic trolley's movements and behaviors. As elucidated by Li [2], the seamless integration of the hardware components and the sophisticated software algorithms is essential for realizing the desired functionality of the autonomous shopping companion. This cohesive brain-and-software approach ensures that the robotic trolley can effectively perceive, interpret, and respond to the user's needs, thereby providing a smooth and assistive shopping experience [2]. The central control system, or "brain," of the robotic shopping companion is responsible for continuously processing the data inputs received from the various sensors integrated into the system. As highlighted by Sanghavi, the use of ultrasonic sensors is particularly well-suited for object detection, as they can provide accurate distance measurements and facilitate the identification of obstacles or potential hazards in the user's immediate environment. The brain's algorithm will be tasked with interpreting the sensor data, particularly from the ultrasonic sensors, and using this information to guide the movement and decision-making of the robotic trolley. By constantly monitoring the surroundings through the sensor inputs, the brain can make informed adjustments to the trolley's trajectory, speed, and overall behavior, ensuring a seamless and safe navigation experience for the user [3]. The real-time processing of sensor data and the brain's capacity to dynamically adapt the robotic trolley's actions are integral components of the system's architectural design. This synergistic approach empowers the autonomous shopping companion to navigate the retail environment in a responsive and effective manner, while simultaneously prioritizing the user's safety and comfort throughout the shopping excursion. By continuously interpreting the sensor inputs, particularly from the strategically placed ultrasonic sensors, the brain's control algorithm can make informed adjustments to the trolley's trajectory, speed, and overall behavior. This ability to dynamically adapt the system's actions based on the prevailing environmental conditions and user requirements is a critical feature that underpins the robotic trolley's seamless and responsive operation. The seamless integration of sensor data processing and adaptive decision-making within the brain's control algorithms enables the autonomous shopping companion to effectively negotiate the complexities of the retail setting. This cohesive approach ensures that the user can engage in their shopping activities with a heightened sense of safety and comfort, as the robotic trolley anticipates and responds to the evolving needs and conditions encountered during the shopping excursion [3]. The utilization of infrared sensors in the robotic shopping companion's design has been highlighted as an efficient approach for people detection, particularly in low-light or nighttime conditions. As analyzed by Nagarajan, the underlying principle of infrared sensing relies on the temperature mapping technique, which allows the system to effectively identify and track the presence of individuals within its operational environment. Infrared sensors operate by detecting the thermal signatures emitted by objects and living beings, enabling them to distinguish between human bodies and the surrounding inanimate elements. This capability is especially valuable in retail settings, where the robotic trolley needs to be aware of the user's location and movements, regardless of the ambient lighting conditions. By incorporating infrared sensors into the overall sensor suite, the autonomous shopping companion can maintain robust people detection capabilities throughout the day and night. This enhanced sensing modality, coupled with the brain's real-time processing of the sensor data, ensures that the robotic trolley can consistently track and respond to the user's presence and actions, thereby providing a seamless and adaptable shopping experience. The integration of infrared-based people detection, as highlighted by Nagarajan's analysis, represents a strategic design choice that enhances the overall reliability and versatility of the autonomous shopping companion system. This multi-sensor approach equips the robotic trolley with the necessary sensory awareness to navigate the retail environment effectively, while prioritizing the user's safety and comfort at all times [4]. In addition to the utilization of ultrasonic sensors for object detection, as discussed earlier, the incorporation of proximity sensors within the robotic shopping companion's sensor suite offers a highly efficient alternative approach. As elaborated by Lee, proximity sensors possess inherent advantages that make them a suitable choice for accident or collision prevention. The proximity sensors' ability to accurately measure the distance to nearby objects, coupled with their enhanced efficiency compared to ultrasonic sensors, empowers the autonomous shopping companion to maintain a heightened awareness of its immediate surroundings. This enhanced sensing capability enables the robotic trolley to anticipate and respond to potential hazards or obstacles in a timely and proactive manner, thereby minimizing the risk of collisions or accidents during the shopping excursion. The strategic deployment of proximity sensors, alongside the ultrasonic sensors, provides the central control system or "brain" with a comprehensive and redundant set of sensory inputs. This multi-modal sensing approach allows the brain's algorithms to cross-reference and corroborate the environmental data, ensuring a robust and reliable detection of potential obstacles or safety concerns. By leveraging the higher efficiency of proximity sensors, as highlighted by Lee's analysis, the autonomous shopping companion can enhance its collision avoidance capabilities, further prioritizing the user's safety and comfort throughout the shopping experience. This strategic integration of sensor technologies represents a well-considered design choice that contributes to the overall effectiveness and reliability of the robotic trolley system [5], [6], [7]. To enable the autonomous mobility of the robotic shopping companion, the integration of a motor system is a fundamental requirement. This motor system will receive directional signals from the central control system, or "brain," which is typically a microcontroller, to facilitate the movement of the trolley. To achieve the desired range of motion, including forward, backward, right, and left movements, the implementation of motor controllers is necessary. These motor controllers serve as the intermediary between the brain's commands and the physical actuation of the motors, translating the electronic signals into the appropriate motor movements. The specific selection of motor types, whether DC motors or servo motors, will depend on factors such as the required speed of the robotic trolley, as well as the intended operating environment and the overall design considerations. The number of motors employed can also vary, as multiple motors may be utilized to provide a more precise and responsive control over the trolley's movements. The emergence of smart assistive trolleys represents an innovative approach to enhancing the shopping experience for diverse user groups. Recent research and development efforts have yielded specialized solutions tailored to the needs of specific demographics. For the elderly population, [8] have developed robotic trolleys that leverage face detection technology to follow users throughout the retail environment, while also tracking their walking distance to provide personalized assistance. These trolleys offer a heightened level of support and independence for elderly shoppers navigating the retail space. Similarly, authors in [9] have introduced AI-powered trolleys equipped with RFID technology, optical character recognition, and audio feedback systems to cater to the needs of visually impaired individuals. These smart trolleys enable visually impaired shoppers to navigate the retail setting, access product information, and complete their shopping tasks with increased autonomy and confidence. Furthermore, authors in [10] have explored the integration of smartphone sensors and microcontrollers to facilitate autonomous movement and indoor positioning for smart trolleys. This approach leverages the ubiquity of smartphones and the capabilities of microcontrollers to provide seamless navigation and location tracking, enhancing the overall shopping experience. Recognizing the potential for streamlining the shopping and billing process, authors of [11] have designed IoT-based smart trolleys that incorporate RFID readers, Wi-Fi modules, and integrated databases. These advancements enable seamless transactions, seamless product identification, and efficient inventory management, benefiting both customers and businesses. The collective advancements in smart trolley technology, as evidenced by these studies, aim to improve accessibility, convenience, and efficiency for diverse groups of shoppers. These innovative solutions have the potential to revolutionize the retail experience, catering to the unique needs and preferences of various customer segments and contributing to a more inclusive and efficient shopping landscape. The paper [12] proposes a Smart Mobile Autonomous Robotic Trolley (SMART) to address the inefficiencies associated with traditional shopping experiences. The increasing popularity of shopping malls has led to congestion, particularly during peak hours, characterized by lengthy queues at checkout counters. The manual process of scanning barcodes and calculating totals is time-consuming for both customers and cashiers. The SMART system aims to expedite the shopping process by automating product detection, billing, and trolley navigation. It incorporates RFID technology for product identification, wireless communication via ZigBee for data transfer, and a microcontroller for system control. The trolley's autonomous capabilities include obstacle avoidance and user-guided movement. The paper details the system's architecture, hardware components, software algorithms, and implementation. Ultimately, the SMART trolley is designed to enhance the overall shopping experience through reduced wait times, streamlined checkout, and improved efficiency [13]. The cohesive integration of the motor system, motor controllers, and the central control architecture is a fundamental design consideration for the robotic shopping companion. This holistic approach ensures the trolley's seamless autonomous navigation within the retail environment, enabling it to respond effectively to the control brain's commands and the sensory inputs. This synergistic integration is essential to giving the user a seamless and effective shopping experience. Prior to the microcontroller issuing any directional commands to the motors, it must first establish the location of the individual the trolley is intended to follow. This critical step is achieved through the incorporation of a camera system within the trolley design. The camera can be utilized to track the user based on their distinctive features, or alternatively, it can follow an object the user is holding, effectively establishing the user's position.

Additionally, the integration of a transceiver system can further enhance the trolley's ability to locate and track the user. The transceiver can facilitate bidirectional communication, allowing the control brain to receive signals from a device carried by the user, thereby enabling precise tracking and positioning of the individual within the retail environment [14]. By seamlessly integrating the motor system, motor controllers, and the central control brain, in conjunction with advanced sensing technologies such as cameras and transceivers, the robotic shopping companion can navigate the retail space autonomously [7]. This holistic approach ensures that the trolley can reliably follow the user, respond to their movements, and provide a smooth and efficient shopping experience, catering to the user's needs and preferences throughout their retail journey. The design and development of the smart trolley project has been inspired by the effective utilization of advanced control strategies employed in wind turbine systems [15]. These control mechanisms, which have demonstrated their efficacy in enhancing power extraction efficiency, are now being explored for their potential to optimize the autonomous navigation and operational capabilities of the smart trolley. Specifically, the implementation of Neurofuzzy algorithms and modified PI-Neurofuzzy controllers is being investigated as a means to adaptively manage the smart trolley's movements and interactions with users [16]. By leveraging similar adaptive control methodologies, the smart trolley can dynamically adjust its behavior to ensure seamless and efficient assistance in various scenarios, catering to the diverse needs and preferences of the individuals it serves. This cross-application of control techniques from the renewable energy domain to the realm of intelligent assistive devices underscores a shared emphasis on maximizing performance and functionality. The strategic incorporation of these advanced control strategies, proven effective in wind turbine systems, aims to imbue the smart trolley with the agility and responsiveness required to provide a superior shopping experience for users. The parallels drawn between the control challenges faced in wind turbine systems and the smart trolley project highlight the potential for cross-pollination of innovative solutions across different domains. This interdisciplinary approach to design and development not only leverages the lessons learned from related fields but also holds the promise of unlocking new frontiers in the realm of autonomous mobile robotic systems and their integration within the retail environment.

2. Methodology and Experimental Setup

The project's methodology is explained in this chapter, along with the mathematical techniques and correlations pertaining to the smart follower trolley and the component selection, which are shown in Fig.1.

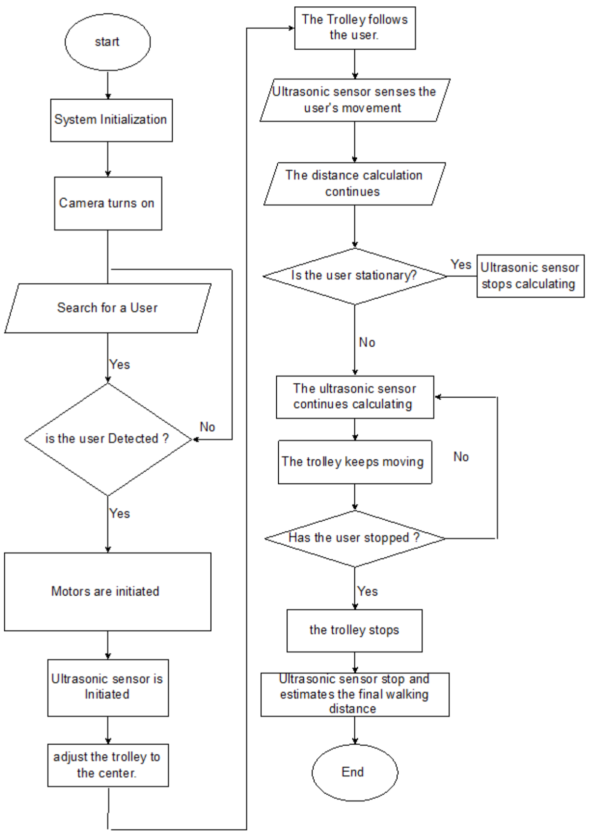

Fig.1 Project flow chart

The proposed robotic shopping trolley system primarily leverages visual user detection and ultrasonic distance measurement as its core sensing modalities. The flowchart of the system is projected in Fig. 1. This integrated approach allows the system to first identify the presence of a user and then continuously calculate the distance between the trolley and the user. Once a stationary user is detected, the trolley initiates movement and dynamically adjusts its position to maintain a centered alignment with the user. This user-following behavior represents a fundamental framework for the trolley's operation, enabling it to provide a seamless and responsive accompaniment to the user during the shopping experience. However, for practical implementation and deployment, further enhancements to the system would be necessary. These may include the incorporation of obstacle avoidance mechanisms, the development of environmental mapping capabilities, and the implementation of robust error handling protocols. Such advancements would enhance the trolley's situational awareness, navigation proficiency, and overall reliability, ensuring a more comprehensive and dependable shopping assistant for the end-user. The reliance on visual detection and ultrasonic distance measurement underscores the system's emphasis on leveraging established sensor technologies to enable user-centric functionality. This design approach reflects a pragmatic and evidence-based approach to system development, drawing upon well-understood principles and techniques to create a functional and adaptable robotic shopping companion. Overall, the proposed system represents a foundational framework for user-following trolley behavior, which can be further refined and expanded upon to address the evolving needs and requirements of modern retail environments and customer expectations.

The main system core, or brain, of this project is a Raspberry Pi 4 model B. The motors are controlled by an Arduino UNO and a permanent magnet DC motor. The Raspberry Pi 4 model B and Arduino UNO are linked via USB to serve as a communication interface. Three types of sensors are used: an infrared sensor for user detection, an ultrasonic sensor for obstacle avoidance and detection, and a camera fixed on the trolley.

2.1. *Hardware the trolley*

Raspberry pi 4 Model B

The Raspberry Pi 4 Model B is the most recent model in the Raspberry Pi computer line. It maintains power consumption and backward compatibility while providing revolutionary improvements in multimedia performance, processor speed, memory, and connectivity over the previous generation's Raspberry Pi 3 Model B+. The desktop performance of the Raspberry Pi 4 Model B is comparable to that of entry-level x86 PCs for the end user, as indicated by Raspberry Pi [6].

Its powerful 64-bit quad-core processor allows for dual displays to be supported at up to 4K (Kilo) resolution via the micro-HDMI (High Definition Multimedia Interface) ports, and modular compliance certification for Bluetooth and dual-band wireless LAN (Local Area Network), this fourth-generation Raspberry Pi model is selected to serve as the project's primary system core, or the brain of the robot. This shortens the time to market and reduces cost. Also, the raspberry pi 4 model B features better connectivity than other Raspberry Pi computer types, with 2.4 GHz and 5.0 GHz bands, and a higher memory option (2/4/8GB RAM). Its two USB 3.0 ports and two USB 2.0 ports allow for extremely fast data transfer. Forty GPIO pins are present.

Arduino UNO

A microcontroller board based on the ATmega328P is called the Arduino UNO. It features six analogue inputs, a reset button, a USB port, a power jack, a ceramic resonator operating at 16 MHz, and an ICSP (In Circuit Serial Programming) header. Its fourteen digital input/output pins have six PWM output pins available for use. All the components required to operate the microcontroller are present; all you have to do is supply power through a battery, an AC-to-DC converter, or a USB cable to connect it to a computer. You don't have to worry too much about making mistakes when experimenting with your UNO, as demonstrated by the Arduino memory guide [7].

Using an Arduino UNO to control PMDC motors is very effective because of its simplicity, which makes it easy to work with low-power components and efficiently handle real-time projects. Changing the speed of a DC motor is also relatively easy with an Arduino UNO. There are several advantages to using an Arduino UNO for PMDC motor control. When PWM is applied to an Arduino's analogue output pin, a DC motor's speed can vary. For this reason, it's an easy task. In contrast to the Raspberry Pi 4 Model B, it functions well with high power-consuming components. For example, it can operate with a PMDC motor, though not as well as the Arduino UNO, as the DC motor speed explains [8].

High-precision ultrasonic sensor range finder

The raspberry pi 4 model B (brain) will be directly connected to three ultrasonic sensors, each of which will be used for obstacle avoidance. The ultrasonic sensor ESP32 was selected because it offers Bluetooth Low Energy (BLE) and performs better than the ultrasonic sensor ESP8266.

PMDC motor

Because of its high torque and low power consumption, a PMDC motor is selected for this project. The type of PMDC motor is selected based on its torque speed; this decision is made after the trolley is selected and the ideal size is determined in order to realize this concept.

43A H-Bridge driver

Any motor would only be able to move in one direction if it were left to operate on its own, which is forward. Nevertheless, in order to control the direction and speed of the motor we use—in this case, a PMDC motor—it requires a driver. The driver receives instructions from the main system core (a Raspberry Pi 4) about what direction and at what speed to move the motor in response to logic added to the core.

LM2596 3A Buck module with display

A converter is required because prototyping requires it. Various components were selected for this project, and each requires a certain voltage. The converter's function is to reduce the voltage so as not to damage the components.

2.2. *Software*

The most significant library used in this project is OpenCV, a Python package that offers image processing capabilities that were selected for use in the software portion of the project for user detection. Processing a video entails carrying out actions on it frame by frame. A frame is just one distinct instance of the video at one particular moment in time. Several frames could even occur in a single second. Frames can be handled in the same way as an image. As a result, we can do anything on frames that we can do on images, as precisely described by [9].

3. Results and Discussion

3.1. *Software Results*

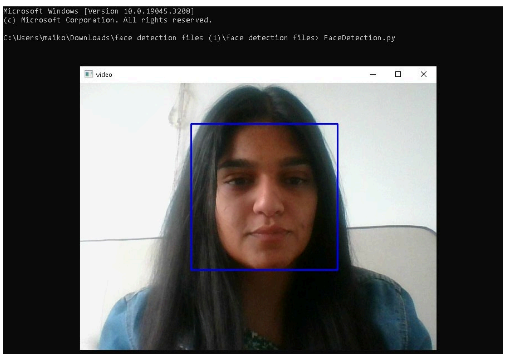

Fig. 2 Face Detection

One of the project's objectives is to perform real-time face detection. To do this, the numpy and OpenCV libraries were added to the code, and then an XML file containing all the necessary information was added. This allowed the camera to recognize the person in front of it, and after that, a 640 x 480 cm video with the sole purpose of continuing to capture images was started. A while loop was then created to continue taking photos continuously. For a higher-quality formation, the pictures (frames) will be converted to grayscale inside the while loop. The system will then wait for the person using the trolley to press the "ESC" button to end their shopping expedition, marking every face that has been detected in each frame with a blue box that will continue to appear even if people move around in the area captured by the camera. When this button is pressed, all data is erased and the system is prepared for the next user. The outcome of the facial recognition process is shown in Fig, 2.

3.2. *Hardware Results*

The Raspberry Pi 4 model B has the ability to connect to the internet without the need for an Ethernet cable, allowing it to be used as a remote control device for Raspberry Pi desktops of any kind. The brain requires a power source, in this case, the laptop, in order to perform its function of controlling all other components. Once the connection is established, the VNC viewer is used to set up the Raspberry Pi (or any kind) desktop remotely from another computer. A USB C-type cable is used to activate the brain itself. The Raspberry Pi used in this project has a wireless internet connection.

When connecting the Arduino UNO to the Raspberry Pi, a USB B type cable is used. This connection is made solely for powering the device and enables the Arduino UNO to receive commands from the Raspberry Pi. When connecting the Arduino UNO to the PMDC motor, a converter is primarily needed because the motor operates at 250 watts and must be stepped down. The motors are made to only move in one direction when they are operating; a motor driver is needed to make the motor move in all directions. The motor driver is connected to the PMDC motor through positive and negative terminals, and the step-down converter is connected in the same manner. The connections are made as follows: first, the Arduino UNO is connected to the motor driver's ENA pins and IN1. The power supply will be connected to this converter. Additionally, on the used breadboard, every component is connected to the same ground.

In order to accomplish the second goal, the ultrasonic sensor must first be mounted in front of the trolley so that it can detect a person and determine how far they have to walk. This requires four main wires: one from the ultrasonic sensor's VCC to the positive railway, one from the ground wire to the negative railway on the breadboard, and one from the ultrasonic sensor to the positive railway. Regarding the Raspberry Pi, pin number two, or GPIO pin 5 volts, is connected to the breadboard's positive railway, and pin number six is connected to the negative railway, which is where the ultrasonic sensor is plugged in. Next, attaching the ultrasonic sensor's trig connection to GPIO 23 (pin number 16) via a breadboard blank rail, and lastly attaching the ultrasonic sensor's ECHO to GPIO 24 (pin number 18) via a breadboard blank rail. Fig. 3 shows the primary fabrication of the proposed smart trolley.

Fig.3 Automated Trolley

3.3. *Testing*

For testing purposes, the trolley has been showcased in three distinct positions labeled as "Position 1," "Position 2," and "Position 3” as shown in Fig, 4.

Fig.4 Positional Analysis of Motor A

Fig. 4 presents the sequential movement of a modified shopping trolley driven by Motor A. The three positions captured in the image demonstrate the forward motion of the trolley, executed under controlled conditions as part of the project's testing phase. The modifications made to the trolley, such as the added electronics and components, are integral to its functionality and the specific objectives of the movement testing.

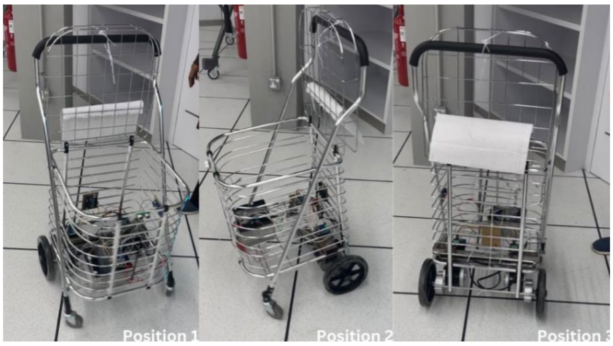

Fig.5 Positional Analysis of Motor B

Fig. 5 depicts the sequential forward motion of a modified shopping trolley driven by Motor B. These results show the satisfactory level of movement of the trolley.

Supported Sustainable Development Goals

Over fifteen years, from 2015 to 2030, the Sustainable Development Goals ("SDGs") are meant to guide international development efforts. As part of its development agenda, the United Nations General Assembly (UNGA) is scheduled to endorse them in 2015. The 2000–2015 Millennium Development Goals (also known as the "MDGs") have been replaced. Sustainable development refers to improving the world without destroying opportunities for future generations while keeping in mind the three pillars of development: social progress, economic development, and environmental and climatic conditions. The smart follower trolley for elderly care project supports as explained by Pogge [10]. The design and implementation of an automated shopping companion directly correlates with SDG 3, Good Health and Well-being. By providing elderly individuals with a supportive and mobility-enhancing tool, this project contributes to improving their overall health and quality of life. The device can help prevent falls and injuries by assisting with carrying heavy loads, reducing physical strain, and enhancing balance. Furthermore, by facilitating independent shopping, it promotes mental well-being and social interaction, crucial factors in maintaining good health in later life. Ultimately, this technology empowers elderly individuals to live healthier, more independent lives, aligning with the broader goal of SDG 3.

4. Conclusion

The development and implementation of an automated shopping companion, as embodied in the smart assistive trolley, represents a significant stride in the field of assistive technology for the elderly. By integrating innovative features such as face detection and walking distance estimation, the system effectively addresses the multifaceted challenges associated with aging, including mobility limitations and safety concerns. The trolley's capacity to enhance autonomy, comfort, and overall well-being underscores its potential as a transformative tool in improving the quality of life for seniors. While this research demonstrates promising outcomes, future investigations should explore opportunities to expand the trolley's functionalities through advanced navigation, product recognition, and integration with healthcare platforms. Such developments could lead to a more comprehensive and personalized elderly care solution, ultimately contributing to healthier, more independent aging.

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He completed his B.Eng studies in Electronics and Communication Engineering and pursued studies in Electronics and Control Engineering in India. He later received a Diploma in Drives and Controls from Woo Sun in Korea in 2014. His academic journey culminated in a Ph.D. program in the United States in Robotics, Power Electronics, and Controls. He is acknowledged as a Professional Engineer (PEng) in the USA and holds the designation of a Chartered Engineer (CEng) in the UK. Moreover, he is a Senior member of the IEEE in the USA and a member of MIET in the UK.

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