AI & SUSTAINABILITY IN VET EDUCATION

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KOCAELİ - DARICA İLÇE MİLLÎ EĞİTİM MÜDÜRLÜĞÜ

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AUTONOMOUS VISION-GUIDED INDUSTRIAL ROBOTIC ARM FOR INTELLIGENT SORTING

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1. Project Title:

Autonomous Vision-Guided Industrial Robotic Arm for Intelligent Sorting

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2. Project Category:

- AI in Robotics

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3. Project Description:

This project demonstrates an autonomous sorting workstation using a robotic arm equipped with computer vision. Utilizing a Raspberry Pi 5 and a high-resolution camera, the system identifies objects based on visual characteristics (color/shape). Once detected, a robotic arm utilizes a pneumatic vacuum gripper to pick up the items and sort them into designated target zones. This simulates a real-world industrial automation line, bridging the gap between AI theory and practical mechanical execution.

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4. Keywords:

AI, Computer Vision, Raspberry Pi 5, Robotic Arm, Industrial Automation, Vacuum Gripper

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5. Target Audience:

- Both Educators and Students

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6. Project Objectives:

- To implement real-time object detection and localization using Python and OpenCV.

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- To master the integration of Raspberry Pi 5 with servo motor controllers and pneumatic systems.
- To understand the logic of "Pick-and-Place" operations in an autonomous environment.
- To develop skills in troubleshooting hardware-software synchronization in a robotics context.

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7. Project Timeline:

- **Start Date:** Jan 2, 2026
- **End Date:** May 14, 2026
- **Milestone:** Successful integration of the pneumatic vacuum system with CV-triggered logic.

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8. Resources Provided:

- Python source code for image processing and motor control.
- Wiring diagrams for the pneumatic vacuum motor and servo drivers.
- 3D modeling files for the robotic arm assembly.
- Instructional video demonstrating the calibration process.Raspberry Pi and sensor kits (AI-SAVES Kit)
- Python programming guides for AI implementation
- Lesson plan: "Introduction to AI for Beginners" (PDF)
- Project report template (DOCX)

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9. Tools and Technologies Used:

- **Hardware**: Raspberry Pi 5, Pi Camera, Servo Motors, Pneumatic Vacuum Pump, Relay Module.
- **Software**: Python 3.x, OpenCV Library, RPi.GPIO or pigpio for motor control.

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- **Algorithms**: Color-based thresholding (HSV) or YOLO-based object detection for precise sorting.

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10. Step-by-Step Implementation Plan:

1. **Hardware Architecture and Assembly:** Assemble the robotic arm structure, install the servo motors at the joints, and attach the pneumatic suction cup as the end-effector. Position the Raspberry Pi 5 and the camera module directly above the workspace to ensure a top-down, distortion-free view.

2. **Pneumatic and Power Integration:** Connect the vacuum motor to the Raspberry Pi using a relay module or MOSFET driver. Utilize an external power supply (5V-6V high current) for the servo motors to prevent voltage drops and protect the Raspberry Pi's circuitry.

3. **Software Environment Setup:** Install the 64-bit Raspberry Pi OS on the Pi 5. Set up the development environment by installing essential libraries via pip install opencv-python numpy RPi.GPIO and ensure the libcamera stack is active.

4. **Computer Vision Logic Development:** Develop a Python script using OpenCV for object detection. Implement a pipeline that converts BGR frames to HSV color space, applies color masking via cv2.inRange(), and identifies object centroids (Cx, Cy) using cv2.findContours().

5. **Coordinate Mapping and Calibration:** Establish a transformation matrix to map pixel coordinates from the camera feed to physical workspace coordinates (Xmm, Ymm). This step is vital to ensure the robotic arm aligns perfectly with the detected object.

6. **Robotic Kinematics Implementation:** Write Inverse Kinematics (IK) functions to calculate the necessary motor angles for any given (X, Y, Z) target. These functions translate spatial coordinates into precise PWM signals for the high-torque servos.

7. **Vacuum Control and Sequence Logic:** Once a target is locked, the arm moves to the calculated position. The script triggers the vacuum via GPIO.output(VACUUM_PIN, HIGH). After picking, the arm moves to the designated sorting zone (left or right) and releases the object by cutting the vacuum power.

8. **Optimization and Looping:** Wrap the system in a continuous while True loop. To maximize the performance of the Raspberry Pi 5, implement multi-threading to separate the camera acquisition from the motor control, ensuring a smooth and responsive autonomous operation.

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11. Evaluation Criteria:

Detection Success Rate: The algorithm must correctly identify the color and shape of objects with at least a 95% success rate over 100 trials.

Positional Precision: The vacuum tip must focus on the center of the object with a maximum deviation of ±2mm to ensure a successful grip.

Cycle Efficiency: The total time taken to detect, pick, and place an object should be completed in under 5 seconds.

FPS and Processing Speed: Maintaining a high frames-per-second (FPS) rate on the Raspberry Pi 5 while keeping CPU usage optimized during real-time processing.

Exception Handling Performance: The system's ability to return to a "home position" safely if an object is dropped or if the camera view is obstructed.

Pneumatic Reliability: The capacity of the vacuum system to maintain a secure hold on various object weights despite the mechanical vibrations of the arm.

Software Cleanliness: Ensuring the Python code is modular, with clearly defined HSV thresholds and well-documented kinematic calculations.

Educational Impact: The ability of participants to explain and demonstrate the mathematical relationship between computer vision and inverse kinematics.

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12. Languages Available:

English, Turkish.

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13. Contributors:

- **Ali İmran Şahin (Project Lead)** – Lead educator responsible for project development and coordination.
- **Mert Furkan Gülünay (Technical Expert)** – Provided expertise in AI programming and robotics.

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14. Feedback and Continuous Improvement:

- **Optimization:** Analyzing vibration data to refine servo movement smoothness.
- **Scaling:** Plans to integrate a conveyor belt system to further simulate a factory floor.

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