Digital Chess Board based on Array of Hall-Effect Sensors

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Abstract-This paper addresses a novel concept of digital chess board realized with an array of Hall-Effect sensors. Main task of digital chess board is autonomous detection of player's moves. Therefore, players do not have to write down their own moves on a sheet of paper. Non-invasive piece moves detection is considered, with minimum required installations in a game room. The digital chees board presented in this paper has a Hall-Effect sensor placed under the middle of each field on the chess board, while each chess piece has a permanent magnet placed on its bottom. Sensors, total of 64, are organized as 8x8 array. Microcontroller reads sensor data and sends them to a remote PC for storage in a database and board visualization. Rows are multiplexed in time, i.e. one row is active in a certain time instance. States in the column of the currently active row are stored in a corresponding matrix column. Con to this approach is in its ability to detect piece presence on the field, without the information about the piece type. The proposed approach is low cost, non-invasive and requires only power and communication cable.

I. INTRODACTION

Development of computer science and technology advances are followed by integration of new technologies into social games, and chess is one of them. First aspirations were focused on creating a computer system that can beat the chess Grandmaster. One of the most famous chess games, which marked a milestone in the pursuit of creating a superior chess computer system is a chess game between, at that time the world's best chess player, Garry Kasparov and IBM supercomputer Deep Blue in 1997. Deep Blue defeated Kasparov and became the first computer which defeated world chess champion [1]. With further development of computer technology, there is a remaining tendency of creating new algorithms for chess playing and chess learning. On the other hand, there is a need for automation of chess game itself and developing possibilities of remote access and control. A novel approach is an implementation of Hall-effect sensors for detecting the presence of chess pieces and getting access to a current position on a chess board, cf. Fig. 1.

Figure 1. Digital chess board with: 64 Hall-effect sensors placed under each field, PC communication and power cables.

II. RELATED WORK

In recent years, many papers and projects are published about computers and chess. Chess playing combine elements of artificial intelligence for player's move decision, computer vision and robotics for position detection and performing a movement of pieces. Considering developments in computer vision, numerous papers are published in the field of recognition and detection of chess pieces. Despite that, some of the papers are published with the aim to improve automation of the game. This allows playing against computer in real world, playing from remote location and improving playing possibilities for people with disabilities.

Usually, camera-based systems for visual inspection require adequate and constant level of light source without shadows from surrounding objects. Therefore, overhead camera is used in [2] with ambient lightning to detect player's moves. Human and chess piece shadows caused difficulties in moves detection. Lightning source was adjusted so that each white piece does not have a black shadow. Specular reflection from pieces is removed with image filtering. Like a chess game, Janggi chess board detection under severe conditions in camera point of view is described in [3]. Using Hough transform, Harris corner detection and Canny edge detection, Janggi chess board and pieces are detected. Piece detection problem is relaxed in Janggi chess due to smaller piece heights and less lines hidden with pieces. Another camera-based approach is presented in [4] where authors created multimodal interface for making chess moves. Using a stereo camera and difference in image entropy, hand gestures are detected and translated to chess moves.

One approach in detection of chess position is detection based on player's hand movement (not piece's). Authors in [5] realized their project named "Hand-Motion Chess" using gloves with sensors and a microcontroller. Hand gestures are detected with sensors and are translated into chess move. This approach can be implemented in creating universal equipment (glove) which could detect chess moves regardless of variations in size and color of pieces and chess board.

Due to rapid development of commercial robotic arms, accessibility to this technology is increasing. Numerous projects were made with educational purposes on moving chess pieces around the chess board using robotic arm. Authors in [6] presents autonomous chess playing system based on robotic manipulator arm. Fully autonomous chess playing robot "MarineBlue" is presented in [7]. It combines elements of computer vision, chess engine and robot control. Authors in [8] implemented detection of chess pieces using reed sensors that are triggered by the magnetic field from permanent magnet placed on the bottom of each piece. Computer Numerical Control (CNC) machine with 2D Cartesian coordinate system is used for moving chess pieces around the board. Interactive chess board is presented in [9]. It detects player's move based on 8x8 membrane keypad, and makes its own move using 2D CNC machine. The idea behind proposed approach is to enable players to play chess over the internet on a real chess board. Thus, when player makes a move on his board, chess piece moves on another board, keeping synchronized positions between boards.

A commercial product commonly used in FIDE chess tournaments is digital chess board named "DGT e-Board" [10]. The board is using passive LC-circuits with ferit core in pieces with active LC-circuit in each chess field [11]. Passive LC-circuits are induced with active LC-circuit and resonant frequency is measured. However, development of digital chess board using Hall-effect sensors is an approach for educational purposes because of relatively low price and simplicity of assembling.

III. DEVELOPMENT OF CHESS BOARD

This section describes the main components of the digital chess board proposed in this work. The board consists of embedded microcontroller system for detection of chess pieces, chess pieces with integrated permanent magnets and acrylic board with printed wooden chess board image. System for detection of chess pieces is connected to a PC with a USB cable.

A. Chess Board and Chess Pieces

Chess is a game that is usually played on wooden chess board with corresponding pieces. That is not an explicit rule, but more a part of tradition of a chess game. Chess is a two-player game, where each player has 16 chess pieces: 8 pawns, 2 rooks, 2 bishops, 2 knights, 1 queen and 1 king. The game is played on board with 8x8 (64) chess fields (32 black and 32 white) [12]. According to the World Chess Federation (FIDE) official width of each chess field is ranging from 5 to 6 cm [13]. To make a digital chess board applicable for real tournaments, a width of 5 cm is used in this work. The total dimensions of the digital chessboard are 52x52 cm, of which 40x40 cm goes for chess fields and 6 cm for borders. In the bottom part of each chess piece two permanent are placed. Magnets diameter is 10 mm, with height 2 mm. Experimental testing of 3 and 5 mm acrylic board thickness showed that both are good for detection of magnetic field. Due to better mechanical properties, 5 mm acrylic board is used.

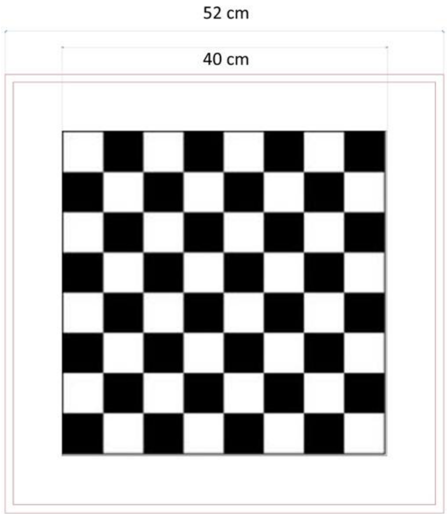

Figure 2. Dimensions of the board

B. Microcontroller System for Chess Position Detection

The system for detection of chess pieces is consisted with platform Arduino Nano platform, a set of 64 A3144 Hall-effect sensors and 5V power supply. Additional power supply is involved since the overall current consumption is 100 mA per pin, while the maximum is 40 mA. Connecting a single Hall-effect sensor A3144 requires one 10kΩ pull up resistor per pin, cf. Fig 3.

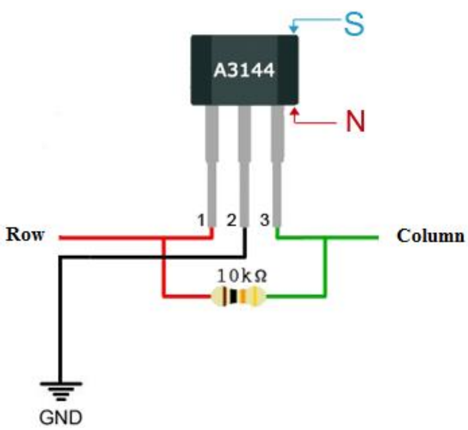

Figure 3. Connecting Hall-effect sensor to row and column of an array.

Printed Circuit Board (PCB) is made for detection of chess position method proposed in this work. Electronic scheme of designed PCB is presented, cf. Fig 4, as well as the final look of the board, cf. Fig. 5.

Internal pull-up resistors, which ATmega328p microcontroller has, can't be used since 8 sensors in a row require more power per pin than available. P-channel MOSFET transistors are used to activate each row with

5V power supply. Total of 4 dual-transistor ICs APM4953 are used with 10kΩ pull up resistors, cf. Fig 4.

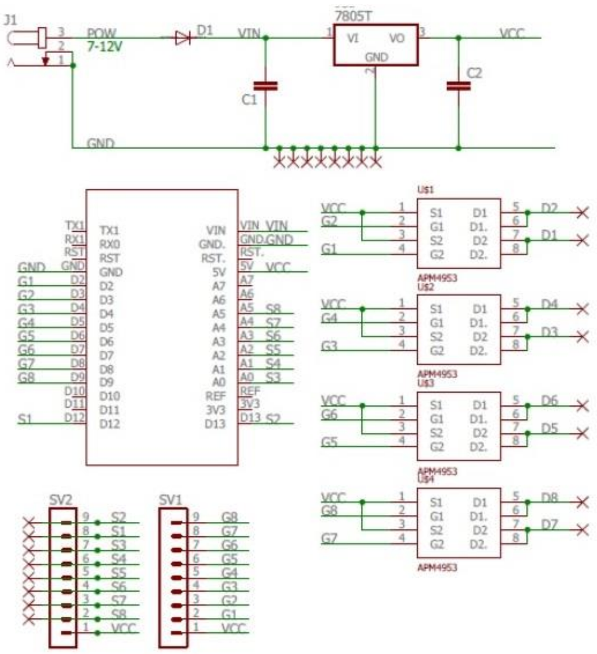

Figure 4. Electronic scheme of proposed system for chess position detection.

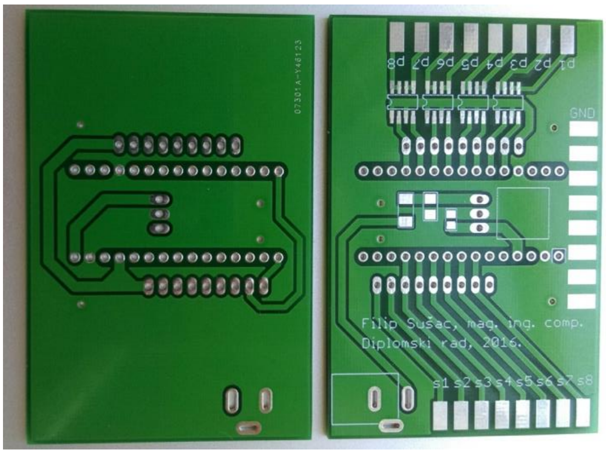

Figure 5. Designed Printed Circuit Board (PCB): bottom layer (left); top layer (right).

C. Programming Microcontroller

Serial communication (UART) is used as a communication protocol between a microcontroller and a PC. Communication is done in two directions, in a master (PC) and slave (microcontroller) fashion. Firstly, master is requesting data from slave by sending request character "R". Subsequently, slave collects data from sensors and responds with 8 bytes of data, where each bit corresponds to an occupied (1) or free (0) field, cf. Fig. 6.

Microcontroller (slave) is programmed to receive states from 64 sensors and send data to a PC. Due to a limited number of input and output pins, an array of 64 sensors is multiplexed [14]. Multiplexing is done row-wise, meaning that at one time instance only one row is active. Columns are active all the time and states from entire row can be read. In this way, 8x8 binary matrix is reconstructed, where 1 (0) corresponds to an occupied (free) field.

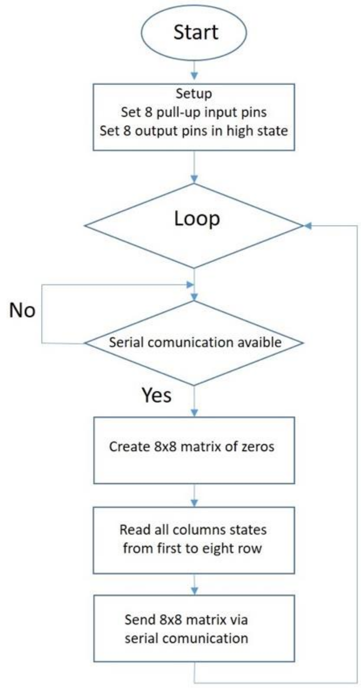

Figure 6. Flowchart of Arduino code

D. Player's Move Detection

Algorithm for player's move detection is done on a PC. It is based on a difference between two subsequently received binary matrices. Proposed method compares the currently received and previously received matrix. Difference between the two is calculated with

$$\Delta M(x,y) = M(x,y,n) - M(x,y,n-1), \qquad (1)$$

where x and y are denoting chess field index, ranging from 1 to 8, respectively, n is the current time instance and $n-1$ is the previous time instance.

In the case when there are no changes on the chess board (no moves), 8x8 matrix ΔM is a zero matrix, cf. eq. (1). On the other side, when a player starts a move, one must take a chess piece and lift it up and away from the chess board field. Moving the piece from the field will be detected at a corresponding x, y location, and a value -1 is assigned to $\Delta M(x,y)$. The first occurrence of value -1 in $\Delta M(x,y)$ denotes either a *moving chess piece* or *taking chess piece*. Distinction between the two is done by knowing the player's color. If a piece's color corresponds to player's color, it is a *moving chess piece*, otherwise it is a *taken chess piece*. *Taken chess piece* is removed from the board. Finally, when a value +1 appears in $\Delta M(x,y)$ it denotes a *destination location* of a *moving chess piece*. Commonly used algebraic chess notation is used for tracking chess moves [12].

E. Visualizing the Game of Chess

Instead of using an open-source chess Graphical User Interface (GUI) (Winboard, Stofkfich, GNU Chess, etc.), our own GUI is made for educational purpose and further development of chess programs. GUI is done on a PC and is integrated with the logic described in Section III. D. When the chess board position is set, GUI requires an information about it. Therefore, a user can set-up an initial position by a button click, cf. Fig. 7. Chess positions, beside initial position, must be manually synchronized in a GUI to start from a desired position.

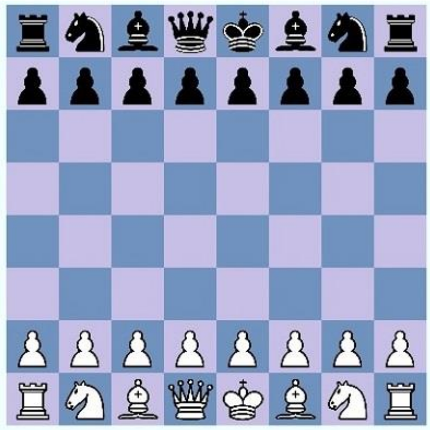

Figure 7. Chess game Graphical User Interface (GUI).

F. Performance analysis

Proposed approach is incrementally reconstructing a chess game by recognizing each move independently. In this paper, a chess move is recognized by detecting presence or absence of a chess piece. Limitations of proposed approach are in terms of inability to reconstruct starting chess position without a user interaction. Except starting position, the user interacts in pawn promotions. One can choose to automatically promote to queen, or to manually set each promotion. However, even if the chess board position could detect piece's type and color, it would still require the following inputs from the user: possibilities of the chess position: side to move, allowed castling moves, allowed *en-passant* move, piece move counter without taking (required for a 50-move rule) [12].

If the program fails to recognize one move, following moves will also be incorrect. Therefore, a user interaction is required to correct a false move detection. An experiment is done to objectively express. Total of 50 trials for every type of chees move is tested and illustrated in Table 1. Moves are made on an empty and occupied, respectively.

TABLE 1. SUCCESSFULLY DETECTED CHESS MOVES.

Number of experiments N=50	Successful detection	
Move a chess piece on an empty field	48 / 50	96 %
Capture an opponent's chess piece	43 / 50	86 %

IV. CONCLUSION AND FUTURE WORK

Chess remains a popular domain for experimenting in the field of robotics, computer vision and artificial intelligence. This paper gives an overview of the design and implementation of an autonomous digital chess board. Proposed approach combines low-cost elements with an array of Hall-effect sensors controlled by a microcontroller. Con to proposed approach is in possibility to detect only piece presence and not its type and color. Also, false move detection requires a user interaction to correct misdetections.

In the future, we intend to improve robustness of proposed system by considering better wiring and improved noise resistance in hardware and software, respectively.

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