# Augmented Reality Chinese Checkers

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## ABSTRACT
This paper presents an application, Augmented Reality Chinese Checkers that we created to investigate user interface issues for table top projected augmented reality entertainment applications. A new tangible interaction device, the wireless button enhanced fiducial, is introduced to support selection tasks in mixed reality environments. The Augmented Reality Chinese Checkers game is built on a framework which can be used to create other computer supported collaborative games. The system is built using the Passive Detection Framework to track the 6 degrees of freedom position in real time of marked objects in the environment. The game supports up to six players at a time.

## Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces – input devices and strategies, interaction styles. H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces – collaborative computing. K.8.0 [Personal Computing]: General – games.

## General Terms
Design, Experimentation, Human Factors.

## Keywords
Entertainment Computing, Computer Based Board Games, Tangible Interaction, Augmented Reality.

## 1. INTRODUCTION
Much work has been undertaken to investigate collaborative work in next generation work environments [1-3]. We believe that a key step in the adoption of these environments is their use for multiple tasks. In this paper we describe an investigation we have undertaken to examine interaction technologies appropriate for entertainment computing and next generation work environments.

Augmented Reality Chines Checkers (ARCC) is our new mixed reality game developed for a table top projected augmented reality environment. We used this game to explore user interface issues for table top projected augmented reality entertainment applications. Chinese Checkers was chosen for this purpose because it can be played by up to six players and it has relatively simple rules for a board game. There are many advantages to playing games on a computer, rather on a physical board, as the ability to introduce animation and other multimedia presentations. For example the game of "Wizard's Chess" depicted in the movie *Harry Potter and the Philosopher's Stone* provided graphic animations of chess pieces fighting whenever a piece was captured [4]. This animation can do more than add excitement to the game play, it can also aid the players to learn the game and help them to understand invalid moves. Figure 1 depicts the virtual game board we developed for Chinese Checkers.

The paper provides the following contributions:

- Demonstrates a playable augmented reality version of the classic game Chinese Checkers.
- Demonstrates the use of Passive Detection Framework tracking system in an entertainment context.
- Describes a framework on which other similar boards games may be built.
- Describes a new form of tangible interaction, the wireless button enhanced fiducial marker.

The remainder of the papers begins with an overview of the related work. Our 6DOF optical tracking technology is described in the next section. The main section of the paper provides a detailed description of the ARCC system. This is followed by a discourse on the interaction techniques developed for ARCC. The paper finishes with some concluding remarks.

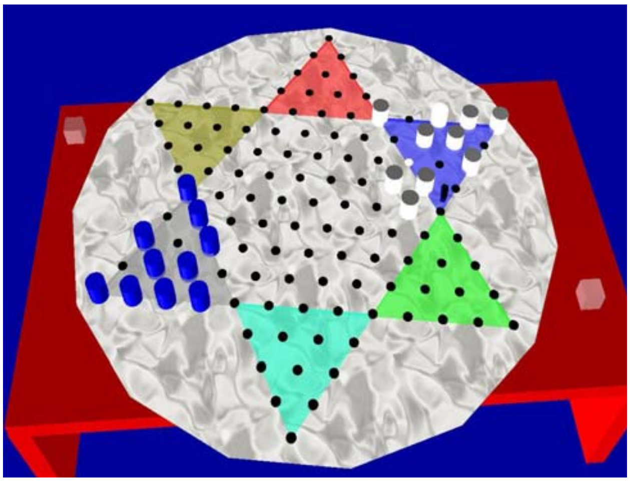

**Figure 1. The Augmented Reality Chinese Checkers virtual model.**

## 2. RELATED WORK

There are a number of AR board games. Balcisoy et al. [5] presented a novel approach to the presentation of AR board games, the use of real and virtual human interaction in an AR context. A combination of vision-based tracking and conventional chroma-keying techniques allows human-like avatars to simulate the physical actions of the opponent in a game of checkers (draughts). Szalavári, Eckstein, and Gervautz have developed a collaborative gaming environment for AR [6]. Using this environment, they have created an AR version of Mah-Jongg.

There have been a number of head mounted display based AR games. Ohshima et al. developed a collaborative augmented reality game AR2Hockey [7], a virtual air hockey table game. An interesting feature of this game is the ability to play in either video or optical see-through mode for the head mounted display. They reported over 250 people have played this AR game. Another virtual air hockey game was created using the Hi-Space table at Human Interface Technology Labs (HITLabs) [8]. The Hi-Space table uses a rear view screen mounted at desk height with tracking performed by three cameras fixed at ceiling height. Interaction is performed with the table using either touches of the surface and gesture recognition. Virtual Hockey is an application that allows two players to use their hands as virtual paddles to interact with the virtual puck. Each player can place two physical objects on the table to act as virtual defenders. Their position is calculated and a virtual representation of them is added to the game. Touch-Space [9] is a mixed reality game that is situated in a physical room-size space. A key aspect of the game is the human-to-human and human-to physical touch interaction. Physical objects (boxes) are opened and users physically move around each other. Sato and Koike developed a force feedback mixed reality version of the famous puzzle Rubik's cube. The user places their hands in a string-based haptic device with a LCD monitor at a comfortable viewing height. The user "sees and feels" the virtual cube puzzle, and they are able to rotate the faces in the normal fashion of the puzzle.

A novel aspect of this work is attention to the "privacy" issues in some gaming contexts. Starner, Leibe, Singletary, and Pair have been investigating the MIND-WARPING system, a collaborative augmented reality game [10]. This system allows for one set of players to operate "magicians" from a tabletop perceptive workbench, and second group of stationary standing players to operate their players via a wearable computer. The interaction on the perceptive workbench is by the direct manipulation of physical objects on the tabletop, a nice tangible interface. The interaction with wearable computer is multi-modal interface combining a Kung Fu yell with a short fist and arm gesture.

ARQuake is an outdoor AR game that places users in a first person perspective view of virtual worlds [11, 12], displaying their relevant information via AR. In particular we have developed ARQuake, an outdoor AR version of the game Quake [13]. ARQuake is a first-person perspective application with the following attributes: 1) The application is situated in the physical world. 2) The point of view, which the application shows to the user, is completely determined by the position and orientation of the user's head. 3) Relevant information is displayed as augmented reality via a head-mounted see-through display. 4) The user is mobile and able to walk through the information space. 5) The user interface additionally requires only a simple hand-held button device. In the ARQuake application, the physical world is modelled as a Quake 3D graphical model. The AR information (monsters, weapons, objects of interest) is displayed in spatial context with the physical world. The Quake model of the physical world (walls, ceiling, floors) is not shown to the user: the see-through display allows the user to see the actual wall, ceilings and floors which ARQuake need only model internally. Coincidence of the actual and virtual structures is the key to the game; the AR application models the existing physical outdoor structures, and so omission of their rendered image from the display becomes in effect one of our rendering techniques. Cheok et al. [14] have developed a human pacman game that combines AR, tangible, local and remote users. The "players" in the games, Pacmen and Ghosts, are played by humans. The cookies are physical bluetoothed enabled plastic jars that have to physically be picked up. The Ghosts catch the Pacmen by touch them on the shoulder. The game is played over a campus size area, may involve a scalable number of players indoors and outdoors.

We believe other game domains are suitable for use with AR. One question we are asking is, "Should the games be more quest and problem solving or should they be bash 'em up?" The nice aspect of quest and problem solving games is the users do not have to move quickly, and they can focus more on the physical world. This may lead to saver games. One area we would like to explore is fake sports events - cricket games, football, or golf [15]]. The user may play outside without requiring all the team mates to be present at the same location, or they can play against couch potato friends who do not wish to leave the house. These forms of games may accommodate with a wireless network. A less physical game could be multi-person music making[16-18].

## 3. PASSIVE DETECTION FRAMEWORK

Figure 2 shows the current configuration of the Passive Detection Framework (PDF) [19] in our environment at e-World Lab. Five of the cameras that make up the framework have been highlighted in the image. All cameras are roof mounted using a simple clamping mechanism. This allows cameras to be moved both along the surface of the roof and moved further from / closer to the roof surface.

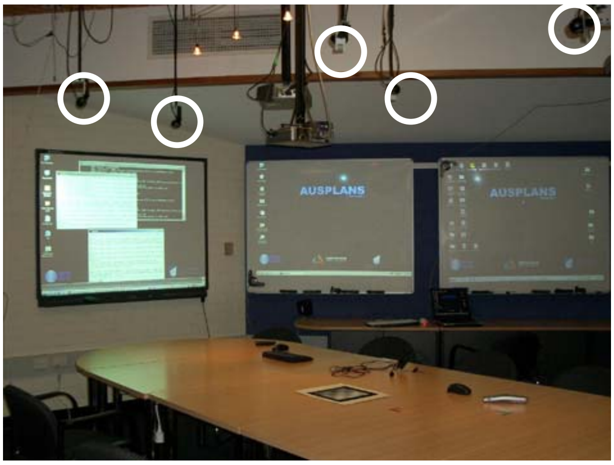


**Figure 2. PDF configuration at e-World Lab**

There are two key steps in the process of transforming a traditional work area to a tracked working volume. Firstly the pose of cameras in the room must be calculated. Secondly using this information, the pose of marker cards can be calculated in physical world coordinates

The PDF was created as an infrastructure for physical meeting rooms that can be used to rapidly augment the space and transform it into a tracked environment. The PDF uses optical tracking to calculate the six degrees of freedom (6DOF) pose (position and orientation) of black and white patterns, known as fiducial markers in real time. The user can track an object in the environment by attaching a fiducial marker to the object and moving the card around the workspace. The pose of the marker card is calculated using an image based recognition library called ARToolkit [20] Once the pose is determined, it is placed on a shared location called the Event Heap [21].

The Event Heap is a component of Stanford's Interactive Room Operating System (iROS) [2]. It provides a message passing mechanism for next generation work environments. Instead of using a traditional event queue, it uses a tuplespace environment which uses a central event heap architecture as the main message passing mechanism in a work environment. The event queue metaphor, which works well for a single user sitting in front of a single computer using a GUI, breaks down in an interactive workspace with multiple users all using common hardware and software applications. The Event Heap is a mechanism by which multiple users, machines and applications can all simultaneously interact as consumers and generators of system events.

The task of tracking fiducial markers is carried out passively on dedicated machines so that a wide range of devices (PDAs, tablet PCs, laptops, and traditional workstations) can utilise the infrastructure without draining the resources of the device. Cameras are mounted on the ceiling to provide the most complete view of the workspace, whilst still being discrete.

The minimum size of a marker is dependent on the distance between the marker and the camera. If a marker is to be correctly identified from a distance of 1.5 metres for example, the width of the marker must be at least 12 cm. Because of the well-documented problems with vision-based systems of obstruction of visual path from the camera to the marker, a number of methods have been proposed to circumvent this problem. Kato and Billinghurst [22] suggest the use of multiple marker patterns on the one fiducial marker card. This method relies on only one marker pattern being visible and being used to calculate the relative position of the other patterns on the card. If this approach was to be applied in our environment where the distance between the cameras and the tabletop plane where most interaction occurs is at least 1.5 metres, the marker cards would be large and cumbersome. For example, if four patterns were printed on the same pattern, the card would need to be at least 39 cm in width (leaving 5cm borders between each pattern). We have taken the reverse approach to the solution: instead of providing multiple patterns, we fuse together views from multiple cameras viewing the same environment from multiple angles. If an obstruction lies in the line of sight between the marker and one of the cameras, another camera is used to detect the markers position.

Unlike many tracking techniques, an advantage of the PDF is that the hardware components of the framework can be easily reconfigured to suit the requirements of the users of the workspace. Cameras can be repositioned in the environment using simple clamping mechanisms to attach to ceilings, desks etc, and computers can be relocated.

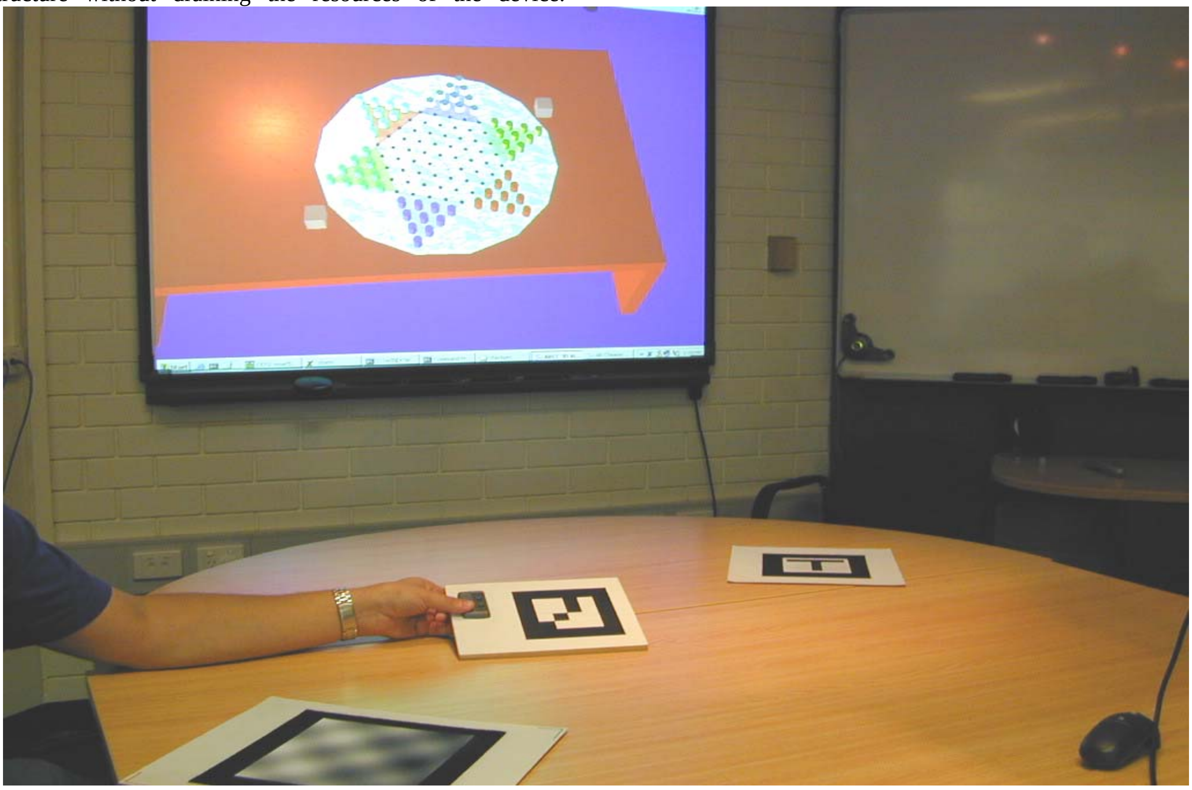

**Figure 3. A six player ARCC game with two board defining markers and the piece controller marker.**

For example, the default position of the cameras may be to spread them out over the entire meeting room, to provide the largest tracked volume possible. However, if a small group were to use the room they may want to reposition the cameras to give a more complete coverage of a section of the workspace.

The PDF is one of many possible tracking solutions. For working indoors, a number of tracking technologies have been developed such as: the first mechanical tracker by Sutherland, ultrasonic trackers by InterSense, magnetic trackers by Ascension and Polhemus, and optical trackers such as the Hi Ball. These systems all rely on infrastructure to provide a reference and produce very robust and accurate results. Kato and Billinghurst's ARToolKit produces reasonable results with the use of fiducial markers, and as mentioned is the underlaying tracking technology used for the PDF. This tracking does not drift over time and produces reasonably accurate results.

We will describe ARCC operating within the PDF configuration detailed here, but the ARCC and PDF systems may be operated on a single workstation with a camera connected to it. This facilitates the ability to provide a higher portability and to lower the cost of the system.

## 4. AUGMENTED REALITY CHINESE CHECKERS

Augmented Reality Chinese Checkers is an interactive game designed for next generation entertainment. It takes full advantage of the functionality of the PDF by letting the user communicate with the computer system through a tangible interface. This is done by the use of fiducial markers for input and a large screen display for the output of the virtual board.

Three fiducial markers are used for playing the game; two for defining the board's position, orientation, and size, and one for moving the pieces. In Figure 3 the fiducial markers for defining the board are the checkerboard central pattern at the bottom of the image and the "T" central pattern at edge of the table. These board defining fiducial markers are positioned on the tabletop when the game is started and stay there throughout the game. They determine the game space by defining the two opposite corners of the Chinese Checkers board. These markers can at any time be moved closer or further away from each other to rescale the board to a suitable size. Throughout the game, the players share a single marker to move the pieces, the marker in the user's hand shown in Figure 3. This marker is equipped with a wireless control device with 2 buttons that are used for selecting, picking up, and putting down pieces. Once a player has had their turn, the interaction marker is passed on to the next person. At any time, the players can change the camera output shown on the screen to their convenience. This is done by simply choosing a camera from a drop down list.

The reminder of this section is separated into three subsections. In the first section we explain the basic rules of Chinese Checkers. The second section describes our implementation of ARCC. The final section provides design details of the piece controller marker.

### 4.1 Chinese Checkers Rules

Chinese Checkers is an old board game which can be played by a maximum of six players. The original game is played on a star shaped wooden board with holes slightly smaller that the accompanying marbles.

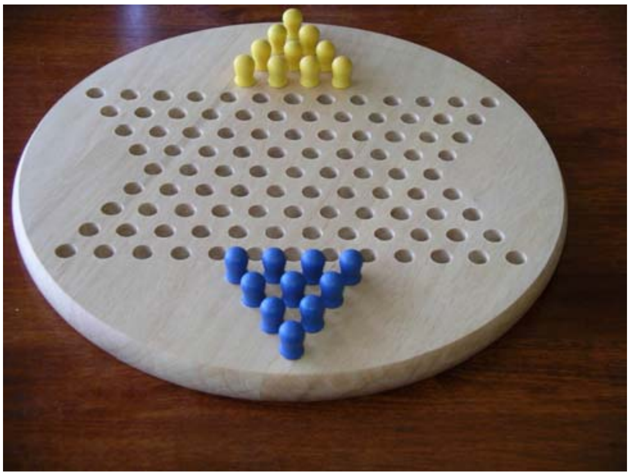

**Figure 4. Traditional Chinese Checkers Board**

Figure 4 depicts a traditional Chinese Checkers game board. Each player is allocated a home area, which is situated in a point of the star. All players have 10 marbles, or pieces, each in their home area, and the aim is to move all these pieces into the opposite area of the star shaped board. Whoever first moves all the pieces to the opposite area wins the game.

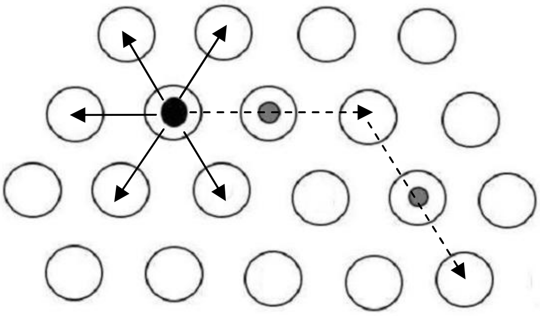

**Figure 5. Move to an adjacent empty position (solid arrows), or jumping over another piece to an empty position (dashed arrows).**

There are rules that define how the player is allowed to move the pieces. As shown in Figure 5, a player has two choices when moving pieces. The obvious way is to move a piece to an adjacent empty position. This can be up, down or sideways, and is a legal move as long as the position is empty. The other choice is to jump in a straight line over another piece to an empty position. The player can then continue to jump over pieces as long as it is a legal move, i.e. there is an empty position to jump to. The colour of the piece(s) being jumped over does not matter. The player is not allowed to combine these two techniques within the same move. After a player has had their turn, the next player will be selected in clockwise order. A player only wins at the end of each round, allowing all players the same number of turns.

Unlike in a normal game of Checkers (or draughts), after you jump over a player's piece it still remains on the board.

A good strategy for this game is to build so called ladders which in best case make it possible for a piece to travel from one side of the board to the other in one jumping sequence. The danger of this is when the opponent starts to take advantage of your ladders.

The game can be played by 2, 3, 4 or 6 players, and in all but one case the players are positioned so that they can move into someone else's zone. The exception to this rule applies for three players where the opposite zone should be empty. This rule enforces equality amongst the players, so that in all games, all players opposite areas are either empty or full.

## 4.2 Implementation

The main part of ARCC is the 3-dimentional model of the Chinese Checkers board. Figure 1 shows a screen capture of the ARCC board game. The body of the gray pieces are white, as it is this player's turn. There is also a piece that is completely white, meaning that a player has selected this piece. Each player has a home area, and a target area. The aim for a player is to get all their pieces to their target triangle, which is the same colour as their pieces.

### *4.2.1 Board Set up*

The size, position and rotation (around the z-axis) of the board are determined by positioning the top-left and bottom-right markers. If either or both of the markers are moved, the board will automatically adjust its position and size accordingly. The size of the board can be increased or decreased by moving the markers further apart or closer together. The board position is measured from the centre of board, which lies in the middle of the vector joining the position of both markers. To rotate the board, both markers can be moved around the circumference of the board, while keeping the position of the board the same. The top-left and bottom-right markers must be a sufficient distance apart, so that the piece controller marker does not collide with more than one piece or position (potential place of a piece) at a time.

Our current setup has the cameras mounted on the roof as this allows users to move markers throughout a large portion of the room with greater freedom. A simpler implementation of the PDF could use a camera on a tripod, connected to a single computer. The camera would have to be calibrated every time it is moved, but this is a simple procedure. Having just one camera and one computer would minimise the cost of setting up ARCC, but it has increased the problems with occlusion of markers. Such a configuration would allow ARCC to be played in any environment that a camera and computer are setup.

### *4.2.2 Interaction*

To specify selection events, we have attached a set of two buttons (as seen in Figure 6) to a fiducial marker to create a piece controller tool (refer to Section 4.3 for more details). The buttons are used to signal a selection event. As it is only a prototype, we attached a remote control switching unit to the marker. A wireless receiver is attached through a parallel port to a computer to receive the button press events from the fiducial marker. The current state (either on or off) is constantly sent through the parallel port. When a state change is detected, an event is sent to a shared location in the environment to be used by ARCC. However, as the device is based on a remote control switching unit, repeated presses of the same button (for example two "on" presses in a row) do not result in a state change and only the first press is detected. This allows the user to press the on button first every time. We now will refer to a button press event as a click of the "on" button and then the "off" button

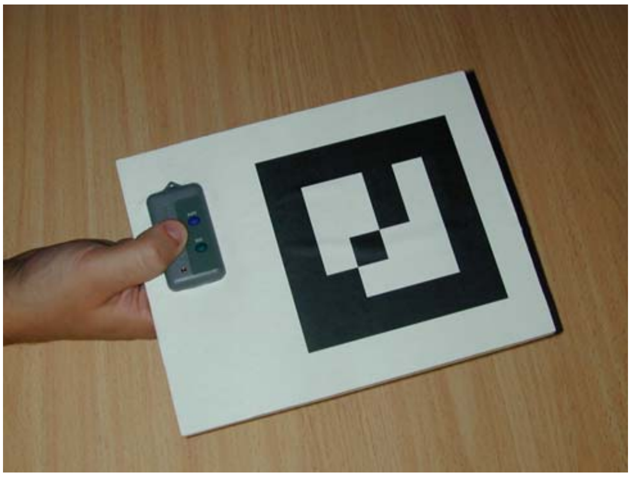

**Figure 6. The wireless button enhanced fiducial marker.**

Interaction between the user and the board occurs through the piece controller marker, either with a button click, or by movement of the piece controller markers. There is only one piece controller marker used in the game. This allows the game to be easily extended by not requiring additional hardware for each player. Finally, it also allows the piece controller marker to act as token, which gives the person controlling the piece controller marker controls over the game.

We decided to limit movement of the board to 4 DOF (x –axis, y-axis, z-axis and rotation around the y-axis), as a real game of Chinese Checkers is always played with a horizontal board. This horizontal constraint allows the game to be played on a level board, even when the markers are not (or can not be) placed at the same height

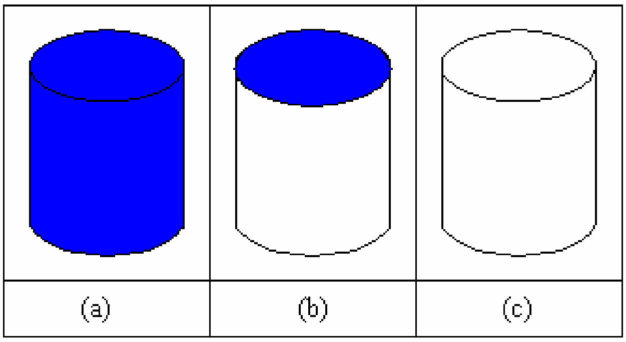


**Figure 7. (a) A normal piece, where it is not the player's turn (b) A piece where it is the player's turn (c) A piece where it is the player's turn and the piece has been selected.**

### *4.2.3 Game Logic*

The colour of the pieces is used as a cue to the players as to the next users turn. The player who has the next turn will have the walls of their pieces highlighted white, as shown in Figure 7 (b). To pick up a piece, the player must have the piece controller marker colliding with a virtual piece, and then press the button to confirm that this is the piece they want to select. As shown in Figure 7 (c) the piece will then have a white top to show that it has been selected. To move a piece, the player selects the position on the board that they want to move it to. If it is a legal move, that position is selected and highlighted white as well. The player can either continue their move (jumping) by selecting another position or finish the turn by selecting the same location again. The player can perform as many jump moves as they wish, providing they are all legal moves. If it is an illegal move then the piece will remain highlighted but the piece will not be moved, and all positions selected will remain highlighted so the player may continue the turn by selecting a legal position or end the turn.

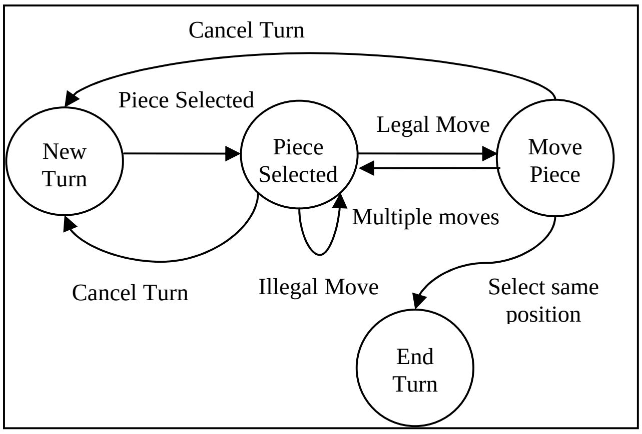


**Figure 8. The state transition diagram for a player to move one piece in Augmented Reality Chinese Checkers**

To cancel a move at anytime, the piece controller marker can be moved to the original position of the piece that is selected. When the button is pressed in this position, the move will be cancelled. We choose this method of cancelling a move, as it closely mimics the traditional interaction a user would have with a Chinese Checkers game piece. An overview of the game logic for a user to move one piece is shown as a state transition diagram in Figure 8.

**Figure 9 Wireless receiver**

## 4.3 Piece Controller Marker

This section describes in detail the design steps we have taken to create the piece controller marker. This design was chosen for its simplicity and speed of implementation. It also provided a cost effective solution. Figure 6 shows the wireless transmitter and button box under the user's thumb, and Figure 9 shows an image of our wireless receiver. The transmitters we use have an operating range of 50m which provides a clear accurate signal within the room's environment. We have used a Garrison LK-102R2 remote control switching unit transmitter/receiver box to transmit button press events. Each event state is indicated on an input pin of a parallel port. Our software polls the parallel port and transmits UDP packets containing the buttons current state to an application that posts the information on the event heap.

As shown in Figure 10, the flow of the communications begins with a button press at the fiducial marker. An RF signal transmits the button press event to the receiver box. Upon receiving a signal the receiver changes the output to either high or low at the parallel port. This is continually polled by the receiving software which sends UDP packets every 10ms to the IROS software. The repeating software and iROS software can be installed on separate computers.

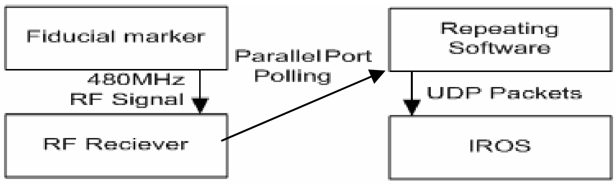


**Figure 10 Flow of communication**

One of the primary factors that influenced our design of the fiducial marker was the location of the remote controlled transmitter. It was discovered that a 2cm boarder between the outer edge of the black pattern on the fiducial marker and the transmitter unit was the minimum clearance to ensure no interference (in the form of occlusion of the pattern) for the optical tracking. The pattern was mounted on MDF to provide a robust marker.

Figure 11 shows the circuit we used to interact with the parallel port. The controller consists of three parts. The left hand side of the circuit diagram shows the Garrison LK-102R2 receiver chip. The middle section shows the circuit we created to transfer the signal from the chip to the parallel port. This circuit was chosen so as to protect the parallel port from damage in case of a voltage spike. In the event of a voltage spike, the transistor will be damaged instead of the computers motherboard. Status LED's were included on the top of the box to indicate the current state of the parallel port. These LED's were used as a visual cue to the player that the button press had been received. The right hand side of the circuit diagram shows the parallel port. The inputs were connected to pin number 12 of the parallel port.

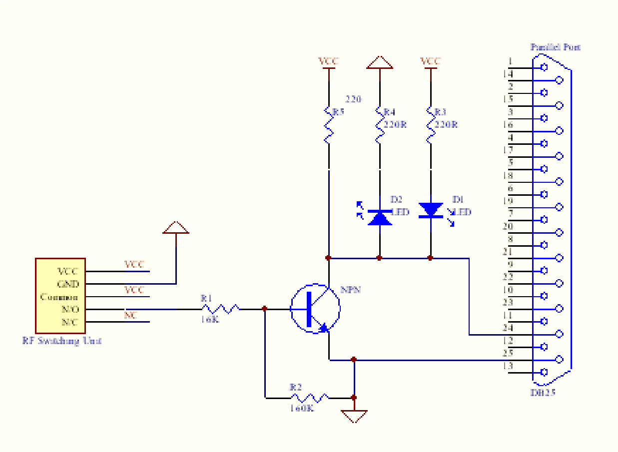


**Figure 11 Circuit diagram for piece controller**

# 5. INTERACTION TECHNIQUES

Interaction within this framework can be broken into two components: interaction with the board and interaction with the game pieces.

## 5.1 Board Interaction

The main interactions that can be performed with the board are to resize, move or to rotate. As discussed in Section 4.2.1, the method we use to determine the size and position of the board is to assign the positions of two board defining fiducial markers to the positions of two corners of the board. If a marker is moved, the board would be resized so that the centre of the board lies in the middle of the vector joining the positions of the two markers. To rotate the board, one or both of the markers can be moved and the virtual representation of the board is translated and rotated to follow the markers.

To set the current position of the game board, the fiducial markers can be flipped over so the patterns are no longer visible. This is implemented so the game board position can remain stable where the board defining fiducial markers become occluded.

The virtual board is currently displayed on a screen at one side of the room. This makes the game less enjoyable because it requires the players to look at the screen while they make their move and compensate for the difference in orientation. Depending on where the player is sitting, movement of the piece controller marker to the left could result in a left, right, forward or back movement on the screen. This situation is improved by the ability to select an angle for the virtual camera from a list. This makes it possible to select a camera angle that is similar to a player's view, meaning that it is possible to make movements that correspond to the same movement on the virtual board. To enable more fine grained control of the viewing angle, we will allow players to change the angle using arrow keys on a keyboard.

The cameras cannot be positioned in a manner that obstructs the users. Consequently, the cameras have to be mounted high in the room and at approximately 1.5m from the table. For ARToolkit to produce accurate pose results over this range, the markers have to be at least 120mm square. This means that a game of ARCC can not be played on a similar scale to a traditional game but must instead be played over a larger area. Therefore the board must be setup sufficiently large so that the virtual positions are far enough apart. This has the result that the board can completely cover a table and players have to get out of their seats to reach the other side of the table and make a move.

## 5.2 Game Piece Interaction

The interaction techniques used in ARCC have the potential to be more intuitive than playing Chinese Checkers on a computer screen with a mouse. This is because the player can make the physical action of picking up and moving a piece that is similar to playing Chinese Checkers on a board with marbles. The player can move the piece controller marker to a piece and select it (pick it up) and then move the piece controller marker that represents the selected piece (piece they are holding) to another location. The analogy is continued to a player cancelling a move by moving the piece controller marker back to the selected piece's original location. This is the same as a player repositioning their marble in its original position when they wish to cancel their move. This style of interaction closely mimics the method that players use to interact with a real board. The result is that the players are presented with a natural form of interaction.

In addition to the intuitive interaction techniques, where there is an advantage over other forms of computerised Chinese Checkers, ARCC can also improve on the real world Chinese Checkers Board. When a game is to be finished later, a real board has to be carefully carried away and put in a safe place but an ARCC board can be packed up by collecting the corner markers. When the players are ready to start the game again, the markers can be repositioned and the game board will reappear. ARCC also has the ability to introduce animation and other multimedia presentations that may enhance the player's experience. Such enhancements can not be produced on a physical board.

These advantages formed some of the motivation to develop ARCC. However, we discovered that there are a number of possible disadvantages in playing Chinese Checkers in such a way. The largest problem that we encountered was manipulating the pieces. When a player can pick up a physical marble there is no problem with selecting a piece. The haptic feedback provided by the physical object, along with the visual cues that we have become accustomed to allow the user to efficiently select and manipulate game pieces. The challenge was to find a suitable virtual equivalent to the real pick up and put down actions.

We originally implemented a system where the virtual piece controller marker had six degrees of freedom. The player could move the piece controller marker over the top of pieces and then move down to the piece that they wanted. The ability to move up and down magnified problems with accuracy. The problems were increased by limited depth perception as the game currently uses a two-dimensional display, meaning that the player cannot accurately discern the exact height of the virtual piece controller marker. Both problems were solved by constraining the virtual piece controller marker to the three degrees of freedom (3DOF) on the tabletop but still allowing the user to move the real piece controller marker up and down.

The four interaction techniques considered for the ARCC are as follows: scoop, dwell time, button press, and non verbal audio cues. Pictures of two of the interaction techniques are shown in Figure 12. Figure 12 (a) shows the button press interaction tool, and Figure 12 (b) shows the dwell time interaction tool. All four interaction techniques will now be discussed separately.

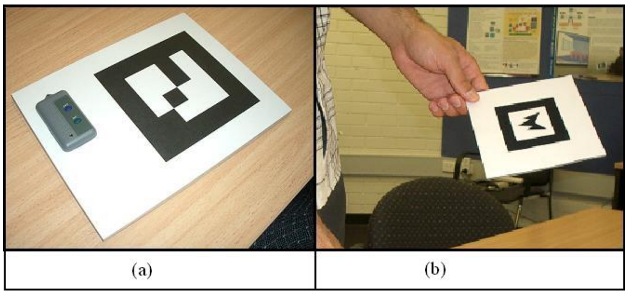


**Figure 12. (a) Button press interaction tool (b) Dwell time interaction tool**

The first interaction technique we considered using was a scoop action to pick up the piece, similar to that described in [3]. Using this technique, the marker is placed above the position of the virtual object to be selected. To signal a selection event, the fiducial marker is tilted above an angle of 30 degrees. In doing so, it acts as a scoop to "scoop" up the virtual piece. To place the virtual piece in a new location the fiducial marker is again tilted above an angle of 30 degrees. This action allows the piece to "slide" off the virtual scoop. Although we found this interaction to be intuitive and easy to use, we decided not to use it because of the relative sizes of the fiducial markers and the game pieces. As the markers are required to be at least 12cm in width, the interaction became cumbersome and confusing for the user to select a new position for the game piece.

The next interaction technique we used to signal a selection was dwell time. Figure 12 (b) shows a player using the interaction tool we created during the implementation of this technique. When a piece was to be selected, the player would hold their marker above the piece for 3 seconds. Each intermediate step that was taken with the piece was selected by dwelling in the same position for 0.5 seconds. The end position was selected by dwelling in the position for 3 seconds. This system was implemented, but after informal user testing we discovered that players found it frustrating to use. They found themselves always having to wait for the computer to recognise their actions as selections, and the fiducial marker had to be held steady for extended periods of time. The users experienced slight muscle fatigue.

The third interaction technique was to attach a button to the fiducial marker. Our prototype marker is shown in Figure 12 (a). Section 4.2 describes the implementation steps we took to create this interaction device. After informal user testing, we found that the use of a button made selection of pieces and positions less awkward and improved the player's enjoyment of the game. As discussed earlier, the kit that is currently in use requires the player to press two buttons (on, off) rather than just one. While this was the source of some concern during the implementation phase of this investigation, we found that the user adjusted to the interaction quickly as it is analogous to interactions (such as double clicks on a mouse) that have been adopted as everyday interaction techniques. In particular, we found that the player often adjusts to the multiple button presses after two turns and no longer consciously thinks about it.

The final interaction technique that we considered can be seen as an extension of the dwell time technique. Although the button press technique is by far the most efficient and intuitive interaction technique that we had experimented with, we were hesitant to add extra hardware to the fiducial markers. One of the primary advantages of using fiducial markers is their cost. However, after further investigation we found that although the set-up cost of buying a wireless receiver is relatively large (around $100), each additional fiducial marker can be created with buttons for an additional $20. We decided to investigate the addition of hardware to the environment instead of the tracking cards. In particular, we investigated the addition of microphones to the environment to detect non verbal audio cues such as knocks on tables.

## 6. EXTENSABILITY

Due to the component-based architecture of ARCC, the framework could be used to develop similar games. There is a requirement that the interaction techniques of the game are similar and involve mainly picking up and putting down pieces. Only having a single piece controller marker increases the flexibility of the framework, as the number of players is not restricted to the number of piece controller markers. Therefore, any game could be played from a game of chess to a 10 player game of snakes and ladders.

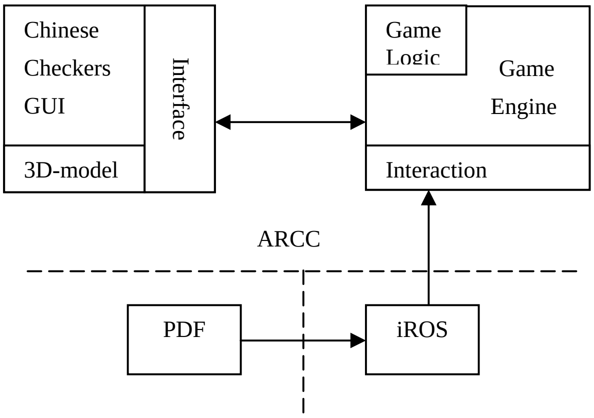


**Figure 13. The interaction between different components of ARCC and its use of the PDF.**

Figure 13 shows the architecture of ARCC and how it uses the pose values obtained form the PDF. The position of the piece controller marker is determined and placed on the Event Heap of the iROS tuple space. The game engine registers for these events and the engine is therefore notified when a new event occurs. Tracking information enters ARCC in the interaction interpreter which processes the values to interpret the movements. The game engine then coordinates all other sections to determine collisions, validate moves and position pieces. The 3D model is written in Java3D and determines the shape and layout of the board. It is also notifies the game engine whenever the interaction devise is colliding with a piece or position.

This model could be replaced with another to implement a different game. For instance, the GUI could be changed to represent a chess board with a square grid and different shaped pieces. There is a requirement that each square has a smaller area within that is collidable. The area can be of the same colour as the square and hence invisible to the player. The reason for the area being smaller is to ensure that the interaction devise cannot collide with two positions or pieces at one time. It is also required that an event is sent out to any subscriber whenever a collision occurs.

Different game logic must also be developed to represent the state of the board and comply with an interface for the game engine. This interface consists of generic methods to perform actions such as picking up and putting down a piece. The rest of the ARCC framework does not require any changes for a different game.

# 7. FUTURE WORK

In the future, ARCC could be enhanced by making improvements in the areas of selection and display technologies.

## 7.1 Selection

The current method of selection is an off-the-shelf remote locking system which requires the player to press two buttons to make a selection. While this method of selection is satisfactory it would be desirable to implement a better alternative. We can see two possibilities to improve this arrangement, either improving the button or using a different selection technique. A different wireless button system could be used that allows consecutive presses of the same button. This would give players a simpler interface but would not provide any additional benefit. The other alternative is to use something other that a button, which will provide us with the opportunity to conduct further research into interaction techniques. One potential technique that could be used for selection is a knock on the table. This would require the introduction of new hardware into the environment. A microphone placed on the table would pick up low-frequency knocks but could only be used as a replacement for the button and not the marker. Several research organisations have investigated the use of such interaction [23] and we have also developed a trial implementation of a knock detector. The detection of knocks, as with any audio processing is slightly affected by loud background noises such as loud music or a bump of the table. This also has the disadvantage that the game has to be played on a table. Due to the potential for such spurious events, we decided to stay with a button.

An alternate approach to using the parallel port connection for the wireless receiver, see Figure 9, is to use an Universal Serial Bus (USB) connection. The parallel port is limited to 8 inputs with the functionality determined by the remote controlled switching unit. The function of the current system is controlled by two buttons either ON or OFF. An alternate would be to use one button with a pulse controlling both states.

## 7.2 Display

Currently the virtual model of the Chinese Checkers board is displayed to the players on a large screen display. As discussed in Section 5.1, this method of display requires a player to adjust for differences in orientation between the real and virtual worlds. Additional problems are encountered when the display too far away and the players can not easily see the pieces because they are too small. Instead of displaying the virtual board on this display at one side of the playing area, there are other means of viewing the board. Display devices such as a Head Mounted Display (HMD) or table-top projector would improve the players' perspective of the virtual model. A see through HMD would also provide a 3D view of possible animation which is not as impressive on a two dimensional display. However, the HMD would restrict interaction between the players because part of their face would be covered and subtle facial expressions that aid communication would not be visible. As ARCC is originally designed for a room that supports collaboration between people, we consider that a tabletop projector would be a better alternative to a HMD.

To setup a table-top display a standard video projector would be mounted directly above the table and the image would be projected onto the horizontal surface. The table-top projector alternative will not obstruct the users and will therefore provide a more natural environment. This display device would have to be calibrated so that the displayed coordinates exactly match the environment. To achieve this, a calibration system would be required to set up the game and adjust for any movements of the table or projector. A disadvantage of the table top projector is that it would confine the game to the table, restricting the players' freedom to play the game where they like.

An alternative to implementing a new display device would be to keep the current arrangement but improve the players' ability to change the view. If the players can change the view so that it corresponds to their own there will no longer be a difference in orientation. This could be achieved by using the arrow keys on a keyboard to increment the view angle but some of the motivation for this project is to use new interaction devices. In keeping with this, a piece controller marker that acts as a virtual camera could be used to specify the virtual camera position. These positions can be set at the start of a game and recalled for each player's turn.

# 8. CONCLUSION

In this paper we have described ARCC, an augmented reality Chinese Checkers computer supported virtual board game. We have described a system that is able to provide a natural and intuitive method of computer game play. This is achieved by using a physical game area that contains a virtual game, creating a space where players' movements directly correspond to actions in the virtual game. To track these movements we have used the Passive Detection Framework, an optical tracking solution that was created for use within next generation work environments. We have investigated various interaction techniques that can be used in the environment for selection and manipulation of game pieces in a Chinese Checkers game. Four different techniques were presented and analysed. After informal user testing, we found that a wireless control switching unit attached to a fiducial marker was the most effective tool for selection of small objects in a collaborative environment.

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