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Human-Computer Interactive Gaming System - A Chinese Chess Robot

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Abstract—**In this paper, the system of Chinese chess robot is demonstrated, and it presents the latest development of artificial intelligence. The robot could play Chinese chess with human autonomously – with "eyes" it can recognize the pieces on the chessboard and move them with its mechanical arm. Furthermore, it has high intelligence which could approach the "master" level. The paper will be organized as follows: Firstly, the general structure and seven subsystems will be introduced briefly; then some key techniques used in Chinese chess gaming system will be discussed.**

I. Introduction

Computer game is recognized as one of the most challenging research directions of AI (Artificial Intelligence) and considered as "drosophila". A large number of amazing achievements derived from the research on computer game such as military gambles, economic regulation as well as many other areas. In 1997, Kasparov, as a chess world champion, was defeated by "Deep Blue" [1], which made computer game the hottest topic, and more and more people focused specially on it. There are various Computer Games, e.g., Othello, Chess, Shogi, Chinese Chess and Go. Table I shows the state-space and game-tree complexity [2] of some typical computer games.

TABLE I
STATE-SPACE COMPLEXITY AND GAME-TREE COMPLEXITY

Game	Chessboard	State-space complexity	Game-tree complexity
Othello	8*8	28	58
Chess	8*8	50	123
Chinese Chess	8*8	52	150
Go	8*8	172	400

Among those games, Chinese Chess with a long history is one of the most popular games in East Asia. It is obvious that the complexity of Chinese Chess is close to that of western chess. Studies suggest that there is no significant difference between them, but the discrepancy in history, geography and cultural background between Chinese and the Western makes the rules as well as moves diverse [3], which determines the differences in the process of playing chess, e.g., data structure, generating moves and evaluating positions. Many researchers devoted themselves to the Western chess for a long time. So the algorithm is relatively mature now. Compared with Western chess, the research on Chinese chess has not been explored as much as western one. Moreover, the moves are more specific and the strategy is more complicated. But the research on Chinese chess has made rapid progress because of taking advantages of previous work on western chess. In the past twenty years, experts have verified their research results by international competitions like "Computer Olympiad" [4]. The competitions proved that a lot of well-known Chinese chess gaming systems had reached or approached the "master" level. Considering the developing trend, the research on Chinese chess could not only optimize the algorithms, but also promote the development of AI. Chinese chess is supposed to be the next "Deep Blue".

However, even the "Deep Blue" cannot complete a competition all by itself. With the development of robotics technology, a growing number of experts are working on the human-computer interactive gaming system which has an ability to execute independently. In recent years, more and more excellent chess robots have been developed, e.g., Lego Chess Robot designed by the University of Glasgow [5], REEM-A produced by Pal Technology [6], etc. In China, many institutes work on gaming robot, e.g., "Cai Xiang" which can play renju[7], "Chess robot" developed by Shougang Corp[8], etc. The robots mentioned above are able to finish a process of thinking, identifying pieces as well as moving pieces, and those robots are more entertaining and realistic than traditional gaming systems.

II. Chinese Chess Robot System

A. System Architecture

The Chinese chess robot is capable of thinking, seeing, manipulating and communicating with people. The process of playing chess between a robot and human is similar to that of gaming between two people. The Chinese chess robot is composed of seven subsystems: intelligent chessboard, manipulator, vision, audio, fault diagnosis, chess logic control and gaming subsystem. The system architecture is shown in Fig. 1. These subsystems will be introduced in the following part.

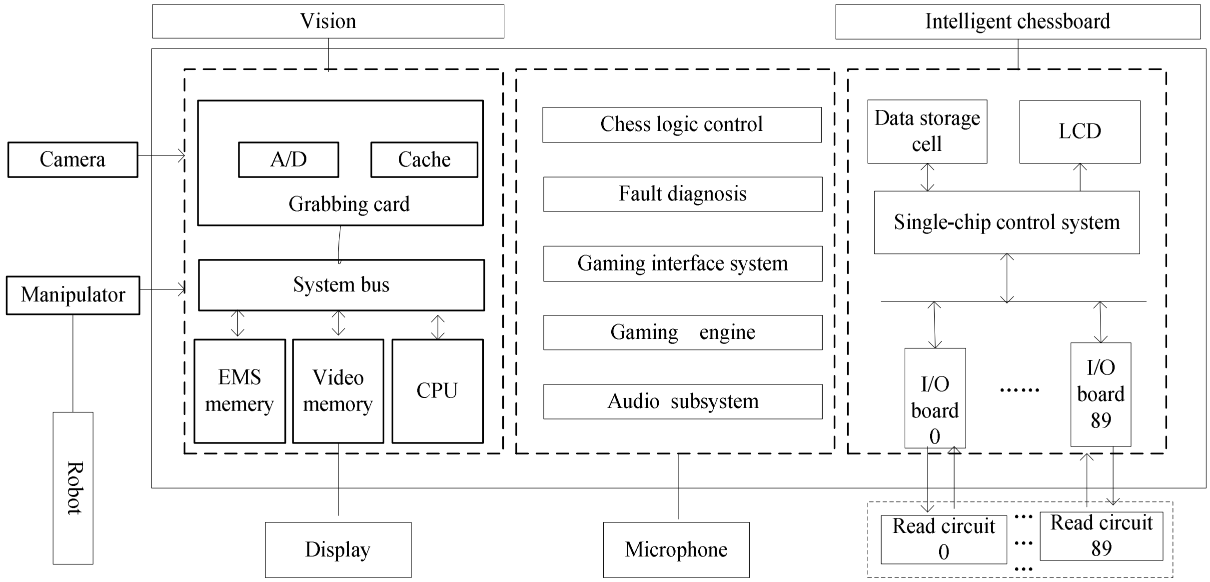

Fig. 1. Systematic structure of the software and hardware

B. The Subsystem of Robot

The intelligent chessboard is based on the technology of radio-frequency identification (RFID). Each chessman is inserted an ID card that can be recognized by card reader under the crossing of the chessboard grid. This subsystem provides accurate information to the manipulator and detects whether the movement is valid. Meanwhile, it can generate and store the chess-book data.

The manipulator is responsible of picking up and moving pieces with reliable, flexible and safe performance.

The vision subsystem acquires images of the chessboard with a camera. Through image processing, the subsystem delivers the actual coordinates and text messages to the chess logic control. Its function is equivalent to the eyes of the robot which provide information to the manipulator for moving pieces.

The primary function of the audio subsystem is to notify the human player of error messages or illegal movements with charming accent and respectful language.

The fault diagnosis subsystem performs several functions, e.g., self-checking, status detection, fault diagnosis, performance test and system maintenance.

The whole system is managed by the chess logic control subsystem. Its capabilities are enumerated below: initializing system, allocating buffer for data exchange, initiating and controlling multi-threads, task scheduling, time assignment, releasing resources, communicating with external device for exchanging information, maintaining the I/O data information among subsystems, keeping scheduling and correctness when exchanging data, designing the reliability, robustness and fault tolerance of the system.

The gaming subsystem includes two parts: the interface and the chess engine. The chief work of gaming subsystem is to tell the robot where to move and determine whether it will win the competition or not. Its structure is illustrated in Fig. 2. Some of its key algorithms will be summarized below.

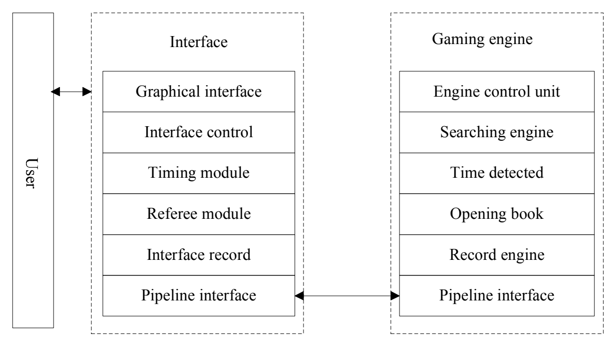

Fig. 2. The structure of the gaming system

III. ALGORITHMS USED IN CHINESE CHESS

For the gaming engine, the quality of algorithm influences the result of a competition directly. Currently, the research on Chinese chess algorithm mainly focuses on data structure, generating moves, evaluating positions, searching engine and opening book. In this section, some key techniques will be stated.

A. Data Structure

Excellent data structure could reduce the size of data storage and accelerate the computing and searching. In addition, chess engines often utilize more than one data structure during different periods for efficiency. The data structure of Chinese chess gaming system can be described with several encoding methods [9]: state coding of different pieces, state coding of board, offset board representation and bitboards representation. According to the codes of different pieces, the chess board can be presented by $S^{B}_{0\,[10*9]}, S^{M}_{0\,[10*9]}$, in which the chess board is represented by an array where each crossing of the chess board is mapped to one element. The coding of every piece is shown in the following expression:

$$S_0^M = \begin{pmatrix} 2 & 4 & 10 & 8 & 1 & 9 & 11 & 5 & 3 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 6 & 0 & 0 & 0 & 0 & 0 & 7 & 0 \\ 12 & 0 & 13 & 0 & 14 & 0 & 15 & 0 & 16 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 28 & 0 & 29 & 0 & 30 & 0 & 31 & 0 & 32 \\ 0 & 22 & 0 & 0 & 0 & 0 & 0 & 23 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 18 & 20 & 26 & 24 & 17 & 25 & 27 & 21 & 19 \end{pmatrix} \qquad (1)$$

During the competition, in order to avoid real-time searching, the offset board representation is also necessary. It can be written as $P_0^M = [P_{i,j}^M]_{2*32}$, where the first row displays which row the pieces are located in, while the second row describes which column the pieces are located in. Sometimes in a process of calculation, the chess board can also be written with the bitboards representation, as shown in formula (2), so that we can determine whether the crossings of chessboard have pieces.

$$B = \begin{cases} 1, S_{ij} \neq 0 \\ 0, S_{ij} = 0, 0 \leq \mathrm{i} \leq 10, 0 \leq j \leq 9 \end{cases} \qquad (2)$$

Finally, the chessboard is given by S_N, the set of formulas mentioned above:

$$S_N = \left\{ S_N^B \ , S_N^M , P_N^M , B_N \right\} \qquad (3)$$

B. Evaluating Positions

Another difficulty of Chinese chess gaming is to evaluate positions, which requires not only a basic knowledge of Chinese chess, but also a practical evaluating method. Nowadays, various methods, such as direct quantification, model based quantification, random assessment and fuzzy evaluation [10], have been proposed and utilized. Because of the complexity and flexibility in Chinese chess, the evaluation function must be considered in many aspects. Generally, in the function five factors should be contained, i.e., base value, position value, flexibility value, threat and protection value, dynamic modification value. Moreover, each evaluation function has more than one parameter, and it is difficult to build up evaluating model only by the programmer's chess knowledge. So this paper introduces the Genetic Algorithm [11] to the field of Chinese chess gaming system, deriving combinations of the optimal parameters from offline self-learning training [12].

Genetic Algorithm is global optimization algorithm based on natural selection and natural genetics. It can enhance the adaptability of individuals by selection, crossover, and mutation. Our operating process of Genetic Algorithm can be described as follows: First, a population of m individuals is divided into n groups. Each group carries out the tournament training inside the group and chooses the champion of every group. Then a new group which includes $m - n$ individuals can be constructed by making selection and mutation with n champions. Second, the potential crossover point is chosen from the interval between the parameters. Even crossover randomly produces 0-1 mask codes whose lengths are equal to the number of parameters according to the cross probability P_c. The children are determined by these mask codes and the chosen individuals. The third step is mutation which changes one or several genes with mutation probability P_m. As for binary cluster, it means 0-1 overturns of genes according to P_m. Mutation is a local stochastic search which ensures the efficiency of Genetic Algorithm and keeps the population diversiform. Meanwhile, it can avoid non-mature convergence. P_c and P_m can be calculated with the following formulas.

$$P_c = \begin{cases} P_{c1} - (P_{c1} - P_{c2})(F^{'} - F_{AVG}) / (F_{MAX} - F_{AVG}), F^{'} \geq F_{AVG} \\ P_{c1}, F^{'} < F_{AVG} \end{cases} \qquad (4)$$

$$P_M = \begin{cases} P_{M1} - (P_{M1} - P_{M2})(F_{MAX} - F) / (F_{MAX} - F_{AVG}), F^{'} \geq F_{AVG} \\ P_{M1}, F^{'} < F_{AVG} \end{cases} \qquad (5)$$

Where, P_{c1}=0.9, P_{c2}=0.6, P_{m1}=0.1, P_{m2}=0.001, F_{MAX} is the maximal fitness in the population; F_{AVG} is the mean fitness in each generation of the population; $F^{'}$ is the higher fitness between the two individuals to cross; F is the fitness of the individual to be mutated.

Such adaptive P_c and P_m can provide the optimal parameters and ensure the convergence of Genetic Algorithm while keeping the diversification of population.

C. Searching Engine

Besides a few simple chesses, a majority of chesses could not set up a complete game-tree when gaming. As for Chinese chess, every round has at least 40 types of possible moves. It means if both sides move 4 steps respectively, 40^8 nodes will be generated. With number of the steps increasing, the nodes will increase exponentially. Thus it is impossible to set up a complete game tree to find the global optimal results. So the goal of the searching engine is to find the local optimal state that has the highest assessed value without exchanging pieces in finite depth.

Obviously, a single search algorithm could not complete efficient and optimal search. The searching algorithms can be divided into three classes [13]: exhaustive search, selective search and heuristic search. The exhaustive search does not abandon any branch that might be the best move, but waste a lot of time. At present, the developing trend of searching engines is to adopt selective search and heuristic search which focus on the ordering of moves and the utilization of illuminating information for expediting searching.

In the system, the searching algorithms used by the robot are a congregation of many algorithms based on depth-first search and principal variation search (PVS). Besides, in order to improve the searching efficiency, some heuristic search algorithms are used, e.g., Null-move, Killer, Transposition Table, History Table, Iterative Deeping and so on [14]. The depth-first search [15] and PVS [13] will be introduced in the flowing section.

Generally, there are two basic searching methods, i.e., depth-first search and breadth-first search. The depth-first search and breadth-first search are similar. The only difference between them is the expansion of nodes. As for breadth-first search, the next expansion is the brother node, while the next expansion is one of the child nodes in depth-first search. Compared with breadth-first search, depth-first search saves more storage space, because it only needs to trace the routing information from the current node to the root node.

PVS, a kind of depth-first search, is adopted in the system. PVS is developed from Alpha-Beta pruning algorithm, which narrows the window during the process of searching. However, the estimating method of Alpha-Beta is reliable but not efficient. With the utilization of the minimal window, PVS is more effective, and the big window is only used in main variables in order to produce smaller game-trees.

In the process of gaming, some heuristic information is helpful during searching. So the heuristic search algorithm is introduced to improve the efficiency and the depth of searching. The heuristic searching focuses on the ordering of moves and the utilization of specific features in Chinese chess, thus the process of searching is simpler and more rapid than previous algorithms.

IV. CONCLUSIONS AND FUTURE WORK

In experiments, the seven subsystems could coordinate with each other. The gaming system could reach a depth of 16 levels in the game-tree when searching on a computer with 4 CPUs and the ultimate gaming level approaches the human master. In 2006, this gaming system won the champion in the first China Computer Chess Championship. Fig. 3 shows the human-machine interface of the system and the interface of the gaming system is shown as Fig. 4.

In the future, the efficiency and accuracy of searching algorithms will be improved, and some human-robot interactive methods, like speech recognition and hazard prevention, will be integrated into the current prototype.

Fig .3. The interface of the Chinese chess robot

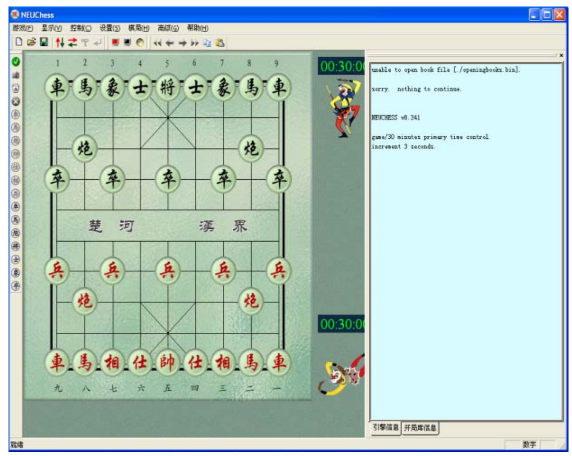

Fig .4. The interface of the gaming system

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