




# Designing of low-cost spectrometer for sensor application

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Received: 29 January 2021 / Accepted: 17 April 2021 / Published online: 30 May 2021  
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**Abstract** Increase in the population demands healthy food, clean air, fresh water and high secured life. To fulfil the above demands, spectrometers such as ultraviolet, Fourier transformation infrared, Raman, HPLC, gas chromatography are used as confirmation tool for identification of materials. The cost and space of above-mentioned instruments are more and to build low-cost spectrometer with high efficiency is a challenging research area for material scientists and engineers. In the present work, an attempt has been made to manufacture a low-cost spectrometer. The spectrometer has been designed using cardboard, DVD, a webcam and free available spectrum software named as theremino. The DVD is used as a diffraction grating and webcam as an image sensor with an overall cost of Rs 1000. This can be used as an instrument for practical demonstration for students and other research purposes for detecting pesticides level in fruits and vegetables, sensing water purity level, edible oils, etc. The spectral range can be improved by removing infrared filter integrated in webcam. The performance of the constructed spectrometer could be upgrade using effective filters and high intense low-cost lasers. This designed spectrometer will be a boon towards application in healthcare, biomedical and food processing applications.

**Keywords** Spectrometer · Camera · DVD · Dye solutions · Light source

## Introduction

Spectroscopy plays a vital role in human life due its wide application in agriculture, water and soil. Many researchers use it as conformation tools for material characterization and identification of unknown compounds. Designing low-cost spectrometers are becoming a significant demand in various fields such as education, research, testing centre, medical, agriculture and defence. Designing of low-cost spectrometer and its usage are carried out in past one decade. However, we are still facing challenges such as recent COVID-19 PCR or antigen analysis using spectrometer [1–5]. The whole idea behind construction of low-cost spectrometer is to make it available for all kinds of users. It is highly used in spectroscopy studies by material scientist and engineers. It has advantage of being non-destructive and can be used as qualitative analysis. As most of the spectrometer is based on grating or mirror based, in the present work, an attempt has been made for constructing low-cost spectrometer using cardboard and wooden box. Usage of webcam is to overcome the tedious arrangement of grating and prism. The cameras on smartphones have automatic adjustments for focus and white balance making it difficult to obtain consistent readings [6–8]. There have been several reports attempting to characterize the camera sensor to carry out reliable measurements. Webcam-based spectrometer is used for the titration technique. The imaging techniques used will be helpful for ripening of fruits and vegetables and help in classifications of types of food. Many articles have been published in low-cost spectrometer such as spectrometer

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for graduate students [7]. Grating-based spectrometer to find out the titration of solution, 3D printer-based spectrometer, low-cost Raman spectrometer [9–11]. All the above one needs complex alignments, filters. In the present work, a simple low-cost spectrometer replacing DVD with grating and using 900 rupees camera, we have built box type spectrometer for detections of dyes, pesticides and oil contaminants. General public depends on testing kits with high accuracy. Similarly, in laboratory, especially in chemistry, the flame test results and other studies such as spectrophotometer need high end instruments. Regarding the above, the present work will be very useful. Here, the arrangement of sample is easy for end user due to box type spectrometer. In the present work, we have compared the spectrum in cardboard box and wooden box for different angles and compared the results of both with applications point of view.

## Materials and methods

### Materials

Cardboard, wooden box, DVD, Logitech camera, colour papers, cutting tools, sodium vapour lamp, He–Ne laser, red dye-rhodamine 6G, oil, pesticide, food colourant.

### Designing of spectrometer

Rough prototype has been designed in cardboard box having width and height  $10 \times 15$  cm. The camera is fixed at  $30^\circ$  such a way that the reflected laser light after interacting with sample decreases the dark intensity. The camera is connected to the laptop for analysis of the spectrum (Fig. 1).

### Preparation of web cam

We need to fix the webcam opposite to the slit at angle of  $30^\circ$ . The  $30^\circ$  of inclination provides a good compromise between resolution and amount of light collection, but it is

possible to do experiment with different angles. By decreasing the angle, the resolution increases, the lines move to the left and the light intensity decreases. By increasing the angle, the reverse happens. Depending on the light sensitivity of the camera, the focal length of its objective, its number of pixels, the number of rows in the grid (CD, DVD or Grating) and how much resolution you want to get, you might choose an angle different from these  $30^\circ$ . In order to measure the infrared light (from 750 nm up to 1000 nm approximately), it is necessary to remove the IR filter which is located on the rear of the lens (Fig. 2).

### Preparation of DVD

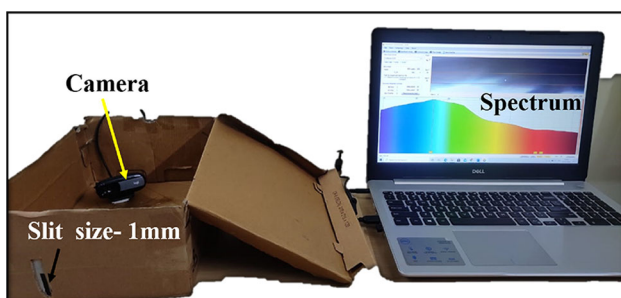
A blank DVD disc is separated into two halves with razor blade. Half of the disc is discarded and thin silver layer was torn off with adhesive tape. Precise care was taken during breaking and separation to avoid scratches. The obtained piece shown in Fig. 3 was used as grating for spectrometer by placing it in front of webcam.

### Software

Theremino\_spectrometer-Tool for spectrum analyser available free in online [12].

### Working/methodology

The working of portable or low cost spectrometer is based on the source and the detector. In the present spectrometer the absorbance of different wavelengths of a sample was captured through the DVD fixed on the webcam and recorded in system. The basic idea of splitting light is to change the angle of the light. The spreading of colours over a large area detected separately from each other. DVD act as grating and separate out colours by the different path lengths between different rays reflecting and interfering. This leads to different wavelengths of light being reflected at different angles. The output is obtained as spectrum by software [9–11].



**Fig. 1** Cardboard type spectrometer

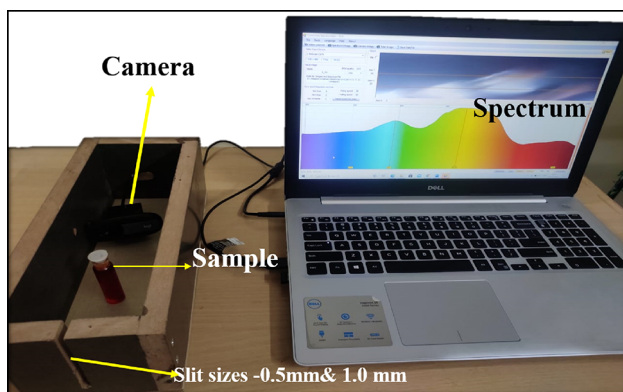


**Fig. 2** Logitech web camera



**Fig. 3** DVD as grating source for spectrometer

The light has been passed through the slit to reduce the width of the light beam. The light falls on the sample solution, then some part of the light has been reflected and some part of the light has been transmitted. The transmitted light falls on the DVD grating to split the light into different colours with different wavelengths. The splitted light can be captured using the image sensor (WebCam). By using the Theremino\_Spectrometer, we can get the spectrum of wavelengths of the captured light by passing through the sample solution. We tried with the different sample solutions like red dye, blue dye to absorb the spectrum. We also observed the spectrum by using different lights red, blue, violet, white and in dark mode (Fig. 4).



**Fig. 4** Box type spectrometer

## Result and discussion

The analysis of the spectra obtained for several light sources is presented in the figures [5–7]

Figure 5a represents the dark spectra recorded in order to know the background noise and to confirm the individual spectra from respective samples. While recording dark spectrum, the VIBGYOR colours are obtained in the spectrum due to the presence of green light in the webcam as shown in the Fig. 2. Figure 5b represents spectrum of mobile flash light. When the flash light passed through the slit and recorded by the image sensor, it results into different wavelengths of peak colour such as blue, green, yellow and red. As we know that the white light mainly consists of RGB, we have also observed peak yellow colour spectrum due to external noises like moisture. While passing mobile flash light on red colour paper, we have observed same RGB spectrum where the intensity varies from 601 to 651 nm; however, blue peak also absorbs due to flash light transmittance. Figure 5d represents spectrum of violet paper showing range wavelength of the violet from 400 to 420 nm, by passing a light through the violet paper. We obtained a wavelength at 405nm. When a light passes through the blue dye solution, it absorbs the blue colour and spectrum shows the peak at 436 nm, but actually it ranges from 440 to 490 nm. The analysis of the spectra obtained for several dye solutions such as red and blue dyes. We have also recorded spectrum for sodium vapour lamp as shown in Fig. 6.

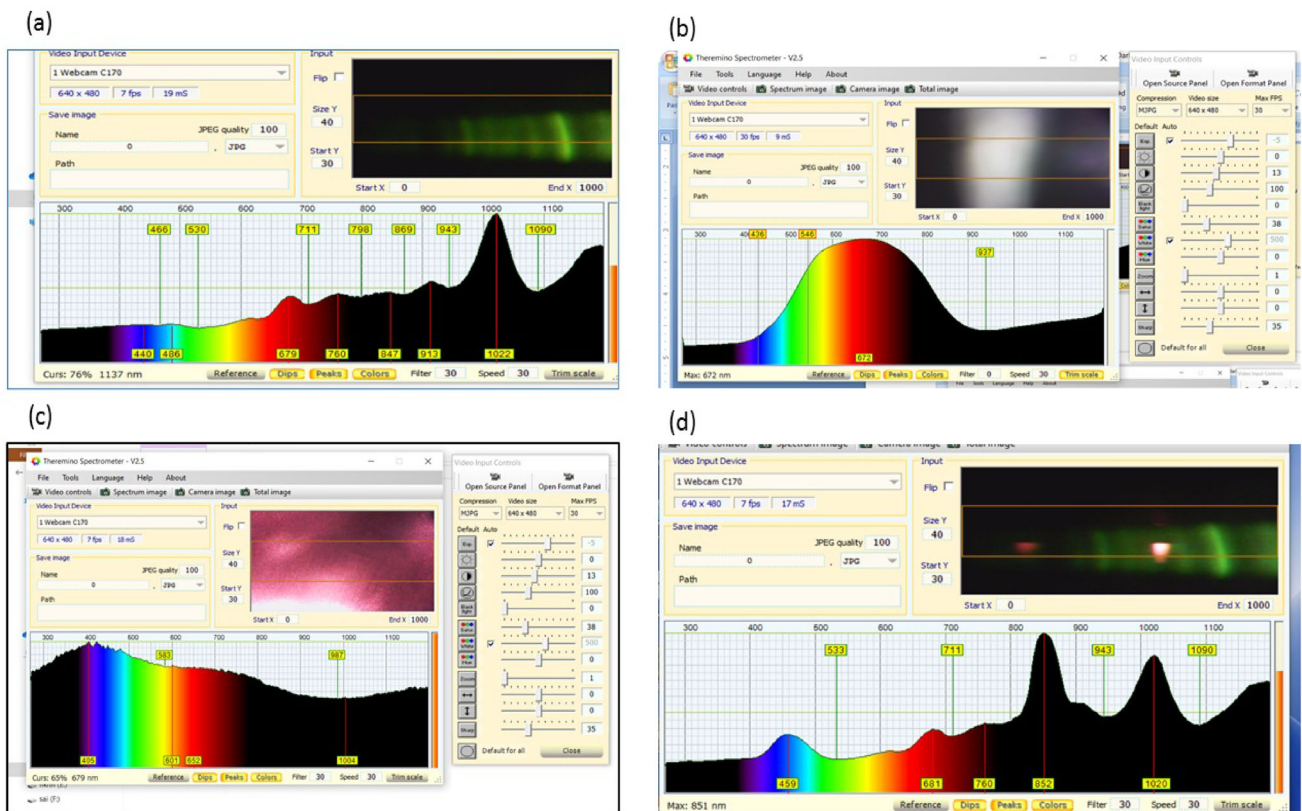
## Applications

### Cardboard type spectrometer

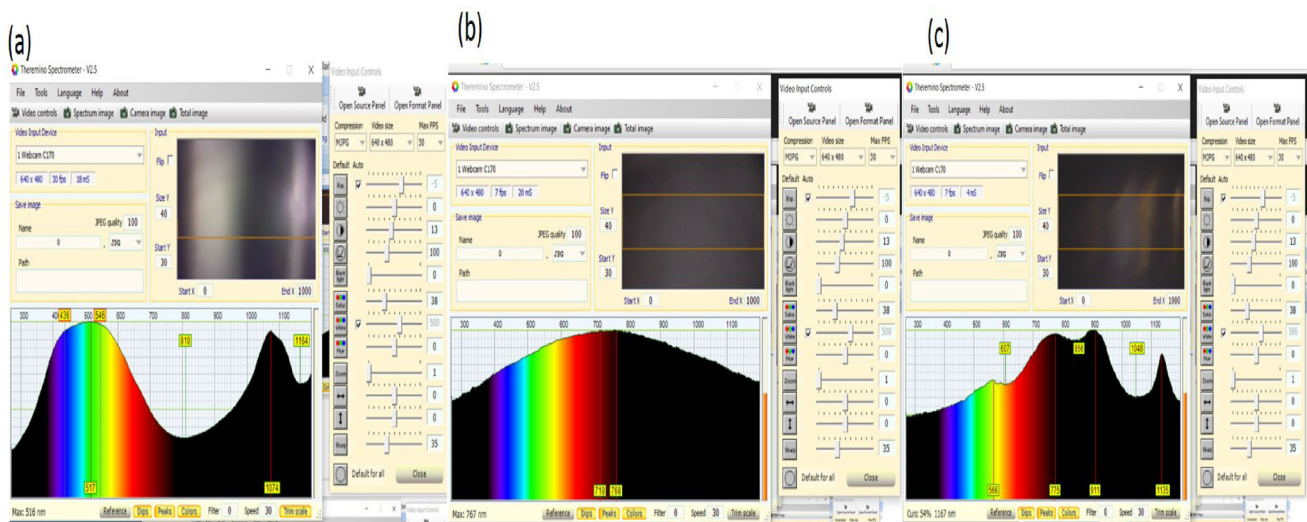
*Recording spectrum in cardboard box for different applications such as oil is challenging task due to infrared*

Figure 7a shows the spectrum of rhodamine 6G dye. It is fluorescent dye used as biosensing or imaging. It is mostly used in textile industry. It's highly toxic due to repetitive use in textile industry if used without photo degradation. The peak at 567 nm shows the major peak of the dye in wooden box. Raman spectral analysis of this dye shows strong peaks at  $612\text{ cm}^{-1}$  and above 1000. Figure 7b represents spectrum of food oils are part of daily life and contains carotene and chlorophyll. Adding food colour is becoming trendy and attractive to peoples; however, adding food colourant beyond limit is also not advisable due to adverse effect such as nausea and diarrhoea. In the present work, we have made an attempt to find out the spectrum of orange colour food dye. Figure 7c represents spectrum of





**Fig. 5** a Spectrum for dark mode. b Spectrum for white light. c Spectrum for red colour paper. d Spectrum for blue colour paper

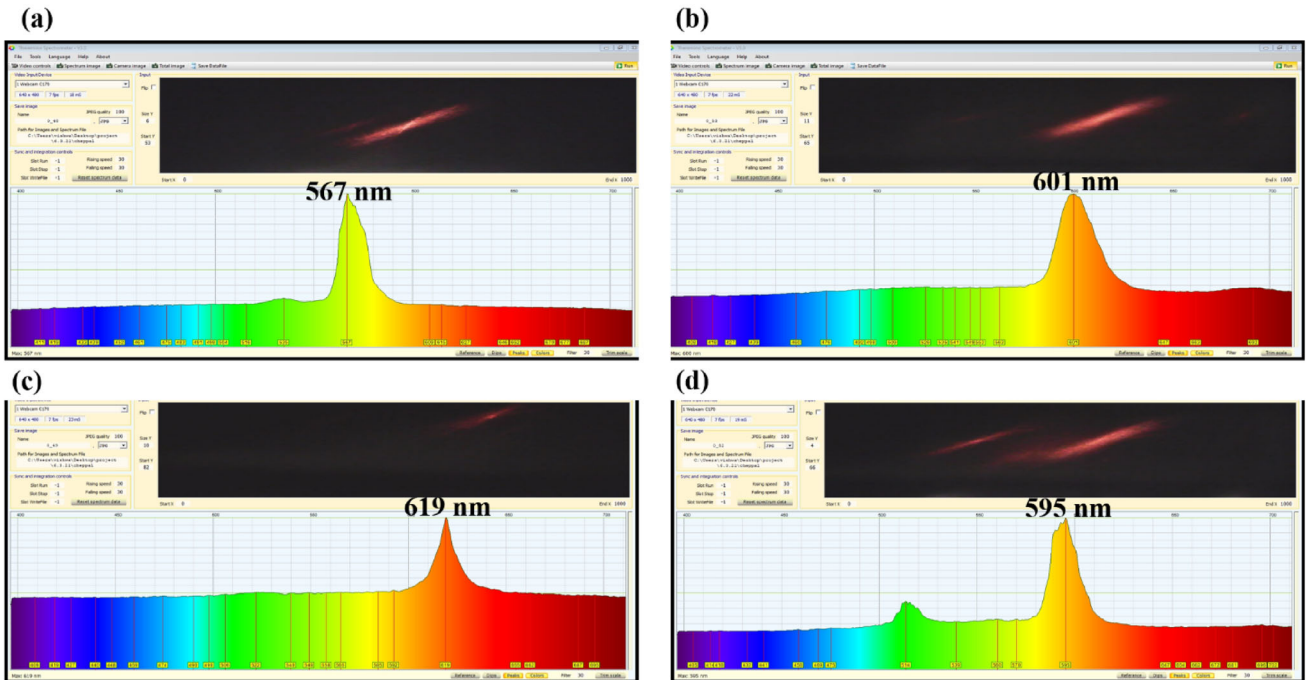


**Fig. 6** a Spectrum for blue dye use for industry. b Spectrum for red dye use for industry. c Spectrum for sodium vapour lamp

imidacloprid which is publicly used insecticide control sucking insects, soil insects, and fleas on pets. In addition, applied to structures, crops, soil, and as a seed treatment. Reported adverse effects included skin irritation and rashes, numbing and tingling on fingers and lips, facial

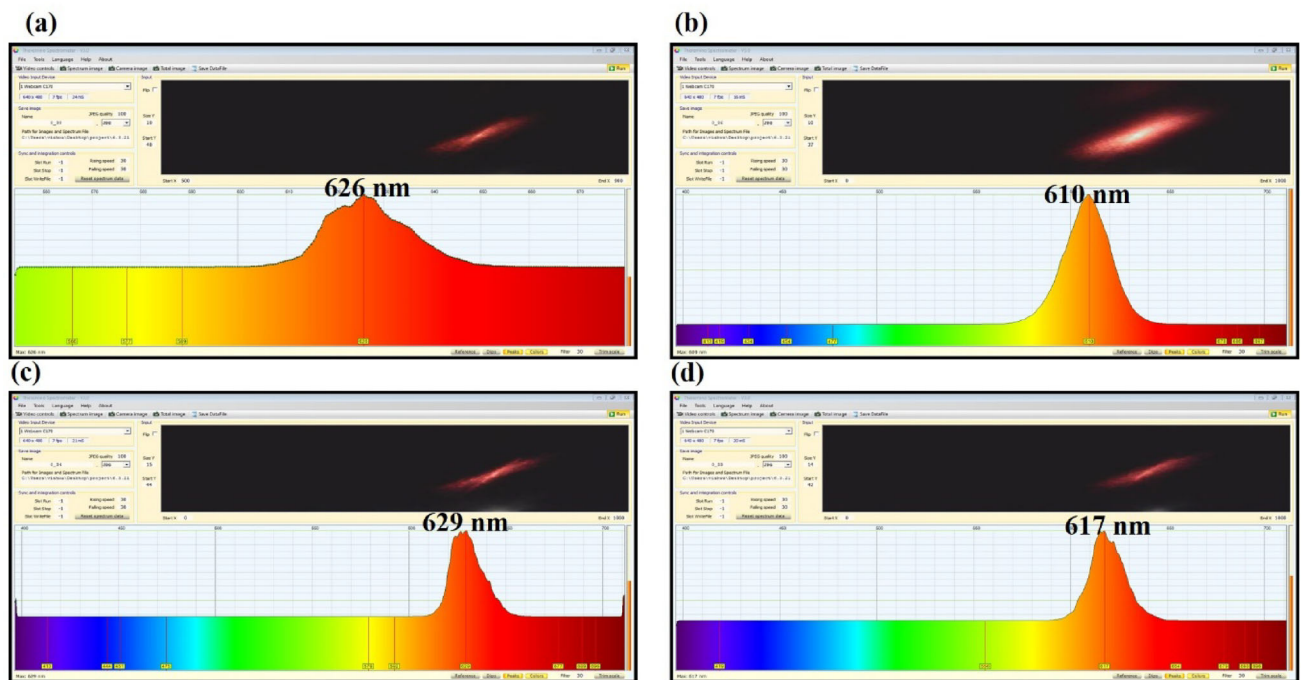
numbness and swelling, lethargy and nausea. Figure 8d represents spectrum of food colourant red. The peak obtained in the cardboard type box was at 595 nm which almost represents red dye peak.

**Cardboard Box**



**Fig. 7** a Rhodamine 6G dye. b Edible oil chicken fried. c Pesticide-imidacloprid. d Food colourant-orange

**Wooden Box**



**Fig. 8** a Rhodamine 6G Dye. b Fried oil chicken. c Pesticide-imidacloprid. d Food colourant-orange

The above-mentioned application such as detection of pesticide, food colourant and dyes was repeated in wooden box. Here, we have fixed the camera at 30 degree and

length of box decreased, also we have covered the box from top. The purpose of doing the experiment in the box is to get the difference in spectrum recording in box and

**Table 1** Comparative spectrum Table for different samples in cardboard and wooden box

Sl. no.	Name of the sample	Spectrum peaks in cardboard (nm)	Spectrum peaks in wooden box (nm)
1	Textile dye rhodamine 6G	567	626
2	Fried oil	601	610
3	Imidalcoprid	619	629
4	Food colourant-orange	595	617

cardboard. While repeating the experiment in the box, following changes occurred as shown in Table 1.

### Wooden box

While recording spectra in the wooden box, wavelength shifted to higher range. In the case of rhodamine 6G dye, the spectra shifted from 576 to 626 nm. This huge shift occurs due to the arrangement of sample, camera and slit in wooden box. Camera position plays vital role in recording correct spectrum. A similar result has been observed in fried oil, pesticides and food colourant. The detail of shift in spectrum is discussed in Table 1.

### Conclusion

The designing and building a low-cost, easy-to-use spectrometer device. The presented device is convenient for analysis of liquid solutions such as oils, pesticide solution and dye solutions. Several exposures must be taken and stacked together for a full spectrum. The device can be a useful tool for undergraduates for experimental and educational purposes. We conclude that an affordable and easy-to-use spectrometer can be built with low-cost equipment. The most expensive parts of the system are webcam. In addition to DVD for better performance, we can use grating. As aforementioned, one needs to take several measurements, provided with a reasonable exposure time, to obtain the spectrum of the liquid sample under investigation. The critical problem is reducing the noise caused by the laser, container and DVD. Spectrometer, without a doubt, it is a useful tool in research and many industrial fields. However, it is not yet commonly known and used by the public. An affordable spectrometer has the potential to pave the way for many applications in daily life of our connected world. Spectrometer may become an affordable device for public to purchase. Introducing spectrometer to students during their pre-college and/or undergraduate era has the potential to draw children's and students' attention to science and gain their interest. Educating undergraduate students in relevant science and engineering areas with an easy-to-use, low-cost spectrometer could help universities educating their students in

physics laboratory lectures with this technology, without causing any damage or repair costs to professional equipment. Paving the way in education has the potential to increase the possible applications of spectrometer in the future by educating students with this technology at an early stage. This will raise visionary students for the future of the world. Eventually, making spectrometers cheaper and better is likely to lead to more applications and widespread usage of spectrometers, especially in the future smart cities, where many elements of the city will require monitoring and quality checks. The spectrometer has the potential to be a part of smart city citizens' daily life. This prototype may pave the way for further improvements to mobile devices and 3D printing.

**Acknowledgements** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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