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Interactive Simulation: A Virtual Instrument to Unleash Sampling and Aliasing

"What we 'see' is not what it is!"

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Abstract:

A virtual instrument is developed to simulate measurements while arbitrary changing instrument properties, including the damping, and natural and sampling frequencies. The effect of instrument properties on any measured signal is observed interactively, both qualitatively (visually/graphically) and quantitatively (numerically). Sampled signal distortion, including the magnitude change, time or phase lag, as well as peculiar interference phenomena, like "beat" wave, aliasing, and others, are effectively demonstrated. The virtual instrument may be set for online use over the Internet. Users may change the signal and virtual instrument characteristics and witness first hand, interactively, that "*what we 'see' is not what it is!"*

Introduction

Learning is a challenging intellectual process, and new technologies have tremendous potential to make an immense difference with its interactive (computational) and multimedia features. When a user/learner is in "the driver seat," the virtual-reality, if well designed, may have many advantages over the reality itself – remember, *"I hear…and I forget, I see…and I remember, BUT, I do…and I understand!"* That is why kids love video games, like TV, but hate old-fashioned lectures. For many, since we are in the beginning of the information revolution, it is hard to comprehend that interactive/computational simulations will make another revolution in the 21st century in many areas, the way steam power or electricity made industrial revolution in previous centuries.

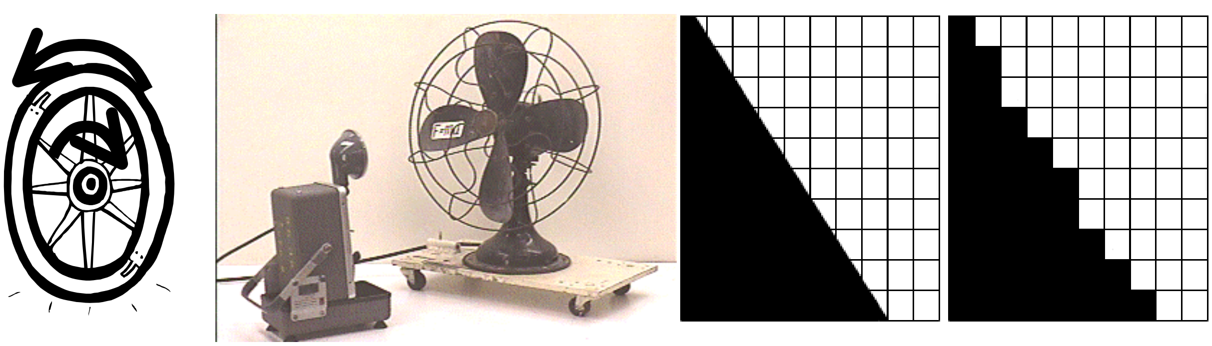

Figure 1: The aliasing examples: "wagon wheel illusion," appearance that a spoke wheel rotates backward while it moves forward (left); a stroboscope experiment to "freeze" rotating fan blades or to make them appear to move slowly forward or backward (center); and appearance of staircase steps along edges (jaggies) in an image (right).

What are "*sampling*" and "*aliasing*" and why they are important? In science and engineering, sampling means discrete observing or measuring, or probing with a certain "sampling" rate or frequency. Aliasing happens when analog object, signal or data are represented (measured or "seen") by a digital system, i.e. in

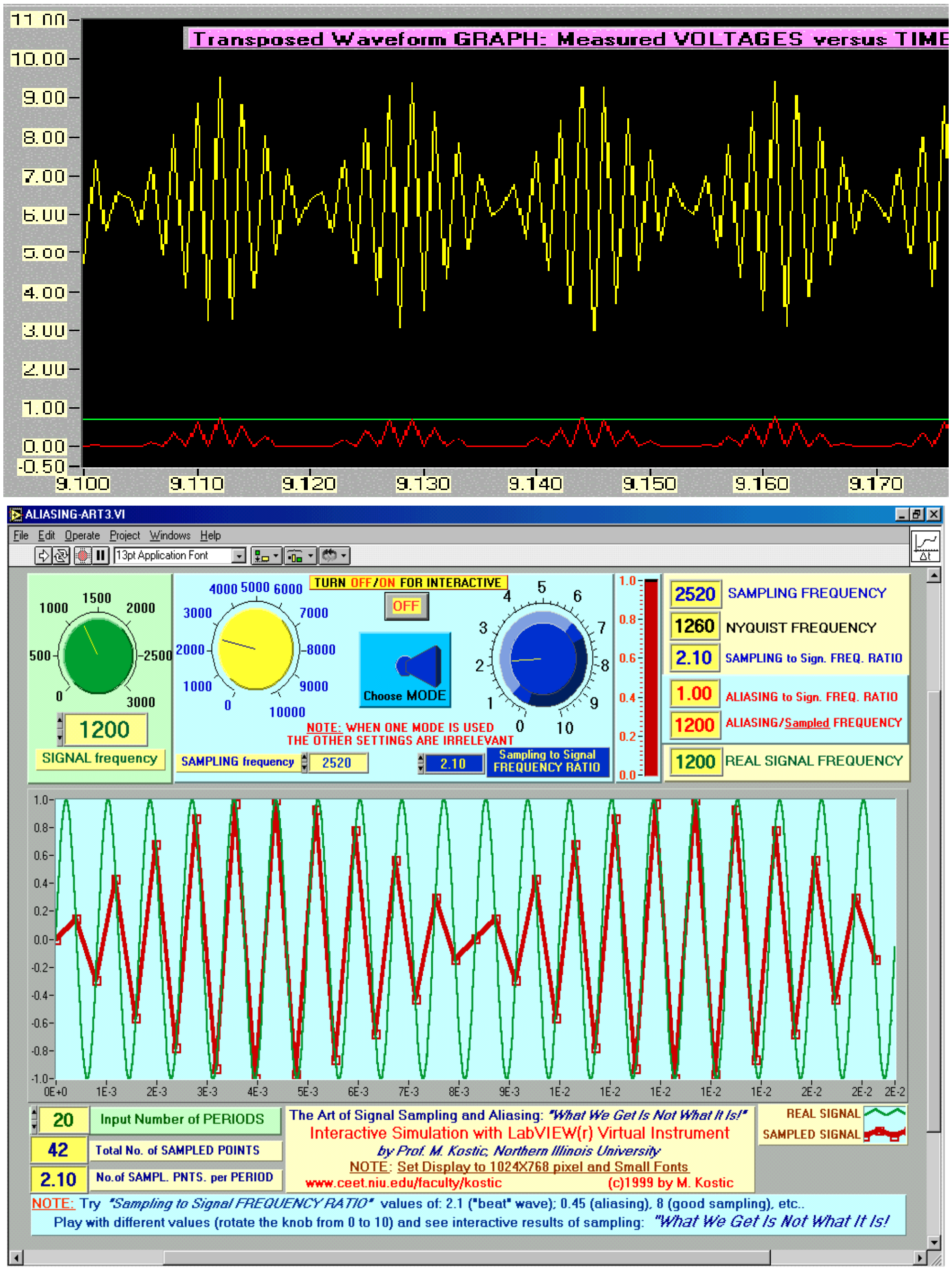

Figure 2: More illusions: if the sampling to signal frequency ratio is close to 2 (i.e. 2.10), the sampled simple periodic signal will appear as a very peculiar, so called "beat" wave shape (simulated at the bottom), similar to one obtained in real measurement in the lab (top).

a discrete domain or a grid. Used in the context of processing digitized waveform signals (e.g. audio) and images (e.g. video), aliasing describes the effect of under-sampling during digitization which can generate a false (apparent) low frequency for signals, or staircase steps along edges (jaggies) in images, as depicted and described in Figure 1.

When the analog data/information is converted to discrete or digital, certain problems arise. In addition to missing the details (fidelity) in-between the successive sampled data, the data may "fold-back" and give us wrong impression (illusion) that something exist that actually does not. That is why it is very important, but not always easy, to fully understand the sampling and aliasing. It is much more than what is learned in basic science and measurements courses, still we have to simplify it in order to explain and understand it,

> ***SAMPLING IS A DISCRETE OBSERVATION OR MEASUREMENT, WHILE ALIASING IS AN ILLUSION, APPEARANCE OF SOMETHING THAT IS NOT, DUE TO SHORTCOMINGS OF SAMPLING, THUS EVERYTHING WE PERCEIVE OR MEASURE IS, TO A LESSER OR GRATER DEGREE, AN ILLUSION, RESPONSIBLE FOR MANY DISCOVERIES AND RE-DISCOVERIES IN INVENTION HISTORY.***

> ***EVEN IF WE ARE NOT INTERESTED IN THOSE HIGH-FREQUENCY SIGNAL COMPONENTS, THE PROBLEM IS THAT THEY MAY "FOLD-BACK" AND FALSELY APPEAR AS LOW-FREQUENCY COMPONENTS THAT DO NOT EXIST IN REALITY AT ALL, THUS TRICK US. SUCH PHENOMENA ARE WELL-KNOWN AS ALIASING, WHICH IS ACTUALLY AN ILLUSION.***

which is a challenging objective of this work. Even if we are not interested in those high-frequency signal components, the problem is that they may "fold-back" and falsely appear as low-frequency components that does not exist in reality at all, thus trick us. Such phenomena are well-known as aliasing, which is actually an illusion. Each and every of these and other false appearances of something that is not, is due to limitations and interference of the perceiving or measurement system and perceived or measured signal, as effectively illustrated in Figures 2 and 3a-c, with the developed virtual instrument.

The Challenge

In order to better understand and utilize different phenomena and processes, which are occurring in the nature, we have to detect, "sense," or measure them somehow. Since there is much more out there than what our eyes could see, what our ears could here, and what our other senses could feel, we creatively design and use different measurement sensors and systems to "see, hear, and feel" for us. However, we should be aware that every real (measurement) system has its limitations in trustworthiness (fidelity) and ranges, very much like our own senses. Most of today's measurements systems, in addition to continuously sensing the input and reacting on it with its own output (like in analog systems), they also probe or sample the measured continues (analog) input in discrete instances with a certain (limited) probing or sampling rate and represent the output in digital form, i.e. discrete and/or digital systems. In addition to static sensitivity (proportionality between the output and input), the physical (analog) systems have their peculiar dynamic characteristics, namely, in what proportion and how quickly they could react to a (fast) changing input. This is usually represented with the well-known parameters, i.e. the output-to-input magnitude ratio and delay or phase lag, commonly called the system frequency response, which is, for a given input and environmental conditions, solely dependent on a measurement system's design and physical characteristics. With system discrete probing or sampling at a finite rate or frequency, at least two more fundamental problems are developed: First, in-between the two successive sampling or probing we are missing the input signal or phenomenon completely, and second, the desecrate sampled data may "fold-back" and form a characteristic "pattern," like interference fringes due to infringement and resonance phenomena, giving as illusion that something exist which actually does not, the latter being called "aliasing." Thus, every discovered and measured natural phenomenon is only as authentic as our senses or instruments were able to "see" or detect it. It is up to our ingenuity and creativity, or intelligence, as to how to interpret it. But we must always be aware that there is more than to what our 'eye' or instrument could 'see' (we are always missing something, some fine details), and even more importantly, that what we 'see' might be illusion (aliasing) of something that is quite different from its appearance. The bottom-line, *"What we 'see' is not what it is!"* The developed interactive simulation modules will effectively demonstrate, visualize and quantify these critical sampling and aliasing phenomena.

Virtual Instrument and Results

The simulation presented here expends on similar previous work [1] by accounting for influence of instrument natural frequency and damping on the magnitude ratio and phase shift of the measured signal, in addition to the sampling frequency influence on aliasing. Here, an interactive virtual instrument is developed to simulate the second-order (measurement) system, a basic concept in many science and engineering courses, like physics, dynamics, control, and measurement methods [2].

To interactively sample or virtually measure (evaluate and plot) a signal versus sampling time, the appropriate simulation procedure is developed as a LabVIEW® virtual instrument, to sample or measure a 'real' signal of arbitrary frequency with any sampling frequency, any instrument's natural frequency and damping ratio, as explained elsewhere [3]. In addition to real measurements, the LabVIEW® is very effective application for interactive what-if simulation in education. It has an advantage to further enhance the simulation applications due to its powerful features and an appealing, real-like "front panel" interface [4].

As seen in Figure 3a-c, the input variables are presented as the virtual instrument controls on its control panel. Several characteristic examples are presented on Figures 3a, 3b, and 3c, and are discussed in the following section. As seen on these Figures, the same signal 'measured' with different damping ratios and natural and sampling frequencies, appears quite differently in form, shape, and even frequency. This paper's theme phrase, *"What we 'see' is not what it is!"* is compellingly self-evident, especially during interactive presentation, or in a limited form, available as an interactive online experiment on the Web [5].

Discussion and Conclusion

It is evident in Figures 2 and 3a-c that the output signal does not represent the exact image of the input signal, which is always the case to a smaller or a larger degree. For a signal of 1000 Hz, in Figure 3a for example, the sampling frequency of 7500 Hz (7.5 ratio) is good enough to avoid aliasing and get a good shape of the signal. However, the instrument natural frequency of 5000 Hz and 3.5 damping ratio are not good enough, thus attenuating signal magnitude to 59% of its original value (0.59 the magnitude ratio) and resulting in a phase lag of 56 degrees. In Figure 3b the under-sampling with 1880 Hz, results in aliasing with measured (or aliasing) frequency of 880 Hz, and with a peculiar, so called "beat-wave" shape of frequency of 120 Hz, since the sampling-to-signal frequency ration of 1.88 is smaller than 2 (thus aliasing), but close to 2 (thus "beat-wave" phenomena), the critical Nyquist ratio value of 2. The aliasing phenomena are explained elsewhere [1-3], as well as related online experimentation is made available over the Internet [5]. Also, the small damping and signal-to-natural frequency ratios (0.25 and 0.33 respectively) result in a small resonance (1.11>1 magnitude ratio) and a phase lag of 11 degrees. Finally, in Figure 3c, a good representation of the input signal is achieved by selecting the sampling-to-signal frequency ratio of 8 (no aliasing, good shape), magnitude ratio of 1 and phase shift or lag of 0 (this time using the "right-flip" Choose-MODE).

This interactive module will stimulate users' curiosity and motivate them to conveniently "check out" different options and possibilities, and thus accelerate experience and by active, what-if inquiry and "experimentations" enhance their comprehension and interest for deeper thinking and understanding. These new learning tools are not and cannot replace the traditional learning by cognitive thinking, but, if designed well, the new simulation tools may qualitatively enhance learning environment by stimulating inquiry and building confidence and motivation – in short, may become a *"virtual eye and mind opener"!*.

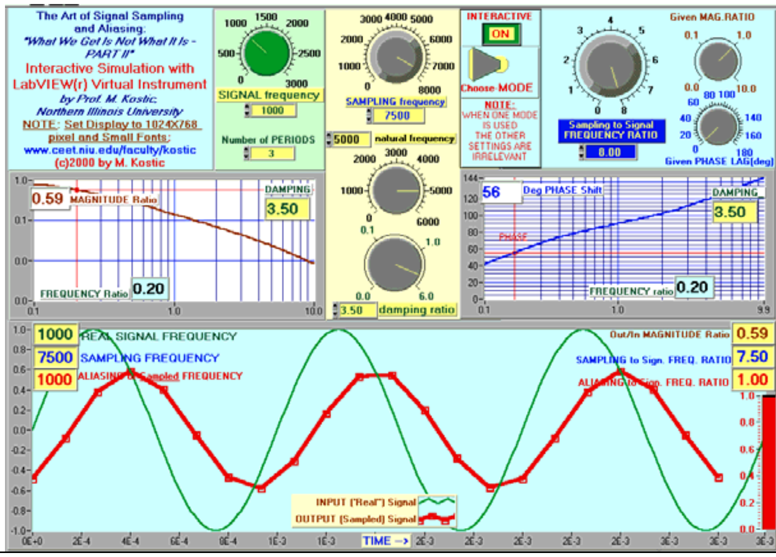

Figure 3a: Front Panel Interface:

"Choose-MODE": Left-flip

"Input":
- Signal frequency: 1000 Hz
- Number of periods: 3
- Sampling frequency: 7500 Hz
- Natural frequency: 5000 Hz
- Damping ratio: 3.5

"Measured Output":
- Frequency ratio: 0.20
- Magnitude ratio: 0.59
- Phase lag (shift): 56 deg
- Measured (aliasing) frequency: 1000 Hz
- Sampling-to-signal frequency ratio: 7.50
- Aliasing-to-signal frequency ratio: 1.00

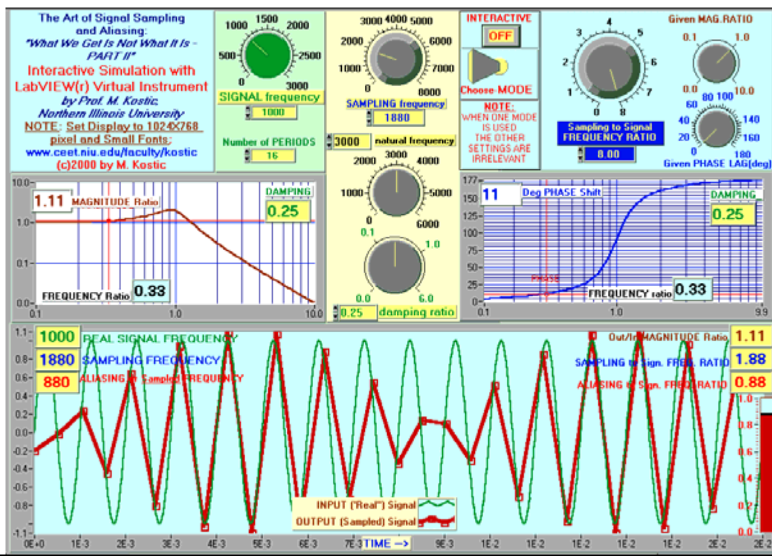

Figure 3b: Front Panel Interface:

"Choose-MODE": Left-flip

"Input":
- Signal frequency: 1000 Hz
- Number of periods: 16
- Sampling frequency: 1880 Hz
- Natural frequency: 3000 Hz
- Damping ratio: 0.25

"Measured Output":
- Frequency ratio: 0.33
- Magnitude ratio: 1.11
- Phase lag (shift): 11 deg
- Measured (aliasing) frequency: 880 Hz
- Sampling-to-signal frequency ratio: 1.88 (close to 2, "Beat-wave")
- Aliasing-to-signal frequency ratio: 0.88

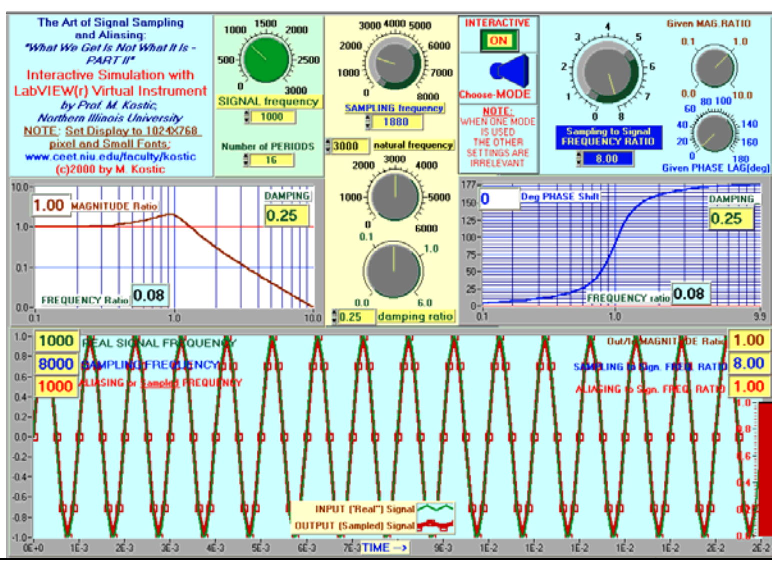

Figure 3c: Front Panel Interface:

"Choose-MODE": Right-flip

"Input":
- Signal frequency: 1000 Hz
- Number of periods: 16
- Sampling-to-signal frequency ratio: 8.00
- Given Magnitude ratio: 1.00
- Given Phase Lag: 0 deg

"Measured Output":
- Frequency ratio: 0.08
- Magnitude ratio: 1.00
- Phase lag (shift): 0 deg
- Measured (aliasing) frequency: 1000 Hz
- Sampling frequency: 8000 Hz
- Aliasing-to-signal frequency ratio: 1.00

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