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Autonomous Mobile Trolley Robot: Int-Cart

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ABSTRACT

Int-Cart is an autonomous shopping cart designed to provide a convenient and centralized location for consumers to engage in shopping activity. The cart addresses common shopping challenges, including difficulty in finding desired items and limited cart maneuverability. It features dual-mode configurations—following and navigation modes—and is equipped with a LiDAR sensor and RealSense camera for store mapping and obstacle detection. A display monitor allows users to select their preferred cart mode and view the price of selected items. Int-Cart aims to promote inclusive engagement for the elderly, parents with tots, and people with disabilities, aligning with the growing consumer demand for eco-friendly and responsible industry practices. The project is expected to benefit disabled individuals, parents with young children, and elderly shoppers in shopping malls and retail environments.

Keywords: *Autonomous; navigation; trolley; obstacle; shopping malls*

1. Introduction

Shopping malls play a crucial role in modern society, serving as important commercial and social hubs. It is a large, enclosed building or a cluster of buildings that houses multiple retail stores, restaurants, entertainment venues, and other commercial establishments. It is designed to provide a convenient and centralized location for consumers to engage in shopping, dining, and entertainment activities. An autonomous shopping cart with dual-mode configuration which follows, and navigation mode integrated with a LiDAR sensor and RealSense camera that allow store mapping and obstacle detection. Furthermore, the shopping cart is also equipped with a display monitor. This advanced technology not only allows users to select their preferred cart mode but also projects the price of items selected for purchase.

1.1 Literature Review
1.1.1 Autonomous navigation and customer tracking

The concept of autonomous shopping carts aims to reduce the physical strain of shopping, particularly for individuals who may have difficulty pushing a trolley. Bello-Salau *et al.,* [1]. developed

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an autonomous shopping trolley that employs a camera and Raspberry Pi for image processing. This technology enables the trolley to follow customers by tracking them using pre-saved color frames and position data. The system includes a billing module, using RFID tags to automatically bill items, and a database for transaction updates [1]. Similarly, Praveen *et al.,* [2] created a voice-controlled trolley that uses RFID for tracking items and handling billing. This design enables customers to specify their desired store section through voice commands, allowing the trolley to navigate there on its own, which improves convenience and accessibility for users.

1.1.2 Billing automation and inventory management

Several systems utilize RFID technology to make billing processes more efficient. The smart trolley developed by Al-Hakmani *et al.,* [3] combines an RFID reader with an LCD display to provide real-time information on item details and total costs. This system also allows customers to set a budget and send alerts when they exceed their specified spending limit [3]. In a similar vein, the Intelligent Shopping Trolley (IST) developed by Low *et al.,* [4] employs RFID for billing and incorporates IoT capabilities, enabling real-time updates and tracking of bills. This solution not only streamlines the billing process but also includes a positioning system and social distancing features, helping to manage safety during the pandemic in retail environments.

1.1.3 Smart cart navigation and positioning system

To assist customers in finding items, smart trolleys have been fitted with positioning systems. Low *et al.,* [4] Intelligent Shopping Trolley utilizes a Wi-Fi-based indoor positioning system to track the trolley's location in real time. This system not only helps customers navigate large stores but also allows store staff to effectively manage customer flow, which is especially beneficial for maintaining social distancing during the pandemic. In contrast, Praveen *et al.,* [2] design employs a pre-programmed store layout and motorized navigation directed by voice commands, reducing the need for manual trolley handling.

1.1.4 Technological limitations and future directions

Despite notable advancements, some designs encounter practical challenges. RFID-based systems, although effective for billing, can experience interference issues that may affect their range and accuracy in busy retail settings. Additionally, positioning systems that rely on Wi-Fi require a dense network of access points for precise indoor tracking, which can be expensive and complicated to maintain. Future developments could investigate the use of machine learning algorithms for object detection to enhance navigation accuracy and lessen reliance on the line-following or color-based tracking methods.

2. Methodology

Before doing the real prototype, the idea has been expressed by doing the 3D design in AutoCAD software. The 3D designation using AutoCAD has clearly visualized the final product, offering an in-depth view of how the components will fit together and how the completed prototype will appear and operate. It leads to validating the design concept and uncovering potential issues before physical production begins. This early validation helps avoid costly errors and modifications during the prototyping phase.

Figure 1 shows another critical function is design iteration and refinement. In a 3D modelling environment, it's easy to adjust and explore different design options without the need to rebuild physical prototypes. For instance, if the base of your design is constructed using an aluminium profile, 3D modelling can help the team to fine-tune the connection points and ensure that the structure is both sturdy and aesthetically pleasing. By creating a detailed 3D model, the team can define exact measurements, tolerances, and alignments, ensuring that all parts will fit together perfectly during assembly. This is particularly important when combining different manufacturing methods, such as using an aluminium profile for the base and 3D printing for the tablet holder. Accurate modelling helps prevent issues such as misalignment or poor fit, which could compromise the final product's performance or appearance.

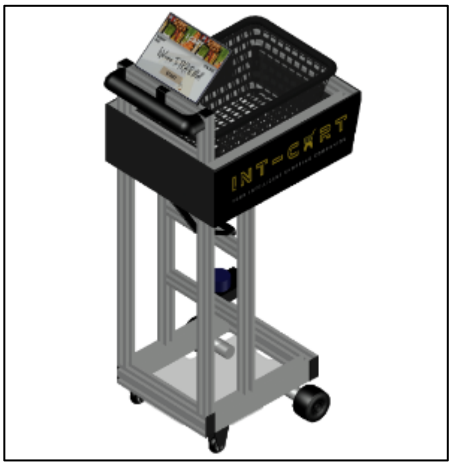

Fig. 1. 3D model of int-cart

2.1 3D Printing Design

Figure 2, Figure 3 and Figure 4 showed the 3D design that attached to the trolley to fit the monitor display to show the Graphical User Interface (GUI) and the camera holder to fit the camera for the following person system. The monitor display is designed to exactly fit 10-inch display, and the hole is made at the side so that the wires that will be used to power the display can be fitted. The display was cut in half because the 3D printer cannot fit the whole size of the design. The bottom part will be attached to the 20x20 mm aluminium profile. The top part is designed with a screw hole to connect the display with the camera holder that is also designed with screw hole. Both the front part and back part of the camera holder is equipped with hole for camera lens and camera wire respectively.

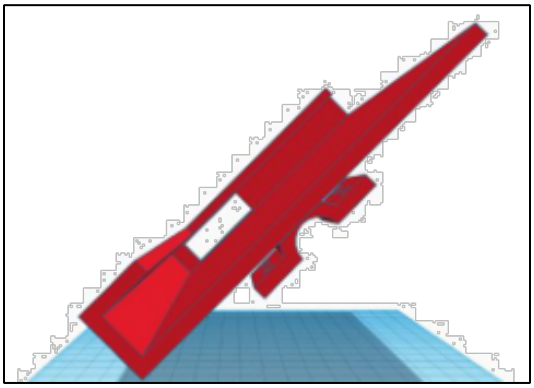

Fig. 2. Side view of tablet holder

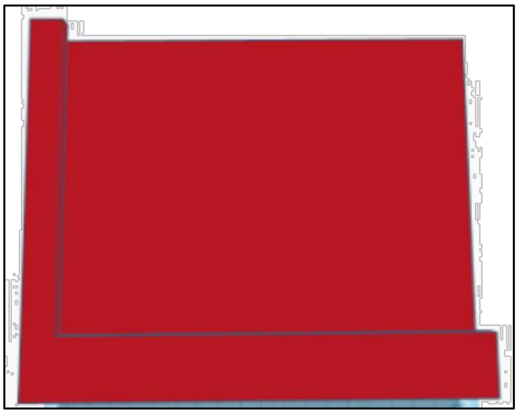

Fig. 3. Front view of tablet holder

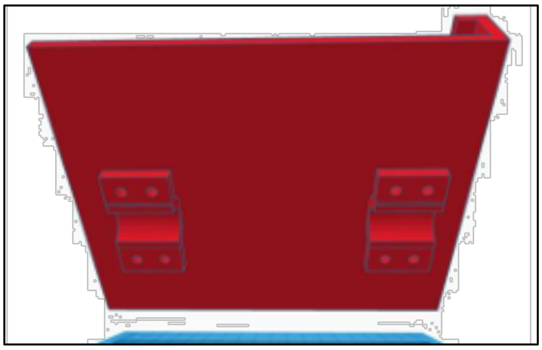

Fig. 4. Back view of tablet holder

2.2 Circuit Diagram

Below are the functionalities of each component, as illustrated in Figure 5:

i. Intel® NUC 10 Performance kit - NUC10i3FNK: Acts as the central controller that manages the operations of the trolley navigation system. It sends commands to the trolley and navigate the trolley to the desired items.
ii. Lithium Iron Phosphate (LiFePo4) Battery 12V: Four units are used, totalling 48V, to support and power the entire prototype.
iii. Brushless DC (BLDC) Motor Controller: Two units of motor controller are used to control the right and left motorized wheels. Both motor controller will be attached to Adafruit PWM / Servo Driver. By attaching both motor controllers to the same driver, you can synchronize their movements more easily, which is critical for tasks requiring coordinated motion, like driving a pair of wheels on a robot [5].
iv. DC/DC Converter: A unit of DC/DC Converter acts as boost converter for the circuit. The converter will step up 12V battery to different voltage values; 19V and 36V [6].
v. Inter-Integrated Circuit (I2C) Extension Board: I2C extension board known as a board that enables a larger network of sensors, displays, and other I2C peripherals to operate simultaneously.
vi. Adafruit 16-Channel 12-bit PWM/Servo Driver (PCA9685): The Adafruit PWM (Pulse Width Modulation) module allows for fine-tuned control over the speed and position of motors. By generating precise PWM signals, it can control the motor's speed and direction accurately, which is crucial in applications like auto-navigation trolleys that require smooth and reliable movement [7].

vii. Inter-Integrated Circuit (I2C) Module: Allows for simple and efficient communication between the NUC and the PWM module. I2C uses only two wires (SDA and SCL) to communicate with multiple devices on the same bus, reducing the complexity of wiring [8].
viii. Encoders: Encoders will measure the speed and direction of rotation or movement. This data is used in feedback loops to control the speed of motors and other moving parts, ensuring smooth and accurate operation
ix. Emergency Stop Button (E-Stop): When activated, the emergency stops button cuts off power that connected to motor driver causing it to immediately cease all DC motor operations. This prevents accidents and reduces the risk of injury or damage.
x. Splitter: Acts a voltage or power distribution to other components.
xi. Depth Camera: Acts as human tracking and being used to identify and follow the users at the airport.
xii. 10-Inch Display Monitor: Display the Graphical User Interface (GUI) that consists of following and returning mode.
xiii. Motorized Wheels: Equipped with sensors, such as encoders, that provide feedback on the wheel's position, speed, and rotation. This feedback is used in control systems to ensure precise movement and to correct any deviations from the desired path [9].
xiv. Switch: Used to control the flow of electricity for the entire of prototype.
xv. Light Detection and Ranging (LiDAR): Used for obstacles avoidance detection and do the 3D mapping for the trolley navigation system [10].

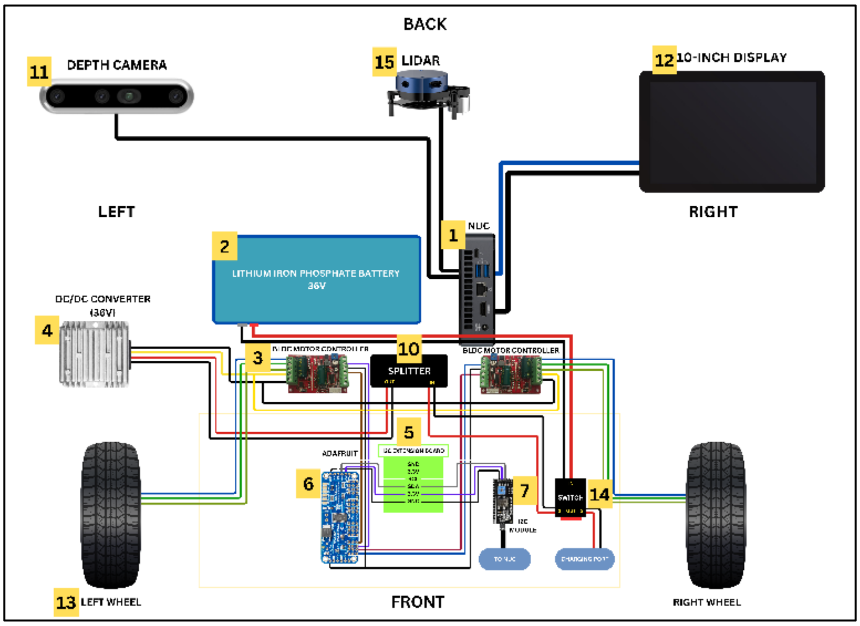

Fig. 5. Circuit diagram of the system

2.3 Application of Engineering Principles

Applying engineering principles to an autonomous trolley involves integrating various concepts and methodologies from engineering disciplines to design, develop, and optimize the system. Mechanical engineering principles are used to design the structural components such as motorized wheel, sensors and mounting brackets and covers. Factors like material strength, load-bearing capacity, and durability are considered to ensure that the trolley can support its intended load and operate reliably in various environments. Kinematics and dynamics principles are applied to understand and predict the trolley's movement, including its speed, acceleration, and stability. This helps in designing effective steering mechanisms and motion control systems.

In addition, robotics principles are applied to enable the trolley to follow autonomously and navigate to the trolley nest. Techniques from robotics are used for localization and mapping (creating a map of the environment). This helps the trolley navigate accurately and perform tasks efficiently. The design of the prototype circuit incorporates key engineering principles to enable Int-Cart operation in retails application, focusing on two main mechanisms: following and navigating. The engineering principles applied to the prototype involve integrating components such as motorized wheels, LiDAR, and cameras. These components work together for environment perception and the development of algorithms for path planning and obstacle avoidance.

2.3.1 Motorized wheels (connected to BLDC motor controller):

The Brushless DC (BLDC) motor controller is used to manage the operation of the BLDC motor within the motorized wheel as shown in Figure 6. It controls the motor's speed and direction, which in turn affects the movement of the wheel [11]. The controller adjusts the phase currents in the motor windings to achieve the desired rotational speed and torque. This precise control allows for smooth and efficient wheel operation.

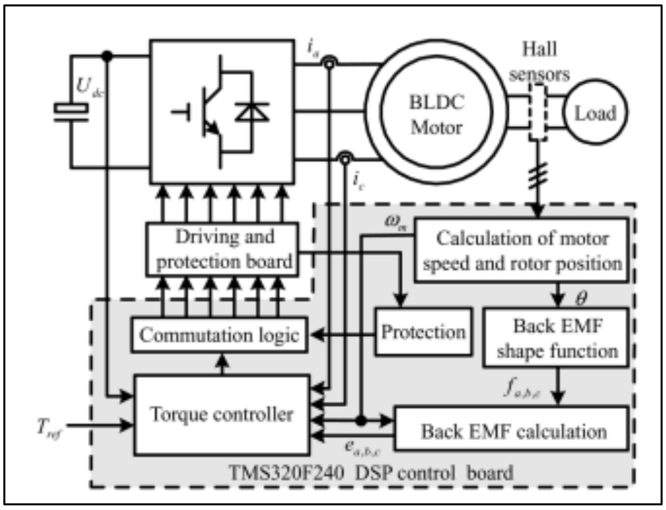

Fig. 6. Function of BLDC motor control system [12]

The torque equation for brushless DC motor can be expressed as:

$$T_e = \frac{e_a e_a e_b e_b e_c i_c}{w_m}$$

The If the back electromotive force (EMF) of brushless DC motors is proportional to the motor speed, the EMF can be calculated from the rotor speed using the shape functions f_a, f_b, and f_c, as outlined in equation.

$$\begin{cases} e_a = f_a\ (\theta)\ .\, w_m \\ e_b = f_b\ (\theta)\ .\, w_m \\ e_c = f_c\ (\theta)\ .\, w_m \end{cases}$$

2.3.2 Light detection and ranging (LiDAR):

Based on Figure 7, the laser emits an infrared signal that reflects off the object being detected. This reflected beam passes through a pinhole lens and strikes a Charged-Coupled Device (CCD) camera sensor. Due to the design, the triangles formed by (b, d_k) and by (b', d') are similar. This similarity means the distance to the object is nonlinearly proportional to the angle of the reflected light. When the camera measures the distance b', the actual distance d_k can be estimated using the principles of triangle similarity [13].

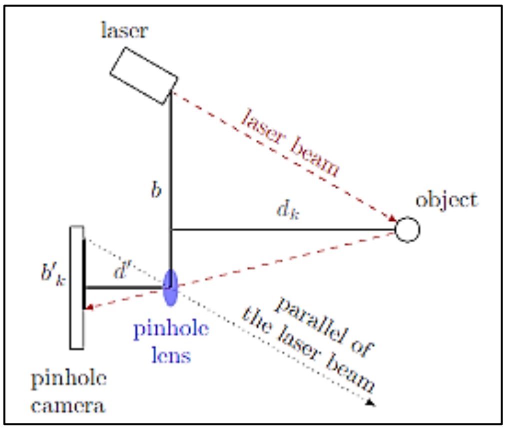

Fig. 7. Circuit diagram of the system

As shown in Figure 8, the LiDAR sensor emitted light beams that bounce off walls, allowing the robot to create a map of its surroundings. This map is saved and visualized in RViz, a tool used for graphing two types of data: odometry readings from wheel encoders and information from sensors like LiDAR. With this environmental recognition method, the autonomous learning-based control algorithm can determine the robot's position and detect obstacles to avoid collisions [14].

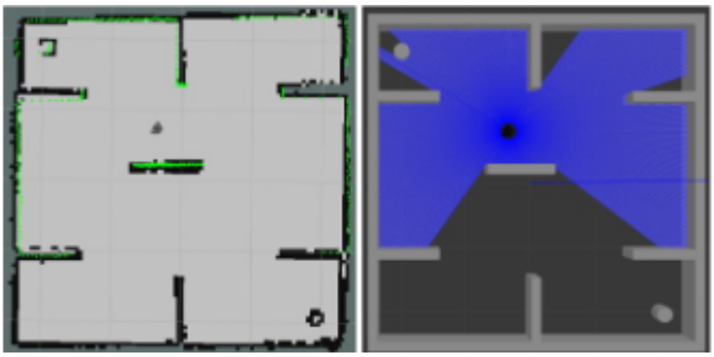

Fig. 8. Obstacle detection and spatial mapping [14]

2.3.3 Depth camera

Real-time object recognition using a depth camera and deep learning is an advanced application that utilizes artificial intelligence to detect and classify objects in live video feeds. This technology integrates computer vision, neural networks, and real-time processing, allowing machines to "see" and comprehend their surroundings.

Fig. 9. Obstacle detection and spatial mapping [14]

3. Conclusion

The project is expected to benefit disabled individuals, parents with young children, and elderly shoppers in shopping malls and retail environments.

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