

Illustrating how hydraulic machinery works

submitted by

Garoe Dorta-Perez

for the degree of Master of Science

of the

University of Bath

Department of Computer Sciences

January 2015

COPYRIGHT

Attention is drawn to the fact that copyright of this thesis rests with its author. This copy of the thesis has been supplied on the condition that anyone who consults it is understood to recognise that its copyright rests with its author and that no quotation from the thesis and no information derived from it may be published without the prior written consent of the author.

This thesis may be made available for consultation within the University Library and may be photocopied or lent to other libraries for the purposes of consultation.

Signature of Author

Garoe Dorta-Perez

Summary

In this research proposal we present a method for automatic depiction of how it works illustrations of hydraulic machinery.

Chapter 1

Introduction

How things work visualizations have been used as an efficient method to explain how a wide range of systems work. This technique usually involves displaying where each part is in relation to the system, showing how force is transmitted from one piece to the next and animating motion. In order to perform this task a range of visual transformations are used. Such as viewing the system from different angles, zoom degrees, transparency levels, as well as displaying only a subset of the parts. Generating material of this sort typically involves manual methods, usually in the form of an expert drawing each illustration by hand or composing a fixed animation using specific software.

Hydraulic machinery is commonly used in our everyday lives. Such as lifting cars with jacks, rams on excavators or gerotors to control fuel intake. Their popularity is based on their faculty to transmit a force or torque multiplication independently of the distance between input and output. A typical hydraulic equipment has a contained liquid fluid that becomes pressurised when a force is applied to it. Then that force is transmitted to the other end of the fluid. Understanding how the pressure is directed and how it interacts with other parts in the machinery is essential in order to grasp how the whole system works. Therefore, to illustrate the general process, the spatial configuration of each part in the system must be unveiled. As well as the chain of motions that takes place within the gears and the liquid fluids.

There are some common visualisation and illustration techniques used for hydraulic machinery. **Motion arrows** can point out how the solid parts move and they also indicate fluid flow movement. **Frame sequences** display complex motions key frames and they can highlight temporal interactions between the parts. **Animations** are a useful tool in highly dynamic systems, for example when an excessive number of frame

sequences are needed in a particularly complex motion.

Generating visualisations and illustrations for hydraulic machinery is challenging for designers. They must understand in detail what forces are generated when the parts interact with each other and what kind of flow movements are entailed. Furthermore, with 2D illustrations it is impossible to change the viewpoint to explore the object from different angle. Moreover, hydraulic visualizations are usually costly animated by hand, which in addition leads to infrequent updates.

There has been some work done on automatically generating illustrations and visualizations on mechanical assemblies. Nevertheless, it has been restricted to gear to gear interaction only. Whereas work on fluid simulation and visualization has not been applied to hydraulic equipment. As they are usually designed to, either generate complex visualizations for engineering purposes, or at producing visually plausible but not physically accurate results in animation and games.

Simulations can be used to illustrate how hydraulic machinery works. This research proposal aims to introduce a method for generating *How things work* illustrations for hydraulic machinery. This illustrations would help users understanding how this kind of equipment works.

In summary, the main contributions would be:

- An application for creating how things works illustration for hydraulic machinery 3D models.
- A method for detecting motion and interaction of fluid inside model parts.
- Algorithms to automatically generate illustrations with motion arrows and frame sequences

1.1 The Problem

Given a 3D CAD model of some hydraulic machinery we want to generate how things work visualizations. Namely, adding arrows depicting the fluid movement.

The problem can be subdivided into:

1. Part analysis: Detecting fluid containers and fluid handling parts.

2. Fluid simulation: Simulate how the fluid behaves in the previously detected parts.
3. Fluid visualization: Generate arrows to show the results of the simulation.

Part analysis involves detecting the part type and how it interacts with others. So the information saved for type would be gear, cylinder, valve, reservoir, etc. In this section there is a clear difference between the parts that interact with fluids and the ones that do not. With respect to types of interaction, it would be direction of movement, axis of rotation, axis of translation, etc.

1.2 Previous Work

This proposal is based on the following three main areas of previous work.

1.2.1 Explanatory illustration

Explanatory illustration has been effectively used to show complex and/or copious amounts of scientific and technical data. Researchers have have look into generate automatic illustrations for mechanical assemblies [MY*10].

1.2.2 Fluid simulation

Fluid simulation is a well known research area. One of the firsts papers in this area introduced a Grid method [FM96] to solve Navier-Stokes equations by applying forward Euler time integration. Stam [Sta99] extended this method in order to overcome stability issues. More recent simulations introduced the Smooth Particle Hydrodynamics (SPH) technique [Des96]. However the previous techniques assumed the fluid to have no interplay with any rigid body (solid-coupling). Carlson [CMT04] proposed solid-fluid coupling algorithm for grids models using distributed Lagrange multipliers. On the other hand, Muller [MST*04] presented his own method for SPH simulations, which Akinici [AIA12] further improved with the inclusion of friction and dragging. Shao [SZMTW14] also solved stability issues in the previous SPH solid-fluid coupling techniques.

1.2.3 Flow visualization

Streamlines are the standard approach to produce flow visualization. Extensive work has been done in this area as visualizing fluid movement has a broad range of applications. This includes visualizing 2D flow in images using an image-guided algorithm [TB96] and using the fewest number of streamlines [LHS08]. Seeding techniques for

curves on 3D surfaces were explored by Wicke [WST09], who developed a technique to combine model reduction with with grid based methods. And Spencer [SLCZ09] whose method generates streamlines only for visible parts of the surface, thus providing a significant gain in efficiency.

1.3 Related Work

Chapter 2

Data Structures Used in this research

2.1 The 4D-Stack - A Revolutionary Data Structure

The 4D-Stack turned out to be a complete disaster as traversal time approached $O(n^9)$. It is best illustrated by the following equation: $F(x) = \prod_{0 \leq i < k} d_i(x)$ but the following may not be true:

$$-f(x) = -\log \prod_{0 \leq i < k} d_i(x) = -\sum_{0 \leq i < k} \log d_i(x)$$

2.2 More Irrelevant Stuff

If you want to put numbers on equations use this form:

$$f(x) = \int_0^L h(\langle x - p(t), n(t) \rangle) dt. \quad (2.1)$$

Chapter 3

Results

Due to a time quake during the research, the results were catapulted into the future. They will appear in about 20 years. In the meantime to demonstrate the use of tables, please see table ?? for a list of students who took more than 30 years to graduate.

Chapter 4

Conclusions and Future Work

No conclusions can be drawn until the results appear and no future work is recommended.

Bibliography

- [AIA12] AKINCI N., IHMSEN M., AKINCI G.: Versatile rigid-fluid coupling for incompressible SPH. *ACM Transactions on ...* (2012).
- [CMT04] CARLSON M., MUCHA P., TURK G.: Rigid fluid: animating the interplay between rigid bodies and fluid. *ACM Transactions on Graphics (TOG)* (2004), 377–384.
- [Des96] DESBRUN, MATHIEU AND GASCUEL M.-P.: *Smoothed particles: A new paradigm for animating highly deformable bodies*. Springer, 1996.
- [FM96] FOSTER N., METAXAS D.: Realistic Animation of Liquids. *Graphical Models and Image Processing* 58, 5 (Sept. 1996), 471–483.
- [LHS08] LI L., HSIEH H.-H., SHEN H.-W.: Illustrative Streamline Placement and Visualization. *2008 IEEE Pacific Visualization Symposium* (Mar. 2008), 79–86.
- [MST*04] MÜLLER M., SCHIRM S., TESCHNER M., HEIDELBERGER B., GROSS M.: Interaction of fluids with deformable solids. *Computer Animation and Virtual Worlds* 15, 34 (July 2004), 159–171.
- [MY*10] MITRA N. J., YANG Y.-L., YAN D.-M., LI W., AGRAWALA M.: Illustrating How Mechanical Assemblies Work. *ACM Trans. Graph.* 29, 4 (July 2010), 58:1—58:12.
- [SLCZ09] SPENCER B., LARAMEE R. S., CHEN G., ZHANG E.: Evenly Spaced Streamlines for Surfaces: An Image-Based Approach. *Computer Graphics Forum* 28, 6 (Sept. 2009), 1618–1631.
- [Sta99] STAM J.: Stable fluids. *Proceedings of the 26th annual conference on Computer graphics and interactive techniques* (1999), 121–128.

- [SZMTW14] SHAO X., ZHOU Z., MAGNENAT-THALMANN N., WU W.: Stable and Fast Fluid-Solid Coupling for Incompressible SPH. *Computer Graphics Forum* 00, 0 (Oct. 2014), n/a–n/a.
- [TB96] TURK G., BANKS D.: Image-guided streamline placement. *Proceedings of the 23rd annual conference on ...* (1996).
- [WST09] WICKE M., STANTON M., TREUILLE A.: Modular bases for fluid dynamics. *ACM Transactions on Graphics* 28, 3 (July 2009), 1.