IoT-Enabled Solar Electric Cart for Accessible and Sustainable Tourism

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ABSTRACT Ashesi University is a premier destination for diverse visitors, including researchers, scholars, tourists, and industry professionals. However, challenges such as limited tour guides, weather-dependent accessibility, and expansive campus layouts often hinder seamless exploration. To address these issues, this project introduces a smart electric tour cart powered by solar energy and enhanced with IoT-driven automation. The proposed system combines renewable energy and advanced automation to deliver a sustainable, accessible, and interactive touring experience. Key features include GPS-enabled navigation, real-time location-based multilingual audio guidance, and IoT-triggered automation, making the system inclusive for all users, including individuals with disabilities. The cart incorporates a monocrystalline photovoltaic (PV) solar panel to enable on-the-go recharging, reducing reliance on traditional power sources and increasing operational runtime by 30%. Testing validated the cart's performance, achieving a 0.3-meter error margin in location recognition under optimal conditions and reducing CO_2 emissions by 420 kg annually. These results demonstrate its potential to revolutionize campus and recreational tourism, with scalable applications for amusement parks, industrial complexes, and other large venues.

KEYWORDS IoT, location-based services, renewable energy, solar energy, smart electric vehicles, tourism.

1. INTRODUCTION

Tourism remains one of the fastest-growing and most impactful global industries, contributing significantly to economic development. In Ghana, for instance, the tourism sector generated approximately $3.1 billion in GDP in 2021, highlighting its vital role in national progress [1] [2]. Educational institutions, such as Ashesi University, contribute uniquely to this industry by providing opportunities for academic, cultural, and scenic exploration. Ashesi University, renowned for its innovation and sustainability culture, frequently attracts visitors ranging from scholars to industry professionals and international tourists.

Despite its appeal, several challenges hinder the campus touring experience. The scarcity of dedicated tour guides, coupled with accessibility limitations for individuals with disabilities, often leaves visitors without the resources to fully experience the campus. Furthermore, environmental factors such as unfavorable weather or the university's expansive, hilly terrain can deter exploration. Traditional transport options, though convenient, contribute significantly to greenhouse gas emissions, exacerbating environmental concerns. Globally, the transport sector accounts for over 25% of total emissions, with road vehicles comprising 70% of that figure [4] [5] [6]. This dual challenge of accessibility and sustainability calls for innovative, environmentally responsible solutions. This has earned electric vehicles (EVs) admiration due to their eco-friendly nature, which is why designing an electric tour cart has become necessary. Electric carts are becoming an excellent choice due to their inherent advantages: quiet operation, zero operational emissions, and comparatively lower maintenance costs [7].

This paper introduces a solar-powered electric tour cart designed to address these challenges through the integration of Internet of Things (IoT) technologies, advanced automation, and renewable energy. The cart features GPS-enabled navigation, location-based multilingual audio tours, and accessibility-friendly features, ensuring inclusivity for users with diverse needs. Additionally, the system incorporates a monocrystalline photovoltaic (PV) panel that enables on-the-go solar recharging, reducing reliance on grid power and extending operational range by 30%.

By leveraging IoT to automate functions such as location-triggered guidance and reverse warnings, the cart provides an interactive, self-guided experience. Beyond the campus setting, this innovation serves as a scalable model for sustainable mobility, with applications spanning amusement parks, industrial facilities, and other large venues. The project aligns with global sustainability goals, showcasing how renewable energy and intelligent automation can redefine transportation and enhance tourism accessibility.

2. LITERATURE REVIEW

The rapid evolution of transportation systems has seen a growing emphasis on sustainability, accessibility, and user-focused innovation. Existing research and projects have attempted to integrate IoT, software automation, and renewable energy into mobility solutions, yet significant gaps remain in areas such as scalability, accessibility, and operational efficiency. This review examines relevant advancements and identifies opportunities for improvement.

2.1. Interactive Self-Guided Robot for Tours

The interactive self-guided robot was developed by a group of students at Ohio Northern University (ONU) to provide tours at the James Lehr Kennedy Engineering Building at ONU to prospective students [8]. The system can also be used to offer guided tours inside museums, college campuses, and airports. The robot has dimensions of 24×24 inches base and 70 inches tall [8]. However, this system was constrained by its indoor-only functionality and lack of features to assist individuals with disabilities. Its inability to transport passengers further limits its scope for broader tourism applications, presenting an opportunity for outdoor and accessible alternatives.

2.2. MIT Self-Driving Golf Cart Project

A team of researchers at the Massachusetts Institute of Technology (MIT) called the Singapore-MIT Alliance for Research and Technology (SMART) developed a self-driving golf cart for tourists' rides [9]. However, the absence of guided tour functionality and renewable energy integration presents significant opportunities for improvement [9]. Solar charging and interactive guidance systems could elevate such systems to meet contemporary demands for sustainability and interactivity.

2.3. The Turtlebot Tour Guide

Ashesi University alumni pioneered the TurtleBot Tour Guide (TTG), a self-driving indoor navigation robot designed to assist with campus tours [10] [11]. While the project demonstrated the potential of autonomous navigation, it lacked outdoor capabilities, passenger transport options, and renewable energy integration. These limitations underscore the need for scalable solutions capable of operating in varied environments while offering accessibility for all users.

Research on electric vehicles (EVs) highlights the environmental benefits of transitioning to zero-emission transport. However, widespread adoption faces challenges such as inadequate charging infrastructure and dependence on nonrenewable energy sources [12] [13]. IoT integration has emerged as a transformative solution, enabling automation and real-time monitoring, while solar energy systems provide a viable alternative to traditional power grids. Combining these technologies can address existing gaps and enhance operational efficiency.

Tourism systems must prioritize inclusivity by addressing the needs of diverse users, including individuals with disabilities and those from various linguistic backgrounds. Many existing solutions lack features such as multilingual audio guidance or accessibility-friendly interfaces, limiting their appeal to a global audience. Integrating IoT-driven automation with features like location-based audio tours and wheelchair accessibility can bridge this gap, improving the user experience while broadening the system's applicability.

This project aims to address these limitations by developing a solar-rechargeable electric cart that combines IoT-driven automation, user-centric design, and sustainable energy systems. By bridging these gaps, the cart provides a scalable and inclusive solution for guided tours in diverse settings.

3. DESIGN AND SIMULATION

The design of the solar-rechargeable electric cart prioritizes efficiency, accessibility, and sustainability. The smart tour cart utilizes a modular architecture that integrates hardware components with IoT-driven software functionalities. A Raspberry Pi serves as the central processing unit, orchestrating GPS navigation, multilingual audio guidance, and real-time system automation. The modular design simplifies maintenance and upgrades, ensuring compatibility with future work.

3.1. Site Selection

The cart was designed to meet the specific needs of Ashesi University, a 2.3 km campus located in the hilly terrain of the Aburi Mountains. Figure 1 is the map as of June 2023.

Figure 1. Location – Ashesi University campus on a scale of 100m.

The design accounted for the environmental challenges posed by steep gradients and uneven surfaces. The vehicle's dimensions and performance parameters were optimized to navigate this terrain efficiently while maintaining stability and safety.

3.2. Design Objectives

The project aimed to meet the following design objectives:

- Accommodate at least two passengers, with a weight limit of up to 180 kg.
- Operate at a maximum speed of 20 km/h, ensuring safety and ease of control.
- Utilize solar panels to recharge batteries during operation, extending travel range.
- Enhance inclusivity through audio guidance and wheelchair accessibility.
- Enable straightforward maintenance with modular and replaceable parts.
- Incorporate a user-friendly dashboard for navigation, location recognition, and entertainment.

3.3. Requirements Specifications

To ensure that the design effectively meets the defined objectives, a comprehensive checklist of requirements was created as shown in Table I. This checklist serves as a structured guide to verify that all critical aspects of the system or product are addressed during the design and development phases. The requirements are typically categorized into functional, non-functional, and technical specifications, ensuring a holistic approach to the design process.

TABLE I. FUNCTIONAL REQUIREMENTS

Label	Functional Requirement
Mechanical Subsystem	
MFR001	It should be a four-wheel vehicle and allow for at least two-seater which should allow up to 180 kg of weight.
MFR002	The system should have a mechanical backup braking system in additions to any electric motor braking system.
MFR003	Most of the connecting parts should use fasteners as much as possible and should allow for easy change, repairs, inspections, and analysis in case there is any problem.
Electrical Subsystem	
EFR001	The cart should be electrically powered and should be run by a simple DC motor(s)
EFR002	The system should be energy efficient and not consume more than 500 W of electrical Power and should have a recharge ability of up to 30% whilst running during day.
EFR003	It should onboard charge controller and simple switches, accelerator padel for general control
EFR004	Electrical layout should be designed to avoid any form of electromagnetic interference.
Computer Subsystem	
CFR001	The microcontroller should swiftly detect sensor activation, triggering immediate actions like activating the rearview camera and playing reversing sounds as needed.
CFR002	The system dashboard should provide at least 165.0×100.0 mm screen interface for users. It should be able to display real locations, maps, live camera feed when reversing, music, and any other crucial information about the cart.
CFR003	The microcontroller's performance, including a CPU speed range of 1.3 to 1.7 MHz, must ensure smooth multitasking to handle GPS data processing, camera feeds, sensor inputs, and audio playback without performance issues.
CFR004	The Operating System (OS) should be robust and versatile, tailored for both infotainment and automation tasks, ensuring seamless integration and reliable performance.
CFR005	The GPS should maintain accuracy within a 1.5 meters margin to provide highly precise location data crucial for navigation and vehicle tracking applications.

**MFRxxx – Mechanical Functional Requirement, EFRxxx – Electrical Functional Requirement, CFRxxx – Computer Functional Requirement

3.4. Criteria for Selecting Microcontroller

The smart tour cart required a central processing unit capable of managing multiple IoT components while ensuring reliable performance under diverse operational conditions. The Raspberry Pi was selected for constructing the head unit due to its versatility as both a microcontroller and a minicomputer. Its relatively high computational power and robust connectivity features made it an ideal choice for this application. Key advantages of the Raspberry Pi include integrated connectivity options being equipped with USB (Universal Serial Bus) ports, built-in Wi-Fi and multiple GPIO (General Purpose Input/Output) pins that allow easy interfacing with external sensors, and it also allows for easy integration with other devices and networks. These capabilities were critical in meeting the project's requirements for real-time IoT automation, seamless GPS integration, and user-friendly interactions, solidifying the Raspberry Pi as the optimal choice for the tour cart's head unit.

3.5. Hardware Components

Table II outlines the primary IoT components utilized in the designing of the smart electric tour cart, with the selection of these components being driven by a combination of design requirements and component availability. Each component was carefully chosen to ensure compatibility with the system's functional and technical specifications, such as real-time data processing, reliable communication, and energy efficiency, while also considering ease of integration. This strategic selection process ensures that the hardware architecture aligns with the overall design objectives, enabling the tour cart to operate intelligently and reliably in its intended environment.

TABLE II. OTHER MAIN ELECTRICAL COMPONENTS

Components	Description
Solar Panel & Charge Controller	100W monocrystalline PV panel for efficient energy harvesting, paired with an MPPT charge controller.
Battery	Two 12V lead-acid batteries connected in series to store energy and power all cart components, including the motors.
GPS Module	Provides real-time navigation and accurate location tracking for automation and guidance.
Touchscreen Interface	A 7-inch display serving as a user interface for navigation, diagnostics, and infotainment.
Raspberry Pi Camera	Provides real-time rearview footage during reversing to avoid obstacles and enhance safety.
Speaker	Delivers audio output for location-triggered multilingual guidance and onboard entertainment.
Headlamp	Ensures safe nighttime operation by providing adequate illumination for navigation and visibility.

Solar Panel Performance:
- Maximum Power Voltage (Vmp): **18.6V**
- Maximum Power Current (Imp): **5.38A**
- Maximum System Voltage (Vdc): **600V**

Two 250W brushed gear DC motors deliver reliable propulsion at **120 RPM**, ensuring smooth movement across varied terrain.

3.6. System Simulation
Simulation was essential to analyze some parameters of the electrical, IoT and software design before proceeding to build the final model. Simulink was used to simulate the effectiveness of the solar-to-battery charging ability. For the mechanical subsystem, SolidWorks enabled Finite Element Analysis (FEA) of the chassis, confirming its ability to withstand a load of 1800 N, meeting passenger and equipment weight requirements. In addition, several benchmarking applications such as GPS Test were used for IoT component design and analysis, enabling visualization, assessment, and loading operation simulation. Navigation simulations were conducted with **OpenStreetMap (OSM)** data. These simulations allowed the team to improve component choices based on results and effectiveness in the environment, validating the final system design.

3.7. Electrical Subsystem Design
The electrical subsystem integrates advanced energy and control components to optimize energy utilization, reliability, and scalability. The system is powered by two 12V lead-acid batteries connected in series, delivering 24V to the motors and electronic components. A 100W monocrystalline photovoltaic (PV) solar panel, coupled with a Maximum Power Point Tracking (MPPT) charge controller, ensures efficient solar energy conversion and battery recharging. This configuration significantly reduces dependency on grid power, with the system supporting up to 30% rechargeability during daylight operation. The inclusion of two 250W brushed gear DC motors provides stable propulsion, with speed regulated through a Pulse Width Modulation (PWM) motor controller. An accelerator pedal integrated with the PWM controller allows precise user control over speed, offering a balance between simplicity and cost-effectiveness. Figure 2 shows the schematic diagram of the power system of the cart.

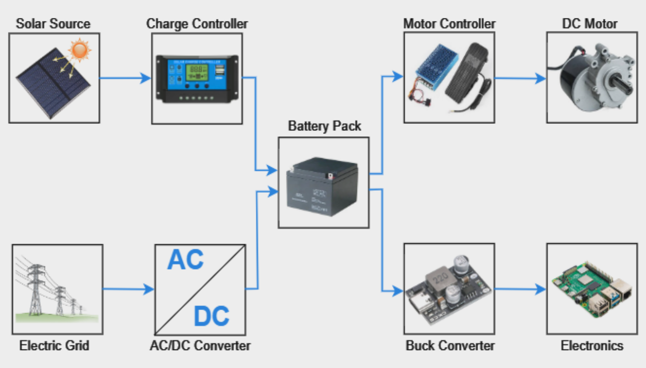

Figure 2. Schematic diagram of the power system of the tour cart

To prevent electromagnetic interference (EMI) that could affect sensitive IoT components, the wiring layout incorporates shielded cables and a structured power distribution system. Additionally, a buck converter steps down the 24V supply to 5V, ensuring stable power delivery to onboard electronics, including the Raspberry Pi, GPS module, and reverse camera. The strategic arrangement of these components ensures reliable performance across diverse operational conditions. The power output of the PV panel is influenced by solar irradiance and temperature, which vary based on location [13]. Ghana's equatorial positioning provides optimal solar conditions, with average daily irradiation ranging from 4 to 6.5 kWh/m² [14]. Research by F. Odoi-Yorke et al. highlights Wa as the region with the highest solar fraction (78.5%), while Accra, where the system was tested, achieves 64.4% [15]. These favorable conditions make Ghana an ideal environment for harnessing solar energy effectively. Figure 3 illustrates the results. The PV panel was connected to the batteries via a Maximum Power Point Tracking (MPPT) charge controller. The MPPT charge controller is used to extract the maximum power from the PV panel [16].

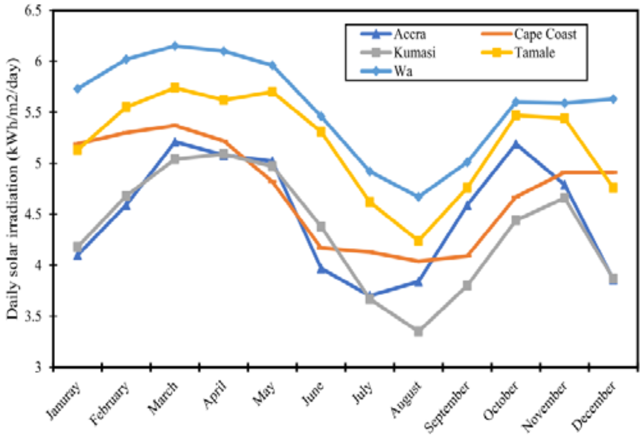

Figure 3. Daily solar irradiation for different cities in Ghana [15]

3.8. Mechanical Subsystem Design

SolidWorks was used to design the 3D Computer Aided Design (CAD) model of the chassis for analysis and preview before implementation. Figure 4 shows the 3D model.

Figure 4. 3D Isometric view of the tour cart model designed in SolidWorks.

The chassis of the smart electric tour cart was rigorously evaluated using Finite Element Analysis (FEA), as illustrated in Figure 5, to ensure its structural integrity under operational conditions. A maximum load of 1800 N, equivalent to the combined weight of two passengers, was applied to simulate real-world usage. Constructed from galvanized steel square pipes measuring 1.25×1.25 inches, the chassis demonstrated exceptional strength and durability under stress. The FEA results revealed that the maximum von Mises stress (3.516×10^6 N/m^2) was significantly lower than the material's yield strength (2.039×10^8 N/m^2), as indicated by the color bar in the simulation. This substantial margin confirms that the chassis does not yield under the applied load, validating its robustness and suitability for safely supporting the intended passenger weight while maintaining structural stability.

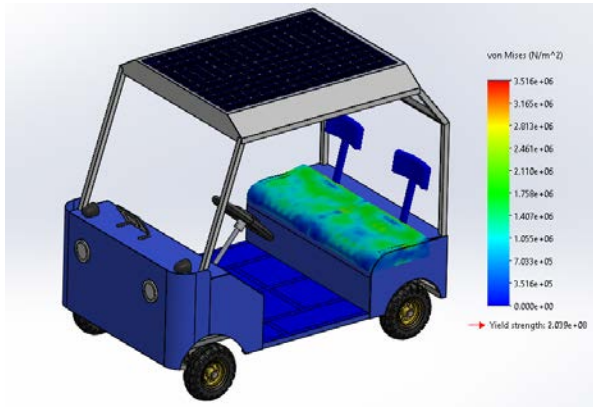

Figure 5. Finite Element Analysis of Chassis when 1800 N is applied.

4. IMPLEMENTATION

4.1. Electrical Subsystem

The electrical system integrates solar panels, batteries, motors, and electronic controls to ensure reliable and efficient power delivery. A 100W monocrystalline photovoltaic (PV) panel is used to harness solar energy, converting it into electrical power to charge two 12V lead-acid batteries. The solar panel operates at a maximum power voltage (Vmp) of 18.6V and a current (Imp) of 5.38A, ensuring efficient energy capture even under variable lighting conditions. The two 12V batteries are connected in series to provide the required 24V supply, powering the 250W brushed DC motors and other onboard electronics, including the GPS module, reverse camera, and the Raspberry Pi control unit.

To optimize solar panel efficiency, a Maximum Power Point Tracking (MPPT) charge controller is integrated into the system. This device ensures maximum power extraction from the PV panel while preventing battery overcharging or deep discharging, thus maintaining system reliability and extending battery lifespan. Additionally, a buck converter steps down the voltage from 24V to 5V for powering sensitive electronic components like the Raspberry Pi and GPS module.

The total current required by the electronic components was calculated using Equation (1) below:

$$I_{TOTAL} = I_{PI} + I_{SCREEN} + I_{SPEAKER} + I_{LAMP} + I_{GPS} + I_{FAN} + 2I_{MOTOR} \quad (1)$$

$$I_{TOTAL} = (3000 \text{ x } 10^{-3}) + (400 \text{ x } 10^{-3}) + (1000 \text{ x } 10^{-3}) + (1000 \text{ x } 10^{-3}) + (60 \text{ x } 10^{-3}) + (200 \text{ x } 10^{-3}) + 2(10000 \text{ x } 10^{-3})$$

$$I_{TOTAL} = 25.66 \text{ A } \textit{(Maximum Total Current)}$$

The total system requires approximately **25.66A** with a varying voltage range of **5V to 24V DC**, depending on the component.

4.2. Software Subsystem

4.2.1. Operating System

One of the primary objectives of the smart tour cart was to provide guided tours across the campus with an interactive and user-friendly system. To achieve this, the design included a head unit, similar to those found in modern vehicles, offering a combination of infotainment, navigation assistance, and entertainment. Unlike conventional systems relying on mobile device pairing (e.g., Android Auto or CarPlay), this head unit was tailored to the cart's specific needs and designed to operate independently.

The team used a Raspberry Pi as the core of the head unit, running a customized version of Android built from the Android Open-Source Project (AOSP). This stripped-down Android 13 system excluded most Google services and unnecessary features to reduce CPU load and optimize resource usage. Hardware acceleration and dynamic CPU frequency adjustment ensured stable performance and prevented overheating.

The 7-inch touchscreen interface integrated functionalities like maps, a speedometer, music controls, and a clock, offering an intuitive and engaging experience for users. This system enables the cart to deliver an enhanced touring experience, combining guidance and entertainment. The dashboard layout, shown in Figure 6, reflects its simplicity and usability, catering even to first-time users.

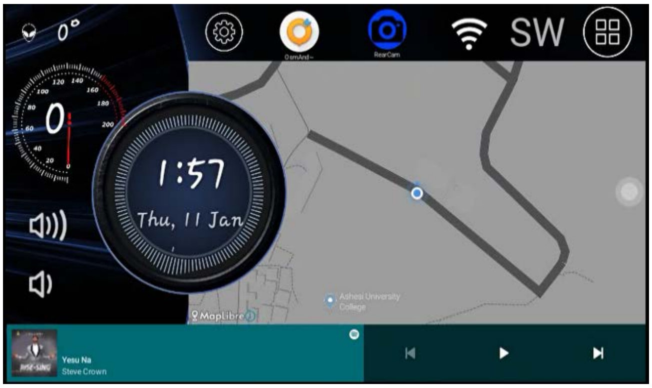

Figure 6. Head-unit dashboard.

This customized solution demonstrates how off-the-shelf hardware like the Raspberry Pi can be adapted to meet specific project needs, offering a cost-effective and scalable alternative to commercial automotive head units.

4.2.2. Navigation System

Navigation is a central feature of the tour cart's functionality, enabling precise location tracking and guided tours. Integrating GPS and navigation software into the head unit was therefore a critical aspect of the system's design. Unlike conventional automotive head units that rely on paired mobile devices for map functionality, the tour cart utilizes a standalone GPS module directly connected to the Raspberry Pi via its USB interface.

To facilitate this integration, a mock GPS location setting was employed, allowing the operating system to interpret coordinates sent and received from the USB-connected GPS module as originating from an onboard GPS system. While an alternative such as the UBlox NEO7M GPS chip could have been used, this would require kernel-level modifications in the operating system to recognize GPIO connections for GPS data—an approach deemed cumbersome for this application.

The selected GPS module, the **GlobalSat G-Star**, utilizes the SiRF Star IV GPS chipset from SiRF Technology Inc. This module supports connectivity to up to 48 channels simultaneously and has a high sensitivity of -163 dBm, making it well-suited for outdoor navigation and vehicle applications. Its performance ensures reliable connectivity even in challenging environments, ensuring accurate location recognition critical for triggering audio guides and enabling real-time navigation. For mapping software, **OpenStreet Maps** was chosen due to its customization, lightweight design and compatibility with the Android platform. Figure 7 shows the OpenStreet Maps view of a section of the Ashesi University campus.

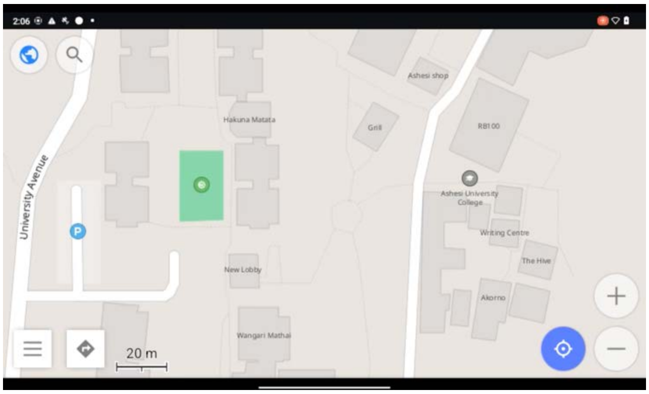

Figure 7. OpenStreet Maps view of section of Ashesi University.

Its ease of integration with the Raspberry Pi allows the system to deliver smooth navigation while minimizing the computational load on the hardware. Together, the GPS module and mapping software provide a robust and efficient navigation subsystem, ensuring seamless location-based guidance for the cart's users.

4.2.3. Rear-View Camera

The rear-view camera in the smart tour cart serves as a critical safety feature, providing real-time video feedback when the vehicle is in reverse. This functionality is implemented using a Raspberry Pi as the central control unit, which manages the camera's activation and integrates it with the vehicle's dashboard interface.

In the absence of an onboard diagnostics (OBD) module, the system relies entirely on the Raspberry Pi to detect the engagement of the reverse switch. Upon activation, the Raspberry Pi triggers the rear-view camera and emits a reverse warning sound through the cart's speakers. When the gear shifts back into a forward position, the camera automatically deactivates, and the dashboard interface reverts to its standard display, providing navigation and other system information.

Although the Raspberry Pi lacks official support for Android, the use of long camera ribbon cables ensures flexible placement of the camera from the front to the rear of the vehicle. This placement offers a clear view of obstacles behind the cart. However, the camera's operation is limited to rear-view functionality, which initially resulted in a horizontally inverted image. To resolve this issue, a custom application named **Rearview Dash** was developed. This lightweight application corrects the inversion and enhances the user experience by overlaying reverse guidelines, aiding in precise and safe maneuvering. This subsystem demonstrates the Raspberry Pi's versatility in managing essential safety features and highlights the adaptability of open-source hardware and custom software in creating reliable, low-cost solutions for specialized applications. A snippet of Rearview Dash can be found in Figure 8.

Figure 8. Rearview Dash when vehicle is in reverse.

4.2.4. Voice Guidance and Audio Tours

To enhance the touring experience, the project aimed to provide users with the freedom and excitement of self-guided tours. This feature empowers visitors to explore the campus independently, at their own pace and direction, without the need for a physical tour guide. Recognizing the diversity of visitors' linguistic backgrounds, the team incorporated multilingual support into the system, offering tours in languages such as English, French, and German, with the capability to expand to additional languages as needed. The tour cart delivers a rich multimedia experience through location-triggered audio guides. These pre-recorded audio files are stored locally on the Raspberry Pi, which acts as the central control unit. The multilingual support ensures accessibility for a wide range of users, enhancing inclusivity and usability. By removing the reliance on a physical guide, the system provides a more flexible and personalized experience for users.

To automate audio playback, **Tasker software** was employed. This software links GPS coordinates to specific audio files. When the cart enters a predefined location radius, Tasker automatically triggers the corresponding audio description, allowing users to receive relevant information about landmarks as they pass by. The GPS-triggered automation ensures smooth transitions between landmarks, providing an engaging and uninterrupted user experience.

This system not only enhances the educational and recreational value of the tour but also represents a scalable solution for various environments such as amusement parks, historical sites, and large industrial complexes. The seamless integration of multilingual audio guidance with location-based automation underscores the potential of IoT in creating user-centric, interactive systems.

4.2.5. Location Services

The voice recordings for each recognized landmark are stored locally on the cart's Raspberry Pi system. To automate the audio tour experience, **Tasker**, an automation software, was employed to create profiles that link specific GPS coordinates to corresponding audio files. Unlike location name recognition, which is limited in precision, Tasker utilizes the precise GPS coordinates of landmarks. A 3-meter radius is defined for each landmark, representing the designated region for triggering the audio playback. Whenever the cart enters this predefined radius, the system automatically plays the corresponding audio tour, ensuring users receive informative and contextually relevant guidance as they travel. This approach empowers users to freely explore while maintaining an immersive and educational experience. The automation eliminates the need for manual intervention, providing a seamless tour experience. The GPS system's performance was thoroughly tested under both outdoor and indoor conditions to evaluate its accuracy and reliability.

During **outdoor testing**, the GPS achieved an error margin of **0.6 meters**, maintaining robust connectivity with 12 to 16 satellites out of a possible 20 satellites in view. This high level of accuracy ensures reliable location detection and audio triggering in outdoor environments. In contrast, **indoor testing** revealed reduced accuracy, with an error margin of **3.5 meters** and connectivity limited to a maximum of 6 satellite channels. These findings highlight the system's suitability for outdoor applications, where unobstructed satellite visibility facilitates optimal performance. Conversely, indoor environments with structural obstructions, such as roofs, pose challenges to GPS accuracy and satellite connectivity.

This location-based audio guidance system demonstrates the potential of combining GPS technology with automation software to deliver an engaging and user-friendly experience. It underscores the importance of environmental factors in system design and highlights opportunities for future enhancements, such as integrating complementary sensors for improved indoor performance. The Figure 9 shows the complete software system flow chart.

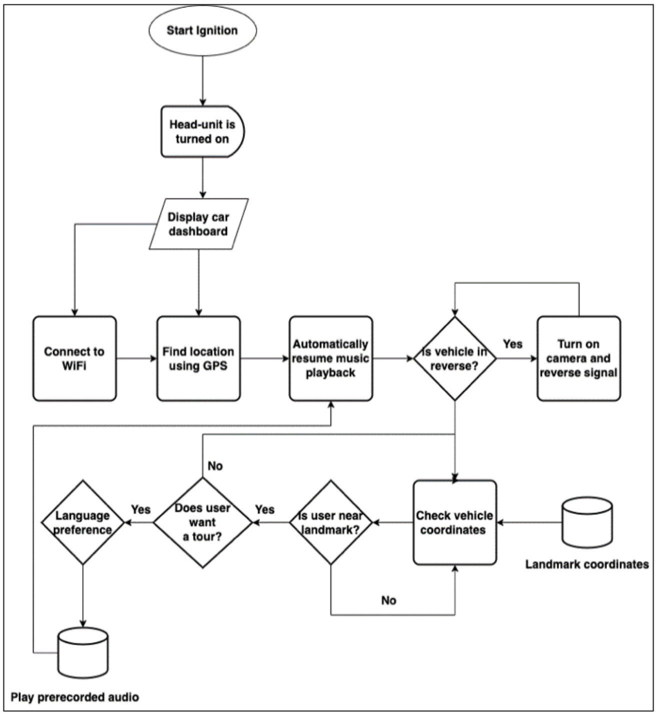

Figure 9. Software system automation flow chart.

4.2.6. Automation and System Flow

Given the standalone nature of the tour cart system, integrating components like an onboard diagnostics (OBD) module was impractical due to the absence of a complete car system. Instead, the Raspberry Pi served as the central control unit for all IoT and automation tasks. This control unit integrates key components, including the camera, GPS module, speakers, touchscreen display, and transmission system, forming a cohesive diagnostic and infotainment system.

Tasker, an automation software, was utilized to handle various system tasks. Custom profiles were created to enable the system to interpret input signals from GPIO pins as button presses, allowing it to execute specific actions when data was received from connected devices. For instance:

- When the vehicle is shifted into reverse gear, a low data signal is sent to the GPIO pin. This triggers the activation of the rear-view camera by launching the corresponding app and plays a reverse warning beep through the speakers.
- Shifting the vehicle back into neutral or drive deactivates the rear-view camera app and stops the warning sound, returning the display to the dashboard interface.

The GPS coordinates for landmarks were identified manually and compiled into a database. Each landmark was linked to a directory containing the corresponding audio files for that location. As the cart approaches a specific landmark, Tasker uses GPS data to trigger the playback of the associated audio file. This ensures seamless delivery of location-based information during tours.

In the absence of a physical pedometer or integrated dashboard for speed measurement, the system relied on GPS data to estimate the vehicle's speed. While this method does not provide precise speed measurements, it offers a reasonable approximation that is sufficient for the cart's operational needs.

This automation and system flow demonstrate the flexibility and scalability of the Raspberry Pi as a control hub for IoT applications. By leveraging open-source tools like Tasker, the project achieved a highly functional and cost-effective system capable of meeting diverse user needs.

4.3. System Assembly

The system assembly process for the smart electric tour cart was meticulously executed to ensure seamless integration of mechanical, electrical, and IoT components, guaranteeing both reliability and functionality. Shielded cables were extensively employed to mitigate electromagnetic interference (EMI), particularly between power and signal cables, thereby maintaining stable communication and operational efficiency across the system. The 100W monocrystalline photovoltaic solar panel was strategically mounted to optimize sunlight absorption throughout the day, enhancing energy generation for sustained operation. Critical internal components, such as the lead-acid batteries and the Raspberry Pi control unit, were housed in weatherproof enclosures to safeguard them against environmental challenges like rain, dust, and extreme temperatures. The final assembled cart incorporates all designed features, including GPS-enabled navigation for precise route tracking, location-triggered audio guidance for an enhanced user experience, and an intuitive touchscreen dashboard for easy interaction and control. This comprehensive assembly process ensures that the cart is not only robust and durable but also equipped with advanced functionalities to meet the needs of its users effectively. Figure 10 shows some of the critical components in the final assembled model.

Figure 10. Final model of electric smart tour cart.

The first complete working model, as shown in Fig. 11, demonstrates the system's viability for various applications. These include university campus tourism, amusement park tours, estate rides, beach shore visits, tours at recreational centers, airports, and large industrial complexes.

In addition to technical development, the team conducted an economic analysis to evaluate the project's market potential. The global golf cart market, which shares similarities with the tour cart, is valued at $3.4 billion as of 2023 and is projected to grow to $5.76 billion by 2033, with a Compound Annual Growth Rate (CAGR) of 5.4% [17]. In comparison to existing golf cart systems, which range in price from $6,000 to $18,000, the smart electric tour cart was developed at a significantly lower cost of approximately $1,500.

Figure 11. Final model of electric smart tour cart.

This substantial cost advantage positions the project as a viable solution for the African market, where affordable and sustainable transport options are in demand. Additionally, the lack of similar technologies in the region enhances the project's potential for adoption in both tourism and industrial applications.

5. RESULTS AND DISCUSSION

5.1. Software Benchmark Tests

The performance of the Raspberry Pi 4 head unit was evaluated to ensure its capability to manage the computational demands of the tour cart's various functions. The evaluation was conducted using PassMark benchmarking tools, which highlighted the performance of the BCM2835 processor under different clock speeds.The Raspberry Pi's processor exhibited optimal performance at a clock speed of **1.8 GHz**, which was found to provide a reliable balance between computational power and system stability. Testing included varying the clock speed from **1.5 GHz to 2.0 GHz**, revealing marginal performance improvements at higher speeds. However, increasing the clock speed beyond **1.9 GHz** introduced risks such as overheating and reduced system stability. This was particularly evident in the disk score, where a slight decline was observed at 2.0 GHz, suggesting a point of diminishing returns.

The results, depicted in Figure 12, showed that system and CPU performance peaked at **1.9 GHz**, while memory and disk performance varied with clock speed. Based on these findings, the recommended operating clock speed for the Raspberry Pi 4 is **1.8 GHz**, which ensures efficient and stable operation without the risks associated with excessive heat generation or system instability. This benchmark analysis validates the Raspberry Pi 4's suitability as the central processing unit for the smart tour cart, confirming its ability to efficiently handle real-time GPS processing, camera feeds, audio playback, and automation tasks.

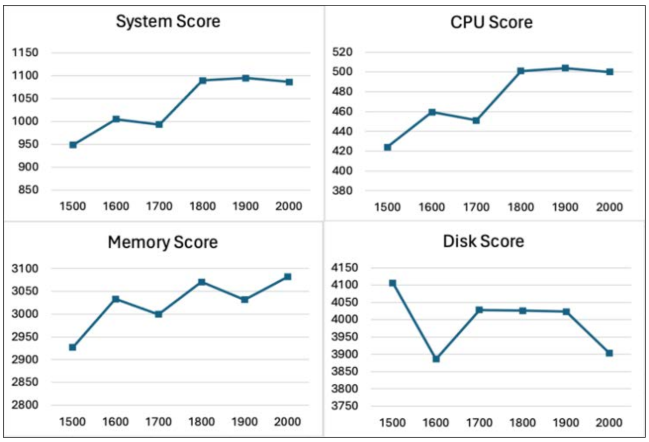

Figure 12. Plot of the different operation frequencies.

5.2. Solar Charging Test Results

The performance of the integrated photovoltaic (PV) system was assessed through a two-week testing period, during which the cart was operated daily for 3 to 4 hours under real-world conditions. The results validated the system's effectiveness in harnessing solar energy to sustain operations and recharge the onboard batteries. Key findings from the tests include:

- **Average Power Output**: The PV system delivered an average power output of **78.48 W** under standard sunlight conditions, demonstrating its ability to efficiently convert solar energy into electrical power for battery charging.
- **Runtime Extension**: Continuous solar recharging extended the cart's runtime by approximately **30%**, significantly reducing dependence on grid power and enhancing operational flexibility.
- **Battery Discharge Reduction**: During peak solar hours, the rate of battery discharge was significantly reduced, underscoring the sustainability and efficiency of the solar energy integration.

These results confirm that the PV system is capable of maintaining sufficient power for all electronic and mechanical systems, even under variable sunlight conditions. This performance ensures that the cart can operate for extended periods without compromising functionality or reliability.

The outcomes highlight the practicality of solar energy as a primary power source for the tour cart, reinforcing its potential as a sustainable solution for guided tours in diverse environments. Figure 13 is the plot of the solar output power on different test days.

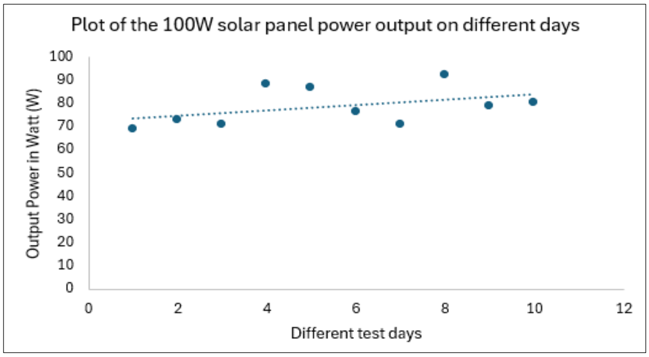

Figure 13. Plot of the 100W solar panel power output.

5.3. Navigation and GPS Accuracy

The navigation system was tested in both outdoor and indoor environments to evaluate its reliability and accuracy under varying conditions. The results provided valuable insights into the performance of the GPS module in different scenarios:

- **Outdoor Performance**: Under optimal outdoor conditions, the GPS system achieved a highly accurate error margin of **0.6 meters**. Connectivity was consistent, with the module maintaining connections to **12–16 satellites** out of a possible 20. This level of accuracy ensures precise location recognition, which is critical for automated audio tour triggering and real-time navigation.
- **Indoor Performance**: In indoor environments, the GPS module faced reduced connectivity, with a maximum of **6 satellites** in view. This limitation resulted in an error margin of **3.5 meters**, which, while sufficient for basic navigation tasks, highlights the challenges of maintaining precise location tracking in obstructed environments such as buildings. Enhancements, such as integrating complementary sensors or leveraging alternative positioning technologies, could improve indoor performance.

These results demonstrate the robustness of the navigation system in outdoor applications, where unobstructed satellite visibility facilitates optimal performance. For environments with structural obstructions, additional optimizations will be required to ensure reliable operation. Overall, the navigation system's performance validates its suitability for the cart's outdoor touring functions, enabling accurate, location-based automation and enriching the user experience.

6. CONCLUSION AND FUTURE WORK

The development of the Smart Solar-Recharge Electric Cart for location recognition and guided tours successfully demonstrated the integration of IoT devices to implement a sustainable, efficient, and user-friendly electric vehicle. The photovoltaic (PV) panel installed on the cart was shown to produce an average of **78.48 W**, enabling solar recharging and reducing reliance on traditional energy sources. This system can significantly decrease environmental impact, with the potential to reduce **CO2 emissions by 420 kg annually**. The developed cart embodies sustainability, reliability, and environmental friendliness, making it an ideal solution for eco-conscious touring applications.

Future Improvements: Several enhancements can further improve the performance, usability, and scalability of the smart electric tour cart:

1. **Autonomous Features**: The implementation of **Simultaneous Localization and Mapping (SLAM)** technology could enable self-driving capabilities, allowing tourists to select ride options and navigate autonomously without manual intervention.
2. **Booking Application**: Developing a dedicated app would enable users to conveniently book rides, schedule trips in real time, and customize routes, thereby enhancing operational convenience and user satisfaction.
3. **Increased Capacity**: Expanding the seating capacity to accommodate **4 to 6 passengers** would attract larger groups and improve ride occupancy rates, particularly in tourist-heavy areas

such as amusement parks, recreational centers, and campuses.

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