Design software for adjusting the frequency of the laser modulation infrared diode portable photoacoustic spectroscopy

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Abstract. Photoacoustic spectroscopy can apply in various fields, including in the fields of biology (measuring trachea volume and observing insect breathing patterns), medicine (a measurement of internal disease biomarkers through respiratory gases), environment (measuring NO_2 gas in the environment near roads), and agriculture (measurement ethylene gas in postharvest fruit). The existing photoacoustic spectroscopy still has a large size and high operating costs, so it is necessary to design photoacoustic spectroscopy portable and low operating costs. Photoacoustic effects can occur when a modulated radiation source is present in this research, designing software to adjust the infrared diode laser's modulation frequency. There are two tests to see the characteristics of the software made in this study, test for Arduino and the software programs created. Arduino testing resulted in a calibration factor of $f_o = 0.9068 f_i + 109.33$. Meanwhile, software testing resulted in a calibration factor of $f_o = 0.7343 f_i + 462.74$. The two tests that have been carried out have different output results. The frequency of the software being made has a smaller calibration factor than the Arduino program's direct output.

Keywords: frequency modulation, diode laser, infrared, photoacoustic spectroscopy.

1. Introduction

The detection and diagnosis of a disease are often made in an invasive manner that can be expensive or require time-consuming biological (culture), microscopic (cell or tissue biopsy), or complex analytical (chemical) examinations. Some of the conventional clinical diagnosis methods include many invasive and potentially dangerous biopsy procedures, such as endoscopy, computed tomography, magnetic resonance imaging (MRI), mammography, serological blood tests, ultrasound, or x-ray imaging of other organs. Many of these methods present some risk of severe adverse side effects. Still, they are often painful enough that the patient usually does not participate in the procedure to detect the disease early. These human sentiment factors continue to point to an increasing need for improvements in diagnostic methods towards more non-invasive and painless procedures in disease screening for early diagnosis and examination and examination of patients in routine clinical practice [1].

One of the disease detection methods being developed is the analysis of exhaled gas. Breath analysis is a promising field with great potential for the non-invasive diagnosis of several diseases by analyzing the concentration of volatile organic compounds (VOC) in breath [2]. The exhaled breath contains more than 3,500 components, most of which are organic compounds that are volatile in minimal amounts. Many of these organic compounds characterize the function of the organism as a whole (systemic biomarkers). Some are still related to processes that occur in the respiratory system and airways in particular (lung biomarkers) [3]. The concentration of volatile organic compounds in the exhaled gas is in ppm and even ppb units, so it requires a high sensitivity detection device.

The photoacoustic spectrometer is a highly sensitive tool that can be used to detect gas concentrations [4] so that it can be used to measure the concentration of volatile organic compounds in exhaled gas, which is in the ppm to ppb range [5]. Another significant advantage of photoacoustic spectroscopy is its ability to provide a direct spectrum of any solid crystal, powder, gel, or biological tissue-spectra that are impossible to obtain by other techniques [6]. Photoacoustic detection provides high sensitivity and the selectivity required to analyze multi-component mixtures using an adjustable infrared laser, such as a CO laser or a CO2 laser [5].

The CO2 laser is exciting because it has a high output power in the wavelength region (9-11 μm). More than 250 molecular gases/vapors exhibit strong absorption, so it has become a concern of environmental, industrial, or medical research [5]. Analysis using a CO2 laser photoacoustic spectrometer has been carried out by Mitrayana et al. [7] measured the concentration of acetone in breath of Lung Cancer patients, Tyas et al. [8] measured the concentration of acetone in exhaled gas in type 2 diabetes mellitus patients, Oktafiani et al. [9] measured the concentration of ethylene gas in people around the dumpsite and research by Darmawan et al. [10] tested the performance of a CO2 laser photoacoustic spectrometer to measure the concentrations of ethylene, acetone and ammonia gas in smoker's blown gas. However, the use of a CO2 laser photoacoustic spectrometer is relatively expensive. Also, the overall shape of the CO2 laser photoacoustic spectrometer does not allow it to be carried at any time, so a photoacoustic spectrometer with a radiation source in the infrared spectrum is needed more portable and does not require expensive costs to operate.

One of the types of equipment, a crucial component in photoacoustic spectroscopy, is a modulated radiation source with the appropriate spectrum. Amplitude modulation is generally used more frequently than laser source frequency modulation[11]. Techniques to modulate amplitude include mechanical, electric, electro-optical, and acoustic-optical choppers. In this research, the electrically designed infrared diode laser modulation by adjusting the laser source voltage. This arrangement is made with the help of Arduino as a laser modulation frequency change processor. The process of changing the frequency, which is done by changing the program that is inserted into the Arduino, looks inefficient, so software that can change the modulation frequency is needed without having to delete and upload the program into the Arduino. Therefore, at this stage, software that can change the modulation frequency is carried out without deleting and uploading the program into Arduino.

2. Research Method

It was controlling the frequency of the diode laser modulation using the Arduino Mega 2560 hardware, Arduino IDE software to create programs that are included in the Arduino, Visual Studio as a display interface in providing the desired modulation frequency value, and a calibrated digital oscilloscope to test the modulation signal output from Arduino. The process of controlling the frequency of the diode laser modulation is as shown in **Figure 1**. The software will provide frequency modulation input to Arduino. Then Arduino will adjust the Arduino leg's output connected to the diode laser according to the modulation frequency given by the software. The test is carried out in two steps, namely Arduino testing and software testing, in producing the modulation frequency.

Figure 1. The process of controlling diode laser frequency modulation.

2.1 Arduino's Characterization

Arduino testing is carried out to determine Arduino's characterization in making square wave signals by assembling the tools, as shown in **Figure 2**. The Arduino output pins are connected to the digital oscilloscope to see the compatibility between the frequency of the square signal issued by the Arduino and the desired frequency. The output frequency varies from 100 Hz to 20,000 Hz. The amount of frequency read on the oscilloscope will be compared with the input frequency on the Arduino to determine the linearity of the Arduino output from the program is made.

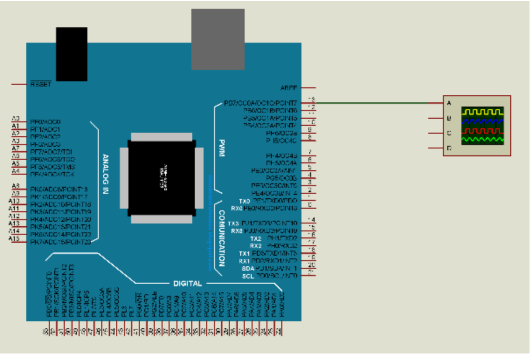


Figure 2. circuit for testing Arduino's output.

2.2 Software's Calibration

Software calibration is made by calibrating the software's frequency with the output on the Arduino, which is connected to a digital oscilloscope. The circuit for software testing is shown in **Figure 3**. The frequency set for the Arduino via the software varies from 100 Hz to 20,000 Hz. The amount of frequency read on the oscilloscope will be compared with the frequency of the Arduino.

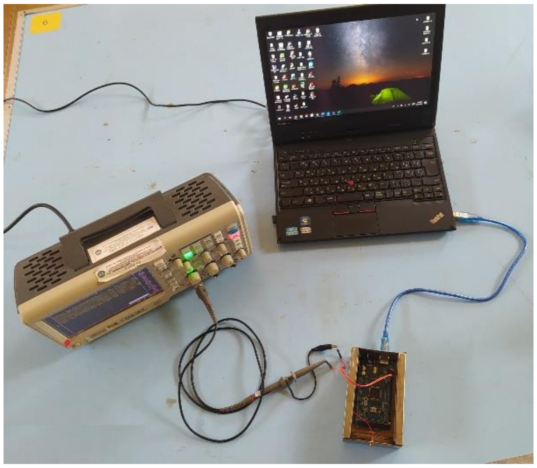
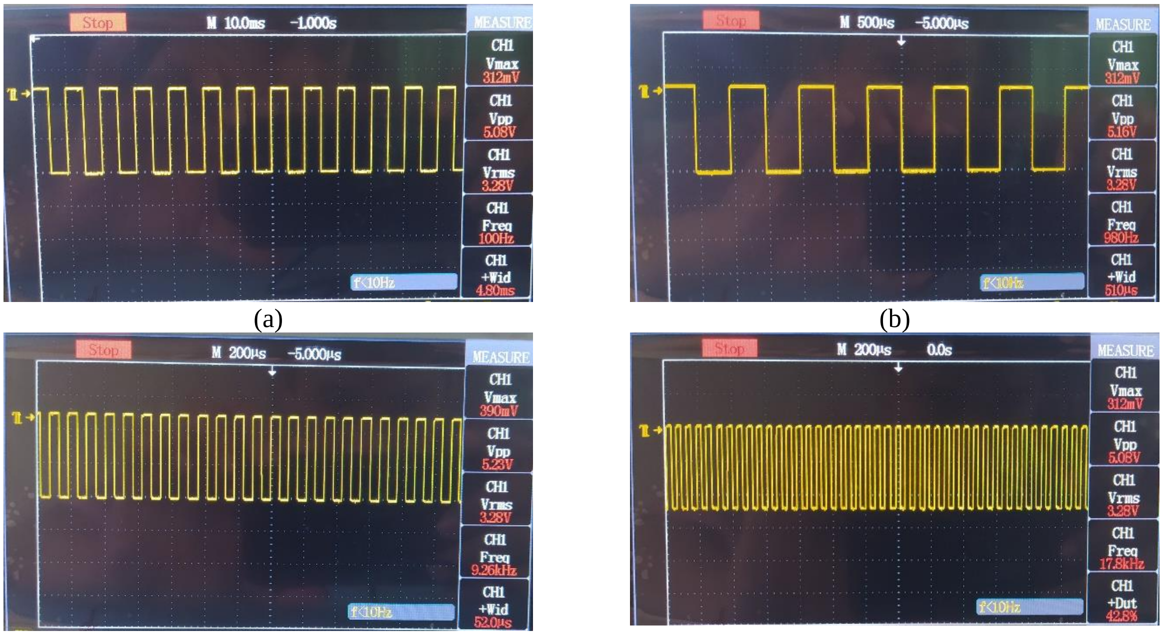


Figure 3. Circuit to test the software’s output.

3. Results

3.1 Arduino’s Characterization

The results of the square waves from the Arduino output are given in **Figure 4**. This figure shows that the Arduino output always produces square signals with different frequencies according to the program input uploaded to the Arduino.



(a) (b)

(c) (d)

Figure 4. Arduino’s output signal. (a) Output signal at 100 Hz (b) Output signal at 1 kHz (c) Output signal at 10 kHz (d) Output signal at 20 kHz

The characterization between the input program made and the Arduino output used produces a graph that is still linear, as shown in **Figure 5** with the calibration factor in Eq. (1).

$$f_o = 0.9068 f_i + 109.33 \quad (1)$$

The graph results show that the frequency issued at the output pin has shifted by ± 0.0932. This shift is due to Arduino's delay in reading the commands in the program that is made in each line.

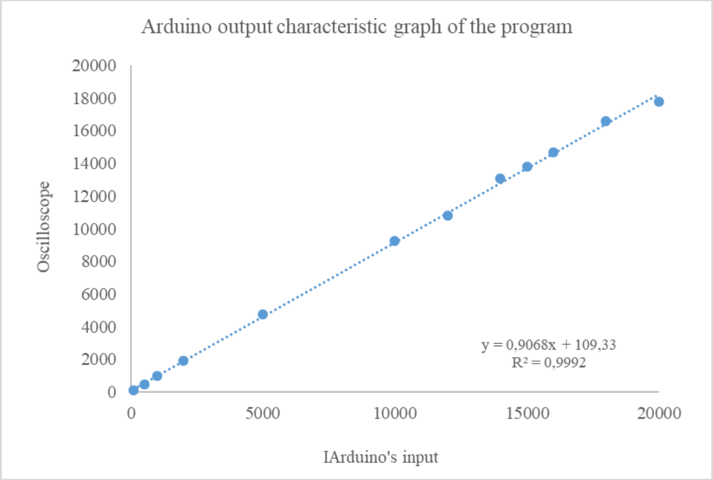
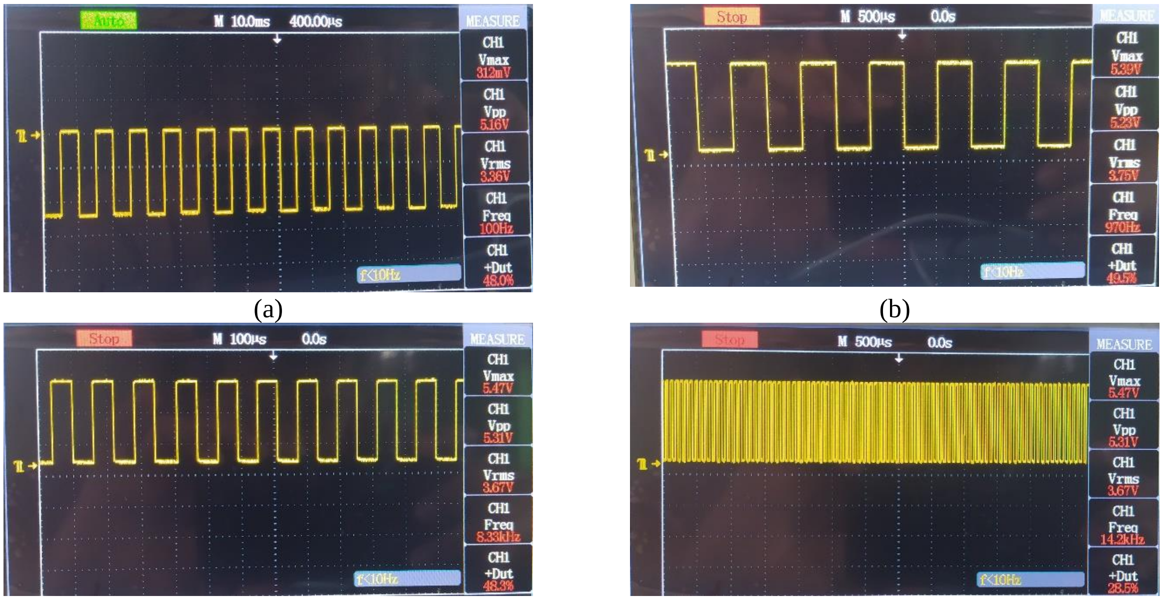


Figure 5. Arduino output characteristic graph of the program.

3.2 *Software's Calibration*

The results of the square wave from the program output are given in **Figure 6**. From this figure, we can see that the Arduino output produces square signals with different frequencies according to the software program's input.



(a) (b)

(c) (d)

Figure 6. Software's output signal. (a) Output signal at 100 Hz (b) Output signal at 1 kHz (c) Output signal at 10 kHz (d) Output signal at 20 kHz

Characterization between the input program made and the Arduino output used produces a graph that is still linear, as shown in **Figure 7** with the calibration factor in Eq. (2).

$$f_o = 0.7343 f_i + 462.74 \tag{2}$$

The graph results show that the frequency issued at the output pin has shifted by ± 0.2657.

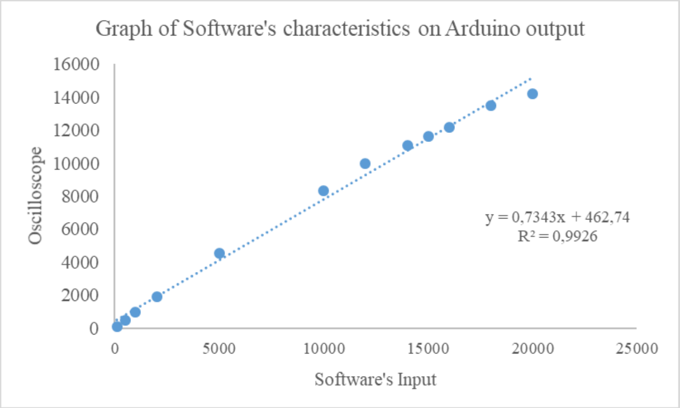


Figure 7. Graph of Software's characteristics on Arduino's output

The two tests that have been carried out have different output results—graph comparison of the two, as shown in **Figure 8**. The software output created has a smaller calibration factor than the direct production of the Arduino program. However, this is still acceptable, considering the error value in the software calibration factor of 0.9926. This smaller calibration factor is due to the program first reading the serial connection between the Arduino and the PC to get the frequency inputted on the Arduino. The software that is made will be more efficient and will not reduce the service life of the Arduino because we don't always need to upload the program every time we change the desired modulation frequency.

To anticipate the modulation output to match what it should be, we can increase the software's input frequency by applying Eq. (2). For example, if we want a modulation output of 20 kHz, the software input frequency is 26.6 kHz.

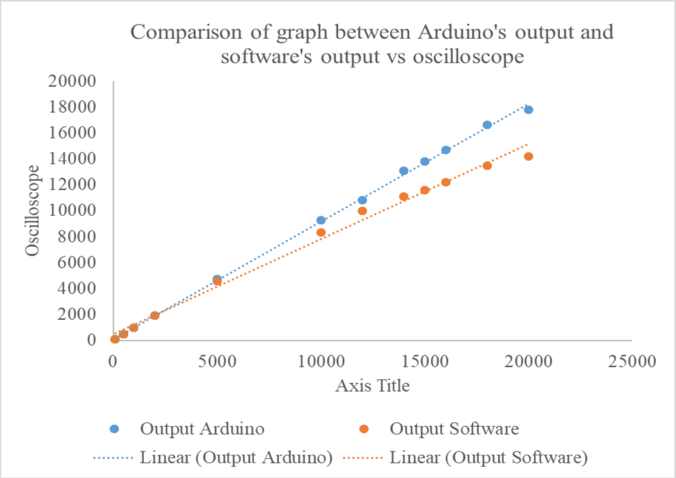


Figure 8. Graph comparison between Arduino output and software vs. oscilloscope output.

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4. Conclusions

The modulation produced by the software can still be tolerated because it has a calibration factor of $f_o = 0.7343f_i + 462.74$ with an error of 0.9926. This calibration factor is smaller than direct modulation by entering the program into the Arduino at ± 0.1725.

5. References

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