Exploring Mixed Reality Robot Gaming

David Robert
MIT Media Laboratory
20 Ames Street, E15-468, Cambridge, MA
lifeform@media.mit.edu

Ryan Wistort, Jesse Gray, Cynthia Breazeal
MIT Media Laboratory
20 Ames Street, E15-468, Cambridge, MA
{rwistort, jg, cynthiab} @media.mit.edu

ABSTRACT
We describe an interactive, mixed reality (MR) robot gaming platform in which the user controls a tangible, physically embodied character. Miso, an expressive tele-operated robot plays with its virtual peers by passing a graphical object back and forth seamlessly through an integrated physical and virtual environment. Special emphasis is placed on the importance of maintaining perceptual continuity by closely coupling the simulated world's physical laws to our material reality. We present our implemented MR robot gaming environment and describe the design of an interreality portal at the boundary of the physical and virtual realities.

Author Keywords
Robot gaming, Blended Reality, interreality portals

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous. I.2.9. Robotics

General Terms
Design.

INTRODUCTION
Mixed Reality (MR) encompasses and merges both real and virtual worlds to produce new environments where physical and digital objects coexist and interact in real-time. Exploring the critical design parameters of creating a simple robot video game that effectively extends MR and spans the continuum from the fully physical to the fully virtual can yield insights for designers of novel gaming platforms. As blending reality becomes more commonplace for recreational, educational and other endeavors this paper focuses on methods for maintaining cognitive continuity throughout the user interface. If done effectively, the MR boundary window becomes transparent to the user.

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RELATED WORK
Recently, several projects combining Mixed Reality and robots have been described in the literature. In *Physical Interfaces for Tabletop Games* Leitner and Haller describe a collaborative tabletop, mixed-reality game.[5] Their system uses a small robot that can be moved with augmented fiducial markers across the table's surface area. Similarly, Calife et al explore the influence of virtual objects on real objects.[1] Our approach shares many similarities with these projects but extends the game play context onto a larger space on the floor.

Justine Casell's shared reality concept introduced a novel interface in which objects are passed from the human user to a conversational agent in the virtual world.[3] Our work focuses on a similar type of transfer between the physical and digital but places emphasis on the kinetic continuity of objects transiting over the interreality boundary. Gintautas and Hubler present experimental data detailing the transition from an uncorrelated dual reality state to a mixed reality state system by adjusting simulation parameters of the virtual world to match those of the real world.[3] Our project aims to establish a simple superphysics model that models a singular, fused game play context across the interreality boundary.

THE SYSTEM
Input
The user operates a wireless joystick traditionally used as a game controller. Incoming button presses and joystick movements are parsed by a computer running the robot control subsystem. The simple, open loop control system translates the user's input into serial commands output to the robot's motor controllers thus actuating movement. To ensure the robot is untethered and free to move within the play space, it's connected to the simulation framework by an RF serial link facilitated by Xbee radio transceivers. In tandem, a 3D motion capture system localized the robot and updates both the graphics engine and the simulation software with live 3D coordinates using a custom inter-application communication protocol, IRCP (inter-robot-communication-protocol).

Robot
Miso [Fig.1], a small, socially-expressive and tele-operated mobile robot represents the game player's tangible character and engages in cooperative play with its' on-screen counterparts. Using two servo-controller motors, the

robot can translate and rotate simultaneously in response to the user's joystick commands. Miso is a third-generation robot created as an exploration into realizing animated characters embedded in the physical world.

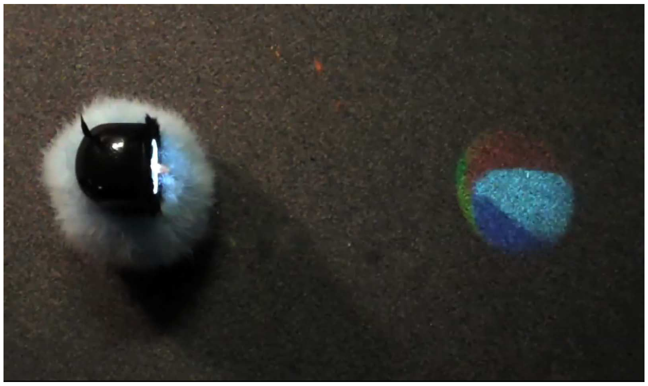

Figure 1. Miso robot, the game player

Hybrid Spaces

A rectangular, physical floor space measuring approximately ten feet long by five feet wide serves as a hybrid tangible augmented reality game play space and human-robot interaction area. An affixed and carefully aligned ceiling mounted projector covers the carpeted floor area with sparse, real-time 3D graphics output from Touch, the integrated graphics engine.[6] At the far end of this space a plasma screen computer monitor measuring approximately five feet wide by three feet tall is floor-mounted perpendicular to the ground. The width of the projected area matches the width of the precisely aligned computer monitor fluidly negotiating the boundary between the physical (floor space) and the virtual (on-screen graphics). Small reflective dots placed on the robot are used in conjunction with the motion capture system to localize and track the robot's movement through the Augmented Reality(AR) physical play space.

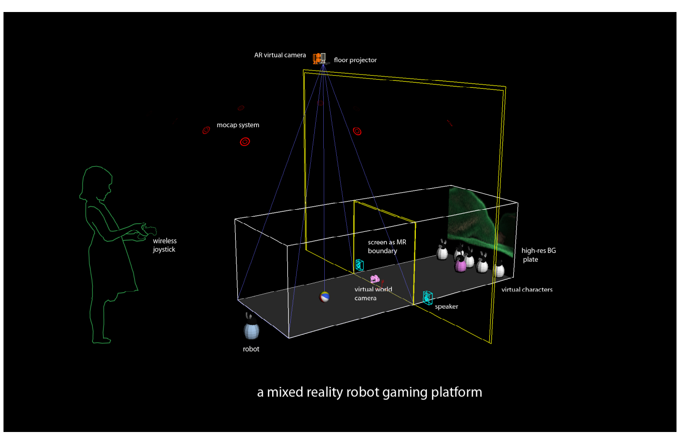

Figure 2. Play context modeled as singular, fused reality

C6 Mixed Reality Simulation Framework

C6, our research group's Java code base provides the framework that computes the mixed reality environment and integrates all subsystems. C6 handles live user input, the robot controller and motion capture sensor data dispatching signals to the designated subsystems. A fused representation of both the physical and virtual spaces is synthesized in the software and mathematically normalized as a single geometric bounding box. A superphysics model is generate in order to coordinate and pair the physics of the real with its simplified virtual counterpart.[3] This approach minimizes perceptual discontinuities as graphic objects transit between realities. C6 communicates with Touch over IRCP providing the graphics engine with user-input events and live robot location coordinates informed by real-time, filtered motion capture data. Additionally, C6 preview renders debugging information to assist the mixed reality robot game architects in calibrating the various systems involved.

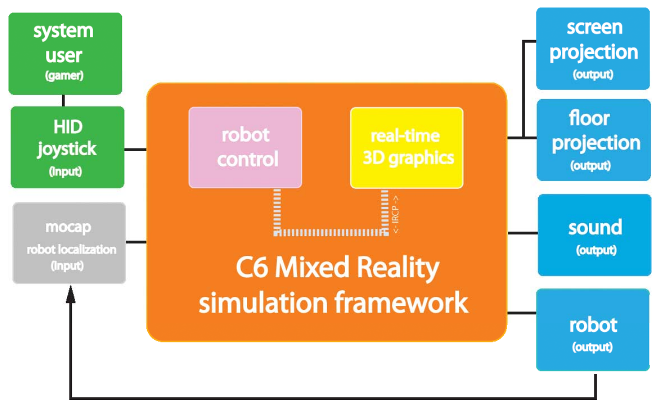

Figure 3. System framework

Graphics and Content

Linked to the C6 simulation framework via a C++ authored custom IRCP to Touch interoperability executable, the graphics engine simultaneously renders two live 1280 by 720p HD streams connected to the floor-mounted screen and ceiling-mounted projector. Rendering is done on the GPU and optimized for real-user and robot interaction.

The floor-mounted screen placed at the far end of the physical play space depicts a nocturnal scene populated by several procedurally animated characters playing with a ball that is passed through the screen. These characters' respective geometries are based on the physical robot's virtual 3D model. Additionally, the virtual characters' behavior and movements mimic (and are constrained to) the robot's own expressive, signature squash and stretch animations. The virtual characters' animations are parametrically varied per instance in both duration and sequence resulting in a more natural and unpredictable feel.

The characters are set in a grassy, fantasy environment that appears to have depth and detail beyond the capabilities of current real-time rendering. This is achieved by compositing the characters on top of a pre-rendered background plate. Created through a lengthy pre-production process, the background (see Figure 2) is the result of a 420 frame high-resolution simulation of 2 million blades of grass grown on various 3D surfaces and blown by artificial wind. The lighting in the background scene matches both the lighting of the characters as well as the ambient light conditions of the physical play space the user and robot are interacting in. This technique extends the notion of the aforementioned superphysics system and underlines the importance of matching the rendered world's lighting to the real world's lighting as coherently as possible within a certain tolerance. By smartly combining high-resolution background assets with the real-time, interactive characters in the foreground we were able to render a compelling and visually rich virtual world scene.

The camera is locked down and positioned to view the world from the diminutive perspective of the two-foot tall physical robot. Consequently, the virtual scene (when rendered from this angle) correctly lines up the ground plane of the virtual world with the ground plane of the real world. The virtual/real ground plane alignment plays an integral role in establishing a transparent, interreality boundary giving the illusion that the floor is a window. It effectively extends the physical play space on to the screen. In turn, the on-screen virtual world's ground is thus extended off the screen into material reality.

To take advantage of this affordance the ceiling-mounted projector is oriented downwards at the floor play space and projects graphic assets as they travel on and off the screen. For our game, Touch renders a 3D ball from a top view through a camera matched to the real world position of the projector. The resulting projection augments physical reality with a virtual ball that appears to travel along the length of the physical play space.

Figure 4. High-resolution background plate

Sound

Two mid-sized speakers are hidden out of view and placed behind the screen at the far end of the physical play space. Field recordings of a quiet summer night in the country provide some ambiance and create a sense of space. Game event sound effects are triggered by default. Additionally, an optional sound effect can be toggled on to highlight the moment a graphics asset moves off the screen into the augmented reality in the physical play space. The robot's motors also produce sound as long as they're activated.

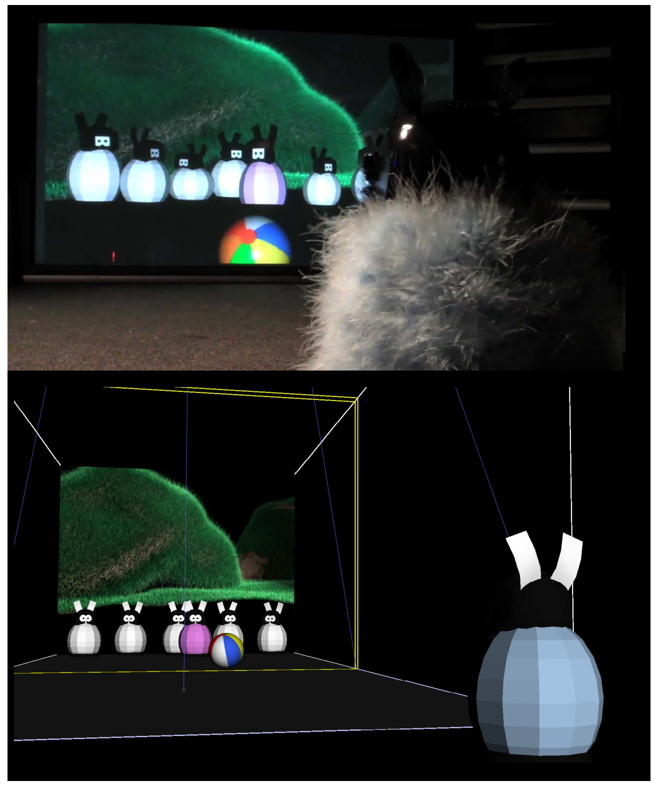

Figure 5. User view(top), Simulation view(bottom)

PLAYING THE GAME

The ball is the focus of the cooperative game play. The virtual characters invite the user to play a simple, Pong-like game. The robot, controlled by the player, orients itself to face the virtual characters. With the robot positioned at the near end of the physical play space, the session begins with the virtual ball projected in front of the robot. Once the initial kick-off is triggered by C6 the ball begins to move away from the robot towards the screen and the game begins. As the ball crosses the interreality boundary it appears in the virtual world and the on-screen characters always kick it back out towards the physical space and the robot. The user then proceeds to use the joystick to drive the robot to intercept the ball, now projected onto the physical play space. If the robot gamer successfully returns the ball the game continues. Otherwise, the game starts anew. The game's difficulty level is adjusted through the expansion or contraction of the margin of error by scaling the definition of the ball-robot intersection in the C6 simulation framework. Our goal as game designers is to enable the user to project herself into the robot's perceptual frame of reference. The mixed reality robot game would thus become akin to a first-person video game with the player embodied in the robot and embedded in the blended reality.

DISCUSSION

The co-presence of Miso, the physically embodied robot character, with the game's user creates a unique tangible interface and adds a point of access to the fantasy world.

An important consideration in designing a fluid interaction that maintains the user's perceptual continuity throughout the game's duration is the creation of a superphysics that coherently models the mixed reality environment. Although no formal evaluation was conducted, altering the gravity and speed parameters of the virtual model seemed to fracture the continuity across the MR boundary as the ball inexplicably sped up once on-screen.

FUTURE WORK

Currently, our system employs an AR projection technique to display a graphical asset in both spaces. We would like to explore methods for designing characters that inhabit both real and virtual spaces. To this effect, we plan to create a "robot-hutch", a physical portal device placed at the boundary of the virtual and material realities that aids in transporting the character on and off the screen. As the character enters the physical hutch, its presence is detected and the door shuts behind it and reopens in the virtual world representation of the portal to continue its adventures on screen. In order to preserve the illusion of life during the character's on-screen time, the physical robot should be hidden from view instead of remaining motionless at the boundary line in material reality.

CONCLUSION

Although still in its initial, exploratory phase mixed reality robot gaming holds a tremendous amount of potential for new ways to entertain, learn and communicate. To build these new gaming platforms we should make sure systems designed can fluidly extend virtual and eventually real objects on and off the screen. Beyond a simple game feature, the importance of blending the realities together augments the play context and may aid in bringing the game's fantasy world off the screen and our world on to it.

ACKNOWLEDGMENTS

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