AUTONOMOUS ROBOTS FOR REAL-TIME MYCOTOXIN DETECTION IN GRAIN STORAGE UNITS

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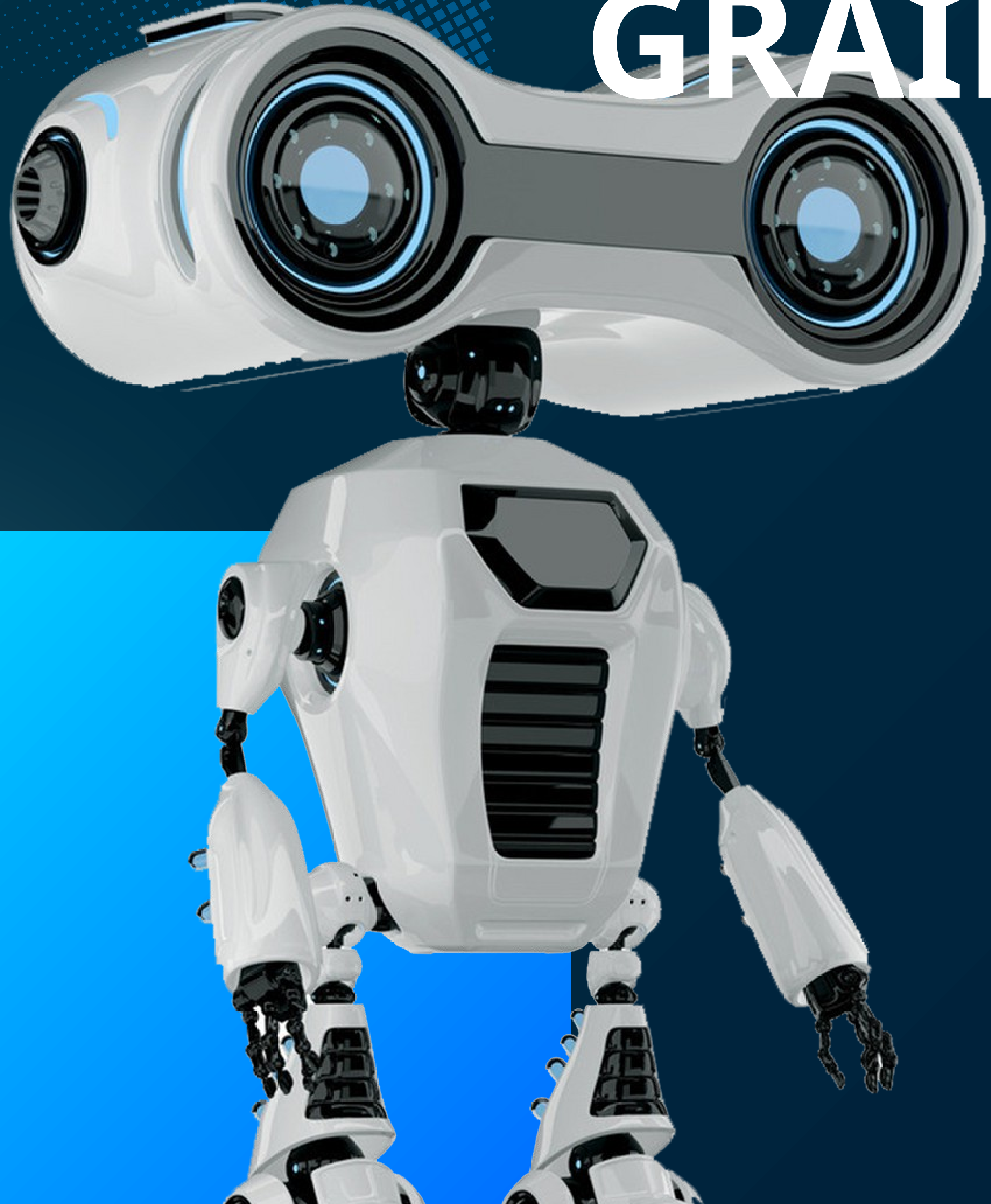

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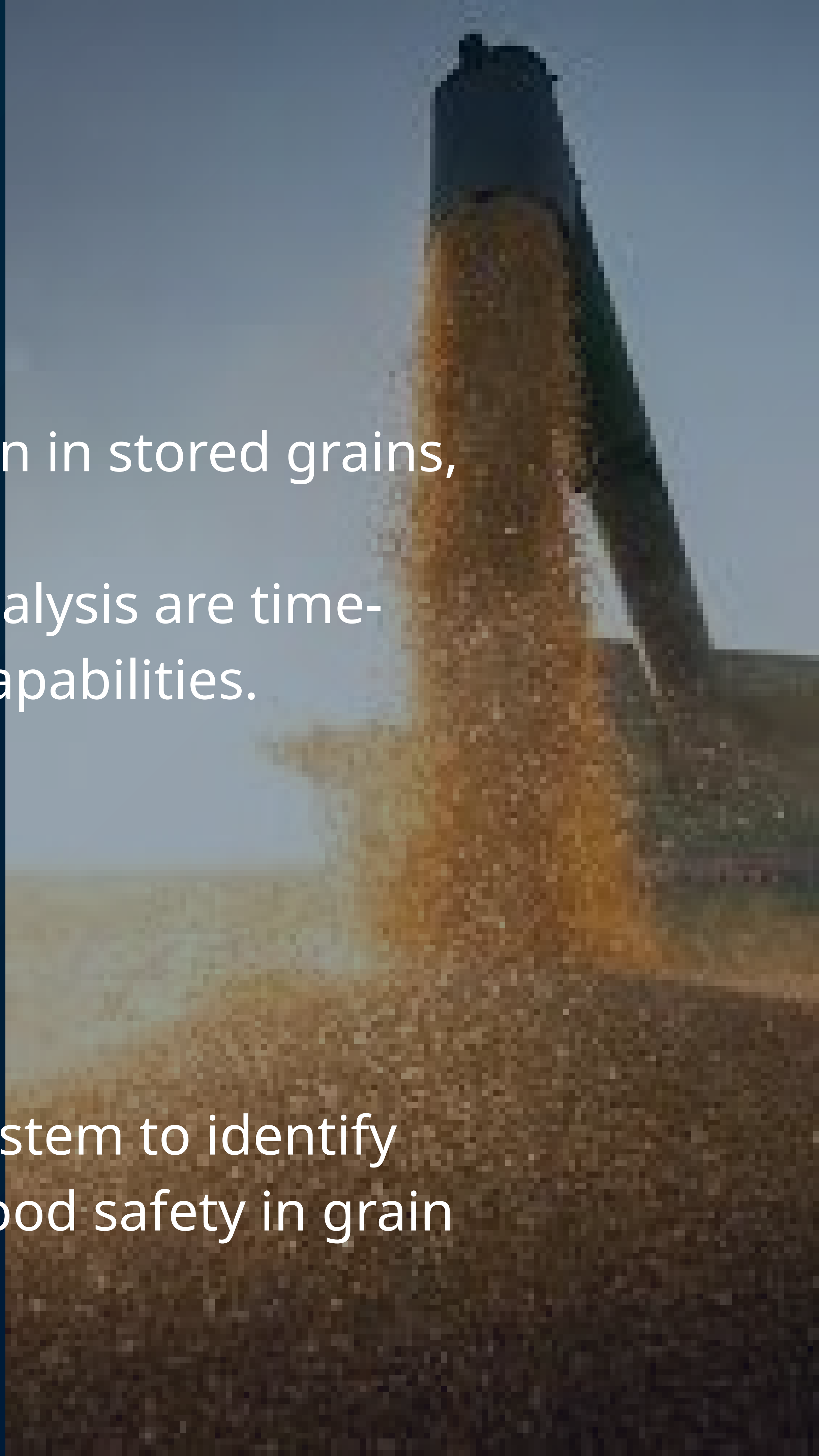
INTRODUCTION

- Mycotoxins, such as aflatoxins, pose significant health risks when present in stored grains, leading to food poisoning, economic losses, and compromised food security.
- Traditional detection methods rely on time-consuming laboratory analysis, making real-time monitoring challenging.
- To address this, we propose an autonomous robotic system integrated with an Overhead Conveyor System to navigate grain silos, detect mycotoxin contamination in real time, and ensure food safety.

OBJECTIVES

- Develop an autonomous robot for real-time mycotoxin detection in grain storage units.
- Integrate an Overhead Conveyor System for efficient movement across large grain silos.
- Utilize advanced mathematical models (Fourier Transform, Kalman Filter, Bayesian Models) for precise contamination detection.
- Improve food safety by minimizing manual sampling and lab dependency.

PROBLEM STATEMENT



- Grain Safety Challenge: High risk of mycotoxin contamination in stored grains, leading to severe health hazards and economic losses.
- Inefficient Traditional Methods: Manual sampling and lab analysis are time-consuming, labor-intensive, and lack real-time monitoring capabilities.

Critical Gaps:

- No real-time detection system for immediate intervention.
- Lack of predictive models to track contamination spread.
- Difficulty inspecting large, confined grain silos efficiently.
- Need for Innovation: An autonomous, real-time detection system to identify mycotoxin contamination, predict its spread, and enhance food safety in grain storage units.

LITERATURE REVIEW

SL No	Title	Journal & Year	Authors	Outcomes	Limitations
1	Real-Time Detection of Aflatoxins Using Gas Sensors	Food Control, 2021	Zhang et al.	Demonstrated gas sensors' effectiveness in aflatoxin detection	Limited to lab conditions
2	Autonomous Robots in Agriculture: A Review	Robotics, 2020	Singh & Patel	Highlighted applications of robots in crop monitoring	Limited focus on grain storage
3	Fourier Transform Applications in Sensor Signal Processing	IEEE Sensors Journal, 2019	Kumar & Liu	Improved contamination detection via spectral analysis	High computational complexity
4	Kalman Filtering Techniques for Noisy Sensor Data	Sensors, 2022	Wang et al.	Enhanced data accuracy in volatile environments	Struggles with highly dynamic noise
5	Bayesian Models for Predictive Analytics in Agriculture	AgriTech, 2020	Brown & Taylor	Improved prediction of crop diseases and contamination	Requires extensive historical data

LITERATURE REVIEW CONT

SL No	Title	Journal & Year	Authors	Outcomes	Limitations
6	Overhead Conveyor Systems in Industrial Automation	Automation Today, 2018	Lopez et al.	Increased efficiency in material handling	High initial installation cost
7	IoT-Based Grain Storage Monitoring Systems	Journal of IoT, 2021	Ahmed & Sharma	Enabled real-time monitoring of environmental factors	Limited to temperature and humidity data
8	Robotic Systems for Hazard Detection in Confined Spaces	Robotics & Automation, 2020	Chen et al.	Successful navigation and detection in tight environments	Energy consumption issues
9	Gas Sensor Networks for Environmental Monitoring	Environmental Sensors, 2019	Gupta & Rao	Effective in detecting air pollutants and toxins	Limited accuracy under fluctuating humidity levels
10	Real-Time Food Safety Monitoring Using Robotics	Food Safety Journal, 2022	Johnson & Lee	Demonstrated real-time contamination detection	High maintenance requirements

RESEARCH GAP

- Limited real-time monitoring solutions for mycotoxin detection in large-scale grain storage environments.
- Existing robotic systems are not optimized for confined silo spaces and lack integrated predictive models.
- Insufficient integration of advanced mathematical models (Fourier Transform, Kalman Filter, Bayesian Models) with autonomous systems for contamination analysis.
- Need for cost-effective, scalable solutions that combine automation with high detection accuracy.

PROPOSED METHOD

- Robotic Platform: An autonomous robot mounted on an Overhead Conveyor System for flexible movement across silo sections.

- Detection Mechanism: Equipped with gas sensors to detect volatile compounds emitted by contaminated grains.

- Data Analysis:
  - Fourier Transform: Analyzes variations in sensor data to identify contamination patterns.
  - Kalman Filter: Reduces noise and ensures accurate sensor readings.
  - Bayesian Probability Model: Predicts the potential spread of contamination within the silo.

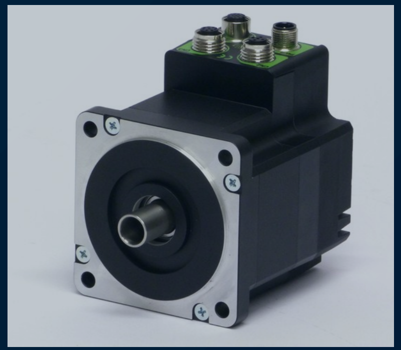
- Automation: Real-time data processing and automated alerts for detected contamination.

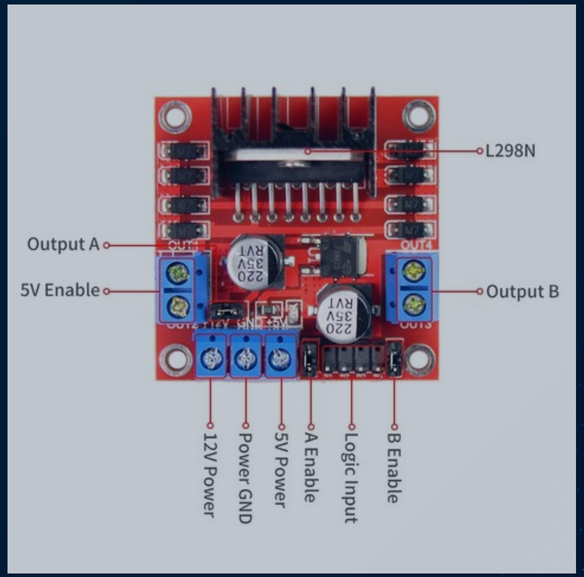
HARDWARE REQUIREMENTS

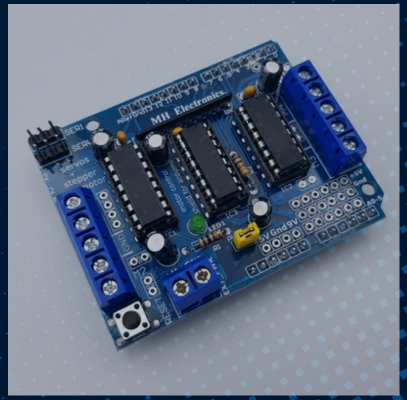
1. Main Controller/Processor
   - Raspberry Pi 4 or NVIDIA Jetson Nano for running AI algorithms and real-time processing.
   - Arduino Uno or ESP32 for handling sensor data acquisition and motor control.
2. Motors and Movement Components
   - DC Motors for controlling movement along the conveyor system.
   - Servo Motors for precise control of sensor positioning and robotic arms.
   - Stepper Motors for accurate positioning on the conveyor tracks.
   - Motor Drivers (L298N, L293D) to interface motors with microcontrollers.
   - Overhead Conveyor System:
     - Conveyor Belts/Rails for smooth movement across grain silos.
     - Pulley System for tension control and directional changes.
     - Trolley/Carriage Mechanism to mount the robot for flexible overhead movement.
   - Chassis Frame to mount components securely.
3. Power Supply
   - LiPo or Li-ion Batteries for portable power.
   - Power Distribution Board for efficient power management.
   - Battery Charger compatible with the power system.
4. Sensors for Mycotoxin Detection
   - Gas Sensors (e.g., MQ-135, MQ-7) for detecting VOCs linked to mycotoxins.
   - Electrochemical Sensors for specific gas detection like ammonia or ethanol.
   - Analog-to-Digital Converter (ADC) for processing analog sensor outputs.
5. Navigation and Obstacle Detection
   - Ultrasonic Sensors (HC-SR04) for obstacle avoidance along the conveyor path.
   - Infrared Sensors for line-following and edge detection.
   - IMU (Inertial Measurement Unit) for stability and orientation control.
   - Limit Switches to detect the endpoints of conveyor movement.





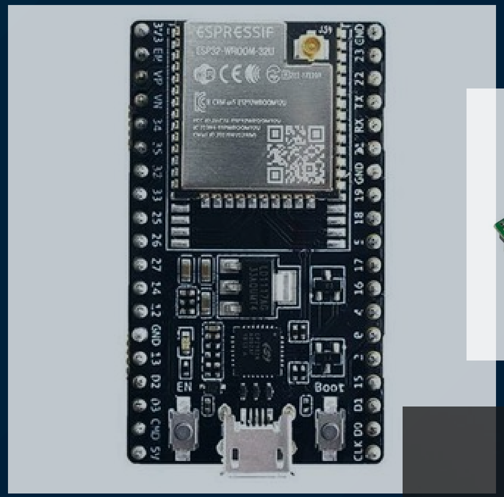


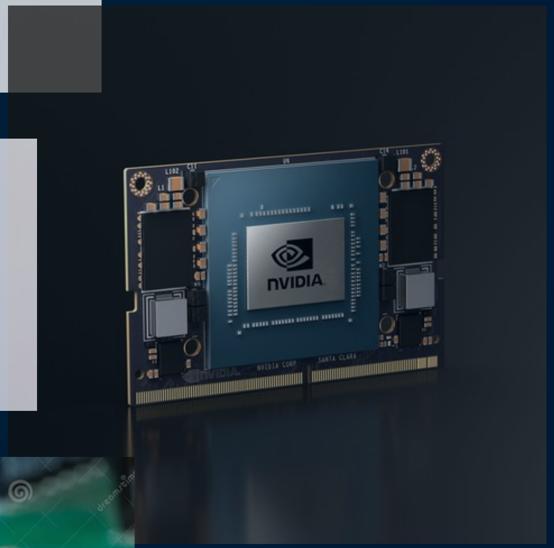
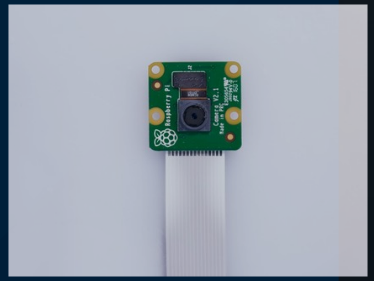


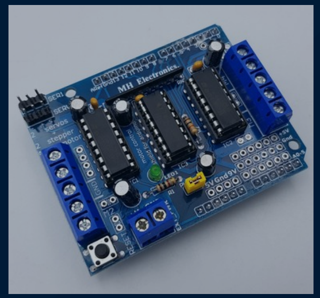


HARDWARE REQUIREMENTS

6. Communication Modules
    - Wi-Fi (ESP32) or Bluetooth for short-range communication.
    - LoRa Module for long-range communication inside large silos.
    - GSM Module for remote alerts and system updates.
7. AI and Signal Processing Hardware
    - Edge AI Devices like NVIDIA Jetson Xavier for real-time AI model execution.
    - FPGA Module for ultra-fast data processing (optional).
8. Display and User Interface
    - Touchscreen Display for monitoring system performance and alerts.
    - LED Indicators for quick visual status updates.
9. Camera and Imaging System
    - Raspberry Pi Camera Module V2 for visual inspection of grains.
    - LED Lights for enhanced visibility in low-light silo conditions.
10. Sensor Data Processing and Calibration
    - Kalman Filter Algorithm for reducing sensor data noise.
    - AI-Based Algorithms for real-time contamination prediction and decision-making.
11. Robot Control and Navigation
    - PID Controllers for precise control of the conveyor's movement and robot stability.
    - Wheel Encoders (if mobile platform used in addition to conveyor) for accurate distance tracking.
    - Motor Shields for managing multiple motor operations effectively.
12. Additional Components
    - Buzzer/Vibration Motor for immediate contamination alerts.
    - Relay Modules for controlling additional devices, like external alarms or ventilation systems.




SOFTWARE REQUIREMENTS

1. Operating Systems & Programming:
   - Raspberry Pi OS/Ubuntu for robot control, Arduino IDE for microcontroller programming.
   - Python, C/C++ for AI algorithms, data processing, and hardware interfacing.
2. AI & Data Processing:
   - TensorFlow/PyTorch for deep learning-based contamination prediction.
   - MATLAB/OpenCV for Fourier Transform analysis and image processing.
3. Robot Control & Automation:
   - ROS for autonomous navigation and sensor integration.
   - Kalman Filter & PID controllers for noise reduction and precise movement control.
4. Communication Protocols:
   - MQTT for IoT-based communication, I2C/SPI/UART for sensor data exchange.
   - Wi-Fi/Bluetooth integration for real-time data transmission.
5. Data Storage & Cloud Integration:
   - SQLite/MySQL for local data storage, Firebase/AWS IoT for remote monitoring.
   - Cloud dashboards for real-time contamination alerts.
6. Visualization & User Interface:
   - Dash/Plotly for real-time data visualization dashboards.
   - Mobile/Web interfaces for remote robot monitoring and control.
7. Simulation & Testing:
   - Gazebo for robot movement simulation in virtual environments.
   - Proteus for circuit simulation and testing before hardware implementation.
8. Version Control:
   - Git/GitHub for code version control and team collaboration.
   - Ensures project consistency across development phases.

Mathematical Models in Contamination Detection

1. Fourier Transform (Signal Analysis):
   - Purpose: Converts time-domain sensor data to the frequency domain to identify contamination patterns.
   - Equation:

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} dt$$

   - Application: Detects frequency signatures of VOCs (Volatile Organic Compounds) emitted by contaminated grains.

2. Kalman Filter (Noise Reduction):
   - Purpose: Filters out noise from real-time sensor data, providing accurate contamination readings.
   - Equations:
   - Prediction Step:

$$\hat{x}_{k|k-1} = A\hat{x}_{k-1|k-1} + Bu_k$$

$$P_{k|k-1} = AP_{k-1|k-1}A^T + Q$$

   - Update Step:

$$K_k = P_{k|k-1}H^T(HP_{k|k-1}H^T + R)^{-1}$$

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k(z_k - H\hat{x}_{k|k-1})$$

   - Application: Smoothens noisy gas sensor data for precise detection.

MATHEMATICS CONT

3. Bayesian Probability Model (Contamination Prediction):
   - Purpose: Predicts the spread of mycotoxin contamination within the grain silo.
   - Equation:

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)}$$

   - Application: Estimates contamination risk in untested silo areas based on sensor readings.

4. PID Controller (Robot Navigation):
   - Purpose: Ensures stable and precise movement of the robot on the conveyor system.
   - Equation:

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$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}$$

   - Application: Maintains accurate positioning for sensor data collection.

5. Data Fusion Algorithms:
   - Purpose: Combines data from multiple sensors for more accurate contamination detection.
   - Equation (Weighted Average Fusion):

$$X_f = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

   - Application: Increases reliability of contamination detection by integrating gas, motion, and environmental data.

PHASES AND TIMELINE

Month 1: Research, Design & Development

- Conduct literature review on mycotoxin detection and robotic systems
- Design the robot and Overhead Conveyor System architecture
- Select sensors and hardware components
- Assemble hardware and integrate components
- Develop software algorithms (Fourier Transform, Kalman Filter, Bayesian Models)

Deliverable:

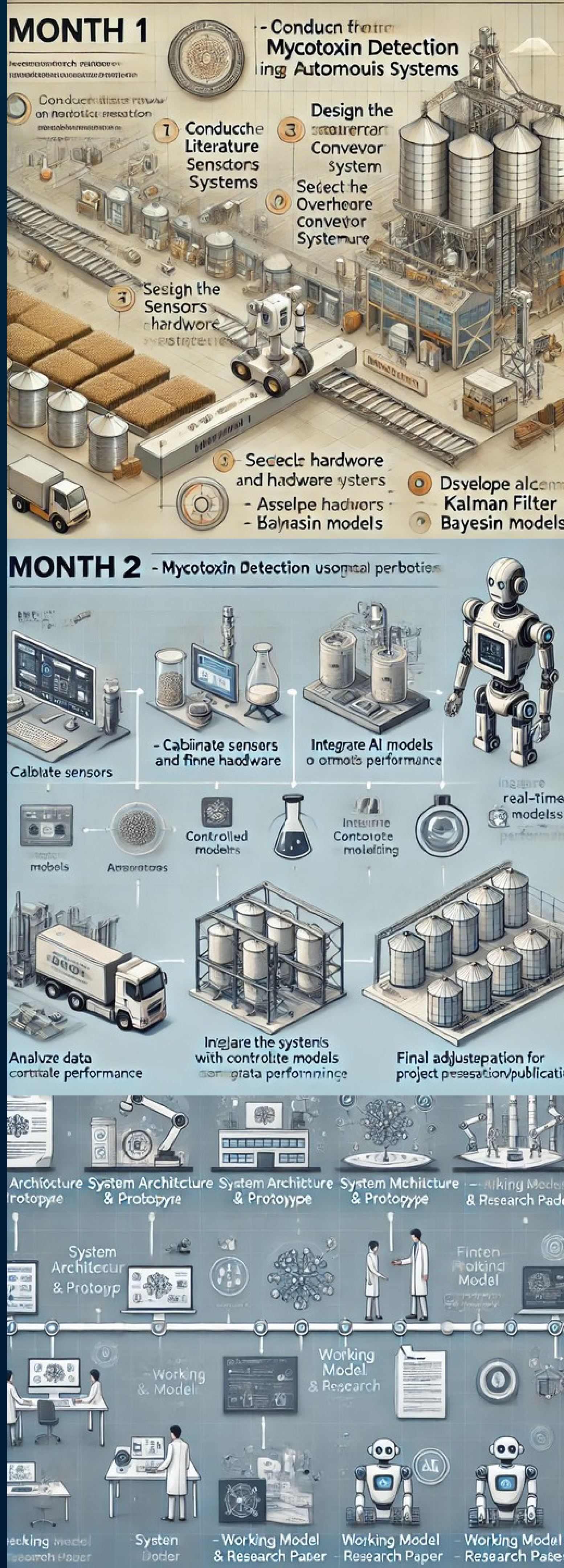
- System Architecture & Prototype

Month 2: Integration, Testing & Evaluation

- Calibrate sensors and fine-tune hardware for optimal performance
- Integrate AI models with real-time data processing
- Test the system in controlled grain storage environments
- Analyze data, optimize models, and evaluate performance
- Final adjustments and preparation for project presentation/publication

Deliverable:

- Working Model & Research Paper




Fourier Transform
THANK YOU
Bayesian
ANALXY FIETER
Fourier Transform
Kalmsan Filter