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Designing and Prototyping a Light Flicker Detector

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Designing and Prototyping a Handheld Light Flicker Detector

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By

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Acknowledgements:

For starters, I would like to thank everyone in my life who have helped me achieve my academic success up to this point. My family and friends have always supported me at every step. Special thanks go to my professor Dr. Demir for guiding this project and fellow electrical engineering senior design team members Brent Rinchiuso and Corey Roys. Above all, I would like to thank my mother for always being there for me; she has gotten me through tough spots in life and always pushed me to do my absolute best.

Electrical Engineering Senior Design Team:

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- Corey E. Roys Z1691594

Full Project Report:

Please review the attached official report of our senior design project.

Contributions to the Project:

Each member of my senior design team played a crucial role in developing our project. Brent was our primary code developer. He developed the majority of the code that drives the sampling of light and then sends the draw command to the TFT-LCD screen. Corey was the lead researcher in addition to masterfully assembling the device and soldering all electrical components into place on the circuit board. My role in the project was that of the project manager and head designer. On the project manager spectrum, I organized the team meetings, managed the budget, ordered parts through the university, submitted official files for senior design, and made any necessary executive decisions. On the design spectrum, I created the Solidworks model of the device to ensure that all the components would mesh as desired. Using digital calipers for precise measurements, I recorded dimensions for each and every main part that went into the design. After creating models of said parts, I design a customized housing that would contain all the parts. The housing utilized slots to hold key parts in place and a snap/hook design to allow for the top and bottom of the device housing to be easily connected or separated. I then sent this design to be created through the process of 3-D printing, courtesy of the mechanical engineering department of NIU. Once the device was assembled, I conducted the testing it was to undergo and used the equations listed in the report to fine tune the lux measurement. Together, we formed and efficient team that meshed quite well together.

Handheld Light Flicker Detector (May 2017)

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***Abstract*—Light flicker in common light sources can cause negative symptoms in individuals with light hypersensitivity, particularly those with autism spectrum disorder. The purpose of this project is to design, build, and test a portable handheld device that is capable of testing whether or not a light source possesses enough flicker to aggravate hypersensitive individuals. The prototype is a small handheld unit which contains at its core a microprocessor, a light sensor, and a display screen. Testing confirms the ability of the device to identify light flicker in several types of bulbs. The completed device meets design criteria and performs as intended during testing.**

I. Motivation

FLUORESCENT lighting is as useful as it is ubiquitous. It can be found in virtually all modern buildings. Studies have shown, however, that there may be a significant drawback for individuals with light hypersensitivity [1]. The design of fluorescent lights involves rapid cycling of a light source between high and low states, which can aggravate light-sensitive individuals. Medical studies have confirmed that this cycling causes distraction, irritation, inability to focus, fatigue and several other negative symptoms [2]. A solution has been proposed in the form of specialty types of light with a much higher frequency which are supposed to be beyond the detection threshold of human notice. Research is ongoing in this field [3] with debate as to an ideal solution, with at least one autistic contributor reporting that they still experienced symptoms of their light hypersensitivity even when using the mental-health friendly specialty bulbs [4].

Children with Autism Spectrum Disorder (ASD) are particularly at risk as ASD can involve Sensory Processing Disorder (SPD) in the form of light hypersensitivity [4, 5]. These children may suffer from the symptoms without being adequately able to identify or express what the problem is. As such our solution is a product designed for individuals with ASD and more importantly parents of children with ASD.

We propose a solution in the form of a small portable device which will be able to measure a light waveform and identify the cycling frequency and variance at which the light in a room or building operates. It will provide to the user a simple graphical representation of the waveform and display information on the frequency of cycling between high and low states, the average intensity of the light (measured in lux), and the variance between the high and low states as a percentage of the calculated average. The device can be taken to anywhere the child will be spending a significant amount of time, such as a classroom or office and used to evaluate whether or not the lighting at the location will aggravate the child's SPD. Armed with this knowledge, the parent(s) of the child may then take appropriate action to ensure the child's mental health and well-being.

A secondary market for this device lies in the field of research. As we have acknowledged in the first motivation paragraph, research in the field of light flicker is ongoing and significant results have not yet been published that clearly defines the types or parameters of a light source that affects someone who is hypersensitive to light. To our knowledge, there is no standard among tests on light sensitivity in humans. A handheld light flicker device like the one we are proposing could be used in such testing. Not only would this device make it easier for the researchers to record data, but it would allow them to define and analyze light waveform profiles alongside the documentation of any effects on the subject.

II. Design

The prototype design is built around an Arduino Nano microcontroller. Figure 1 shows a block diagram of the logic. A standard 9-volt battery is selected to power the device; it is connected to the microcontroller by an on/off toggle switch. When toggled on, the 9-volt battery powers the microcontroller, which produces a regulated 5 volts for any circuit components requiring power. The microcontroller drives a Vishay TEMT6000 phototransistor to sample light input at a rate of 1 kHz (1,000 samples per second). The resulting time domain signal is sent to a 4D Systems 1.44" *microLCD* GOLDELOX Display uLCD-144G2 thin-film-transistor liquid-crystal display (TFT-LCD) screen to be displayed. In addition to the shape of the waveform, the screen

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also identifies other useful statistics such as the frequency of the signal, average light intensity measured in lux, and variance of the signal intensity as a percent of the average.

All components requiring an electrical connection are connected by jumper-wires; the connection points are soldered onto a small circuit board. All parts of the design are then mounted inside a 3-D printed lightweight custom housing (shown in Figure 2 and 3), which we designed in Solidworks and printed through the Northern Illinois University Mechanical Engineering department. The prototype housing is made of Duraform PA plastic, a durable, flexible, and inexpensive nylon polyamide. Aside from accurate functionality, the most significant design goal is minimal cost; this handheld device needs to be affordable and thus accessible to anyone that may need it.

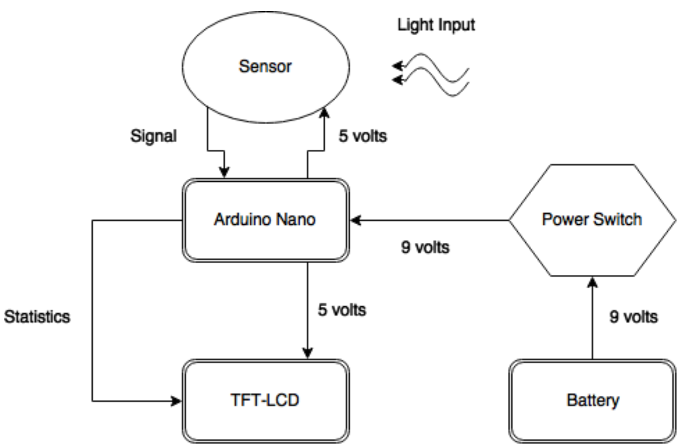

Figure 1. Block diagram of handheld light flicker detector.

III. Important Equations

$$I_{avg} = \frac{\sum_{n=0}^{1000} I[n]}{1000}$$

$$T_{I(t)} = \frac{\sum_{n=0}^{1000} peak\_diff(I[n])}{peak\_cnt(I(t))}$$

$$f_{I(t)} = \frac{1}{T_{I(t)}}$$

$$Var_{I(t)} = \frac{avg\_max(I(t)) - avg\_min(I(t))}{I_{avg}} * 100\%$$

$$B(lux) = \frac{L\ (lumens)}{4\pi\ (steradians) * d^2\ (meters)^2}$$

$$B_{real} = \frac{B_{meas}}{\alpha}$$

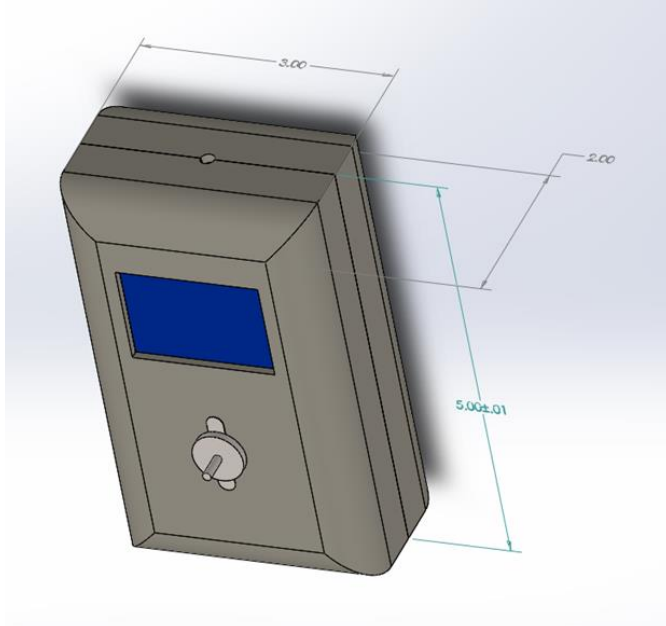

Figure 2. Housing design, exterior.

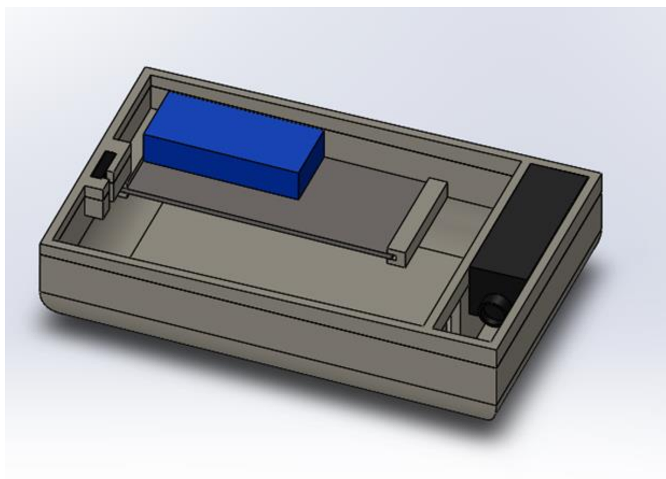

Figure 3. Housing design, interior.

IV. Failure Mode Effect Analysis

This device has two principal failure modes for consideration. The first is that the device does not give adequate output to identify a hazard. In this case, the result is the potential for the hypersensitive individual to suffer from the symptoms caused by the light flicker. This cannot be directly overcome as the time interval and lack of system redundancy does not allow for error correction or testing. It is further complicated by the wide array of environmental factors that can cause similar symptoms.

The second failure mode is that the device falsely gives the impression that a hazard condition is present where there is none. In this case it may result in unnecessary investigation of lighting systems in the area where the test was being performed. This could potentially be solved by system redundancy or a built-in test feature to check for system operation.

The third and most basic failure mode is that the device simply does not turn on. In this event a diagnostic service could be offered by the vendor which checks for mechanical defects such as loose or broken wires, damaged circuits or broken screens. Given the inexpensive nature of the device this diagnostic and repair service would have to be implemented based on a cost-benefit analysis to determine if it would be more economical than simple replacement. Additionally, unit replacement could allow for the vendor to refurbish damaged units for resale to offset repair costs and ensure adequate supply.

V. Testing and Results

The testing procedure consists of an operational check of the device using several light sources to observe the behavior of different light types at different ranges. Each test is performed using the same desk lamp to prevent errors caused by differences in power feed or any other influencing factors that can be attributed to a separate housing. The test consists of measuring the light stimuli from the desk lamp with the device using three different bulbs: compact fluorescent (CFL), light emitting diode (LED), and incandescent. The light was measured at distances of 1, 0.5, and 0.25 meters away from the bulb. A spread of distances allows us to tune the lux reading on the display, yet they are far enough away to keep the phototransistor from going into saturation.

One challenge in the reading was getting the true lux value of the light intensity. Calculations were made using the inverse square law; the lux value at the sensor should be equal to the lumen rating of the bulb divided by 4π times the distance traveled squared. The values we were getting were based on the relative magnitudes that the sensor was capable of handling. After data was collected, a correction factor was determined to shift the relative value of light intensity to the true value of intensity based on the readings of the incandescent light, which was determined to be the least time-variant source. The CFL and LED bulbs do not reach the steady state of intensity described in their specifications in a reasonable amount of time; they continue to increase in intensity slowly for a long period of time. Choosing the incandescent bulb as the baseline ensures for an accurate correction factor without running tests that take an extensive amount of time.

The output displayed on the TFT-LCD screen is a plot of the light intensity as a function of time. In most cases, a sinusoidal waveform is exhibited due to the 120 Volt 60 Hz line voltage supplied to the desk lamp. See Figure 4 for our experimental resulting displays. In our tests as shown, most waveforms exhibited a frequency of 125 to 142 Hz due to the on/off switching state of the bulb. As the device doesn't discriminate with direction of current, the light frequency becomes equivalent to the line voltage frequency doubled.

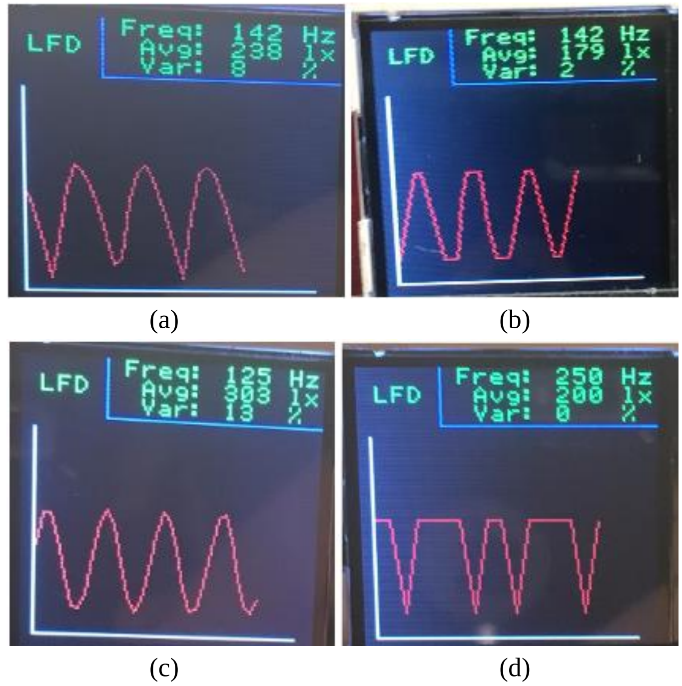

Figure 4. Output plots for (a) fluorescent array, (b) CFL, (c) incandescent, and (d) LED light sources, respectively.

Another noteworthy comment on the results is that the equations/code that calculate the frequency is entirely based off of seeing maximum and minimum peaks; low variance in the waveform creates an inaccurate reading of frequency. In the case of the LED bulb, it is essentially in a constant on-state and the peaks exhibited are negligible because the variance in the waveform is zero percent and may be attributable to noise.

VI. Budget

One of the core requirements of this project is to keep the costs to a minimum. It is a priority of ours to make this device be affordable to the average person so that anyone can have access to this device. As such, it is important to minimize spending where possible. Below in Figure 5, an itemized budget is provided.

If this project were to be taken to full scale production, costs could be minimized further. Prices shown are based on the small amounts that were necessary. Items can be purchased in bulk, resulting in lower unit prices. Additional effort could be put into finding cost efficient alternatives; most selections were based on what was readily accessible. We are confident that if these actions were taken, the cost per device could be reduced to approximately $70.

Item	Cost	
9-Volt Battery	$ 4.61	Costs per device
9-Volt Battery Connector	$ 0.30	
Arduino Nano	$ 21.49	
Circuit Board	$ 4.99	
Duraform PA Housing	Covered by NIU	
Serial Mini TFT-LCD Screen	$ 35.95	
TEMT6000 Light Sensor	$ 4.95	
Toggle Switch	$ 6.31	
Adhesive	$ 3.99	Costs of Production
Jumper Wires	BULK	
Micro-USB Cable	$ 2.43	
Spray Paint	$ 3.95	
USB-to-Serial Bridge	$ 24.95	
Unit Cost	$ 78.60	
Production Cost	$ 35.32	
Total	$ 113.92	

Figure 5. Itemized budget

VII. Professional and Ethical Problems

The main dilemma faced with regards to this device would be the reception of incorrect data which results in a decision that may unilaterally be unneeded or otherwise expensive. Being certain of the device's output characteristics and explicitly making it well known and documented about any problems or bugs with the device should help avoid issues of this nature.

VIII. Conclusion

The purpose of this project was to construct an affordable handheld device that would allow for analysis of light sources to identify potentially hazardous light flicker. The resulting prototype costs less than $100 for a mass-market version and is small enough to be easily portable. It is able to sample the output of light sources at a rate of approximately 1 kHz and outputs a plot on the device screen that describes the rate of flicker as well as the average luminous intensity and percent variance of the source under test. The sampling rate exceeds the minimum required by the Nyquist criteria of sampling at twice the rate of the projected flicker of the lights. Overall the design meets both requirements and expectations and, while there is certainly still room for improvement, the handheld light flicker detector can be called a successful realization of the project concept.

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Jonathan Harvell was born in Rockford, Illinois in 1995. He is currently pursuing B.S. degree in electrical engineering at Northern Illinois University.

He has worked at Taylor Co. from 2014 to 2016 during the summers as a Lab Assistant and Process Engineering Intern. He currently works through ACCESS PAL at Northern Illinois University as a Tutor and Center Supervisor. He tutors math, engineering, physics, and computer science courses. His research interests include microprocessor optimization and digital signals processing.

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Corey Roys was born in Aurora, Illinois, in 1984. He is currently pursuing the B.S. degree in electrical engineering at Northern Illinois University.

From 2003 to 2012, he was enlisted in the United States Navy as an Aviation Electrician's Mate. Since 2012 he has been enrolled at Northern Illinois University as an undergraduate student. His research interests include sensor design for cancer detection.

Mr. Roys was a founding member of the Northern Illinois University chapter of Out in Science, Technology, Engineering, and Mathematics (oSTEM) in 2014.

Brent Rinchiuso was born in Chicago, Illinois in 1995. He is currently pursuing a B.S. degree in electrical engineering at the Northern Illinois University.

He has worked at ARRIS during the summer of 2016 as the Precision Timing Distribution Intern. His research interests include automation, embedded systems, and programming.