Modeling Unsynchronized Motion Dynamics for Truthful VR Visualizations

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Abstract: This paper deals with the filtering of images of objects in a CAD system, that simultaneously move in very fast and slow motion, so that their dynamics can be observed in truthfully time scaled VR. Micro-Electro-Mechanical systems (MEMS) are miniaturized mechanical or optical equipment less than a millimetre in size. While some have movable parts, such as membranes, valves, cantilevers, others may have only fixed parts. Those with movable parts, can flick, pump or pulsate at rates of up to 500 Hz, while other components in the same MEMS move at slower speeds. This poses a series of problems for truthfully time scaled visualizations. Due to the human being's vision limitation, and the computer's frame rate (which is normally 30 times per second), very fast movements can not be observed clearly, e.g. when a gear rotating in clockwise direction is in high frequency, it appears rotating counter-clockwise. In MEMS a simple truthful time scaling may result in one of the objects still at non-observable fast motion, while another practically reaches a standstill. To solve the dilemma we simulate to illuminate the moving objects with a simulated stroboscopic light. The stroboscopic simulation is demonstrated with an example of rotating gears created in a virtual interactive VRML environment. In this paper we present the results of a systematic combinatorial analysis for finding the stroboscopic illumination intervals and stroboscopic flash duration that produce useful dynamic images.

Keywords: *Virtual Reality; Physics based modeling; Scientific Visualization; Micro-Electro-Mechanical systems*

1. INTRODUCTION

Virtual prototyping is gaining increasing importance in Engineering, because it can reduce the time between design and delivery by 80%. In specialized CAD design visualizations, the goal is not just to show the object being designed but also to produce simulations of the devices and equipment when functioning, with animated VR visualizations. Virtual reality (VR), characterized by real-time simulation, offers a new quality of visual presentation (Dai, Fan., 1998).

The work presented in this paper is part of an ongoing research project whose objective is to build a CAD simulation environment that aids in the design of Micro-Electro-Mechanical Systems (MEMS). The results of the geometric design are then simulated as animated, truthfully time scaled VR scientific visualizations. Our aim is to detect design flaws or timing issues of the components of MEMS being designed (Li and Sitte, 2001).

MEMS are miniaturized mechanical or optical equipment less than a millimetre in size. While some have movable parts, such as membranes, valves, cantilevers, others may have only fixed parts. Problems arise in time scaled visualizations. In mechanic environments it is possible for one component to move at 500Hz while the others move at a rate of 100 times slower. To display simultaneously such components in action in a CAD-VR environment is a challenge.

The trivial solution is downscaling in time to slow motion. This does not work when we have asynchronous events being displayed, e.g. one very fast, and one very slow, because the slow one would come to a standstill or be distorted. To the observer the relative movements between the two bodies may no longer be truthful.

The shape of the structure also influences the observability in VR. For example, a gear or rotor blade may be spinning very fast, so fast that they appear to our eyes as rotating in the opposite direction, but if the object is for instance, a box, the effect appears only at higher speeds. While this effect is well known, and poses no problem in games, it becomes a problem in a virtual prototyping environment, when mimicking the operation of equipment being designed.

This paper investigates the visualization methods to display the movements in an easier observable image, while maintaining physical truthfulness. An example is given in a virtual interactive realtime VRML (Ames, Nadeau and Moreland, 1997) environment.

2. GRAPHICAL PERFORMANCE

Much of the wealth of visualization techniques is proprietary to the movie or game industry, and thus not published. Current visualization methods in computing help to capture the events of interest in slow motion. The computer thus becomes transparent: one views the data, instead of a movie on a screen. The use of animation adds an extra dimension to the data, especially if the user can steer the animation interactively in simulated environments. Spatial and temporal views on the data aid in the location and analysis of areas and time intervals of interest. Parametric animation techniques have been introduced to show specific moments in slow motion (van Wijk, 1995). Timing control has been an issue in scientific animation. One solution for refresh time control is to use a constant time delay t_{wait} per frame if the frame rate is too high, and an increment for the time step displayed if the frame rate is too low.

The time-concept differs from other concepts available in scientific visualization software (Polthier and Rumpf, 1995). The meaning of time is generalized to be local to an animated object, which allows viewing the same dynamic process at two different speeds simultaneously. Time is also a word for an arbitrary emphasized parameter of a parameter-dependent object.

There is a high requirement of adequate system performance for graphical purposes. Two main factors affect the visualization of dynamic simulations are as follows:

Latency Latency or lag is the delay induced by the various components of a VR system between a user's inputs and the corresponding response from the system in the form of a change in the display. Direct manipulation techniques allow the research to move a visualization to a desired location or a specific time and view that visualization after a short delay, resulting in the effect of exploring the simulation data. While the delay between a user control motion and the display of a resulting visualization is best kept less than 0.2 seconds, experience has shown that delays in the display of the visualization of up to 0.5 seconds for the visualization are tolerable in a direct manipulation context (Bryson and Johan, 1996). Furthermore in MEMS dynamics, with high frequencies, time is very sensitive. A delay of 0.1 second may cause inaccuracy. There are higher requirements that must be met: to minimize the delay, the most recent computation data must be available to the graphics process. Otherwise the visualization dynamics may look jumpy, and can not display the position at a specific time.

Frame rate is another effect of the discrete nature of computer graphics and animation. To give the impression of a dynamic picture, the system simply updates the display very frequently with a new image. In order for a virtual environment to appear flicker free, the system must update the image more than 20 times each second (Adobe Creative Team, 1998). This means that, if a computer's frame rate is 25 times per second, then a frequency of 30 times/second cannot be displayed properly on this machine, because the computer does not update so often. Such a frequency must be scaled down within 25 times/second.

For an object with high speed, for example, a gear rotating 3000 revolutions per second (rps), the computer CPU would not have a problem to calculate the speed, so the object actually runs at that speed in the computer. But this speed cannot be shown on the screen. High-speed movement becomes blurred and undistinguishable.

3. SIMULATED STROBOSCOPIC ILLUMINATION

To overcome the difficulties of presenting simultaneously fast and slow movements on the screen, we simulate a stroboscopic illumination. This is effectively filtering the images, and displaying only a subset at a rate such that they become visible and observable, without sacrificing their relative movement.

We do this by simulating the objects, eg. two gears rotating at different, specified speed, but displaying their displacement only at the stroboscopic illumination intervals (SII). The resulting images may appear jumpy or continuous depending more on the value of the speed than on the value of the SII.

In stroboscopic simulation, there are two main time factors, one is the stroboscopic illumination interval (SII), during which the object moves at its own speed, and another is the stroboscopic flash duration (SFD), during which the stroboscopic light is applied, and the object appears to stop as shown at the position at the SII.

Figure 1 shows a signal representation for stroboscopic illumination cycles, the "low" of the signal is for the SII, the "high" is for the SFD. The total time for a cycle of a stroboscopic flash consists of two parts: the time of SII (t_{SII}), and the time of SFD (t_{SFD}):

$$T_{cycle} = t_{SII} + t_{SFD} \tag{1}$$

The position P_n of the object after n stroboscopic cycles is recalculated as

$$P_n = n * t_{cycle} * f \tag{2}$$

where f is the frequency of rotation of the object.

Another time parameter is the elapsed time, which is the total time for which the object moves, not including the time for SFD. This is calculated by

$$T_{ElapsedTime} = n * t_{SII} \tag{3}$$

The unsynchronized motion dynamics are modeled in truthful VR visualizations. The objects are shown at the intervals (SII) during the flash period (SFD). The SFD is used for the visual purpose, making the object in high speed visible and observable. The SII and SFD can be set at different rates, and determining a suitable SII and SFD is part of this study.

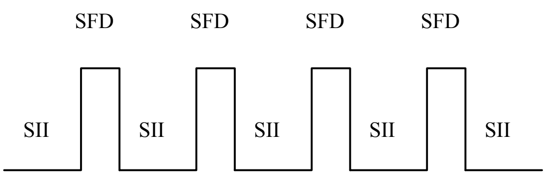


Figure 1. Diagram for stroboscopic cycle

3.1. Combinatorial Experiment

To study the effect and suitability range of the simulated stroboscopic illumination, a combinatorial study was performed, by varying systematically the speeds of two gears in specific and different increments. For each combination the rate of simulated stroboscopic flashes and duration of the flash was simulated. We did this following the *physics based simulation* paradigms, maintaining timing proportions truthfully.

In our visual simulations we used two gears with outer radius 1.6 unit (in VRML), inner radius 1.4 unit, with 30 teeth. A white mark was placed on the gears for easier observation. In our combinatorial experiment we increased the rotation speed of one gear in smaller steps from 2 rps to 200 rps; and the second gear in larger steps from 10 rps to 500 rps. We changed the stroboscopic illumination interval to 10, 20, … seconds

To what extent two moving objects can be seen depends on their shape but also on their relative speed. The gears are observable rotating one cycle in 300 seconds (slowest, 1/300 rps.), and one cycle in 5 seconds (fastest, 1/5 rps.). The relative speed of the gears is 5:300 or 60 times. Within this range of relative speed, stroboscopic simulation is not necessary, but beyond this range (for this type of gear), stroboscopic simulation is needed.

For a gear rotating one cycle at less than 5 seconds, stroboscopic simulation is necessary to observe the movement clearly.

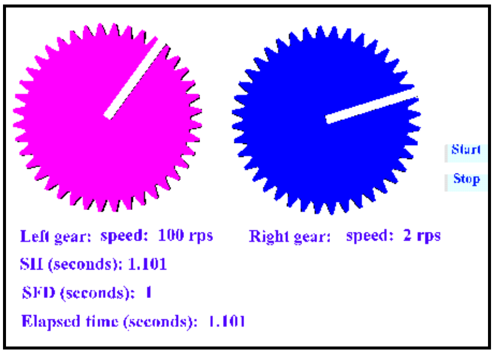
4. RESULTS AND DISCUSSION

Experiments revealed that the size of radius, and the number of teeth of the gear does not influence much. Fewer teeth allow a slightly better observation and faster rotation.

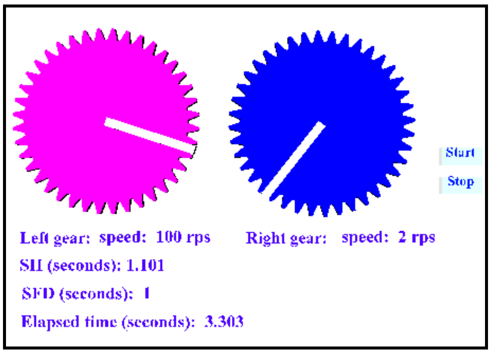
When there are no big differences between the rotating frequencies of the two objects (both either very fast or very slow), one can visualize the rotation by downscaling both rotating frequencies at the same rate for visual animations. When the two objects have a rather large difference in their rotating frequencies, e.g. one is very fast, another one very slow, stroboscopic light is applied to the moving scenes, the movements cannot be displayed in a natural smooth way, and stroboscopic simulation is necessary.

An example applying the stroboscopic simulation to moving gears is shown here. Figure 2 shows a snapshot of the two gears rotating in clockwise direction with the left at 100 rps, and the right one at 2 rps. The marks on the gears help to see the moving gears. Both gears started with their mark reset to a 12 o'clock position.

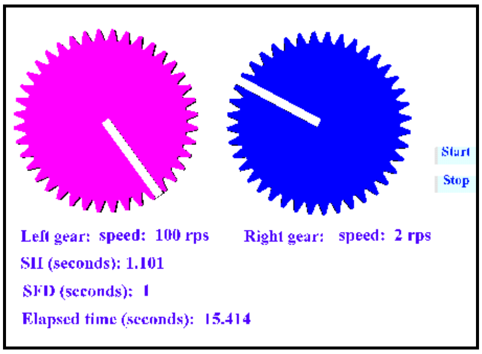
The stroboscopic light flash illuminates both moving gears at the same time. The orientations of the two gears are shown truthfully. Figure 2 shows the orientation of the gears after rotating for different time intervals: i.e. for t=1, t=3, t=14 and t=18 with a SII of 1.101 seconds. The SFD is 1 second. The speed of the two gears, the SII, SFD, the elapsed time, are also displayed on the screen.



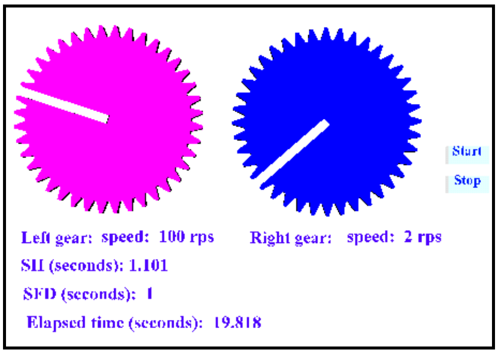
(a)



(b)



(c)



(d)

Figure 2. Orientation of the two gears after (a) 1interval; (b) 3 intervals; (c) 14 intervals; (d) 18 intervals.

Table 1. Stroboscopic Illumination Interval (SII) for different combinations of rotation speed of two gears.

1st gear rps	20	50	100	200	300	
2nd gear rps	SII	SII	SII	SII	SII	Effects
2	0.101	0.101	0.101	0.201	0.201	low limit
2	0.501	0.501	0.501	0.501	0.501	good effects
2	0.801	0.801	0.801	0.801	0.801	good effects
2	1.101	1.101	1.101	1.101	1.101	good effects
2	2.101	2.101	2.101	2.101	2.101	high limit
5	0.101	0.101	0.101	0.201	0.201	low limit
5	0.501	0.501	0.501	0.501	0.501	good effects
5	0.801	0.801	0.801	0.801	0.801	good effects
5	2.101	2.101	2.101	2.101	2.101	high limit
10	0.091	0.101	0.101	0.201	0.201	low limit
10	0.801	0.801	0.801	0.801	0.801	good effects
10	1.101	1.101	1.101	1.101	1.101	good effects
10	2.101	2.101	2.101	2.101	2.101	high limit
20		1.301	1.301	1.301	1.301	low limit
20		0.801	0.801	0.801	0.801	good effects
20		1.101	1.101	1.101	1.101	good effects
20		2.101	2.101	2.101	2.101	high limit

Table 1 gives a subset of the experimental results of SII for combination of gears rotating at different speeds. The table also shows the SII for good observability. The SII has its high and low limit. The SII between the low and high limit is suitable for stroboscopic illumination. If the SII is too short, then the rotation angle displayed is too small, which brings the images almost to a standstill and the images are not very good. Our experiment shows that 5 degrees for each rotation is the low limit. Besides for combination of gears in different speed, the low limit is needed to be different to maintain good dynamic images. Furthermore, there are higher requirements of the computer system for very small SII, the data process should be available to graphics process. If the SII is too long, then the wait time for the viewer becomes unpleasently long. Our experiment shows that the SII up to 2 seconds is tolerable. The SII between 0.5 seconds and 1 second provide good visualization images and comfortable waiting time for viewers.

The SFD of 0.4 seconds up to 1 second appears to be comfortable to the human eye. If the SFD is too short, it looses its stroboscopic effect; and too long is not necessary, as it would distort by freezing the image.

It should be noted that these values of comfortable flash interval and duration are subjective and different for individual observers. However, at this time they do provide an indication about their possible values.

5. CONCLUSIONS AND FUTURE WORK

This paper introduces the stroboscopic simulation that enables observation of objects moving simultaneously at very fast and slow speeds, maintaining their relative speeds truthfully. This visualization method provides good observation objects moving at high speed, or very slow speed. From a set of combinatorial experiments we found the range in which stroboscopic simulation works well , and in which proportions it is not necessary. We also found a duration and interval of stroboscopic flashes that appear comfortable to the human eye. Future research is aimed at stroboscropic illumination to other typical dynamic structures of MEMS components, such as flicking cantilevers, pumping membranes, and combinations of flicking and rotating movements.

6. REFERENCES

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