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Research Article

COMPUTATIONAL METHOD FOR SOLVING RUBIK'S CUBE

Tae Juun Lee[1] and Eunsung Jekal[2]

[1]Yongyeon elementary school, Daehyeon-dong, Nam-gu, Ulsan, South Korea
[2]Jekal's LAB, Shinjeong 2-dong, Ulsan, South Korea

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ABSTRACT

Rubik's cube is a conventional mechanical puzzle that has attracted attention due to its unique characteristics. In this paper, we provide a basic understanding of the Rubik's Cube especially from a computational point of view.

INTRODUCTION

Rubik's cube is a puzzle where one side must be matched with the same color. To solve this puzzle, the most important part is understanding how it works. An average person takes 48 to 100 tries to solve the Rubik's cube and requires more time. Only 5.8% of world population can solve the Rubik's cube efficiently. However, by using computational concept AI & ML concept we are able to do so in under a second with minimum number of moves. Our aim is to develop an autonomous system which is capable to identify colours on the scrambled cube, generate string, developing array apply various algorithms on it and then solve it in minimum time and minimum number of steps.

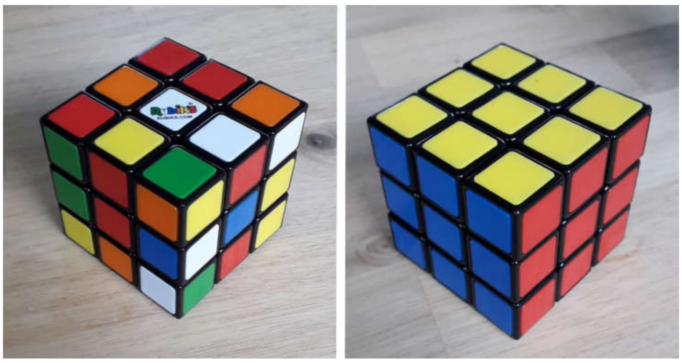

Fig 1 Rubik's Cube in scrambled state and final state

Solving Rubik's cube contains three major steps. First is identifying the positions of different colours at different positions. Secondis 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 as shown in Fig.1. Fig.2 provides stages to solve Rubik's cube which is provided by cube manual.

- **Stage 1** - Solve the first cross. It doesn't really matter which colored side this is, but the convention is usually the white side first. This means the final layer will be the yellow side.
- **Stage 2** - Next, you should solve the corners of whichever side you have chosen to start with. By doing this, you will also get the colored "T's" too when the solved layer (aka the first row) is rotated to match the fixed centerpieces on each "side".
- **Stage 3** - Once stage 2 is complete, flip the entire cube over so that the solved layer (by convention white) is at the bottom and start working on solving the middle layer (aka second row) corners. Remember that the middle pieces are always fixed.
- **Stage 4** - Once complete, you now need to complete the top cross (aka on the third row). You may also get lucky and have the cube already solved, but this is pretty rare.
- **Stage 5** - If needed, move the edge pieces of the "Yellow Cross" to their correct places.
- **Stage 6** - If needed, move the corner pieces on the top layer into their correct places.
- **Stage 7** - If needed, the final step is to get the final layer's (third row's) corners oriented correctly

Fig 2 Algorithm for solving Rubik's Cube in scrambled state

With the development of mechanical structure, implementation of image processing and development of algorithm is performed to solve the cube. This paper deals with all these processes that are involved. Image processing plays the most silent role of all, and thus its accuracy is considered very

Corresponding author:* **Tae Juun Lee
Yongyeon elementary school, Daehyeon-dong, Nam-gu, Ulsan, South Korea

vital.Identifying the colours is essentially the first process and generation of algorithm is the next step.

LITERATURE REVIEW

The Rubik's cube has been one of the most interesting and challenging puzzles ever built. It continues to remain in the top among the puzzle games because of the design of the puzzle [1].The Rubik's can be solved using a range of different algorithms which are already implemented and one can develop his/her own algorithm to solve the cube. [7]. Rubik's cube has attracted people from all around the world and also has been used for research purposes by scholars in various disciplines in account of its unique feature [5]. In order to recognize colors on each faces of the cube, Image processing is used. Image Processing plays a vital role in recognizing scrambled faces of the cube. [6]. Three popular algorithms that Thistlethwaite's algorithm, Kociemba's Algorithm and Korf's Algorithm exist for solving the cube. The Thistlewaite's algorithm was the least effective method of solving the Rubik's cube requiring an average of 42 moves and 3 mins and 48 seconds. This method was found to be not much effective and useful[7]. Kociemba's Algorithm was an improvement on Thistlethwaite's algorithm. The Kociemba's algorithm proved to be the 2nd most effective algorithm, requiring an average of 28 moves and 2 mins and 32 seconds [7].The Korf's algorithm proved to be the most effective algorithm, requiring an average of 20 moves and 2 mins and 5 seconds.Korf's algorithm is based on a multi-phase coding, which means the equations are divided into numerous sub problems which are then solved [7].

PROPOSED APPROACH AND METHODOLOGY

Hardware Implementation

One of the most important parts of the Rubik's cube solver is its mechanical design. To design a system with proper and accurate measurement is essential for proper working of the system. The mechanical design requires a very high precision. Even the slightest error of few millimetres can result in failure. When looking at a Rubik's Cube, there are six sides, each containing nine pieces. The sides can be rotated in many ways, the centre pieces don't move with respect to each other. Therefore, when the cube is being solved, the central pieces cannot move position. The initial state of the Rubik's Cube is determined through a camera that captures each of the six faces of cube. Then an array of data is produced which contains location and colour of all the pieces, string is generated using that data. Then a solving algorithm is applied on it that takes as input the scrambled state of the Rubik's Cube and outputs a sequence of moves which provides desired solution steps. As the algorithm for solving the Rubik's Cube produced sequences of moves. Each move is then translated into a series of steps by one of the six stepper motors attached to one face of the Rubik's cube. Each stepper motor which is controlled by stepper motor drivers turns a face of the cube. The stepper motors then execute the moves produced by the algorithm for solving the Rubik's Cube completely. At the end, we will have a Rubik's cube which is solved in minimum number of moves and in minimum time.

Stepper Motors

To physically rotate and solve the cube we will use NEMA 17 bipolar stepper motors. Stepper motors are selected over other types of motors because they are continuous (i.e. they can rotate in one direction infinitely), they have a relatively high torque, and they are relatively precise without additional feedback. The stepper motor operates using two coils and a permanent magnet rotor. When the coils are energized in a particular sequence, the stepper rotates by precisely 1.8 degrees (i.e. it takes 200 steps for the shaft of the motor to make a complete rotation). There are six such stepper motors attached to six faces of the main frame i.e. all six faces of the scrambled Rubik's cube which can provide the rotation of six faces at that particular instant and rotate in particular angle.

Motor drivers

Rotating stepper motors is a nontrivial task and often requires a specialized driver. In order to reduce the control complexity, we use six stepper motor drivers to control six stepper motors. The stepper motors are connected through a L298 motor driver which acts as a switch and helps to rotate the motor. The motor driver pins are connected to the microcontroller which provides appropriate instructions to it to perform necessary actions. They have PWM (pulse width modulation) pins which can be used to control the speed of stepper motors and to instruct how much to move and in which direction to move.

Electronics

The electronic part basically contains a microcontroller which is the brain of the robot or any mechanical design to solve the system. Without a microcontroller, it is not possible to solve it. The microcontroller used is "Raspberry Pi". Stepper motors can be interfaced with any controller through the motor controller but the reason for using Raspberry Pi to control the stepper is its high computational power that makes it suitable for self learning robots. The motors are connected to the pins of the microcontroller which gives commands to motors.

These commands are based on a code/instructions stored inside the chip of microcontroller. The chip of microcontroller is very small but is used for storage purpose of instructions and plays a vital role. The motor driver pins are connected to the microcontroller which provides appropriate instructions to it. They have PWM (pulse width modulation) pins which can be used to control the speed of stepper motors.

Programming

The programming consists of image processing concept, somewhat pattern recognition, various algorithms for finding the solution of the scrambled Rubik's cube and coding of microcontroller to direct the motors accordingly. The microcontroller used in this project is Raspberry Pi. Programming language used is Python.

Image Processing

In order to recognize the colors on each faces of the cube, image processing concept is used. It allows a much wider range of algorithms to be applied to the input data and avoid problems. Image processing is a technique to store the colours of any object in a format that can be processed through codes and programs. In this project, image processing concept is used to recognize the scrambled faces of the cube either by using web camera or mobile camera. The images of the six faces of the cube are taken to obtain the solution or the steps which can solve the cube. The image of each side of the scrambled cube is captured using the camera and sent via wi-fi to the computer. The acquired data is then processed to generate the algorithm required to solve the cube.

ALGORITHM

After storing the colours and positions of the individual blocks of the six faces of the cube, an algorithm is required to solve the Rubik's Cube which provides the steps that can solve the cube with time efficiency i.e. to solve the cube in minimum number of moves and in minimum time. Various algorithms are implemented to solve the Rubik's cube. The main purpose of applying various algorithms is to find out which algorithm suits best and which one is efficient to solve the Rubik's Cube. Algorithms are used to find the solution that is given to the microcontroller autonomously which further instructs the motors according to it and unscrambles the cube. The algorithm can solve the cube in maximum twenty-five steps and hence provides a good optimalsolution for descrambling the cube. Three popular algorithms exist for solving the cube. The Thistlewaite's algorithm solves the Rubik's cube requiring an average of 42 moves and 3 mins and 48 seconds. Instead it works on all the pieces at the same time, restricting them to fewer and fewer possibilities until there is only one possible position left for each piece and the cube is solved. Thistlewaite's algorithm lies in the "upper bounds" meaning it takes more moves to solve. This is due to the fact that the sub problems are only split into 4 subgroups which restricts the amount of moves the equation can be simplified too. To solve this we use sequence of nested groups. The whole cube group is generated by the moves {U, D, R2, L2, F, B} and this is the first group G0 in the sequence.

G0 = < U, D, R, L, F, B> G1 = G2 = G3 = G4 = 1

The Kociemba's algorithm requires an average of 28 moves and 2 mins and 32 seconds to solve the cube. It reduces the number of groups to only two therefore making a substantial decrease in required moves and time. It may well find an optimal solution to a position fairly soon, but it may take a long time for it to actually prove the solution is optimal by trying out all shorter sequences. In Kociemba's Algorithm, it uses only two phases for solving the cube. First phase moves from G0 to G1 and second phase moves from G1 to G2. G0 = < U, D, R, L, F, B> G1 = G2 = 1

The Korf's algorithm requires an average of 20 moves and 2 mins and 5 seconds. It is seen that Korf's algorithm is most effective among all.Korf's algorithm is based on a multi-phase coding, which means the equations are divided into numerous sub problems. Furthermore, when it is split into tables, normally in the other methods there are a number of ways to reach the solution, however, the Korf's algorithm limit the search depths of later phases therefore further optimising the number of moves required, instead of creating multiple solutions. It works by first identifying number of sub problems that are small enough to be solved optimally. 1. The cube restricted to only the corners, not looking at the edges. 2. The cube restricted to only 6 edges, not looking at the corners not at the other edges. 3. The cube restricted to the other 6 edges. The data fed to Python as a list data type is further used to solve the Rubik's cube. The algorithm is converted into Python code and fed to the data fed to create signals for the actuators which controls the cube rotation.

CONCLUSION

The Rubik's cube still proves to be a very difficult challenge for humans to solve, but it is even more challenging to make a system that solves it. The proposed system is a challenge for solving the Rubik's cube in minimum number of moves and in minimum time. With the knowledge of image processing and algorithm development it could be made possible. Finally the implementation of various algorithms gives the solution of the Rubik's cube which can be then finally used to instruct the motors to solve the cube and we will get the solved Rubik's cube. From all the three algorithms studied, it is observed that Korf's algorithm will take the least amount of time and moves to solve a Rubik's cube.Fig.4 shows the final output of the Rubik's Cube Solver.

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