LA-UR- 10-04623

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*Title:* Augmented Reality: Don't We All Wish We Lived In One?

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*Intended for:* 51st Annual INMM Meeting, July 11-16 2010 - Conference Proceedings

Los Alamos NATIONAL LABORATORY
EST. 1943

January 27, 2010

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LA-UR-10-00492

**Abstract Submitted for the INMM 51st Annual Meeting, July 11-15, 2010**

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Augmented Reality: Don't We All Wish We Lived In One?

## ABSTRACT:

From stereophonic, positional sound to high-definition imagery that is crisp and clean, high fidelity computer graphics enhance our view, insight, and intuition regarding our environments and conditions. Contemporary 3-D modeling tools offer an open architecture framework that enables integration with other technologically innovative arenas. One innovation of great interest is Augmented Reality, the merging of virtual, digital environments with physical, real-world environments creating a mixed reality where relevant data and information augments the real or actual experience in real-time by spatial or semantic context. Pairing 3-D virtual immersive models with a dynamic platform such as semi-autonomous robotics or personnel odometry systems to create a mixed reality offers a new and innovative design information verification inspection capability, evaluation accuracy, and information gathering capability for nuclear facilities. Our paper discusses the integration of two innovative technologies, 3-D visualizations with inertial positioning systems, and the resulting augmented reality offered to the human inspector. The discussion in the paper includes an exploration of human and non-human (surrogate) inspections of a nuclear facility, integrated safeguards knowledge within a synchronized virtual model operated, or worn, by a human inspector, and the anticipated benefits to safeguards evaluations of facility operations.

# Augmented Reality: Don't We All Wish We Lived In One?

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## Abstract:

*From stereophonic, positional sound to high-definition imagery that is crisp and clean, high fidelity computer graphics enhance our view, insight, and intuition regarding our environments and conditions. Contemporary 3-D modeling tools offer an open architecture framework that enables integration with other technologically innovative arenas. One innovation of great interest is Augmented Reality, the merging of virtual, digital environments with physical, real-world environments creating a mixed reality where relevant data and information augments the real or actual experience in real-time by spatial or semantic context. Pairing 3-D virtual immersive models with a dynamic platform such as semi-autonomous robotics or personnel odometry systems to create a mixed reality offers a new and innovative design information verification inspection capability, evaluation accuracy, and information gathering capability for nuclear facilities. Our paper discusses the integration of two innovative technologies, 3-D visualizations with inertial positioning systems, and the resulting augmented reality offered to the human inspector. The discussion in the paper includes an exploration of human and non-human (surrogate) inspections of a nuclear facility, integrated safeguards knowledge within a synchronized virtual model operated, or worn, by a human inspector, and the anticipated benefits to safeguards evaluations of facility operations including less reliance upon inspector memory, attentional focus, and mental computation.*

KEY WORDS: diversion detection, virtual environments, 3-D modeling, design information verification, personal dead reckoning system, inertial motion

## Introduction:

As part of their nuclear non-proliferation and safeguards activities, inspectors for the International Atomic Energy Agency (IAEA) perform design information verification (DIV) of nuclear facilities. DIV inspectors typically use hand tools such as construction tape-measures, and laser distance instruments, combined with facility plot plans, overhead images, magazine articles, construction drawings, etc. to determine if the building locations and dimensions match the declarations. Inside the facility, they make use of the declared information, photographs (typically Polaroid photographs), blueprints and piping diagrams, and in limited cases, a 3-Dimensional Laser Range Finder (3DLR) to collect information about the layout of the facility and make a determination about whether the design and use of the facility match the declaration. The inspector also verifies essential equipment through a compiled Essential Equipment List (EEL) for that facility. This lists the equipment necessary for the plant to operate as declared. Omissions or additions installed in the facility would be cause for further investigation. Finally, the inspector will also verify the IAEA safeguards set-up at the facility. This includes the equipment, communications pathways, cameras, seals, and other equipment or devices utilized by the IAEA. The inspector is looking to ensure that the safeguards systems have not been tampered with, and thus maintain their independence to assist with drawing a safeguards conclusion about the facility.

One of the major challenges facing nonproliferation design verification inspectors is parsing safeguards relevant information. Often inspectors have a short period of time, a large amount of information to review and perform their verification in an unfamiliar facility. In addition, the same inspector may not perform subsequent inspections of the same facility. Detecting minor differences in configurations or other key parameters can be difficult, thus encumbering the verification process. The current practice of DIV is labor intensive, and very dependent upon the individual experience and capabilities of the selected inspector.

A systems approach of implementing an intelligent information system that spatially highlights safeguards relevant information in a photo-realistic virtual model has the potential to reduce the inspector's workload, cue performance, and improve accuracy while improving information verification. The following sections of this paper will articulate the design approach being conducted to create a facility information system (FIS) that provides plug-ins for search and comparison, data fusion, information-to-spatial correlation, display/control interface and provides archival capability. The system leverages advances in virtual modeling engines and data reduction strategies to tie information to spatial representations of the facility specifics and making this information available to support the decision process.

## System Description

### 3D Virtual Environment

There has been a rising interest in computer-generated visualization and virtualization for safeguards applications. While the initial focus has been on the obvious value to training new inspectors and providing review tools for seasoned professionals, the value gained by building tools for direct application to an inspector's tasks is becoming easier to demonstrate. Since operational facilities tend to be visually chaotic, with intertwined pipe runs, purely functional aesthetics, and, in some cases, layers of patina obscuring what little color was there to begin with, it is understandable that an inspector would naturally focus on the elements that were familiar or within their areas of expertise and perhaps miss important elements that lay outside their sphere of knowledge or intuition.

Current research into Augmented Reality has been centered on video overlay, where information is presented on top of a video stream.[cite] Sports fans have been enjoying this approach during televised events for several years. Given the complexity and poor lighting of many facilities, this approach does not seem to be the best option. By providing a simplified 3D virtualization of the space that is oriented and keyed to the inspector's position and view, safeguards relevant systems and information can be highlighted in something akin to the GPS systems that many automobile drivers rely on daily. A stylized, 3D map of a facility that tracks the inspector's movements provides a streamlined flow of important data to the user without crowding their view or overwhelming them with perhaps pertinent but distracting levels of information. The 3D environment can provide markers or highlights on relevant systems in order to queue the user's attention, the user then has the option of selecting an object and retrieving any available data that they believe to be relevant.

Figure 1 Virtualized Robotics Lab at INL, includes an overlaid 5 meter grid

## Positioning

Witmer et al [1] have demonstrated that physically walking enables system users to create a more accurate mental model of the virtual environment as compared to using traditional computer input devices. Ruddle and Lessels instrumented treadmills to provide input to the virtual environments in their experiments [2]. Their efforts differ from our work since the success of the Facility Information System (FIS) will require an accurate positioning input that ties human movement in the physical environment, rather than treadmill walking, to movement in the virtual world. The positioning solution will serve as system input to maintain the VE perspective consistent with the operator's perspective in the true environment.

There are two components in maintaining an accurate VE perspective: the first problem is accurately tracking human movement in the physical space, i.e., the ***egocentric*** localization problem. The problem of maintaining accurate positioning information in global positioning system (GPS) denied areas is an open research problem. The second positioning problem is accurately correlating the egocentric position to the abstract virtual environment. This second positioning challenge is the ***exocentric*** positioning problem. The exocentric positioning problem is what has prevented Virtual Reality (VR) systems portrayed in film and literature from becoming a reality. What has plagued VR systems from the inception of the idea has been accurately maintaining and correlating the 1380 degrees of freedom of the human body (or at least a substantial subset thereof). Fortunately for the FIS to be successful in maintaining accurate perspective for use only relies on maintaining the operator's X displacement, the operator's Y displacement, and the operator's heading (see Figure 1 **BIRCH WE NEED A FIGURE HERE**). Although it can be argued that the exocentric problem requires an egocentric solution the fundamentals are such that the two problems can be pursued in parallel as articulated below.

## Egocentric Positioning

Human movement cannot be tracked without the use of instrumentation or perceptual sensing. Solutions to the egocentric positioning problem can be derived using wearable sensors as well as leveraging statically placed sensors in the environment. In an effort to minimize the required equipment for system deployment, we will e focus our investigation on wearable sensing options i.e. inertial sensing systems, and stereo and monocular vision systems.

The initial FIS implementation utilizes a Personal Dead Reckoning System (PDR). The PDR system is associated with personnel walking and does not require GPS, beacons, or landmarks. In some applications the PDR system employs an inertial measurement unit (IMU) that, based upon rate of rotation and acceleration, can provide near real time estimates of the wearer relative to a known starting point (see Ojeda and Borenstein 2007).[3] The system is therefore useful in GPS-denied environments, such as inside buildings, tunnels, or dense forests. In the current application PDR can be used to keep track of the person and which rooms have been cleared and which have not. It should be noted that the PDR yields linear displacement in addition to the subject's orientation with respect to the of x, y, and z axis.

Figure 2 is a plot of PDR system output take in the North Boulevard test facility. During the data collection exercise the PDR system was worn as the data collector (surrogate inspector) traversed the entire laboratory environment. The straight-line distance of the path during the data collection exercise represented in Figure 2 is 181.08 meters. The PDR system reported a 1.17-meter error, < 1%, over the course of the data collection exercise. Overall, FIS system performance is tied to the ability to maintain user movement through the environment. Future efforts will investigate the use of Visual Simultaneous Localization and Mapping (VSLAM) [4] to further reduce egocentric positioning system error.

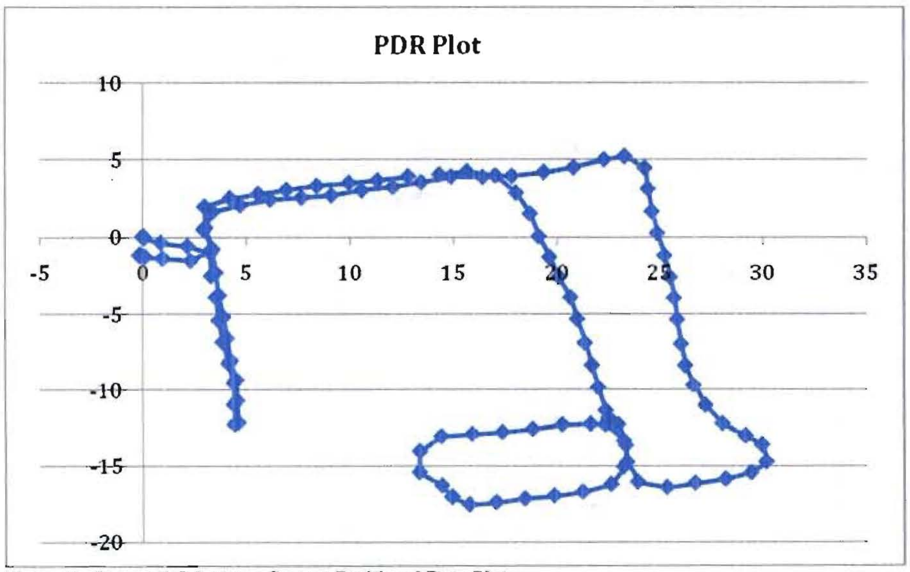


**Figure 2: Personal Odometry System Positional Data Plot**

## Exocentric Positioning

Independent of egocentric positioning system's accuracy, if the system inspector's initial starting point is not accurately registered in the virtual model the resultant system will not be not usable. To establish the initial position correlation and provide calibration spots within the virtual model the authors have implemented a mixed initiative approach. Calibration or "relative ground truth" positions have been added to the virtual model. System users will be able to course correct at the predefined locations in the virtual mode. In addition system users will have a continuous ability to adjust the virtual model camera perspective and heading with respect to their corporeal view.

### DATABASE

Recently Virtual Environment software engines have begun supporting component level scripting. The addition of component level scripting is enabling feature to turn the virtual model into an augmented reality system. With the ability to attach database query script to safeguards relevant components in the photorealistic virtual model we transform an artistic rendition into a valuable tool. As a tool, the virtual model will serve the dual role of user interface and database client. Safeguards relevant components will be highlighted to inform system users of the presence of a data association to the component. The virtual model will serve the dual role of user interface and database client. Through interaction with the virtual model system users have to ability to execute requests (e.g. scripts) to the database web server. Given the request the database server forwards the request via the associated software controller to the access the data in the database. The database query results will then be presented to the user in a display suitable for the data type.

The integration of the data with the virtual reality model leverages concepts from the area of Knowledge Engineering and man-machine interface studies. A MYSQL nuclear safeguards specific database is being defined to contain the following safeguards pertinent data types: 3D Laser Range Finder (3DLR), blueprints (locations or possibly raw data elements, and measures), piping diagrams, electronic radiation and contamination maps, and digital images, as well as a variety of document formats to support historic notes from prior inspections. Each data type has an association to locations or components within the physical facility under review. Once these associations are defined, either a priori or at the time of data creation, the data can be presented to the user on demand, or automatically when the user has physically moved into a given area of the environment under inspection.

## Task Analysis

From a human systems perspective there are two fundamental difficulties when inspecting nuclear facilities. The first is sifting through facility documentation in search of relevant information (i.e. safeguards information) and the second is spatially correlating relevant information to the facility physical design. In order to inform DIV design regarding human factors requirements, task analysis with an IAEA relevant subject matter expert was conducted the purpose of which was twofold; to develop information requirements for the design of a data base and to identify tasks and task requirements with significant physical and mental workload.

The inspector tasking is focused upon verification of the safeguards relevant features of the facility and to periodically ensure that those features have not changed. Design information for all facilities within a State is made available to the International Atomic Energy Agency (IAEA) and includes:

1) identification of the facility—general character, purpose, capacity, geographic location,
2) description of layout—including form, location and flowpath, and exits and entries of nuclear material,

3) description of features relating to accountancy, containment and surveillance,
4) description of existing and proposed procedures of accountancy and control, with references to material balance areas.

Detecting minor differences in configurations or other key parameters can be difficult, thus encumbering the verification process. Cognitive processes involved include spatial ability, recall (of objects from the environment), recognition, and anomaly detection. Ongoing facility construction can alter the path in the environment from the previous inspection and thus interfere with the processing of change sequence coupled cues that change has occurred.

A technical and perceptual/cognitive challenge exists in developing an approach that allows inspectors to seamlessly switch from VR environments to 2D data base information and back to the surrounding environment with minimal errors, and fatigue associated with cognitive switching between presentation modalities and styles. Providing an intelligent information system with archival capability that can both prompt an inspector to look for location specific key information and bring up previous instances of that information (photographs, blueprints, piping diagrams, and key equipment lists) could go a long ways toward reducing cognitive demands upon the inspector. Opportunity exists for aiding travel in the inspection environment. For example, a trail through the environment can be generated by the inspector's movements, stored, and recalled during the next inspection. Thus, in walking through the environment a second time, the inspector can be cued as to where to go next and what to look for. The analogy is one of breadcrumbs or virtual footprints. For a review of the value of generating trails automatically and a number of approaches in virtual worlds see for example Ruddle (2008).[5]

In order to support the design of a supporting data base and human machine interface, task analysis was undertaken to identify key information requirements, task flow, and measurement tools used to support the inspectors decision making process and to provide insights regarding the crafting of a usability experiment planned for later this year. Task analysis was conducted using an interview process aided by a human factors walk down of a fuel conditioning facility on the prior day. A series of structured questions were administered and used to guide the task analysis process. The subject matter expert, an ex IAEA inspector, was encouraged to bring forth general as well as specific insights regarding the inspection process including the routine, time available, and any data sources used to support the inspection process. The questions asked could be grouped into the following: general questions and demographic information, verification of instruments, verification of operator's procedures and records, verification of the operation status of the facility, and assessing the safeguards approach of the facility. The list below is a sample of the nature of the questions used in supporting the interview process:

1) How long is typically needed to complete this task
2) How much time is typically available
3) Are there any potential environmental factors that make the verification of the operator and inspector safeguards instruments difficult?
4) What information do you need to complete verification of the operator and inspector safeguards instruments?'
5) How would you describe the mental workload associated with the verification of the operator and inspector safeguards instruments?
6) Is the information necessary for the verification of the operator and inspector safeguards instruments available and reliable?
7) What kind of strategies do you use to complete this task? Do you use any rules of thumb to make decisions?

As a result of the task analysis findings a number of cognitively or physically demanding aspects of the DIV were identified. In the case of verification of essential equipment components and configurations this includes: inspection of closely located functional related equipment at the same time often against operator provided engineering drawings, process flow schematics, P&IDs, equipment installation diagrams, and photographs from previous inspections. As part of this process an inspector may use digital cameras, video cameras, architectural tape measures laser distance meters and 3DLR. Key in the inspectors mind is the notion of the proper placement of equipment, does the sensor in place have the sensitivity to measure amounts of concern, are shared surveillances available, are they independent, is there the presence of unwanted shielding in front of equipment, are samples coming from the correct source, etc. Similar information was collected for the majority of inspector tasks. This information is being integrated into the development of the system including informational aspects. For a review of task analysis methods a number of references may be consulted (see Crandall, Klein, and Hoffman 2006; Kirwan and Ainsworth 1992; Ainsworth and Marshall 2000). [6-8]

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Usability Test and Human Reliability associated with system use. A Usability test of the proposed system is being conducted as part of human factors and human reliability evaluation. Usability is a well researched field that has been applied numerous domains and a number of well qualified references exist (see Dumas and Redish 1994; Nielsen 1993, Bais and Mayhew 2005, Scheneiderman and Plaisant 2004)[9-12]. Usability refers to the functional quality of a product and focuses upon the user's ability to get the job done with tools designed conform to what is known about human mental and physical limitations for making decisions and taking actions. As part of usability test the memory requirements, information display, retrieval, and user actions will be assessed before and after deployment of the tool. Usability engineering and test is iterative throughout the product life cycle. Since the system(s) that supports the DIV process will accompany the inspector, basic usability questions include weight, lugability, legibility, feedback, navigation, concept for interaction, and general ease of use. In the parlance of Donald Norman, we propose a "tool for thought" consistent with the inspectors mental model and information requirements associated with our understanding of the DIV process. [13] One unique aspect of the current project is to assess inspector interaction in terms of human reliability. Human reliability analysis (HRA) is a process that provides a reproducible logic structure and approach to human performance characterization that identifies, models, and quantifies human error within a probabilistic framework. The context of the human performance is characterized by series of influencing factors know as performance shaping factors that include time available, task complexity, human machine interface (HMI), stress, and work practices. Separate base failure rates are assumed for actions and diagnoses, and then, are adjusted on the basis of these performance factors. Although traditionally, HRA has been used as a risk analysis method, there is ample evidence that HRA is beneficial as a human systems design analysis tool. There is considerable breadth in HRA, some techniques are more tuned to error classification, others to formal error quantification. Insights for the design process and overall evaluation are determined by running scenarios and assessing the expected failure rates which are then placed in logic structures to determine the overall impact on task performance and risk. This information will be used to determine refinements to the inspector's 3D visualization system data base and HMI. Numerous HRA sources can be accessed by the reader to gain a more in-depth understanding of HRA models and techniques (Gertman and Blackman 1994; Chandler, Chang, Mosleh, Marble, Boring, and Gertman 2006; Boring, and Oxstrand 2009, Gertman et al 2005). [14-17]

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## Discussion and Future Work

This paper articulates ongoing efforts at the Idaho and Los Alamos National Laboratories to address a need in the area of nuclear non-proliferation design information verification. The initial results show the feasibility of synchronizing a photorealistic model's virtual perspective to that of the corporeal environment by coupling proprioceptive sensors to track human movement in a global positioning system denied area. Moreover, the utility of the capability is enhanced by connecting components in the model to a database containing information pertaining to their physical equivalents.

Future work will include a series of system usability tests to ensure general usability of the system as well as baseline performance enhancements or impediments that may be introduced by augmented reality toolsets in the design information verification domain.

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