Illustrating how hydraulic machinery works

submitted by

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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, as shown in Figure 1-1. 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

Figure 1-1: Cross section of a typical hydraulic cylinder.

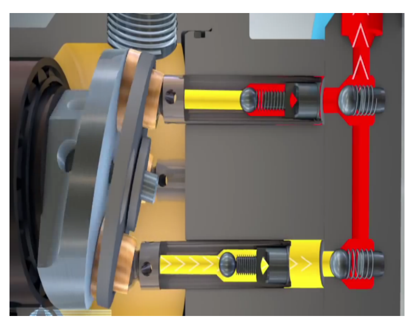

Figure 1-2: Frame of manually generated animation of a hydraulic pump.

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, as shown in Figure 1-2. **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 an 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: Display the fluid simulation data in a intuitive format.

Part analysis involves detecting the part type, how it moves and 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 movement, it would be direction of movement, axis of rotation, axis of translation, etc.

Once the parts have been categorized and given an input force, we will have to simulate how the force is transmitted along the different parts. In the special case where a part is a container of a fluid or is in direct contact with one, that force will have to be introduced in a fluid simulation algorithm. The output of the simulation will then carry the information along to the next parts.

Lastly, in order to visualize the fluid simulation data we will need to generate a visual cue that will indicate intuitively the fluid movement. A simple approach would be to place arrows indicating the overall fluid movement.

1.2 Previous Work

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

1.2.1 Explanatory illustration

Explanatory illustration has to adequately transmit motion on a still image, consequently transforming from the temporal space to the image domain. This is usually found in comics books or in instructions sets.

Nienhaus proposed a technique to depict motion in 3D animations [ND05]. Scene and behaviour descriptions from specialized scene graphs were analysed in order to create the motion cues. Researchers have have look into generate automatic illustrations for mechanical assemblies [MYY*10]. Furthermore, Lowe showed that even though animations have become a generalized tool for visualizing dynamic systems, special care have to be taken as users can fail at extract the necessary information due to the nature of the animation [Low14].

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 1.1 and 1.2 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 Akinci [AIA12] further improveded with the inclusion of friction and dragging. Shao [SZMTW14] also solved stability issues in the previous SPH solid-fluid coupling techniques. For more information on real time fluid simulations see Vines survey [VLM12]. While for survey specific to SPH fluid simulation see Ihmsen [IOS14].

$$\nabla \cdot \mathbf{u} = 0 \tag{1.1}$$

$$\mathbf{u}_t = -(\mathbf{u} \cdot \nabla)\mathbf{u} + \nabla \cdot (\nu \nabla \mathbf{u} - \frac{1}{\rho} \nabla p + \mathbf{f}) \tag{1.2}$$

These two equations represent the conservation of mass and momentum, respectively. Where $\mathbf{u}_t$ is the time derivative vector field of the fluid velocity, p is the scalar pressure field, ρ is the density of the fluid, ν is the kinematic viscosity and $\mathbf{f}$ represents the body force per unit mass, usually gravity.

1.2.3 Flow visualization

Extensive work has been done in this area as visualizing fluid movement has a broad range of applications. However this is a challenging area as it has to effectively display either complex and copious amounts of data, as fluid simulation is usually solved using highly divided grids or with large number of particles, as explained in section 1.2.2. Given the constrains of our problem we will exclusively visualize steady flow.

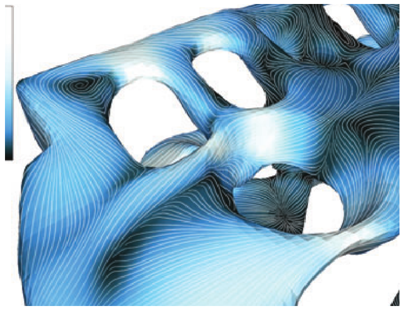

Figure 1-3: Streamlines on a 3D surface [SLCZ09].

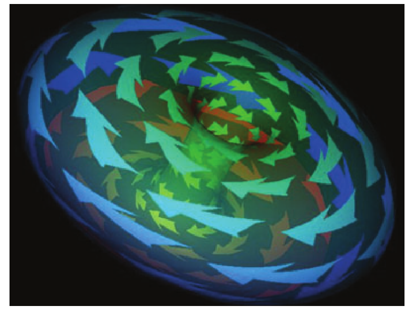

Figure 1-4: Arrows placed on streamlines paths in on a 3D surface [Löf98].

Streamlines are convenient tools to describe and visualize flow, as shown in figure 1-3. A streamline is defined as curve that is everywhere tangent to flow field, i.e. it is parallel to the local velocity vector. Therefore, they provide an intuitive mechanism to show the fluid travel direction. Furthermore, they have properties such as: streamlines will not cross each other (flow will not go across them), or a particle in the fluid starting on one streamline will not leave it. Once the streamlines has been calculated, instead of displaying them as such, they are arrows are replaced by arrows arranged using some criteria. For instance, on the path of each streamline or after clustering some streamlines together, as shown in figure 1-4.

On the 2D image domain, an image-guided algorithm for visualizing 2D flow in images was proposed by Turk [TB96] and which Li improved to use 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. For more information on flow visualization see McLoughlin survey on the topic [MLP*10].

1.3 Related Work

Chapter 2

Conclusions

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.

[IOS14] Ihmsen M., Orthmann J., Solenthaler B.: SPH fluids in computer graphics. *... 2014-State of the Art ...*, 2 (2014), 21–42.

[LHS08] Li L., Hsieh H.-H., Shen H.-W.: Illustrative Streamline Placement and Visualization. *2008 IEEE Pacific Visualization Symposium* (Mar. 2008), 79–86.

[Löf98] Löffelmann H.: *Visualizing Local Properties and Characteristic Structures of Dynamical Systems*. Citeseer, 1998.

[Low14] Lowe R. K.: Dynamic Visualizations: A Two-Edged Sword? In *Handbook of Human Centric Visualization*, Huang W., (Ed.). Springer New York, New York, NY, 2014, pp. 581–604. URL: `http://link.springer.com/10.1007/978-1-4614-7485-2`.

[MLP*10] McLoughlin T., Laramee R. S., Peikert R., Post F. H., Chen M.: Over Two Decades of Integration-Based, Geometric Flow Visualization. *Computer Graphics Forum 29*, 6 (Sept. 2010), 1807–1829.

[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.

[MYY*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.

[ND05] Nienhaus M., Dollner J.: Depicting dynamics using principles of visual art and narrations. *Computer Graphics and Applications,* ..., June (2005), 40–51. URL: `http://ieeexplore.ieee.org/xpls/abs\_all.jsp?arnumber=1438257`.

[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).

[VLM12] Vines M., Lee W.-S., Mavriplis C.: Computer animation challenges for computational fluid dynamics. *International Journal of Computational Fluid Dynamics 26*, 6-8 (July 2012), 407–434.

[WST09] Wicke M., Stanton M., Treuille A.: Modular bases for fluid dynamics. *ACM Transactions on Graphics 28*, 3 (July 2009), 1.