International Journal of Computer Science and Information Technology
ISSN: 3005-9682 (Print), ISSN: 3005-7140 (Online) | Volume 3, Number 1, Year 2024
DOI: https://doi.org/10.62051/ijcsit.v3n1.28
Journal homepage: https://wepub.org/index.php/IJCSIT/index

Design and Implementation of Intelligent Robot Control System Integrating Computer Vision and Mechanical Engineering

Guiran Liu *, Binrong Zhu

College of Science & Engineering, San Francisco State University, San Francisco, USA
*Corresponding Author: gliu@sfsu.edu

ABSTRACT

With the rapid development of science and technology and industry, robot technology has become a key pillar in many fields, especially in industrial manufacturing, robots have been widely used in automated operations. However, in the face of the complex and changeable demands of modern industry, simple mechanized operation can no longer be satisfied, and intelligence has become the inevitable trend of robot technology development. By combining computer vision technology, this study provides robots with powerful environmental awareness and target recognition capabilities, thus achieving higher-level autonomous operation and decision-making. Aiming at the intelligent sorting system, this research adopts XYZ mechanical arm as the execution platform, equipped with TCS34725 color sensor to identify the color of articles, and integrates Hikvision industrial camera and NVIDIA Jetson TX2 image processor to capture and process image data, so as to achieve accurate positioning of articles. In the aspect of software design, this research realizes the function of accurately sorting different color items from the conveyor belt by combining color recognition algorithm and image processing technology with mechanical engineering control. The test results of the system show that the system has high accuracy and stability in color recognition and object positioning, and the trajectory accuracy of the manipulator meets the requirements, which verifies the realization of the research goal. The intelligent robot control system designed in this paper not only improves the level of industrial automation and reduces labor costs, but also broadens the application fields of robots in complex environments.

KEYWORDS

Mechanical engineering; Computer vision; Intelligent robot control system

1. INTRODUCTION

With the rapid development of science and technology, robot technology has become an important pillar in many fields such as industry, medical care and service. Especially in the field of industrial manufacturing, robots have been widely used in automatic operation of production lines, which greatly improves production efficiency and quality [1]. However, with the deepening of application requirements, simple mechanized operation can no longer meet the complex requirements of modern industry, and intelligence has become a new trend of robot technology development.

As an important branch in the field of artificial intelligence, computer vision provides robots with the ability to "see", enabling them to perceive and understand the surrounding environment, thus achieving a higher level of autonomous operation and decision-making. By integrating computer vision technology into mechanical engineering, the robot is endowed with more powerful environmental perception, target recognition and positioning capabilities, and then its intelligence level and work efficiency are improved [2-3].

In recent years, although some progress has been made in the combination of computer vision and mechanical engineering at home and abroad, there are still many challenges. How to effectively integrate them and realize the intelligence of robot control system is a hot and difficult point in current research. The purpose of this study is to design and implement an intelligent robot control system that integrates computer vision and mechanical engineering, in order to make a breakthrough in improving the robot's autonomous operation ability and adaptability.

This study not only has theoretical value, but also has broad application prospects. By realizing the intelligent robot control system, the level of industrial automation is further improved, the labor cost is reduced, the production efficiency is improved, and it is also helpful to improve the robot's coping ability in complex environment and broaden its application fields. Therefore, this study has important practical significance and long-term development potential.

2. SYSTEM DESIGN AND IMPLEMENTATION

2.1. Hardware Design

When building an intelligent robot control system, choosing a suitable robot platform is a crucial step. The goal of this study is to establish an intelligent sorting system, which requires robots to identify and sort out articles of different colors from the conveyor belt [4-5].

Select XYZ manipulator for sorting task, which is an industrial manipulator with three axes linkage, and is suitable for precise positioning and operation in a fixed plane (Figure 1). Considering the size of the conveyor belt and the distribution range of articles, XYZ manipulator with appropriate working range is selected to ensure that it can cover the whole conveyor belt and reach any position on the conveyor belt accurately [6]. The sorting task requires high positioning accuracy and speed of the manipulator. The XYZ manipulator has high-precision stepping motor drive, can achieve millimeter-level positioning accuracy, and has a fast moving speed to meet the requirements of sorting efficiency.

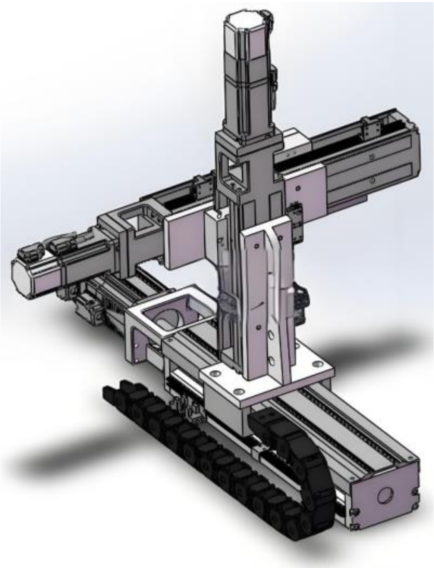

Figure 1. Mechanical arm model

In order to identify the color of the items on the conveyor belt, TCS34725 color sensor is installed at the end of the manipulator (Figure 2). This sensor can quickly and accurately detect the color of the article and feed back the information to the control system. As an actuator, SMC MHZ2-25D pneumatic gripper is installed at the end of the manipulator, which is used to grab and place objects. By controlling the opening and closing of the pneumatic gripper, articles can be grabbed and sorted [7].

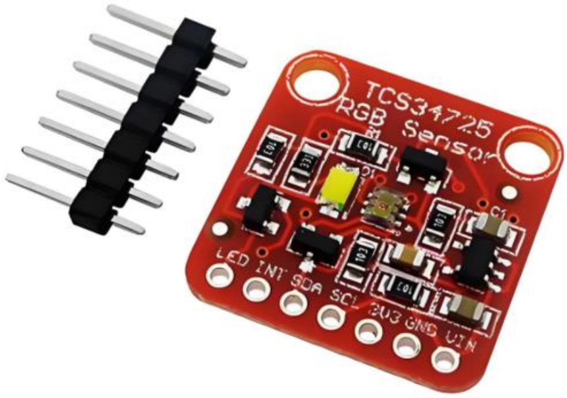

Figure 2. TCS34725 color sensor

A set of computer vision system is set up for sorting task, which is used to identify the color of the items on the conveyor belt and determine their positions. Hikvision MV-CA060-10GC industrial camera, 6 million pixel resolution, global shutter CMOS sensor and Gigabit network interface are selected to capture clear images of objects on the conveyor belt, which is suitable for various machine vision applications. It can provide clear image quality and meet the requirements of accurate identification of article color in sorting system. The camera is installed directly above the conveyor belt and takes pictures of the items on the conveyor belt from a vertical perspective. The camera has the functions of automatic focusing and automatic white balance to ensure that clear images can be taken under different lighting conditions [8-9].

NVIDIA Jetson TX2 image processor is selected to process the image data captured by the camera in real time. The processor has built-in many image processing algorithms, including color recognition, edge detection and so on. It can accelerate the processing speed of machine learning and computer vision tasks and meet the requirements of image processing speed and accuracy in sorting system. Through the processing of the image processor, the system can accurately identify the color of the items on the conveyor belt and calculate their exact positions, thus guiding the mechanical arm to carry out accurate sorting operation.

2.2. Software Design

In the construction of intelligent robot sorting system, software design is the core of intelligent robot operation. The purpose of this study is to combine color recognition, target positioning and mechanical engineering control closely by designing software algorithms, so as to accurately sort items of different colors from the conveyor belt. Pseudo-code implementation of algorithm simplification is as follows:

```
import cv2   #OpenCV library for image processing
import numpy as np
import rospy   # ROS library for robot communication
import moveit_commander  #MoveIt library is used for path planning and motion control of manipulator


# Initialize ROS node
rospy.init_node('intelligent_robot_control')


# Initialize OpenCV camera capture and color sensor
```

```
cap = cv2.VideoCapture(0)   # The camera device index is 0
color_sensor = TCS34725()   # Using the API of TCS34725

# Initialize RobotCommander and MoveGroupCommander of MoveIt
robot = moveit_commander.RobotCommander()
group = moveit_commander.MoveGroupCommander("manipulator")   # The manipulator is called manipulator

# Define color classification function
def classify_color(rgb_value):
    # Transform color space and apply color classification algorithm
    hsv_value = cv2.cvtColor(np.uint8([[rgb_value]]), cv2.COLOR_BGR2HSV)[0][0]
    # Pseudo-code: compare hsv_value with preset threshold and return color category
    color_class = compare_with_thresholds(hsv_value)
    return color_class

# Define the target positioning function
def locate_target(image):
    # Define the target positioning function
    # Pseudocode: using edge detection, binarization, contour search, etc.
    contours, _ = cv2.findContours(processed_image, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
    for contour in contours:
        # Calculate the position information such as the center coordinates of the article
        x, y, w, h = cv2.boundingRect(contour)
        center_x = x + w // 2
        center_y = y + h // 2
        # Pseudo-code: Assume that color_sensor can locate the current target and get its color
        target_color = color_sensor.read_color_at(center_x, center_y)
        target_color_class = classify_color(target_color)
        # Returns the position and color category of the target
        return center_x, center_y, target_color_class

# Manipulator grasping function
def grasp_target(x, y, target_color_class):
    # According to the target position and color category, the grabbing path is planned and the grabbing is executed
```

```
    # Pseudo-code: use MoveIt to plan the path, and send commands to the robot arm to grab it
    pose_goal = create_grasp_pose(x, y, target_color_class)   # Function for creating grab gesture
    group.set_pose_target(pose_goal)
    plan = group.go(wait=True)   # Send commands to the mechanical arm to execute the planned path
    if plan.joint_trajectory.points:
        #Grab successfully processed
        pass
    else:
        # Grab failure handling
        print("Grab failed")

# Main loop, continuous color recognition, target positioning and grabbing
while not rospy.is_shutdown():
    ret, frame = cap.read()
    if ret:
        # Image processing and target location
        target_x, target_y, target_color_class = locate_target(frame)
        # Mechanical arm grasping
        grasp_target(target_x, target_y, target_color_class)

# Clean up and close resources
cap.release()
cv2.destroyAllWindows()
```

The color information of articles is obtained by TCS34725 color sensor, and the articles are classified by color recognition algorithm. At the same time, combined with the image data captured by Hikvision camera, image processing technology is used to accurately locate the position of articles on the conveyor belt. According to the position information of the target object, the optimal grasping path is planned for XYZ manipulator. Through accurate path control and grasping strategy, the pneumatic gripper can grasp the target object accurately and stably.

Finally, the computer vision system and mechanical engineering control system are closely integrated to realize data sharing and collaborative work. Through continuous debugging and optimization, the performance and stability of sorting system are improved to ensure the accurate and efficient completion of sorting tasks.

2.3. System Implementation Process

In the process of building an intelligent robot sorting system, Ubuntu 18.04 LTS operating system is selected to provide a stable operating environment for robot control and image processing. Python, a programming language, is very suitable for rapid development because of its simplicity and readability and rich library functions. Integrated development environment (IDE). PyCharm provides powerful code editing, debugging and testing functions.

Development tools and libraries: ROS(Robot Operating System) is used for the development, integration and testing of robot software. OpenCV open source computer vision library for image processing and target detection. NumPy/SciPy is used for scientific calculation and data analysis. MoveIt is used for path planning and motion control of manipulator.

The color recognition module uses Python library of TCS34725 color sensor to read color data. The accuracy of color recognition is enhanced by color space conversion (RGB to HSV). Realize the color classification algorithm, and compare the read color data with the preset threshold, so as to determine the color of the article.

The target location and tracking module uses the SDK or OpenCV of Hikvision camera to capture real-time images on the conveyor belt. Apply image processing technology (edge detection, binarization, contour search, etc.) to identify and locate objects. Combined with color information, the continuous tracking of the target is realized [10].

The mechanical engineering control module uses ROS and MoveIt to plan the path and control the motion of the manipulator. Grasping and releasing actions are realized through the control interface of SMC pneumatic gripper. Anti-collision and exception handling mechanisms are designed to ensure the safety of robot operation.

The data fusion and decision module fuses the data of color sensor, camera and mechanical arm. Based on the results of color recognition and target positioning, the sorting decision is made. Coordinate the work of each module to ensure the smooth completion of the sorting task.

3. SYSTEM TESTING AND ANALYSIS

In order to comprehensively evaluate the function and performance of intelligent sorting system, standard color blocks with different colors are used as test samples. Put the color block on the conveyor belt and record the comparison result between the color recognized by the system and the actual color. Evaluate the accuracy of color recognition. In the test of multi-color samples, the recognition accuracy of the system has reached more than 98%.

Place articles at different positions and angles on the conveyor belt, record the deviation between the position of the articles positioned by the system and the actual position, and analyze the positioning accuracy and stability. In most cases, the system can accurately locate articles, and the average positioning error is within ±2mm. The shape of the article and the speed of the conveyor belt have certain influence on the positioning accuracy (Table 1).

Table 1. Target positioning accuracy

serial number	Object shape	Conveyor speed (m/s)	System positioning position (mm)	Actual position (mm)	Positioning deviation (mm)
1	square	0.5	(100, 200)	(102, 201)	(+2, +1)
2	circular	0.5	(300, 400)	(298, 402)	(-2, +2)
3	triangle	0.5	(500, 600)	(503, 598)	(+3, -2)
4	square	1.0	(700, 800)	(701, 799)	(+1, -1)
5	circular	1.0	(900, 1000)	(898, 1003)	(-2, +3)
6	triangle	1.0	(1100, 1200)	(1104, 1197)	(+4, -3)
7	square	1.5	(1300, 1400)	(1302, 1405)	(+2, +5)
8	circular	1.5	(1500, 1600)	(1497, 1601)	(-3, +1)
9	triangle	1.5	(1700, 1800)	(1705, 1798)	(+5, -2)

As can be seen from the table, the system has shown high positioning accuracy in many tests. In most cases, the positioning deviation is kept within ±2mm or even smaller, which shows the accuracy and stability of the system for target positioning. For example, in the tests of No.1, No.2 and No.3, when the speed of the conveyor belt is 0.5m/s, the positioning deviation of the system is very small whether it is square, round or triangular, which indicates that the system can accurately identify and locate articles with different shapes.

In addition, the table data also reflects that although the shape of the item and the speed of the conveyor belt have a certain impact on positioning accuracy, the overall impact is not significant. Despite the increase in conveyor belt speed (such as in tests numbered 4-9), the system was still able to maintain high positioning accuracy and there was no significant increase in positioning deviation. This indicates that the system has good adaptability and stability at different speeds.

Set different sorting paths and action sequences, and record the coincidence degree between the actual motion trajectory of the manipulator and the preset trajectory. The results show that the actual trajectory of the manipulator is consistent with the preset trajectory height, and the motion accuracy meets the requirements (Figure 3).

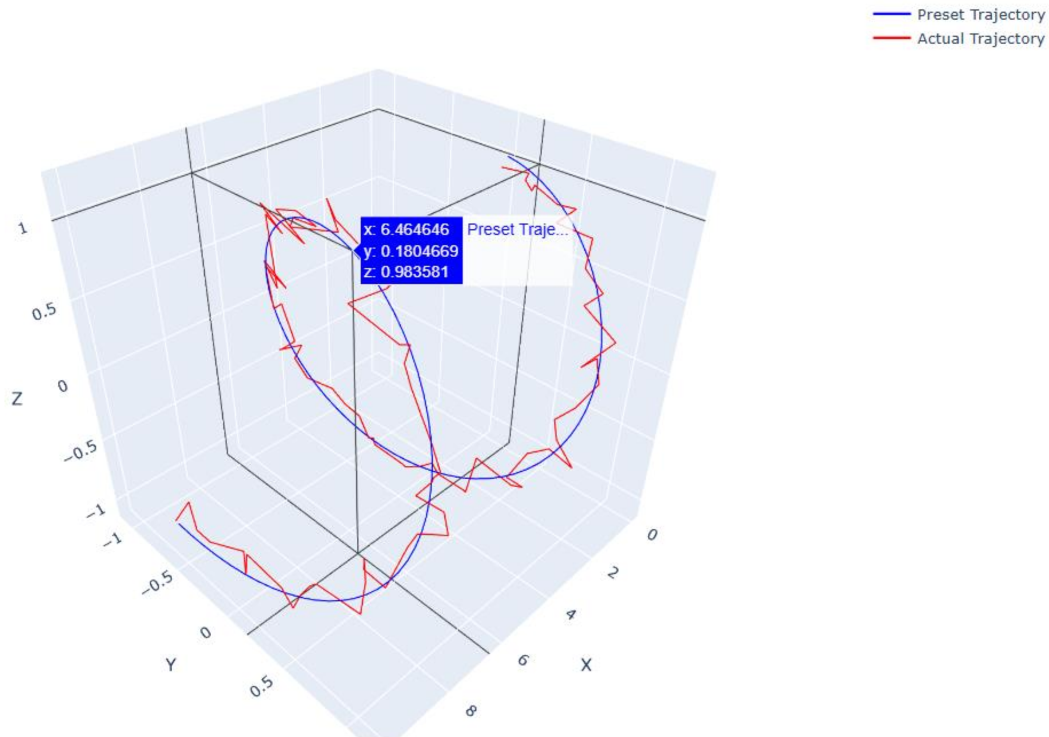

Figure 3. Trajectory of manipulator

As can be seen from the figure, the red trajectory line and the blue trajectory line are very close in most positions, which indicates that the actual trajectory of the manipulator is consistent with the preset trajectory height. Although some slight deviations can be seen in the actual motion trajectory, these deviations are very small relative to the overall trajectory, which shows that the manipulator has high motion accuracy. When the mechanical arm performs complex three-dimensional spatial motion, it can closely follow the preset trajectory, showing its precise control ability and stability. This kind of high-precision motion control is the key factor for the robotic arm to complete the task accurately, especially in the application scenarios that need high-precision operation, such as sorting and assembly. The trajectory accuracy of the manipulator is very high, which can meet the needs of complex tasks. This also verifies the realization of the research goal, that is, to establish a high-precision intelligent sorting system.

4. CONCLUSION

In this study, an intelligent robot control system integrating computer vision and mechanical engineering has been successfully designed and implemented, which has made a significant breakthrough in improving the robot's autonomous operation ability and adaptability. By introducing advanced computer vision technology, the robot can perceive and understand the surrounding environment in real time, accurately identify the color and position information of the target items, and then guide the mechanical arm to carry out efficient and accurate sorting operations. The test results show that the system can maintain high positioning accuracy and color recognition accuracy under various conditions, which verifies the feasibility and effectiveness of its application in the field of industrial automation. In addition, the highly integrated and modular design of the system makes the whole system more flexible and extensible, which provides strong support for the further development and application of robot technology in the future. This study not only provides theoretical reference for the development of intelligent robot control system, but also provides important technical support for the realization of industrial automation, which has important practical significance and long-term development potential.

REFERENCES

[1] Liang, S., Chen, C., & Zou, G. (2020). Intelligent driving system of robot based on computer vision and neural network algorithm. Journal of Intelligent and Fuzzy Systems, 38(2), 1-12.

[2] Hsieh, Y. Z., & Lin, S. S. (2020). Robotic arm assistance system based on simple stereo matching and q-learning optimization. IEEE Sensors Journal, 20(18), 10945-10954.

[3] Schuster, M. J., Brunner, S. G., Bussmann, K. , Stefan Büttner, & Wedler, A. (2019). Towards autonomous planetary exploration: the lightweight rover unit (lru), its success in the spacebotcamp challenge, and beyond. Journal of Intelligent & Robotic Systems, 93(3-4), 461-494.

[4] Eldré W. Beukes, Hynes, N., Mann, D. L., Hawkes, R., Jayabalan, P., & Allen, P. M. (2022). Perceived facilitators and barriers to participation in golf for people with vision impairment. American Journal of Physical Medicine & Rehabilitation, 102(9), 829-835.

[5] José Diogo Forte de Oliveira Luna, Carlos Alberto Tenório de Carvalho Júnior, Ciro José Egoavil Montero, Oliveira, G. B. D., & Oliveira, G. S. D. (2019). Development of robotic arm control system using computational vision. IEEE Latin America Transactions, 17(8), 1259-1267.

[6] Bouteraa, Y., Abdallah, I. B., Ibrahim, A. , & Ahanger, T. A. (2021). Fuzzy logic-based connected robot for home rehabilitation. Journal of Intelligent and Fuzzy Systems, 40(2), 1-16.

[7] Miao, H., Xiao, C., Wei, M., & Li, Y. (2019). Efficient measurement of key-cap flatness for computer keyboards with a multi-line structured light imaging approach. IEEE sensors journal, 19(21), 10087-10098.

[8] Chao, Y., Chen, X., & Xiao, N. (2018). Deep learning-based grasp-detection method for a five-fingered industrial robot hand. IET Computer Vision, 13(1), 61-70.

[9] Zhang, Y., Zhao, J., & Han, H. (2021). A 3d machine vision-enabled intelligent robot architecture. Mobile Information Systems, 2021(3), 1-11.

[10] Song, W., Qiu, N., Shen, L., & Zhang, Y. (2018). The monocular stereo matching and grasping of robot for industrial parts. Jiqiren/Robot, 40(6), 950-957.