Virtual reality application on MFL gas pipeline inspection system

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Abstract This paper describes a visualization technique that animates geometrical defect data that are extracted using a magnetic flux leakage (MFL) operating system on nondestructive evaluation (NDE). Since data are collected from different locations and often not regular, the data must be converted to the standard format that is used within the pipeline in visualization procedures. In order to navigate inside of the pipeline, 3D virtual objects are generated and are able to explore the pipeline continuously. The major objectives of this paper are to characterize, generate general shape of defects, and enable computer interaction in virtual environment. Pipeline navigation system (PNS) has introduced the framework for interactive visual applications based upon the principles of modeling 3D objects. PNS presents some preliminary efforts to enable the user to interact human and computer with each other.

Key Words : Pipeline navigation simulation, virtual reality, magnetic flux leakage, nondestructive evaluation, gas pipeline inspection

1. Introduction

Nondestructive Evaluation (NDE) is concerned with the examination of materials in such a way that the intended use of the inspected material is not impaired [1]. NDE methods are used extensively in manufacturing environments for quality control as well as for examining and monitoring the integrity of engineering structures. Such methods are used for detecting and characterizing flaws in structures such as bridges, nuclear power plants and aircraft.

Magnetostatic methods are used very widely for the inspection of ferromagnetic materials such as steel billets, tank shells and automobile crank shafts [2]. One of the more interesting applications of magnetostatic methods is related to the inspection of underground natural gas pipelines. Natural gas is an important component of a country's energy resource. Unfortunately natural gas is produced at well sites that are far removed from consumer locations. Therefore the inspection of pipelines is very important in transporting natural gas to consumers. The magnetic flux leakage (MFL) method [3] is one of the most popular methods used to detect flaws in gas and oil pipelines. MFL techniques provide a comprehensive analysis of metal loss defects, as well as other discontinuities that could have a potentially detrimental effect on the pipeline's operation if they are not discovered and remedied in a timely fashion.

During a pipeline inspection, an inspection vehicle known as a "pig" is launched into the pipeline and conveyed along the pipe. The pig contains a magnetizer, an array of sensors and a microprocessor-based data acquisition system for logging data. The data is subsequently retrieved and analyzed off-line. Virtual reality (VR) display

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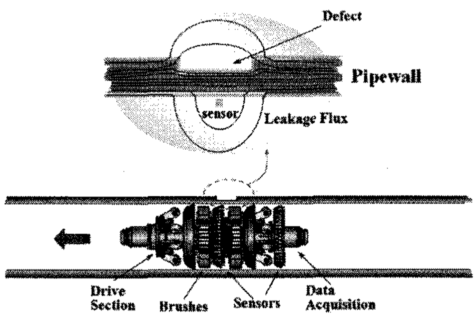
techniques represent an attractive mechanism for presenting this huge amount of data effectively. The application of VR techniques enables the operator to explore the virtual environment generated by the computer. This technique can serve as an important bridge between human operator and the computer and also presents some preliminary efforts in achieving this interface.

2. Pipeline navigation simulation for MFL Inspection

The MFL system is a robot that explores the inside surface of the pipe and detects flaws. The MFL system consists of a vehicle moving at a reasonably fixed velocity and the data used in a virtual environment to display the flaws in the pipeline. PNS is the virtual environment that allows the visualization and continuous exploration of the pipeline.

Although natural gas pipelines are designed, constructed, and tested with considerable margins of safety, the need of monitoring their integrity is of the utmost importance. Some of the more important reasons to maintain a pipeline system include public safety, environmental protection, public relations, and product throughput reliability. Internal pipeline inspection tools have been very successful in revealing loss of pipe wall thickness due to corrosion and other causes. Inspection tools employing magnetic flux leakage (MFL) inspection techniques have proved capable of locating pipeline irregularities such as corrosion pitting, mechanical damage, manufacturing defects, construction defects, hard spots, bends, and dents in addition to metal loss due to corrosion. Also, depending on the mass of the metal, MFL can normally detect such features as circumferential welds, valves, casings, and sleeves.

A schematic diagram of the inspection tool is shown in Figure 1. The magnetic circuit consists of a pair of high energy permanent magnets, a backing iron plate, and a pair of steel brushes that establishes contact with the pipe, and the pipewall itself. A very high magnetic field produced by Neodinium-Iron -Boron magnets ensures that the pipewall is highly saturated. Several Hall plate sensors are mounted circumferentially around the pipe to detect leakage fields that are generated by defects. The volume of data generated is very large because the signals are sampled at intervals that are fractions of an inch apart. The total data generated by all the sensors is typically in excess of several gigabytes.



<Figure 1> Schematic diagram of a typical pig used for gas pipeline inspection [4]

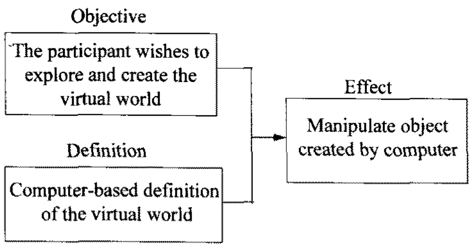
3. Virtual reality

Virtual reality (VR) [5, 6] is an advanced human-computer interface (HCI) that allows the user to interact with the virtual environment which looks "real". The central component to the virtual reality system is a graphics engine that has the requisite speed and capacity to manipulate large volumes of data in real time. Well designed virtual reality environments can enhance the scientist's ability to explore a phenomenon through computers and gain a better understanding of the underlying physical process.

3.1 Definitions

Virtual reality is defined as "the environment and technology which is created artificially to generate sufficient and sensible cues for users" or "a combination of various interface technologies that enables a user to intuitively interact with an immersive and dynamic computer generated environment" [6]. However, implementations of virtual environment worlds have taken different shapes and forms. A popular environment allows human beings to explore "reality" in artificial computer generated worlds using special glasses, gloves, suits or other input devices in 3D environment created by computers [7].

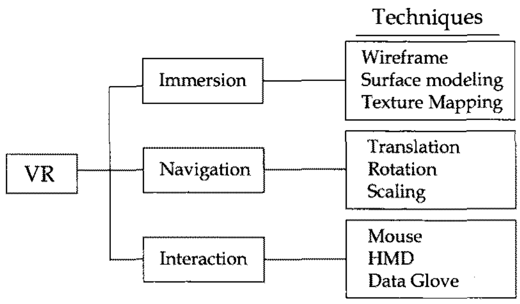
The central objective of VR is to place the participant in an virtual environment that is not normally or easily experienced. Reaching this objective involves establishing a relationship between the participant and the created environment. Accordingly, the basic paradigm of VR is shown in Figure 2. In order to design a specific system, these must be a precise and consistent definition of VR that relates to the human. Meanwhile, qualitative definitions such as the conceptual VR model of [8] are helpful in providing descriptions of the human perceptual system.



<Figure 2> Objective, Definition, and Effect of Virtual Reality

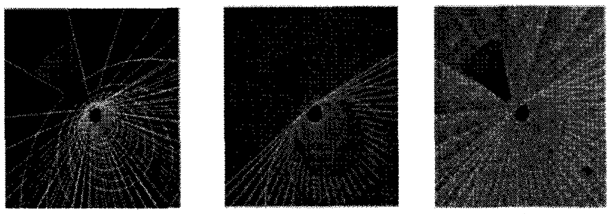
3.2 Elements of VR

Virtual reality consists of the following 3 elements: immersion, navigation and interaction [7] as shown in Figure 3. Immersion represents the degree of visual simulation offered to users while defining the depth of involvement and the extent to which the user can feel the reality. Immersion is a function of the level of user interaction, the type of display, the dimension, proximity and intimacy of viewing environment, image frame rate and sound effects. Immersion can be achieved by techniques such as wireframe, surface modeling, and texture mapping for a gas pipeline application. These are shown in Figure 4. Navigation is the ability to



<Figure 3> Elements of VR

explore the cyberspace created by the computer. To explore the cyberspace, we can use translation, rotation, and scaling techniques. Interaction allows users not only to receive information from the virtual reality system but also to provide a mechanism for mutual exchange of data and interaction. The difference between computer animation and virtual reality lies in the degree of interactivity. For example, in the virtual world, we are not only allowed to replicate actions and behavior in the virtual world but also to interact freely with it. In other words, an interactive system allows the user to create, control, observe and communicate with the environment.



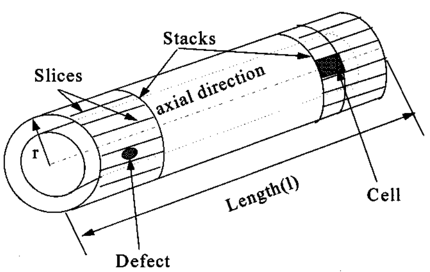
(a) (b) (c)

<Figure 4> An example of VR immersion in gas pipeline (a) wireframe transformation (b) surface modeling (c) texture mapping

4. Virtual pipeline and defect geometry

The 3D objects (pipeline and defects) are reconstructed and displayed on a Silicon Graphics Iris Workstation with OpenGL graphics library [9, 10]. OpenGL is an evolving technology that offers a higher level of sophistication than either PHIGS or PEXlib that is standard graphics software extensively used in industries.

There is a simple primitive cylinder shape provided in OpenGL. However, this simple cylinder only represents a generic pipeline and does not provide any information about the defect such as its location or orientation. Consequently, it is necessary to generate a more complicated pipeline. A pipeline is defined as points consisting of a circle on the xy-coordinate system. The number of points used is 40. Then a circle passing by each point is extruded to the inside screen along the z-axis that can be arbitrarily long. Also, this pipeline can be segmented using the concepts of slices and stacks. Slices are segments cut in radial direction while stacks are segments cut in the axial direction. The concept of stacking can be applied to each section of the pipeline. Figure 5 shows typical pipeline geometry.

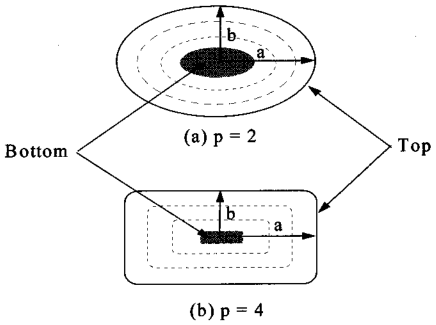


<Figure 5> A typical pipeline

Since the data generated by the defect characterization systems can be huge running into several gigabytes, we use some simple defects as a basis for demonstrating the concept. This simulation employs five parameters that include length, width, surface angle, depth, and type in order to specify the defect in three dimensions. Mathematical modeling with proper parameter values implies that a various number of shapes can be represented. Since the defect characterization can only generate a two dimensional profile, we simplify the task further by considering only two dimensional defects. The simulation assumes that the defect has a "elliptical" cross section defined as

$$\left(\frac{z}{a}\right)^{p}+\left(\frac{\theta}{b}\right)^{p}=1 \qquad (1)$$

where, z is a value of z-direction, θ is a degree from origin locating a defect, and p is the order. We allow two different choices of p, 2 and 4, to obtain distinctly different cross sections as shown in Figure 6.



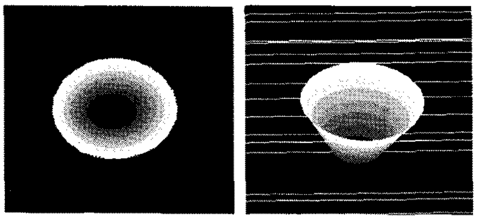
<Figure 6> Top view of a 3D defect

B-spline interpolation technique [11] has been used for rendering smoother. The shape of the B-spline is an approximation of special data points called control points in equation (2).

$$C(u)=\sum_{i=0}^{n} N_{i,p}(u)P_i \qquad (2)$$

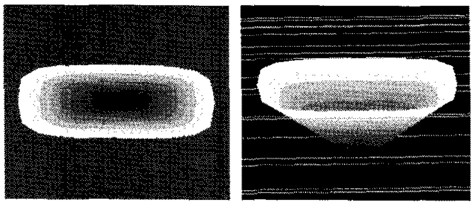
where, n is the number of control points, $C(u)$ are the coordinates of the curve at the parameter value u, $N_{i,p}(u)$ are the p-th degree B-spline basis functions at the parameter value u, and P_i are the coordinates of the control points.

Unlike the two dimensional case, performing the viewing operation in three dimension has the advantage of the impression of reality. Figure 7 and 8 show two different defects obtained using p = 2 and 4 in equation (1). It is apparent that when p = 4, the defect has a rectangular shape. In the wireframe model, it is easy to generate and manipulate since they contain only line segments. Unlike surface and solid models, the wireframe model allows the user to experiment very quickly. Figure 9 shows a defect profile obtained using real defect MFL signal employing wireframe transformation. From MFL data, defect profile can be represented with value of p=4. By using equation (2) and interpolation, MFL data were rendered for smoothing.



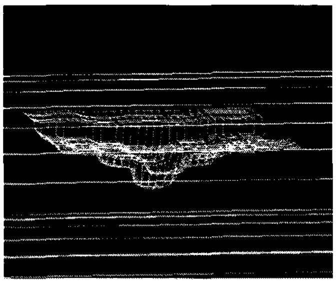
(a) (b)

<Figure 7> Top and side view snapshots of the defect (p=2) obtained using wireframe transformation



(a) (b)

<Figure 8> Top and side view snapshots of the defect (p=4) obtained using wireframe transformation



<Figure 9> Defect generated using real data employing wireframe transformation

5. Conclusions

Unlike the visualization of the defects in two dimensions, the use of virtual reality for 3-D visualization seems revolutionary. Virtual environments are not intended to be a panacea for every computer graphics interface problem. However, the advantages of virtual reality and the unambiguous display of 3-dimensional structures along with the intuitive control of objects in the virtual environment has a great potential in the scientific visualization of data. The ability to explore complex data by selectively displaying certain aspects of that data is the most dramatic of many advantages. This paper has introduced a framework for interactive visual display of 3D objects. The major objective of this work is to develop a virtual reality interface, using a mouse for visualizing defects in NDE applications. With the use of VR techniques, it is possible to explore the environment that the computer generates. These techniques can ultimately connect the analyst and the computer enabling more efficient interaction.

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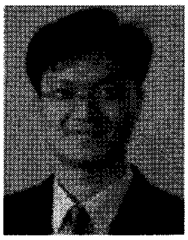

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