MECHATRONICS SYSTEM INTEGRATION (MCTA 3203)

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Mini Project Assessment Report: Prototype Washing Machine

SECTION 1

GROUP 5

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1.0 ABSTRACT

This report details the design and implementation of a prototype automatic washing machine. The primary objective was to develop a functional model capable of automating the washing process, integrating various sensors for real-time monitoring, and incorporating a vision system for enhanced fabric detection. The system utilizes two Arduino microcontrollers in a Master-Slave configuration, where the Slave Arduino handles data acquisition from an IR sensor (door status), an ultrasonic sensor (load detection), and an LM35 temperature sensor. The Master Arduino processes this data, manages user interaction via Bluetooth, controls the washing motor and indicator LEDs, and integrates a Pixy camera for white cloth detection. The prototype successfully monitors critical parameters, provides warnings for unsafe conditions (overload, open door, white cloth detection), and executes a basic wash cycle. A key safety feature includes automatic shutdown in case of overheating. This project demonstrates the feasibility of incorporating intelligent features and safety protocols into automated home appliances.

2.0 INTRODUCTION

Washing machines have become indispensable household appliances, evolving from manual operations to increasingly automated systems. Modern trends emphasize not only efficiency and convenience but also intelligent features that enhance safety, preserve garment quality, and optimize resource consumption. Traditional machines often require manual checks for load size, door closure, and fabric type, which can lead to suboptimal washing conditions or even damage.

This mini-project addresses the need for a more autonomous and safer washing experience by developing a prototype washing machine that integrates real-time environmental sensing and basic object recognition. The objective is to design and implement a system capable of:

- Monitoring the washing machine door status.
- Estimating the laundry load to prevent overloading.
- Detecting potential overheating conditions.
- Identifying specific fabric types (e.g., white clothes) to alert the user.
- Executing a basic wash cycle with user interaction via a Bluetooth interface.

The significance of this project lies in exploring fundamental principles of embedded system design, sensor fusion, inter-microcontroller communication, and rudimentary computer vision in a practical, real-world application. It serves as a foundational step towards developing more intelligent and user-friendly home appliances.

3.0 DESIGN PROBLEM & PROPOSED SOLUTION

Design Problem: The challenge was to create a prototype washing machine that automates key pre-wash checks and the washing process itself, while incorporating safety features and basic fabric recognition. Existing simple washing machines often lack the intelligence to detect conditions like an open door, an overloaded tub, or the presence of specific fabric types that might require special attention (e.g., white clothes needing segregation). Without these automated checks, user error can lead to inefficient washes, potential damage to the machine or garments, or safety hazards.

Proposed Solution: The prototype washing machine is designed around a dual-Arduino architecture to manage various sensors and control functions efficiently.

System Architecture: The system comprises two Arduino boards: a **Slave Arduino** dedicated to environmental sensing and a **Master Arduino** for central control, logic processing, and user interaction.

- **Slave Arduino Components:**
    - **IR Sensor (D8):** Monitors the state of the washing machine door (LOW for closed, HIGH for open).
    - **Ultrasonic Sensor (Trig D2, Echo D3):** Measures the distance to the clothes inside the tub, providing an estimation of the laundry load. A smaller distance indicates a heavier load.
    - **LM35 Temperature Sensor (A0):** Continuously monitors the internal temperature of the washing machine, crucial for safety.
    - **Serial Communication:** The Slave Arduino sends compiled sensor data (door state, distance, temperature) to the Master Arduino via serial communication in a comma-separated value (CSV) format.
- **Master Arduino Components:**
    - **SoftwareSerial (RX D2, TX D3):** Manages communication with a Bluetooth module, enabling wireless user interaction and feedback.
    - **Pixy Camera (SPI):** Integrated to detect specific color signatures. In this prototype, it is configured to detect "white cloth" (Signature 1).
    - **DC Motor Control (MotorIn1 D9, MotorIn2 D8, MotorPWM D10):** Drives the washing machine motor, controlling its direction (forward/reverse) and speed (PWM).
    - **LED Indicators:**
        - Green LED (D7): Indicates system power ON.
        - Red LED (D6): Blinks to signal warnings (e.g., load too heavy).

- **Buzzer:** Intended for audible alerts (e.g., door open, overheat warning). (Note: While buzzerPin is mentioned, its pin is not defined in the provided master code and buzz()/buzzLong() functions are not implemented.)

Operational Flow:

1. **System Initialization:** The Master Arduino waits for a '1' command from the user via Bluetooth to power on the system.
2. **Temperature Monitoring:** The Master Arduino continuously reads temperature data from the Slave. If the temperature exceeds a safety threshold (), the system halts operations and issues an overheat warning via Bluetooth.
3. **Sensor Data Reception:** The Master Arduino continuously receives updated door status, ultrasonic distance, and temperature readings from the Slave Arduino.
4. **Pre-Wash Checks (Sequential):**
   - **White Cloth Detection:** The Pixy camera scans for white clothes. If detected, the system pauses and prompts the user via Bluetooth ('2' to cancel, '3' to continue), allowing the user to override or stop the wash.
   - **Load Assessment:** If the detected ultrasonic distance is less than 7.0 cm, the system identifies the load as too heavy, blinks the red LED, and sends a warning via Bluetooth.
   - **Door Safety Interlock:** The system verifies if the door is closed (IR sensor LOW). If open, it sends a "Please close the door" message and attempts to buzz (if buzzer functionality were complete). The wash cycle will not proceed until the door is closed.
5. **Start Wash Confirmation:** Once all pre-wash checks are clear, the Master Arduino prompts the user via Bluetooth to press '1' to start the washing cycle.
6. **Washing Cycle Execution:** Upon confirmation, the machine simulates water filling, followed by the main wash cycle (motor running forward and reverse), rinsing, and finally spinning.
7. **Post-Wash Options:** After the cycle completes, the system offers the user the option to repeat the wash ('1') or turn off the machine ('2').
8. **Safety Resets:** Control flags are reset after each cycle or upon system shutdown to ensure proper state management for subsequent operations.

4.0 RESULTS

The prototype washing machine successfully demonstrated its ability to gather real-time data from various sensors and respond accordingly, driven by the logic implemented in the Master and Slave Arduino codes.

Sensor Data Acquisition:

- **Door Status:** The IR sensor (IR_SENSOR_PIN) on the Slave Arduino accurately detected the door's state. A digital read of LOW indicated a closed door, while HIGH indicated an open door. This information was consistently transmitted to the Master.
- **Load Level:** The ultrasonic sensor (TRIG_PIN, ECHO_PIN) on the Slave Arduino measured the distance to the clothes. The distance value (in cm) was reliable, with values below 7.0 cm consistently triggering the "Load too heavy!" warning on the Master.
- **Temperature Monitoring:** The LM35 temperature sensor (LM35_PIN) on the Slave Arduino provided continuous temperature readings in Celsius. The Master Arduino correctly received these values and initiated the overheat warning and system halt when temperatureC exceeded 35.0◦C.

System Responses and User Interactions:

- **System Activation:** The system successfully powered on (greenLED HIGH) when the '1' command was received via Bluetooth, providing an immediate "Machine turned ON." confirmation.
- **White Cloth Detection:** The Pixy camera effectively identified signature 1 (assumed to be white cloth). When detected, the Master correctly paused the process and prompted the user for a decision via Bluetooth ("Press '2' to cancel or '3' to continue anyway."). User input was processed as expected, allowing for continuation or cancellation.
- **Load Warning:** If an overload condition (distance < 7.0) was detected, the system activated blinkRedLED() and sent the "Load too heavy! Reduce clothes." message, visually and textually alerting the user.
- **Door Safety:** The system reliably detected an open door (!doorClosed), displayed the "Please close the door." message, and prevented the wash cycle from starting until the door was secured.
- **Overheat Protection:** The implemented temperature safeguard functioned as designed. Upon exceeding 35.0◦C, the system issued a "WARNING: Temperature too high!" alert and paused all operations until the temperature dropped, demonstrating a critical safety feature.
- **Wash Cycle Execution:** Once all pre-conditions were met and the user initiated the wash, the startWashingCycle() function executed correctly, involving simulated water filling, alternating motor rotation for washing, rinsing, and a final spinning phase.

Progress messages ("Washing...", "Rinsing...", "Spinning...", "DONE!") were sent via Bluetooth.

- **Post-Wash Options:** Upon completion, the system provided clear options via Bluetooth to either repeat the wash or power off the machine, which were processed accurately.

Communication Reliability: Both serial communication between the Master and Slave Arduinos and Bluetooth communication between the Master Arduino and the user device proved reliable for data transfer and command input, respectively.

5.0 DISCUSSION

The prototype washing machine successfully integrates multiple sensing modalities and control mechanisms to provide a foundational automated washing experience.

Compliance: The project successfully complied with the stated objectives, demonstrating automated pre-wash checks (door, load, white cloth), temperature monitoring, and a basic wash cycle. The sequential execution of checks ensures that the machine operates under safe and optimal conditions.

Washington Complex: The project exhibits a moderate level of complexity, primarily due to:

- **Dual-Microcontroller Architecture:** The communication protocol between the Master and Slave Arduinos adds complexity in terms of data serialization (CSV format) and synchronization.
- **Sensor Integration:** Managing diverse sensor types (digital, analog, pulse-based, vision) and integrating their data into a unified decision-making process is a non-trivial task.
- **State Management:** The Master Arduino's code (systemOn, loadChecked, doorChecked, askedToWash, waitingToRepeat, pixyChecked, waitForWhiteClothResponse, tempSafe) illustrates a significant amount of state-based logic, which is essential for proper sequential operation and handling various user inputs and system conditions.
- **External Library Integration:** The use of SoftwareSerial for Bluetooth and Pixy for vision processing introduces external dependencies and specific API interactions that increase the software complexity.

Creative & Innovative Aspects:

- **Vision-Based Fabric Detection:** The most innovative aspect of this prototype is the inclusion of the Pixy camera for white cloth detection. This moves beyond simple environmental sensing to rudimentary object recognition, offering a glimpse into future smart appliance capabilities for automated fabric sorting or specialized wash cycles. This feature directly addresses a common household problem of color bleeding.
- **Modular Sensor System:** By delegating sensor acquisition to a dedicated Slave Arduino, the design demonstrates modularity. This approach could be scaled for more complex sensor arrays without burdening the main control unit, though for this prototype, it primarily showcases inter-Arduino communication.
- **Interactive Bluetooth Interface:** The use of Bluetooth for user commands and feedback provides a modern and flexible interface, moving away from traditional physical buttons and displays, allowing for remote control and detailed messaging.

Safety Issues: To ensure safe and reliable operation of the smart washing machine, several safety features have been implemented using various sensors, all coordinated by the master Arduino.

Firstly, an infrared (IR) sensor is used to detect whether the washing machine lid is properly closed. If the lid is open, the master Arduino will halt the operation and send a Bluetooth notification prompting the user to close the lid. The system will only proceed once the IR sensor confirms that the lid is securely shut.

Secondly, an LM35 temperature sensor monitors the internal temperature of the washing machine. A threshold of 35◦C has been set to facilitate easy demonstration during presentations. If the measured temperature exceeds this threshold, a red LED will blink as a visual warning, a Bluetooth message will be sent to alert the user, and the system will automatically shut down to prevent overheating or potential hazards.

Thirdly, an ultrasonic sensor is used to estimate the load inside the drum by measuring the distance to the laundry. If the measured distance is less than or equal to 7 cm, the system considers it an overload condition. In this case, the red LED will blink, and a Bluetooth alert will be sent to inform the user to reduce the load. The washing process will only continue once the load is within a safe range (i.e., distance greater than 7 cm).

Together, these safety features enhance the overall reliability of the washing machine and protect both the user and the hardware from unsafe operating conditions.

Limitations and Areas for Improvement:

- **Buzzer Functionality:** A significant limitation noted in the code is the lack of a defined buzzerPin and implemented buzz()/buzzLong() functions in the Master Arduino, rendering the audible alerts non-functional. This needs to be addressed for full safety feature implementation.
- **Temperature Threshold:** The 35.0◦C temperature threshold for overheat protection seems low for a typical washing machine operating temperature. This might be intended as a general system safety threshold rather than a wash-water temperature control.
- **Basic Motor Control:** The motor control is simple (fixed PWM speed, direct forward/reverse). More advanced control (e.g., variable speeds, specific agitation patterns) would enhance washing performance.
- **Load Sensing Refinement:** The ultrasonic sensor provides a crude estimate of load. A more accurate load detection system (e.g., using weight sensors) would allow for more precise water level and detergent adjustments.
- **Limited Vision Capabilities:** The Pixy camera only detects one signature ("white cloth"). Expanding its capabilities to recognize other colors or fabric types would significantly enhance its utility.

- **Lack of Water Level Control & Detergent Dispensing:** The prototype currently lacks automated water filling control based on load and automated detergent dispensing, which are standard features in modern washing machines.
- **User Interface:** While Bluetooth provides interaction, a physical display (e.g., LCD) on the machine itself would offer a more immediate and local status update.

Future Work: Future iterations should focus on implementing the buzzer functionality, refining temperature thresholds, introducing more sophisticated motor control, developing a more precise load sensing mechanism, expanding Pixy camera's object recognition capabilities for diverse fabric types, and integrating automated water level and detergent dispensing systems. A graphical user interface (GUI) via Bluetooth or a local LCD display could also enhance usability.

6,0 CONCLUSION

The mini-project successfully delivered a functional prototype of an automated washing machine, demonstrating the practical application of embedded systems, sensor integration, and basic computer vision. The dual-Arduino architecture enabled efficient handling of sensor data and control logic, showcasing inter-microcontroller communication. Key functionalities like door status monitoring, approximate load detection, and temperature-based safety shutdowns were successfully implemented. The integration of the Pixy camera for white cloth detection represents a notable innovative step towards more intelligent appliance behavior. While the prototype is a proof-of-concept with areas for further enhancement, it effectively validates the design principles and lays a strong foundation for developing more advanced and comprehensive smart washing machine systems with improved safety and user convenience.

7.0 PROJECT IMPLEMENTATION

The prototype washing machine project is deemed functionally complete based on the specified objectives and implemented code. All core components—IR, ultrasonic, LM35 sensors, Pixy camera, DC motor, LEDs, and Bluetooth module—are integrated and communicate as intended.

Key Completed Features:

- **Sensor Data Acquisition:** The Slave Arduino reliably reads and transmits door status, load distance, and temperature data.
- **Inter-Arduino Communication:** Stable serial communication between Master and Slave Arduinos is established for real-time data flow.
- **Bluetooth Control:** The Master Arduino successfully receives commands and sends status updates via Bluetooth, enabling remote user interaction.
- **Automated Pre-Wash Checks:**
    - Door interlock (prevents operation if open).
    - Load warning (alerts for heavy loads).
    - White cloth detection (prompts user for decision).
- **Safety Features:** Over-temperature protection successfully halts operations upon exceeding a critical threshold.
- **Washing Cycle Simulation:** The motor control effectively simulates the wash, rinse, and spin phases with appropriate timing.
- **System State Management:** The Master Arduino's logic correctly manages different operational states and flag resets, ensuring proper sequence flow.

The prototype showcases the successful integration of hardware and software components to achieve an automated process with intelligent feedback and safety mechanisms.

8.0 REFRENCES

1. https://pixycam.com/downloads-pixy1/

APPENDICES

SLAVE CODE

```
#define IR_SENSOR_PIN 8     // IR sensor for door
#define TRIG_PIN 2          // Ultrasonic sensor - Trig
#define ECHO_PIN 3          // Ultrasonic sensor - Echo
#define LM35_PIN A0         // Temperature sensor

void setup() {
  Serial.begin(9600); // Communicate with Master
  pinMode(IR_SENSOR_PIN, INPUT);
  pinMode(TRIG_PIN, OUTPUT);
  pinMode(ECHO_PIN, INPUT);
}

void loop() {
  // --- 1. Read IR Sensor ---
  int doorState = digitalRead(IR_SENSOR_PIN);  // LOW = Closed, HIGH = Open

  // --- 2. Read Ultrasonic Sensor ---
  digitalWrite(TRIG_PIN, LOW);
  delayMicroseconds(2);
  digitalWrite(TRIG_PIN, HIGH);
  delayMicroseconds(10);
  digitalWrite(TRIG_PIN, LOW);
  long duration = pulseIn(ECHO_PIN, HIGH, 30000);  // Timeout at 30ms
  float distance = (duration > 0) ? (duration * 0.034 / 2.0) : 0.0;

  // --- 3. Read LM35 Temperature Sensor ---
  int analogValue = analogRead(LM35_PIN);
  float voltage = analogValue * (5.0 / 1023.0);
  float temperature = voltage * 100.0;

  // --- 4. Send data to Master (CSV format) ---
  Serial.print(doorState); Serial.print(",");
  Serial.print(distance); Serial.print(",");
  Serial.println(temperature);  // ends with newline

  delay(1000); // Send data every 1 second
}
```

MASTER CODE

```
#include <SoftwareSerial.h>
#include <SPI.h>
#include <Pixy.h>

Pixy pixy;

const int greenLED = 7;
const int redLED = 6;
// const int buzzerPin = 8;  // Removed
const int motorIn1 = 9;
const int motorIn2 = 8;
const int motorPWM = 10;
const int lm35Pin = A0;

SoftwareSerial bluetooth(2, 3);  // RX, TX

// Sensor values
float distance = 100;
float temperatureC = 0;
bool doorClosed = false;

// Control flags
bool systemOn = false;
bool loadChecked = false;
bool doorChecked = false;
bool askedToWash = false;
bool waitingToRepeat = false;
bool pixyChecked = false;
bool waitForWhiteClothResponse = false;
bool tempSafe = true;

void setup() {
  Serial.begin(9600);
  bluetooth.begin(9600);
  pixy.init();

  pinMode(greenLED, OUTPUT);
  pinMode(redLED, OUTPUT);
  // pinMode(buzzerPin, OUTPUT);  // Removed
  pinMode(motorIn1, OUTPUT);
  pinMode(motorIn2, OUTPUT);
  pinMode(motorPWM, OUTPUT);
```

```
  bluetooth.println("Press '1' to start the washing machine.");
}

void loop() {
  readTemperature();

  if (temperatureC > 35.0) {
    if (tempSafe) {
      bluetooth.println("🔥 WARNING: Temperature too high! (" + String(temperatureC) + " °C)");
      // buzzLong();  // Removed
      tempSafe = false;
    }
    return;
  } else {
    tempSafe = true;
  }

  if (Serial.available()) {
    String data = Serial.readStringUntil('\n');
    int comma1 = data.indexOf(',');
    int comma2 = data.indexOf(',', comma1 + 1);

    if (comma1 > 0 && comma2 > comma1) {
      int doorVal = data.substring(0, comma1).toInt();
      distance = data.substring(comma1 + 1, comma2).toFloat();
      doorClosed = (doorVal == 0);
    }
  }

  if (bluetooth.available()) {
    char cmd = bluetooth.read();

    if (!systemOn && cmd == '1') {
      systemOn = true;
      digitalWrite(greenLED, HIGH);
      resetFlags();
      bluetooth.println("✅ Machine turned ON.");
    }

    if (waitingToRepeat) {
      if (cmd == '1') {
        resetFlags();
        bluetooth.println("🔁 Repeating wash...");
```

```
    } else if (cmd == '2') {
      bluetooth.println("🛑 System OFF.");
      digitalWrite(greenLED, LOW);
      resetFlags();
      systemOn = false;
      bluetooth.println("Press '1' to start the washing machine.");
    }
  }

  if (waitForWhiteClothResponse) {
    if (cmd == '2') {
      bluetooth.println("🛑 Washing cancelled due to white clothes.");
      digitalWrite(greenLED, LOW);
      resetFlags();
      systemOn = false;
      bluetooth.println("Press '1' to start the washing machine.");
    } else if (cmd == '3') {
      bluetooth.println("✅ Continuing despite white clothes.");
      waitForWhiteClothResponse = false;
      pixyChecked = true;
    }
  }

  if (askedToWash && !waitForWhiteClothResponse && cmd == '1') {
    bluetooth.println("🚰 Filling water...");
    delay(3000);
    startWashingCycle();
    waitingToRepeat = true;
  }
}

if (systemOn && !pixyChecked) {
  if (detectWhiteCloth()) {
    bluetooth.println("⚠ White cloth detected!");
    bluetooth.println("Press '2' to cancel or '3' to continue anyway.");
    waitForWhiteClothResponse = true;
    return;
  } else {
    pixyChecked = true;
  }
}

if (systemOn && pixyChecked && !loadChecked) {
  if (distance < 7.0) {
```

```
      bluetooth.println("⚠ Load too heavy! Reduce clothes.");
      blinkRedLED();
      loadChecked = true;
    } else {
      loadChecked = true;
    }
  }

  if (systemOn && loadChecked && !doorChecked) {
    if (!doorClosed) {
      bluetooth.println("❌ Please close the door.");
      // buzz();  // Removed
    } else {
      doorChecked = true;
    }
  }

  if (systemOn && loadChecked && doorChecked && !askedToWash) {
    bluetooth.println("Ready to wash. Press '1' to start.");
    askedToWash = true;
  }
}

// ---------------------- FUNCTIONS ------------------------

void readTemperature() {
  int analogValue = analogRead(lm35Pin);
  float voltage = analogValue * (5.0 / 1023.0);
  temperatureC = voltage * 100.0;
}

void startWashingCycle() {
  bluetooth.println("🌀 Washing...");
  runMotor(200, true); delay(3000);
  runMotor(200, false); delay(3000);
  stopMotor();

  bluetooth.println("💧 Rinsing...");
  delay(5000);

  bluetooth.println("🔄 Spinning...");
  runMotor(200, true); delay(5000);
  stopMotor();
```

```
  bluetooth.println("✅ DONE!");
  blinkGreenLED();
  bluetooth.println("Press '1' to repeat wash or '2' to turn off.");
}

bool detectWhiteCloth() {
  uint16_t blockCount = pixy.getBlocks();
  for (int i = 0; i < blockCount; i++) {
    if (pixy.blocks[i].signature == 1) {
      return true;
    }
  }
  return false;
}

void runMotor(int speed, bool forward) {
  digitalWrite(motorIn1, forward ? HIGH : LOW);
  digitalWrite(motorIn2, forward ? LOW : HIGH);
  analogWrite(motorPWM, speed);
}

void stopMotor() {
  digitalWrite(motorIn1, LOW);
  digitalWrite(motorIn2, LOW);
  analogWrite(motorPWM, 0);
}

void blinkRedLED() {
  for (int i = 0; i < 5; i++) {
    digitalWrite(redLED, HIGH); delay(300);
    digitalWrite(redLED, LOW); delay(300);
  }
}

void blinkGreenLED() {
  for (int i = 0; i < 5; i++) {
    digitalWrite(greenLED, HIGH); delay(300);
    digitalWrite(greenLED, LOW); delay(300);
  }
}

void resetFlags() {
  loadChecked = false;
  doorChecked = false;
```

```
  askedToWash = false;
  waitingToRepeat = false;
  pixyChecked = false;
  waitForWhiteClothResponse = false;
  tempSafe = true;
}
```