Arduino-based Laboratory Instruments for an Undergraduate Laser Cooling Experiment (K1.00015)

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INTRODUCTION

Arduino is an open-source micro-controller platform designed for quick development and easy interfacing, making it ideal for novice programmers and instrument designers. Based on Atmel ATMEGA microcontroller chips, the Arduino boards are programmed with standard C/C++ code. The Arduinos have six 10-bit analog (ADC) inputs, fourteen digital I/O, pulse width modulated outputs, as well as hardware for SPI and I2C serial communication and USB encoding hardware. We have chosen to use the Arduino because it streamlines data acquisition and processing when compared to circuits using discrete components and has robust enough software to run complex algorithms and control routines on the microprocessors themselves. The first device we describe is a temperature controller used to cool a potassium vapor cell. This circuit reads the output of a temperature sensor to the Arduino, which uses digital PID feedback to control heater output through Pulse Width Modulation (PWM). This gives consistent temperature stability of 7 millidegrees.

The second instrument is an automated wavelength meter for pico-meter resolution measurement of visible and infrared lasers. The optics include a Michelson interferometer containing two parallel beams an unknown and a Helium-Neon reference beam. This requires a counting circuit and motor driver circuit, both of which are controlled by the Arduino. The Arduino also monitors temperature, pressure, and humidity sensors for on board calculations of the index of refraction of air using known equations (Ref. 1). In addition, it controls an interactive LCD display for inputting preset information and displaying statistics.

TEMPERATURE CONTROLLER Design

We present a temperature control (Fig. 1) circuit driven by an Arduino microcontroller. The bridge and instrumentation amplifier map a temperature range of 0 to 80°C, as read by a PTC10 platinum resistance thermometer, to a voltage range of 0V to 5V. Since all components are driven by the same Vref = 5 V, the signal is insensitive to supply fluctuations. Precision, low temperature coefficient components are used for stability and repeatability. Oversampling of the 10-bit analog-to-digital converter (ADC) in the Arduino allows us to use an effective 14 bits, resulting in a temperature resolution of 8 mK. We modified a PID feedback algorithm (Ref. 3) to use integer math for faster calculation, resulting in a speed-up of 30%. The output is a PWM digital signal modulated at 1 kHz, which switches a high-side p-channel MOSFET to drive a 15 W resistive heater. The circuit consists of two parallel channels, reading two sensors and outputting to two heaters. We optimized the stability of the temperature by varying only the proportional and integral gain parameters (P and I₁) as shown in Fig. 2. Our best parameters are P = 1/4, I₁ = 1-94, D = 0 for a sampling rate of 0.6 s (Fig. 2a). At those settings we measured mean $T = 55.073 \pm 0.002$ °C (compared to our setpoint of 55.5 °C, with a standard deviation = 0.007 °C. The settling time of the circuit is about 120 s (Fig. 2a). To characterize the long-term behavior, we measured the Allan deviation for a 17 hour data run (Fig. 2b). The highest stability is $0.002 \pm 0.002$ °C over ~100s measurement times.

Figure 1 – Simplified schematic of the temperature controller circuit.

WAVELENGTH METER Design

We designed a pico-meter-resolution wavelength measurement apparatus for lasers in the visible range. A digital counter circuit interface with a Michelson interferometer. Initial concepts were derived from Ref. 2 using the relationship $\lambda_d = 2L_d\sin\theta_d$. Where $L_d$ and $\lambda_d$ are the wavelengths of the unknown and reference laser, respectively. $L_d$ is the number that will be counted down by the fringes of the unknown laser and $N_d$ is the number that will be counted up by the fringes of the reference laser. By setting $N_d$ to be the numerical value of the reference wavelength in picometers, $N_d$ will be the wavelength of the unknown laser in pm. The counting is done with parallel sets of counters recording counts from photodiodes. We modified this design to take advantage of an Arduino, in order to simplify the circuit and the collection of data. Additionally, the Arduino reads atmospheric temperature, relative humidity and temperature sensors to correct the measurement for the index of refraction of air.

Characterization

Testing indicates that the wave-meter counting circuit operates more quickly than the anticipated fringe rates for the measurement of visible or near infrared lasers. When fed with a digital signal generator, the circuit operates entirely without error over a large number of trials (n=100) with input frequencies of up to 2Mhz, a full order of magnitude above the highest frequency output that could be expected from the Michelson wave-meter design.

Future Work

The wave-meter circuit will be constructed using surface-mount components to save space and to reduce noise. The interferometer optical and mechanical system is under construction and will need to be finished before full evaluation of the effectiveness of the wave-meter setup is complete. The Helium Neon reference laser will be stabilized using polarization based temperature feedback, as the effectiveness of this design depends on an accurate known wavelength reference beam.

CONCLUSIONS

Arduino is a useful and versatile laboratory tool, facilitated by its support of general-purpose programming languages, extensive electronic communications interfaces, and powerful enough processing for precise lab equipment.

REFERENCES


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