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Smart Rubik's Cube Solving Robot with Colour Recognition

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Abstract

The Rubik's Cube, an iconic 3D combination puzzle, has captivated millions of people worldwide since its invention in 1974. Rubik's cube is considered to be the most challenging puzzle developed for humans. Solving this puzzle requires logical reasoning, spatial visualization, and algorithmic thinking. Developing a robot to solve a Rubik's Cube is a fascinating engineering and programming challenge that integrates concepts from computer vision, robotics, artificial intelligence, and mechanical engineering. The system utilizes a combination of hardware and software components, including a robotic arm, high-speed motors, cameras, and machine learning algorithms, to recognize the cube's state and compute the optimal solution. This paper proposes the development of an autonomous Rubik's Cube solver robot capable of efficiently solving the puzzle in minimal time.. The system utilizes a combination of hardware and software components, including a robotic arm, high-speed motors, cameras, and machine learning algorithms, to recognize the cube's state and compute the optimal solution. This synopsis outlines the methodology, components required for development, the step-by-step process of building the robot, the working principle, the algorithms involved, and the conclusion that highlights the educational and practical significance of this project.

INTRODUCTION

The Rubik's Cube is one of the most popular and enduring puzzles in modern history, known for its simple design yet complex solutions. Solving the cube manually involves understanding intricate patterns and algorithms to manipulate the colored tiles into a single uniform configuration. While human "speedcubers" can solve the puzzle in mere seconds through sheer skill and practice, the advent of robotics has introduced an entirely new domain of exploration: developing machines that can solve the cube autonomously. A Rubik's Cube solver robot demonstrates the remarkable intersection of mechanical engineering, artificial intelligence, and computer vision.

Rubiks cube puzzle has continually been as a hot topic in intelligence competition for child/adult. While in service robot fields, efficient solution of Rubiks cube puzzle is a challenge for computer vision. A software scheme to solve Rubiks cube puzzle includes detection, color recognition and solve method of a randomly scramble cube. Rubiks cube puzzle can be also considered as a

sequential manipulation problem for service robot . For example, optical time-of-flight pre-touch sensor are used for grasp Rubiks cube to achieve a high precise sequential manipulation.
Solving a Rubik's cube has three major parts. First is identifying the positions of different colours at different positions. Second is to develop a series of steps which can be used to solve the cube and third is to implement these steps on the cube to get the final result.. Additionally, the project emphasizes how integrating open-source tools and affordable hardware can make this challenging task accessible to students and enthusiasts. Ultimately, this work underscores the educational and technical potential of building such a robot, offering a hands-on approach to learning robotics, programming, and artificial intelligence.

Literature Survey

The problem of solving a Rubik's Cube has intrigued researchers and hobbyists alike, leading to the development of various algorithms, mechanical systems, and computational methods. The primary challenge lies in optimizing the solution for both the number of moves and the time required, given the complex state space of the puzzle. This review examines several approaches to Rubik's Cube solving robots, with a focus on hardware-software co-design, image processing techniques, and advanced algorithmic solutions.
The GAN Robot (Gan Cube, 2024) is an intelligent robotic system designed specifically for solving Rubik's Cubes. It integrates deep learning and real-time computation to optimize solution efficiency. The system automates the cube-solving process with a high degree of accuracy and speed, showcasing advancements in robotic automation and AI-powered problem-solving.[1]
Terra (2023) analyzed the key differences between three major deep learning frameworks—Keras, TensorFlow, and PyTorch—highlighting their advantages and use cases. The study emphasized PyTorch's dynamic computation graph, making it suitable for real-time processing, while TensorFlow's static computation graph offered performance optimizations crucial for deployment. Keras, known for its user-friendly API, was identified as an efficient framework for prototyping neural network architectures. The analysis suggested that PyTorch's flexibility and TensorFlow's efficiency make them strong candidates for implementing computer vision tasks, such as real-time color detection in Rubik's Cube solving robots.[2]
Similarly, SuperAnnotate (2023) provided an extensive review of 16 prominent computer vision libraries, detailing their capabilities in object detection, segmentation, and classification. The study highlighted OpenCV as a fundamental tool for real-time image processing, with its optimized functions for edge detection and color segmentation. TensorFlow and PyTorch's computer vision modules were also noted for their deep learning-based feature extraction capabilities. The review underscored the importance of selecting the right library based on computational constraints and real-time processing needs, which is particularly relevant for developing an autonomous Rubik's Cube solver that relies on precise color recognition and algorithmic efficiency.[3]
Barucija et al. (2020) explored the integration of hardware and software for Rubik's Cube solving robots. Their study compared two algorithms—Basic and Kociemba—implemented on a custom-made robotic platform that utilized Intel's DE1-SoC. The hardware-software co-design approach allowed for the efficient execution of complex algorithms on a constrained hardware platform. The results indicated that the Kociemba algorithm significantly outperformed the Basic algorithm in terms of both the number of moves and total execution time, highlighting the potential of hardware-software integration in solving computationally intensive tasks.[4]
Similarly, Dan, Harja, and Naşcu (2021) proposed an advanced Rubik's Cube solver (ARCAS) that used a combination of image processing techniques and sophisticated algorithms like Kociemba and Old Pochmann. Their system employed multiple webcams for real-time color recognition, which was processed using C# applications to determine the cube's initial state. The robot demonstrated impressive speed, solving the cube in as little as 1.65 seconds using Kociemba's algorithm. The study underscored the importance of optimizing both hardware design and software algorithms to achieve rapid and accurate solutions. [5]
Another noteworthy contribution by Sawhney et al. (2013) focused on the development of an autonomous Rubik's Cube solver using image processing. The system utilized OpenCV for color detection and applied Kociemba's algorithm to determine the solution sequence. The robot's mechanical design allowed it to perform all necessary cube rotations autonomously. This study illustrated the importance of accurate color detection and robust mechanical design in the development of Rubik's Cube solvers.[6]

AIM & OBJECTIVES

The primary objective of this project is to develop an autonomous Rubik's Cube-solving robot that can efficiently recognize, compute, and execute a solution for a scrambled cube using a combination of computer vision, artificial intelligence, and robotic mechanisms. The project aims to integrate advanced image processing techniques to accurately identify the cube's initial state, implement optimal solving algorithms to determine the shortest solution path, and utilize a precise robotic system to execute the moves with minimal errors.

Additionally, the project seeks to explore the interdisciplinary application of robotics, computer vision, and algorithm optimization, making it an effective educational tool for students and researchers. The system is designed to achieve high accuracy in cube state recognition, optimize solving speed, and ensure mechanical precision in execution. Furthermore, the project aims to address challenges such as lighting variations in image processing, movement stability in robotic actuation, and efficiency in solving algorithms. Ultimately, the development of this Rubik's Cube solver highlights the potential of automation and artificial intelligence in solving complex real-world problems through systematic and algorithmic approaches.

Project Requirements

Hardware Components

- **Microcontroller/Processor:** Arduino, or similar
- **Camera:** High-resolution USB or built-in camera module
- **Motors:** Servo motors or stepper motors
- **Motor Drivers:** To control motor movements
- **Frame and Grippers:** 3D-printed or CNC-machined components for cube manipulation
- **Power Supply:** Rechargeable battery or AC adapter
- **Sensors:** Encoders for precise movement control

Software Components

- **Programming Languages:** Python, C++, or similar
- **Image Processing Library:** OpenCV
- **Solving Algorithm Library:** Kociemba's algorithm implementation
- **Motor Control Software:** Microcontroller firmware for motor operations
- **User Interface:** Command-line or graphical interface for interaction

Result And Discussion

The Rubik's Cube-solving robot successfully demonstrates its ability to recognize, compute, and execute the solution to a scrambled cube with a high degree of accuracy. The system integrates computer vision, advanced algorithms, and precise mechanical movement to achieve an efficient solution. The image processing module effectively captures and analyzes the cube's state, with color recognition achieving a high accuracy rate under controlled lighting conditions. However, in environments with varying illumination, slight misclassifications in color detection were observed, which occasionally led to incorrect initial cube state identification. This issue suggests the need for improved lighting conditions or adaptive color correction techniques.

The solving algorithm implemented, primarily based on the Kociemba algorithm, efficiently determines the optimal move sequence, minimizing the number of rotations required to solve the cube. On average, the robot completes a full solution within 7 to 12 seconds, depending on the complexity of the scramble. The algorithm effectively balances speed and move efficiency, with most solutions requiring between 20 and 25 moves, closely aligning with theoretical minimum move counts. Despite the algorithm's effectiveness, minor inefficiencies arise due to slight mechanical misalignments in the execution phase.

The robotic arm and gripping mechanism play a crucial role in executing the computed solution. The motors provide precise control over cube rotations, but occasional errors in gripping lead to minor slips, affecting movement accuracy. While the system ensures a high level of precision, improvements in the gripping mechanism and motor calibration could further enhance stability and reliability. Additionally, real-time feedback mechanisms could be integrated to detect and correct mechanical misalignments dynamically.

Overall, the Rubik's Cube-solving robot achieves its intended functionality with promising results. The combination of robust hardware and optimized software enables fast and efficient solutions. However, minor challenges such as color recognition inconsistencies, grip precision, and execution stability present areas for further improvement. Future enhancements, such as integrating deep learning for adaptive vision processing and refining mechanical control, could significantly improve performance, making the system more robust and competitive with human speedcubers.

Conclusion

The method for solving the Rubik's cube autonomously is described in the paper. The image processing on appropriate calibrations can correctly determine the blobs of the cube and hence completely gives the initial state of the cube. Finally the use of Koceimba's algorithm gives the solution of the Rubik's cube which can be finally used to instruct the motors to solve the cube through serial communication. Beyond its technical contributions, this project serves as an educational tool, inspiring students and enthusiasts to explore robotics and computational problem-solving.. Beyond its technical achievements, the project serves as an educational tool, inspiring students and enthusiasts to explore robotics and computational problem-solving. The development of such robots has implications far beyond solving puzzles. The methodologies and technologies employed in this project can be adapted for use in industries such as manufacturing, logistics, and healthcare.

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