Preliminary Design Report

Team 8 - PlayPal

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Abstract

This preliminary design report presents the initial design solution for the PlayPal Interactive Learning System, an innovative educational toy designed to enhance early childhood development through interactive play. The system incorporates modern sensor technology, engaging visual feedback, and adaptive learning algorithms to create a personalized learning experience for children aged 3-6 years. This report details our engineering requirements, functional decomposition, behavioral models, and project management plan based on feedback received from our initial proposal.

1 Comment and Response

This section summarizes major instructor comments and changes made based on feedback. The primary feedback from our initial proposal focused on three key areas: (1) clarifying the target age range and specific learning objectives, (2) providing more detailed technical specifications for the sensor systems, and (3) expanding the safety analysis. In response, we have narrowed our target demographic to children aged 3-6 years, specified the use of capacitive touch sensors and RGB LED arrays, and conducted a comprehensive safety analysis including material selection and electrical safety considerations.

2 Problem Statement

2.1 Need

Traditional educational toys often lack the adaptability to grow with a child's learning pace and fail to provide meaningful feedback to parents and educators. Current market solutions are typically static, offering limited interaction patterns that quickly become repetitive and lose the child's interest. There is a clear need for an intelligent learning system that can adapt to individual learning styles while maintaining engagement through dynamic, responsive play experiences.

2.2 Background

Existing educational toys in the market can be categorized into three main types: passive toys (blocks, puzzles), electronic toys with fixed responses, and app-based learning systems. While each category has merits, none successfully combines the tactile benefits of physical play with the adaptability of digital learning systems. Recent advances in embedded systems, sensor technology, and machine learning algorithms present an opportunity to create a hybrid solution that addresses these limitations.

2.3 Objective

The objective of this project is to design and prototype an interactive learning system that combines physical play with intelligent digital feedback. The system shall adapt to individual learning patterns, provide engaging multi-sensory feedback, and offer progress tracking capabilities for parents and educators.

3 Requirements Specification

3.1 Marketing Requirements

- The system shall be suitable for children aged 3-6 years
- The system should be priced competitively with premium educational toys ($150-$300)
- The system shall operate for at least 8 hours on a single battery charge
- The system should be easily cleanable and durable for daily use
- The system shall comply with all relevant child safety standards

3.2 Objective Tree

The primary objective of creating an adaptive learning system breaks down into three main sub-objectives:

1. Hardware Development: Create robust, safe, and responsive physical interface
2. Software Development: Implement adaptive algorithms and user interface
3. Integration and Testing: Ensure seamless operation and validate learning outcomes

3.3 Engineering Requirements

ER 1: Touch Response Time

Rationale: Children require immediate feedback to maintain engagement and associate actions with outcomes

Verification:

- Response time shall be less than 100ms from touch detection to visual feedback
- System shall detect touch pressure variations of at least 3 distinct levels

ER 2: Battery Life

Rationale: Extended play sessions are essential for meaningful learning experiences

Verification:

- System shall operate for minimum 8 hours of continuous use on single charge
- Battery level indicator shall provide clear status to users
- Low battery warning shall activate when 15% capacity remains

ER 3: Safety Standards

Rationale: Child safety is paramount in all design decisions

Verification:

- All materials shall be non-toxic and comply with CPSIA standards
- Electrical components shall be fully enclosed and inaccessible
- Surface temperature shall not exceed 104°F (40°C) during operation

3.4 Impact Statements

Standards Impact

The PlayPal system must comply with multiple safety and regulatory standards including CPSIA (Consumer Product Safety Improvement Act), FCC Part 15 for electromagnetic emissions, and ASTM F963 for toy safety. The design incorporates these requirements from the ground up, with material selection, electrical design, and mechanical construction all following relevant guidelines. Regular testing and validation will ensure continued compliance throughout the development process.

Economic Impact

The economic impact of this project extends beyond the immediate development costs. By creating an adaptive learning system, we address a growing market demand for intelligent educational tools, potentially generating significant revenue. The modular design approach allows for cost-effective manufacturing scaling and future product variations. Additionally, the system's durability and adaptability provide long-term value to consumers, justifying premium pricing in the educational toy market.

Environmental Impact

Environmental considerations have been integrated into our design approach through material selection and energy efficiency optimization. The system uses rechargeable batteries to minimize waste, and all plastic components are selected from recyclable materials where possible. The long operational life and adaptable software reduce the need for replacement products, contributing to reduced electronic waste in the educational toy sector.

4 Design

4.1 Design Summary

The PlayPal system consists of three main subsystems: the Interactive Playmat, the Smart Toys, and the Parent/Educator Dashboard. The Interactive Playmat serves as the central hub, featuring a grid of capacitive touch sensors beneath a durable, washable surface. Smart Toys contain embedded RFID tags and LED indicators that interact with the playmat to create dynamic learning scenarios. The dashboard provides real-time progress tracking and learning analytics.

4.2 Functional Decomposition

4.3 Level 0: System Overview

The top-level system accepts user inputs through touch interactions and toy placement, processes these through the central controller, and provides multi-modal feedback through visual, audio, and haptic channels. [Figure placeholder - Level 0 Functional Block Diagram would be inserted here]

4.4 Level 1: Subsystem Breakdown

The system decomposes into five major subsystems:

- Sensor Array Subsystem
- Processing and Control Subsystem
- Feedback Generation Subsystem
- Power Management Subsystem
- Communication Subsystem

4.5 Level 2: Component Level

Each subsystem further breaks down into specific components:

Playmat Components:

- 64-element capacitive sensor array
- RGB LED matrix (8x8)
- Embedded microcontroller (ARM Cortex-M4)
- Wireless communication module

Smart Toy Components:

- RFID tags for identification
- Integrated LED indicators
- Accelerometer for motion detection

4.6 Behavioral Models

4.7 Overall Behavioral Model

The system operates in two primary modes: Active Learning Mode and Free Play Mode. In Active Learning Mode, the system presents structured challenges and tracks progress. In Free Play Mode, the system responds to user actions without specific objectives, encouraging creative exploration.

4.8 Stop Mode Behavior

When in Stop Mode, the system maintains minimal power consumption while monitoring for wake-up conditions:

- Touch sensor monitoring at reduced frequency
- Status LED breathing pattern
- Wireless connectivity maintained for remote wake-up

4.9 Go Mode Behavior

In Go Mode, the system provides full functionality:

- Real-time sensor monitoring
- Dynamic LED feedback
- Audio feedback generation
- Data logging and transmission

5 Project Plan

5.1 Work Breakdown Structure (WBS)

Sub-project: Hardware Development

Lead: John Smith

Deliverables:

- PCB design and fabrication
- Sensor integration and testing
- Enclosure design and 3D printing
- Hardware validation testing

Sub-project: Firmware Development

Lead: Jane Doe

Deliverables:

- Microcontroller programming

- Sensor driver development
- Communication protocol implementation
- Real-time system optimization

Sub-project: Software Application

Lead: Bob Johnson

Deliverables:

- Mobile application development
- User interface design
- Database design and implementation
- Cloud integration services

Sub-project: Learning Algorithm Development

Lead: Alice Wilson

Deliverables:

- Adaptive learning algorithm design
- Data analysis and machine learning implementation
- Progress tracking system
- Educational content development

5.2 Gantt Chart

The project timeline spans 16 weeks with four major phases:

1. **Phase 1 (Weeks 1-4):** Requirements finalization and initial prototyping
2. **Phase 2 (Weeks 5-8):** Hardware development and firmware implementation
3. **Phase 3 (Weeks 9-12):** Software development and algorithm implementation
4. **Phase 4 (Weeks 13-16):** Integration, testing, and validation

Critical path activities include PCB fabrication (3 weeks), firmware development (4 weeks), and final integration testing (2 weeks).

Table 1: Project Cost Breakdown

Category	Estimated Cost	Actual Cost
Electronic Components	$450	$487
PCB Fabrication	$200	$195
Enclosure Materials	$150	$142
Development Tools	$300	$300
Testing Equipment	$100	$95
Total	$1,200	$1,219

5.3 Cost Analysis

The total project cost remains within the allocated budget of $1,500, providing a 23% buffer for unexpected expenses.

6 Implementation Examples

6.1 Python Algorithm Implementation

```
class AdaptiveLearningEngine:
    def __init__(self):
        self.difficulty_level = 1
        self.success_rate = 0.0
        self.attempt_history = []

    def update_difficulty(self, success):
        self.attempt_history.append(success)
        if len(self.attempt_history) >= 5:
            recent_success_rate = sum(self.attempt_history[-5:]) / 5

            if recent_success_rate > 0.8:
                self.difficulty_level = min(10, self.difficulty_level + 1)
            elif recent_success_rate < 0.4:
                self.difficulty_level = max(1, self.difficulty_level - 1)

    def generate_challenge(self):
        return f"Challenge level {self.difficulty_level}"
```

Listing 1: Adaptive Learning Algorithm

6.2 MATLAB Signal Processing

```
function filtered_signal = process_touch_data(raw_data, fs)
    % Apply low-pass filter to remove noise
    fc = 10; % Cutoff frequency (Hz)
    [b, a] = butter(4, fc/(fs/2), 'low');
    filtered_signal = filtfilt(b, a, raw_data);
```

```
    % Threshold detection
    threshold = 0.1;
    touch_detected = filtered_signal > threshold;

    % Debouncing
    min_touch_duration = 0.05; % 50ms
    touch_events = find_touch_events(touch_detected, fs,
       min_touch_duration);
end
```

Listing 2: Touch Sensor Signal Processing

6.3 System Configuration

```
$ sudo apt-get update
$ sudo apt-get install python3-pip
$ pip3 install numpy matplotlib scipy
$ git clone https://github.com/team8/playpal-firmware.git
$ cd playpal-firmware
$ make all
$ make flash
Device programmed successfully!
System ready for testing.
```

Listing 3: System Setup Commands

7 Conclusion/Outlook

The preliminary design presented in this report demonstrates a comprehensive approach to creating an adaptive learning system that addresses identified market needs. Our engineering requirements provide clear, measurable objectives, while the functional decomposition ensures systematic development. The project plan establishes realistic timelines and resource allocation within budget constraints.

Moving forward, the next phase will focus on detailed hardware design and initial prototype fabrication. Key milestones include completing the PCB design by week 4, achieving first sensor readings by week 6, and demonstrating basic adaptive behavior by week 10. Risk mitigation strategies have been developed for critical components, including backup suppliers for key sensors and alternative algorithms for learning adaptation.

The team is confident that this design approach will result in a successful product that advances the state of educational technology while providing meaningful learning experiences for children.

Appendix

.1 Additional Technical Specifications

.1.1 Sensor Specifications

The capacitive touch sensors operate at 100kHz with 12-bit resolution, providing sensitivity down to 0.1pF changes. The sensor array covers a 400mm x 400mm active area with 50mm pitch between sensing elements.

.1.2 Communication Protocols

The system implements multiple communication protocols:

- I2C for internal sensor communication
- SPI for LED matrix control
- WiFi 802.11n for cloud connectivity
- Bluetooth LE for mobile device pairing

.1.3 Power Consumption Analysis

Table 2: Power Consumption by Subsystem

Subsystem	Power (mW)
Microcontroller	45
Sensor Array	120
LED Matrix	200
Wireless Module	80
Audio System	150
Total	595