SYNTHETIC ENVIRONMENTS DON'T HAVE TO BE DIGITAL

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Abstract

Synthetic environments have typically been perceived as testing and training facilities that provide visual, digital information about the world surrounding a task. This paper explores a more comprehensive interpretation that involves utilizing perceptual cues appropriate for the task and is not dependent on digital presentation of the task environment. AFRL/HESR has developed a three-phased approach to testing that includes laboratory, synthetic, and field-testing. In this method, the synthetic environment is a transitional platform between pure laboratory evaluation and field-testing. Appropriate environments are determined through selection, isolation, categorization, validation and analysis of the elements in the system to determine their relationship and interaction. Critical elements are used in the synthetic environment to test task performance. Examples showing the effectiveness of appropriately designed, non-digital synthetic environments, as used in maintenance task environments, are reviewed. Tools or mechanisms used in building appropriate synthetic environments are examined and the benefits associated with these intermediary platforms are discussed.

Author's Biographies

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Barbara L. Masquelier: Barbara L. Masquelier is a senior human factors engineer for the Logistics Readiness Branch of the Air Force Research Laboratory, Wright-Patterson AFB, OH. Ms. Masquelier's research interests include development of advanced human computer interface techniques, application of alternate computer control devices and monocular display devices for maintenance support, and application of information technology for logistics command and control applications. Ms. Masquelier graduated from the Air Force Institute of Technology in 1991 with a Master of Science degree in Logistics Systems Management, and from Wright State University in 1982 with a Bachelor of Science Degree in Human Factors Engineering.

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Overview

The term "synthetic environment" has typically been used to describe testing and training facilities that provide visual, digital information about the world surrounding a task. Furthermore, synthetic environments have traditionally provided a means of measuring task performance in a safe, controlled manner. Used extensively for operational tasks, such as flight training, the synthetic task environment, to date, has relied heavily on control of visual stimuli.

This paper discusses a three-phased approach which relies heavily on the utilization of a synthetic environment. Used by AFRL/HESR for testing newly developed logistics and maintenance systems, the three phases of the LSF approach are: 1) Laboratory testing, 2) testing in a Synthetic environment, and 3) Field tests. The philosophy behind the LSF approach is to gradually immerse the technology in the setting for which it is designed while collecting empirical user performance throughout the entire process. The use of a synthetic environment provides a transitional step from the lab setting, which allows increased experimenter control but may lack key characteristics of the end-user's environment, to the field test, which represents the end-user's environment but generally lacks the controlled nature of a laboratory. The synthetic environment, therefore, allows the experimenter to represent the key elements of a realistic end-user environment without sacrificing experimenter control. The experimenter is then able to not only measure user performance, but also address potential issues and challenges when transitioning to the field test. In contrast with the common definition of synthetic environments, synthetic environments used in the LSF approach do *not* rely on visual, digital representations of the real world.

A very important issue when designing artificial environments involves utilizing perceptual cues which are *appropriate* for the task being tested or trained. For example, aircraft maintenance requires physical interaction with objects in the environment. Therefore, the corresponding synthetic environment must rely on tactile, as well as, visual stimuli. For many maintenance skills, purely digital representations of the environment can not and will not provide the fidelity necessary to train or test the task. However, an appropriate synthetic representation of the environment will provide a smooth transition from laboratory to field test, thus enhancing the overall process of design, development, and implementation.

Defining Synthetic Environments

Kelly (1998) defines synthetic environments in terms of 2-D computer worlds and immersive virtual environments. In this article, Kelly emphasizes the common understanding that synthetic environments are synonymous with computerized simulation systems. Clearly, this "digital" interpretation is a widely accepted definition of the term. However, analysis of these words, individually, can lead to a more comprehensive interpretation—that is, an interpretation not limited by digital mechanisms associated with the environments (e.g., simulators).

While the word *synthetic*, by definition, means "not real" or "artificial," the root of the word, "synthesis" means putting together of parts or elements so as to form a whole. Environment refers the circumstances or conditions that surround a person—their surroundings. Therefore, the comprehensive definition of synthetic environments might be *to artificially join the elements of one's surroundings*. Given this definition, a process is needed for identifying the elements of the system, and methodically joining those elements to increase complex learning for all types of tasks.

Synthetic Environment Design Process

The Air Force Research Laboratory Logistics Readiness Branch (AFRL/HESR) has developed the LSF as an incremental process for testing maintenance task performance. The design process typically includes selection, isolation, categorization, validation, and analysis of those elements to determine their relationships and interactions. This is followed by three phases of testing. During the second phase of testing, the synthetic environment provides a transitional platform between pure laboratory evaluation (the first test phase) and field-testing (the third test phase).

Edwards' SHEL model (1988) provides a structure for selection, isolation, categorization, validation, and analysis of system elements (see Figure 1). The SHEL model identifies four components to every system. These components are software (S), hardware (H), environmental (E), and liveware (human beings) (L). According to the model, successful system designs must consider all of the interactive links between its component parts. For example, a small hardware change needs to be regarded in terms of its effects on other interactive links to software (H-S), liveware (H-L), and environment (H-E). Small changes in any component can have major impacts on other components and links between components.

Using the SHEL model, the sample elements from an aircraft maintainer's surroundings might be as follows:

- Software – on-line maintenance technical orders, and forms.
- Hardware – computers to support display of technical orders and forms, maintenance tools, and aircraft components and wiring
- Environment – temperature and humidity, ambient lighting, and mobility around the aircraft
- Liveware – training, experience, and maintenance specialty

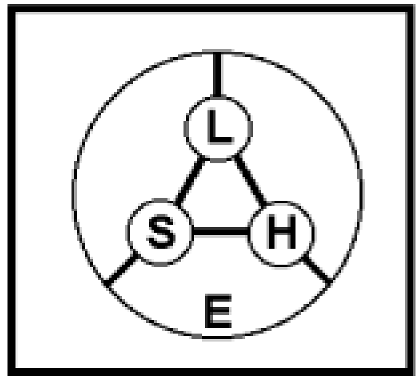

Figure 1. SHEL Model adapted from Edwards (1988)

Under the LSF process, categorized elements are validated and analyzed to identify potential influences of the elements on each other. Any or all of these elements can affect aircraft maintenance; this is even more likely as the elements are put together. For example, providing technical manuals on head-mounted displays (HMDs) during high temperature and high humidity causes excessive perspiration. The HMD was found undesirable in this synthesized circumstance. Additionally, preserving the hygienics of the HMD was also found to be quite difficult. In accordance with the SHEL model, early validation and analysis of the interactive link between hardware and environmental elements was a valuable step in the HMD evaluation process. Use of the model assured that the field test included testing the HMD in high temperature and humidity conditions.

Once initial analyses have been conducted, the system elements are methodically tested. Element testing occurs in laboratory, synthetic, and field environments. This phased sequence provides findings that can pinpoint system elements influencing one another—thereby increasing understanding of performance.

The first phase involves laboratory-type testing. The purpose of this phase is to collect empirical data on individual parts of the task. For example, laboratory tests are conducted on new hardware and software configurations. A laboratory test may compare two types of control input devices to see which is most compatible for interacting with maintenance technical data.

The second phase provides empirical data on the interaction of a few key elements in a controlled setting. This phase is termed the *synthetic environment test*. Selection of the appropriate elements to test and appropriate representation of those elements is the most important step to identifying how the parts will interact in the real-world environment. For example, in operational environments such as flight training, the appropriate elements are predominantly visual; therefore, synthetic environments frequently include virtual reality simulations of the visual environment. In many logistics environments, however, appropriate elements are tactile—requiring physical manipulation of elements in the environment. The important design aspect in this second phase is careful selection and suitable representation of the elements to be tested, thus creating an appropriate and representative synthetic environment. The results from testing can be used to: 1) validate findings of the laboratory based testing, and 2) provide direction for the following phase, the field test.

The third and final phase involves field-testing. The purpose of a field test, as defined by this approach, is to supplement information found in the synthetic environment by providing real-world feedback about the task. In the field test, all elements are *synthesized* to recreate the system in its working environment. While collecting objective data is possible in a field test, it is often very difficult to control extraneous factors in the actual environment. Therefore, the field test is used primarily to collect subjective feedback on the system.

Sample Non-digital Synthetic Environments

The use of *appropriate* synthetic environments for testing task performance maximizes the amount and validity of information gained in system development and test while minimizing the cost associated with building these environments. Using the LSF process, AFRL/HESR has developed and tested several systems. The non-digital, synthetic environment has proven to be a valuable step in the method.

Hands-Free Computer Controls

In cooperation with AFRL/HECP, a research program was initiated to compare hands-free computer control devices with conventional wearable computer controls. Wearable computer systems for maintenance applications provide repair information to the technician at the job site (e.g., in the engine bay). Many maintenance tasks require both of the technician's hands, making conventional wearable input devices inadequate for computer control. Voice-driven computer control is not always possible due to the changing noise spectra and noise levels on the flight line, (Chapman & Simmons, 1995). The intent of the cooperative research program was to evaluate alternative hands-free controls.

In the first step of the process, elements of the system were identified and methodically joined. In this case elements related to computer hardware control was of paramount importance. Many alternative hands-free input devices were considered (the term *alternative controls* is used to describe nonstandard input devices, such as EMG, EKG, EEG, EOG, head tracking, and voice input). Analysis and laboratory testing helped to pair down the alternative control options to a reliable, practical suite of controls. Further laboratory testing compared the standard, voice-only, and alternative control suites. The alternative control suite incorporated a head-mounted Gyropoint Pro II inertial mouse (for head-based cursor movement), the CyberLink electromyographic (EMG) controller (for discrete control using facial gestures), and the Verbex Voice Systems Rev 4.0 for text entry. In the laboratory setting, the controls were compared when paging through electronic technical manuals (no hands-on maintenance was performed). There were no apparent differences among the control devices.

Following the laboratory tests, a synthetic environment examination was initiated. The tasks selected for the synthetic environment were a series of wire continuity checks using Cannon plug connectors. A workstation was designed to simulate a bench where aircraft components would be tested by a maintainer. Other aspects of the synthetic environment included a multimeter (necessary to check continuity), wire bundles (used to connect individual pins on the Cannon plug), and a set of maintenance manuals provided in electronic format. Note that the mechanisms used to replicate the maintenance environment were non-digital (e.g., multimeter and wire bundles). The maintenance manuals were digital; however, the intent of the research was indeed to test the effects various non-standard input devices on the usability of electronic technical data manuals.

The maintenance tasks were performed while using the each of the control suites and referencing the electronic technical manuals (see Figure 2). Research findings indicate that an alternative control suite provides equivalent performance to voice control, thereby offering a substitute for high noise environments (McMillan, Calhoun, Masquelier, Grigsby, Quill, Kancler, Nemeth, & Revels, 1999). Additionally, the two hands-free controllers, voice and alternative, result in better performance than a standard controller in situations where hands-on maintenance was required.

Figure 2. Synthetic Environment for Hands-Free Controls

In this case, the non-digital synthetic environment showed performance differences that the laboratory test did not. Adding the tactile requirement of the maintenance environment revealed the benefit of the hands-free controls. As hands-on activities are required for flight line maintenance, performance degrades with standard wearable computer controls such as wrist-worn keypads and hand-held trackballs; whereas, performance remains constant with alternative and voice controls.

Glasses-Mounted Display Research

Use of non-digital synthetic environments has also been used for researching glasses-mounted displays for wearable systems. The purpose of wearable computers is to allow users to perform tasks requiring direct interaction with their environment while using the computer as a performance aid. Displays, therefore, must support performance without adverse side effects (e.g., discomfort, occlusion of visual field). The glasses-mounted display (GMD) provides lightweight, continuous wear, low-cost commercial-off-the-shelf (COTS) optical components for use in mobile computing.

In a Phase I Small Business Innovative Research (SBIR) program with The Technology Partnership, the Logistics Research Division funded development and test of a prototype GMD. Evaluation of the prototype posed many test constraints and challenges. Both objective and subjective data were gathered for effects such as adjustments in lighting conditions, maneuverability in confined spaces, and comfort of the device. The purpose of the Phase I study did not require the evaluation of the GMD in its intended working environment; therefore, the less expensive synthetic environment was used. Manipulation of these effects in the working environment would have been costly in terms of aircraft use, hangar and tarmac use, personnel time, etc.

Two specific environmental characteristics were determined necessary in the selection of the synthetic environment for this research: 1) varying degrees of ambient light levels, and 2) varying levels of mobility and visual obstructions. The intent was to simulate the range of lighting levels and the physical obstructions associated with moving within and around the various confining service spaces of an aircraft. Given these requirements, the Wright-Patterson Super Playground proved to be the perfect setting. This exceptional playground offered enclosed rooms with varying light levels, winding staircases and confined crawlspace areas. Thus, the environment provided mobility requirements, obstructions, and restrictive spaces representative of engine- or landing gear bays. Data obtained from the synthetic test provided both benefits of the display and areas for improvement.

In this first phase of the SBIR effort, the non-digital synthetic environment provided a platform for inexpensive testing. The mechanisms used for the test included existing equipment and a few simple objects in the environment to simulate the hands-on activities associated with aircraft maintenance.

The Phase II SBIR award for this GMD effort provided the funding and time to fully implement the LSF development approach. The three-phased testing approach has been set up and is currently underway. The laboratory test evaluated the GMD in relation to a standard LCD-type display. The intent was to determine the conditions under which the GMD performed at least as well as the LCD display. Initial findings indicate that when information is presented in the environment, external from the display, then entered into the system via the display, subjects perform equally well with the GMD and LCD.

The synthetic environment test was designed to evaluate dual task performance in a mobile environment (Revels, Kancler, Quill, & Nemeth, in press). The primary intent of this study was to evaluate the potential effects of obscured vision (due to the display image on the glasses) on one's ability to move around an obstructive environment. The dual task paradigm provided the synthesis between computer-based task performance and mobility performance (see Figure 3).

Figure 3. GMD Synthetic Environment

The field test for this Phase II effort is scheduled for late 1999. The intent of this final effort is to fine-tune the display usability in areas such as fit, comfort, safety, and hygiene. The flight line maintenance environment is necessary to prove the concept that the GMD is usable in an environment for which it is intended. AFRL research has shown that detailed subjective feedback is best obtained from real end-users on the flight line.

An important benefit realized by implementing the LSF process is the ability to build upon empirical evidence found in each phase of testing. That is, the synthetic test builds upon information gathered from the laboratory test, and the field test building upon the findings of the two previous tests. This "building block" approach is commonly used in training curricula and is a major justification for digital synthetic task environments—the student builds skills in a safe, controlled environment. The primary difference between this training approach and the phased test approach used by HESR, however, is the use of inexpensive, non-digital apparatus in the LSF synthetic environments.

Mechanisms Used in Synthetic Environments

A well-constructed synthetic environment operates like a fine-tuned machine—it is a conglomeration of elemental pieces and parts that come together to perform the function of the synthetic environment. To achieve this end, the elemental pieces, or "mechanisms," which will create the appropriate synthetic environment must be carefully selected and integrated into the synthetic environment's design. For example, a mechanism might be a simulator that digitally presents visual stimuli to the user or it could be a balsa wood mock-up. A key aspect in the selection of such mechanisms is that they are not the actual environment; rather, they are simply tools used in the process of building the environment. These tools directly emulate some key aspect of the actual environment.

When building the synthetic environment for the hands-free control device study (alternative control study mentioned earlier), several mechanisms were assimilated. A tall stand was used that required subjects to stand erect while performing the task. The stand did not accommodate laying objects on it; therefore, subjects were required to hold all test equipment in their hands. Wire bundles attached to a breakout box were used for the wiring continuity checks. The breakout boxes allowed for the insertion of resistance variation. A standard multimeter was used to take resistance measurements.

The GMD mobility test (Phase II of the GMD SBIR) incorporated obstacles into the synthetic environment. These mechanisms were made from simple materials, such as PVC pipe and plastic chains. The obstacles were adjustable so that they could be placed at the subject's knee, hip, shoulder, and eye height. While using the GMD display for a series of tasks, the subject needed to move through a 100' course without touching the obstacles. The course, also a mechanism, was a long narrow hallway. A specific set of criteria was used to select an appropriate hall for the test.

In each case, the mechanisms used to assemble the synthetic environment were based on the needs of the study. For the hands-free control study, it was important to provide tactile stimuli that closely resembled actual maintenance tasks. The GMD evaluation placed obstacles at various locations around the body, imitating hazards faced by the technicians as they move around an aircraft.

Benefits of Appropriate Synthetic Environments

Cost savings associated with the LSF approach are substantial. Savings can be realized in both testing and system design. For testing, inexpensive mechanisms can often be used in synthetic task environments. The systematic approach to critical element identification eliminates unnecessary mechanisms. Finally, the building-block nature of the LSF approach eliminates extraneous, expensive field testing by limiting field tests to critical issues identified in laboratory and synthetic testing. System design solutions, resulting from the LSF approach, are also less costly because they pinpoint *real system* problems as proven in the laboratory or synthetic tests or as identified in the field evaluation.

The benefits associated with non-digital synthetic environments reach beyond the cost-savings inherent to them. These safe, controlled settings maximize the potential for emerging technologies. For example, flight testing with digital, visual synthetic environments has furthered the development of virtual reality. Subsequently, the fidelity of these virtual environments has increased steadily. Much like the way in which digital synthetic environments have assisted in the advancement of various technologies, non-digital synthetic environments have provided AFRL/HESR with significant findings relevant to use of wearable computer technologies on the flight line. The key to designing synthetic environments is not whether they are digitized, but instead selecting and implementing suitable mechanisms to train or test the task. As appropriate synthetic environments are used for applications such as maintenance, advances in other technologies, such as augmented reality may also realize their full potential.

Augmented reality systems are digitized displays that expand the actual environment through graphical overlays, textual descriptions or other enhancements. The hardware link between these displays and wearable computers is extensive—they both permit direct interaction with the environment while using the display or computer as a performance aid. For these technologies, direct interaction with the environment includes both visual and tactile perceptual cues. If these perceptual elements and the interaction among with other elements can be better understood, appropriate settings for these emerging technologies can be determined. The LSF process provides a cost-effective means of exploring applications for emerging technologies, such as augmented reality systems.

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