Playing Pylos with an Autonomous Robot

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I. Introduction

Since the beginning of mankind games played an important role. People love to play games. People play games just for leisure but nevertheless games are also important for education and the development of various skills of humans.

Playing games has also been a part of research in Artificial Intelligence (AI) and Robotics ever since computers have been introduced. Researchers either tried to develop algorithms to efficiently solve games or used games themselves as testbeds for research.

For instance, chess computers and programs have been attracting a lot of attention as a research area but also from the general public. One highlight was when chess computer Deep Blue defeated a chess world champion [1]. As another example, the RoboCup initiative uses the soccer game between robots and agents as a testbed for research in AI and Robotics [2].

While chess programs and computers do not play interactively on a real chess board and in RoboCup the robots play against each other, people always dreamed about an artificial companion who is able to play any game with them. Already in the late eighteenth century an automated chess player, called the *Turk*, was developed which was able to physically play chess against a human. Later, after a gigantic success, it turned out that the automaton was a fake, as a person inside controlled the arms of the automaton. Figure 1 shows a historical copper engraving of the automaton.

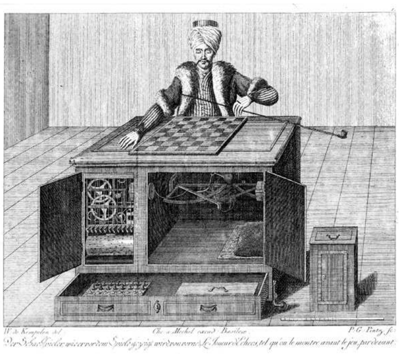

Fig. 1. The chess playing automaton form the late eighteenth century.

In this paper we present an autonomous robot which is able to play the board game Pylos[1] with a human opponent. See Figure 2 for a scene in a game of Pylos. Our underlying main idea is to develop an artificial companion which is able to play several different games. There are already attempts to build such systems [3]. But these systems do not allow game play in a fully interactive manner. Moreover, game playing robots are also used for rehabilitation purposes for children with severe physical impairments [4].

Fig. 2. A wooden version of the board game Pylos.

The rules of Pylos are rather simple. The game board consists of 4×4 initially empty fields and there are 30 spheres to build up a full pyramid on the board, 15 light spheres for the first, and 15 dark spheres for the second player, respectively. The aim of the game is to be the one who places the last sphere on top of the pyramid. The two players play in turns, and in each move they can make one out of two possible moves with spheres of their own color.

- Play a sphere on a field of the board or on top of an existing 2×2-square.
- Raise a sphere which is already in the game up at least one level onto an existing 2×2-square.

If a move results in a new 2×2-square of spheres of the same color, the player can take back 1 or 2 spheres which do not support other spheres, and put them into his reserve.

There are two ways to end the game:

- A player puts the last sphere (number 30) on top of the pyramid and wins.
- A player runs out of spheres, thus can not move, and loses.

Unlike many other games, like e.g. Connect Four, Pylos does not end after a fixed maximum number of moves. The possibility of taking spheres back from the board allows for interesting variations and prevents having trivial winning strategies.

Beside the fun of playing a board game with a real board against an autonomous robot there exist several interesting research questions. The most interesting topics arise from the combination of Robotics and game research, which usually focus on very different problems and are hardly combined.

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II. Game Theory

Pylos is a perfect information two-player zero-sum board game. That is, there is no hidden information (like hidden cards) and no element of chance (like flipping a coin or rolling a dice). Moreover, the two players make their moves in turns, have full information when making their decisions, and improve their situation at the expense of their opponent.

In principle it is possible to compute perfect strategies for such games. But of course for many interesting games, like for example chess, time and space constraints disallow that task. The interested reader might look for two-person zero-sum games in any text book on game theory to learn more about the basic theory behind this class of games.

There are several degrees of 'solving' a game. The weakest version, usually called *ultra weakly solved*, is to just know which player (first or second) will win a game, without knowing how this can be achieved. If a game is *weakly solved*, there exists a winning strategy, if the player uses it from the very beginning of the game. In a *strongly solved* game we can compute optimal moves for any reachable position. Here a reachable position is a situation of the game which can be reached from the starting position through any sequence of valid moves - regardless whether they are optimal or not. Thus this last version is of special interest for interactive games, where the user might want to challenge the robot by giving it difficult situations.

We have been able to solve Pylos in the strong way. The resulting game database has about 30 GB and contains for each reachable position a rating reflecting the quality of possible moves. This allows to obtain optimal moves for any possible game situation, as well as to crosscheck the plausibility of follow-up positions during an interactive game.

III. The Playing Robot

The setup of the Pylos playing robot is shown in Figure 3. It is rather simple and uses only *off the shelf* components. The active part is a standard Katana robotics arm (6 joints) equipped with a two-finger gripper. The control of the arm is done by the *Katana Native Interface (KNI)* C++ library. The game board, the moves of the robot, and its human opponent are observed by a standard firewire camera (Sony DFW-V500) providing color images in VGA resolution.

Our Pylos board is a regular game board painted white in order to ease image processing. Ping-pong balls painted orange and blue are used in the game. These colors allow for an easy distinction of the robot's and the opponent's balls. The game board also comprises a sloped ball pool to allow easy access to the robots reservoir.

The classification of the game situation is based on the position of the different balls which are on the game board. The position and the color of the balls are recognized by combining edge-detection, circle fitting, and color matching. In order to rule out implausible situations or invalid moves by the opponent, the estimated situation is crosschecked with the possible successor situations provided by the game database. This plausibility check is also necessary to figure out at which level of the stack a ball is located.

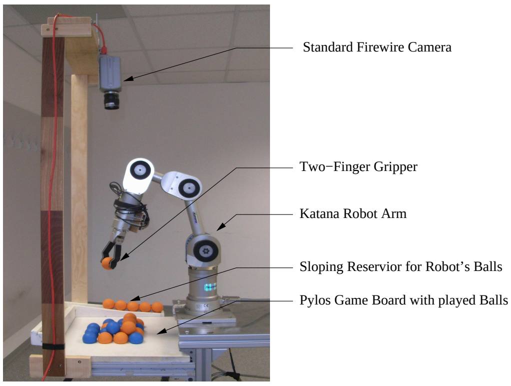

Fig. 3. System Overview.

The control loop of the robot works as follows. In the robot's turn it estimates the game situation based on the camera image and the previous game situation. Given this information the game data base delivers a rating-sorted set of possible moves. Considering the user-chosen difficulty level the robot selects a move (higher ratings for higher difficulty) and executes it. A move of the robot consists of one or more of the following phases: (1) place a ball from the reservoir onto the board, or (2) raise a ball up one level, and possibly (3) take one or two balls back to the reservoir. Afterwards the human opponent can make his or her move while the robot observes the board for changes of the situation. Once there are no changes for a predefined time span, the robot continues with its turn as described above.

IV. Conclusion and Future Work

We have built an autonomous robot, out of standard components, and combined it with optimal game winning strategies. This results in an artificial companion which plays the board game Pylos in a fully interactive manner and up to the highest possible level.

Challenging tasks for the future are on the one hand to extend our approach to other popular board games, like connect four or checkers. On the other hand we would like to use standard hardware platforms, i.e., robots off the shelf. In the long term this could lead to interesting competitions between various autonomous robots playing several board games in an interactive way, possibly at exhibitions very similar to what happens for soccer in the RoboCup initiative.

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