Measurements on liquid solutions using low cost, low power, light emitting diode photo-acoustics

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Abstract. We have developed a low cost, low power, photo-acoustic cell using a light emitting diode (LED) light source with monotone modulation for the purpose of measuring concentrations of aqueous liquid solutions in a non-invasive manner. The apparatus is smaller and cheaper than a conventional instrument such as a photo-acoustic cell in conjunction with a spectrometer.

1. Introduction
Photo-acoustic spectroscopy is a widely used technique for the analysis of solids, liquids and gases. Its non-invasive nature is a very attractive feature [1]. When used with a spectrometer for spectral analysis, however, the instrumentation is large, complex and very expensive. There are many applications which could make use of photo-acoustics but the equipment required can be large and expensive. Furthermore, photo-acoustic instrumentation is delicate and is normally only operated in a controlled environment such as a chemical analysis laboratory rather than outside in the field. If a way could be found to reduce the size, cost and complexity of photo-acoustic instrumentation, it could be used for many more applications - and possible many new ones.

2. Problem
Photo-acoustic spectroscopy has been used in research for the determination of blood glucose levels in humans [2]. The results have been encouraging but the development of a portable, non-invasive blood glucometer using photo-acoustics has been restricted due to practical problems associated with cost, size and complexity of instrumentation. The scientific principles of such devices have already been successfully demonstrated in vitro but more work is required before a practical solution can be realized. Unless a small size, low cost photo-acoustic measurement process can be devised, it will be difficult to advance the development of a non-invasive blood glucometer using photo-acoustics.

3. Method
For applications such as a blood glucometer, the basic requirement is to measure the concentration of a liquid (glucose in this case) in a non-invasive manner. Photo-acoustic spectroscopy, normally operates by taking absorption measurements over a wide range of wavelengths. For measurements of liquid concentrations, however, there is no need for a full spectral analysis and all that is required is to determine how much of a known substance is present. This means that the complex mirror and optics associated with interferometer measurements can be omitted from the process and readings can be taken at a single wavelength using a monotone modulation system.
Light sources used in photo-acoustic instruments are expensive and delicate. If a small size, low cost, low power light source could be used instead, this would also help to achieve a low cost measurement process for new applications. There are many compact low cost light sources available and these include semiconductor lasers, light emitting diodes (LEDs).

Although lasers have been used for photo-acoustic applications, they tend to be large, high power and can be expensive. Smaller lasers have been used with photo-acoustics but they are mainly used for gas analysis [2]. Recently light emitting diodes have also been used for gas analysis [3]. It is clear that as technology advances, smaller sized and lower power light sources are being used in photo-acoustic measurement processes. Unfortunately, most of the applications here have been restricted to gas analysis and there is very little reported for other forms of matter – liquids and solids. If light emitting diode technology could be combined with a mono-tone modulation system, this would significantly help to reduce size, cost and complexity of photo-acoustic measurement processes for portable blood glucometers and many other new applications.

Several investigations were conducted resulting in the development of an LED photo-acoustic cell for the purpose of measurements with liquid solutions. The LED photo-acoustic cell used a near infra-red (NIR) LED with a peak wavelength of 810nm (Fig 1). This device was an ELJ-810-22B Jumbo LED (Epigap Optoelektronik GmbH, Germany). The radiant power was quoted as 225mW at a forward current of 250mA.

![Fig1.Jumbo NIR Light Emitting Diode](image)

A 25ml glass sample jar was used to hold the liquid sample and the LED light was applied though the walls of the glass jar onto the upper surface of the liquid under test. The photo-acoustic signal produced at the liquid surface was detected using a 6mm diameter Electret microphone attached to the underside of the sample jar plastic lid. The sample jar and LED were held in position with a small wooden jig – see Fig 2.

To demonstrate the LED photo-acoustic cell, quantitative measurements were made with water, 1000ppm Methylene Blue dye and 1000ppm glucose. In the first set of tests, water and a 1000ppm Methylene Blue solution were tested using the empty jar as a control. These tests were repeated six times to ensure consistent results. In the second set of tests water and 1000ppm glucose were tested, again using the empty jar as a control.
Fig 2. LED Photo-acoustic Cell

The LED was modulated by constructing a simple transistor switching circuit with the LED acting as the collector load. The input signal to the transistor switch was a 1V square wave supplied from a Hewlett Packard 33120A signal generator. The transistor modulator was mounted inside a small metal box to avoid external interference.

A high gain (X 100,000), low noise amplifier was constructed to amplify the photo-acoustic signal to produce an output peak to peak amplitude of 1 to 2V. The signal output from the high gain amplifier was displayed on a TDS2012 two channel, digital storage oscilloscope (Tektronix Inc., USA) with a signal averaging facility and a digital measurement display.

Background acoustic noise and electrical / magnetic interference was addressed by placing the LED photo-acoustic cell and the high gain amplifier inside an electrically screened wooden box with a lid. To reduce the effects of low frequency vibrations through the floor and bench, the screened wooden box was mounted on several layers of cloth for damping purposes.

To determine the best mono-tone modulation frequency, the LED was modulated over the range 10 Hz to 1 kHz.

4. Results
The main problem, as expected from the apparatus, was the low level of photo-acoustic signal compared to background noise levels; in other words, a poor signal to noise ratio – initially about 0dB. However, steps were taken to address each of the possible contributory noise sources in turn until an improved signal to noise ratio was obtained which enabled quantitative results to be taken. High frequency noise was removed from the signal using a low pass filter with a cut-off frequency of 2 kHz. Even after all the attempts to combat noise had been implemented, there was still a residual random noise present. This was further reduced by using the signal averaging facility of the digital oscilloscope to average the output signal over 128 cycles. The final signal to noise ratio resulted in a noise amplitude of 10dB to 30dB down on the signal amplitude. We observed a time delay of around one minute for the signal to grow to its maximum value. This meant that when measurements were performed, the signal was left for one minute before readings were taken and the final value was the mean of the readings recorded during the second minute of recording – see Fig 3.
Fig 3. Growth of peak to peak photo-acoustic signal amplitude plotted against time

Good results were obtained with a modulating frequency of around 30 Hz. At modulating frequencies above about 30 Hz, the photo-acoustic signal had a smaller amplitude. At modulating frequencies below about 30 Hz the photo-acoustic signal waveform was distorted – possibly due to cooling at the sample surface in between light pulses.

The results for the tests with water and 1000ppm Methylene Blue Dye are shown in Fig 3 where it can be seen that it was possible to distinguish between water and 1000ppm Methylene Blue. The tests with water and 1000ppm glucose were not so clear, however, and although a good signal was obtained from both, it was difficult to distinguish between them.

5 Conclusions
Our LED photo-acoustic cell was successful with 1000 ppm Methylene Blue dye and water but similar solutions with glucose and water were more difficult to analyse.

References
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