

Tangible Interfaces for Real-Time 3D Virtual Environments

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ABSTRACT

Emergent game formats, such as machinima, that use game worlds as expressive 3D performance spaces have new expressive powers with an increase of the quality of their underlying graphic and animation systems. Nevertheless, they still lack intuitive control mechanisms. Set direction and acting are limited by tools that were designed to create and play video games rather than produce expressive performance pieces. These tools do a poor job of capturing the performative expression that characterizes more mature media such as film. Tangible interfaces can help open up the game systems for more intuitive character control needed for a greater level of expression in the digital real-time world.

The TUI3D project (Tangible User Interfaces for Real-Time 3D) addresses production and performative challenges involved in creating machinima through the development of tangible interfaces for controlling 3D virtual actors and environments in real-time. In this paper, we present the design and implementation of a tangible puppet prototype for virtual character control in the Unreal game engine and discuss initial user feedback.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces---input devices and strategies, interaction styles; I.3.6 [Computer Graphics]: Methodology and Techniques---Interaction techniques; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism---Animation; I.3.8 [Computer Graphics]: Applications; J.5 [Arts and Humanities]: Performing Arts; K.8.0 [Personal Computing]: General---games.

General Terms

Design, Human Factors.

Keywords

Tangible interface, puppetry, 3D space, virtual character, game engine, machinima, video games.

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1. INTRODUCTION

Emergent game forms and game modifications have become a wide-spread cultural development in digital media. Player-created content and modifications of game systems emerge as important factors for new and innovative game designs and invigorate the gameplay options of existing titles. This importance is reflected in a growing attention to emergent game forms in games research [10, 23].

Since the earliest days of commercial gaming, the player community has produced cheats, hacks, game modifications and developed unexpected play behavior. In one way or the other, these acts allowed players to perform actions in the game world that designers did not foresee. They are ultimately empowering the player and open up the game for unexpected performances. In order to access these actions, most emergent game forms have grown from a modification of the software. Laudable as these software-driven game modifications are, they are generally unable to address the levels of the hardware and the interface. However, it is on this level that human expression is captured from the player and mapped onto the game performance. In order to improve the range of expressive performances, we thus have to investigate new interfaces and connect them to the underlying game engines.

Machinima is a premier form of emergent play that heavily relies on these expressive qualities. It has evolved from a geek-culture obsession to an accepted cinematic technique presented at established film festivals, such as the *Sundance Film Festival* in 2005. Machinima is an animation technique that uses interactive real-time computer-generated imagery (CGI). It usually uses games as underlying render engines and interactive virtual production studios. Thus, machinima has been defined as 'animated filmmaking within a real-time virtual 3D environment' [14]. Others see it as 'part theatre, part film, part videogame' [22]. One definition is game-driven, the other is performance-driven but both imply a meaningful mapping of player performance onto a virtual character. While a range of tools have been developed to improve player access to the game engine, the question of the interface remains largely open in the machinima community.

The machinima community has been largely driven by game enthusiasts. Thus, any hardware-modifications need to tie into the commercial game base used by these player-artists. They have to be modular because the update cycle of these engines is fast. And they have to be accessible and reproducible because the machinima culture is a subculture that lives in a legal grey zone, and no machinima producer can afford expensive hardware or a high-tech solution. Instead, any interface modifications have to

seamlessly plug into the existing technology. At the same time, they must be intuitive and allow for complex new expressions.

This paper presents the TUI3D (Tangible User Interfaces for Real-Time 3D) research project, which seeks to address some of the production and performative challenges involved in creating machinima through the development of tangible interfaces for real-time control of 3D virtual characters and environments. We begin by looking at the background and related research in the areas of virtual spaces and tangible interfaces. Next, we provide an overview of our system and describe the hardware and software implementation of our initial tangible puppet prototype. Finally, we discuss user feedback and conclude with a look at future directions for the project. Our system primarily targets machinima production but it presents a control scheme that could also be applied to innovative game designs as well as other entertainment formats. Innovation in game interfaces has been a current driving force in the industry (see the EyeToy, the Dancemat, and the Wii-mote) and a puppeteering interface offers additional width to this development.

2. BACKGROUND

The performative aspect of video game players as they engage with the game is a phenomenon largely accepted in different approaches towards games research [1, 12, 17, 32]. In a 3D game world, players usually learn to master the controls of an avatar in order to explore the virtual stage. Efficient control is one factor for the mastering of the game world itself. That is why outstanding game players often have customized control schemes and optimized hardware. These controls are optimized towards the most successful game performance, which typically involves beating other players in the game and reaching the goal in the fastest possible way. They are not geared towards expressive virtual theatre or performances.

Machinima emerged from the recordings of these kinds of player feats. Players, especially of the *Quake* [20] community, demonstrated their abilities and recorded them for later analysis and improvement, much like sports coaches do with athletes. The performance was judged in relation to the game: the fastest, most dominating, tactically most advanced player would shine through, winning the game. This remained the case until 1996, when players of the Quake clan called "The Rangers" released *Diary of a Camper*, the first machinima that used staged action. These performers did not play the game to win, but rather to express and situate a story. From a gameplay documenting form, machinima expanded into an expressive animation technique that used the game engine as a virtual production studio. Instead of mastering the game, players had to master the expression provided by the game engine.

While the intentions changed, the technology remained the same, and machinima artists henceforth had to deal with the restriction of game interfaces that were originally optimized for effective game performance and not for expressive virtual theater performances. Although many game engines included editors that allowed players to add their own content including animations, the animation control as such remained largely opaque and saw little improvement until recently. By now, players have gained more access to the character animation, especially with the release of the Source SDK of *Half-Life 2* [5] that includes the FacePoser tool. But even FacePoser lacks new interface options and relies on

a linear editor much like the professional animation packages that are used to generate these animations upfront.

Other modern game engines like *The Sims 2* [25] and *The Movies* [16] specifically include machinima techniques in their design, but have opted to completely exclude the player from the character animation and rely exclusively on pre-fabricated animation controlled by the game. The expression of the virtual character stems from pre-canned animations and cannot be changed directly by the player.

This growing gap between better visual expression and an interface that remains on the level of the original *Quake* during live performances has led to the following paradox: after ten years of development, machinima artists still have difficulties to fully utilize the game engine's possibilities. Many have to code their own engine modifications, or even create their own engines in order to be able to implement their own expressive freedom.

Like "The Rangers," the "ILL Clan" evolved from a group of Quake players into machinima producers. Instead of using pre-fabricated animations, they perform their machinima pieces live as virtual theater productions realized in a game engine. Like many other modern machinima productions, their pieces, such as the *Tra5hTalk* series (2006-present), rely on expressive characters and fast improvised performance that is very difficult to achieve with standard interfaces. To achieve this, they have developed their own unique setup of hardware and software. Likewise, virtual performer Jon Lippincott's explorations in virtual worlds are hand-coded to allow them to be performed with the necessary control of camera and animation.

Similar to other emergent game cultures such as the art of modding (i.e. game modifications), machinima is mainly software-driven. Key developments have stemmed directly from the constant battle of the machinima artist with the game engine at work, and they have rarely experimented with new interfaces.

3. VIRTUAL PUPPETRY MEETS TANGIBLE INTERFACES

The human body is a powerful expressive machine. In physical performance such as live theater, the performers move their bodies around the stage, their movements enacting a narrative in real time. Not only can humans perform many kinds of physical actions and convey a broad range of emotions, but they can also switch seamlessly from one action or expression to the next. This extends naturally to the art of puppeteering, where the actions of human puppeteers are mapped onto physical puppets and integrated into an unfolding narrative performance in real time. Puppeteering also opens up a space for new forms of expressive communication, since puppets can be made to perform actions that would be unachievable with the human body alone.

In cinematic storytelling on the other hand, the actors express themselves in real time in front of a camera, but the effects of their physical actions and performances are not immediately seen in their final narrative form. The editing stage imposes a delay on the narrative experience, since the bits of recorded footage have to be cut and assembled together into a final piece that can be screened for an audience. Nevertheless, as the actors perform their scenes, they exist inside the narrative world, literally taking on the roles of the fictional characters and acting them out in real time

with their bodies. Expression grows from the assembly of actor performance in the pro-filmic space, mise-en-scene, camera, editing, and post-production.

Machinima incorporates elements of both live performance and cinematic production. Machinima artists control the characters in a 3D virtual world in real-time, much like puppeteers control their physical puppets in the real world, generally following some kind of narrative script. Sequences captured from these digital performances by virtual cameras are later edited together to create a final machinima piece. While the tools for editing and assembling the video sequences can be similar to those used in regular digital moviemaking, the 3D interactive performance spaces in which machinima works are created lack intuitive control mechanisms. The tools currently used by virtual performers and machinima creators were designed to play video games, and fail to capture the performative expression that characterizes the more mature medium of film or theatre. We believe that tangible interfaces can be used to help direct the emotional and dramatic energies of digital filmmakers toward more rewarding results.

The research area of tangible interfaces seeks to better bridge the physical and digital worlds by creating physical interfaces that act as both controls and representations for digital information [7, 30]. By coupling digital information with persistent physical embodiments (either new kinds of objects, or digitally enhanced existing objects or surfaces), these interfaces can more easily fit into the way we engage with our everyday physical environment using our body and hands than traditional computer input devices such as mice and keyboards. Given their physical nature, tangible user interfaces are often suited for collaborative use, and for applications designed for children. For example, the area of digitally enhanced learning toys for children has gained prominence in recent years, such as plush toys or building blocks that can be used for storytelling or as physical/digital construction kits and simulation systems. Examples include the ActiMates Barney doll from Microsoft [26], and the work on Programmable Bricks from the MIT Media Lab [21]. Our work on puppet interfaces for 3D virtual environments builds on some of this research, but expands beyond the scope of children's interactions.



Figure 1. Belkin Nostromo Speedpad N52 controller used by the ILL Clan group for live machinima performances.

To date, existing machinima groups have used standard off-the-shelf PC input devices for character control during their performances, such as mice, keyboards, gamepads and joysticks. The ILL Clan has also used non-standard devices, such as

Belkin's Nostromo Speedpad N52, which can allow a greater level of customized control during live performances (see Figure 1). Nevertheless, devices like this do not support intuitive mappings between a performer's physical actions and their effects in the virtual space, and as such can be difficult to learn and use. The field of tangible interface design can offer a natural solution to this problem, through interfaces that provide intuitive physical controls and representations of the interactive elements within the virtual space. The following section looks at some related work in new interfaces for digital puppetry and virtual character control.

4. RELATED WORK

Since the early 90s, researchers have recognized that one of the core problems of 3D character manipulation stems from the fact that most input devices provide only two degrees of freedom. Ideally, the control space of the input device should match the perceptual space of the interaction task [8]. For this reason, a number of production and research endeavors have centered on the creation of new interfaces for control in 3D virtual spaces. These approaches have generally been costly and have not focused on the integration with existing commercial gaming platforms for real-time character performance or machinima.

Over the past decades, production companies have increasingly turned to various forms of puppetry and body or motion tracking in order to inject life into 3D character animation. These approaches can more easily translate the nuances of natural life-like motion to 3D animated characters, greatly increasing their expressive potential. The Character Shop's trademark Waldo devices are telemetric input devices for controlling puppets and animatronics that are designed to fit a puppeteer or performer's body [3]. They allow puppeteers or performers to control multiple axes of movement on a virtual character at once. For example, many of Jim Henson's Muppets are Waldo-controlled. In the late 1980s, Pacific Data Images developed a real-time computer graphic puppet named "Waldo C. Graphic" for the TV show called *The Jim Henson Hour*. This digital puppet's motion could be performed in real-time together with conventional puppets using a simple armature that controlled its position, orientation and jaw movements [31]. During the performance, the puppeteer watched a simplified graphical representation of the character superimposed over live video of the physical puppets. The movement data captured during this performance with the armature was later cleaned and applied to a more complex representation of the character in a non real-time mode. A similar approach is used in the "Elmo's World" segment at the end of *Sesame Street* episodes, in which traditional Muppets and a virtual set of animated characters consisting of animated furniture (chairs, tables, doors, etc.) are performed together in real-time. The necessity to clean sensor data during post processing is typical for most motion capture and puppetry systems, and is not practical for real-time machinima performance. Furthermore, the price of these controllers far exceeds the budget of every machinima production house.

Other examples of digital animated character control in the production realm include the Dinosaur Input Device (DID) digital stop-motion armature created by Stan Winston Studio and Industrial Light and Magic for the movie *Jurassic Park* (1993) [24]. In this case, a miniature dinosaur armature was instrumented with encoders at key joints. Stop-motion animators could

manipulate the model while keyframe data was sent to the animation system. Also, the French video and computer graphics production company Videosystem developed a real-time computer animation system that used a variety of input devices, such as DataGloves, MIDI drum pedals, joysticks, and Polhemus trackers to control an animated character called "Mat the Ghost" [29]. In this case, the character was chroma-keyed with previously-shot footage of live actors and there was no post-rendering involved.

In the 1990s, glove-based interactions became popular for certain digital applications, and were explored for both computer animation and video games. For example, the DataGlove system developed by VPL Research was used with virtual reality environments. At the Massachusetts Institute of Technology, Dave Sturman created an expressive finger-walking puppet that was controlled by a DataGlove, and used it to evaluate his "whole-hand" input method for controlling the walking character in comparison with conventional input devices [28]. The Mattel toy company developed a low-cost glove called the Power Glove as a controller for Nintendo video games. Today, the recently released Nintendo Wii console includes a new kind of input device for video games, in the form of the Wii Remote, a wireless controller that can be used as a handheld pointing device, and can also detect motion and rotation in three dimensions.

Other notable research efforts that have centered on new interfaces for character control and animation include the Monkey Input Device, an 18" tall monkey skeleton that was equipped with sensors at its joints in order to provide 32 degrees of freedom from head to toe for real-time character manipulation [4]. The work on sympathetic interfaces from MIT used a plush toy to manipulate and control an interactive story character in a 3D virtual world [9]. More recently, the predecessor to the TUI3D project used a paper hand puppet tracked by computer vision to control a character in the Unreal game engine and was used for machinima creation [6]. As a final example, researchers at Oregon State University have demonstrated a tabletop tangible interface to provide a high level of animated character control in specifying the movements of many characters during the simulation of moves in a sports game [15].

5. TUI3D PROJECT

The TUI3D project is a joint research effort between the Synaesthetic Media Lab, Experimental Games Lab and the Digital World and Image Group at Georgia Tech that seeks to address the production and performative challenges of machinima creation and real-time interaction within commercial game environments. The goal of the project is to design a suite of tangible interface tools that can be used to control three core aspects of 3D virtual space: **character**, **camera** and the **space** itself. In order to be useful, these controls need to be easily connected to a commercial game engine, in our case Unreal Tournament 2004.

In the first phase of the project, we chose to focus on the character aspect of the real-time 3D environments. Subtle forms of character control are traditionally absent in video games and machinima, but the technology increasingly provides better access to animation systems as well as better 3D character models. In this way, virtual characters can embody a range of expressions and emotions, from spatial movements, to complicated body/skeleton movements or animations, all the way to changing

facial expressions. Creating a controller that can allow performers to capture this range of expression is a challenging task. At the moment we focus on the body movement of a single character, however we envision extending our interface to support different levels of control.

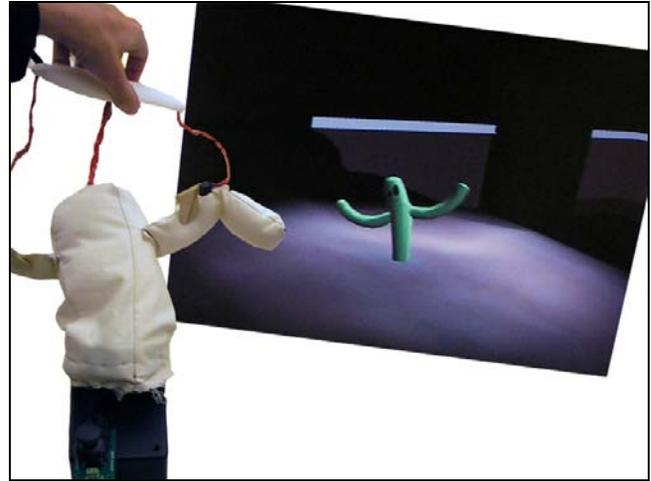


Figure 2. A tangible puppet equipped with sensors provides intuitive real-time control for the virtual Cactus Jack character in the Unreal game engine.

Our first prototype takes the form of a cactus-shaped marionette that is used to control a virtual character named Cactus Jack (see Figure 2). Marionettes are a form of puppet that is indirectly controlled by strings attached to a control frame (e.g. a paddle or cross) above. We settled on the marionette form after an inspirational excursion to the Center for Puppetry Arts [2] in the early stages of the project, which allowed us to study a number of different forms of puppetry. For example, hand puppets are used like a glove on the operator's hand, and are relevant to the interactive glove controllers that gained popularity in the 80s and 90s [27]. With glove control, the expressions and actions of the physical puppet or virtual character are limited by the shape and affordances of the human hand. Rod puppets are similar to marionettes, but instead of strings they are operated by rigid rods typically from below. The flexible nature of the strings used for marionettes allows easy and fluid control of the puppet's movements, which maps well to a real-time 3D space. Marionettes also support multi-handed or even multi-person interactions, since multiple hands or people can help control the different strings at once.

In the following subsections, we provide an overview of our marionette system for controlling characters in a virtual space that runs in the Unreal Tournament 2004 game engine. We describe the hardware and software implementation, and also discuss the design of the 3D virtual space and content - a child's bedroom where the different toys (such as the Cactus Jack doll) provide a cast of characters for unfolding performances.

5.1 System Overview

The theme for the first implementation of the TUI3D system drew inspiration from classic children's adventure radio shows of the "golden age" of radio, such as *The Cinnamon Bear* or *Tom Mix*.

Accordingly, the virtual stage is a reproduction of a children's room in the London of 1940. The girl who used to live here has been evacuated to the safer countryside to escape German bombs. Alone in the dark: her toys remain, waiting for her return. These toys and other usually inanimate objects were selected as the main protagonists for the project. With the help of the TUI3D system we bring these toys to life, and ultimately use the room as a virtual stage. The first puppet fully implemented is a toy cactus that springs to life, his movements and facial expressions controlled by the player.

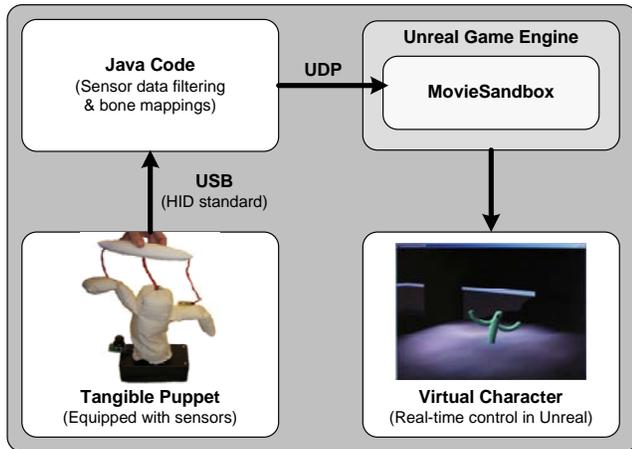


Figure 3. TUI3D system overview, from tangible puppet to virtual character in the Unreal game engine.

The TUI3D system uses a tangible cactus-shaped puppet equipped with sensors to control this virtual cactus character in real-time. The diagram in Figure 3 provides an overview of the different parts of the system, which are described in greater detail in the following subsections. Data from the puppet sensors is transmitted to a Java applet running on a PC via the HID (Human Interface Device) standard. The applet cleans and interprets the data, and sends it via the UDP protocol to the MovieSandbox tools [11] running within the Unreal game engine. This is processed in real-time, and the virtual character can be seen moving on screen as users manipulate the physical puppet.

5.2 Hardware Implementation

The tangible puppet is sewn from cloth and filled with a soft foam material to give it the feeling of a plush toy. The arms and head of the puppet are attached to a plastic control paddle by nylon strings. By moving the paddle, the user can control the body movement of the puppet (tilting side-to-side and back-to-front), and raise or lower its arms. A greater range of independent arm movement is gained if a second hand is used to pull directly on the strings (see Figure 4). The puppet stands on a rigid base which houses a hardware I/O board that communicates sensor data to a standard consumer-level PC that runs Unreal.

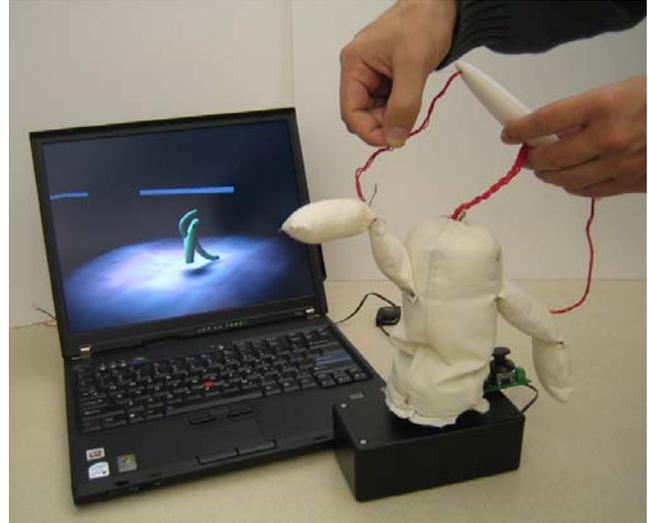


Figure 4. Users can pull directly on the marionette strings with a second hand to gain a greater range of independent arm movement beyond the paddle control.

The puppet is equipped with three 2-axis accelerometers, one mounted on each arm and one inside the paddle at its center. This sensor configuration allows us to get the up and down movement of the arms, as well as the side-to-side and front-to-back tilt of the puppet with respect to its base. We are planning to incorporate additional sensors in order to detect other axes of movement, such as the rotation of the puppet's body. A joystick mounted on the puppet's base provides another means of control for the virtual character, and is currently mapped to Cactus Jack's facial expressions (done through texture swapping). We have also implemented the ability to move the puppet around the virtual space by jerking the paddle in forward, backward or sideways directions.

The puppet uses the Create USB Interface (CUI) board [18] to communicate data from the sensors to the PC. The CUI board is configured to send data via USB as a standard Human Interface Device. The puppet can thus be recognized by the PC as a Game Controller and can be calibrated with the standard joystick calibration system, for example through the Windows Control Panel. The advantage of this approach is that the puppet interface can easily be used with a variety of different platforms and also with different commercial game engines. In this way, the tangible puppet can easily work together with other standard game controllers or customized devices, and is simply a modular part of a large set of interfaces and controllers.

Figure 5 shows the anatomy of the tangible puppet interface. A big appeal of our tangible puppet design is its low cost of around \$100 in parts and materials. We are also publishing our puppet-making tutorials on the internet so that others in the machinima community will be able to try it out for themselves.

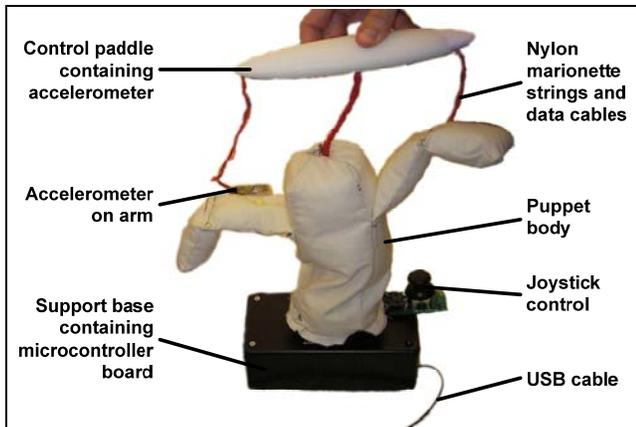


Figure 5. The physical design of the cactus marionette includes the paddle, body and base. Sensors are in the arms and paddle, and the hardware I/O board is inside the base.

5.3 Software Implementation

A Java applet written in Processing [18] is used to clean and interpret the data received from the puppet via USB. Raw sensor data is first sent through a filter to produce smoother results, and then sent to the Unreal game engine via the UDP protocol. Data packets sent from Processing are read by a customized version of the Unreal modification MovieSandbox by Friedrich Kirschner [11].

MovieSandbox is a form of modification, a special gametype, for Epic's Unreal Tournament 2004 game engine. It allows for enhanced scripting and editing of content within the game engine. Although it was originally intended for better control of scene-scripting in Unreal to improve the production process of pre-staged machinima pieces, it can easily be further modified for experiments like TUI3D that focus on live performances. The tool is available as a free download.

Keyframes for the poses of the main cactus puppet were set in Maya and exported as single frame animations to Unreal. These poses defined the furthest points of possible character animation available to the virtual puppet. TUI3D blends between these poses with the marionette controller as the tangible interface. We do not change the underlying basic animation principles of the Unreal engine, which depends on animation blending between pre-defined key poses. Instead, we built on this existing technique but modify its blending as we incorporate the data from the physical puppet interface. This concept is at work in the commercial engine in its head animation control. TUI3D extends this higher granularity of animation control to the whole character. While any animation except the head movements in Unreal is triggered and can only be blended but not interrupted, TUI3D allows for smooth control of all intermediate states, reversal of the blending, and stop of the animation. TUI3D thus uses existing game software but modifies it to considerably raise the expressive range.

5.4 3D Content Design

The generation and implementation of the 3D world, characters, and animations mirrors typical machinima production practices

that combine different tools to generate additional content when necessary.

The design of the virtual stage references classic children's book styles, such as *Beatrix Potter* and *Brambly Hedge*. The color palette and objects created to equip the virtual child's room were inspired by art from children's literature and featured a range of furniture items and virtual toys. After various tests of different textures, we used mainly handcrafted textures. All objects as well as the main stage were modeled and textured in Maya and then exported to the Unreal engine. In Unreal, textures had to be reassigned, and objects were re-scaled and arranged on the virtual stage using the UnrealEd editor.

Animations were set as keyframes in Maya and exported as single frame animations to Unreal to provide the necessary poses for the animation blending in TUI3D. Facial animations are currently implemented as swapping textures that are mapped onto the cactus' face and use pre-fabricated images to flip between different facial emotions.

The lighting was set in the Unreal editor and baked into the textures. Virtual cameras remain under the direct control of the player and can be arranged freely in the MovieSandbox Unreal modification. The same mod provides elaborate editing and event scripting tailored to the needs of a machinima production. In that way TUI3D combines the direct puppet control for detailed character animation with the free camera that is typical for many machinima productions. Both are controlled and rendered in real-time.

6. USER FEEDBACK AND DISCUSSION

On various occasions, we have presented TUI3D to a large number of game players, students, machinima artists, as well as CGI professionals and academics. This has included several large scale open houses and demo sessions in our laboratory, as well as presentations at a film festival and industry events.

After initial problems with the accelerometers, the prototype has proven its stability and durability throughout. The feedback has been very positive, and some users have already asked for a higher level of control. We interpret this as a sign of intuitive operation of the current marionette interface. There were no difficulties to understand the underlying principle and the marionette was widely accepted as an expressive and accessible interface. Questions were raised as to why we opted for a marionette interface instead of some form of motion capture, which again points to the need for more direct and wider control schemes.

In contrast to motion capture, where the actual movements of a human performer herself are mapped onto the virtual characters, tangible puppets allow a greater level of abstraction, where a single performer can control multiple different characters through the same or different interfaces, either in sequence or at once. During our visit to the Center for Puppetry Arts, we observed a single professional puppeteer staging a puppet show, and operating multiple different puppets, switching between them quickly and seamlessly, often controlling more than one at a time. Our goal is to achieve this form of fluid control over the characters in a virtual space, which would be difficult to do with sensors affixed to the performer's body. Furthermore, motion capture systems are typically costly and complicated to set up and

calibrate, which makes them unfeasible for the emergent games and machinima community.

Although the TUI3D current prototype is still limited, the level of control provided has already raised interest in professional machinima producers. Our presentation of the project at the 2006 *Machinima Film Festival* (New York, NY, November 4-5, 2006) was met with great interest. Representatives of a prominent game company have already offered assistance with the implementation of the interface into their own animation system.



Figure 6. User controlling the cactus jack virtual character.

Additionally, we have presented the project to professional CGI artists, television directors, and producers and we are currently organizing tests of the interface as a tool for CGI animation together with the Atlanta campus of the Savannah College of Art and Design. In a school context, TUI3D is welcomed as a simple yet intuitive and innovative animation tool for computer animators and as a new input option for game designers. Television executives were interested in using our combination of real-time game technology and tangible interfaces in areas such as pre-visualization. Real-time pre-visualization with the help of game engines has been applied in professional productions like Spielberg's *A.I.* (2001) [13] and high-end solutions for a real-time camera control in special effect scenes has been used, for example, in Jackson's *Lord of the Rings – Fellowship of the Ring* (2002). Combining the two in a low-cost application using 3D game engines and new interfaces like the marionette was lauded as cost effective and helpful for the practical production.

Among the open issues is the need for more control over spatial movement and directional control. For example, in the current form, the virtual puppet has no legs, nor the necessary control points to access such animations. He also lacks detailed facial expressions and an elaborate bone structure for his face.

7. CONCLUSIONS AND FUTURE WORK

Based on the implementation of our first virtual game marionette we are continuing our work on refining the interface. To begin with, we are already working to include additional accelerometers to capture more degrees of freedom in the tangible puppet's movements. Future work will also include experimentation with different kinds of sensors, such as gyrometers, bend sensors, and potentially some form of position tracking technology.

On the software side, we aim to improve control by including different animation passes that would add a finer granularity and more complex character control. In such a system, the interface would be more abstracted, controlling different skeleton sections at different passes, which would be added to each other in real-time to show the individual changes. We can assign the control to any bone in the game character's skeleton and will use this to experiment with different setups to provide a finer animation control in multiple passes. We would also like to use the same tangible interface to take control of completely different skeletons and skeleton structures in the virtual world. In this way, a puppeteer could easily switch between different characters on the virtual set in real-time during a performance.

Finally, we recognize that real-time performance in virtual worlds depends on more than character control, and we intend to expand our approach to other key factors of the performance. This includes a new paradigm for a stage director for virtual sets as well as for direct camera control. The ultimate goal is to increase artistic practice in machinima and related emergent game forms by opening up more expressive options through accessible, affordable and intuitive interfaces. The character control is certainly key to this but needs support from all the other elements in the performance itself.

TUI3D has proved that more intuitive and expressive animation control is in the reach of a gaming community that has long accepted the idea of games as an expressive medium, and is in dire need for accessible and feasible interfaces to better control of these expressions.

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