Radiation Exposure Modeling and Project Schedule Visualization

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Biography

Bill Jaquish is a Principal Engineer at ICF Kaiser Hanford Company. He received his Bachelors degree in Mechanical Engineering from Washington State University in 1983, and a Masters from the University of Wisconsin-Madison in 1987. He has been using IGRIP to develop complex mechanical simulations of robotic and remote systems for remediation of the Department of Energy's Hanford site since 1992.

Valerie Enderlin is an engineer in ICF Kaiser Hanford's Engineering Services Division. She earned her Bachelor's of Science in Mechanical Engineering from Washington State University in 1987 and has been working with IGRIP since 1991. Applications of IGRIP include control of multiple robotic systems and technical evaluations of engineering designs.

Abstract

This paper discusses two applications using IGRIP (Interactive Graphical Robot Instruction Program) to assist environmental remediation efforts at the Department of Energy (DOE) Hanford Site. In the first application, IGRIP is used to calculate the estimated radiation exposure to workers conducting tasks in radiation environments. In the second, IGRIP is used as a configuration management tool to detect interferences between equipment and personnel work areas for multiple projects occurring simultaneously in one area. Both of these applications have the capability to reduce environmental remediation costs by reducing personnel radiation exposure and by providing a method to effectively manage multiple projects in a single facility.

Radiation Exposure Modeling

Problem Statement

Radiation exposure to personnel working in radiation zones represents a large expense to many environmental cleanup projects. This cost is estimated at between $2,500 and $20,000 per man rem. Procedures to minimize radiation exposure rely heavily on pre-job planning. This type of review is a qualitative evaluation and is of limited accuracy in predicting the accumulated radiation dose for a given task. What is needed is a more quantitative method to optimize remediation tasks to minimize the cost, task duration, and personal radiation exposure. A proof-of-principle IGRIP workcell has been created to demonstrate the capability of IGRIP to do this.

Simulation Requirements

In order to accurately model radiation exposure there are two key requirements. The first is that the simulation software accurately represent the time and motion of the personnel and equipment required to model the task. The second is that radiation exposure data must be incorporated into or accessible by the simulation software.

IGRIP is a very suitable software tool for radiation dose modeling since it is a time-based simulation program that can accurately model the movement of personnel and mechanical equipment. IGRIP also fulfills the second requirement. IGRIP has the capability to include radiation field information within the workcell using the Graphical Simulation Language (GSL) programming language. A more modular approach is to use IGRIP's ability to communicate via Unix sockets with external executable programs. These external programs then provide the radiation exposure information to the workcell.

Methodology

The workcell was designed with two requirements in mind. The first was that the workcell be able to access radiation field data from multiple sources. Radiation field maps describe the dose rate using two- or three-dimensional grids. The radiation field maps can be either theoretically calculated or actually measured in the field. Monte Carlo N-Particle (MCNP) is a theoretical radiation transport code used at Hanford to predict radiation fields. MCNP is typically used to model radiation fields associated with highly radioactive equipment. MCNP calculates the radiation dose at points on a user defined grid for a given environment. Field survey data can be gathered manually or by using remote equipment. Field survey data is typically available for low radiation field environments. The second requirement was that the workcell accommodate changing radiation field information. These changes can be due to refinements in the theoretical calculation or to changes in the facility that alter the real world radiation field and require the radiation map to be recalculated. Since this information is often subject to change, this requirement is necessary for a workable solution.

In order to handle a variety of radiation environments, the radiation sources are separated into two categories: background radiation and radiation from discrete sources. The difference is that the background radiation field is fixed relative to the facility and does not move. Discrete sources are associated with unique devices which can be manipulated and relocated within the workcell.

The radiation maps for background radiation and the discrete sources are structured slightly different. The background radiation map describe the radiation dose rate using a coordinate system relative to some benchmark in the room or facility. This map describes the radiation field at various locations within the room , but contains no information as to the direction of the source of the radiation. The dose rate is a function of location in the room only. For discrete sources, the radiation map defines the radiation field around the source with the assumption that the source is suspended in air. The map considers only the effects of radiation transmission through open air. The map describes the radiation dose rate using a coordinate system relative to the discrete source. The dose rate is then a function of position relative to the discrete source.

To provide the mechanism to calculate the radiation dose accumulated by workers in the simulation, a separate device was created to implement the radiation dose modeling. This approach provides a measure of modularity by separating the GSL programming which controls the movement of the workers and equipment from the mechanics of calculating the radiation dose for each worker. This modularity also makes it relatively simple to include these radiation modeling capabilities into IGRIP workcells that have already been developed.

The GSL program for the radiation modeling device contains a loop that cycles once each simulation time step. The function of this device is to determine the instantaneous radiation dose rate received by each worker during every simulation time step and to accumulate the total dose. The dose rate is the sum of the background dose rate and the dose rates from all discrete radiation sources. At each simulation time step this device sends position information of each worker to an external executable program via a Unix socket. An external executable program exists for each radiation source in the workcell. For the background dose, the coordinates of the worker relative to the room is transferred. For discrete sources the coordinates of the worker relative to the discrete source is transferred. This approach can accommodate multiple workers and multiple discrete sources.

The function of each external executable program is to determine the instantaneous radiation dose based on the position information passed to it. The program reads the external data file that contains the radiation dose map and interpolates through the data to determine an instantaneous dose rate at the given location. The program then passes the instantaneous dose rate back to the radiation modeling device.

Take, for example, a workcell with two workers, a background radiation field, and a single discrete source. At each simulation time step the radiation modeling device calls two unique external executable programs two times, once for each worker. The coordinates of the first worker relative to the workcell are sent to the program which calculates the instantaneous background dose. The coordinates of the first worker relative to the discrete source are sent to the program which calculates the instantaneous dose from the discrete source. These same two programs are then called for the second worker. The dose modeling device calculates the dose received at each time step which is the product of the instantaneous dose rate and the time step length. The cumulative dose rate is the summation of the radiation dose for each simulation time step.

Limitations

One of the limitations of this methodology is that the instantaneous dose rate from each discrete source considers only the straight line path from the source to the worker. This approach disregards radiation that may be reflected off dense objects adjacent to the worker or the discrete source. For some tasks this may result in a low estimate of the radiation dose, but in most cases, the dose transmitted by indirect paths is several orders of magnitude lower then the direct path dose.

Other Considerations

A necessary feature to apply this methodology is the ability to account for shielding effects due to solid objects that come between the workers and the discrete sources. In this approach shielding has no effect on lowering the background radiation dose since the background radiation field is assumed to be non-directional. The effects of shielding, however, can be included for the discrete sources since the radiation field is emitted from a known location. IGRIP can detect objects constructed as parts or devices that are on the straight-line path between a worker and a discrete source. The dose reduction due to the shielding can be approximated using an attenuation factor. The shielded dose is then the dose rate assuming no shielding times the attenuation factor.

Accuracy

The absolute accuracy of the radiation dose levels calculated by this method have not been checked to date. The accuracy is dependent upon many factors. The two major factors are the quality of the radiation dose maps and the accuracy of the simulation of the task performed by the workers. Future work on this application will include a measurement of the absolute accuracy of the approach. Regardless of absolute accuracy, this approach provides a common method to compare alternative procedures to complete remediation tasks.

Project Schedule Visualization

Problem Statement

Environmental remediation activities are being planned for many facilities at the DOE Hanford Site. These operations typically consist of a series of discrete cleanup projects that will be conducted, many simultaneously, over a period of several years. As an example, at the K-East Basins 1,150 metric tons of spent nuclear fuel will be removed from the current storage pools and will be relocated to a more suitable interim storage facility. This operation will consist of up to 15 distinct cleanup projects to be conducted over several years within the confines of one room, the storage pool. Given the limited space of this one room, it is difficult for each of these planned projects to complete their respective missions on schedule. What is needed is a method to effectively manage multiple simultaneous projects conducted within one room or workspace.

Project scheduling applications are capable of tracking and coordinating multiple projects and are especially well suited to analyzing the use of resources such as personnel and equipment. Scheduling applications are however not well suited to managing interferences between equipment and personnel workspace for multiple projects such as this. For a few simple engineering tasks this effort can be performed manually, but as the number and sophistication of the projects grow, the effort grows exponentially and an automated method becomes desirable. Scheduling applications also lack the capability to visualize the sequence of events. This capability is extremely helpful for analyzing the interaction between multiple projects.

To demonstrate the capability of IGRIP to help manage multiple projects, a subset of the problem was selected as the target for a proof-of-principle workcell. The target problem was to develop a workcell that would visualize a task sequence as defined in a project schedule. The workcell would read a schedule (as a tabular text file) and make the resources associated with each scheduled task visible when the task was being performed and invisible otherwise. There would be no motion of any of the devices in this simulation. The simulation would also be required to detect interferences between the various equipment items and workers identified as schedule resources.

Simulation Requirements

In order to develop a simulation to visualize a project schedule, a simulation tool is needed that can access and manipulate external text files and that can detect collisions between objects. Most scheduling programs can create a tabulated text file that includes the task name, task start time, task finish time, and resource names. In order to use this information the simulation tool must be able to access the text file that contains this information.

IGRIP has the capability to access external data files directly and to read the records into the GSL program. IGRIP also includes the ability to detect collisions between objects. This feature is used as the mechanism to detect interferences between equipment and personnel workspace as the simulation executes. Both of these features were key in selecting IGRIP as the simulation tool for this application.

Methodology

The objective of this approach was to provide an environment that combines the "What", "When", and "Where" information for multiple projects. In the prototype workcell the "What" and "Where" information is defined by the devices placed in the workcell. Typical equipment items include boxes, pallets, carts, tool chests, and hoses. All of these equipment items are located in the workcell per the installation drawings. The personnel workspace areas are included in the workcell as transparent blocks which identify the area that workers will occupy to conduct various tasks for each project. The workspace areas are also structured as devices with unique names. The size and location of the workspace areas are determined from the installation drawings and the task procedure description. The schedule provides the "When" information by defining the start and finish times for the use of the equipment items.

The implementation of this approach is straightforward. The workcell uses the schedule to define when each device is made visible and invisible. None of the devices move during the simulation. With the Collision mode activated, IGRIP detects collisions between devices that are visible and that intersect.

The workcell was constructed with one GSL program. The first step in the program is to open the schedule text file. For all tasks in the schedule, the task name, start time, finish time, and resource names are read into arrays in the GSL program. The next step is to initialize the visibility of all of the resource devices by making them invisible. The collision queue is then constructed for all devices listed in the schedule. The program then begins a continuous loop which cycles once each simulation time step. The loop executes two actions. It checks to see if the current simulation time matches the start time of any of the scheduled tasks. If the simulation time matches the start time, the resources for that task are made visible. The loop also checks to see if the current simulation time matches the finish time of any of the scheduled tasks. If the simulation matches the finish time the resources for that task are made invisible. The simulation ends when the simulation time exceeds the latest finish time for all of the tasks. Throughout the execution of the simulation, when collisions are detected, the device names and time of collision are reported in an external file.

As a result of executing the simulation, problem areas between multiple remediation projects can be detected. Since all of the "What", "When", and "Where" information is located in one place, the user can optimize all of the remediation tasks by changing the location of equipment or altering the timing of the projects.

Future Work

The proof-of-principle workcell has demonstrated a powerful approach to managing multiple projects. In the future this work will be expanded to explore other potential benefits of merging the output of scheduling programs with IGRIP.

Summary

The proof-of-principle workcells that have been developed to date have shown the capability to assist environmental remediation activities at Hanford. The ability to use IGRIP to calculate the estimated radiation exposure to workers conducting tasks in radiation environments has been demonstrated. It has also been demonstrated that IGRIP can be used as a configuration management tool to detect interferences between equipment and personnel work areas for multiple projects occurring simultaneously in one area. These two applications of IGRIP have shown the potential to improve task management and planning while lowering the total life cycle costs for environmental cleanup actions.