Sudoku solver using

Artificial Intelligence

Yash Gujare[1] Shlok Bhalerao[2] Nandkishore Waghmare[3] Dr J.W.Bakal[4]

[1,2,3,4] *Department of Information Technology,Shivajirao S. Jondhale College of Engineering Dombivli*

[1]ogujare@gmail.com
[2]shlokbhalerao12@gmail.com
[3]waghmarekishore168@gmail.com
[4]J.W.Bakal@gmail.com

Abstract*—Our project, Artificial Intelligence based real time Computer Vision and puzzle solver using web-cam allows to provide the computer system with the Sudoku-puzzle in real-time and give the optimum solution to it. This project not only involves use of Artificial Intelligence, but also makes use of Computer vision, thus combining the two major concepts and increasing the future scope. In this project the computer tries to analyze the environment by capturing the multiple image bursts from the real time and from those images it would detect the Sudoku grid. For the detection of the grid the use of Hough Transform technique has been made. Then the numbers are detected using OCR i.e. Optical Character Recognition. Thus, the system gets the total knowledge of the puzzle and then computes the final solution by making the use of Artificial Intelligence based strategies for getting the optimal solution to the Sudoku puzzle problem.*

Keywords *– Sudoku puzzle, Artificial Intelligence*

1. INTRODUCTION

In this project, on the high-level three steps are performed:
1) See/Capture the image from the real time. 2) Identify/Detect whether the captured image is the same object or the puzzle query. 3) Solving the puzzle by making use of Artificial intelligence based strategies.
Computer vision is a field that includes methods for acquiring, processing, analyzing, and understanding images and, in general, high-dimensional data from the real world in order to produce numerical or symbolic information, e.g., in the forms of decisions. A theme in the development of this field has been to duplicate the abilities of human vision by electronically perceiving and understanding an image. This image understanding can be seen as the disentangling of symbolic information from image data using models constructed with the aid of geometry, physics, statistics, and learning theory. Computer vision has also been described

as the enterprise of automating and integrating a wide range of processes and representations for vision perception.. The image data can take many forms, such as video sequences, views from multiple cameras, or multi-dimensional data from a medical scanner. As a technological discipline, computer vision seeks to apply its theories and models to the construction of computer vision systems.

Artificial intelligence (AI) is the intelligence exhibited by machines or software. It is also the name of the academic field of study which studies how to create computers and computer software that are capable of intelligent behavior. Major AI researchers and textbooks define this field as "the study and design of intelligent agents", in which an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success. John McCarthy, who coined the term in 1955, defines it as "the science and engineering of making intelligent machines". The central problems (or goals) of

AI research include reasoning, knowledge, planning, learning, natural language processing (communication), perception and the ability to move and manipulate objects. General intelligence is still among the field's long-term goals. Currently popular approaches include statistical methods, computational intelligence and traditional symbolic AI. There are a large number of tools used in AI, including versions of search and mathematical optimization, logic, methods based on probability and economics, and many others. The AI field is interdisciplinary, in which a number of sciences and professions converge, including computer science, mathematics, psychology, linguistics, philosophy and neuroscience, as well as other specialized fields such as artificial psychology. Here, in the project AI strategies are used to solve the puzzle acquired using computer vision. For solving the puzzle, the brute force attack strategy, standard Sudoku puzzle solving algorithms can be used.
After performing the OCR the following data is then provided to the brute force attack or the problem solving engine. Thus, we get the final output here, i.e. the solved Sudoku puzzle.
In our project, use of computer vision is been made for detecting the puzzle itself from the real time environment. It plays a key role as the Sudoku puzzle i.e. the query or input for processing is been captured and provided to the system. The system should get the appropriate information for further processing and to maintain optimality while producing the output. According to the steps mentioned above, we need to see and detect the puzzle from the real time environment and this is possible by computer vision. For recognition of the object in real time the system actually needs to capture the time-burst when the video is been taken. Now from around 30-50 images the system compares them and processes them to extract the required object (here, Sudoku puzzle grid) from them. After the detection of puzzle grid, the characters i.e. the numbers are identified from the grid. These numbers are identified using Optical Character Recognition. OCR makes use of Principle Component Analysis(PCA). This was the role of Computer vision in this project. Now the next task comes up of Artificial intelligence.

I. EXISTING SYSTEM

The existing system i.e. the solvation of Sudoku puzzle needs huge mathematical computations as it contains 81 cells, in a 9 by 9 grid, and has 9 zones, each zone being the intersection of 3 rows and 3 columns. Each cell may contain a number from one to nine; each number can only occur once in each zone, row, and column of the grid no digit can appear twice in a unit. This implies that each square must have a different value. At the beginning of the game, many cells begin with numbers in them, and the goal is to fill in the remaining cells. If solved manually there is a wide range of strategies to solve Sudoku puzzles and will need huge efforts to do so and compute the optimal solution of the puzzle.

Furthermore, several researches have been made to solve Sudoku problems in a more efficient way. It has conclusively been shown that solving the puzzle, by using different algorithms, is definitely possible but most developers seek for optimizations techniques such as genetic algorithms, simulated annealing.

Different authors have made relative works already. Nelishia Pillaygives a solution for solving Sudoku by combining human intuition and optimization. However, we seek a solution to solve Sudoku puzzle based on human strategies, which uses techniques such as: naked single method, hidden single method etc. J.F. Crook have also discussed about solving Sudoku and presented an algorithm on how to solve the puzzles of differing difficulty with pencil-and-paper algorithm.

Flaws of the current system:

1) If solved manually players needs to check different alternatives and place the numbers in the empty squares by guessing as many options are valid.

2) Needs feeding of random numbers by player and then it is checked whether valid or not for all possible solutions to the puzzle until a valid solution is found which is a time consuming procedure resulting an inefficient solver.

3) As compared to real time it is time consuming and needs human efforts too which is not the case in real time puzzle solver.

Example of Sudoku puzzle is been shown below. It shows the initial and the goal state that should be.

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Fig 2.1 initial state

5	3	4	6	7	8	9	1	2
6	7	2	1	9	5	3	4	8
1	9	8	3	4	2	5	6	7
8	5	9	7	6	1	4	2	3
4	2	6	8	5	3	7	9	1
7	1	3	9	2	4	8	5	6
9	6	1	5	3	7	2	8	4
2	8	7	4	1	9	6	3	5
3	4	5	2	8	6	1	7	9

fig 2.2 Goal state

II. PROPOSED SYSTEM

After getting the brief idea about the existing system it will now become more effortless to understand the proposed system. Also we are now aware of the problems related to the existing system.

As we have seen that the existing system solves the Sudoku Puzzle using the artificial intelligence but in this proposed system we are using the computer vision concept where the computer will detect the puzzle on its own and then it will solve the puzzle. This will make it real time puzzle solver and this the essence of the project.

Requirements in proposed system

As compared to the existing system lots of resources as well as features needs to be implemented. Because the project will be solving the puzzle in real time environment. Along with it a strong AI is needed to solve the puzzle. And since it is Real time based the computer will detect the puzzle and then it will proceed.

- Using computer vision detects the puzzle in real time.
- Identify the puzzle automatically.
- Solve the puzzle using artificial intelligence.

Advantages of the proposed system

- No human intervention required.
- The data of the puzzle need not be given manually because the puzzle will be detected in the real time itself.
- Less time consuming.

2. LITERATURE SURVEY

- Literature survey is the study done to analyse the methods used previously and how we could improve the methodology used in our proposed system. In recent literature paper AI Based Strategy To Play Tic Tac Toe Game that was made in 2009[10], they have used backtracking algorithm to solve the puzzle. This method was well suited for tic tac toe game as there was no heavy data to implement and solution possibilities are less as compared to Sudoku puzzle. But implementing backtracking in Sudoku would require too much of time for getting the solution.
- A Genetic Algorithm Based Solver For Very Large Jigsaw Puzzles[11] proposed in year 2013 has used Genetic algorithm. Genetic algorithm has set of population and population consists of chromosomes of solution possibilities. And it keeps on traversing this chromosomes until the suitable solution is found. Implementing this for Sudoku puzzle would cause the problem of slow convergence and local minima. The next literature paper i.e. Solving Sudoku using genetic algorithm[12] in year 2009 has highlighted the flaws of using genetic algorithm for Sudoku puzzle. Further study was done on Finding solution to Sudoku puzzles using human intuitive heuristics[15] in year 2012 which also used genetic approach.

- Next Study Was Done On Objects Recognition And Pose Calculation System For Mobile Augmented Reality Using Natural Features.[14] and SURFTrac: Efficient Tracking And Continuous Object Recognition Using Local Feature Descriptors[18], year 2009 . They used Speed Up Robust Features(SURF) Algorithm which is used for continuous tracking of objects in the environment in real time. Comparing our system to this algorithm, continuous detection of object is not really needed as after the extraction of puzzle would get us the essential data for solving the puzzle.
- Similar case is with Real Time Object Detection For Smart Vehicles[14] which used Distance transform simulated annealing which is detects random shapes but Hough transform in our system would detect only grid lines of the puzzle which is needed here. Further study was done on Finding solution to Sudoku puzzles using human intuitive heuristics[15] in year 2012 which also used genetic approach.
- Another survey was made on Real Time Traffic Sign Recognition Based On Color Image Segmentation[16] implemented in year 2013. They have made use of joint transform correlation technique which is used for pattern matching. Similarly we use OCR(Optical Character Recognition) for recognizing the characters.
- Next is Paper and Pencil approach for Sudoku puzzle solving [19] in which Combination of naked single, hidden single and backtracking is done. This is the best method for solving Sudoku puzzle as it computes the solution in short span of time.

- **2.1 Literature Survey**

Sr. No.	Literature paper	year	Algorithm used	Advantages	Disadvantages
1	AI based strategies to play tic-tac-toe game	2009	Backtracking	Calculates optimum solution	Time consuming
2	A genetic Algorithm based solver for very large jigsaw puzzle	2013	Genetic Algorithm	Contains population of chromosomes that are actually the solution to the problem. Get to the solution in case of simpler problems	Using GA faces problem of Slow convergence and local minima.
3	Solving Sudoku using Genetic Algorithm	2009	Genetic Algorithm	Not advantageous when using for Sudoku like real-time problem	Problems like slow convergence and local minima are faced.
4	Objects recognition and pose calculation for mobile	2015	Speed up robust features(SURF)	Used for continuous object detection.	Continuous object detection not required, thus, hough

	augmented reality.				transform is used.
5	Real-time object detection for smart vehicle	--	Distance transform,simulated annealing	Used for detection of random shapes from the environment.	Detection of lines needed thus, simulated annealing not preferable.
6	Finding solution to Sudoku puzzles using human intuitive heuristics	2012	Human intuitive heuristics, genetic approach	Can use it for small/simple Sudoku puzzle but still could be slow.	In a very small space, considering that sudokus that have only a single solution rarely have more than a handful of permutations that can't be seperated in less time.
7	Real time traffic sign recognition system based on color image segmentation	2013	Joint transform correlation	Used for pattern matching, patterns of images are being matched	On small scale, rather than using pattern matching OCR could be used.
8	A segmentation free approach to recognize printed Sinhala script.	2004	Edge detection algorithm using linear symmetry	Sinhala script being complicated for detection Edge detection is used.	Numbers being a simple characters for detection OCR could be used rather than using complicated Edge detection algorithm and slowing down the system.
9	SURFTrac: efficient tracking and continuous object recognition.	2009	SURFTrac algorithm using local feature descriptor.	Used for continuous object detection.	Not relevant to our system thus not used.

10	Paper and pencil approach for Sudoku solving	2013	Bactracking plus naked single and hidden single.	Fastest method for solving Sudoku puzzle.	No disadvantageous to our system, hence will be used for puzzle solving.

- Table no.2.1 Literature Survey

3. OVERVIEW OF OUR PROJECT

Our proposed system have 2 basic components.

- Computer vision
- Artificial intelligence.

Computer vision detects and identifies whether there is puzzle existing or not. And once it is detected the artificial intelligence solves it using the Brute force.

Steps or working model is as follows

1. Take a frame of video in real time.
2. Convert it to black and white image, for OCR color information is not of any use.
3. Detect if the image is at any rotation; perform the correct rotation in opposite direction.
4. Detect and perform OCR on all the characters.
5. Solve the puzzle using brute force method.

Working details

The image is an example of how the image can be converted from color to black and white for further OCR processing.

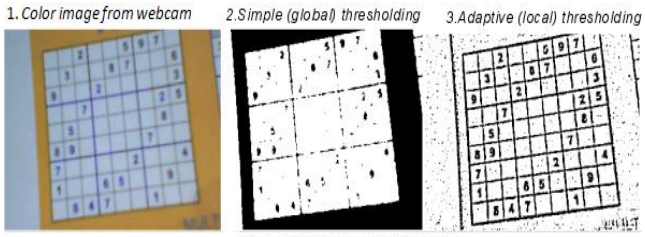
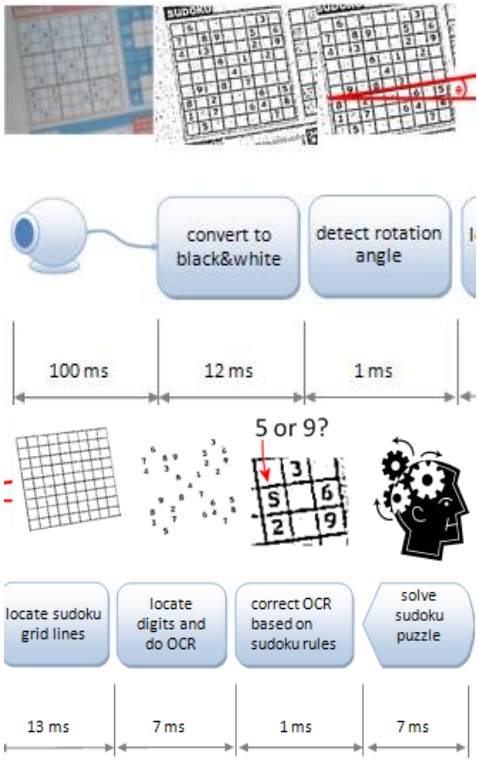


Fig.2 – converting color to black&white

The second image is an example of how the image can be checked for any rotation and hence rotated in opposite direction to correct rotation error. There are other possible improvements. Professional OCR engines use many different features. Some of them can be very unique.



Fixing the OCR result

After OCR is done, the results are given to a brute force engine for puzzle solving.

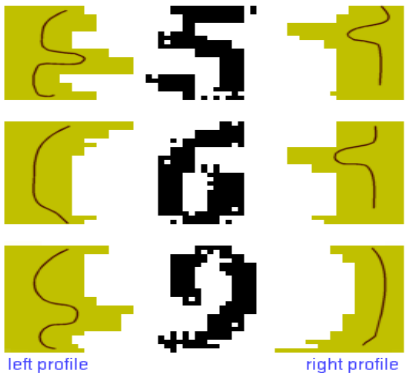


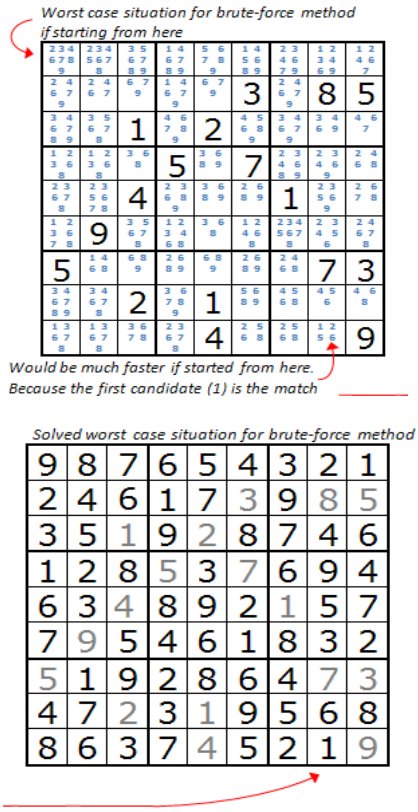
Fig.14 - profile feature

Brute force

Also called backtracking. This is the most common method used by programmers and which always gives a solution, no matter how difficult it is. But brute force could be very slow, depending on the number of recursive iterations needed. You can never know in advance how much iteration is needed. Brute force is a “trial and error” method. It tries all the combinations of possible values 1-9 on all empty cells until all the cells are filled with consistent values. There could be more than one solution, but we are happy to find the first one only.

The first step is to prepare the table of candidates – possible values for each empty cell. The image below explains what the candidates are. They are in blue color. By Puzzle rules, the first cell can contain only 1, 4, or 8. For example, 3 cannot be there, because it is already present two cells below.

The brute force will try to combine all the little blue numbers until it finds a solution. See the first cell. The algorithm will start with the value 1, and then on the fifth cell, it will take number 3 and so on. If any of the selected numbers is not consistent with the other values, the algorithm will try with a different one. For example, the sixth cell from the left has also number 3 as a candidate, but since this is not consistent with the fifth cell, the algorithm will try with the next candidate, which is 4, etc.



4. CONCLUSION

There are also some systems that solve the puzzle using artificial intelligence, but then the input to the system should be given in digital format.

The Sudoku solvation needs many computations and when tried doing it manually it requires too much of time and efforts to find the optimal solution to the puzzle. Here, to fill the blank spaces in the puzzle we need to try every value and get the answer which consumes more time.

In our proposed system, we make use of computer vision to capture the input itself in the real-time environment, which also cut downs the efforts and time of giving entries to the computer manually via keyboard. And then the system makes use of artificial intelligence to solve the puzzle problem. Thus, overcoming the flaws of the existing system and hence, promising for the better future scope.

5. ACKNOWLEDGMENT

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