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IrStage: Automatic Chess Recording System Using Photoreflectors

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Abstract

Image processing, proximity sensors, and touch panels have been used in research and products for recognizing chess piece positions. However, these suffer from insufficient recognition rates of chess piece positions for game records, poor operability from having to push chessboard squares with a piece, or restrictions from using dedicated pieces. In this research, we constructed a novel system using photoreflectors, with the objective of automatically producing game records. The proposed system is relatively inexpensive and compact, and accurately records games in a general playing environment. Also, any piece that reflects infrared rays can be used, and it is not necessary to push the squares of the chessboard with the pieces.

1. Introduction

Chess is a game widely enjoyed around the world. The rules of chess are standardized internationally, with the World Chess Federation (FIDE) as a governing body [1]. There are many methods for notating chess game records, but FIDE uses a method called "Algebraic notation", which is widely accepted. Game records are used for commentary and replay purposes, and producing such records is important for those wishing to improve at chess. Records are easily produced when playing chess electronically, but using an actual chessboard and pieces is still important for enjoyment and to allow a deeper focus on the game. The objective of this research is to develop an automatic game recording system for playing environments with a physical chessboard and chess pieces.

Researches regarding chess have primarily been concerned with computer chess [2], [3]. These researches have aimed at creating powerful programs, capable of playing matches against humans. These researches range widely in scientific area and details, from searching and databases, to architecture and other related domains [2]. The supercomputer Deep Blue developed by IBM with a chess specialized architecture [3] first defeated the then world-champion Garry Kasparov in 1997. Meanwhile, there were many people engaged in developing systems for automatic recognition of chess piece positions, both aiming at automatic recording of chess games [4], [10], and at developing chess playing capable robots [5]-[9], [11], [12]. In addition, there has been research concerning methods to search chess databases for records with high degrees of similarity, to allow for better retrieval and utilization of recorded games [13].

Figure 1: Proposed system using photoreflectors.

Researches of position recognition have primarily used image processing techniques, but some issues remain concerning the achievable recognition rate [4]-[10]. Systems that track piece positions using proximity sensors have shown greater reliability, and have in fact been distributed as commercial products [2]. However, they require specialized pieces to trigger the sensors, or alternatively the board squares must be pressed using the pieces. The use of touch panels as chessboards has recently become conceivable, but even then, it is still difficult to accurately recognize chess piece positions without using specialized chess pieces [18], [19].

Object tracking is a major problem in the field of tangible user interfaces (TUI). In this field, although the approach by image processing is often used, there are cases where a problem in robustness exists. The tracking latency may also be a problem in some cases [20]-[25]. This approach is combined with an infrared camera to reduce the influence of lighting and improve the robustness of position detection [22]-[25]. However, arranging the camera at a certain distance is necessary because placing the detection area in the image is necessary, and the whole system becomes relatively large. Magnetic tracking, electromagnetic tracking, ultrasonic detection, and object tracking systems using the existing multitouch display are promising considering the robust detection and tracking latency [26]-[33]. These systems are constructed by incorporating the circuit into the object to be tracked.

In this research, we intend to create a compact system that is easier to carry while achieving sufficient robustness and tracking latency in a general playing environment by using ready-made chess pieces. The system achieves superiority over the existing chess recording systems in terms of operability.

A millimeter wave radar that detects a hand gesture was developed in recent years [34]. This system analyzes reflected waves from fingers by signal processing and machine learning. This system can track the chess pieces of the existing product using millimeter waves. However, the robust detection of various chess pieces is a difficult problem to solve. In the case of a system that irradiates millimeter waves toward the bottom surface of a piece, making a compact configuration like a system based on image processing is difficult. Accordingly, a compact system is constructed in this research by placing photoreflectors in each square of a chessboard (Refer to Figure 1.). A similar approach may be possible with millimeter wave radars. However, it contributes to a compact system configuration because the photoreflectors is easier to downsize than the millimeter wave radars. Moreover, the photoreflector is inexpensive, has a simple circuit configuration, and is easily assembled with a microcomputer.

Previous result of our system has been described in a paper [37]. The photoreflector reacts to an object approaching within a certain distance. In the previous study, it was necessary for the players to handle their chess pieces with care and deliberation so as to activate only the photoreflectors of squares involved in the departure and destination positions of moving pieces, and hence the operability was remarkably poor. In the current research, we improved the algorithm so that we only need to extract information related to movements of the pieces from detection information produced by photoreflectors, and the operability was improved. We evaluate the system in this paper.

2. Related researches and products

An automatic game recording scheme using image processing has been presented by Illeperum [4]. In this research, a camera was installed directly above a chessboard; the shadows of the pieces could lead to erroneous recognition of piece positioning, and a light shining from above the board was therefore required. Intricate patterns on a chessboard could also affect grid recognition; hence, their use should be avoided. Piece positions could be recognized with a considerable degree of accuracy, as long as these environment requirements were considered, and both the filtering of the captured images and the threshold settings were fine-tuned for grid and piece position detection. Chess robot research [5]-[8] has also used image processing to recognize piece positions and thus support adequate arm movements. These researches have restrictions as well, in that the camera has to be installed directly above the chessboard, and filtering and thresholds must be fine-tuned. However, there is insufficient discussion in the literature concerning the impact on recognition rate of the chessboard pattern or the light source positioning.

To overcome the limitation of having to install the camera directly overhead, it is helpful to refer to a research on automatic detection of chessboard patterns [14]. In this research, line detection based on a Hough transform enables accurate detection of chessboard patterns even with a camera positioned at a low angle. However, when detecting the chessboard grid during an actual game, it is necessary to solve the problem of grid corners becoming obscured by the pieces in the captured image. Tam et al. use the Hough transform in addition to size information on the chessboard grid to extrapolate the corner points, thus achieving high grid recognition accuracy even when there are pieces on the board and with low-angle camera placements [10]. Neufeld et al. also use the Hough transform in combination with probabilistic inference to address missing information during grid edge detection [11], but fall short of the recognition rate achieved by the method of Tam et al. [10]. These researches [10], [11] are both aimed at grid detection, and do not recognize the pieces. Danner et al. performed piece recognition while supporting a low-angle camera placement [12]. The piece recognition method in this research used a database of binary images of the pieces captured at different angles, and identified pieces during play by means of Fourier descriptors. It achieved a recognition rate of 70–80% at a camera angle of 60 degrees, and is thus a foundational investigation. A chess robot research presented in [9] also supports a low-angle camera disposition. This research detected the chessboard grid by combining a Hough transform with edge detection data from a random sample consensus algorithm [15]. Support vector machine learning was used to determine the presence of pieces in each square and the color of the detected pieces during play [16], and a scale-invariant feature transform was used to identify the piece type [17]. This method recognizes the position in a relatively robust manner, and any given set of chess pieces can be used with the system. When recognizing chess piece positions using image processing, both the grid and pieces must be recognized. Some researches addressing this problem [5], [6] do not state the position recognition rate, and other researches [4], [7]-[9], [12] were also not able to achieve a sufficient recognition rate to record accurate game records. Among these researches, only the referred chess robot research [9] involves a method having a degree of freedom in the set of pieces that can be used, but the position recognition rate via this method remains at 93.22%. Correct recognition of chess piece positions by image processing with the freedom to use any set of chess pieces has been a difficult problem.

Meanwhile, according to the document [2], Fidelity sold a product in 1980 that uses a membrane switch to recognize the movement of pieces by pressing the square at the beginning and end of a move. In the same year, another company sold a product that detected magnetic pieces using a reed switch. Membrane switches have the advantage that commonly distributed chess pieces can be used to play, as long as the size of the pieces can be accommodated within the dimensions of the chessboard grid. However, user-friendliness is poor because the chessboard squares must be pressed with the pieces. With reed switches, a dedicated board and pieces are required, and no other pieces can be used.

SPEED CHESS was proposed in recent years [35]. This system uses a conductive piece and a touch panel to track a chess piece. Aside from this method, several other methods of the touch panel were also proposed. However, these systems do not satisfy the requirement of the system, which is being referred to in our research. The main touch panel detection methods are resistive, capacitive, surface acoustic wave, optical, and electromagnetic induction [18]. To use a touch panel as a chessboard, input must be possible with chess pieces of different materials, and the pieces must be detected solely from their own weight if user-friendliness is to be maintained unblemished. In addition, official chessboards frequently have sides of approximately 45 cm, and a 16:9 aspect ratio display would hence ideally need to have a size of at least 37 inches. Resistive touch panels detect conduction at a pressed location, so the squares would need to be pressed. Capacitive touch panels detect contact by conductive objects; surface acoustic wave touch panels detect that elastic waves are absorbed at a section touched by a soft object; electromagnetic induction touch panels detect objects that generate a magnetic field; these three methods would therefore require producing dedicated chess pieces. There are a number of methods for optical touch panels. In infrared optical imaging touch panels, an infrared LED and an image sensor are placed on a panel, and retroreflective tape is adhered at the left, right, and bottom sides. When a finger or an equivalent object touches the screen, the infrared rays are blocked, and this is detected by the image sensor; the touch position is then obtained by triangulation. In addition, in projected infrared touch panels [19], photo interrupters are placed in a matrix at the frame portion of the panel, and a position is specified by detecting the light interruptions resulting from infrared rays being blocked by an object. Optical panels are suited to larger sizes and multitouch detection, and allow the use of a large range of materials in the chess pieces. However, it is not possible to detect chess pieces that are superposed with respect to the sensors, and so they cannot be used for chess piece position recognition.

DigitalDesk [20] introduced an interactive tabletop concept, wherein the user interacts with the system by touching the content on the desk projected from the projector. The user's touch is detected using a camera and a microphone. Accordingly, many vision-based approaches are used in the field of TUI. The I/O bulb [21] made identifying multiple objects easy by attaching markers to objects. However, limitations of the identification robustness and the tracking latency in the vision-based approach were still evident. In metaDESK [22], in addition to cameras, infrared cameras are also used to track objects, thereby reducing the influence of lighting and improving the robustness of position detection. The introduction of markers and infrared cameras was also adopted in PlayAnywhere [23], SLAP [24], and Lumino [25].

Several object-tracking techniques can also be utilized aside from the vision-based approach. Bricks [26] detected the pulsed direct current magnetism in objects with connected wires. MediaBlocks [27] embedded different electronic ID tags in each mediaBlock. Sensetable [28] tracked objects by electromagnetic sensing. Audiopad [29] decided on the position and direction by attaching two radio tags to the object. Dolphin [30] used ultrasonic transmitters and receivers to track objects. Meanwhile, an object-tracking method using a multitouch display was also proposed. Manual deskterity [31] examined the simultaneous input of pen and touch. VoodooIO [32] realized a slider on a multi-touch display. Accordingly, TUIC [33] simulated the touch of a finger on a display using an active modulating circuit embedded in the object.

In recent years, Soli [34] was proposed as a research on-hand gesture recognition that analyzes the reflected waves obtained by irradiating the millimeter waves to the hand using signal processing and machine learning and recognizes hand gestures with complicated and fine movements.

The reasons why the previous researches in the field of TUI and millimeter wave radar were not adopted in our research are described in Chapter 1.

3. Automatic chess recording system

The system presented in this paper uses commonly distributed chess pieces and dedicated hardware for the chessboard. Placing a photoreflector in each square of the chessboard, the moved pieces are identified; this information, together with player identification (via a button operation) is sent to a computer for data analysis; if there are no problems, game record is created, using algebraic notation. The game record is displayed with an application graphical user interface (GUI) at a liquid crystal display incorporated into the chessboard, and is also saved as a file. Figure 2 shows the system block diagram.

In chapters 1 and 2, we discuss problems and constraints of previous research and products that automate game recording. In addition, we describe system configurations that apply previous research and incorporate products of other fields. This is summarized below.

(1) Previous research and products that enable game recording functionality

- Recognition rates in systems using image processing are not enough to automatically generate accurate game records. Furthermore, the space required to set up a camera makes these systems relatively large.

- In products using proximity sensors, there are problems of operability, such as having to push squares of the chessboard with pieces, or having to use dedicated pieces.

- In a system that adopts a touch panel, players are restricted to using dedicated pieces.

(2) Application of previous research and products in other fields

- When the touch panel is adopted in a system, it is not possible to specify piece positions depending on a detection method to be selected. As for detection methods that can be specified, we encounter the same problems as those found in systems using proximity sensors.

- When attempting to construct a system by applying the object tracking technique used in TUI applications, we encounter problems similar to those found in image processing-based systems. We may also be restricted to using dedicated pieces.

- When attempting to construct a millimeter wave system, problems that need to be addressed include recognition rate, system size, and cost.

In contrast, the proposed system has the following features:

1) It is possible to accurately record chess games in a general playing environment.
2) It is a compact design that constitutes a detection device in the chessboard, which has a thickness of 12 cm.
3) It is relatively inexpensive.
4) It works with any piece that reflects infrared rays.
5) It does not require players to push pieces into chessboard squares.

From the above, the advantages of the proposed system are the achievement of accurate game records, inexpensiveness, compactness, fewer restrictions on available pieces, and good operability. We are not aware of any other system that implements these features.

3.1 System overview

Figures 3 and 4 depict images of the chessboard created in this research, and of the button layout and liquid crystal display, respectively. Chessboards commonly have a checkered pattern of a

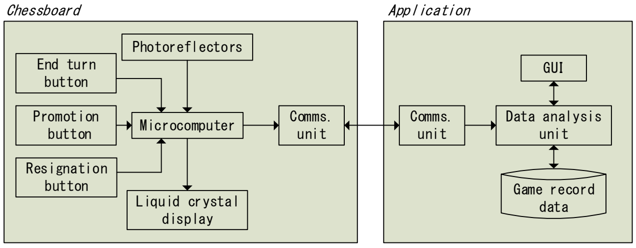


Figure 2: Block diagram of the proposed automatic chess recording system.

Figure 3: Chessboard.

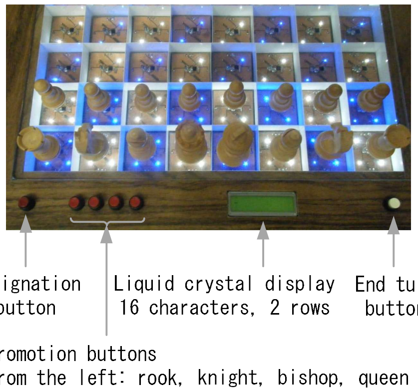


Figure 4: Button and liquid crystal display layout.

(a) Game record (b) If piece movement is erroneous

Figure 5: Liquid crystal display indication examples.

Figure 6: Graphical user interface.

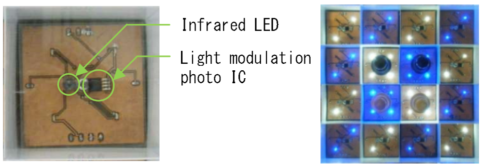
light color and a dark color; this was implemented with glowing white and blue LEDs. Ending a turn, promoting a piece, and resigning are performed via push-button input. Draws are supported by pressing both players' resignation switches followed by the end turn button. Figures 5 and 6 show liquid crystal display indication examples and the GUI, respectively.

3.2 Detecting piece movement using photoreflectors

The presence of pieces is detected using photoreflectors, which are configured with an infrared LED and a light modulation photo IC. Photo ICs with a maximum allowable ambient illumination of 2000 lux were used. Figures 7 and 8 illustrate the operation of the photoreflectors. Each square is segmented by partitions and has an acrylic plate placed on top. If a piece is on a square, the infrared light reflected from the bottom of the piece is detected, and thus the piece's presence is recognized. Detection is difficult with pieces made from transparent glass or plastic that transmits infrared rays, but pieces of wood, colored plastic, metal, and similarly opaque materials can be detected. Even if detection is difficult for a particular set of pieces, it can easily be improved by simply adhering a sticker to the bottom of each piece, thus improving its infrared reflectivity. Visual confirmation of the detected presence of a piece on a square is easily achieved by increasing the brightness (raising the number of lit LEDs) of occupied squares.

3.3 Identifying moved pieces

The photoreflectors are used solely for detecting the presence of pieces in each square; they do not themselves identify the moved pieces. A microcomputer was thus used to manage piece movement, by detecting the squares were transitions were detected. A change from presence to absence indicates a piece being picked up, and a change from absence to presence indicates that a piece has been placed down.



(a) Before operation (b) During operation

Figure 7: Photoreflector.

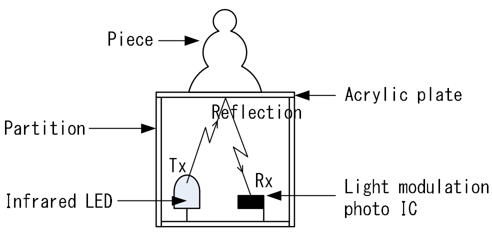


Figure 8: Photoreflector operation.

As indicated in Figure 9, a piece can be operated by players in four different ways: movement, capture, en passant, and castling. Table 1shows the correspondence between the piece operation contents and the state transition counts that characterize these operations. The photoreflectors are adjusted in each square to detect objects reflecting infrared rays within 3 cm of the board. A detection will thus be made, even in squares unrelated to an operation, if a piece is moved across the board without being lifted away, or if a hand or object comes into proximity of the chessboard. Therefore, the state transitions from piece operation cannot be properly identified if spurious state transition detections arise at random times, caused by non-related sources. To address this problem, when a player's turn ends, the chessboard is considered to have solely pieces that have already finished moving, and the presence/absence information at each square is compared to the situation existing when that turn began. The state transition counts obtained in such a case are indicated in Table 2. As shown, it is possible to identify the piece operation for all operations other than capturing. The state transitions corresponding to captures are identified with the following procedure:

(1) Record the presence/absence of pieces in each square at the beginning of the turn.
(2) Detect the positions where a presence turned into an absence during that player's turn, by comparing with the data from step (1).
(3) Detect the positions where a presence turned into an absence at the end of the turn, by comparing with the data from step (1).
(4) A matching square between steps (2) and (3) is the position of the player's piece before the movement, and a non-matching square is the position of a removed opponent's piece. Therefore, the state transitions necessary for creating the corresponding record can be obtained appending the two state transitions from presence to absent, and the absent to presence transition in the position of the captured piece.

When using this method of identification, lifting a piece from the chessboard other than the one to be moved will result in a failure to detect the necessary state changes. However, the rules of chess prohibit touching a piece other than the one to be moved. This case was therefore handled by displaying a message to the player on the chessboard liquid crystal display saying that there has been an illegal move; the moved piece must then be returned to its original position, and the move repeated.

3.4 Data communications

Data communications in the developed system take place between the chessboard and a computer. The data transmitted from the chessboard to the computer are shown in Figure 10. These data are divided into a header section and a data section. The computer first receives a one byte header section, and then receives the subsequent

Table 1: Piece operation contents and state transition counts; the necessary information for operation identification.

Operation	Operation content		State transition count		
	Operating-side piece movements	Opponent-side piece removal count	Total	Changes from present to absent	Changes from absent to present
Movement	1	0	2	1	1
Capture	1	1	3	2	1
En passant	1	1	3	2	1
Castling	2	0	4	2	2

Table 2: Piece operation contents and state transition counts; comparison of piece presence/absence information in each square at the beginning and end of each turn.

Operation	Operation content		State transition count		
	Operating-side piece movements	Opponent-side piece removal count	Total	Changes from present to absent	Changes from absent to present
Movement	1	0	2	1	1
Capture	-	-	1	1	0
En passant	1	1	3	2	1
Castling	2	0	4	2	2

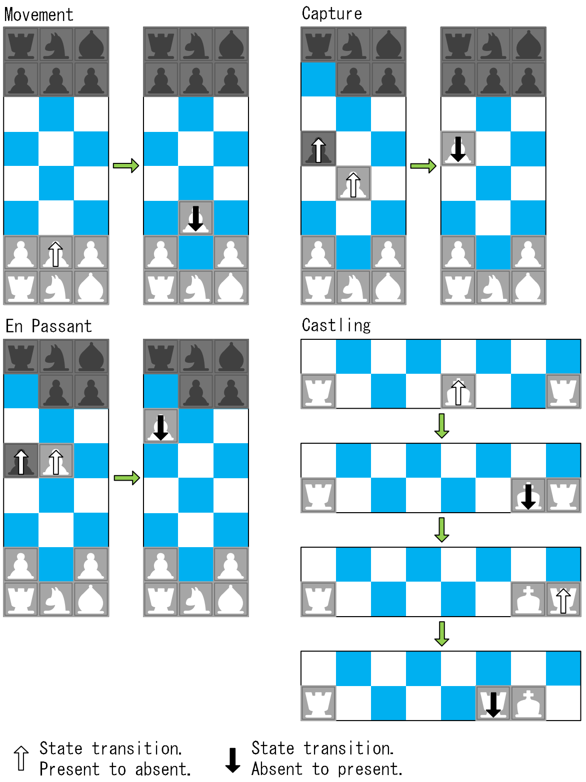
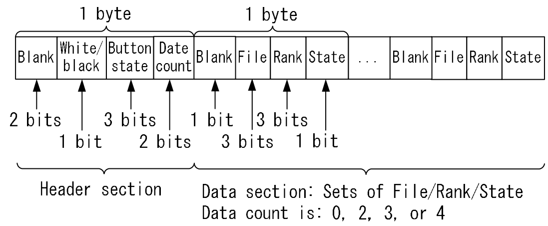


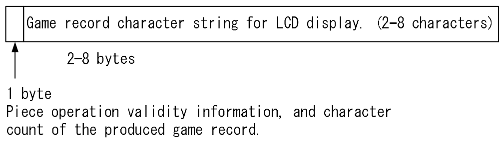
Figure 9: Chess piece operations.



Header section: (1 byte)
・ White/black turn distinction (2 types: 0 if white, 1 if black) (1 bit)
・ Button state (7 types: 0 to 6 assigned to "not pressed", four types of promotion—queen, bishop, knight, rook—, resignation, and, draw, respectively) (3 bits)
・ State transition data count (4 types: 0 to 3 assigned to 0, 2, 3, and 4, respectively) (2 bits)

State transition data section: (1 byte × data count)
・ File (8 types: 0 to 7 assigned to a–h, respectively) (3 bits)
・ Rank (8 types: 0 to 7 assigned to 1–8, respectively) (3 bits)
・ State transitions (0 if present to absent (piece is lifted up), 1 if absent to present (piece is placed down)) (1 bit)

Figure 10: Data transmitted from the chessboard to the computer.



・ Piece operation validity information (0 if not valid, 1 if valid) if valid, the character count of the produced game record (1 byte)
・ Character string for game record display (2–8 characters) Forwarded only if the piece operation was valid. (2 bytes)

Figure 11: Data transmitted from the computer to the chessboard.

movement data, as long as the state transition data count is 2, 3, or 4. If there is a resignation or a draw, the state transition data count will be 0. Thus, the transmitted data can have 1, 3, 4, or 5 bytes. The data transmitted from the computer to the chessboard are indicated in Figure 11. The chessboard first receives a one byte header, and then receives subsequent data if (and only if) the previous piece operation was valid. These data are constituted by a character string information concerning the game record as specified so far by the valid piece operations received in the computer. In the case of the game record generated by the developed system, it consists of two to eight characters (two to eight data bytes). If the piece operation is not valid, the computer transmitted data is only the one initial byte, and a pre-defined error message is displayed at the LCD; this error message is pre-defined in the chessboard's microcomputer program.

4. Evaluation

This section discusses the recognition rate and its dependence on illumination conditions, the photoreflector detection ratio, the player switching time (turnaround time), and player evaluation.

4.1 Recognition rate dependence on illumination conditions

As shown in Chapter 2, light sources and shadows affect the recognition of chess positions in image processing-based systems. In the system using photoreflectors, as the infrared light it emits is reflected by the bottom of a piece, the influence of light sources and shadows is small. However, further experiments are needed to confirm recognition rate. Therefore, we conducted an experiment to evaluate the effect of illumination conditions on the system recognition rate, by playing a game of chess indoors under each of the conditions described below, and checking the accuracy of the game records generated by the system.

Condition 1: During the day, with closed window blinds and indoor ceiling lights.

Condition 2: During the day, with sunlight entering through a window and no indoor lighting.

Condition 3: At night, without indoor lighting. Near-darkness.

Condition 1 was considered to represent the average indoor brightness level; Conditions 2 and 3 were deemed to represent bright and dark environments, respectively. Figure 12 shows photographs taken under each condition at game start. During the experiment, the pieces were moved according to the records of the Kasparov vs. Deep Blue match, May 1997, Game 1 [36]; the position recognition rate was checked by comparing the historical match record with the record produced in the experiment. This game record includes moves until the black's resignation (at move 45), resulting in 90 specified operations. In Condition 1, almost no shadow can be seen from the pieces, partly owing to the illumination by the LEDs placed in the chessboard squares. In Condition 2, dark shadows are cast by the pieces onto the wooden frame section of the chessboard, due to sunlight. For example, the shadow length for a 4.8 cm piece was approximately 10 cm long. Piece shadows were noted on other chess pieces, but almost no shadows could be observed on the chessboard squares, because of the LED lights. In Condition 3, there was almost no illumination or

(a) Condition 1 (b) Condition 2 (3) Condition 3

Figure 12: Illumination conditions.

```
 1 Record the states of photoreflectors in state_data_1.
 2
 3 Loop until the Turn End button is pressed
 4   Compare the current state with state_data_1,
 5     Record square positions that changed from a presence to an absence in
       state_transition_data_1.
 6
 7 Record buttons' state data (on / off).
 8
 9 Compare the current state with state_data_1,
10   Record square positions that changed from a presence to an absence in
     state_transition_data_2.
11
12 Compare state_transition_data_1 and state_transition_data_2,
13   If there is an unmatched square position,
14     Set it as a square position from which an opponent piece has been removed.
15
16 Add state transitions from a presence to an absence, or an absence to a presence,
   using the specified square position.
17
18 Confirm the number of state transitions.
19   If there is no problem,
20     Send the data to a computer along with the buttons' state data.
```

Figure 13: Pseudocode for processing related to state transition detection.

sunlight, but piece movement was possible due to the LED lights. A complete game record was produced in all Conditions (1 to 3), and no decrease in recognition rate caused by the light source was observed. To avoid having players' manner of operation affect the recognition rate, in this experiment, the pieces were operated by the author.

4.2 Piece presence/absence detection ratio

As indicated in Section 3.3, identification of the en passant, movement, and castling operations is achieved by detecting the presence/absence of pieces when the end turn button is pressed, thus detecting state transitions only after they have been completed. These operations are sequential processes, and so the photoreflectors' detection ratio is not critical in detecting player operations. However, the capture operation requires accurately detecting operations during a player's turn, and so a sufficient detection ratio is required.

In the developed system, the chessboard microcomputer executes a looping program that checks the state of the chessboard buttons during the turns, detects whether the 64 photoreflectors installed in the respective squares are on or off, and detects state transitions resulting from changes in piece presence. Pseudocode for this process is shown in Figure 13. The third, fourth, and fifth lines represent the process of detecting when a player raises a piece and acquires an opponent's piece, after which the scanning of photoreflectors' states is repeated. Within the loop, a pulse is generated at the output terminal of the microcomputer. An oscilloscope measurement of this pulse showed a loop time of 217.5 μs. This means that the photoreflecting state of each square is detected at a ratio of 4,598 times per second. An erroneous detection of the capture operation (which would affect the detection ratio) would occur if a player's piece was placed in the position of the opponent's piece within the space of 217.5 μs. However, the operation of capturing a piece involves removing the opponent's piece from the chessboard and then moving one's own piece into the vacated position, and this requires at least a few seconds to perform. Thus, the detection ratio of piece presence/absence by the photoreflectors ensures sufficient overall performance.

4.3 Turnaround time

We evaluated the time required by the system from the moment when one player presses the end turn button, until the other player is able to move a piece. The processing tasks that must be executed during this time include the microcomputer creating the data to be forwarded to the computer (as soon as the turn button is operated), transmission of these data from the microcomputer to the computer, game record analysis processing at the computer, and data forwarding from the computer to the microcomputer. We designate the total time taken by these processes by turnaround time. Moving the pieces according to the game record [36], we measured the turnaround time for the 90 operations specified by it. A 25 MHz microcomputer was used, and the computer had a 2 GHz CPU. Serial communication was adopted, with a 9600 bps connection. The maximum turnaround time was 54 ms. In actual play, a player would need to think or react (even if for a short period of time) before moving a piece; the determined turnaround time is much smaller than any such amount of human time, ensuring that the system achieved sufficient performance levels.

4.4 Player evaluation and recognition rate when recording different players

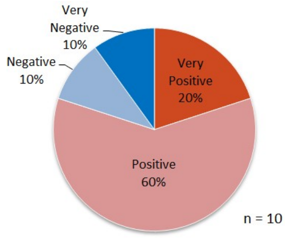
In the developed system, there are locations where the photoreflectors cannot detect the position of pieces in squares. The chessboard squares have 5 cm long sides, and if a piece has a bottom surface diameter of 2.5 cm, for example, it might not be detected if placed at approximately 3 mm from the side of the square. When playing, it is thus necessary to correctly place the pieces near the center of the squares and check that they have been detected (through the increase in LED light intensity, as previously discussed). In addition, in capture operations, it is necessary to ensure that the photoreflector has definitely shifted from on to off when removing the opponent's piece.

For reference, ten players played chess games with the developed system and were surveyed afterwards. The surveyed aspects were:

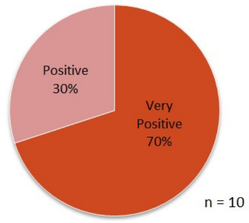
Question 1: User-friendliness of the photoreflectors.

Question 2: User-friendliness of the photoreflectors, when compared to membrane switch implementations.

Question 1 means to compare with games played on ordinary chessboards. We check whether the aforementioned notes on plays impair operability. A system that uses a membrane switch, which is compared in Question 2, is capable of recording games accurately, and there is flexibility in which pieces can be used. Among systems proposed in previous research and products with recording functionality, this system is unique in having these features. However, this system requires one to push pieces into chessboard squares, and



(a) Question 1



(b) Question 2

Figure 14: Player evaluation.

Table 3: Recognition rate when recording different players

Game	Number of operations of pieces	Recognition rate [%]
1	42	100
2	28	100
3	34	100
4	20	100
5	29	100

operability is not good. A product based on it was sold by Fidelity in 1980 [2], but since then, sales of the product and its successors have ended. Owing to these circumstances, plans to compare the proposed system with a membrane switch system were abandoned. In the experiment, we asked players to compare play with the proposed system to play that involves pushing pieces into squares while moving them. The evaluation results are presented in Figure 14, in the form of pie graphs. Five evaluation levels were used: Very Positive, Positive, Average, Negative, and Very Negative.

For Question 1, 8 subjects replied Very Positive or Positive, and there was 1 evaluation in the Negative or Very Negative range. The player who responded Very Negative had the habit of, when making captures, using his capturing piece to displace the opponent's piece before removing it. The evaluation was affected by the repeated misdetections that occurred because the photoreflector of the captured position was not being given the chance to change from the on-state to the off-state. Many players did not mind playing with a system based on photoreflectors. On the other hand, all subjects replied "Very Positive" or "Positive" to Question 2, demonstrating a tendency for our system to be favorably viewed when compared to the user-friendliness of membrane switch chessboard.

In addition to the evaluated items, one of the ten players expressed the concern that player could not concentrate on play owing to the light emitted by the LED. The light emission of the LED indicates a check pattern on the square, and it is used to indicate to the player that the photoreflector reacted and the detection was performed correctly. As the system allows for the adjustment of the LED's intensity, it is possible to adjust it so it is not distracting.

The proposed system recorded games accurately in five games with 10 different players. Table 3 shows the number of piece operations and recognition rate in each game. Experiments in this section have confirmed the system's good operability and accuracy.

5. Summary and open issues

In this research, we developed an automatic game recording system. This system uses a proprietary chessboard with sensors, but most existing chess piece sets can be used to play without any modification. Chess pieces are highly collectible, and come in a variety of materials, differing widely in shape, including shapes inspired by movies or fairy tales. Our system can be used with all pieces that can reflect infrared light at their bottom surface; in fact, even poorly reflective pieces can be used, by simply pasting a sticker to their bottom surfaces. In addition, the use of photoreflectors as sensors suppresses the negative effects of light sources or shadows on the recognition rate, thereby generating an accurate game record in a general playing environment. This perfect detection performance is also obtained by membrane switch systems, but unlike such systems, our system does not require pressing the squares when moving the pieces. Furthermore, the system can be made relatively inexpensive and compact.

On the other hand, the possibility of a misdetection exists; these can be caused by a nearby infrared emitting device or by overly bright lighting conditions, exceeding the maximum allowable ambient illumination of the light modulation photo ICs used in the photoreflectors; this would be the case if playing outdoors under strong sunlight.

Finally, in the system using photoreflectors, we explore the possibility of constructing a complete automatic recording system without the need to press a Turn End button. Since photoreflectors embedded in squares react to all approaching objects, it is only necessary to extract the information related to the operation of the piece. In this system, the filtering process is made easy by detecting the timing of the Turn End button. In the system that does not require pressing the Turn End button, the operations of “white turn” and “black turn” are specified from time series data of 64 photoreflectors, as well as data not related to operation. We will consider using machine learning for this filtering process. However, even if the number of plays increases, it is a challenge to achieve a recognition rate that can produce accurate game records.

References

[1] FIDE. [Online]. Available: http://www.fide.com

[2] D. Levy and M. Newborn, “How Computers Play Chess”, *ISHI PRESS International in New York and Tokyo*, Apr. 2009.

[3] M. Campbell, A. J. Hoane Jr., and F. Hsu, “Deep Blue”, *Artificial Intelligence* 134, pp.57-83, Jan. 2002.

[4] G. D. Illeperuma, “Using Image Processing Techniques to Automate Chess Game Recording”, *Proc. of the Technical Sessions, Sri Lankan Journal of Physics* 27:76-83, Jan. 2011.

[5] T. Cour, R. Lauranson, and M. Vachette, “Autonomous chess-playing robot”, *Ecole Polytechnique*, Jul. 2002.

[6] D. Urting and Y. Berbers, “MarineBlue: A Low-cost Chess Robot”, *IASTED International Conference Robotics and Applications*, pp.76-81, Jun. 2003.

[7] E. Sokic and M. Ahic-Djokic, “Simple Computer Vision System for Chess Playing Robot Manipulator as a Project-based Learning Example”, *IEEE International Symposium on Signal Processing and Information Technology*, pp. 75-79, Dec. 2008.

[8] N. Banerjee, D. Saha, A. Singh, and G. Sanyal, “A simple autonomous robotic manipulator for playing chess against any opponent in real time”, *Proc. of the International Conference on Computational Vision and Robotics*, Aug. 2012.

[9] C. Matuszek et al, “Gambit: A robust chess-playing robotic system”, *Proc. of the IEEE International Conference on Robotics and Automation*, May. 2011.

[10] K. Y. Tam, J. A. Lay, and D. Levy, “Automatic grid segmentation of populated chessboard taken at a lower angle view”, *International Conference on Digital Image Computing: Techniques and Applications* (*DICTA*), pp. 294-299, Dec. 2008.

[11] J. E. Neufeld and T. S. Hall, “Probabilistic location of a populated chessboard using computer vision”, *Midwest Symposium on Circuits and Systems*, pp. 616–619, Aug. 2010.

[12] C. Danner and M. Kafafy, “Visual Chess Recognition”, *Stanford University*, E368, Spr. 2015.

[13] G. Debasis, L. Johannes, and J. F. J. Gareth, “Retrieval of Similar Chess Positions”, *Proc. of the ACM SIGIR conference on Research & development in information retrieval*, pp.687-696, Jul. 2014.

[14] A. D. Escalera and J. M. Armingol, “Automatic chessboard detection for intrinsic and extrinsic camera parameter calibration”, *Sensors*, vol. 10, no. 3, pp. 2027-2044, Mar. 2010.

[15] M. A. Fischler and R. C. Bolles, “Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography”, *Comm. of the ACM*, pp. 381-395, Apr. 1981.

[16] R. Fan, K. Chang, C. Hsieh, X. Wang, and C. Lin, “LIBLINEAR: A Library for Large Linear Classification”, *Journal of Machine Learning Research*, pp.1871-1874, Aug. 2008.

[17] D. Lowe, “Distinctive Image Features from Scale-Invariant Keypoints”, *International Journal of Computer Vision*, vol. 60, pp.91-110, Jan. 2004.

[18] EIZO. How can a screen sense touch? A basic understanding of touch panels. [Online]. Available: http://www.eizo.com/library /basics/basic_understanding_of_touch_panel

[19] GENERAL Touch. The Working Principle of Projected Infrared Touch (PIT) Technology. [Online]. Available: http:// www.generaltouch.com/index.php?do=tech&cla=014005&lang =en

[20] P. Wellner, “The DigitalDesk calculator: Tangible manipulation on a desk top display”, *Proc. of ACM Symposium on User Interface Software and Technology*, *UIST ’91*, ACM Press, pp. 27-34, 1991.

[21] J. Underkoffler and H. Ishii, “Urp: A Luminous-Tangible Workbench for Urban Planning and Design”, *Proc. of Conference on Human Factors in Computing Systems CHI '99*, ACM Press, pp. 386-393, 1999.

[22] B. Ullmer and H. Ishii, “The metaDESK: Models and Prototypes for Tangible User Interfaces”, *Proc. of Symposium on User Interface Software and Technology UIST '97*, (Banff, Alberta, Canada, October, 1997), ACM Press, pp. 223-232, 1997.

[23] A. D. Wilson, “PlayAnywhere: a compact interactive tabletop projection-vision system”, *Proc. of UIST 2005*, 83-92.

[24] M. Weiss, J. Wagner, R. Jennings, Y. Jansen, R. Khoshabeh, J. D. Hollan, and J. Borchers, “SLAP widgets: bridging the gap between virtual and physical controls on tabletops”, *Proc. of CHI 2009*, 3229-3234.

[25] P. Baudisch, T. Becker, and F. Rudeck, “Lumino: tangible blocks for tabletop computers based on glass fiber bundles”, *Proc. of CHI 2010*, 1165-1174.

[26] G. W. Fitzmaurice, H. Ishii, and W. Buxton, “Bricks: laying the foundations for graspable user interfaces”, *Proc. of CHI 1995*, 442-449.

[27] B. Ullmer, H. Ishii, and D. Glas, “mediaBlocks: physical containers, transports, and controls for online media”, *Proc. of SIGGRAPH 1998*, 379-386.

[28] J. Patten, H. Ishii, J. Hines, and G. Pangaro, “Sensetable: A Wireless Object Tracking Platform for Tangible User Interfaces”, *Proc. of CHI 2001*, 253-260.

[29] J. Patten, H. Ishii, and B. Recht, “Audiopad: a tag-based interface for musical performance”, *Proc. of NIME 2002*, 1-6.

[30] M. Minami, Y. Fukuju, K. Hirasawa, S. Yokoyama, M. Mizumachi, H. Morikawa, and T. Aoyama, “Dolphin: A practical approach for implementing a fully distributed indoor ultrasonic positioning system”, *Proc. of UBICOMP 2004*, 347-356.

[31] K. Hinckley, K. Yatani, M. Pahud, J. Rodenhouse, A. Wilson, H. Benko, and B. Buxton, “Pen + touch = new tools”, *Proc. of UIST 2010*, 27-36.

[32] F. Block, M. Haller, H. Gellersen, C. Gutwin, and M. Billinghurst, “VoodooSketch -- extending interactive surfaces with adaptable interface palettes”, *Proc. of TEI 2008*, 55-58.

[33] N. Yu, L. Chan, S. Lau, S. Tsai, I. Hsiao, D. Tsai, L. Cheng, F. Hsiao, M. Y. Chen, P. Huang, Y. Hung, “TUIC: Enabling Tangible Interaction on Capacitive Multi-touch Displays”, *Proc. of the SIGCHI Conference on Human Factors in Computing Systems 2011*, 2995-3004 .

[34] J. Lien, N. Gillian, M. E. Karagozler, P. Amihood, C. Schwesig, E. Olson, H. Raja, I. Poupyrev, “Soli: ubiquitous gesture sensing with millimeter wave radar”, *ACM Transactions on Graphics 2016*, Volume 35, Issue 4, No. 142.

[35] SPEED CHESS. [Online]. Available: https://vimeo.com/139496901

[36] WIKIPEDIA. Deep Blue versus Garry Kasparov. [Online]. Available: https://en.wikipedia.org/wiki/Deep_Blue_versus_Garry_Kasparov

[37] D. Takeshita, M. Jyunya, Y. Hiroyuki, K. Kazuki, H. Shugo, and I. Keiichi, “Automatic Recording System of the Chess Score Sheet using Piece Position Detection with the Optical Sensor”, *Proc. of NICOGRAPH International*, pp.121-122, Jun. 2013.

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