Scaling for MEMS Virtual Prototyping: Size and Motion Dynamics Visualizations

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ABSTRACT

This paper deals with the challenges found in scaling velocity and size for a CAD virtual prototyping system for Micro-Electro-Mechanical Systems (MEMS). These are miniaturized machines or devices used e.g. in medical or motorcar applications. In a MEMS the size and velocities of its moving parts can be vastly different, spanning several orders of magnitude. This makes it difficult to show the devices being designed in virtual action on a computer screen. A simple down scaling to bring the fast moving object into an observable range, can bring the slow one to a standstill. The image would no longer be a truthful scaling. A similar dilemma happens with the downscaling of small objects, because they would not be observable anymore. Our research aims at finding default values and their boundaries for the parameters that determine the scaled size and motion of objects relative to each other on a computer screen. This is required for informative and pleasant, truthful images that are suitable for a Virtual Prototyping system. In this paper we analyze and illustrate these issues with the example of a micropump and the layered fluidic flow in a microchannel.

Keywords

Virtual Prototyping, Scientific Visualization, MEMS, Stroboscopic Illumination.

1. INTRODUCTION

Since the proliferation of CAD tools, visualizations have gained importance, providing feedback at the time of design. Traditionally the results of simulations are displayed as plots and curves. Multi-dimensional multivariate visualizations have now been around for several decades, e.g. environmental maps of pluviosity. In our research, we are going a step further: displaying results of predictive calculations on the very design images of the structures they represent thus adding to the information content they can offer. Our environment is in Micro-Electro-Mechanical systems (MEMS) CAD development. MEMS are minute devices that are in widespread use, e.g. in airbag triggers, inkjet print heads, optical, medical, or other applications. With ever increasing new applications development tools with sophisticated modeling and simulation software are required to reduce the lengthy prototyping and optimization period. By their very nature, MEMS devices are microscopic, hence difficult to observe. In the macroscopic world, inertia and gravity dominate the motion of objects. To the contrary, in the microscopic domain of MEMS adhesion and friction are the dominant forces. Therefore, MEMS designers cannot use their intuition on how things behave. Because of the different dominant forces, MEMS cannot be simply downscaled counterparts of larger mechanical machines, requiring innovative designs and arrangements of their components, whose effects are often not fully understood.

Virtual reality can provide valuable assistance for data analysis. Human factors contribute significantly to the visual perception process. Perception, visual illusion, color, depth perception, contrast sensitivity, are vital in computer graphics and VR, but there is still need for human perceptual research [KS04]. The effectiveness of a visualization depends on perception, cognition, and the user's specific task and goals. Studies are usually confined to human-

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computer-interaction (HCI). Studies on specific problems of visual data presentation are rare [TM04]. Our research aims at producing VR dynamic images of MEMS in design. We have addressed the problem of displaying different velocities using simulated stroboscopic illumination, but we still need to find the boundaries of to what extent this can be used. In this paper, we examine the boundaries to which scaling and filtering are meaningful from a human perspective. The idea is to place an image with a default size and motion on the screen, but allow a user to change those settings for an individually pleasant image, or zoom in/out for observation of detail. By pleasant we mean not flickering, not moving backwards, no confusing lines, or other optical illusions. One of the questions we seek to answer is, from what resolution values on is it worthwhile to show minute dynamics such as layers in a microchannel's fluidic flow, when initially a whole pump is shown with its flexing membrane, and channels that are very thin in comparison with the other structures. To do this we need not only default settings, but also any constraining boundary values as maximum settings

2. BACKGROUND ON MOTION PERCEPTION

The computational problem of motion perception is to convert information about image motion, stored in a space-time diagram, into information about the velocity of a moving object.

An observer can experience motion as long as it is neither too slow nor too fast. Motion perception, changes with time and object's vertical positioning [Pal99]. Experiments show that the threshold for motion perception depends on many factors, including the duration of the motion and whether the moving object is seen alone or against a background of stationary objects. A single light moving in the dark for a long period of time has a threshold for motion perception of 1/6 1/3° of visual angle per second [Aub86]. The same light moving against a textured background has a threshold for perceiving it as moving: about 1/60° of visual angle per second. This lower threshold for object-relative motion indicates that the visual system is much more sensitive to the motion of one object relative to another than it is to the motion of the same object relative to the observer. With short-duration motion (250 ms or less), the thresholds are higher, and the presence of a stationary reference does not change the motion threshold [Lei55] [Pal99]. The motion itself appears to slow down, as adaptation occurs when an observer stares for a prolonged period at a field of image elements moving at a constant direction and speed. Even motion after-effects can occur. A temporal contrast sensitivity function plot [DeL58] shows how flickering varies with contrast and vice versa. The eye appears to be most sensitive to a frequency of 15 to 20 Hz at high luminance (photopic vision). At photopic light levels, less than 1% contrast is required to detect the stimulus, the high temporal frequency cut-off is close to 60 Hz. At low light levels the maximum contrast is about 20% and the cut-off is around 15 Hz. To detect flicker of high frequencies, maximum contrast is required. Temporal resolution is not efficient at low luminance. Increasing the background illumination has different effects on the relative sensitivity for low and high temporal frequencies [Kel61].

3. UNSYNCHRONIZED MOTION

In our virtual prototyping of MEMS, we require very high and very low speed unsynchronized motion dynamics for virtual reality simulations. We use simulated stroboscopic illumination to display simultaneously the very fast (up to 500 Hz) and very slow (down to 10 Hz) moving objects on the screen [LS03a] [LS03b]. In this way, the relative motion of the objects is maintained. At the same time, it allows the designer to observe the MEMS being designed. For the stroboscopic simulations, we use two parameters: the Stroboscopic Illumination Interval (SII) and the Stroboscopic Flash Duration (SFD). The position P_n of the object after n stroboscopic cycles is calculated as $P_n = n * t_{SII} * f$, where f is the frequency of rotation of the object. The objects are shown at the intervals (SII) during the flash period (SFD). The SFD is used for the purpose of visibility, making the object in high speed visible at all. This is effectively filtering the images, and displaying only a subset at a rate such that they become observable, without sacrificing their relative movement.

In the displays, the type of movement and the shape of the object are critical e.g. a rotating gear at 400 Hz requires a different setting than a flicking cantilever. We performed a systematic combinatorial simulation experiment to find out what in what range of values of SII and SFD produce images that are comfortable to the eyes. We found that the SFD is best between 0.2 to 1 s, and the SII between 0.02 and 0.1 s. For a non-flickering display, both times, the SII and the SFD depend on the computer screen hardware and on the observer's own perception. However, we want to find default display settings, which on average would give reasonably good visualization, and which can be modified according to personal perception with an on-screen mouse activated sliding dial. To obtain a good stroboscopic effect, when the SII becomes longer, the SFD should become a bit longer too. For a high speed, the SII should be rather longer, but for low speed, it should be rather shorter. This is shown in Figure 1 as the combinations of stroboscopic parameter settings that are suitable for different combinations of fast-fast, fast-slow, and slow-slow moving sets of objects.

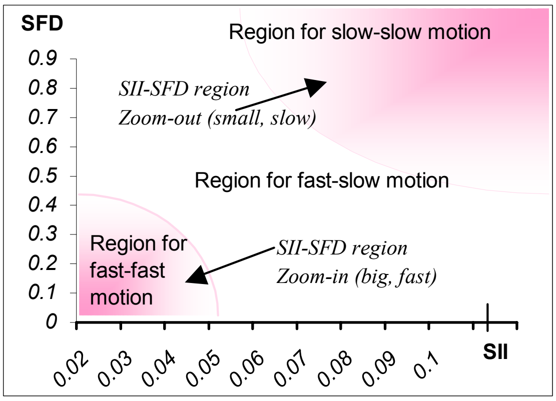

Figure 1 Suitable combinations for SII and SFD.

We use a scaling function to bring the natural speed of the fast and slow objects to be displayed together, into the range of SII and SFD where a good display is warranted, and display the animation at these ranges' mid value. This is the default we are looking for. Alternative personalized values can then be selected by the user via a 2D slider.

4. WHAT TO SCALE AND HOW TO SCALE

Stroboscopic simulation is suitable for very slow and very fast objects shown simultaneously. When objects move at similar speeds, simple down scaling, to an observable speed can be used. We use the following scaling function:

$$SV = \frac{DV - md}{MD - md} \times (UppS - lowS) + lowS \qquad \textbf{Eq 1}$$

DV and SV are the actual data and the scaled value respectively. MD and md are the maximum and minimum data values respectively. UppS and lowS are the upper and lower scaled boundary, they can be the visual system's threshold in size/velocity or the limits of computer capability.

It is difficult to display very big and small objects, rich in details, moving at different speeds because it is hindered by the threshold in the visual system or the computer capability. Too small/slow and too large/fast objects are not visible to humans. A nice list of perception threshold values has been compiled at Stanford University [Sta04]. A person can resolve a size of 0.15 mm at 50 cm distance, but the monitor cannot display it. The smallest size an ordinary monitor can display is one pixel, around 0.3 mm. To avoid eyestrain we use three pixels as our smallest dimension for MEMS structures. Scaling must be done equally in both directions to avoid distortion. We can only use only the shorter of the two measures height and width of the screen, but there are exceptions, as we shall see

5. SCALING MICRO-FLUIDIC FLOW

We show two examples of scaling in this paper, a micropump in operation flicking its membrane, and a microchannel showing the microfluidic flow.

Dimension	Original Size (µm)	Scaled size (pixels)
Membrane thickness	7.80	3
Membrane diameter	10000	421
Pump width	14000	588
Pump length	17500	734

Table 1 Scaled dimensions of the micropump.

Table 1 shows a subset of the critical dimensions. We need to scale such that the thinnest structure is just three pixels. Figure 2 shows a vertical section through the pump. The animated visualization shows the membrane flexing up and down at 50 Hz, and the valves opening and closing alternatively.

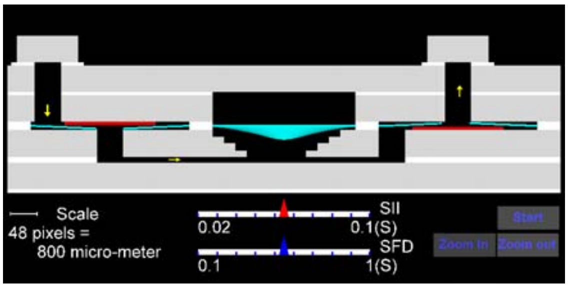

Figure 2 Vertical section through the pump.

For the microfluidic flow, we have a different pump [AS03] with a channel length of 4.8 cm, but with a diameter of just 152µm. The fluidic flow is made up three layers moving at different speeds, with the consequent formation of a bullnose. It is not possible to show the complete channel and the layers of the flow together. We must be above the threshold to see flows at the level of detail of layers. We need now five pixels for the thinnest layer (the external layer), as three are not enough for a good image and the formation of the bullnose. We can use screen *length* to display it, with still enough height to display the full height of the channel. The average flow rate (velocity) of 1.45e10, 4.35e10, and 8.30e10 µm/sec for each of the three layers in the circular channel are scaled to 11, 45 and 91 pixels/s respectively. There are several thresholds in perceiving dynamic images, however several factors, including color, depth, distance, size, texture, length of perceived duration, can affect this human threshold. Humans have a field of view of about 200° horizontally and 135° vertically. A 17" computer display viewed at 50 cm distance spans roughly 37x30° [Red01]. Each pixel spans 1.7x1.7'of an arc. The upper limit for perceiving horizontal velocity comfortably is 91 pixels per second, or 2.67° per second; the lower limit is 11 pixels per second, or 0.33° per second.

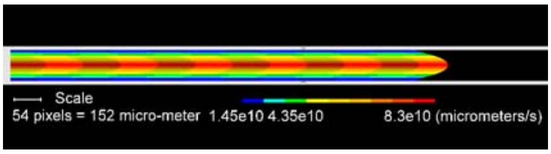

Figure 3 Microchannel showing fluid layers flowing at different speeds and bullet nose.

Our image is shown in 2-D as a cross section of the channel. The flows are parallel to the walls, moving at their relative flow velocity. We used a texture for each layer to show the flow. As the edge of each unit of the faster layer passes by the edge of the unit of a slower layer helps to see the relative motion between them. Experiments show that short tiles help to show slow movement, long tiles for fast movement. The arrangement of tiles influences the informative content and image, as shown in Figure 4. The virtual time unit is one second, as in real time.

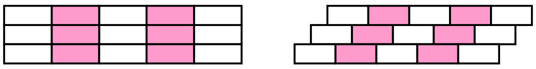

Figure 4 Textures for the fluidic flow

Each pump cycle forms a bullet nose, due to the higher speed in the internal layer, while the external layer is slowed down by friction with the channel walls. For the growth of the bullet nose the data were obtained by using Finite Element Analysis and simulated with ANSYS [AS03a]. To these resulting data a parabola was fitted, whose constant k is a varying function of the velocity, which in turn was used for the velocities of the fluidic flow.

The dynamic visual effects are affected by the distance of a viewer to the observed target. The further away the viewer is to the monitor, the faster animations can be observed, because at longer distance the visual degree becomes smaller. Visual systems are sensitive to light wavelengths from 400 to 700 nm [Fer01]. There is a smooth progression from violets, through blues, greens, yellows, oranges, and reds from shortest to longest wavelengths. We use color mapping to express the velocity of the flows: blue for low speed flows, red for high speed flows. We also use a progression of alternating shaded and non-shaded tiles, of equal length to visualize better the movement of the flow. The difference between shaded and non-shaded tiles is necessary for displaying the relative speed of flows of different layers.

6. CONCLUSIONS

In this paper we have analyzed and presented the scaling of size and speed of moving objects, for MEMS CAD Virtual Prototyping. Microtechnology images pose different challenges than large machine displays due to different dominating physical forces. The visualizations for such an environment must be truthfully scaled and undistorted, because critical dimensions of MEMS are vital to their good functioning. At the same time the moving VR images must be flicker free and pleasant to avoid eyestrain to the MEMS design engineer.

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