A Virtual Model of a Reactor Facility

R. Dowe Dabbs, J. Michael Whitaker, Steven E. Smith
Oak Ridge National Laboratory
Oak Ridge, Tennessee

George T. Baldwin
Sandia National Laboratories
Albuquerque, New Mexico

Michael J. Maston
Public Safety Systems
Oak Ridge, Tennessee

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R. Dowe Dabbs (ORNL), J. Michael Whitaker (ORNL), George T. Baldwin (SNL),
Michael J. Maston (Public Safety Systems), Steven E. Smith (ORNL)

Abstract

A digital model of the High Flux Isotope Reactor (HFIR) located at the Oak Ridge National Laboratory (ORNL) has been created. The model, which utilizes state-of-the-art immersive digital imaging, can allow a user to navigate virtually through permitted parts of the facility from any user location, on site or remote. The use of such a model can minimize the intrusiveness of facility visits by allowing routes to be preplanned and rehearsed, thus reducing the need for both visit-specific training and facility-support personnel. The model can enhance post-visit activities by allowing visitors to virtually revisit the permitted portions of the facility any number of times. The model can also be integrated into larger software applications to simulate host/visitor dialogues, to support emergency-response decisions, etc.

Introduction

A research reactor complex (or similar facility) such as the High Flux Isotope Reactor (HFIR) consists of a large reactor building integrated with a number of ancillary buildings. The multi-storied reactor building typically contains the reactor, its primary coolant system, a majority of its secondary cooling system, fuel-storage pools, reactor-support systems, etc. The ancillary buildings typically house water-chemistry systems, electrical systems, experiment facilities, waste-disposal systems, etc.

Access to a reactor complex requires significant effort. Although this effort is a necessary element for employees, it can be a real impediment for visitors, who typically have limited time at the site. The effort expended by the facility (i.e., for hosting, training, establishing specific plant configurations, etc.) in support of visitors can also be nontrivial. This effort obviously increases rapidly with the size of the visiting delegation. As such, the ability to move virtually through a facility can reduce the impact on normal operation of the facility, allow faster visitor access, and permit easier revisits.

A virtual model of the HFIR reactor building was constructed to demonstrate a methodology of minimizing the facility impact required by increased visits resulting from potential implementation of the Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency (IAEA) for the Application of Safeguards, INFCIRC/540 (Corrected). The facility impact could be reduced not be decreasing the number of visits but by allowing virtual planning for and critiquing of actual visits. The purposes of this model were (1) to establish the resources required for its development, (2) to evaluate the effectiveness of current state-of-the-art immersive digital photography in representing the HFIR reactor building, (3) to define design criteria for subsequent implementation of the model into software applications ranging from simple navigation to web-based inspection simulations, and **(4)** to explore other potential benefits to the facility (i.e., employee training, emergency response, drill preparation and critiquing, etc.).

iPIX Imaging

The digital photographs comprising the virtual model utilized technology available from the Internet Pictures Corporation (iPIX, see www.ipix.com) of Oak Ridge, Tennessee. The software offered by iPIX allows users to create spherical immersive images by automatically de-warping two fisheye images (taken by a standard digital camera equipped with a 185-degree fisheye lens and mounted on a camera-rotator-equipped tripod) and seamlessly generating immersive images from these two 185-degree hemispherical images. The iPIX software creates an image-file size ranging typically between 25 and 160 kilobytes depending on the density of the resulting image.

The iPIX web site includes information on their available image-manipulation software: iPIX 360 Suite Pro, iPIX 360 Suite (included with the purchase of an iPIX camera kit), iPIX Wizard/Builder Bundle, iPIX EGallery Wizard, etc. Unlimited image previewing is available with the software (or via the iPIX plug-in for Internet Explorer), but an iPIX software license must be purchased to save iPIX immersive images. Annual licenses are available for both iPIX 360 Suite and iPIX 360 Suite Pro. Single-use image keys can also be purchased directly from iPIX. iPIX also offers the capability to integrate immersive images with video, audio, and animation.

A static representation (in the default direction) of a medium-density iPIX image is shown in Figure 1 (the HFIR visitor gallery, about 100 feet long). If this were a dynamic iPIX image, the user could change the direction of sight by moving around the encompassing spherical surface. Hitting the up, down, left, or right arrow key would finely move the view in that direction. Moving the cursor toward the edge (top, bottom, left, right, or any corner) of the monitor screen and clicking would grossly move the view in that direction. Hitting the plus or minus arrow key would finely zoom the view in or out. Placing the cursor slightly above or below the center and clicking would grossly zoom the view in or out.

Figure **2** represents the same image looking upward and to the right. Figure 3 represents the same image looking downward (note the camera tripod and image seaming). Figure **4** represents the same image with maximum zooming (in the default direction). Figures 5 and 6 show the two fish-eye hemispherical images from which this immersive image was created.

Virtual Model Construction

The concept of hot spots in an iPIX immersive image allows construction of a virtual model. **A** hot spot is a user-defined area of the image, which can be linked to another image, an audio file, a high-density flat image, etc. When the user clicks the hot spot, the view changes to the linked image or an audio message is played.

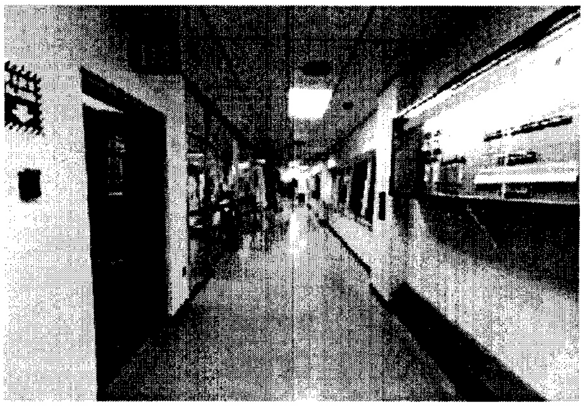

Figure 1. Sample iPIX image (default direction).

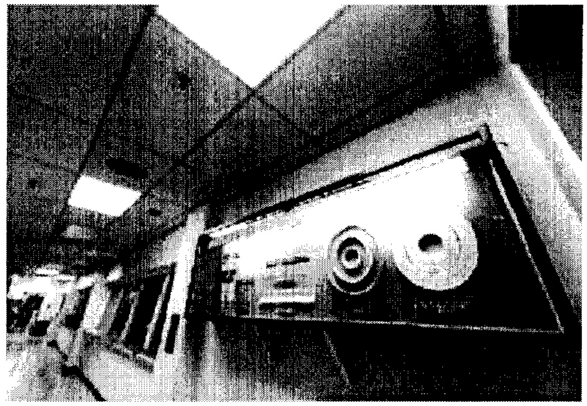

Figure 2. Same image rotated up and right.

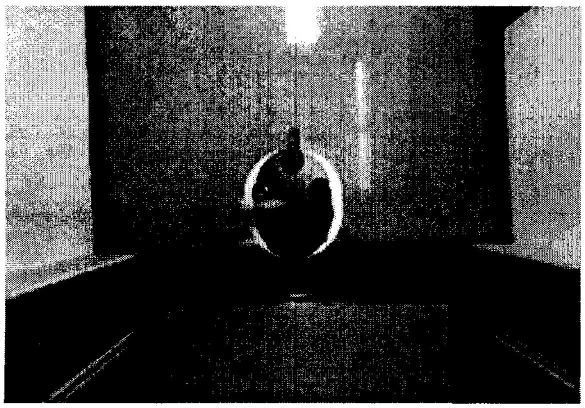

Figure **3.** Same image (rotated downward).

Figure 4. Same image (maximum zoom).

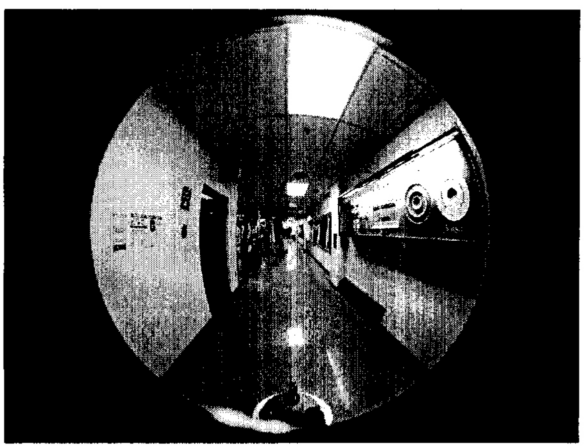

Figure 5. Hemispherical image (forward view).

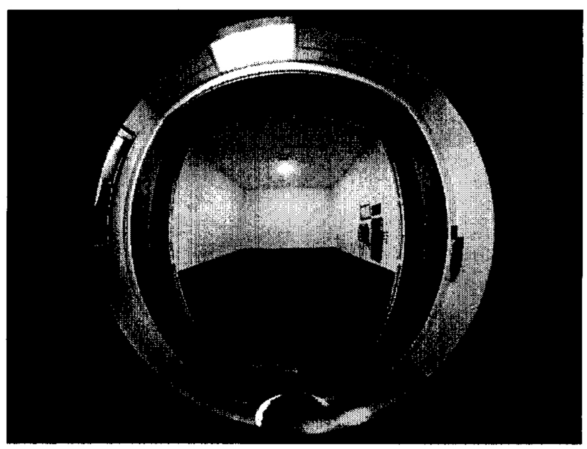

Figure 6. Hemispherical image (reverse view).

The first step in creating the model of the HFIR reactor building was to determine where to locate the iPIX images. Utilizing the floor plan for each story, image locations were chosen to allow a reasonable resolution (i.e., at least line of sight) for navigation through the facility. The reactor-building model required about 220 hemispherical images (making a total of about 110 immersive images). As such, the camera was positioned at each location and two hemispherical images were recorded. This effort took about 5 person days.

The second step of the model construction was to process the raw images to make the iPIX images. The standard iPIX software was used. This effort took about 5 person days.

The third step was to link the images to each other in logical sequence and link selected images to a flat image of its appropriate floor plan. Hot spots were defined on each image (including the floor plan images) to allow movement to the next (or previous) sequenced image. Some images were linked to audio files, which provided additional information. For some images requiring increased resolution of specific facility components, high-density flat images were linked to the appropriate iPIX image. This effort took about 4 person days.

Perhaps the most tedious aspect of assembling the linked images is presenting the correct initial viewpoint of a linked image. When one moves through a door by clicking on the door, the next image should immediately be facing in the same direction as one intuitively expects in moving through the door. When one moves from point A to point B, the initial view for image B is not necessarily the same as if one came there from point C. Such viewpoint control is a major factor in creating a realistic virtual simulation.

Given a starting point of the tour (chosen to be the front entrance to the HFIR), navigation through the sequenced immersive images is possible by utilizing the defined hot spots. One advantage of such a virtual model is that instantaneous movement between any two linked locations is possible. However, care must be exercised if time management (e.g., in a drill where emergency responders can not move instantaneously through the facility) is important to the type of application in which the virtual model is integrated.

HFIR personnel have used the stand-alone reactor-building virtual model as both an emergency-response tool and as a communications tool. For a simulated incident recovery, personnel located in a remote emergency-response center simulated the following of personnel in the building as they transmitted their locations. The emergency-center personnel then used the model to evaluate the path for the personnel in the building and to help determine the cause of the incident. For the communications tool, off-site owners/regulators used the tool to better understand technical discussions with on-site facility personnel.

The linked-image attribute of the virtual model allows the reactor-building model to be easily modified as needed. One level of modifications could incorporate additional interior iPIX and flat images if increased navigation resolution were required in certain locations. Additional levels of modifications could incorporate exterior images of the reactor building, interior/exterior images of the reactor ancillary buildings, site images of all buildings, images of the site perimeter, etc. The size of the iPIX and flat images should allow such a site model to easily fit on one CD-ROM.

Virtual Model Extensions

The applicability of the virtual model could be expanded by integrating it into end-user applications such as (1) the Augmented Computer Exercise for Inspection Training (ACE-IT), a inspection simulator originally developed for the Chemical Weapons Convention, offered by the Cooperative Monitoring Center (see www.cmc.sandia.gov) of the Sandia National Laboratories (SNL) or **(2)** RAMSAFE (see www.ramsafe.com), a crisis-management software application offered by Public Safety Systems (PSS) of Oak Ridge, Tennessee.

ACE-IT incorporates a similar iPIX-based virtual facility model, but for a specific purpose: that of simulating an inspection of a facility using "managed access," primarily for training. The computer simulation is used in an exercise involving multiple participants communicating over networked computer workstations. A participant has an assigned "role", such as a facility host, or an inspector. Each participant's location in the facility is taken to be the center of the image that is currently displayed on his or her workstation. Participants can "move" by using the hot spots that link images. However, individual immersive images are not linked directly, as in the virtual model we've described previously. Instead, the hot spots activate computer code that decides what to do next. Typically, inspector movement is preceded by a managed-access negotiation with the facility host, who may choose not to allow the requested movement.

ACE-IT therefore uses a different architecture than the simple virtual model, and stores in a database the iPIX images, the links between the images, and a great deal of other information. Because ACE-IT involves multiple participants, the virtual model is complicated by a need to keep track of "where" people are in the facility. They may want to move together (e.g., "take me with you") or move independently. Access might be pre-approved, or negotiated during the inspection. One participant may wish to merely watch another, or more precisely, watch where the other is looking by "slaving" one image display to another.

Many different "managed access" measures in ACE-IT make use of iPIX image capabilities. For example, images can be modified with commercial editing software to simulate shrouding. Hot spots can be used in a variety of ways in ACE-IT; for example, to request a chemical sample from a tank, request an inventory list for a storage cabinet, or to call up a menu of several different inspection alternatives.

In some situations, ACE-IT may even create a "pseudo-facility" by deliberately linking images differently than the facility appears in reality. Furthermore, the individual images comprising the virtual pseudo-facility might come from a variety of actual facilities. Such a hypothetical facility model may appear realistic, but can be tailored to meet the needs of the training situation or security concerns.

Another example of an extended model uses RAMSAFE. Coupling the existing reactor-building virtual model to RAMSAFE would allow the iPIX navigation capability to be layered into SQL Server and Internet Explorer to provide facility infrastructure information in a distributed, web-browser-based, format. The resulting application would allow facility personnel, response personnel, government personnel, etc. rapid access to both available and required incident-response resources in the planning, training, recognition, immediate response, and follow-up phases of an incident. Additionally, this information is encrypted and can be selectively distributed to authorized personnel only. As a result of using an application such as RAMSAFE, a facility can achieve a high level of situational awareness prior to an incident, establish comprehensive preparedness plans, enhance incident readiness through automated training, and improve communications between the facility and applicable response agencies both during and after an incident.

To demonstrate the power of RAMSAFE, PSS deployed the technology at the request of the Utah Olympic Public Safety Command to support security operations for the 2002 Salt Lake City Winter Olympics. PSS designed and built a large customized database that enabled intelligence and other information sharing by all public safety agencies at the 2002 Olympics. Approximately 60 federal, state, and local public safety agencies were able to share access to the RAMSAFE distributed database. The database included hundreds of Olympic venue floor plans, several thousand iPIX virtual tour images, numerous maps, aerial and satellite photos, and a broad range of operational documents such as security policies and procedures. Data concerning virtually all important supporting facilities, such as the Salt Lake City International Airport and the entire critical infrastructure of *22* venues spread over a 3,000 square mile Olympic Theatre, were placed into the database. The database was installed in rugged stand-alone laptops, supporting critical decision-making even under severe tactical conditions.

PSS staff took over 3,200 iPIX images to compile an up-to-date Olympic security information database during the 90-day period just prior to the Olympics. Implementation tasks accomplished by PSS and its deployment partner, Electronic Data Systems, also included application installations on more than one hundred computers and training for over 200 Olympic security officials. From hardened command centers to rugged laptops in the field, Olympic officials had unprecedented access to vital information to support Olympic security operations.

Summary

Current immersive-imaging technology enables detailed virtual-navigation models to be quickly and economically created. An iPIX hardware/software package such as the Nikon Coolpix 5000 Starter Pack with Advantage License (for users having a compatible digital camera such as the Nikon 995 or Nikon D1X and a tripod) is currently available from their web site for about $1,400. **A** 185° fisheye lens, an iPIX Rotator, and a Tripod Adapter (to fit the rotator on a standard tripod) are included in the package. Also included in the package is the Advantage License, which combines 100 iPIX image keys with 360 Suite Pro (consisting of iPIX image builders, iPIX image enhancement tools, and iPIX image viewers). Additional iPIX image keys are also available from their web site for about *$25* each (volume discounts are available). A

100-image virtual navigation model can then be made with this package and one to two person weeks of labor. If cost and schedule are an issue in creating a virtual facility model, they can be minimized by contracting with a company such as PSS, who is a licensed distributor of iPIX images, owns the equipment (including high-end Nikon D1X cameras) required to take the images, understands facility mapping, etc.

A virtual navigation model can be extended by integrating it into applications such as RAMSAFE and ACE-IT. Because of the potential complexity of extended models, the effort to create them can be on the order of person months. However, the cost of such an effort remains an excellent investment since it can be rapidly recovered through reduced facility impact, proper incident mitigation, etc.

Assembling the individual images into a linked sequence with intuitive initial points of view is the most cumbersome step in creating the virtual facility model. Developing a "facility builder" to automate the process would be a significant improvement, enabling us to create the virtual facility faster and with less chance for error. Such a builder might work simply by "dragging and dropping" images onto a map that establishes the spatial relationships between images.

A virtual model of a facility (be it either a simple navigation tool or an extended application tool) provides an enormous amount of data to the user in a short time. As such, these tools should be controlled to ensure that facility data is properly used. With proper control, a virtual model can then be an invaluable asset during both normal and off-normal facility operation.

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