# Low-price Optical Microscope for School Science Education

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(Abstract)

In schools, scientific education with an optical microscope is popularly used. However, scanning apparatus for the microscope is very expensive such that the price is several times higher than the microscope itself. In order to activate children's interest in science, a low-price scanning and imaging function unit compatible to conventional optical microscopes used in schools was designed and manufactured using a personal computer (PC) used in all elementally and middle school education.

The designing of imaging apparatus includes two choices: (i) using imaging device (reflection-type), or (ii) using photo-sensor and scanning device (transmission-type). In this paper, the latter method is adopted, considering the educational effect using "Lambert-Beer's law".

This apparatus measures optical transmittance of modulated visible light with a photo-detector, and uses audio-input unit of PC as an A/D converter. Scanning unit with a pair of pulse motor drives was also used. Control software was built on Knoppix (an operating system based on freeware Linux), however it is very easy to rewrite to Windows application. By these reasons, this apparatus is low-price (less than microscope price) so that it is one of the best candidates for science education application in schools. As a biological specimen, a wing of spider wasp (Pompilidae) was used. Measured region was 10mm×10mm and the resolution was 100×100 pixels. The photograph of original specimen and the obtained image were shown in Figures (a) and (b), respectively. The obtained image showed a well-resolved detailed structure of the wing. Scanning was done by an external scanning apparatus. However, feeding of scanning pulses through printer port to stepping motor will be available based on the same method.

## 1. Introduction

In schools, scientific education with an optical microscope is popularly used for science education. Everybody can recognize the importance of visual stimulation in elementary and middle school education so that the importance of low-price image capturing has increased.

However, scanning apparatus for the microscope is very expensive such that that price is several times higher than the microscope itself. For example, a scanning apparatus prepared for an optical microscope manufactured for educational purpose about $100 will cost more than $400 to $500.

In this study, a low-price scanning and imaging function unit compatible to conventional optical

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microscopes used in schools was designed and manufactured using a personal computer (PC) used in all elementally and middle school education to activate children's interest in science.

**2. Imaging scheme and principle.**

As imaging scheme, transmission-type imaging and reflection –type imaging exist. In addition, the designing of imaging apparatus includes two choices: (i) using imaging device such as CCD camera, or (ii) using photo-sensor and scanning device with point-to point detection. For the first case, the digital microscope is sold on many countries (with a price about $400-$1000). However, for the developing countries, it is very difficult to realize for every schools to purchase enough number of CCD imaging apparatus. In addition, scanning of digital microscope for educational purpose is preformed by manual scanning almost all countries because of its high price of scanning apparatus.

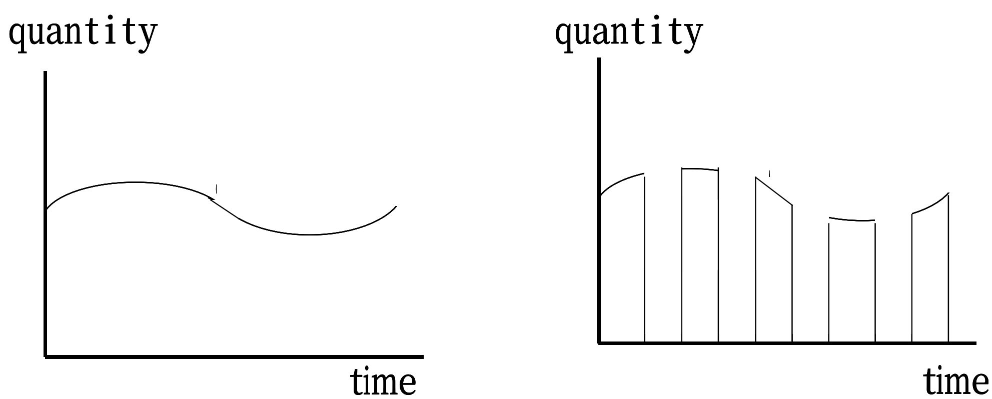
In this paper, the point -to-point (P-P) detection scheme is adopted, which is based on the "Lambert-Beer's law".

$$I(x,y) = I_0 \cdot \exp[-\alpha(x,y) \cdot L\} = I_0 \cdot \exp[-A(x,y)] \qquad (1)$$

where $I_0$ is a constant in light intensity incident to the sample, $\alpha$(x, y) and A(x, y) are absorption coefficient and absorbance at the scanning position (x, y) of the sample with the length L.

The P-P detection scheme is detect a transmitted light intensity by a photodetector for every point of scanning at position (x, y), and reconstruct image of it. For the reflection-type detection, the P-P detection scheme is similar. It detects reflected light intensity at every point of scanning and reconstruct image of a sample.

The basic principle of A/D conversion of this measurement method is schematically shown in Fig. 1(a) and (b) in time domain. The conventional A/D converter shown in Fig. 1(a) works as signal converter in the frequency region from direct current (DC) to the maximum frequency determined by the sampling frequency. On the other hand, audio inputs are DC-isolated so that they cannot sample DC or lower frequency signal as they are. Therefore if we modulate optical source at audio frequency as shown in Fig. 1 (b), the generated




(a) (b)

Fig. 1 (a) Conventional A/D converter (left), (b) A/D conversion of the present study; modulated signal behaves like a "sound"[1,2].

signal with the same frequency behaves like “sound” so that it can be converted to digital signal by audio input unit, which is attached to every PC as a PC standard device! According to the knowledge of Fourier transform, the modulation of optical source will shift signal sideband to modulation frequency from DC. This scheme is shown in frequency domain in Fig. 2[1,2]

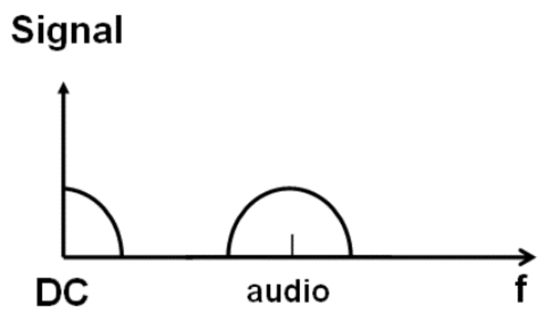



Fig. 2 Frequency shift scheme in utilizing sound input/output devices as A/D and D/A converters.

Furthermore, printer port, standard utility for PCs is also one candidate of driving tool for scanner of a sample set on a slide glass. A line printer working by a LPT port or serial (RS232C or USB) port is a powerful candidate of scanning apparatus.

For a system design, there are many selection of combination of i) detection (CCD or photodiode+sound input), ii) scanning (printer port or sound output drive, independent mechanical movement), etc,

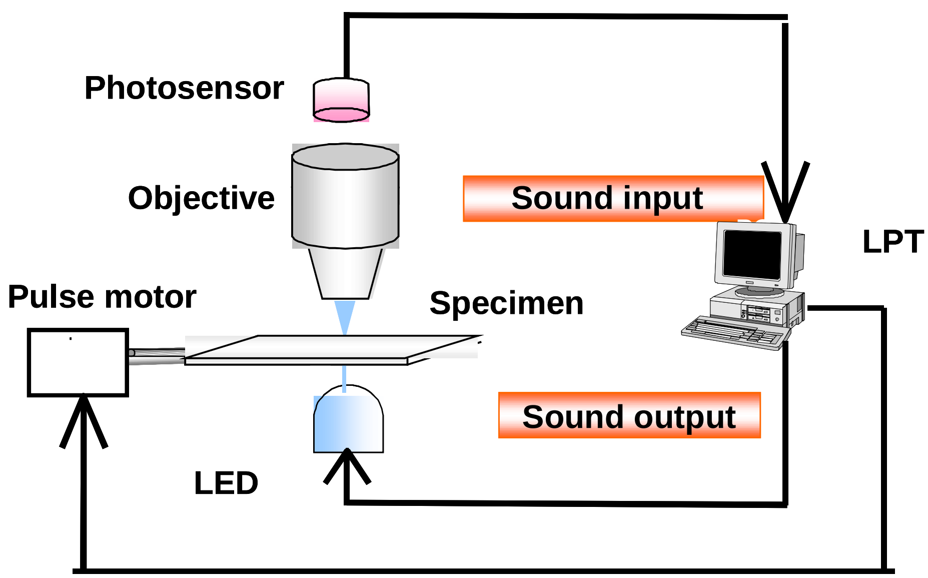



Fig. 3 The expected experimental setup of the low-price optical microscope (transmission-type)

LabVIEW™ supplied by National Instruments offers various “vi (virtual instrument)” subroutines, such as sound acquisition, sound generation, etc. And the compiled program can run under a free supporting utility called “runtime engine”. These are also good candidates for low-price optical microscope for school science education.

The proposed low-price optical microscope is conceptually shown in Fig. 3. This apparatus utilizes sound input/output and printer port (LPT/serial) as control devices. Furthermore, its ability in audio range is comparable to that with conventional A/D and D/A input/outputs facility and scanning devices.

The reason why this microscope does not require lock-in amplifier is that 1) it detects peak-to peak of alternative current (AC) signal generated by the modulated transmitted light intensity, or that 2) it multiplies modulation reference signal with detected electrical signal generated by the transmitted light intensity and detects DC component using software. The detection is performed if we denote sampled signal carrying the information of optical image as e[k] (k=1 to n), n is the number of short time sampling,, and detected sine and cosine components as $I_s$ and $I_c$ as,

$$I_s = \sum_{k=1}^{n} e[k] \cdot \sin(2\pi fkT)$$
$$I_c = \sum_{k=1}^{n} e[k] \cdot \cos(2\pi fkT) \qquad (2)$$

where f and T mean modulation frequency and sampling period, respectively. The detected optical signal is calculated from sine and cosine components as

$$I = \sqrt{I_s^{\ 2} + I_c^{\ 2}} \qquad (3)$$

The time needed for image acquisition by calculating DC component depends upon the audio sampling rate or the performance of the PC.

## 3. Experimental Apparatus

### 3.1 First-stage experiment

In this study, the P-P scheme was adopted. This apparatus measures optical transmittance of modulated visible light with a photo-detector, and uses audio-input unit of PC as an A/D converter. Scanning unit with a pair of pulse motor drives was also used. The basic setup is similar to Fig. 3. An optical source is a conventional halogen lamp (50W) with a DC power supply that is with an infrared (IR) absorber plate (Edmund Optics, 45648-E) attached on it. The output is modulated by a mechanical chopper, a fan driven by a DC motor with a stabilized DC power supply. Modulation frequency was changed about 20Hz-300Hz. Transmitted light is detected by a photodiode (Toshiba TPS501) and an additional detector circuit. The output is connected to sound input.

In the first-stage experiment to verify the A/D conversion ability of the audio input device, the scanning apparatus was replaced by a linear motor stage and the control software was made by LabVIEW™ The basic program was that made for a photoacoustic microscope fabricated by the research group of the first author (TH)[3-5].

Two experiments were compared at this stage: 1) A/D converter unit called DAQ (data acquisition) supplied by National Instruments combined with a lock-in amplifier (NF Circuit Block, LI-5610B) was used, and 2) the sound input and peak-to peak detection of an electrical signal was performed by the software without lock-in amplifier was performed with a similar method described in [ 3]. Time needed to get images with resolution of 50 x 50 pixels were thirty minute.

### 3.2 Second-stage experiment

We would like to describe road map to reach the final version of low-cost optical microscope. In the second-stage experiment, detection and scanning procedure was separated for the more actual trial to realize low-price scanning apparatus. RGB color LEDs driven by a drive circuit are manufactured by electronic parts and driven by audio output of a PC. Frequency domain discrimination is done by changing modulation frequencies of R-, G- and B-colored LEDs, ratio of which are 2:3:5, respectively. Control software is made with language C running on Knoppix (an operating system based on freeware Linux), however it is very easy to rewrite to Windows application.

By the reasons described above, this apparatus is low-price (less than microscope price) so that it is one of the best candidates for science education application in schools.

## 4. Specimens

As a specimen, a slide glass painted by a black paint was used. The paint was cross-shaped with a length and width of 12 mm and 3 mm, respectively.  A wing of spider wasp (*Pompilidae*) was used as a biological specimen. The photographs of two specimens are shown in Figures 4 (a) and (b).

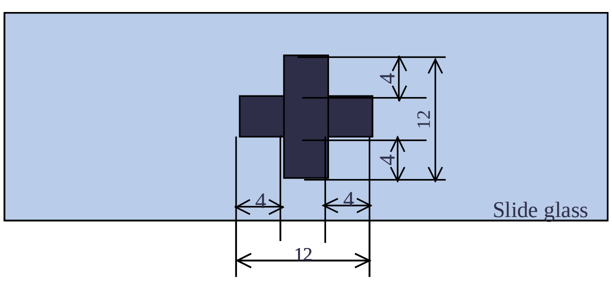



Fig. 4

(a) Black paint painted on a slide glass (left)

(b) wing of Spider wasp (*Pompilidae*) (right)

## 5. Experimental Results

For the painted color paint specimen, measured region was 15mm×50mm and the resolution was 50×50 pixels. On the other hand, the measured region was 10mm×10mm and the resolution was 100×100 pixels. For the biological specimen (wing of spider wasp), the image obtained by sound input experiments are shown in

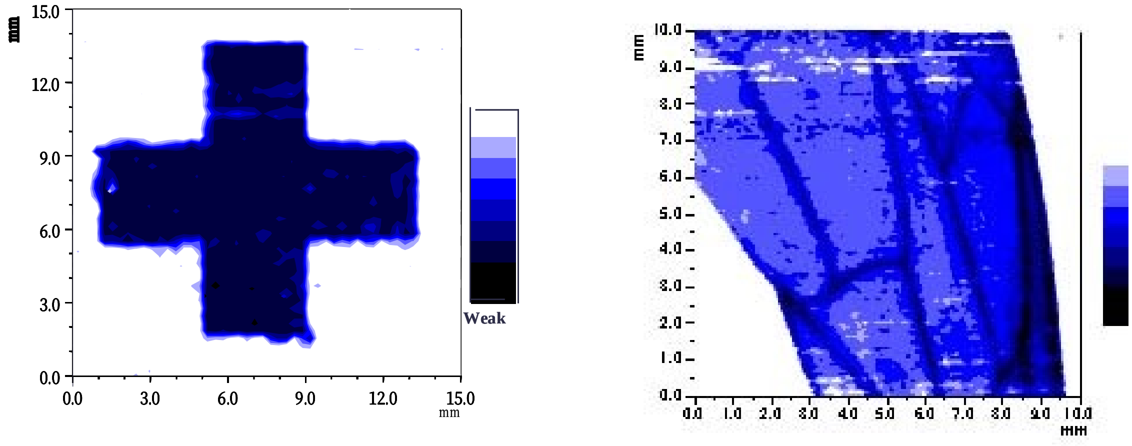



Fig. 5 (a) obtained transmitted image of a painted slide glass (b) obtained transmitted image of a spider wasp

Figures 5 (a) and (b), respectively. The quality of both images obtained for painted color paint and a spider wasp show good quality.

For comparison, the image for painted color paint obtained by a DAQ and lock-in amplifier was shown in Fig. 6. The reason why the image shows more noise is caused by not because the performance of the DAQ input apparatus but the fluctuation of a hand-made chopper.

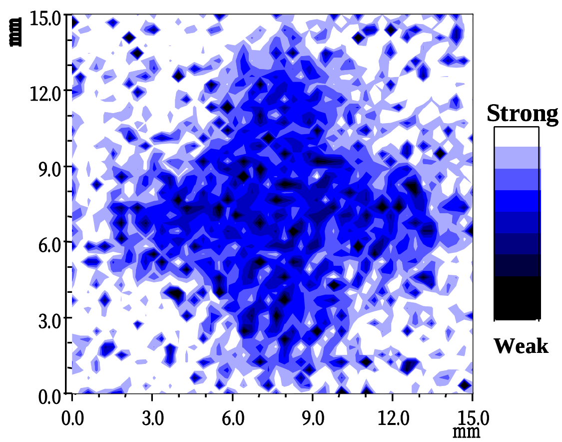



Fig. 6 Image obtained by DAQ and lock-in amplifier

**6. Discussions**

On the colored imaging (second-stage experiment), RGB drive method is in progress. Modulation of RGB LEDs is realized with three different frequencies, the modulation frequency ratio of R, G, and B LEDs are 5; 3; 2, respectively. The scanning apparatus using pulse motor drive is working with a speed of 5 mm x 5 mm 25 round-trip scans for 50 x 50 pixels with 8 seconds. The scanning time limits the minimum time of image capture so that the time (8seconds) is short enough to wait until image appears. Thirty minutes needed for linear-motor drive case (first-stage experiment) is too long time for children to wait. The integration of detection part and scanning part is in progress. The modulation/ detection program and the scanning program are both written in language C running on Knoppics.

For the other candidate of the software for this low-cost optical microscope apparatus, sound acquisition-vi and sound generation-vi supplied by LabVIEW™ are good subroutines, which are easy to be programmed with GUI (graphical use interface). These programs are also in progress, and will be supported in a web by the first author (TH) in the future. The compiled program will run under a runtime engine, which is a free program package downloadable from the site of National Instruments.

## 7. Conclusion

In this study, it is verified that it is possible to use PC sound input /output to use A/D and D/A converter if we modulate light source and detect the signal at audio frequency range. Image reconstruction was succeeded for reflection-type monochrome imaging. Color imaging system using RGB photodiodes modulated at different frequencies is being fabricated and in progress.

The problem to determine which selection is the best candidate of the control software of a low-price optical microscope system, C running on free Unix or LabVIEW™ with runtime engine under Windows, was left as the problem in the future. Subjects to fabricate a reflection−type imaging device and the attempt to integrate this scheme and CCD capture method in a unified optical microscope was also unresolved.

The goals of the present study in the future are; 1) to realize low-price (<$100) optical microscope imaging apparatus, and 2) to establish a center of software download (FREE or at extremely low-price) for microscope application (we would like to contribute to this web site).

For the children's scientific education, the authors would like to realize and deliver low-price optical microscope imaging apparatus to everywhere in the world!

## Acknowledgments

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