Helicopter Aircrew Training Using Fused Reality

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ABSTRACT

This paper describes a novel Mixed Reality [1] technique for robust, real-time chromakey processing for training applications using software and off-the-shelf video hardware. This technique has been coined and patented by the author as "Fused Reality." Until now chromakeying has been conducted using dedicated hardware, imposing substantial restrictions on the visual environments that will support chromakey. Variations on the traditional chromakey setup, such as using retroreflective screens and light-emitting cameras, can overcome some of the technique's original drawbacks (such as lighting difficulties), but they can introduce new problems as well (i.e., a user's hand can obstructing the light projected from the head-mounted source can create an ill-defined silhouette). The novel chromakey method introduced in this paper is applied to training helicopter aircrew personnel using a prototype simulator, the Prototype Aircrew Virtual Environment Training (PAVET) System. The ultimate goal of the PAVET will be to provide training to Navy aircrewmen in all operational aspects of the MH-60S, including aerial gunnery, search and rescue, and vertical replenishment. A key requirement for these types of tasks is for trainees to see and manipulate physical objects (e.g., a jammed gun) at close range while viewing an interactive flight and shipboard environment. In order to satisfy space and cost constraints, some physical objects that the aircrewmen physically interact with (such as a rescue litter) must be capable of being sent out into the virtual environment and later retrieved. Fused Reality accomplishes this critical feature through contraction and expansion of specific real-world objects as they move away and toward the trainee. Fused Reality's adaptive color recognition allows for realistic set lighting, colors, and user movement and positioning. It also enables "lumakey" – preserving only pixels that are above a brightness threshold and rendering all others transparent, allowing for extremely compact and portable training devices. Examples of Fused Reality such as these are demonstrated and discussed.

INTRODUCTION

The effectiveness and safety of complex, multi-role helicopter platforms such as the Pave Hawk and Seahawk require that the cabin crew interact seamlessly with the flight crew and a dynamic external environment. Due to physical constraints and fidelity limitations, however, current simulation designs fail to accommodate a wide range of training. Fused Reality (coined by the author) is a Mixed Reality approach that employs three proven technologies – live video capture, real-time video editing, and virtual environment simulation – offering a quantum jump in training realism and capability. Video from the trainee's perspective is sent to a processor that preserves near-space (cabin environment) pixels and makes transparent the far-space (out-the-cabin) pixels using blue screen imaging techniques. This bitmap is overlaid on a virtual environment, and sent

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to the trainee's helmet mounted display. Thus the user directly views the physical cabin environment, while the simulated outside world serves as a backdrop.

Fused Reality is a technique conceived at STI and prototyped in response to the training requirements called for by the Navy's Prototype Aircrew Virtual Environment Trainer (PAVET). As part of a Navy Phase II SBIR, STI is integrating Fused Reality with PAVET in partnership with Binghamton Simulator Company, which is providing the physical environment (cabin, gun, etc.). Fused Reality should rapidly find application in numerous other sectors, such as the medical, commercial aviation, entertainment, etc. The technique is similar in certain respects to the blue-screening technique that Hollywood is using (employed initially by Hitchcock in *Vertigo*). However, Hollywood processes its blue-screening off-line – STI is conducting it in real-time – and in contrast with blue screening the backdrop required by Fused Reality allows large variations in color aberrations and lighting intensity.

Figure 1 is a basic representation of Fused Reality showing two bitmap layers that are stacked on top of each other. The first layer is video imagery (i.e. the user's immediate, three-dimensional environment) sent from the user's micro-camera, which is converted to a bitmap. The second layer is a simulated, three-dimensional (3D) world through which the user can move and interact with – a head-tracker communicates user head motion to this virtual world so that the fused picture of both worlds is consistent with user motion. The two layers can be processed so as to simulate various lighting effects, such as Night Vision Goggles, or low light environments.

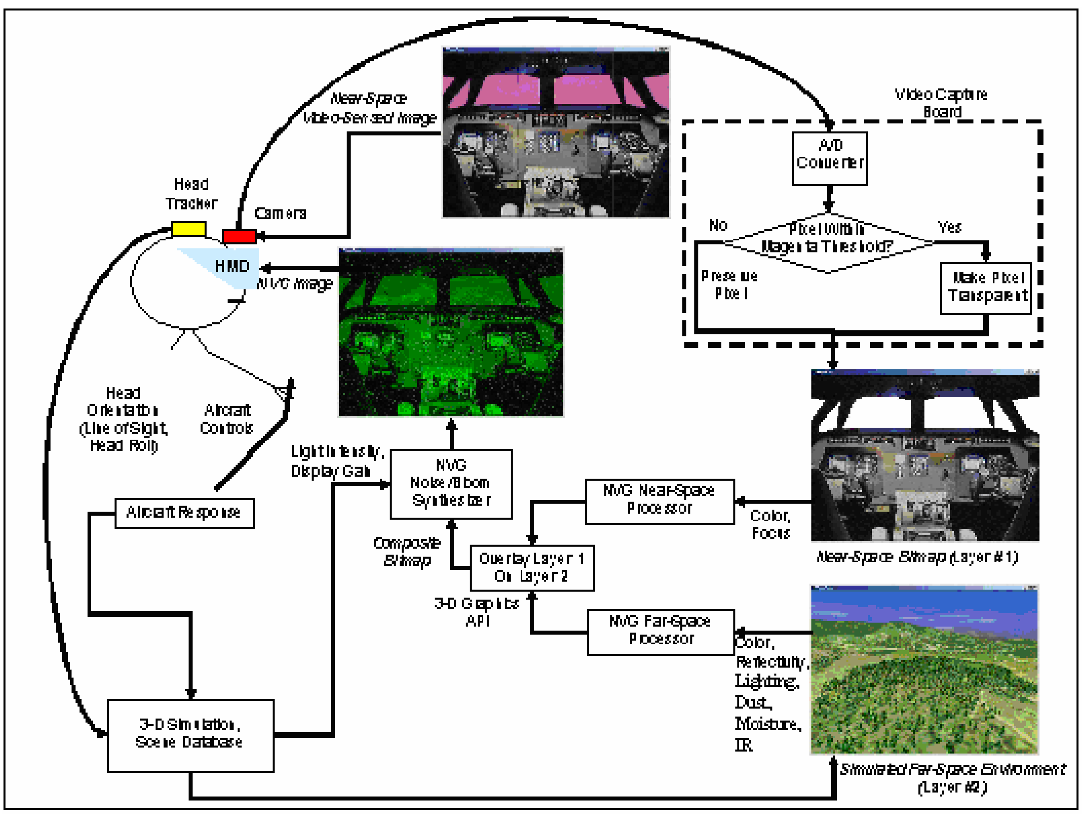


Figure 1: Representation of Fused Reality.

Helicopter Cabin Crew Tasks and Training

From the relatively cramped and noisy cabin area the helicopter crew chief may have to perform a variety of tasks, including: a) Door gunner targeting, b) Cargo hook operations monitoring, including emergency load release, c) Hover position control (fore/aft and lateral) during rescue missions, d) Stokes litter deployment/ recovery, e) Helicopter inflight refueling (HIFR) procedures, and f) Hoist control and cargo hook release. Depending on the mission and actual platform, the crew chief may be called on to execute numerous other tasks, in visual environments ranging from night vision goggles (NVG's) to brown-out (blowing sand or dirt).

Due to the difficulty of simulating many of these tasks and environments, cabin crew training usually transitions directly from classroom to the aircraft. Aircraft training not only requires the presence of a skilled, current crew chief (which strains squadron resources), but it can also expose novices to dangerous, unfamiliar procedures in distracting environments. From the author's experience (former SH-60B pilot), the difference between performing machine hang-fire procedures in the classroom and in the aircraft for real can be half a crewman's foot.

Candidate Simulation Approaches

Several candidate approaches are discussed here that were considered to simulate the helicopter cabin crew environment. With a Virtual Reality approach, tactile interaction with physical objects requires distance sensing between the human touchpoints (hand, elbow, etc.) and all objects that can be touched. This becomes an intractable problem for complex manual tasks such as machine gun disassembly. Even for relatively simple manual tasks such as flight control manipulation, the user cannot see actual positioning of limbs and hands (important elements for manual control) unless the body is peppered with expensive sensors. Additionally, user cannot realistically perceive the facial expressions, body posture, and clothing of other participants.

With the CAVE (Computer Animated Virtual Environment) approach, a hemispherical dome display is placed around the cabin so that trainee will see a projected environment (with the naked eye) beyond the cabin airframe. Disadvantages of technique this include: 1) Large volume required; 2) High-cost displays (a display must be placed wherever an image is to appear); 3) Real objects cannot be processed (such as deploying them into the virtual environment, discussed later in this paper), and 4) Large power requirements (heat generation, component failure).

CHROMAKEY PROCESS

Blue screening involving human filming usually employs a blue or green backdrop, since skin contains little blue or green hue. These backdrops preclude the use of similar colors in the physical environment. Fused Reality uses magenta as the target color, since it is rarely encountered in simulation environments (i.e. the cockpit). The color recognition technique used in Fused Reality can accurately distinguish between skin tones and magenta. Figure 2 shows an image of magenta material, and Figure 3 gives pixel scatterplots of the red, green, and blue (RGB) components comprising the color in Figure 2. Due to non-uniformities across the material surface, as well as sensor artifacts and lens artifacts (note the darker areas in the corners of Figure 2), there is a wide variance in RGB values. In order to algorithmically define the target color, the areas of the scatterplots in Figure 3 are approximated by bounding polygons shown in Figure 4. This technique using polygon templates was initially used by Fused Reality and appeared in the original patent application.

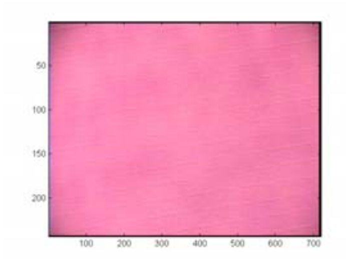


Figure 2: Snapshot of Magenta Background.

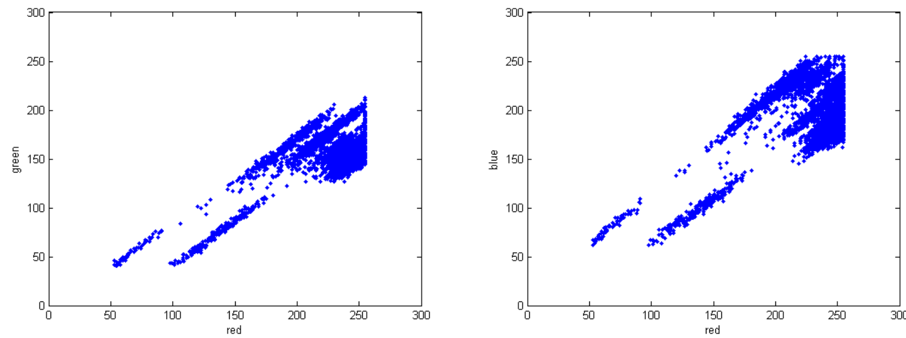


Figure 3: Red vs. Green and Red vs. Blue Scatterplots of Camera Response to the Magenta in Figure 2.

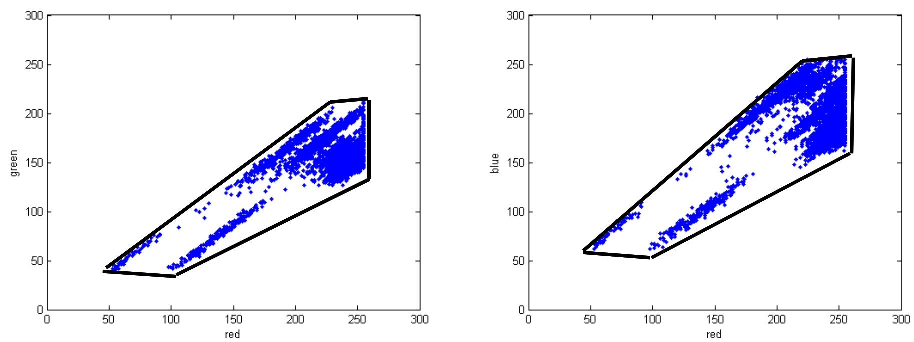


Figure 4: Polygons Bounding Red vs. Green and Red vs. Blue Scatterplots.

A new technique that uses a less complex color decomposition has since been identified and is now used by Fused Reality to define a surface's color. Figure 5 shows the pixel scatterplots for these color coordinates corresponding to the image in Figure 2. Note that these coordinates produce scatterplots that can be defined via bands (instead of complex and relatively imprecise polygons) based on their probability densities, shown below the scatterplots. Thus it is possible to statistically define the color characteristics of a relatively an image simply through lower and upper boundaries – a much simpler process than the RGB mapping (which requires linear interpolation) shown in Figure 4. A modification to the Fused Reality patent is incorporating this new technique.

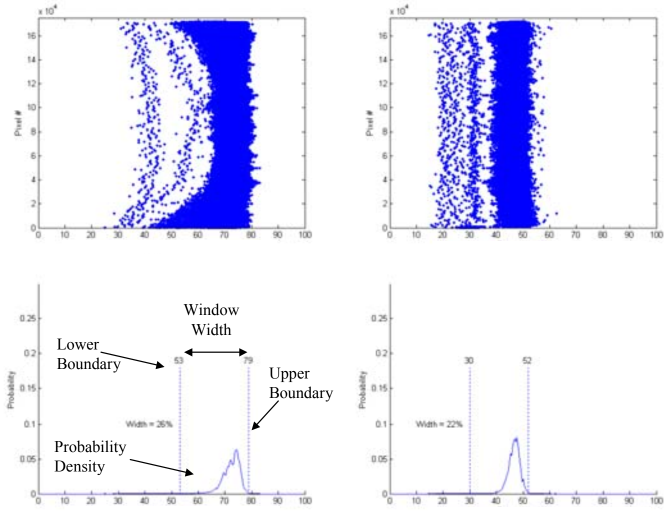


Figure 5: ScatterPlots and their Probability Densities Using the New Color Coordinate System.

The robustness of this technique is demonstrated in Figure 6, where a magenta surface (shown top) mounted serves as a virtual display. The bottom photos in Figure 6 show two very different lighting environments (note the desk reflection brightness), but the magenta is correctly identified despite the variation in lighting.

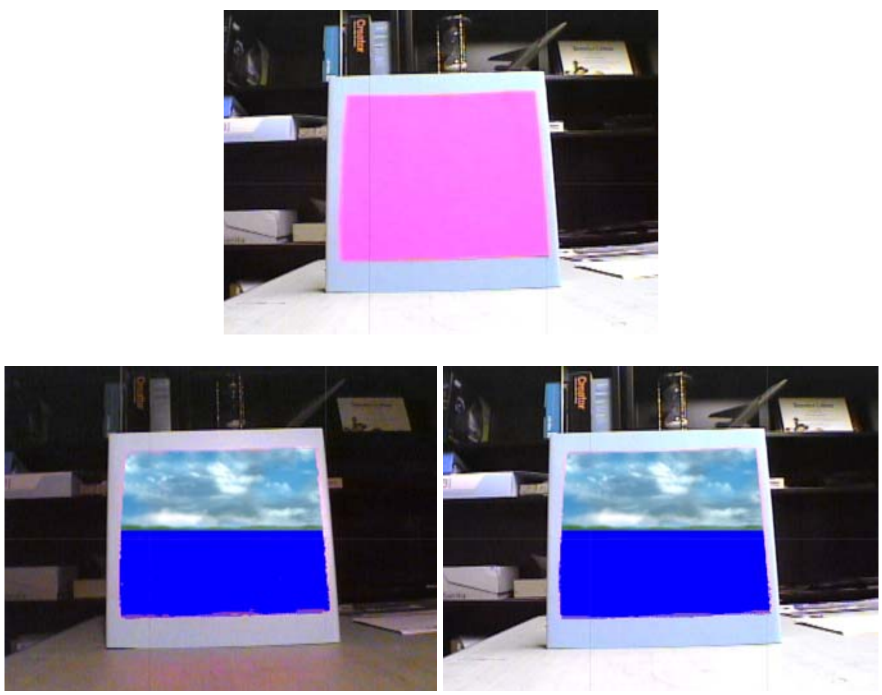


Figure 6: Raw Video Showing Magenta Board (top), Fused Reality under Low Lighting (lower left), and Bright Lighting (lower right) Conditions.

The advantages of Fused Reality and its current recognition scheme thus include: 1) Backdrop can be made from cheap cotton sheet; 2) Chromakey is independent of viewing angle: 3) It can use any lighting (incandescent, fluorescent) and brightness that makes the backdrop visually distinguishable from its surroundings; 4) More than one target color can be used; 5) Lighting level does not have to be low to simulate low light visual environments or Night Vision, as each pixel can be operated on to change light level or color displayed to user. Fused Reality segments space into the near tangible environment and the distant virtual environment, so that high perceptual fidelity is maintained in both domains while minimizing computational expense: a) The user naturally encounters the high detail of the physical world (vision, touch); b) Excellent perception of the distant virtual world generally requires low to medium level of detail.

VISUAL SYSTEM

A preliminary visual system is shown in Figure 7, where a Cohu camera has been mounted onto an eMagin HMD. A flexible cable connects the sensor (mounted center and front) with the control box (mounted on the left hand temple). A 12mm Computar lens is shown mounted on the sensor. In order to eliminate parallax during manual tasks (such as gunnery) a future design will mount the camera level with the eyes in front of the HMD.

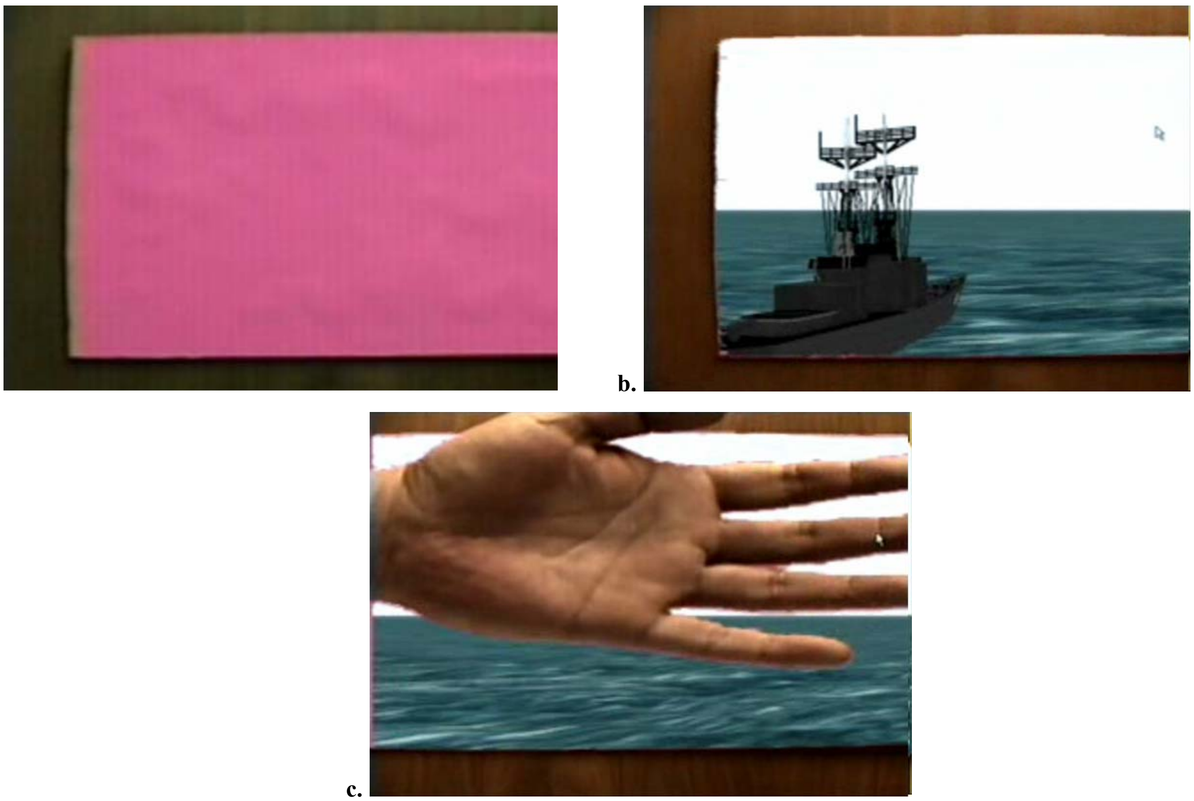
Figure 7: Cohu Camera Mounted on the eMagin HMD.

In Figure 8 the Cohu camera is shown mounted on an Air Force helmet that is currently being used by the Air National Guard with STI's Parachute Simulator, ***ParaSim®***. The eMagin HMD attaches onto the helmet's NVG clip via a swivel mount.

Figure 8: Cohu Camera Mounted on a Gentex Helmet with an NVG Clip.

DEMONSTRATIONS

In Figure 9a a magenta-colored panel is shown hung on a wall, and Figure 9b shows the magenta pixels replaced with a real-time virtual marine scene. Figure 9c demonstrates Fused Reality's capability to: 1) allow physical objects that occlude the magenta background to be viewed, and 2) precisely discriminate between the magenta target color and flesh-tone colors.



a. b. c.

Figure 9: a) Wall-Mounted Magenta Panel; b) Magenta Surface Becomes a Virtual Display Showing a Marine Scene with Navy Ship; c) Hand Placed between the Viewer's Camera and Magenta Backdrop.

A recent helicopter gunnery demonstration to the Navy was conducted for the PAVET SBIR. Figure 10 shows the raw and fused video of the cabin environment (constructed by Binghamton Simulator Company) wth a virtual background scene.

Lumakey

Lumakey is a patented (pending) process that employs the inversion of Fused Reality logic by rendering all pixels transparent unless a brightness criterion is met. The user would be placed in a darkened room and a head-mounted light would illuminate physical objects within reach. This concept is demonstrated in Figure 11. Lumakey would be best-suited for applications where: 1) The user remains fixed in position; 2) User physically interacts with objects that are within arm's reach; 3) The surrounding near-space environment is sparse; and 4) High fidelity, real time viewing of hand and equipment required. Figure 12 shows such an application, where a parachute trainee is suspended in STI's Parasim.

Raw Video | Fused Video

Figure 10: PAVET Cabin Photos of Raw and Fused Video.

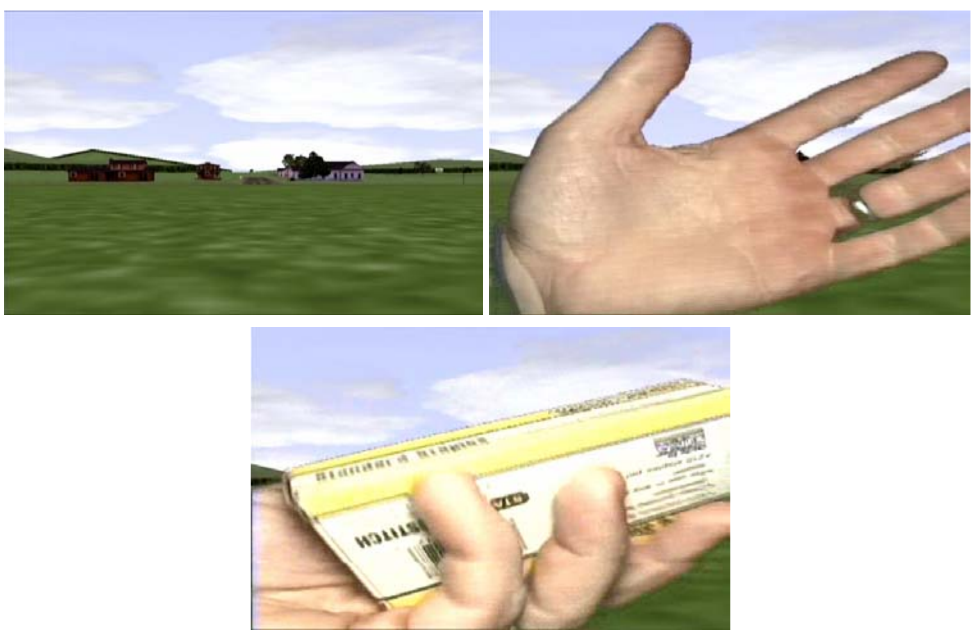


Figure 11: Fused Reality Using Lumakey.

Figure12: Trainee Suspended from Parasim Scaffolding.

Deployment of Physical Objects in the Virtual World

Blue screen production places and moves virtual objects within a physical setting. However, Fused Reality offers a unique capability: transporting physical objects within a virtual environment. This is accomplished by taking real-time bitmaps of actual objects and pasting them onto virtual, simple3D polyhedrons that can be moved in the virtual environment. Thus a user can deploy hand-held physical objects into virtual space and retrieve them, with the objects interacting in sync with other real objects/participants. This obviates need for computationally expensive simulation of complex 3D models (and the creation of those models). Figure 13 demonstrates this concept, where a figurine is suspended from a wire that can be rotated to yaw the figurine about its vertical axis – note that the physical position of the object is fixed. Figures 13a and 13b show the scaffolding and magenta background. In Figures 13c-f a user controls the virtual position of the figurine using a joystick while the figurine physically pirouettes (the wire is rotated). The real-time bitmap sent by the camera is pasted onto a billboard which is translated into the 3D virtual environment via the joystick commands.

This technique could be employed in helicopter rescue litter training, where the physical litter can be hooked up to a hoist, pushed out of the cabin, and lowered on a cable for a few feet. After the litter ceases to physically lower (because of space limitations) the bit map of the suspended litter would be fused to a horizontal billboard, which would then continue its descent in the virtual following the control commands of the aircrewman. It must be remembered that the user would be viewing *the actual image of the litter*, swaying and rotating as it is suspended from the physical cable. When the virtual survivor approaches the litter, an actual person can step into it (which is near the floor) so that the trainee feels the full weight on the hoist cable, and the person's bitmap would be fused to the litter's billboard. During retrieval of the litter/survivor, the virtually transported bitmap would ascend until it reached the distance of the actual litter/survivor, at which point the bit map would be detached from the virtual billboard and the aircrewman would observe the physical litter/survivor for the remaining few feet and be able to pull them both into the cabin. Figure 14 shows a photo of the litter used for Navy rescue.

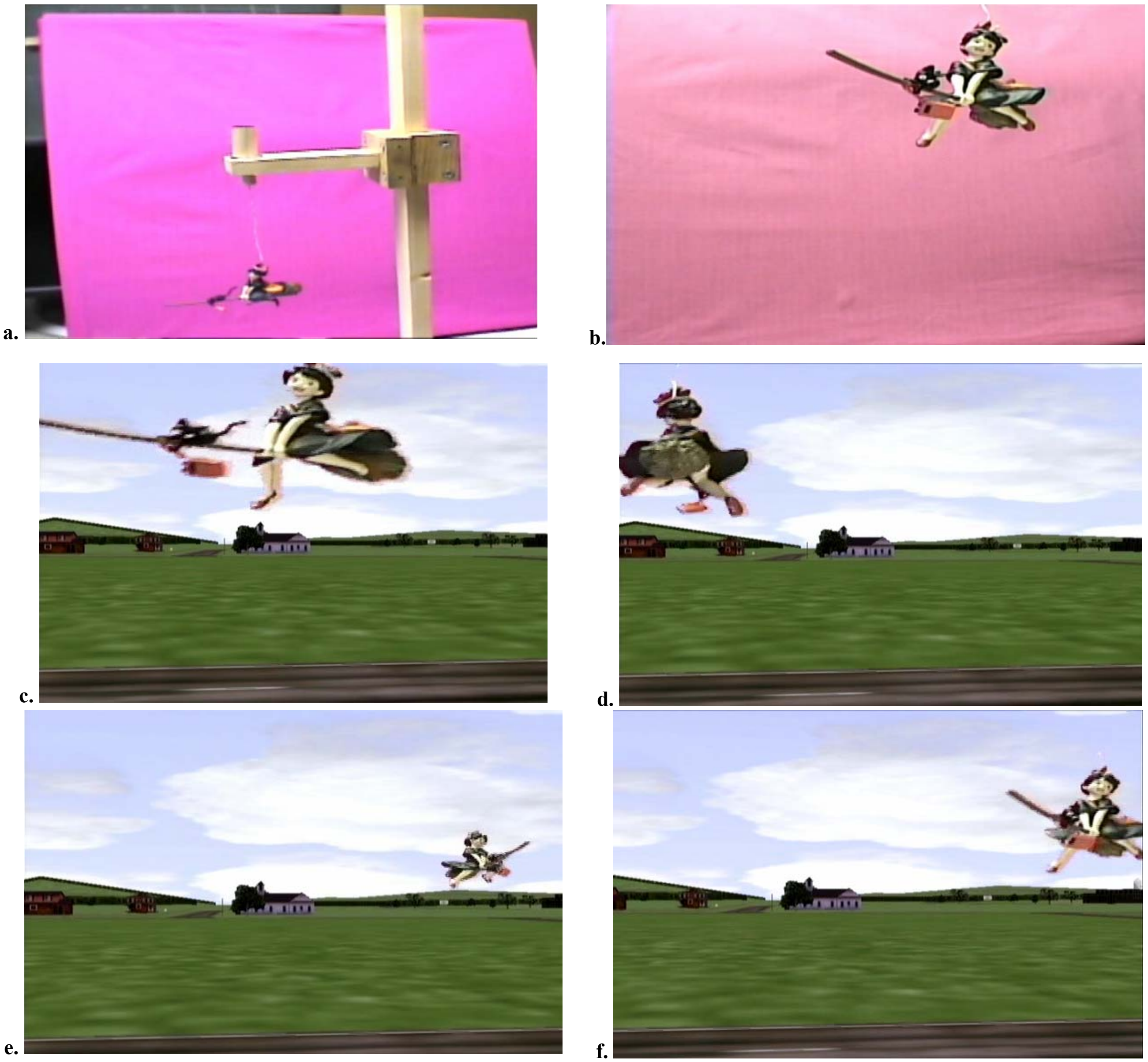


Figure 13: Frames Showing Physical Object (witch figurine) Translated in Virtual Space.

Figure 14: Navy Rescue Litter.

ALTERNATE TECHNOLOGIES TO FUSED REALITY

Z-key is an image keying method that uses pixel-by-pixel depth information of real and virtual objects to form of a depth map, allowing separation of mixed reality objects based on the detailed shape and position of surfaces. Figure 1 is a schema of a z-key method that uses stereographic information as a range-finding mechanism. A close-up of the merged images shows the border of the real objects to be very ragged, due to the noisy stereographic feedback at the edges. The frame rate using this technique is roughly 15 frames/sec, compared to 30 frames/sec using Fused Reality (soon to be 60 Hz). Additionally, a featureless background such as a smooth wall would not provide depth information to this system.

Range-finding user laser is precise, but it gives very low frame rates.

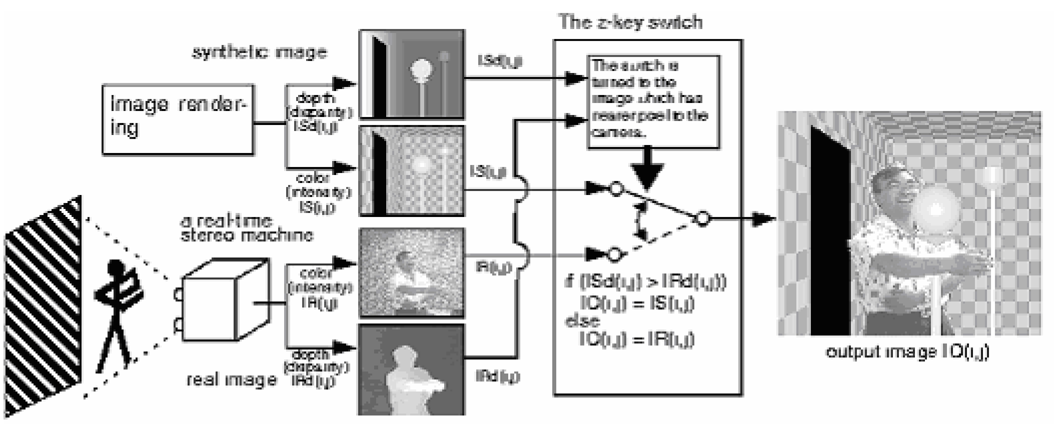


Figure 15: Z-Keying Process Using Stereographic Feedback [2].

Figure 16: Merging of Physical and Synthetic Near-Space Objects Using Z-Keying [2].

Chromakey using a retroreflective background and a LED-ringed camera is another technique that has recently been useful in filming. However, when a user's hands disrupt the light from a helmet-mounted light source, the shadows cast onto the distant background are diffuse and poorly defined. This in turn degrades the chromakey process near the borders of the subjects. In the film industry this is not an issue as the camera is positioned much further away from the subjects than the subjects' distances from the background. Moreover, retroreflection yields poor results when the viewing angle is very oblique to the background plane.

Figure 17: Retroreflective Background and LED-Ringed Camera.

Head Mounted Projection Displays (HMPD's) [3] also make used of a head-mounted light source and retroreflective screens, and have constraints similar to those given above.

FUTURE FEATURES USING FUSED REALITY

Target areas (portals) could be designated by infrared (IR) and ultraviolet (UV) reflection, giving rise to virtual reality portal generation on-command (i.e. directing an IR or UV source toward a reflective surface). Dual reality portals could be made by coating glass with transparent material that reflects IR or UV light, so that the trainee sees a virtual environment while the naked-eye observer can view the actual environment that exists beyond the glass. This would allow training in actual vehicles such as cars (driven in vacant parking lots) and aircraft while a safety observer looks for potential conflicts or other hazards. Thus a trainee would experience the actual forces that he/she is effecting while operating in a virtual world such as the one shown in Figure 18.

Figure 18: View from STISIM.

[1] Dean, Frank, P. Garrity and C. Stapleton, *Mixed Reality: A Tool for Integrating Live, Virtual & Constructive Domains to Support Training Transformation*, Interservice/Industry Training, Simulation and Education Conference (I/ITSEC) 2004.

[2] http://www.cs.cmu.edu/afs/cs/project/stereo-machine/www/z-key.html

[3] Nguyen, Long, A. Mead, C. Fidopiastis, and J. Rolland, *Enhancing Virtual Environment Interaction Using a Head Mounted Projection Display (HMPD)*, Interservice/Industry Training, Simulation and Education Conference (I/ITSEC) 2004.