AirRacquet:
A Gesture Based 3D Ping-Pong Game

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ABSTRACT
In this paper, the iterative design process undertaken in developing the AirRacquet system, a 3D ping-pong game, is described. Through feedback received from user testing and empirical measurements derived from several evaluation procedures, AirRacquet attempts to create a usable, intuitive interface that abandons the traditional keyboard, mouse or gamepad inputs and replaces them with gestures.

KEYWORDS

Human-computer interaction, usability, heuristics, gestural interface, interface design, ping-pong game.

INTRODUCTION

During the past 10 years, the electronic gaming industry has made great strides in enhancing users' experiences. Advanced architectures that include vector processing units and motion engines have allowed 3D games to reach new levels in graphic rendering [8]. Despite these valuable advances, the user input interface has largely remained static over this period of technological enhancement. Most often, users are still restricted to using keyboard, mouse, or gamepad inputs to play their games, like they are in Simple2000's Love Ping Pong game for Playstation [6] or Gamesoft's Ping Pong Pro 3D for PC's [1]. These input devices do not provide a natural mapping to the physical gameplay and they prevent the user from interacting with the system as he or she would if he or she was performing the same actions in the physical world.

The AirRacquet system was designed to examine an alternative paradigm for video gaming input. AirRacquet is a 3D ping-pong game in which users are immersed into the gaming environment. Users have the ability to navigate through the environment and interact with the system as if they were playing an actual game of ping-pong. The system was developed from initial prototype to Beta version over a 10-week period under the auspices of Professor Cooperstock's Human Computer Interaction course at McGill University during the winter semester of 2004.

The main task of the project was to develop a usable, gesture-based human computer interface. The AirRacquet system was designed following an iterative process that responded to user feedback obtained from the various evaluation procedures. The design decisions made during the system's evolution were based on Norman's principles and effective HCI design principles highlighted in the course [5].

This paper will describe the AirRacquet system and outline the different stages involved in its development. The evaluation procedures and the changes motivated by user feedback will be highlighted and their connection to effective HCI principles will be noted [4,5]. Finally, a brief outline of possible extensions to the current system will be provided.

AIRRACQUET USAGE SCENARIO

David is a 21-year-old student in university. He enjoys playing ping-pong recreationally, but cannot find an opponent. David finishes his classes for the day and is looking for some recreational entertainment. He steps into the AirRacquet environment for the first time and sees a menu, which has three buttons: *Start New Game, Difficulty,* and *How To Play*. He moves his arm over the *How To Play* button and pushes it. David then watches a wireframe avatar demonstrate the different supported gestures, forehand, backhand, navigation, and serve, while a pleasant voice explains the function of each action. When the animation is complete, David is brought back to the *Main Menu* and starts a new game. He walks up to the edge of the ping-pong table he sees in front of him and serves the ball using the same forehand motion he would use in a physical game of ping-pong. The computer opponent standing at the opposite end of the table returns David's serve with a slow shot; David easily hits a winning shot. He sees his opponent miss the ball and the score, 1-0, is announced and displayed on the screen. David feels the game level is too easy so he raises one arm over his head and a Pause menu appears. From here, David exits to the main menu and then changes the difficulty setting from Easy to Medium. David starts a new game and is now challenged by the computer opponent's shots. David plays a full game and goes on to beat the computer 21-19.

DESIGN PROCESS

The design of the AirRacquet system was centered on the principles laid out by Gould et. al [2]. They stressed three main principles when designing reliable, easy to learn and useful systems:

- Early focus on users and tasks
- Empirical measurements
- Iterative design

These principles were kept in mind when making modifications to the AirRacquet system. All changes were motivated by user feedback received from evaluation procedures that were conducted during the various iterations of the AirRacquet system [4].

EVALUATION CRITERIA

Early on in the design process, a set of evaluation criteria based on Norman's principles, was established to create objectives to achieving a usable and intuitive interface [5]; the gestural mapping, gameplay and menus were all addressed. As the system evolved, these criteria were slightly modified to account for the added flexibility of the system. The criteria are outlined below under the headings of a few key concepts.

- Feedback: The user should be able to identify when the ball should be hit.
- Natural Mapping: The user should be able to identify which stroke (forehand or backhand) is appropriate for a given shot. During his or her first game of the AirRacquet system, users should be able to hit two forehand shots as well as two backhands shots back to the computer opponent. Users should not require more than three attempts to serve the ball for the first time.
- Conceptual Model: The ball's flight and behavior should mimic that of a ping-pong ball in a real game.
- Visibility: Users should be able to change a specific setting easily within two minutes of being in the environment (established for the gesture interface). Users should be aware of 80% of the settings after navigating through the menu twice (established for the options available in the initial prototype).

EVALUATION PROCEDURES

The design of the system went through four stages: the storyboard, initial prototype, Alpha version and finally a Beta version. For every stage of the design, an evaluation was carried out to find its strengths and weaknesses. After collecting some feedback on the storyboard, the initial prototype was designed and then evaluated using the following evaluation plan. A second evaluation was then carried out on the Alpha version to improve it for the Beta system.

EVALUATION PLAN

Four evaluation procedures were carried out throughout the evolution of the AirRacquest system: a laboratory exercise, a cognitive walkthrough, a heuristic evaluation and a secondary evaluation [4].

Laboratory Exercise

In this exercise, users were asked to perform several tasks and record quantitative results, such as the number of trials required to start the game, serve the ball and hit the ball back; the time required to access the option menu; and the frequency of consulting the tutorial. The users were also asked to compare this system with an existing 3D ping-pong online game [7].

Cognitive Walkthrough

To verify whether the game had a good conceptual model, the users were asked to follow a cognitive walkthrough where they were asked to perform specific actions. This step helped identify ambiguous information and promoted clarity in the game. The focus of this step was on what actions are needed to perform to accomplish a task and how the interface supports these actions. It was assumed that the users had played computer-based racquet games before and that they were literate in English. This exercise simulated a user's problem-solving process at each step in the dialogue to see whether the desired or expected outcome occurred. The tasks that were asked from the user were to start a game, hit the ball back once, pause the game, access the help and option menus, start a new game and change specific settings.

Heuristic Evaluation

Heuristic review is recommended for a product in its early stages as a quick and inexpensive method for finding major user interface problems [4]. It is performed by evaluating the interface, recording the results, and developing a list of usability problems in reference to those principles that were violated. Several heuristic factors based on Nielsen's Usability Heuristics were used for the evaluation of AirRacquet: visibility, match between system and real world, flexibility and efficiency of use, help and documentation and help users recognize, diagnose and recover from errors.

Secondary Evaluation

The secondary evaluation was performed in a similar manner to the cognitive walkthrough. The tasks that were requested to be performed were to manipulate the main menu, go through the *How To Play* section, change level of difficulty, start a game, play 15 points, pause and return to the game, and pause and then exit the game.

STORYBOARD

Before implementing the initial prototype, a storyboard was first designed using simple diagrams to give users a general idea of AirRacquet. This approach was used because modifying the system at this stage was much simpler than in later stages when programming was involved. Also, this was the fastest and least time consuming way to get quick feedback from users. Two figures which give the general representation of the gameplay and menu drawings are given below

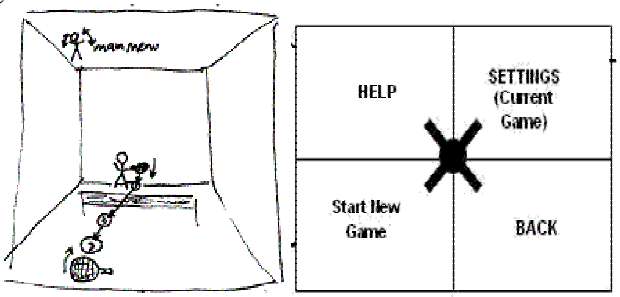

Figure 1 – Paper prototype gameplay scene (left) and menu scene (right).

Three problems were pointed out:

1. Start new game function: this function was not clear because users were unable to know if it resets to default settings. Therefore a *Choose Default Setting* was added to the settings menu to clear the confusion.
2. Names used in the settings: The word gravity which was confusing was replaced by bounciness.
3. Gesture required to select an option: There was a request for a more deliberate gesture for an option selection in order to prevent errors. Therefore, instead of pointing one arm for the option to be selected, the user should be required to close his or her fist to make a selection.

It was difficult to acquire a lot of helpful user feedback on the gameplay in the paper prototype because there is a lot of timing and coordination issues involved when playing a racquet game that is hard to replicate on paper.

INITIAL PROTOTYPE

Based on the improvements suggested to the storyboard, the initial prototype, shown in Fig 2, was designed in Macromedia Flash because its code facilitated action movements. Flash technology also allowed testing on common desktop computers.

The initial prototype was designed to be a tennis game instead of the squash game due to the limitations of the system of the Shared Reality Environment (SRE), such as the system was not able to support multiple users in the same room. Multiple user interaction would however be possible with a tennis game since the two players would be in separate rooms. The figure below illustrates a scene from the initial prototype.

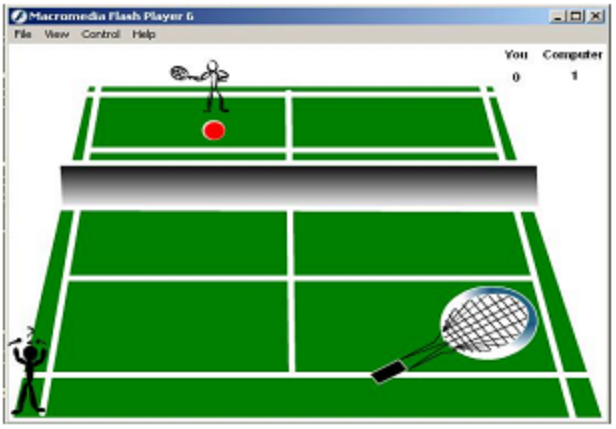

Figure 2 – Screenshot of gameplay in initial prototype.

The ball size in the system was designed to vary according to its proximity to the user. A help icon was displayed at the bottom left and instructions on how to serve flashed across the net before the start of each game; this way, users would receive all the information they needed to play the game without having to navigate through menus or consult a user manual.

The problems pointed out by the evaluating team and TAs after going through the evaluation plan were lack of feedback, difficulty to play, distracting and confusing instructions displayed during the game, and vagueness of the pause state. The suggestions were to add some message display for more feedback, like "out" or "net ball", informing the player why he or she lost the point; make the racquet semi-transparent and make its orientation change according to where the ball is situated; redesign the pause figure so it does not distract the player; explicitly give indications of the state when paused by adding a *Back to Game* button. The strengths identified were the good feedback, ease of access and visibility of the state in the option menu. The user was always aware how deep he or she was in the menu. It was also easy to grab the game concept because it resembles most racquet games.

Note that the game was designed to give a general idea on its looks and functionality for the evaluation. Therefore, the hits were not designed with great accuracy, which is the reason why users evaluating this system found it hard to hit the ball.

ALPHA VERSION

The Alpha version is a significant improvement of the AirRacquet system over the prototype. Many suggestions were provided by the design team *Duck Hunt* [9]. The most substantial change is the change from a 3D tennis game to a 3D ping-pong. A main motivation for the change was the limited physical space in which the user could navigate,

which allowed a better mapping between the user's physical movements and the change of the user's position in the virtual environment. This is due to the comparable size of a ping-pong table and the size of the shared reality laboratory. The modification was also advantageous with respect to the display of the opponent. In the table tennis game, the opponent was far away from the user and therefore small, whereas in the ping-pong game, the opponent was nearer to the user and therefore larger, so that visibility problems due to the limited image resolution of the display vanished. Along with this reason, a perspective view could be incorporated into the game more easily.

Once this decision was made, the open source table-tennis game *Cannon Smash* [3] was taken as a starting point for programming the computer game for the shared reality laboratory at McGill. Many useful ideas addressing the problems of the prototype were already implemented, while others had to be changed to address the specific interaction of the game with the SRE.

Critique points other than the change from the tennis game to the ping-pong game and applied solutions include the following:

Start game in options menu. In the prototype, the game was started directly. It was mentioned by test users and later on implemented that the user should instead start in an options menu, where he or she could access a how-to section, see Fig. 3. All menus were implemented as 3D buttons which seem to stick out of the display plane. 3D buttons provided good affordances to the user for pushing. Once a button was pressed, it appeared to be lowered, comparable to the buttons of a conventional tape recorder.

Figure 3 – Main menu of Alpha system

Feedback about winning and losing points. This feature was already implemented in the original *Cannon Smash* game. Once a player missed a ball or hit the net, the system announced the current score via audio output. An alteration was made to the original *Cannon Smash* code such that the score could be displayed continuously on the side of the table on a scoreboard; this gave the user constant feedback about the state of the game.

Pause menu. In the prototype, it was not clear for the users if the pause option actually quit the game or if it could be resumed. This problem was addressed by displaying the pause menu with the label *Pause* and by displaying it on top of the current game, so that the interrupted game is still visible.

Racquet. In the prototype, an opaque racquet was displayed, whereas in a later evaluation a semi-transparent racquet was suggested. Furthermore, a mapping problem between the racquet positions of a forehand and backhand swing was discovered. Good solutions for these problems were already implemented in the original *Cannon Smash* game, where instead of one racquet, two target ellipses are displayed. Since the implementation of a forehand and a backhand swing was one of the design goals, displaying only one racquet would have caused problems. In a real racquet game, the user would position him- or herself before performing a hitting movement. Therefore, the system cannot know if a forehand or backhand swing will be performed while the user is taking position. If the system assumes a forehand swing and displays the racquet on the right side (assuming a right-handed player), the user might very well perform a backhand swing, only to have the racquet be readjusted to the left of the player, which might easily cause a missed shot. A good solution was to display one area for a forehand swing, and one area for a backhand swing. In this way, the user could position him- or herself to make a forehand or backhand hit and perform the according swing afterward. Since the user cannot have two racquets in reality, it makes sense to exchange the racquet with a see-through target area.

Ball position. In the prototype, the distance of the ball to the user was indicated by the size of the ball. This mechanism proved to be insufficient because the users were not able to estimate the point in time when they were supposed to hit the ball. Two features, which are already included in the original *Cannon Smash* game, solved this problem. The first feature showed the trajectory of the ball that has been returned by the computer opponent. A colored, static ball located at the intersection between the ball's trajectory and one of the target area indicated the moment when the user was supposed hit the ball. The second feature was the ball shadow, which was displayed on the table. It simplified the users' estimation of the location of the ball.

Feedback messages. Feedback messages were displayed directly in the field of view during the first few rallies of the prototype game, which described the basic means of interaction with the system. Since these tips were perceived

as being distracting, they were removed. All instructions have been placed in the audio supplemented *How to Play* section for the game.

BETA VERSION

Improvements of the Beta version over the Alpha version were in response to feedback provided by the teaching assistants of the course and other points for which the design team saw the necessity for modification.

How to Play section: The blinking text instructions were replaced by static ones. The instructions were clarified with respect to forehand and backhand swings. For better visibility, the color of the wireframe avatar representing the user was changed from black to orange. In addition to written explanations, audio instructions were added to reduce the cognitive load for the user. Since the how-to section was improved, it was decided to omit tips about the usage of the system during the game play. The reduced distraction to the user was ranked higher than complimentary usage hints.

Pause figure. Due to an error in the Alpha system, the pause figure was not displayed. In the Beta version, the pause figure was moved to the upper left corner of the screen to minimize distraction of the user while he or she was playing, see Fig. 4. The label was modified to "Raise one arm to PAUSE/MAIN MENU". This was necessary to indicate that the user can access the main menu when pausing the game.

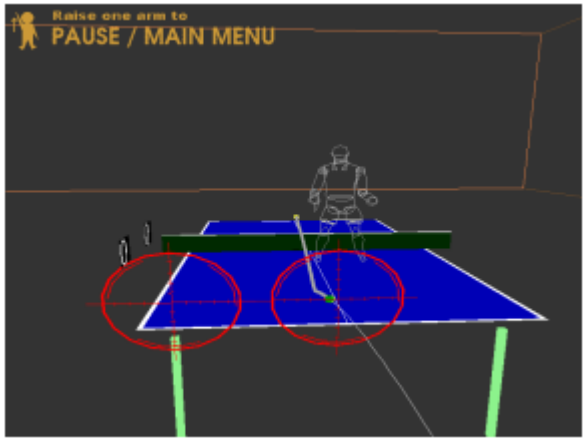

Figure 4 – Screenshot of the Beta System in the game mode

Gestures. The Beta version of the system was able to recognize and process several different gestures. The first was the selection gesture, where the user moves his or her hand vertically and horizontally in order to choose a menu item. The menu items are actually selected by pushing, defined as moving one hand forward toward the screen, while remaining on the option that needs to be selected. In the game mode, the user could move around the environment by moving his or her body. The body position was mapped to the tracking of the head position. Two different movements could hit the ball: the forehand and backhand swing. These gestures tried to emulate the corresponding actual forehand and backhand ping-pong gestures. The pause menu was selected by holding up one arm above the head for a short while. While the gesture recognition worked in principle, it needed to be significantly improved to reduce error rate and increase predictability of the system.

HCI PRINCIPLES INVOLVED

When designing and implementing the AirRacquet system, the design team focused on the principle: 'Do not impose the system on the user, but instead, immerse the user into the system.' Various requirements emerged as a result of this general principle, all pointing towards the direction of simplicity and intuitiveness of the system.

Conceptual Model

The system was intended to reduce the cognitive load of users by providing them with a computer augmented system that remained as close as possible to the physical game of ping-pong. Exploring this area reiterated the need for intuitiveness of the system and furthermore influenced design decisions concerning the feedback provided and the input gestures expected from the users. The idea was to draw upon users previous knowledge of ping-pong an incorporate that into the system.

Feedback

In order to keep the user immersed in the environment, close coupling with the physical game of table tennis was required. Audio and visual cues concerning the score and visual awareness of the opponent are a few design components that point in that direction. On the other hand, there are instances where a computer presence is obvious – yet it still encourages users to use their initial conceptual model of the system being a close replica of the physical world. A good example of this can be derived from the fact that a graphical marker is always made visible during game-play to provide the user with sufficient feedback regarding the virtual locality of their 'virtual person'. This inherently encourages the user to control their body position as they would in a real game of table tennis and swing his or her arm accordingly.

Natural Mappings

By ensuring that the gestures required of the user were as natural as possible, the system tried to impose a minimal cognitive load onto the user. This point is further strengthened by the use of a minimalist menu driven only by the basic and most important settings that could be required by a user.

Help and Documentation

Lastly the importance of a basic *How to Play* mode was stressed. By integrating an animated display with audio information, the design team felt that any discrepancies between the user's perception of the system and the system itself would be dissolved. This was confirmed by encouraging evaluation results regarding this aspect.

FUTURE CONSIDERATIONS

The AirRacquet system is not fully functional. Both time and technology constraints hinder it from being so. However, this initial design effort sets an open stage for future developments in this area. Some of the improvements foreseen by the design team are outlined below.

The AirRacquet system integrated gesture based input along with visual as well as audio feedback to create the human computer interface. This could be further expanded both in terms of input and output of the system. Audio input could perhaps assist the user to communicate with the system, and therefore allow users to tap into the many benefits of multimodal interfaces; for example, saying help when help is required. Feedback received by users could also be extended by providing haptic feedback to physical objects in the environment; for example, a table tennis paddle providing kinesthetic feedback.

Networking functionality could also be added to the current system, thus enabling a shared reality game between geographically separated users. This would facilitate experiments towards bringing multiple users together in a virtual environment – and open an array of possibilities for the AirRacquet system.

Intelligent recognition of individual users could perhaps enrich the experience, by further reducing cognitive load and perhaps providing additional feedback. Giving each user a personal 'virtual look' so that he or she could be recognized by their opponent (in a networked game) would be one of these challenges. The avatar currently used in the AirRacquet system could with advances in image processing, be replaced with a true video representation of the user. Real time audio enhanced with surround sound would certainly provide better immersion of users in the system.

CONCLUSION

The AirRacquet system conceptually began as a racquet ball game for the Shared Reality Environment at the Center for Intelligent Machines at McGill University. Since this system was being designed as a project for the Human Computer Interaction class, the design process brought forward many enlightening observations that drastically changed the project from where it had begun.

This has left the design team with a very important lesson; the system being designed cannot take a correct form before the user and the environment have been studied in detail. This fact can be highlighted from the fact that the final decision to implement a table tennis game was not made until multiple iterations of user evaluations on the initial prototype were made. What may seem like a good idea in a designers mind, cannot even take correct form unless the end user confirms it.

Moreover, the AirRacquet system is a new type of computing environment that is not common to an ordinary user. Therefore, a carefully evaluated, iterative design process is necessary to ensure that the system will conform to the user's conceptual model. The system cannot rely on desktop computing paradigms like user recognition, user adaptation or user dependencies. Instead it must rely on its capability to encourage users to communicate naturally with the system by focusing early on users' ability rather than the computer's functionality.

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