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Computer Vision and Artificial Intelligence Based Puzzle Solver

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Abstract: *This document gives formatting instructions for authors preparing papers for publication in the International Journal. The authors must follow the instructions given in the document for the papers to be published. You can use this document as both an instruction set and as a template into which you can type you're In the last decade or so, solving the Sudoku puzzle has become everyone's passion or you can say hobby. The simplicity of the puzzle's structure and the low requirement of mathematical skills caused people to possess enormous interest in accepting challenges to unravel the puzzle. Therefore, developers have tried to hunt out algorithms so on get the variability of puzzles for human players so as that they could be even solved by programming. AI-based real-time Computer Vision and puzzle solver using webcam allows providing the pc system with the Sudoku puzzle in real-time and provides the optimum solution thereto. The system not only involves the use of AI but also makes use of Computer vision, thus combining the 2 major concepts. During this system the pc tries to analyse the environment by capturing the multiple-image bursts from the important time, and from those images, it might detect the Sudoku grid lines. For the detection of the grid, the use of the Hough Transform technique has been made. Then the numbers are detected using OCR technology i.e. Optical Character Recognition. The system gets the whole knowledge of the puzzle and then computes the last word solution by making the use of AI-based strategies for getting the optimal solution in efficient manner to the Sudoku Puzzle Problem.*

Keywords: Puzzle Solver, Artificial Intelligence, OCR, Grid Detection, Sudoku Algorithm, Brute force neck single Algorithm

I. INTRODUCTION

This system deals with real time puzzle solving system using Computer Vision and AI. Artificial Intelligence based real time Computer Vision and puzzle solver using web-cam allows providing 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. The computer-vision will try to analyse 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 will be done. Then the numbers his system deals with real time puzzle solving system using Computer Vision and AI. This proposed system will be developed will be detected using OCR i.e. Optical Character Recognition. AI strategies are needed 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 or combination of hidden single, naked single and backtracking will be used. Thus, the system will get 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. TN Visual Studio 2008. This kind of application will be useful in real word as well.

II. METHODOLOGY

The proposed system will make use of computer vision technology and Artificial Intelligence. For detection purpose it uses Hough transform technique and Optical character Recognition to detect the characters present in the grid. The basic flow of the system will be as shown below in figure 1

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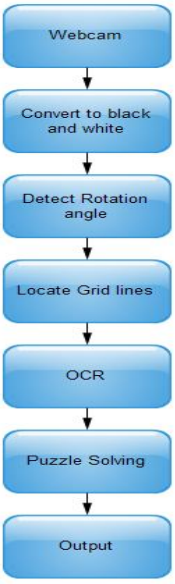

Figure 1: Flow of the System

- Convert to Black & White - This method replace each pixel in an image with a black pixel if the image intensity is less than some fixed constant or a white pixel if the image intensity is greater than that constant. Every computer vision application starts with the conversion from gray scale to monochrome color. The method used to convert color to monochrome is Thresholding. Here each pixel in an image is first replaced with black pixel if the image intensity I is less than some fixed constant T i.e. (I<T), or else with a white pixel.
- Detect Rotation: The puzzle captured by the webcam may not be always aligned; it is to be skewed and rotated. As the puzzle has some horizontal and vertical lines i.e. grid, these lines are used to detect the angle of rotation. The most expressive (strongest) line near to the center of the picture is detected. The most expressive line is not affected by the noise.
- The algorithm used to detect lines from a monochrome image is called Hough Transform.

III. WORKING

The Hough transform algorithm skips the white pixels. Every black pixel draws 180 virtual lines passing through that pixel. The line which is common to all pixels is considered as the strongest line.

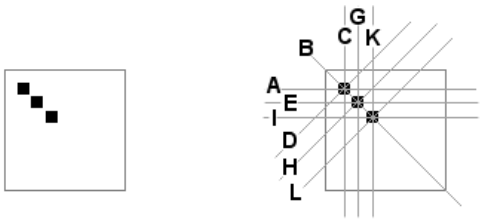

Figure 3

The theta and rho values of this line are then considered.

$$y = (x * \cos(\text{theta}) + \text{rho}) / \sin(\text{theta}).$$

Here, Theta signifies the angle of the line and rho specifies the distance of line from centre coordinate (0, 0).

Locate Grid Lines: To extract the numbers from the grid the Sudoku grid needs to be precisely located. But the grids printed may contain some noise i.e. background data. Due to which it is difficult to distinguish the noise and the actual grid lines. So, white lines are detected instead of detecting black lines. By counting the number of times line is interrupted by black pixels accordingly it is considered whether it is outside the grid or inside. By this the grid border lines are detected. Then Hough transform is again applied inside the boundaries to detect the grid lines of the inner grid lines.

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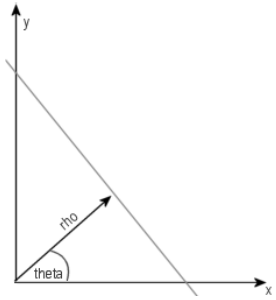

Figure 4

OCR: OCR is the process of turning a picture of text into text itself.
The image below shows how the character recognition would actually take place.

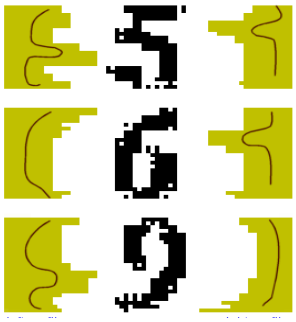

Figure 5: OCR

Optical character recognition is the process of turning the picture of the text into the text itself. Below is the explanation of the role of OCR in the system. After the blobs which are located inside the cell, the next step will be to recognize them. The task is relatively easy in the case of Sudoku puzzle as only the numbers from 1 to 9 needs to be recognized and not all the alphabets. Every recognition algorithm has these steps:

- Determine features
- Train (learning step)
- Classify (runtime recognition)

'Determine features' is a part of the application design. The features for example are: the number 1 is tall or thin. This is what it makes him different from the other numbers. The number 8 has two circles, one above the other, etc.
Zone features: In this application, zone density features will be used. The next step is to train the application by providing training pictures of digits 1-9. The pictures are resized to 5x5 pixels, normalized, and stored in the static array which looks like:

Figure 6: Density feature

The process of resizing the image to 5x5 is called zoning. The above shown image of array is called density features. Normalizing means that those 5x5 pictures have density values in the range 0 to 1024. Without normalizing, the zones would be incomparable. When a blob is recognized and isolated from a webcam's image, it's resized to 5x5 pixels. Then these 25 pixels are compared, one by one, with the nine trained density feature arrays. The goal is to find the minimal difference in pixel intensity. Less difference means more similarity. This is the process which happens at runtime.
Puzzle Solving: The use of three simple methods is merged together in order to find the solution to the puzzle in a better and faster way.
Those three methods are:

1. Brute-Force
2. Naked single
3. Hidden single

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A. Brute Force method

Brute force is a trial and error method. It tries all the combination of values from 1 to 9 on all the empty cells until all the cells are filled with consistent values. There could be more than one solution. Brute force is the most commonly used method by programmers as however the condition maybe, it promises to give the final solution, no matter how much time it consumes. But brute force could be very slow, depending on the number of recursive iterations needed. It can be never known in advance how much iteration is needed. The first step is to prepare the table of candidates – possible values for each empty cell. The explanation of what the candidates are is given by the image shown below. The candidates are given in blue colour. Only 1, 4 and 8 can be contained by reference to the Sudoku rules. For example, as 3 are already present in the two cells below it cannot be there.

Initial puzzle state

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

With list of possible values – candidates

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

Until brute force finds the solution, it will try to combine all the blue numbers. Check the first cell. The algorithm will begin with the value 1; it will take number 3 on the fifth cell then, and so on. The algorithm will try with the different values if any of the selected values are not consistent with the other values. For example, there is number 3 at the sixth cell from the left, but as there is no consistency with the fifth cell, the algorithm will move on with the next candidate i.e. 4, etc.

B. Naked Single Method

The image below would explain what naked single method in detail is. If a cell has a single candidate that could be taken then it is 100% sure that this is a valid value for that cell. After that value is been set, the next step is to rebuild the list of candidates. The list of candidates would gradually reduce until all the candidates are singles.

Step 1. This cell has a single candidate. Fill it.

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

Step 2. Now we have next two single candidates

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

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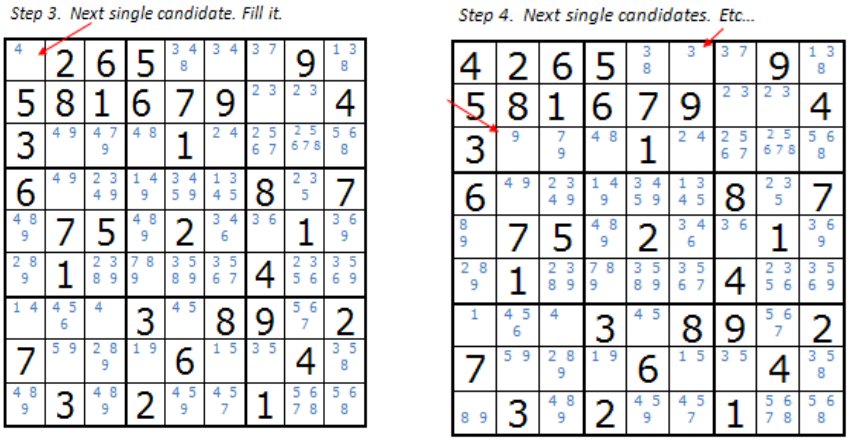

C. Hidden Single Method

The image below here explains the hidden single method. Look at the number 7 in the given image, the regular Sudoku player would be easily able to get that the number 7 would come in the pointed box. Even if the cell has four candidates: 4,7,8,9 in the adjacent figure, the trick is to search for a unique instance of candidates inside the 3x3 block, column, or row. When method 2 runs out of the single candidates, method 3 can help.

For the webcam puzzle solver, the speed is very important aspect. The brute force is not fast enough for this particular application. Therefore a combination of all three methods shall be used. The methods 2 and 3 are very fast, but they are able to solve only simple puzzles. The flowchart mentioned below gives the overview of how these methods would work together. On the left side, there are fast methods and on the right side is the brute force. Only when the left side methods fail, it will jump to the right side for further solution. Even if the left side methods are unsuccessful to solve the whole puzzle, it reduces the burden of the problem at a larger extent for brute force.

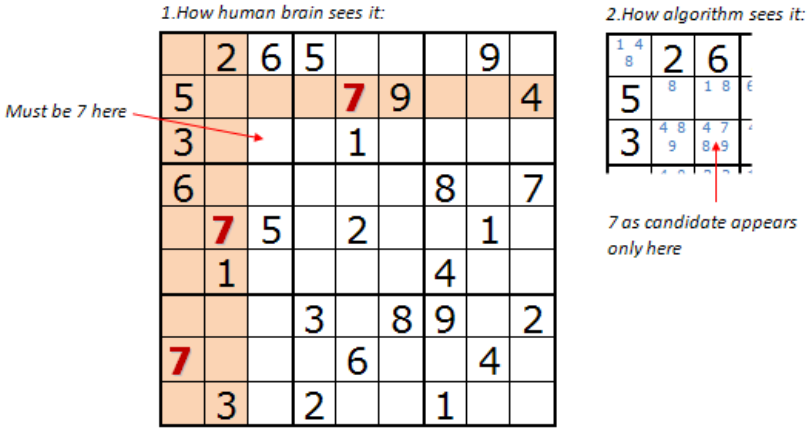

Figure 7: Hidden Single Example

There will be three re-tries after which the program gives up. Between each retry the recursion sequence is rearranged randomly with the hope that the new sequence will lead to the fast solution. If the brute force fails three retires, it may not be the complete failure. The next camera frame might be lucky.

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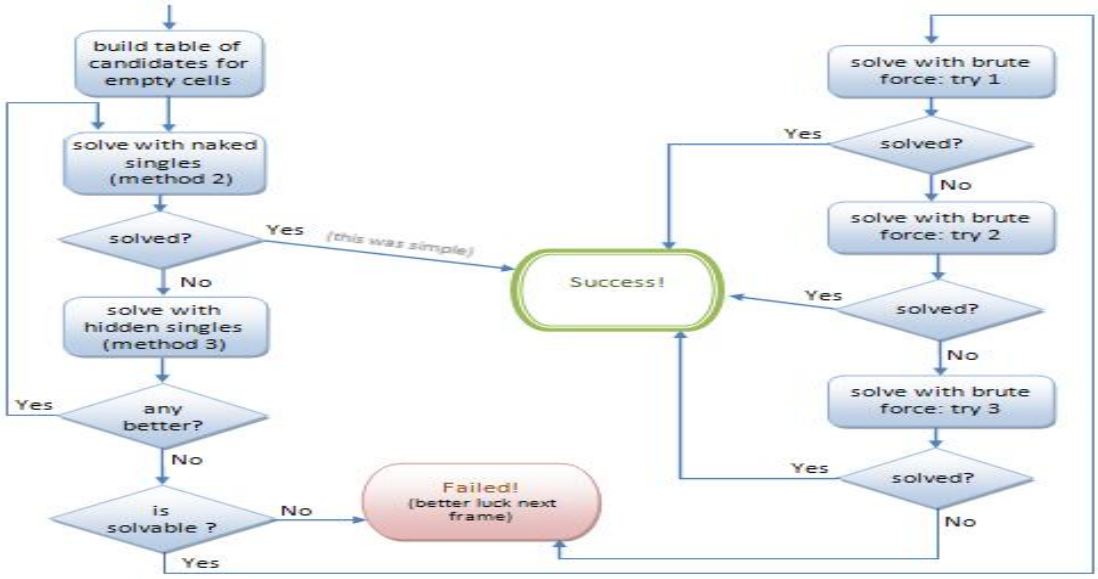

Figure 8: Sudoku Solving Process

IV. LITERATURE SURVEY

All 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, 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 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 these 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 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 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 and Sortras: Efficient Tracking And Continuous Object Recognition Using Local Feature Descriptors, 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 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 in year 2012 which also used genetic approach.

Another survey was made on Real Time Traffic Sign Recognition Based on Colour Image Segmentation 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 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.

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Table 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 augmented reality.	2015	Speed up robust features(SURF)	Used for continuous object detection.	Continuous object detection not required, thus, hough 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.
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.

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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.

V. Result and Discussion

To show the processing of the puzzle image in detail, various options has been provided in the 'View' menu.

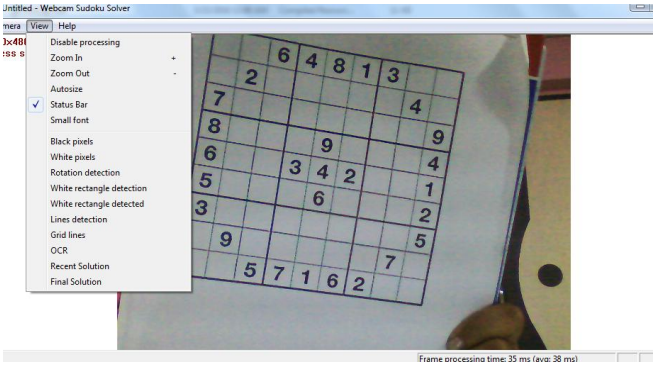

Figure 1: View menu with various image processing options.

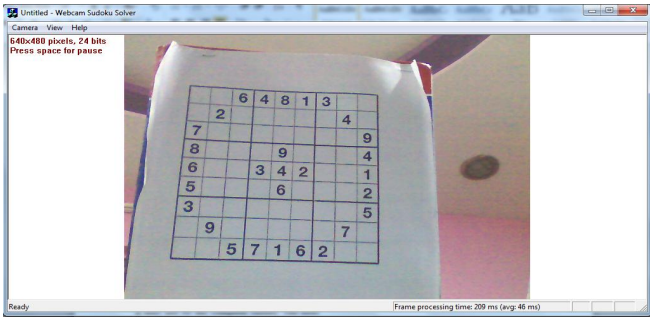

Figure 2: Puzzle image shown to the webcam

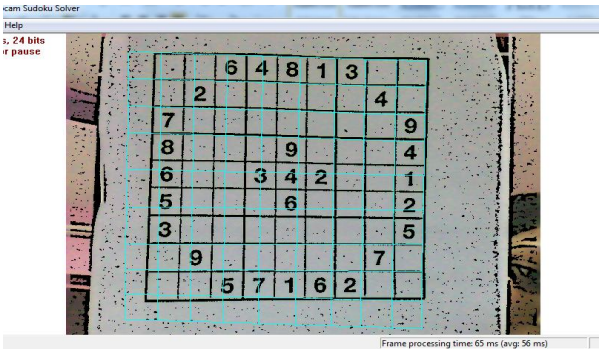

Figure 3: Black pixels option enabled from view menu, showing the conversion of original image to monochrome (here only black pixels enabled, thus on black pixels are shown)

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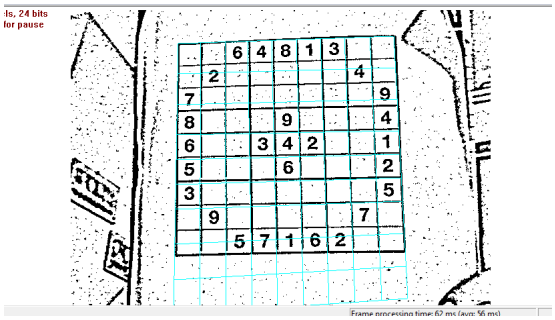

Figure 4: White pixels option enabled from view menu. Image turned to monochrome before processing further.

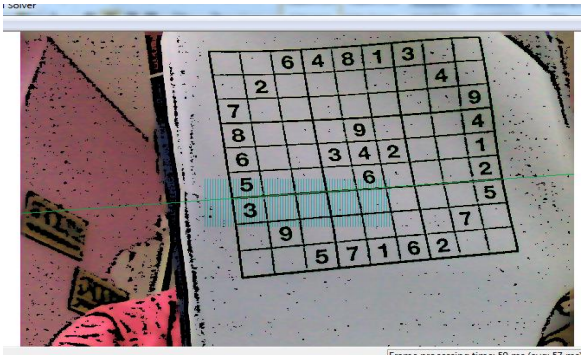

Figure 5: Rotation detection option enabled. Green line detecting the angle of lines detected.

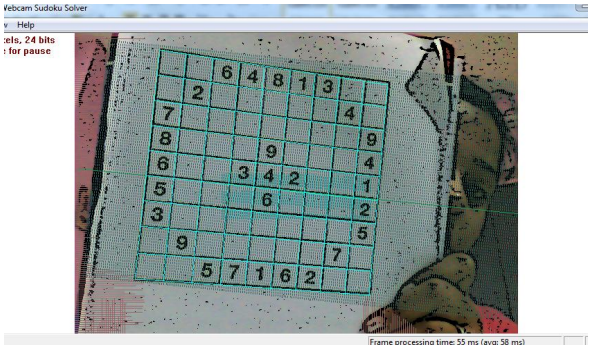

Figure 6: White rectangle detection option enabled.

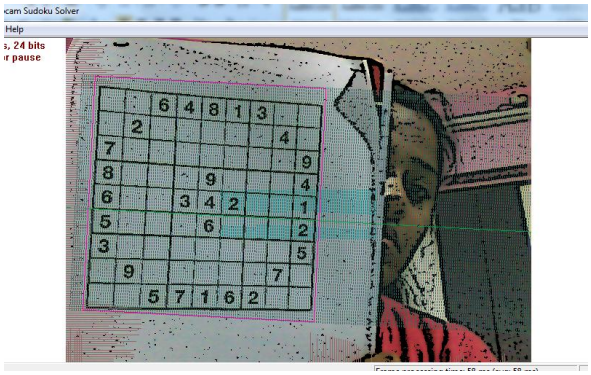

Figure 7: White rectangle detected with the pink border.

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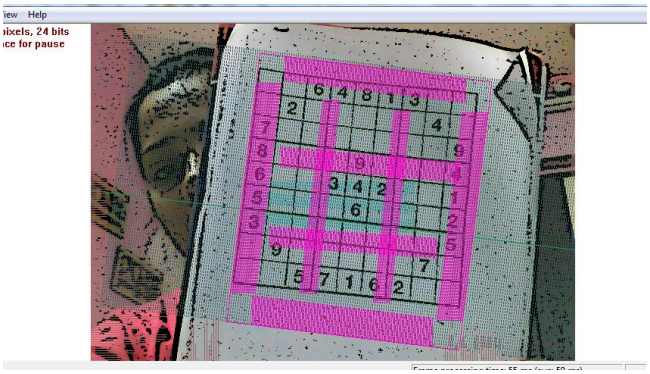

Figure 8: Line detection option enabled.

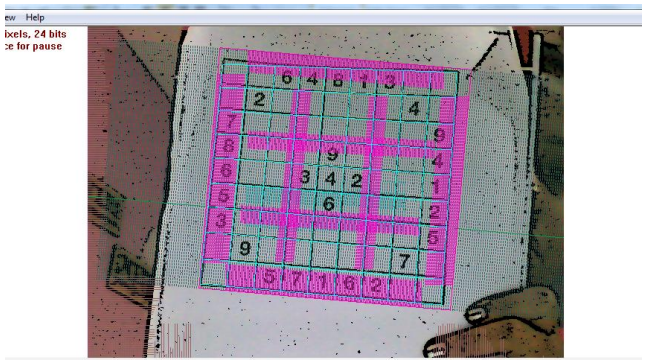

Figure 9: Grid detection option enabled.

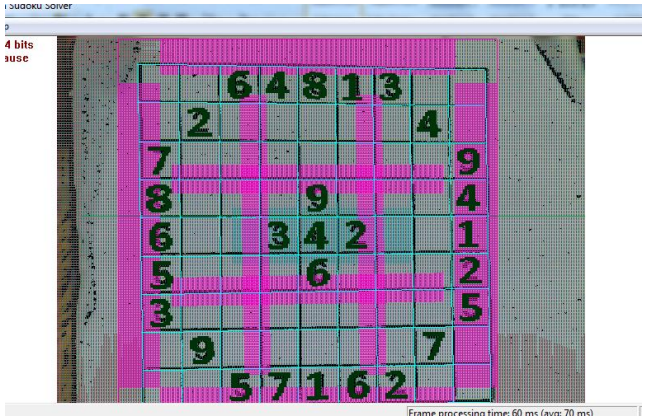

Figure 10: OCR detection option enabled. OCR detects the numbers and matches it with the templates already stored into the system.

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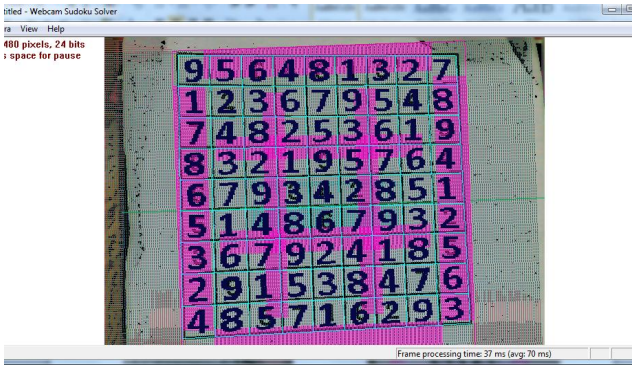

Figure 11: Final Solution option enabled. Thus, giving the final output to the puzzle.

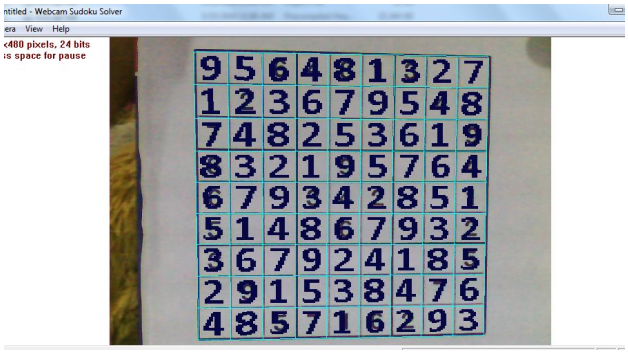

Figure 12: After disabling all the other processing options and only Grid detection and Final solution option enabled, the output screen looks like this.

VI. CONCLUSION

All 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. Thus, the drawbacks of the current system are: If solved manually players needs to check different alternatives and place the numbers in the empty squares by guessing as many options are valid. 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. As compared to real time it is time consuming and needs human efforts too which is not the case in real time puzzle solver. The system overcomes the obstacles of the current 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. The system is less time consuming. It provides more accurate and optimal solution.

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