LabVIEW Based System for Solving SUDOKU Puzzles

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Abstract *–The popular game called Sudoku helps the puzzle solver to manage complicated logical tasks but on the other hand it is often useful in artificial intelligence applications like steganography, DNA computing or encrypting SMS. The paper presents an automated Sudoku solver system that combines simple solving algorithms with the principles of robot vision domain. The proposed automatic system completely solves the Sudoku problems and the solutions are written rapidly on the paper sheet. The application is based on a Sudoku image capture video system, a system that mimics the human solving strategies. The digits are localized, recognized using the Optical character recognition (OCR) technique and then the problem is digitally transposed and solved through the LabVIEW programming environment. A data acquisition board controls the pen on the plotter to fill the blanks with figures resulted from the solution. The shapes of the digits can be designed by the user in an interactive manner by a friendly interface. Based on the obtained system, other implementations can be experimented by using similar elements of signal processing or pattern recognition.*

Keywords – *Sudoku, image processing, LabVIEW, robot vision*

1. INTRODUCTION

Sudoku, a word that comes from Japanese where *sû* means figure and *doku* means unique, is a game grid invented in 1979 and inspired by “Latin square” and by the “problem of 36 officers of Leonhard Euler” [1]. The grid of the game, as in Fig. 1, is a square of 9 × 9 cells, divided into 3x3 identical boxes, sub-grids, called regions.

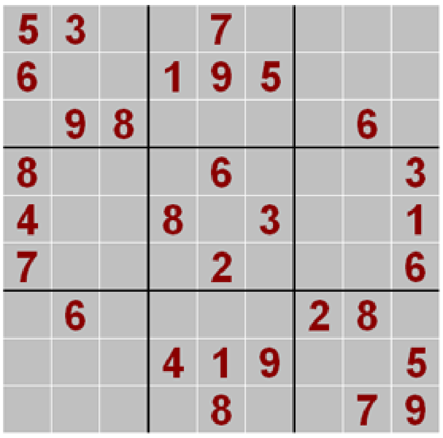

Fig1. The SUDOKU problem grid-Example

The objective of this puzzle game is to place numbers from 1 to 9 in each cell so that every number must occurs only once in each row, column and region.

The numbers are only a convention, the arithmetic relations between them being of no use. The interest of the game lies in the simplicity of its rules and the complexity of its solutions. The difficulty of Sudoku is not only determined by the number of hidden fields, but also by their interdependencies, which can be very complex. Solving Sudoku type grids may take for a medium player, approximately 15-60 minutes. Because Sudoku must have only one solution, the initial grid must have at least 17 digits.

There are many algorithms and techniques used to solve Sudoku puzzles. Different authors proposed different solutions trying each time to optimize their strategies.

1.1. Computer based algorithms

Brute force algorithm is an exhaustive searching algorithm having the main advantage of finding always a solution by trying all the possibilities. Due to the large amount of backtracking and guessing this algorithm is a time consuming one but the optimization is possible [2]. The empty squares are filled with the first digit from the group 1-9 and if the solution is valid the digit remains, if not, the next digit will be chosen and the process will be repeated until the correct numbers will fill all the 81 squares.

The “pencil and paper algorithm” called sometimes the “human algorithm” uses candidates (Fig. 2) that represent all the possible numbers that due to the Sudoku constraints, could be placed in a cell [3].

Fig. 2 Human algorithm principle-the candidates

1.2. Techniques and rules

The human algorithm uses different techniques that are based on the next well known checking rules: Naked Single, Hidden Single, Naked Pair/Triple, Hidden Pair/Triple, Naked Quad, Box Line Reduction, Pointing Pairs/Triples [4]. Each of these rules have specific patterns and actions. If a pattern is matched, the technique's corresponding action will be executed before proceeding to the next technique. If one action is done a number will be either placed in a specific cell or one or more candidates will be removed from one or more cells.

In the presented paper we used the brute force algorithm because this is a very useful method to solve any Sudoku puzzles and it guarantees to find at least one solution (Fig. 3).

Fig. 3 Sudoku solution

1.3. Robotic Vision Systems

In the rapid development process of industrial technologies, the machine vision techniques and robotics became very important. Robot Vision (Fig.4) is one of the most complex domain that incorporates techniques from all the branches of its "Family Tree"[5].

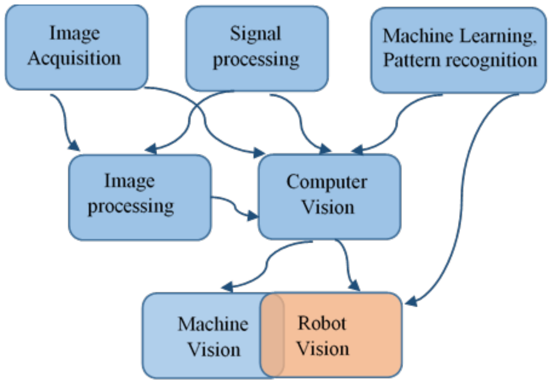

Fig. 4 The "Family Tree" of "Robot Vision" application area

The paper presents a LabVIEW based system for solving Sudoku puzzles. The system can be included in the field of robot vision applications and by using different design and implementation techniques [13], [14] one can identify elements of computer vision, signal processing or machine vision [6], [7], [8]. The system can be included in the area of similar Sudoku solvers applications like those from [9], [10], [11], [12].

2. SYSTEM DESCRIPTION

The proposed system from Fig. 5 has been implemented by using hardware and software components in order to solve the Sudoku puzzle that is printed on the paper sheet and put on the XY plotter working surface.

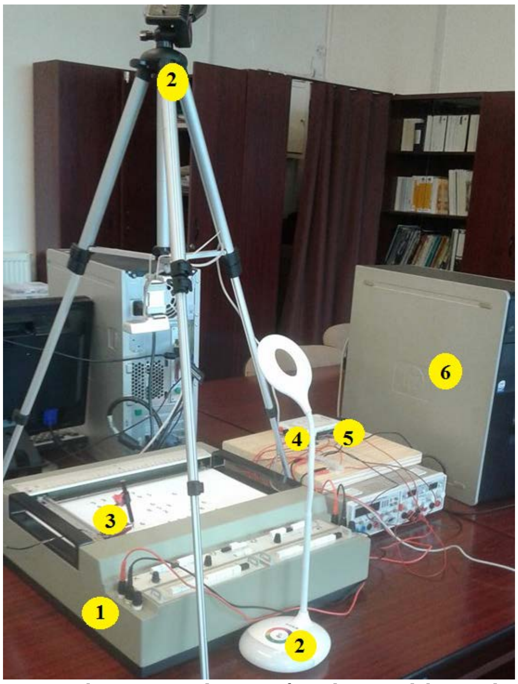

Fig. 5 LabVIEW Based System for solving Sudoku puzzle

The designed system consists of the next main components:

1. A pen-plotter that serves both to move the pencil to the Sudoku cells and to write the solution digits. The control of DC motors on X and Y directions is realized by using the National Instruments' MyDAQ data acquisition board on its analogue outputs (AO1 and AO2).
2. The image acquisition system and the lighting system. The used webcam is attached to a tripod and it takes the image of the entire surface of the Sudoku sheet.
3. The writing tool-pencil
4. A power relay-SRD 05- for pen controlling (up and down)
5. MyDAQ (National Instruments) –data acquisition board
6. Personal Computer (PC) for running the application written in LabVIEW programming language.

2.1. The Pen-Plotter System

The plotter performs the two directions movement of the pencil (XOY plane) and operates with two DC motors.

The plotter can also be controlled with the computer by generating continuous DC voltages on both axes. The displacement on both axes is proportional to the applied voltage. The plotter sensitivity has been adjusted at 0.5 V / cm for both X and Y axis.

2.2. The Image Acquisition System

The image acquisition is made by a Microsoft Life cam VX-7000 with a 1600 × 1200-pixel resolution, 16-bit color depth, built-in microphone and USB 2.0 interface.

The lighting system includes a circular-shaped led lamp, which is parallel to the plotter. It has been preferred to use cold, multipoint light in order to obtain a uniform illumination of the plate and to reduce as much as possible the bright reflections appearing on the acquired images, as was the case of the single point lighting.

2.3. The Writing Tool

The writing tool is an assembly (Fig. 6) consisting of a pen and an electromagnet controlled by the acquisition board. On the mechanical support -that moves in the XOY coordinate system- an electromagnet was fixed and a pen has been glued on its armature. The electromagnet is controlled (On-Off) by a power relay (5VDC).

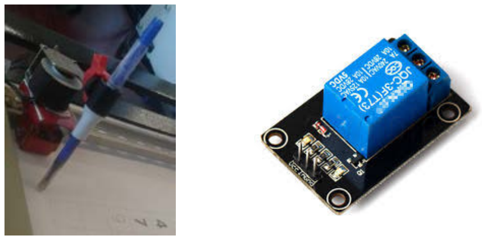

Fig.6 The writing tool

3. THE ALGORITHM FOR WRITING THE SUDOKU SOLUTION

The application was implemented integrally in LabVIEW programming environment. It includes the image acquisition and processing, as well as the pen-plotter control. The Sudoku solving algorithm can be illustrated in a flowchart as in Fig.7

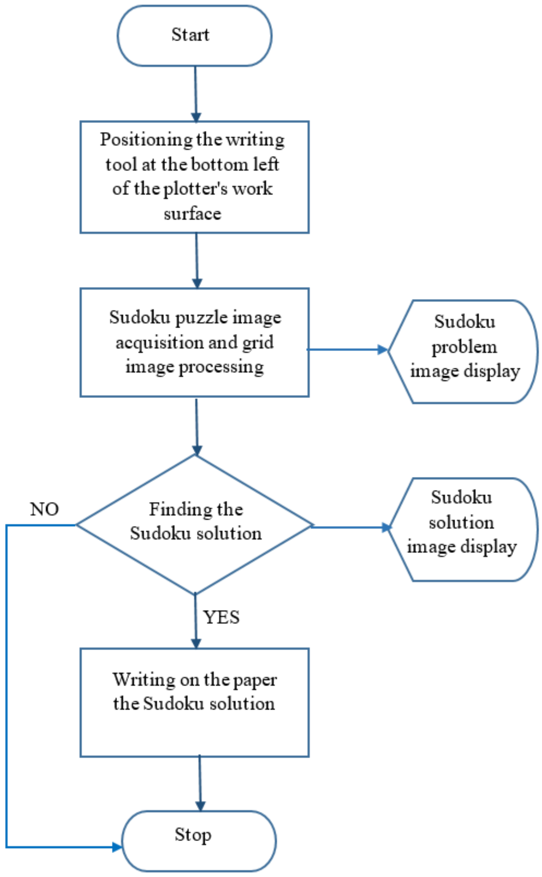

Fig 7. The system flowchart

3.1. The Front Panel

On the front panel of the proposed application (Fig.8) the acquired image is displayed. Here the user can visualize the string with the recognized figures, the 2D array with the Sudoku problem, the 2D array with the Sudoku solution. The buttons on the front panel allow the user to validate the current step in the algorithm. The calibration of the system is made by adjusting the offset applied to both input channels (X and Y). The puzzle solution is written by filling the empty from left to right on the nine top-down lines.

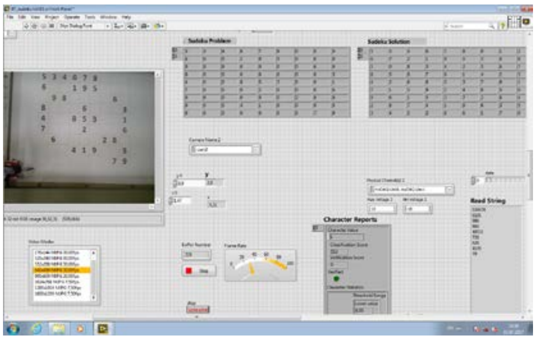

Fig. 8 LabVIEW application front panel

3.2. The Block Diagram

According to the flowchart from Fig.7, the algorithm is based on a sequence structure with five frames.

In the frame 0, the writing tool is brought to the lower left corner for releasing the area in front of the camera.

In frame 1, the image is continuously acquired by choosing the 640x 480 MJPG 30 fps. When the image is stabilized, the user stops the acquisition and the last frame is saved for processing.

In frame 2, the image taken in the frame 1 is processed for a correct optical character recognition (OCR).

In Table 1 and Fig.9 the results after the image processing steps are illustrated.

Table 1. Image processing results

A	Original acquired digital image (RGB)
B	Greyscale image after mask application, smoothing filtering and contrast enhancement
C	Binary image after applying a threshold entropy method for greyscale images
D	Binary image after applying binary morphological operators like deleting small and border objects, inverting image
E	Grayscale image obtained from the processed binary image
F	The Sudoku figures are identified by an Optical Character Recognition (OCR) technique

The results are given in an array of clusters having the character reports: value, classification score and position. Based on these, the initial Sudoku problem can be solved by passing it in the frame 3 where the "Brute Force" method was implemented. The Sudoku solution is displayed on the front panel and so, the user can check it and decide to start the writing process (frame 4).

The writing algorithm (Fig.10) was designed so that only the empty boxes are filled from up to down and on each row from left to right.

For designing the shape and size of the nine different figures, arrays of voltage steps have been computed by using an interpolation algorithm. (Fig. 11). Thus the pen inscription process is similar to the human handwriting.

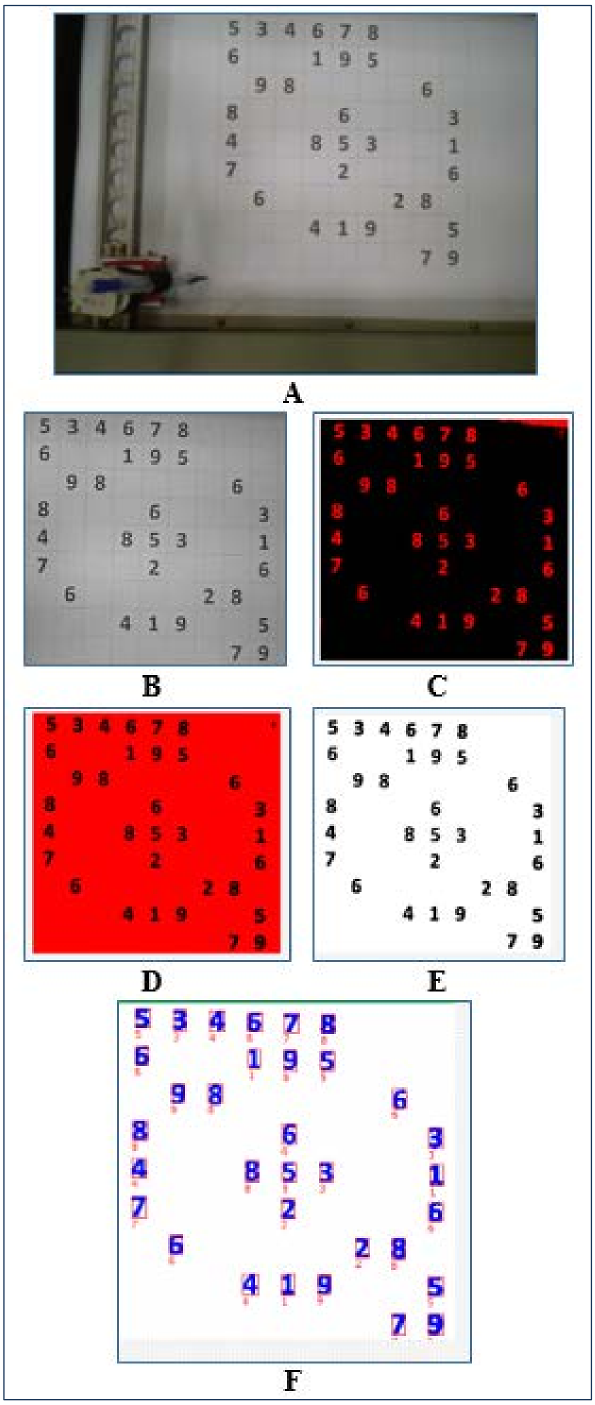

Fig 9. VI Sudoku problem image processing

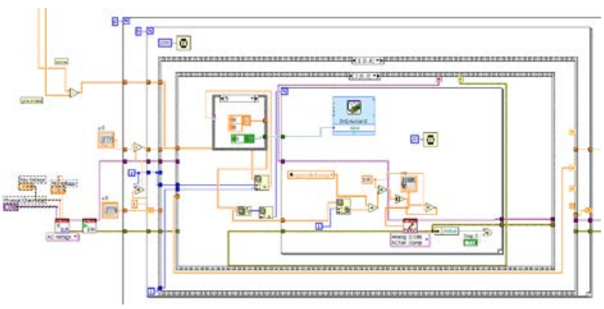

Fig. 10 The writing Sudoku solution algorithm

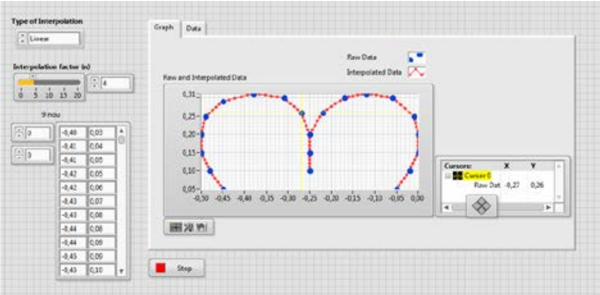

Fig. 11 The interpolation algorithm for figures shape and size design

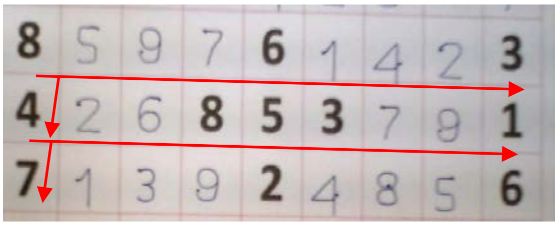

Fig.12 The Sudoku solution written by the pen-plotter system

Finally, after scrolling all 9x9=81 boxes and writing the missing digits the program stops and the solution can be written on the paper (Fig. 12).

Table 2 Robot vision techniques used in proposed system

Input	Output	Technique		Hardware	Software
Sudoku problem on printed on the paper sheet	Sudoku problem on digital image (RGB)	**Image acquisition**	**Robot Vison**	Digital camera Pen-Plotter, MyDAQ board, electromagnet, relay, Lighting system PC	LabVIEW LabVIEW vison acquisition Pen status (up or down)
Sudoku problem on digital image (RGB)	Sudoku problem Greyscale image	**Image processing**		PC	LabVIEW Vision
Sudoku problem Greyscale image	Sudoku character string (array)	**Pattern Recognition**		PC	LabVIEW Vision Optical Character Recognition (OCR)
Sudoku problem array	Sudoku solution array	**Signal processing**		PC	LabVIEW “Brute Force” algorithm
Sudoku solution array	Sudoku solution written on paper sheet	**Signal acquisition**		Pen-Plotter, MyDAQ board, relay, PC	LabVIEW Motors control, Pen status (up or down)

4. CONCLUSIONS

The proposed system solves completely a Sudoku puzzle by writing the solution on a paper and it combines the advantages of many techniques met in the robot vision domain. Table 2 summarizes all of these techniques and it can be a guide for one who wants to develop a similar system. All of these techniques can be improved or developed with other hardware and software components having the same final aim: Sudoku solution.

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