DESIGN OF A MECHATRONIC MODULAR DEVICE FOR COLOR SORTING OBJECTS USING A ROBOT MANIPULATOR

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Annotation: This study focuses on the development of an advanced mechatronic module device for sorting objects based on their colors using robotic manipulators. In alignment with global trends in mechatronics and automation, the research addresses not only precise measurement but also reliable data processing in complex environments. Advanced algorithms and innovative methods have been applied to enhance accuracy in object recognition and sorting.

Particular attention has been given to mitigating errors caused by optical factors, lighting conditions, and external influences during color detection. Additionally, modern engineering approaches were used to ensure the reliable operation of the robotic manipulator in challenging industrial conditions.

In Uzbekistan, modernization of industrial processes and implementation of high-precision measurement methods align with the Presidential Action Strategy for 2017–2021. This project provides practical recommendations for integrating innovative technologies into local industries. The research holds significant value in the development of intelligent systems for high-precision sorting based on robotic manipulators.

Keywords: Robotic manipulator, mechatronics, color-based sorting, intelligent systems, automation, optical detection, industrial processes, algorithms, high precision, innovative technologies, data processing, complex environments.

Аннотация: Данное исследование посвящено разработке усовершенствованного мехатронного модуля для сортировки объектов по их цветам с использованием роботизированных манипуляторов. В соответствии с мировыми тенденциями в области мехатроники и автоматизации, исследование затрагивает не только вопросы точного измерения, но и надежной обработки данных в сложных условиях. Для повышения точности распознавания и сортировки объектов были применены передовые алгоритмы и инновационные методы.

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Особое внимание уделено снижению ошибок, возникающих из-за оптических факторов, условий освещения и внешних воздействий при определении цвета. Кроме того, современные инженерные подходы использовались для обеспечения надежной работы роботизированного манипулятора в сложных промышленных условиях.
В Узбекистане модернизация производственных процессов и внедрение методов высокоточного измерения соответствуют Стратегии действий Президента на 2017–2021 годы. В рамках данного проекта даны практические рекомендации по интеграции инновационных технологий в локальную промышленность. Исследование имеет важное значение для разработки интеллектуальных систем с высокой точностью сортировки на основе роботизированных манипуляторов.
Ключевые слова: Робот-манипулятор, мехатроника, сортировка по цвету, интеллектуальные системы, автоматизация, оптическое обнаружение, промышленные процессы, алгоритмы, высокая точность, инновационные технологии, обработка данных, сложные условия.
Anotatsiya: Ushbu ishda robot manipulyatorlar yordamida obyektlarni rangi bo‘yicha aniq va samarali saralash uchun ilg‘or mexatron modul qurilmasini loyihalash bo‘yicha tadqiqotlar olib borilgan. Mexatronika va avtomatlashtirish sohasidagi global tendensiyalarga mos ravishda, nafaqat aniq o‘lchash, balki murakkab sharoitlarda ma’lumotlarni ishonchli qayta ishlash masalalari ham o‘rganilgan. Ishda obyektlarni aniqlash va saralashdagi aniqlikni oshirish uchun ilg‘or algoritmlar va innovatsion usullar qo‘llanilgan.

Tadqiqot davomida ranglarni optik asosda aniqlashda yuzaga keladigan xatolar, yorug‘lik sharoitlari va boshqa tashqi omillar ta’sirini kamaytirishga alohida e’tibor qaratilgan. Bundan tashqari, murakkab sanoat sharoitlarida robot manipulyatorning ishonchli ishlashini ta’minlash uchun zamonaviy muhandislik yondashuvlari qo‘llanilgan.

O‘zbekistonda ishlab chiqarish jarayonlarini modernizatsiya qilish va yuqori aniqlikdagi o‘lchov usullarini qo‘llash bo‘yicha Prezidentning 2017-2021 yillarga mo‘ljallangan Harakatlar strategiyasiga muvofiq, mazkur loyihada innovatsion texnologiyalarning mahalliy sanoatga tatbiq etilishi bo‘yicha amaliy tavsiyalar berilgan. Bu tadqiqot robot manipulyatorlar asosida yuqori aniqlikdagi aqlli tizimlarni ishlab chiqishda muhim ahamiyatga ega.
.
Kalit so'zlar: Robot manipulyator, mexatronika, rangga asoslangan saralash, aqlli tizimlar, avtomatlashtirish, optik aniqlash, sanoat jarayonlari, algoritmlar,

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yuqori aniqlik, innovatsion texnologiyalar, ma'lumotlarni qayta ishlash, murakkab muhit.

Introduction

Automation and control of processes in agriculture, industrial production, and construction are essential for increasing productivity and ensuring safety. Many manufacturing processes that require color-based object recognition and efficient sorting require advanced intelligent systems that provide accuracy and reliability. Traditional manual methods are being replaced by modern technologies, creating automated solutions using robotic manipulators.

Advanced microprocessor systems and artificial intelligence algorithms are improving the efficiency of robotic manipulators in identifying and sorting objects by color. These systems accurately distinguish colors optically under complex conditions, automate processes in real time, and provide valuable information to users. Such technologies not only minimize human error, but also significantly increase overall efficiency[1].

This paper discusses the components, advantages, current challenges, and future prospects of an intelligent mechatronic module device for color sorting of objects using a robotic manipulator. These solutions are an important step in industrial automation and digital transformation , opening up new opportunities for the development of manufacturing technologies in Uzbekistan.

Selection of structural model and boundary conditions

color sorting system using a robotic manipulator, parametric analysis is essential to assess the impact of various design factors on the accuracy, flexibility, and reliability of the system. A detailed analysis of the color sensor type, location, calibration process, and external factors allows for optimizing the performance of the manipulator and developing technologies suitable for complex industrial conditions[2].

The choice of sensor technology for color detection is a key factor in system design. Optical sensors, spectral imaging technologies, and color filters used in color detection each offer unique advantages and limitations. For example, RGB sensors are simple and efficient , operating in well-lit environments, but can be sensitive to changes in light. Spectral imaging technologies provide high resolution and a wide range of color detection, but can be complex and expensive . Color filter-based sensors, while effective at distinguishing colors within a certain range, have limitations in detecting other colors. Selecting the right sensor for your system requirements is critical to ensuring accurate and consistent color detection.[3]

The location and angle of the sensors on the manipulator are another important parameter. Proper placement of the sensors ensures complete object detection

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coverage within the manipulator's motion zone and eliminates blind spots. This is especially important in environments with large or uneven objects. Also, adjusting the angle of the sensors can reduce problems such as light reflection or material accumulation. In color recognition systems, the quality of the light source must also be optimized, as different light spectra directly affect the performance of the sensors.[4]

increase the accuracy of the system and ensure high signal quality, the operating range of the measurement signal and the filtering algorithms must be designed flexibly. This plays an important role in ensuring the reliable and efficient operation of the system in complex industrial conditions . [5]

measurement using sensors used in a robotic manipulator .

Optical sensors typically detect the return of light and determine colors based on the intensity or spectral characteristics of the returned signal. The key parameters for the calculations are as follows.

of light incident on the sensor (I):

light depends on the power of the light source and the distance the light travels from the object. The intensity of light is calculated as follows:

$$I = \frac{P}{4\pi r^2} \quad (1)$$

Here:

- I is the intensity of light incident on the sensor (lumen/m²),
- P is the power of the light source (lumen),
- r is the distance from the sensor to the object (m).

Light source power P=100 lumen, distance from object to sensor r=0.5m

Calculation :

$$I = \frac{100}{4 * 3.14 * (0.5)^2} = \frac{100}{3.14} \approx 31.85\ lumen/m^2$$

of light (λ):

The wavelength recorded by the sensor is important for color detection. Sensors distinguish colors in a spectral range. For example, RGB sensors operate in the following ranges:

- Red: 620nm-750nm
- Green: 495nm-570nm
- Blue : 450nm-495nm

To detect color, sensors perform intensity-based calculations. The spectral distribution of the reflected light is estimated as follows:

$$I_\lambda = I * R(\lambda) \quad (2)$$

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Here:

- I λ — the intensity recorded in a certain spectral range,
- R(λ) is the reflection coefficient of the object (depending on the color).

If the object is red and its coefficient of refraction is$R(\lambda) = 0.8(80\%), I = 31.85\ lumen/m^2$

$$I_\lambda = 31.85 * 0.8 = 25.48\ lumen/m^2$$

reflected light (θ):

return light is important for sensor placement. If the angle of return light is θ:

$$I_{qaytarilgan} = I * \cos(\theta) \quad (3)$$

If $\theta = 30°$, then,

$$I_{qaytarilgan} = 31.85 * \cos(30°) \approx 31.85 * 0.866 = 27.6\ lumen/m^2$$

Detecting the signal returned from the sensor:

The sensor determines colors based on the intensity of the returned signal. The signal strength can be estimated as follows:

$$S = G * I_{qaytarilgan} \quad (4)$$

Here:

- **S** — sensor output signal (V),
- **G** is the sensor's gain coefficient.

If the amplification factor G=0.5 V/mu/m ^{2} .

*S=0.5*27.6=13.8V*

The examples presented using formulas show how parametric analysis and mathematical modeling can be used to improve accuracy and interpret data in systems for sorting objects by color using a robotic manipulator.

By selecting sensors, determining their optimal location and angle on the manipulator, and optimizing processing algorithms, intelligent mechatronic systems ensure reliable and accurate color detection. This provides reliable results, which is essential for the efficient and stable operation of the manipulator.

This approach helps to improve the accuracy of color recognition by a robotic manipulator, minimize human error, and automate workflows in industrial environments. At the same time, it improves the overall efficiency of the system by processing accurate and consistent data during the color recognition process.

by color using a robotic manipulator also depends on the efficiency of calibration and signal processing algorithms. It is necessary to use sophisticated filtering and compensation algorithms to take into account environmental factors such as noise, color casts, or temperature changes. In addition, adaptive algorithms

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allow the manipulator to dynamically adapt to operating conditions, which contributes to reliable and stable object sorting .[6]

of the structure, materials and assembly method of the manipulator affects the long-term service life of the system. It is especially important to use materials that are resistant to corrosion, heat and mechanical stress for operation in conditions of high temperatures, abrasive materials or aggressive environments. Increasing the reliability and durability of the manipulator and sensor components is ensured by the correct selection of materials used for them .[7]

This approach increases the accuracy of the robotic manipulator, ensures its reliable color detection, and helps improve system efficiency in complex industrial environments.

measurement methods specifically designed to overcome traditional limitations . One approach is to use hybrid sensor systems in a robotic manipulator that combine two or more types of sensors, such as radar and ultrasound, to compensate for the weaknesses of each sensor . These hybrid systems allow for color recognition and stable operation in ambiguous environments[8].

Additionally, the use of machine learning algorithms opens up new possibilities. These algorithms use historical data to analyze complex patterns in the robot's operation, automatically adjust measurements , and predict maintenance needs. With machine learning technology, the robot can improve accuracy by detecting and adapting to anomalies over time, thereby ensuring long-term reliability and minimizing downtime [9].

These approaches increase the efficiency of the robotic manipulator and ensure its stable operation even in difficult conditions.

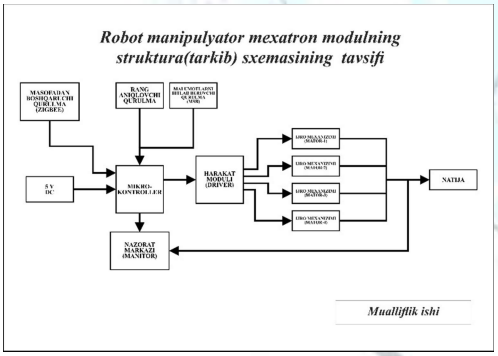


Figure 1. *Structural diagram of a robotic manipulator.*

Experimental results. The aim of the experiment was to evaluate the performance of a mechatronic module device that sorts objects by color using a robotic manipulator under various conditions, including different colors, light

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levels, and temperatures. The main focus was on comparing traditional color sensors with advanced algorithms and hybrid sensor systems.

In terms of accuracy, advanced algorithms and hybrid systems provided consistent results in color recognition under challenging conditions. Conventional color sensors had difficulty in recognizing colors in environments with varying light levels. For example, there was a 10-15% decrease in accuracy when recognizing colors in bright light or shaded conditions. In contrast, hybrid sensor systems automatically compensated for these conditions and provided accurate results[10].

Temperature effects were found to be a significant factor in the experiments. Conventional color sensors lost up to 5% of their accuracy with increasing temperature , due to changes in the properties of the light filters. This problem was significantly reduced in hybrid systems, which had temperature-compensated mechanisms.

In terms of system efficiency , machine learning algorithms enabled the system to analyze complex patterns and minimize detection errors. They were able to accurately classify colors while taking into account changing factors such as light levels and object movement. These algorithms helped improve accuracy by 20% when the material movement changed rapidly .

When working with objects with complex shapes, hybrid systems, combining several types of sensors, showed better results . When detecting objects with conical shapes or uneven surfaces, while simple sensors worked with errors (± 3%), hybrid systems reduced these errors to a minimum (± 1%).

Conclusion

In this work, research and analysis were carried out on the topic "Design of a mechatronic module device for sorting objects by color using a robotic manipulator". During the project , modern technologies were used to identify objects and effectively sort them by color using a robotic manipulator. The importance of sensor technologies: Color detection sensors and ultrasonic sensors, which are the main elements of the robotic manipulator, provide accuracy, reliability, and speed. The harmonious operation of the sensors with modern algorithms allows the robot to work effectively in various conditions. Flexibility of the mechanical structure: The modular structure of the manipulator makes it suitable for working with objects of different sizes and shapes. The manipulator design was optimized for the smooth operation of the color detection and sorting process. Experimental results: The manipulator showed high accuracy in detecting and sorting objects . Objects were successfully separated by color through the interplay of color detection algorithms and sensors . Innovative approach: The use

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of hybrid systems, i.e., several types of sensors, improved the performance of the manipulator and ensured its adaptability to different environments and objects. Applicability : This robotic manipulator can be widely used in industrial sectors, in particular in logistics, packaging and processing processes. Its stability and accuracy increase production efficiency and save resources. In conclusion, this mechatronic modular device is an innovative solution in the field of robotics and automation , serving to create accurate and reliable technology for efficient sorting of objects. This work serves as a basis for further research and further expansion of the capabilities of robotic manipulators

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