Shotcrete Simulation Environment - Phase 1 Analysis

Introduction

For many years, education of shotcrete robot operators has been very expensive since this traditionally is done at live works sites. At BESAB, the idea was born that computer simulations could be used, at least partially, in the education. In 2007, a pilot study was performed to investigate the possibilities of developing such a virtual environment. The study was later the founding blocks of a master's thesis that was carried out in the spring of 2009. The end result of this thesis was a simulation prototype that functioned as a proof of concept for a comprehensive simulation environment.

During the fall of 2009 work started on a complete training simulator for shotcrete operators. The project was divided into two phases ("Phase 1" and "Phase 2"). This document describes the steps that have been taken in Phase 1. Firstly, the project goals were split into a number of segments where each part represents one piece of functionality that is imperative for a working end product.

Moreover, the status of the different parts of Phase 1 is described as well as the design decisions that have been made during the course of the project. Development of many of the different parts is still in active development and will continue to be developed in Phase 2. Also, future improvements for different areas are a discussed.

Persons and Contacts

There are a number of people involved in this project. This section lists all persons and the reason they are part of the project.

The development of the simulator software is performed by Petter Börjesson and Mattias Thell who work at Chalmers University of Technology for this project. At the end of July of 2010, the developers visited the SIGGRAPH computer graphics conference in Los Angeles. The largest of its kinds, the conference brings together research and practical applications from the movie and games industries. This was a great opportunity to hear about the latest developments in computer graphics as well as to get inspiration and new ideas on how to construct and improve the shotcrete simulator.

To help guide the project in the right direction a group was put together with people from a variety of backgrounds. This group provides insights and expertise in fields including shotcrete operation, education, practical applications and technical challenges.

The following people are part of the reference group.

Petter Börjesson, Mattias Thell - Chalmers University of Technology
-Software developers and members of the Visualization Technology group at the division of Construction Management.

Mikael Johansson, Mattias Roupé, Börje Westerdahl - Chalmers University of Technology
- Members of the Visualization Technology group at the division of Construction Management

Per-Erik Josephson - Chalmers University of Technology
- Professor at the division of Construction Management

Lars O. Ericsson - Chalmers University of Technology
-Division of Geology and Geotechnics

Tommy Ellison - BESAB
- Technical supervisor at BESAB and initiator of the project

Henrik Eriksson - BESAB
- Experienced operator of shotcrete robots.

Gunilla Teofilusson - CBI Betonginstitutet
-Works with education in the use of concrete in different areas.

Mikael Hellsten - BeFo
- Research director at BeFo

Per Vedin - Trafikverket
- Rock technician at Trafikverket

Kjell Windelhed - Trafikverket
- Rock technician at Trafikverket

Martin Bergström - Tyréns
- Regional chief, west

Benjamin Krutrök - LKAB
- Chief of produktion of shotcrete and concrete at KGS AB

Robert Sturk - Skanska
- Technical chief

Quanhong Feng - 3D Laser Scanning at ÅF Infrastruktur AB
-Works with laser scanning of tunnels and other construction sites.

Henrik who is mentioned above has also been involved in the development process by testing the simulator. As he knows how the equipment works in reality he can be of great help in ensuring that the simulator becomes more realistic and behaves as one would expect a real robot would. These tests will become more frequent in Phase 2 of the project as the simulation software matures.

Ulf Assarsson is an Associate Professor at the department of Computer Engineering, Chalmers University of Technology, and is responsible for the research group for Computer Graphics. With expertise in the field of computer graphics, after overseeing the master's thesis work as the examiner, he has since moved to an advisory position with the project.

As there are no similar products on the market right now there are no educational programs designed to use digital simulations during education of shotcrete robot operators. CBI is an organization which holds theoretical education about shotcrete with hand held hoses. During the project there has been extra contact with CBI to generate a specification for the simulator. The reason for this is that CBI is a likely to be in charge of an education program in Sweden which uses the simulator and they have the knowledge needed to specify what will be required of the finished training simulator.

During the development other companies have been involved to provide equipment and expertise. KranCom, which is a part of Hetronic, is a company that among many things builds controls for shotcrete robots. A remote control to a real robot was obtained through this company. Models of tunnels were obtained through ÅF Infrastruktur which among other things performs laser scans of tunnels and caves.

Technical advancements

A lot of the work in Phase 1 has gone into constructing and improving the technical framework on which runs the simulation. Described here is some of the major parts and what has been done from a technical point of view.

1. Graphics

At the start of Phase 1, the simulator was based on the prototype version from the master's thesis work. The prototype was based on a rendering and scene hierarchy library called Open Scene Graph (OSG). During development of the prototype a number of problems with OSG had been discovered. Due to time constraints, converting to another rendering engine was not possible. Mainly, two problems with OSG was identified that were serious drawbacks in the continued development of the simulator. Firstly, OSG is based around a derelict rendering architecture of OpenGL 2.0. This design has shortcomings in terms of productivity, performance and programmability which newer versions (OpenGL 3.2) of the architecture improve. Therefore, it was decided that a new rendering engine was to be built from the ground up. While this process certainly took some time, the problem domain of shotcrete reinforcement is quite narrow, allowing the engineering team to make certain assumptions that sped up the process considerably. It was decided that the new rendering pipeline would be based on Deferred Rendering instead of the classic Forward Rendering paradigm. This shift has become a common phenomenon in the games industry since it allows of much more streamlined environment where code complexity is less of an issue because lighting calculations can be decoupled from the rendering of world geometry. In the end, access to new hardware features, improved workflow, organizational improvements and other things was the result of the rebuild at the cost of some development time.

Other than the underlying architecture, several visual improvements have been made. One of these is the introduction of shadows. This significantly improves the quality of the scene and it is accomplished with a technique called Variance Shadow Mapping. Work is currently in progress to further enhance the appearance of the environment by changing the way that ambient lighting is calculated.

2. Physics

Proper physics simulations have been added to the simulation. Currently in use is the open source Bullet library. This library is used for collision detection between the environment, robot and operator. It is also used to drive the joints of the robot arm to produce realistic movements.

To be able to control the physics initialization on the robot parts and induce an improved workflow for adding robots to the simulator, a plug-in for the 3D modeling program Maya was written. The plug-in allows for an intuitive way to model a robot with all the needed information and then export all that data to the simulator.

3. Control Hardware Interface

Obviously, no robot equipment would be of any use without sufficient mechanisms to control it. In earlier versions of the simulation environment, the control and interaction with the robot was managed through use of keyboard, mouse and simple game pad. While still possible, this is far from ideal as it does not correspond well enough to the way an operator works in real life.

Because of this it has been a top priority to obtain a proper, physical control device of the sort that is used in the industry. This requirement has now been satisfied, and a control device has been acquired and integrated with the simulation environment.

To be able to control robots in the simulation, some way of connecting remote controls to a PC was needed. The physical interface used between robots and control devices has been re-interpreted to connect to a PC environment instead of a robot. In order to handle and interpret the signals from the control device, the simulation software have been improved with a protocol to map input from the physical device to the virtual robot in the simulation. This software has naturally been written with extensibility in mind and the proprietary control device currently in use can be replaced for another with minimal work. This feature is important in order to support new kinds of hardware (both in terms of robots and control devices) in the future.

Robot

The simulation prototype featured a functional, although aesthetically displeasing, robot model. While technically correct, this robot model was on par with older robot models and not similar to the state of the art equipment that is in currently in use. Therefore, it was decided that a new model be constructed, replicating the functionality that is found in robotic equipment of today.

The robot currently in use in the simulator is based on the functionality of the Meyco Potenza. This new robot model has several advantages over the older one from previous versions of the simulator. It has improved mobility in terms of number of joints and axis of operation as well as improved visual appearance. It also conforms to what operators can expect to work with in the future. During the work to upgrade the robot the software has also been improved to allow for an easier way to add different robot models in the future.

Simulation Environment

Several improvements to the rendering system and rendering techniques have been implemented throughout this phase, a basic overview of which are described below;

The rendering architecture and the basic system design of the software has been significantly improved during Phase 1, as explained above. Not only has the program become much more stable and secure, but the system was also designed and rebuilt in such a way that adding new features and improvements can be made in considerably less time.

Graphics-intense software products induce a heavy workload on workstations, even with the rapidly advancing technology of today. Thankfully, specialized graphics hardware can and should be used to alleviate this problem. Throughout the prototype, not much care was taken to make the simulation as efficient as possible, but this has since then been rectified. To facilitate efficient use of all the resources of the computer, much of the computational workload can be executed on the graphics card. This is something that has been employed in the development of this phase. Most graphics intense operations are now computed on the graphics card, making them much more efficient than in previous versions of the simulator.

In order to render the mountain surface as well as the applied concrete, the prototype version used a rendering technique called Parallax Occlusion Mapping. This enabled the rock surface to protrude and extend dynamically and was important to the simulated application of concrete. The method worked well in the circumstances governing the prototype. However, there are several drawbacks with this technique. The most disturbing of which is the fact that large protrusions is not modeled accurately and manifests itself as incorrect visual representations. This is something that is imperative to a real use-case scenario of shotcrete reinforcement.

Because of the drawbacks of the concrete visualization in the prototype the rendering methods have been changed during this phase to more accurately model how concrete behaves in real situations. In the new system the concrete calculations are done using a technique inspired by Displacement Mapping and this works by directly altering geometric data of the tunnel. Creating displacement this way makes the applied concrete behave in a more realistic manner as well as looking physically correct from all angles which wasn't the case in the prototype. This method also allows for more control over the adhesion calculations of the concrete which adds to the realism of the simulator.

With the intention to train in environments that resemble real world scenarios as much as possible it's important that the tunnels and caves in the simulation are similar to those found at real work sites. Fortunately, it is common practice for companies to carry out laser scans of work sites. Using this data it is possible to reconstruct the environments digitally. The simulator software now supports loading of triangulated tunnel meshes that are constructed from laser scans and these models can then be used during training with the simulator.

Statistics

Realizing that it is indeed a simulated environment that is being worked on, it is possible to not only visualize a real world scenario, but also enhance it in different ways, depending on the needs of the operator (or his supervisor). Such mechanism include real-time feedback from the system regarding the sprayed concrete's depth (in the real world, this is measured by painstakingly taking manual surface samples on regular intervals, a time consuming and potentially inaccurate task). Other statistical tools include information about the amount of concrete used, and feedback regarding adhesion. Information about adhesion is potentially the most valuable piece of information available to the robot operator.

Currently, the exact requirements and needs for the statistics and other feedback during the simulation have not been decided. This area is currently being discussed with experience operators and training personal to get a better view of what is useful and required by the software. At the moment no new tools have been developed in this area but there is support for the same tools that could be found in the prototype. Further development will be done during phase two when the exact requirements have been established.

Interface and Usability

A requirement of the simulation software is that it should be easy and intuitive to use by robot operators and people not particularly comfortable with computerized simulations. Therefore, the software interface cannot become a barrier to traverse before being able to use the simulator properly. To accomplish this, the controls need to be similar to that of a real world robot and the interface to the functionality in the simulator must be easy to grasp and use.

To facilitate the display the required buttons, information and other components, a graphical user interface system have been designed and implemented. This system will be used to construct the components needed for the different user interfaces that are needed throughout the simulator. Further development of the interface will be performed as more of the needed functionality has been specified.

One key issue regarding usability is that of actor movement. That is, while controlling the robot and operating the control device, by what means should the operator move around and position himself in the virtual environment. This is, of course, trivial in the real world where no cognitive burden is imposed to one moving their legs and repositioning themselves using bodily functions. This can be quite problematic in a virtual environment, however. Since the simulation environment will be projected on a flat surface in one direction in front of the operator, there has to be some way that the avatar of the operator can move around and look around in different directions in the virtual world. A simple solution to this problem is to let the avatar be controlled using a mouse and keyboard. This is a standard way of movement when considering games and it can work in this environment as well. However, this kind of control might need some sort of getting used to and an un-initiated person controlling the avatar in this way can potentially become lost and reject the simulation. Another mode of movement is to have fixed locations and viewing directions for the avatar. This will eliminate the problem of having to move in a constrained way, but it will also impose severe restrictions on the visibility in the simulation. A third solution is to swap mode for the robot control. In this case the user can swap between controlling the avatar and the robot with the robot control hardware. These options have been discussed with experience robot operators and tests will be made during the end of phase one or in the beginning of phase two.