

AI-Enabled Smart Electronic Integrated Eco-Friendly Toys

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Abstract- This invention concerns the development of smart sensor-enabled eco-friendly toys fabricated from banana residue bio-composite materials. The toy enclosure is produced using banana fiber and sheath powder reinforced with bio-resins through compression molding, providing mechanical strength and electrical insulation. An embedded control system built on an ESP32-WROOM-32 low-power microcontroller manages real-time sensing, control and wireless communication. The system integrates capacitive touch (TTP223), PIR motion (HC-SR501), ambient light (LDR), temperature (DS18B20) and sound (KY-038) sensors. Interactive outputs include addressable RGB LEDs (WS2812B), piezo buzzers, vibration motors and audio playback through PAM8403 amplifier driven speakers. Power is supplied via a 3.7 V lithium-ion battery supported by TP4056 charging/protection circuitry and MT3608 DC-DC boost regulation. Firmware is developed in embedded C featuring interrupt routines, sensor fusion and deep-sleep power management. Bluetooth and Wi-Fi interfaces enable user configuration and monitoring. A modular PCB design supports scalable toy variants and ensures safe low voltage operation. This invention demonstrates a sustainable and intelligent embedded electronics platform for educational toy applications.

Index Terms - Banana fiber composite, Raspberry Pi Zero 2 W, Smart educational toy, Embedded system, Sustainable electronics, Sensor integration, Camera-based interaction.

I. INTRODUCTION

The rapid growth of electronic products has significantly increased the consumption of non-biodegradable plastic materials, particularly in the toy industry. Conventional electronic toys are predominantly manufactured using petroleum-based polymers such as Acrylonitrile Butadiene Styrene

(ABS) and Polyvinyl Chloride (PVC), which contribute to long-term environmental pollution due

to their slow degradation rate and high carbon footprint. The accumulation of plastic waste in landfills and natural ecosystems poses serious ecological and sustainability challenges. As global awareness regarding environmental sustainability increases, there is a strong need to develop eco-friendly alternatives that combine biodegradable materials with modern embedded technologies.

Banana cultivation generates large quantities of agricultural residue, especially pseudo-stem and sheath waste, after harvesting. These residues contain strong natural fibers with favorable tensile strength, lightweight characteristics and natural insulation properties. When processed into pulp and reinforced with bio-resins through compression molding, banana fiber composites exhibit adequate mechanical rigidity and electrical insulation suitable for structural applications. Utilizing banana residue for enclosure fabrication not only reduces agricultural waste but also supports circular economy practices and sustainable material engineering.

In parallel, modern educational tools are evolving toward intelligent, interactive and multimedia-enabled systems. Embedded computing platforms such as the Raspberry Pi Zero 2 W provide compact yet powerful processing capabilities suitable for real-time image acquisition, display control and user interaction. The integration of camera modules and touch displays allows dynamic learning experiences through visual feedback and interactive control. Compared to traditional microcontroller-based toys, single-board computing platforms enable enhanced multimedia functionality, wireless connectivity and software scalability.

Despite advancements in embedded educational systems, limited research has focused on integrating biodegradable composite materials with camera-based embedded platforms in toy applications. Most smart toys still rely on plastic enclosures and lack sustainable design consideration. Therefore, there exists a technological gap between sustainable material usage and intelligent embedded electronics integration.

This project presents the development of a smart eco-friendly educational toy fabricated using a banana fiber bio-composite mannequin structure integrated with a Raspberry Pi Zero 2 W platform. The system incorporates a Raspberry Pi camera module for real-time image capture and a color TFT touch display for visualization and interaction. The camera is interfaced via the CSI (Camera Serial Interface), while the touch display operates through SPI (Serial Peripheral Interface) communication. The entire electronic assembly is securely mounted within the biodegradable enclosure, ensuring structural stability, natural insulation and safe low-voltage operation.

The primary contribution of this work lies in the use of banana fiber bio-composite material as a sustainable alternative to conventional plastic toy enclosures. The system integrates embedded multimedia processing using the Raspberry Pi Zero 2 W, enabling real-time camera-based interaction and touch display functionality. The overall design provides a compact, scalable and eco-friendly embedded platform suitable for modern educational toy applications.

By combining sustainable material engineering with embedded computing and multimedia interaction, the proposed system demonstrates the feasibility of developing environmentally responsible smart toys. The design emphasizes reduced plastic dependency, compact integration, structural durability and safe operation while maintaining interactive educational functionality. This approach establishes a foundation for future eco-conscious electronic product development.

II. LITERATURE REVIEW

Recent advancements in sustainable materials and embedded electronics have significantly influenced the development of eco-friendly smart systems.

Several researchers have explored biodegradable materials, agricultural waste utilization and embedded multimedia platforms, which form the foundation for the proposed work.

J. Smith *et al* presented the development of plant-based bio-electrolytes for energy storage applications. Their research emphasized the use of renewable and biodegradable materials to replace conventional synthetic materials in electronic systems. The study demonstrated that plant-derived components can enhance sustainability without compromising system performance. This work highlights the importance of integrating environmentally friendly materials into modern electronic product design.

Kumar *et al* discussed sustainable materials for electrochemical energy storage, focusing on natural and biodegradable materials as alternatives to traditional synthetic compounds. Their findings support the use of bio-based composites in structural enclosures and electronic assemblies, reinforcing the concept of eco-friendly product development adopted in the proposed system.

M. Lee *et al* explored agricultural waste utilization in energy systems, emphasizing waste-to-energy conversion and sustainable material synthesis. Their research demonstrated that agricultural residues can be transformed into value-added materials through scientific processing techniques. This study supports the use of banana pseudo-stem and sheath waste in developing biodegradable composite structures for consumer electronic applications.

R. Gupta *et al* presented the design and fabrication of eco-friendly smart toys using natural fiber composites and biodegradable binders integrated with smart electronics. Their work demonstrated that natural fiber materials can provide sufficient structural strength and electrical insulation for embedded electronic modules. The research validates the feasibility of using banana fiber bio-composites as structural enclosures for smart educational systems.

III. DESCRIPTION OF EXISTING SYSTEM

Existing electronic toys and educational devices primarily rely on plastic-based enclosures and basic microcontroller architectures. Conventional toys are

commonly manufactured using non-biodegradable materials such as ABS and PVC, which contribute to environmental pollution due to their long degradation period. These materials are widely used because of their low cost and ease of manufacturing; however, they lack sustainability and eco-friendly characteristics.

In terms of electronic architecture, traditional educational toys typically employ simple microcontrollers with limited processing capabilities. These systems are mainly designed for basic input-output operations such as LED blinking, simple sound generation and push-button interaction. Most conventional designs do not incorporate advanced multimedia processing, camera integration or touch-based interfaces. As a result, the level of interactivity and educational engagement remains minimal.



Fig.2. Existing system of mosquito repellent

Furthermore, existing systems often depend on disposable batteries and lack efficient power management strategies. They are not designed with modular scalability, wireless communication or image-processing capabilities. The absence of integrated multimedia features restricts their ability to provide dynamic and interactive learning experiences.

Another significant limitation of conventional toy systems is the absence of sustainable design considerations. The enclosure materials are typically synthetic and petroleum-based, and little attention is given to reducing environmental impact during manufacturing. As environmental concerns continue to grow, the need for sustainable alternatives in electronic product design becomes increasingly important.

Existing systems have several limitations, including poor environmental sustainability due to plastic enclosures, limited multimedia interaction features

and the absence of camera-based functionality. Most traditional toys do not support touch display interfaces or advanced embedded processing capabilities, which restricts their interactive and educational potential. These shortcomings clearly indicate the need for developing an eco-friendly and technologically advanced smart educational toy system, which is addressed in the proposed work.

IV. CHALLENGES IN THE EXISTING SYSTEM

The existing electronic toy systems have several technical and environmental problems. One major issue is the use of non-biodegradable plastic materials for enclosures, which causes long-term environmental pollution and increases the carbon footprint. These materials are not sustainable and do not support eco-friendly manufacturing. Another challenge is the limited functionality of traditional microcontroller-based toys. Most conventional toys perform only simple tasks such as LED blinking, basic sound generation or button operations. They do not support advanced multimedia features like real-time image processing, touch-based interfaces or interactive display systems, which reduces user engagement and learning effectiveness. Another challenge is the limited functionality of traditional microcontroller-based toys. Most conventional toys perform only simple tasks such as LED blinking, basic sound generation or button operations. They do not support advanced multimedia features like real-time image processing, touch-based interfaces or interactive display systems, which reduces user engagement and learning effectiveness.

V. PROPOSED SYSTEM

The proposed system is a smart eco-friendly educational toy designed using a banana fiber bio-composite mannequin structure as the outer enclosure instead of plastic materials. The enclosure is made by compression molding banana fiber and sheath powder mixed with bio-resins, which gives good strength, light weight and natural insulation.

The system uses a Raspberry Pi Zero 2 W as the main processing unit. A Raspberry Pi camera module is connected through the CSI interface for real-time image capture. The captured images are shown on a 2.0-inch TFT touch display connected through SPI communication, allowing interactive use.

All electronic components are properly fixed inside the biodegradable enclosure to maintain a compact design and safe low-voltage operation with a regulated 5 V power supply. The system provides an environmentally friendly and scalable solution by combining sustainable materials with embedded multimedia technology for educational applications.

A. BLOCK DIAGRAM

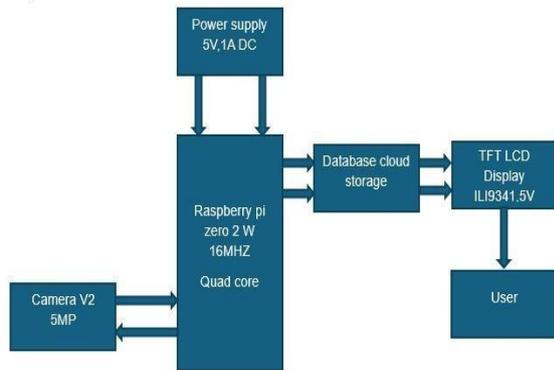


Fig1. Block Diagram

The block diagram illustrates the overall architecture of the proposed eco-friendly smart educational toy system. A regulated 5V, 1A DC power supply powers the Raspberry Pi Zero 2 W, which serves as the central processing unit. The Raspberry Pi is interfaced with a 5MP Camera Module (Camera V2) for real-time image capture. The processed data can be stored or accessed through cloud database connectivity when required. The captured images and system interface are displayed on the 2.8-inch TFT

LCD (ILI9341) display, enabling user interaction. The display acts as the output interface, allowing the user to view images and control system functions. This architecture ensures compact integration, multimedia processing capability and efficient operation within the eco-friendly banana fiber enclosure.

B. FLOW CHART

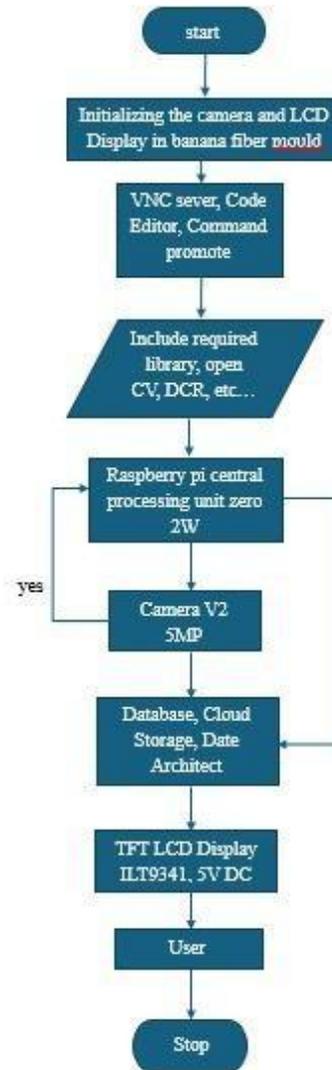


Fig2. Flow Chart

The flowchart represents the operational sequence of the proposed system. The process begins with system initialization, where the camera module and TFT LCD display are configured within the banana fiber enclosure. Required libraries and program modules are loaded through the command interface. The Raspberry Pi Zero 2 W then acts as the central processing unit, controlling the camera and display operations. The Camera V2 captures real-time images, which are processed and optionally stored or managed through database or cloud connectivity.

The processed output is displayed on the ILI9341 TFT LCD screen for user interaction. The system continues operation based on user input and finally terminates when the stop condition is triggered.

C. HARDWARE IMPLEMENTATION

The hardware of the proposed system includes a Raspberry Pi Zero 2 W, a Raspberry Pi camera module and a 2.0-inch TFT touch display placed inside a banana fiber bio-composite enclosure. The Raspberry Pi Zero 2 W works as the main processing unit and controls image capture, display functions and user interaction. The camera module is connected through the CSI interface to capture images in real time, and the TFT touch display is connected through SPI communication to show graphics and allow touch control. Connectors and ribbon cables are used to maintain stable connections between all modules. All components are fixed securely inside the banana fiber molded mannequin body, which provides strength and natural insulation. The system runs on a regulated 5 V power supply to ensure safe and reliable operation in a compact hardware setup.

Hardware Components:

[i] Banana Fiber Raw Material: Banana fiber raw material is collected from the pseudo-stem and sheath of the banana plant after harvesting. The fibers are cleaned, dried and ground into fine pulp. This pulp is mixed with natural binders and molded into the required mannequin shape. The molded structure is then dried and used as the eco-friendly enclosure for the electronic components.

[ii] Mannequin mould: The prepared banana fiber pulp mixed with natural binders is poured into a mannequin mould of the required shape. The material is evenly pressed and allowed to dry properly under sunlight or controlled conditions. After complete drying, the molded structure is carefully removed from the mould. The final product forms a strong and eco-friendly mannequin body for mounting the electronic components.

[iii] Raspberry pi Zero 2 W: The Raspberry Pi Zero 2 W is a compact and low-cost single-board computer used as the main controller in the system. It handles camera capture, TFT touch display control and user interaction, with built-in Wi-Fi and Bluetooth support.

Its small size, low power consumption and reliable performance make it suitable for the eco-friendly smart educational device

[iv] Raspberry pi 5MP Camera Board: A small camera module connected to the Raspberry Pi through the CSI interface. It captures clear images for real-time use in the system. In this project, the camera takes images that are processed by the Raspberry Pi Zero 2 W and displayed on the TFT touch screen. Its compact size and simple connection make it suitable for use inside the eco-friendly banana fiber educational toy.

[v] LCD Touch Panel: The Xcluma 2.8-inch SPI TFT LCD Touch Panel with ILI9341 controller is used as the display unit in the system. It communicates through SPI and supports 5V/3.3V operation, making it compatible with the Raspberry Pi Zero 2 W. The display provides graphical output and touch interaction for image viewing and system control in the eco-friendly educational toy.

D. WORKING OF PROPOSED SYSTEM

The working of the proposed system begins with powering the Raspberry Pi Zero 2 W using a regulated 5 V supply. After booting, the system initializes the camera module and the TFT touch display. When the user interacts with the touch display, the Raspberry Pi activates the camera module to capture an image in real time. The captured image is then processed and displayed on the TFT touch screen. The Raspberry Pi continuously manages the display output and user input through SPI and CSI interfaces. All operations are performed within the biodegradable banana fiber enclosure, ensuring compact integration and safe low-voltage functioning. The system provides an interactive and multimedia-based learning experience while maintaining eco-friendly design principles.



Fig3. Working of Proposed System

VI. RESULT AND DISCUSSION

The developed prototype of the smart eco-friendly educational toy was successfully implemented using a banana fiber bio-composite enclosure integrated with a Raspberry Pi Zero 2 W, camera module and TFT touch display. The system operated reliably under a regulated 5 V power supply, demonstrating stable performance without overheating or communication errors.

The camera module successfully captured real-time images, and the images were displayed clearly on the TFT touch screen. The touch interface responded accurately to user inputs, providing smooth interaction and improved user engagement. The compact hardware arrangement inside the banana fiber mannequin structure ensured secure component placement and efficient space utilization.

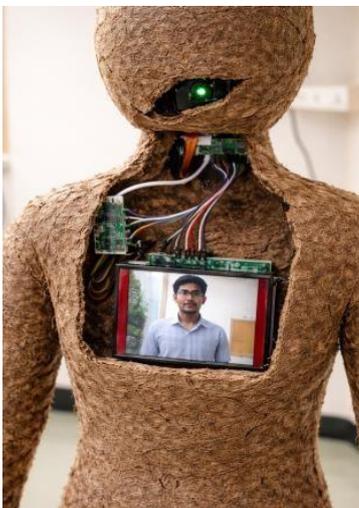


Fig.1 Final eco-friendly smart educational toy prototype with banana fiber enclosure.

The banana fiber enclosure exhibited adequate mechanical strength and natural insulation properties, effectively protecting the internal electronic components. Compared to conventional plastic-based systems, the proposed design significantly reduces plastic usage while maintaining functionality and performance.

The results confirm that biodegradable materials can be effectively integrated with embedded multimedia systems. The proposed system demonstrates the feasibility of combining sustainable material engineering with smart electronic design to develop environmentally responsible educational devices.

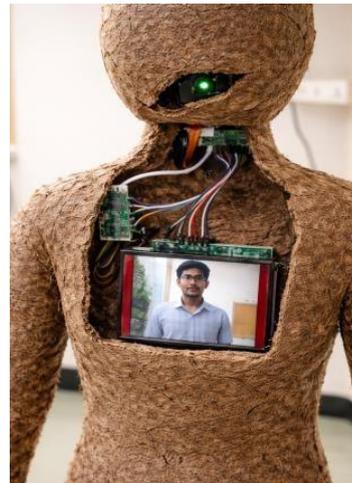


Fig.2 Developed banana fiber smart educational toy prototype with integrated camera and touch display.

VII. CONCLUSION

The proposed smart eco-friendly educational toy successfully integrates banana fiber bio-composite material with embedded multimedia technology. The use of a biodegradable banana fiber enclosure reduces dependency on plastic materials while providing sufficient mechanical strength and natural insulation. The Raspberry Pi Zero 2 W, along with the camera module and TFT touch display, enables real-time image capture and interactive user experience.

The developed system demonstrates reliable performance, compact hardware integration and safe low-voltage operation. The results confirm that sustainable materials can be effectively combined with modern embedded computing platforms to create environmentally responsible and technologically advanced educational devices. This work establishes a foundation for future development of eco-friendly smart electronic products.

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