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Short communication

A method for achieving an order-of-magnitude increase in the temporal resolution of a standard CRT computer monitor

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ABSTRACT

As the frequency of a flickering light is increased, the perception of flicker is replaced by the perception of steady light at what is known as the critical flicker fusion threshold (CFFT). This threshold provides a useful measure of the brain's information processing speed, and has been used in medicine for over a century both for diagnostic and drug efficacy studies. However, the hardware for presenting the stimulus has not advanced to take advantage of computers, largely because the refresh rates of typical monitors are too slow to provide fine-grained changes in the alternation rate of a visual stimulus. For example, a cathode ray tube (CRT) computer monitor running at 100 Hz will render a new frame every 10 ms, thus restricting the period of a flickering stimulus to multiples of 20 ms. These multiples provide a temporal resolution far too low to make precise threshold measurements, since typical CFFT values are in the neighborhood of 35 ms. We describe here a simple and novel technique to enable alternating images at several closely-spaced periods on a standard monitor. The key to our technique is to programmatically control the video card to dynamically reset the refresh rate of the monitor. Different refresh rates allow slightly different frame durations; this can be leveraged to vastly increase the resolution of stimulus presentation times. This simple technique opens new inroads for experiments on computers that require more finely-spaced temporal resolution than a monitor at a single, fixed refresh rate can allow.

1. Introduction

Although medicine utilizes many measures of spatial vision (for example, eye charts, perimetry, etc.), there are fewer ways to measure temporal aspects of vision (Eagleman, 2001, 2008; Eagleman et al., 2004, 2005) – that is, the brain's speed of information processing. One of the most useful and popular is the measure of the flicker fusion threshold: the frequency at which a flickering light is first perceived to be steady (Seitz et al., 2004; Simonson and Brozek, 1952; Tyler, 1975, 1985, 1989, 1991; Tyler and Hamer, 1990, 1993). Flicker fusion measurements in medicine have been used for over a century, both in early diagnosis of diseases such as schizophrenia (Black et al., 1975; Saucer and Sweetbaum, 1958), Alzheimer's (Curran et al., 2004) and glaucoma (Curran and Wattis, 2000; Tyler, 1981), as well as in the measurement of drug efficacy in the pharmaceutical industry (Curran and Wattis, 2000; Danjou et al., 1992). However, even while knowledge about the factors influencing flicker fusion has increased, the basic method for measuring critical flicker fusion threshold (CFFT) still requires a custom-built hardware device – such as a light (e.g. LED, lightbulb) attached to an alternating power source. Rapid visual measures have not taken advantage of the advancement of desktop computers, primarily because commercially available monitors are rarely capable of refresh rates faster than 100 Hz. The resulting problem is that one is restricted to a large step size when changing the period of an alternating visual stimulus: at 100 Hz, a new frame is rendered every 10 ms, thus restricting the period of a simulated flickering stimulus (e.g. alternating between displayed and not displayed) to multiples of 20 ms. For example, one can present a flickering stimulus at 50 Hz (1 frame on, 1 frame off), at 25 Hz (2 frames on, 2 frames off), or at 16.7 Hz (3 frames on, 3 frames off). Since typical CFFT values range in the neighborhood of 35–50 Hz (Herrick, 1974; Simonson and Brozek, 1952; Tyler, 1989, 1991), the large step size in temporal resolution makes a detailed CFFT measurement impracticable using a computer and standard monitor.

2. A novel method for achieving high resolution alternation rates on a computer display

We describe here a simple and novel technique to enable alternating images with many possible periods on a standard cathode

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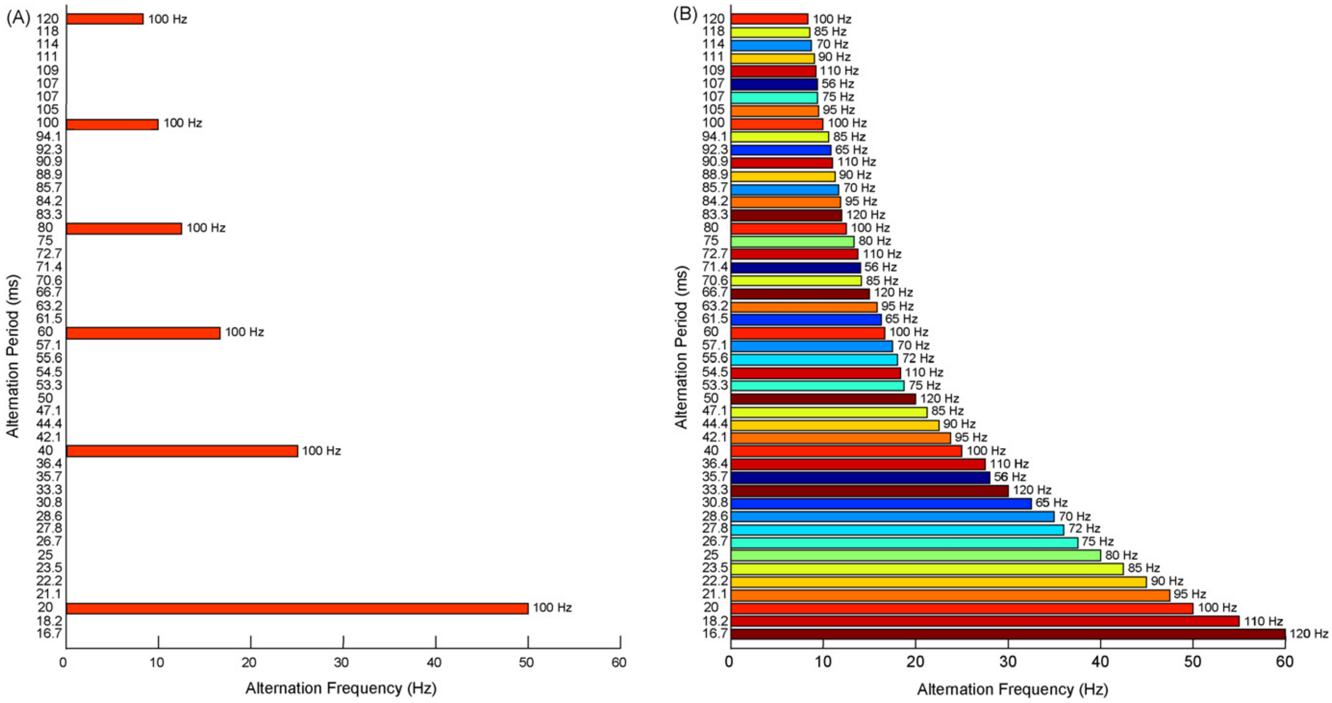

Fig. 1. Achieving an 8-fold increase in possible alternation frequencies available on a standard computer monitor. (A) Using a standard 100 Hz refresh rate, only a handful of alternation rates are available. (B) By dynamically switching between refresh rates available with standard video cards, many intermediate alternation rates of a visual stimulus can be achieved. The rates displayed to the right of each bar (and coded by the different colors) represent the spectrum of refresh rates that are commonly available. When utilizing this technique, it is important to ensure the monitor is capable of displaying at the refresh rates generated by the video card. By using the most modern video cards and lowering the screen resolution, one can achieve even finer temporal resolution than indicated in panel B (see text).

ray tube (CRT) monitor – e.g. 20, 21.1, 22.2, 23.5, 25, 26.7, 27.8, 28.6, 30.8, 33.3, 35.7, 36.4, 40, 42.1 ms. The key element to our technique is to control the video card *from within* a stimulus presentation program to dynamically reset the refresh rate of the monitor. For example, a refresh rate of 100 Hz allows periods of 20 ms (50 Hz). By dynamically resetting this refresh rate from 100 to 95 Hz, we achieve periods of 21 ms (47.5 Hz). Switching the monitor refresh rate to 90 Hz allows a period of 22.2 ms (45 Hz), and so on. Fig. 1 shows the proliferation of alternation periods available on a standard monitor by employing this technique.

Depending on the demands of the experiment, the screen video resolution (width × height) can be leveraged to achieve even higher refresh rates than the ones used in Fig. 1 – for example, one can often include refresh rates of 140, 160, and/or 200 Hz by lowering the screen resolution to 800 pixels × 600 pixels. This technique works with all video cards: even while different video card brands sometimes use different rates, all use the same standard protocol for communicating between motherboards and monitors.

3. An example application

We wanted to construct a computerized test to determine a subject's baseline CFFT with high resolution, based on a portable physical device we had previously built using a computer chip and LED arrays (Stetson et al., 2007). Specifically, we had found that when a character and its negative are presented at a slow rate of alternation (as in Fig. 2A), subjects will have no trouble identifying the character. But as the rate of alternation increases, a threshold is reached at which the information is presented too rapidly, and the letter can no longer be discriminated from a uniform display (Fig. 2B) (Stetson et al., 2007). In this latter case, the character and its negative will perceptually overlap as though they were presented simultaneously. The sum of a character and its negative is a blank field, indistinguishable from any other character and its negative. In one version of our experiment, we presented 4-digit random numbers at different alternation rates on different trials, and subjects reported the numbers they were able to detect. In this way, we could quickly extract a measure of CFFT that was robust against malingering (i.e., if the alternation rate is above a subject's perceptual fusion threshold, the subject had only a 1 in 10,000 chance of guessing all four numbers correctly).

To translate this measurement technique from physical LED arrays onto the computer monitor, we faced a challenge. As described above, if a monitor is refreshed at 100 Hz, the minimum duration for displaying an image is 10 ms, translating to a minimum alternation period (i.e., the image and then its negative,

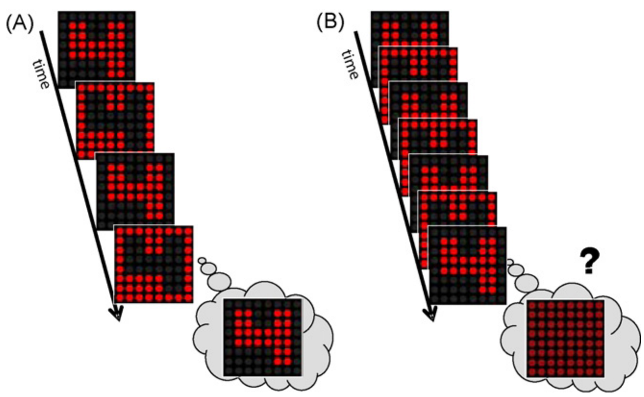

Fig. 2. Using alternating images to measure the rate at which observers can report numbers and how that compares over different brain regions. (A) When a character is alternated slowly with its negative image, it is easy to identify. (B) As the rate of alternation speeds up, the patterns fuse into a uniform field, indistinguishable from any other character and its negative.

Fig. 2) of 20 ms. The next closest alternation rate could be achieved by extending the display duration to 20 ms, yielding a period of 40 ms. Since a threshold period is typically ~35 ms, the temporal resolution is too poor to be useful.

To test subjects at alternation periods that were not multiples of 20 ms, we needed a way to dynamically change the monitor refresh rate while the program was running. Using Visual C++, we programmed an executable called *refresh* which communicates with the video card to change the monitor refresh rate on the fly (code available here: www.eaglemanlab.net/flickercode; note that after downloading, the location of the executable must be placed in the Matlab path prior to use).

For illustration, we now sketch an example using PsychToolbox for Matlab (Brainard, 1997). If the experiment being performed required a period of 22.2 ms (obtained by setting a 90 Hz refresh rate and presenting each frame twice), the *refresh* call would be used as follows:

```
eval(sprintf('!refresh 90'))
while(condition)
        Screen(mainWindow, 'WaitBlanking')
        [stimulus code here...]
end   %while loop
```

In the first line, the *eval* Matlab command runs the executable *refresh* with the argument 90 (for 90 Hz). This sets the monitor to the desired refresh rate. One then ensures that the drawing of the graphics is synchronized with the scanning of the phosphor gun by calling the command *Screen* (*mainWindow*, '*WaitBlanking*') (see Brainard, 1997 and psychtoolbox.org). One can then define the stimulus generation code that will be presented at the desired rate.

Note that some tasks call for dynamically choosing the refresh rate within the course of the program. In this case, one can write the string to be run by the *eval* command in the following manner:

```
evalstr = sprintf('!refresh %d', refreshRateVariable);
eval(evalstr);
```

This allows the variable *refreshRateVariable* (which passes the desired rate as an argument to *refresh*) to be dynamically specified elsewhere in the code.

4. Discussion

The past few decades have witnessed remarkable progress in new hardware techniques for accurately measuring flicker fusion, and a host of new discoveries (Tyler, 1985, 1989, 1991; Tyler and Hamer, 1990, 1993). However, as a result of the relatively slow refresh rates of computer monitors (as compared to stand-alone, custom-built electronic hardware devices) the ability to easily measure flicker fusion with a standard computer monitor has been elusive. The technique described here exploits the different refresh rates available on monitors to surmount this limitation and widen the possibilities for temporal visual processing experiments on computers.

We have demonstrated a new method for obtaining a dramatic increase in temporal resolution using a standard monitor. We hope this technique will be useful for a wide range of applications, both within and beyond psychophysics. As one example, this technique can be used to pilot hardware devices (e.g. ones that use LED or LCD displays), whereas in the past investigators have had no choice but to build hardware devices with very rapid base clock speeds. Our method enables investigators to pilot hypotheses in software prior to the possibly unnecessary development of a hardware prototype. It is hoped that this simple software method will be of benefit in speeding research in temporal visual processing using standard computer equipment.

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