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A New Design of a Cartesian-Axis-Robot Control System for Product Classification

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Abstract: *This article presents the design of a 3-axis Cartesian robot for product classification based on color characteristics, utilizing image processing technology. The proposed product classification system integrates image processing tools within PyCharm with the Cartesian robot to achieve efficient product categorization. Additionally, the system incorporates remote monitoring and control, aiming to enhance its economic viability. The authors employ color recognition algorithms on camera-captured images to detect objects and subsequently instruct the robot to grasp and position the items. Notably, the core of this research revolves around developing intelligent control algorithms but using conventional PID regulators and crafting control rules for the Cartesian robot to guarantee precision and high efficiency. Furthermore, integration with image sensors serves to augment accuracy and optimize production line performance.*
Keywords: *Product classification, image processing, Cartesian robot.*

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I. INTRODUCTION

Since the introduction of industrial robots, their utilization across various sectors as replacements for human labor has been widespread. This shift has led to the reorganization of manufacturing lines, significantly enhancing productivity and efficiency. Over time, the demand for robots has continuously increased, necessitating greater precision and optimization to meet rigorous quality and stability standards.

Among industrial robots, Cartesian robots are the most commonly employed across a broad range of applications. These robots are designed with three axes (X, Y, and Z) and an end-effector, such as a gripper or suction cup. Their linear operation makes them particularly suited for tasks in manufacturing, packaging, and product sorting. Cartesian robots are preferred for their precision, speed, and high repeatability. Their design process is relatively simple and is typically carried out using 2D and 3D design software or by modeling based on the Jacobian matrix, which forms the basis for the robot's real-world model. Control of Cartesian robots usually involves stepper motors, although these can suffer from step loss at very high speeds, presenting a challenge that needs to be addressed. Additionally, Cartesian robots are notable for their ease of programming and control through programmable logic controllers (PLCs) or microcontrollers [1-5].

In a quest to overcome limitations of Cartesian robots, a promising approach combines Proportional-Integral-Derivative (PID) controllers with image processing. PID control, a well-established feedback mechanism in robotics [6], adjusts variables like position to a desired state. This combination offers enhanced stability, faster response, and reduced oscillations in achieving target values. Image processing, prevalent in computer science, medicine, and industry [7], finds applications in object recognition, color processing, and detection. The synergy between Cartesian robots and image processing has proven valuable in tasks such as pinpointing object locations and dimensions for robot movement [8, 9], as well as color identification [10]. This integration undoubtedly presents a beneficial development.

The burgeoning demand for automation within industrial processes has spurred a surge of interest in intelligent Cartesian robots. These robots combine the advantages of a simple and efficient Cartesian design with sophisticated control algorithms and image processing capabilities. This research draws inspiration from advancements in intelligent measurement systems to propose a novel method for building such robots. Our primary focus revolves around crafting intelligent control algorithms and control rules specifically tailored for Cartesian robots. These algorithms are designed to guarantee high precision and efficiency in robot operation. The PID controllers are chosen for their simplicity and efficiency. Furthermore, the integration of image sensors into the system serves a dual purpose: it enhances the overall accuracy of object detection and manipulation, while simultaneously optimizing production line performance by enabling real-time feedback and adaptation to dynamic environments.

II. HARDWARE DESIGN

The hardware used in this work consists of main units: a camera, a personal computer (laptop), an Arduino Mega 2560, a STM32F103C8T6 Bluepill, an encoder STM32F103C8T6. The details are presented below.

- **Camera**

The camera is a crucial element in the image processing system, responsible for supplying images to the PC. A full HD resolution (1920x1080) camera is selected for its high resolution and smooth operation at 30 frames per second. The camera employs USB connectivity, making it compatible with various operating systems and devices that use this standard connection. Additionally, its compact size makes it ideal for continuous movement along the robot's axis.

Figure 1. Camera with HD resolution.

- **Image processing (PC)**

The laptop plays a primary role in image processing and computing various information about the coordinates of detected objects, tracking positions, determining the best path for the robot, and performing many other tasks using libraries and image processing software such as OpenCV. It has the capability to efficiently store and manage data, aiding in storing processed images. Additionally, the laptop serves as the user interface for the system, running software to control the robot, display data from the camera, and interact with the system conveniently.

After completing the processing and computation process, the laptop transfers this data to the Arduino Mega controller via UART communication. With its strong processing capabilities and ability to work continuously with multiple programs simultaneously, the laptop is advantageous. However, its size may be cumbersome for continuous movement.

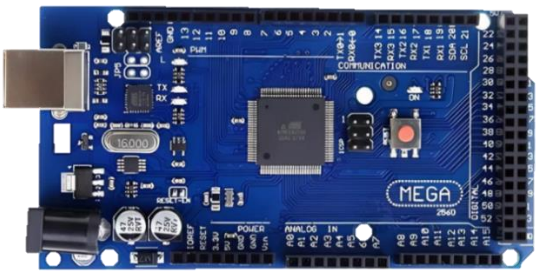
Figure 2. Laptop used in this work.

- **Arduino Mega 2560**

The chosen control center for the Cartesian robot is the Arduino Mega. Equipped with the powerful ATmega2560 chip, Arduino Mega provides high processing speed to efficiently handle data from various sensors and devices in the system. With numerous I/O pins, Arduino Mega allows flexible connections with different devices and sensors in complex projects. Multitasking support enables Arduino Mega to perform multiple tasks simultaneously, such as reading data from sensors and controlling motors simultaneously.

In this study, simultaneous control of the 3 translational joints on the robot is prioritized. The Arduino Mega 2560 is equipped with up to 6 sets of Timer/Counter, enabling the use of multiple interrupt programs simultaneously (see Figure 3).

Figure 3. Arduino Mega 2560.



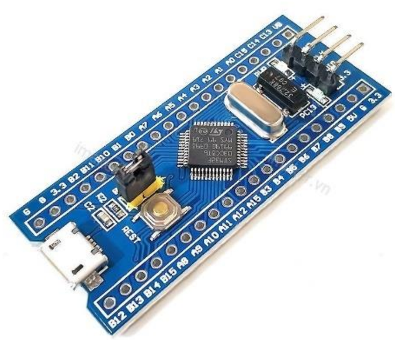
However, Arduino Mega has some drawbacks. Its larger size compared to other Arduino models may pose challenges when integrating into compact or space-limited systems. Due to the powerful chip and numerous I/O pins, Arduino Mega consumes more power than other Arduino variants, which may affect the system's operating time when using limited power sources.

The ATmega2560 microcontroller is an 8-bit microcontroller. Continuous interrupt usage can introduce delays to the system when adding tasks to read data from multiple sensors. The proposed solution is to use the Stm32f103c8t6 to read data from sensors. Leveraging the communication capabilities of the Arduino Mega 2560, which has 4 UART interfaces, facilitates easy data reading from the Stm32f103c8t6.

- **STM32F103C8T6 Bluepill**

The STM32 is a series of ARM-based microcontrollers based on STMicroelectronics' ARM Cortex-M processors. The STM32 product line offers a range of microcontrollers with various features and performance levels, suitable for a diverse range of embedded applications, from small projects to complex systems.

Figure 4. STM32F103C8T6.



Advantages of STM32:

High Performance: STM32 provides ARM Cortex-M microcontrollers with fast processing speed and excellent multitasking capabilities.

Versatile Features: The STM32 product line includes multiple versions with features such as communication interfaces, memory options, and other advanced functionalities to suit various applications.

Strong Hardware and Software Support: STMicroelectronics offers high-quality hardware and software development tools to support application development on STM32.

Energy Efficiency: STM32 offers power-saving modes and energy management features to optimize the energy efficiency of the system.

STM32 Features:

Diverse Communication: STM32 supports various communication interfaces such as SPI, I2C, UART, CAN, USB, facilitating connections with peripherals and networks.

Flexible Memory: STM32 provides versions with flexible Flash and RAM memory options, enabling efficient storage of program code and data.

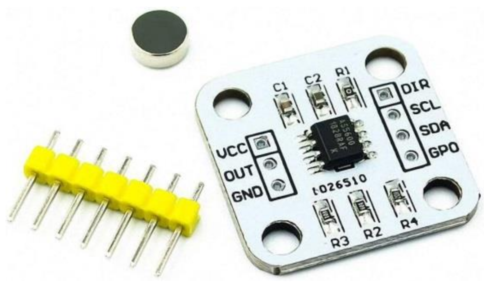
- **Encoder AS5600**

AS5600 is a rotary angle sensor from AMS (Austria MicroSystems), used to measure the angle and position of objects. This sensor has the capability to measure angles up to 360 degrees with high accuracy.

Advantages of AS5600 Encoder:

The AS5600 encoder provides accurate angle measurements with high resolution, suitable for applications requiring precise position sensors. With non-contact remote sensing technology, AS5600 eliminates mechanical wear and provides long-term reliability in various operating conditions. The digital output interface of AS5600 simplifies integration with microcontrollers and digital systems, enhancing usability and compatibility. Reading signals via I2C communication facilitates easy and convenient reading of multiple AS5600 sensors simultaneously.

Figure 5. Encoder AS5600.



Disadvantages of AS5600 Encoder:

The narrow angle range compared to some rotary encoders may limit its applicability in projects requiring continuous rotation sensors. Dependency on the magnetic sensor of AS5600 can be susceptible to interference from external magnetic fields, potentially affecting measurement accuracy in certain environments. Cost factor may arise as AS5600 may have a higher price compared to some traditional rotary encoders due to its advanced features and accuracy.

A major drawback of the AS5600 encoder is the inability to change the I2C address, preventing communication on the same bus. The solution proposed is to use the TCA9548A I2C multiplexer module.

III. SYSTEM BLOCK DIAGRAM

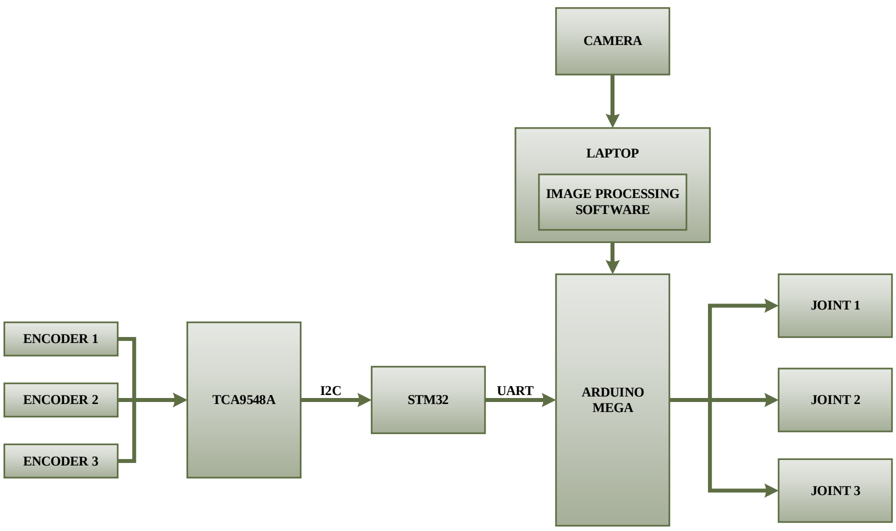
A block diagram in control systems is a visual representation that depicts the flow of signals and the interaction between different components. It's essentially a blueprint for understanding how a control system functions. Here's a breakdown of the concept:

Blocks: Each block represents a specific component or subsystem within the control system. This could be a sensor, actuator, controller, filter, or any element that performs a particular function.

Signal Flow: Arrows connect the blocks, indicating the direction of the signal flow. Signals can be control signals (desired output) or feedback signals (measured output).

In this section, a block diagram as illustrated in Figure 6 is built to represent working principle of the whole system.

Figure 6. A block diagram for whole system.



The block diagram approach (shown in Figure 6):

The previously presented block diagram provides a visual representation of the robot system's architecture. It highlights distinct processing units dedicated to robot control and image processing. This segregated architecture facilitates the efficient execution of control tasks and image processing algorithms.

Data Acquisition for Model Development

A critical step in the research involved creating a dataset of products categorized based on color characteristics. This dataset serves as the foundation for training and evaluating the image processing algorithms employed by the system. For experimental expediency, cylindrical plastic blocks are used as the target objects for image processing tasks.

Image Processing and Feature Extraction

The acquired data undergoes processing through an HSV color filter, which leverages the Hue-Saturation-Value color space. This color space offers distinct advantages in isolating color information from images. As the robot navigates towards the designated sampling area, it captures images. Applying image processing algorithms, the system identifies the products within the captured images. These algorithms delineate object contours, determine their central coordinates, and precisely locate the target object within the image frame. It is important to note that the initial coordinates obtained are expressed within an auxiliary coordinate frame. To enable the Cartesian robot to effectively manipulate the objects, a mathematical transformation is performed. This transformation converts the object's coordinates from the auxiliary frame to the robot's primary coordinate system. This final set of coordinates allows the robot to precisely control its joints, enabling it to grasp and place the items in the designated sorting areas.

IV. RESULTS AND DISCUSSION

Once the system components are connected, the first step is to verify the computer's COM port through the user interface. This verification ensures that the system is ready for communication and control. After confirming that the connection is successfully established, you can proceed to initiate the robot's operation. The user interface plays a critical role by allowing users to verify the results of image processing and to monitor the entire operational process in real time. Following these steps, data is transmitted to the Arduino Mega using the UART communication protocol. This data transmission enables precise control of the robot, directing it to move to the designated positions as required by the task at hand.

Experiment Process: The experimental process is divided into three parts:

Part 1: Position response and position holding experiment. Predefined coordinates are sent to the robot. The robot moves to the specified position and maintains the correct position, requiring position feedback signals. Encoders are used to collect position data from the robot's joints. The PID controller is used to accurately control the joints. This experiment is conducted on MATLAB and compared with the results of the physical model.

Part 2: Image processing experiment. Data is captured from the camera and processed using PyCharm software. OpenCV library facilitates image processing. Software is built to connect with the Arduino Mega through UART communication for flexible data exchange. A user-friendly and easy-to-use interface is developed.

Part 3: Integration of image processing and robot control. Hardware components are connected, image processing is performed, and position data collected from the image processing computer is sent down to the Arduino Mega. The controller receives commands and controls the robot to the exact position for grasping products and sorting them into designated areas.

Figure 7 illustrates the results after running the image processing. According to the image processing results, achieving 92.5% accuracy compared to the actual position, the error primarily stems from the lighting factor. Brightness can affect the camera's recognition, diminishing color saturation compared to the original. Additionally, the robot's connection is partly affected by noise from other devices powered through different outlets. The image processing speed is quite fast, approximately 0.5 seconds per product. The Cartesian robot grasps and places objects in the correct position within a 5-second movement time per product.

Analysis of the real-time response graph reveals the significant stabilizing effect of the PID controller on robot performance (see Figure 8). Notably, the system exhibits fast response in both speed and position control, minimizes error, and demonstrates minimal oscillation compared to the setpoint. These results convincingly demonstrate the suitability of the PID controller for the Cartesian robot. While alternative control methods exist, the PID controller proves to be an excellent choice in this application.

Figure 7. Image processing results.

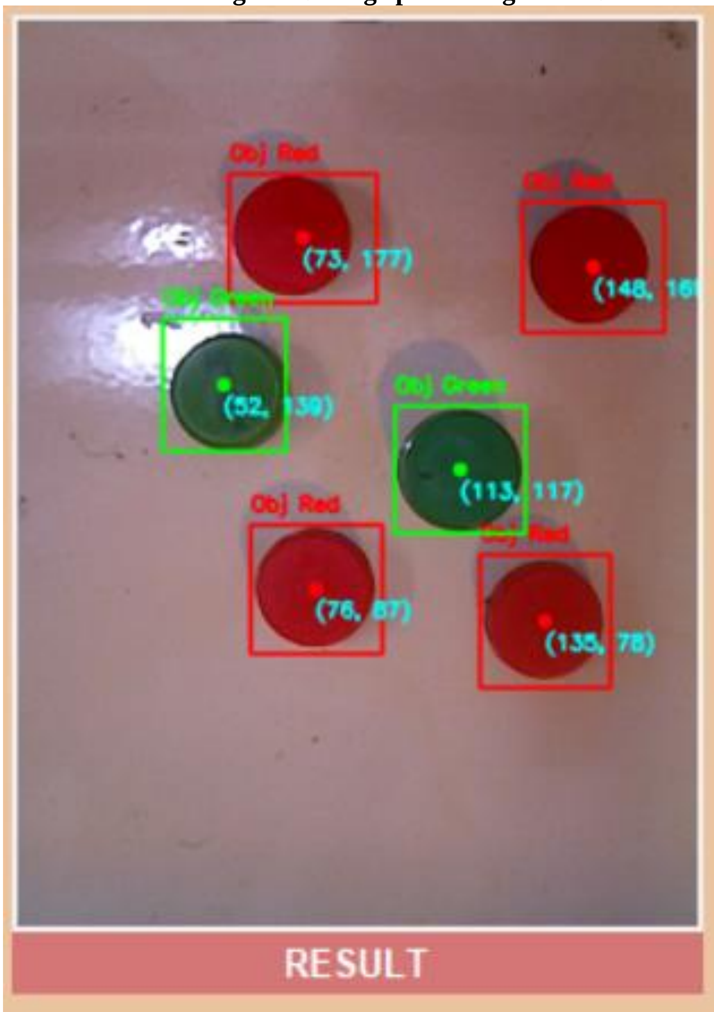
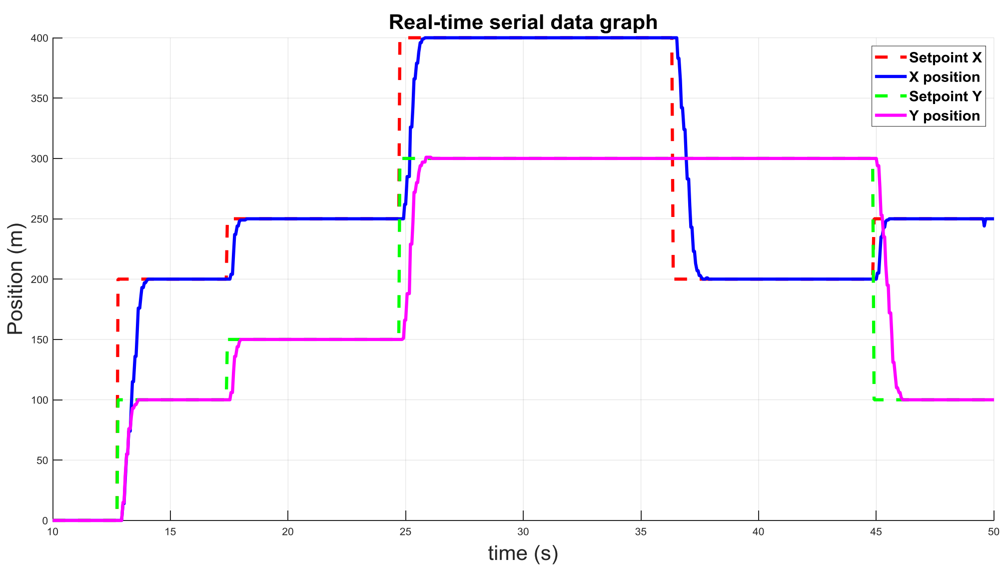


Figure 6. Dynamic responses of the practical model.



V. CONCLUSION AND FUTURE WORK

This research has investigated the design and implementation of a Cartesian axis robot for product sorting applications. The core innovation lies in the synergistic integration of a PID controller with image processing technology. This combined approach significantly enhances the robot's precision, operational speed, and overall sorting performance.

Experimental evaluations were conducted to assess the feasibility and potential of the proposed robot model in a real-world setting. The results are promising, with the system achieving a classification accuracy of 92.5%. This success represents a significant advancement in the field of robot control and underscores the critical role of data processing and pre-processing techniques. The future of Cartesian robots integrated with image processing holds immense potential for various applications, particularly in industrial automation. In this perspective, the current study needs to be further improved in the near future.

Conflict of interest

There is no conflict to disclose.

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