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Sudoku Puzzle Detection using Image Processing Techniques and Solving: A Literature Survey

Paritosh Pujari [1], Saurabh Thorat [2], Suraj Thopate [3], Yash Shah [4], Prasad Kharade [5]

Undergraduate Student, Department of Computer Engineering, Vishwakarma Institute of Information Technology, Pune, India[1, 2, 3, 4]

Assistant Professor, Department of Computer Engineering, Vishwakarma Institute of Information Technology, Pune, India[5]

ABSTRACT: The popular Japanese puzzle game Sudoku is one of the most popular puzzle games of all times which is based on logical placement of numbers. The prime objective of this review is to do literature survey of methods to recognize Sudoku puzzles containing numerical digits from images taken with a mobile camera and puzzle solving techniques. An image in general portrays a visual perception of an artifact, for example a photo or a two-dimensional picture depicting any object, place or a person etc. In Computer Science, a digital image is a numeric representation of a two-dimensional picture, which often contain texts which are in a human readable format. These texts in a digital image are defined by a set of pixels. The paper discusses about various methods for digital detection and interpretation of a Sudoku puzzle using optical character recognition and vision based techniques and solving the subsequent puzzles using various computer algorithms.

KEYWORDS: Sudoku Puzzle, Computer Vision, Optical Character Recognition, Image Processing

I. INTRODUCTION

Sudoku is a single player, logic based, combinatorial, numeral digit placement puzzle. As a logic puzzle, Sudoku is an excellent brain game which at times can be highly addictive in a good way. It is stated that by playing Sudoku on a daily basis has improvements in one's concentration level and overall brain power. The puzzle basically consists of a 9x9 grid, constituting to form 81 cells in total [11]. The main objective of this puzzle is to fill this 9x9 grid so that each row, each column and each of the nine 3x3 sub-grids that forms the grid accommodates all the digits from 1 to 9. A partially completed grid is provided by the puzzle setter, which for a precisely created puzzle has a single solution.

Figure 1 shows a standard Sudoku puzzle. Sudoku puzzles normally appear in newspapers and other text and digital media with varying difficulty levels, but often their solutions are provided the next day. At the same time, learning to play Sudoku can be a bit intimidating for beginners. Our motivation for this project is to develop an Android application which can present an accurate solution to the user in quicktime.

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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. 1. A Standard Sudoku Puzzle

In this paper, we provide a literature survey of the various methods for digital detection and interpretation of a Sudoku puzzle using optical character recognition and vision based techniques and solving the subsequent puzzles using various computer algorithms.

The remainder of the paper is organized as follows. Section II illustrates related work. Section III analyzes the methods used for digital detection of a Sudoku puzzle followed by Section IV which explains methods used for solving the Sudoku puzzle. Finally, Section V concludes the research.

II. LITERATURE SURVEY

Sudoku is an easy to learn logic-based number placement puzzle and thus has been a popular constraint satisfaction research problem amongst many researchers. Plentiful Sudoku puzzle detection and solving techniques have been proposed. Table I provides a general comparison between various techniques used for Sudoku puzzle detection in various literatures.

Literature [4] by Dutta et al. explains a system which can extract text from a Sudoku puzzle, solve it and then provide solution to the puzzle. Their work based on a comparison model, compares each extracted image snippet with already established image database and then maps the snippet to a number text from the database. A simple recursive algorithm was applied in solving the Sudoku puzzle and results were presented.

Literatures [10] and [9] used Neural Network models to recognize the digits in Sudoku puzzles. Chitranshi et al. [9] elaborates the development of an Neural Network Based Skeleton Recognition and Sudoku Solving. Their proposed system uses the mechanism of feed forward backward propagation where effort is taken to minimize the error. The puzzle is solved using a trial and error method and the results obtained are compared with the traditional template matching. Literature [10] proposes a system which takes an input image from camera and steps such as converting the image to grayscale, binarization, angle detection and rotating the image, segmenting the puzzle's border are carried out followed by solving the puzzle.

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TABLE I
LITERATURE SURVEY

Sr. No	Literature	Methodology	Advantage	Disadvantage
1	Development of a Character Recognition Software to solve a Sudoku Puzzle [4]	k-Nearest Neighbor Algorithm	The cost of learning process is zero. Can perform well with sufficient representative data.	It is computationally costly to find the k-nearest neighbor when the dataset is very large.
2	A novel and automatic character extraction and recognition for Sudoku puzzle solving [10]	Neural Networks	No need to reprogram as it learns itself. Character recognition is pretty fast once it's trained.	Needs lot of training data. Training is computationally expensive.
3	Mixed handwritten and printed digit recognition in Sudoku with Convolutional Deep Belief Network [6]	Convolutional Deep Belief Network	Performance improves with more data. Enables learning of character recognition rather than hand tuning.	Requires large dataset. Difficult to tune.
4	Recognition of numbers and position using image processing techniques for solving Sudoku Puzzles [1]	Template Matching	Straightforward to use.	Time consuming. Cannot adapt well to new problems.

Literature [1] provides a method of detecting and recognizing the components of a Sudoku puzzle using MATLAB, which involves a vision based Sudoku solver and the solver is capable to solve any valid Sudoku from an image captured from any digital camera. Appropriate pre-processing techniques are applied to the acquired image and texts are extracted using template matching method for digit recognition.

Wicht [6] proposes a method to recognize Sudoku puzzles which contain both handwritten as well as printed digits. The puzzle grids and the digits are detected using various image processing techniques which includes Hough Transform and Contour Detection [14]. A convolutional Deep Belief Network extracted features on mixed points, printed and handwritten digits and the extracted features were classified using Support Vector Machine.

Many literatures [13] and [2] have employed techniques from Constraint Satisfaction Problem (CSP) involving metaheuristics to detect and solve Sudoku puzzles. Finally, Kamal et al. [5] give a detailed comparison of various techniques used to solve Sudoku puzzles which include Backtracking, Simulated Annealing and Genetic Algorithms.

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III. DETECTION OF SUDOKU PUZZLE

Sudoku puzzles appearing in newspapers and other text and digital media can be detected using image processing techniques. Firstly, the image is separated from its surroundings using thresholding technique. Then, transformation is applied to image and digits are extracted. Lastly, Optical Character Recognition (OCR) is used to extract digits from the puzzle, stored in a grid of size 9x9 based on their pixel locations in the image. Figure 2 gives a basic flowchart of detection of Sudoku Puzzle.

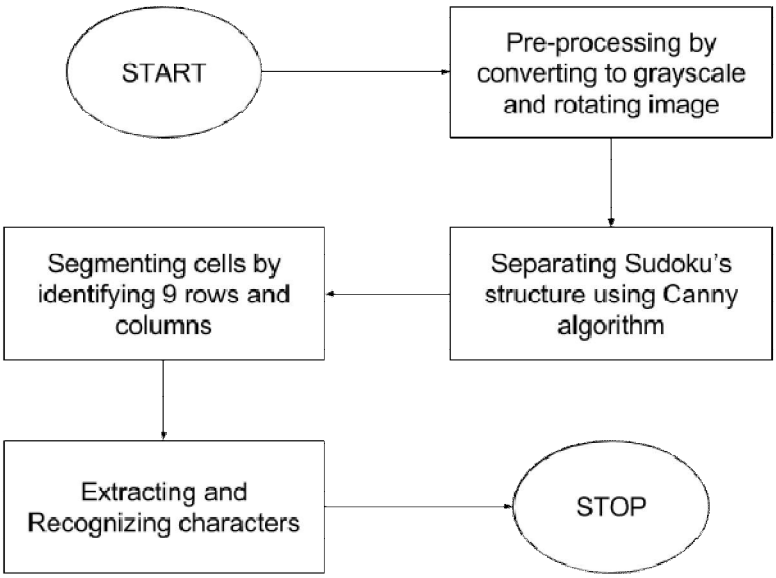

Fig. 2. A flowchart depicting detection of Sudoku puzzle

A. Image Pre-Processing

Images of Sudoku in newspapers have an inconsistent illumination and high levels of noise. Gray levels in the image differ significantly, with background and foreground levels from one part of the newspaper to another having a wide range. Without cleaning the image, it is difficult to perform further operations on it. So firstly, when image of Sudoku is acquired, certain techniques of image pre-processing are applied on it. This is done to make the captured image similar to the baseline image which will be used for further processing like character recognition.

These pre-processing techniques include:

1. **Converting color to grayscale and binarize image:** Converting a color image to grayscale improves recognition performance. Obtained gray-scale image is further converted to binary using adaptive thresholding method. Local thresholding serves as a better algorithm than global thresholding in this situation [10].

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2. **Detect angle and rotate image:** Image taken manually is not perfect and can be tilted and misaligned. In order to accurately recognize characters, this image needs to be de-skewed. Angle is detected and further rotation operations are decided based on this. Hough transform can be used to estimate at what angle is the image deflected. The most reliable line in the image is considered and its tilt is measured. Depending on this, the image is rotated clockwise or anti-clockwise to make it perpendicular [10].

B. Separate Sudoku's Structure

This step segments Sudoku's frame as an individual element. This is done by removing the white background initially. Edges are detected using Canny algorithm [14]. The largest blob in the image holds the puzzle. After checking size of all blobs, the largest one is selected. Image is cropped using the four corner points. Resultant image contains only the Sudoku puzzle comprising of its frame and digits.

C. Segment Cells

After acquiring the Sudoku's outer structure, following procedure is to fragment 81 cells in the image. This divides the puzzle into modular spaces or cells where numbers are entered. Sudoku puzzles are partially filled, so these cells may or may not contain a digit. In any case, they have a similarity that surrounding area is white inside squares. 9 rows and 9 columns are identified, comprising of 81 cells, which are segmented. If these are correctly detected, there will be 100 intersections between these segments and these points will be considered to form the grid. Sudoku puzzles contain 9 grids each of 3x3 cells. These grids will also be identified in this section.

D. Character Recognition

The main aim of this section is to recognize digits in the puzzle. These numbers range from 1 to 9. These characters can be identified by using k-Nearest Neighbor (k-NN) algorithm [7]. Nearest-Neighbor classification algorithm is based on learning by analogy. The given test tuple is compared with the training test tuples that are similar to it. This algorithm is separated into two stages:

1. **Training:** All training vectors are kept in a master database. Different classes are labeled in this. This master database contains pixel information of numbers from 1 to 9. It can also contain these numbers in multiple fonts for better recognition.
2. **Classification:** There is an introduction of a new unlabeled vector which is to be identified. It is then classified corresponding to the most frequent of its k neighbors.

Sudoku puzzles contain some empty cells and some filled cells. This method also classifies these two scenarios accurately.

IV. SUDOKU PUZZLE SOLVING

A typical Sudoku puzzle contains 81 cells, in a 9x9 grid, and has 9 sub-grids or boxes, each box being the intersection of the first, middle, or last 3 rows, and the first, middle, or last 3 columns [12]. Each Sudoku puzzle cell may contain a numerical digit from 1 to 9 and the occurrence of each number is limited to one in each row, column, and box. A Sudoku starts with some cells containing numbers filled by the puzzle setter (also known as clues) and the goal it to fill in the remaining cells. A proper Sudoku puzzle has only one solution.

A wide range of computer algorithms are available to solve Sudokus and such algorithms are capable of solving them in fractions of a second. Here, in this section we discuss methods used to solve Sudoku puzzle after its detection by various vision based and optical character recognition techniques.

A. Backtracking

Backtracking represents one of the most general techniques in the search for fundamental principles of algorithm design [8]. Backtracking is a brute force algorithm that tries to find solutions until a solution that "works" is found [3]. Problems that deal with searching for a set of solutions or the problems that require an optimal solution

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satisfying some constraints can be solved using backtracking formulation. Backtracking uses depth-first search paradigm as it completely explores one branch to a possible solution before expanding another branch. Although it has been established that approximately 6.67×10^{21} final grids exist, a brute force algorithm can be a practical method to solve Sudoku puzzles.

In case of Sudoku, the algorithm visits the empty cells in an order, sequentially filling in the digits, or tracking back when the number is found to be invalid. Briefly, the algorithm starts by placing the digit "1" in the first empty cell and checks if it is allowed to be there. If there are no row, column, and box constraint violations, then the algorithm advances to the next empty cell, and places the digit "1" in that cell. When checking the constraints, if it is discovered that the digit "1" does not satisfy the constraints, the value is incremented to "2". If a cell is discovered where none of the 9 digits is allowed, then the algorithm backtracks and increments the value in the previous cell by one. This continues till the last 81st cell is filled with a valid digit.

V. CONCLUSION

Sudoku, as we discussed, is a popular Japanese puzzle game. This research paper's purpose is to understand different approaches taken to scan and solve a Sudoku puzzle. This is significant because majority of the current Sudoku-solving solutions require the user to manually input numbers. Scanning the puzzle makes this process faster to get a solution to it. We reviewed different techniques implemented by some researchers along with their advantages and disadvantages. Because of constant evolution in computation and algorithms, some methods can get outdated fairly fast such as static template matching while recognizing characters. So it is necessary to update these techniques to keep up with modern computational practices. Methods like detection of characters using machine learning can provide a faster and efficient way.

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