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DEVELOPMENT OF A HOME-BUILT UV-VISIBLE SPECTROPHOTOMETER EMPLOYING ARDUINO MICROCONTROLLER SYSTEM FOR CHEMICAL ANALYSIS

(Pembangunan Spektrofotometer Ultraungu-Nampak Binaan Sendiri Menggunakan Sistem Pengawal Mikro Arduino untuk Analisis Bahan Kimia)

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Abstract

This work demonstrated the development and the application of a home-built spectrophotometer device employing Arduino microcontroller. Arduino UNO microcontroller was utilized as a data acquisition system. Arrangement of the system's hardware was based on the working principle of a commercially available benchtop instrument. For the first time in the scope of Arduino-based spectrophotometer, the developed device consisted of double light sources and innovative monochromator design to cater the requirement of ultraviolet (UV) and visible ranges. A visible white LED and UV LED emitting between 190 and 600 nm spectrum were employed. Light dependent resistor (LDR) and GUVA-S12SD UV sensor were utilized as light detectors. Innovative monochromator system was incorporated with combination of stepper motor and DVD disc as a diffraction grating for wavelength selection. The effectiveness of the UV range in the device was tested using bisphenol A (BPA) and triclosan, while Reactive Orange 16 and Reactive Red 120 dyes for visible range. The device could detect BPA from 10 to 50 ppm concentration (obtained through external linear graph producing $R^2 = 0.9970$), while triclosan from 1 to 5 ppm ($R^2 = 0.9971$). The limit of detection (LOD) and the limit of quantitation (LOQ) for BPA were 7.01 ppm and 23.38 ppm, respectively. The LOD and LOQ for triclosan were 0.60 ppm and 1.99 ppm, respectively. The results obtained from the device on all analytes were validated with a commercially available benchtop UV-vis spectrophotometer. The linearity of BPA from 10 to 50 ppm obtained a correlation of $R^2 = 0.9941$. Triclosan showed $R^2 = 0.9965$ for linearity from 1 to 5 ppm. The LOD and LOQ were 8.58 ppm and 28.61 ppm, respectively. The LOD and LOQ for triclosan were 0.66 ppm and 2.19 ppm respectively. As for visible range, the benchtop spectrophotometer could detect Reactive Orange 16 from 10 to 50 ppm concentration ($R^2 = 0.9967$) while Reactive Red 120 ($R^2 = 0.9958$). The LOD and LOQ for Reactive Orange 16 were 6.76 ppm and 22.52 ppm, respectively. The LOD and LOQ for Reactive Red 120 were 6.94 ppm and 23.13 ppm, respectively. Nearly identical R^2, LOD and LOQ were obtained for both home-built Arduino device and the benchtop UV-visible spectrophotometer. These data indicated positive outcomes with accuracy percentage 95% and 97.2% for BPA and triclosan, 98.6% and 93.5% for Reactive Orange 16 and Reactive Red 120 dye of the home-built Arduino spectrophotometer.

Keywords: arduino, home-built, UV-visible spectrophotometer, dye analysis, pollutant analysis

Abstrak

Kajian ini menunjukkan pembangunan dan aplikasi peranti spektrofotometer binaan sendiri yang menggunakan mikropengawal Arduino. Pengawal mikro Arduino UNO telah digunakan sebagai sistem pemerolehan data. Susunan perkakasan sistem adalah berdasarkan prinsip kerja instrumen komersil. Buat pertama kali dalam skop spektrofotometer berasaskan Arduino, peranti yang dibangunkan terdiri daripada sumber cahaya berganda dan reka bentuk monokromator yang inovatif untuk memenuhi keperluan julat ultraungu (UV) dan boleh dilihat. LED putih yang kelihatan dan LED UV yang memancarkan antara spektrum 190 dan 600 nm telah digunakan. Perintang bergantung cahaya (LDR) dan sensor UV GUVA-S12SD digunakan sebagai pengesan cahaya. Sistem monokromator yang inovatif telah digabungkan dengan gabungan motor pelangkah dan cakera DVD sebagai parut difraksi untuk pemilihan panjang gelombang. Keberkesanan julat UV dalam peranti telah diuji menggunakan bisphenol A (BPA) dan triclosan, manakala pewarna Reactive Orange 16 dan Reactive Red 120 untuk julat yang boleh dilihat. Peranti boleh mengesan BPA dari 10 hingga 50 ppm kepekatan (diperolehi melalui graf linear luaran yang menghasilkan R2 = 0.9970), manakala triclosan dari 1 hingga 5 ppm (R^2 = 0.9971). Had pengesanan (LOD) dan had kuantiti (LOQ) untuk BPA ialah 7.01 ppm dan 23.38 ppm, masing-masing. LOD dan LOQ untuk triclosan ialah 0.60 ppm dan 1.99 ppm, masing-masing. Keputusan yang diperoleh daripada peranti pada semua analit telah disahkan dengan spektrofotometer UV-vis komersil. Kelinearan BPA dari 10 hingga 50 ppm memperoleh korelasi R^2 = 0.9941. Triclosan menunjukkan R^2 = 0.9965 untuk lineariti dari 1 hingga 5 ppm. LOD dan LOQ masing-masing ialah 8.58 ppm dan 28.61 ppm. LOD dan LOQ pula untuk triclosan masing-masing adalah 0.66 ppm dan 2.19 ppm. Bagi julat yang boleh dilihat, spektrofotometer komersil boleh mengesan Jingga Reaktif 16 daripada kepekatan 10 hingga 50 ppm (R^2 = 0.9967) manakala Merah Reaktif 120 (R^2 = 0.9958). LOD dan LOQ untuk Oren Reaktif 16 masing-masing ialah 6.76 ppm dan 22.52 ppm. LOD dan LOQ untuk Reactive Red 120 ialah 6.94 ppm dan 23.13 ppm, masing-masing. R^2, LOD dan LOQ yang hampir sama diperolehi untuk kedua-dua peranti Arduino yang dibina sendiri dan spektrofotometer komersil. Data ini menunjukkan hasil positif dengan peratusan ketepatan 95% dan 97.2% untuk BPA dan triclosan, 98.6% dan 93.5% untuk Reactive Orange 16 dan Reactive Red 120 bagi pewarna spektrofotometer Arduino yang dibina sendiri.

Kata kunci: arduino, binaan sendiri, spektrofotometer UV-cahaya nampak, analisis pewarna, analisis bahan pencemar

Introduction

Water-soluble dye residues in particular from the chemically intensive textile industry's waste fluids have the potential to be a major source of environmental contamination because they can infiltrate several environmental compartments through soil, air, and water [1]. Several studies have shown that a sizeable portion (about 20%) of the dyes used in the textile industry each year, such as Rhodamine B, Victoria blue, Rose Bengal, Indigo Red, Caramine, Red 120, Eriochrome, Methylene Blue (MB), Black-T (EBT), and Thymol blue, are lost during the synthesis and processing processes and end up in wastewater [2]. Azo dyes are a common chemical pollutant found in environmental and water contamination. These dye-polluted effluents include colourful pigments that are toxic, non-biodegradable, and dangerous to living things [2; 3]. Thus, it is crucial to remove dyes from effluent due to being able to cause serious health related problems as well as disruption towards the ecosystems [4]. Azo dyes are typically used in a number of products, including textiles, paper, food or leather. One of the major classes of hazardous organic compounds, according to researchers, is made up of textile and industrial colourants. According to the World Bank, the textile finishing and dyeing sectors account for a significant portion of the 17–20% water pollution [2]. Owing to their toxicity and carcinogenicity, these compounds and their degradation products can be harmful [5]. Furthermore, several forms of dyes can have adverse effects on various organisms, including humans, and certain bacterial and mammalian assays that can be genotoxic [6].

A synthetic molecule known as bisphenol A (BPA) is often employed as a monomer, especially in the creation of epoxy resins and polycarbonate. Polycarbonates are used in a variety of products, including water bottles, baby feeding bottles, toys, cutlery, thermal paper, and medical equipment due to its ability to withstand high temperatures (up to 145 °C) [7]. There is growing evidence that certain chemicals, known as endocrine disrupting chemicals (EDCs), such as estradiol, nonylphenol, medicines, and some pesticides, can interact with endocrine systems if they are present in drinking water at a very low concentration [8]. One of the EDCs is BPA that may give potential threats to human beings, leading to hormonal complications, cancers, hypospadias, miscarriages, endometriosis, and infertility [9]. BPA can increase cellular response by interacting with oestrogen receptors since its structure is similar to that of oestradiol and diethylstilbestrol. Moreover, research on lab animals demonstrated negative impacts on health even at low BPA dosages [7]. The quality and safety of marine products were negatively impacted by the pollutants found in the seawater and sediment columns, which would feed benthic and pelagic animals and enter the food chain. Due to its probable link to harmful health impacts like obesity, neurobehavioral issues, and reproductive and neurobehavioral issues like prostate cancer, bisphenol-A has drawn a lot of attention [10].

The broad-spectrum of the antibacterial agent triclosan is frequently found in pharmaceutical and personal care products (PPCPs). Many bacteria and fungi are fungicidal to TCS [11]. Triclosan is one of the most widely used biocides and it is frequently found in aquatic habitats. To protect against bacteria [11], Triclosan is frequently utilized in pharmaceutical and personal care products, hand soap, and wet wipes [12]. Direct contact with personal care items as well as other sources, such as food, water, and dust, can expose individuals to triclosan [13]. People can be exposed to triclosan as a result of its presence in aquatic and terrestrial areas which has occurred either directly through the use of PPCPs or indirectly through bioaccumulation [14]. Triclosan was discovered in bodily fluids such blood, breast milk, urine, and these substances affect the endocrine system and can cause hormonal abnormalities [14]. Triclosan may hinder the development of species in both terrestrial and aquatic habitats and potentially endanger the health of people who are exposed to these conditions. Broad-spectrum antibacterial activity is a property of triclosan. Triclosan has a negative impact on wastewater because activated sludge microbes are directly exposed to it, which inhibits bacterial growth, reduces bacterial diversity and abundance, and alters the composition of bacterial communities[15].

A device used for analysis called an Ultraviolet-visible (UV-Vis) light spectrophotometer examines the analyte absorbances of light, at specific wavelengths where different materials absorb and reflect these wavelengths differently [16]. For the analysis of pollutants, UV-Vis, atomic absorption spectroscopy (AAS), and tabletop devices with chromatographic bases are frequently utilized. In addition to these benchtop devices, on-site chemical analysis may save overall analysis costs because the result from on-site testing just needs to be validated by a simpler conclusive analysis. Thus, bringing heavy, complex instruments for on-site investigation is also impractical. There is a rising need for straightforward methods for on-site pollutants analysis in industrial wastes, leachates, landfills, and other sources of pollution due to ecological issues. Furthermore, a prospective complimentary element to a chemical analysis is the availability of an affordable and portable instrument to do the pollutant analysis on-site. For instance, applications for civil lawsuits and environmental monitoring both need quick decision-making. Low-cost, effective microcontrollers are employed as control-processing units in a variety of portable and handheld instruments. Amongst the most extensively used open-source microcontrollers is the Arduino. Arduino can be programmed with the measurement algorithms, calibration function, and drift corrections required for the entire instrument activity by using the numerical final result shown on a computer as input [17]. Prior to the previous 20 years, their increased application in industrial machines, cars, and domestic appliances made microcontrollers the top-selling products in the market for electronic chips despite their niche [18].

Portable devices based on the Arduino microcontroller are touted to have low manufacturing costs, simple operations, quick manufacture, and low power consumption [19]. To measure wavelengths for educational purposes, Widiatmoko and a colleague [20] constructed a spectrophotometer out of cardboard, a digital camera for the hardware, a photodiode sensor, and a microcontroller. They used image processing to acquire optical wavelengths with a theoretical resolution of up to 0.2 nm. However, Zhang et al. [21] developed a portable spectrophotometer for measuring the quality of water utilizing LEDs as the light source and photodiode sensors to detect specific wavelength peaks at 420 nm, 455 nm, 515 nm, 560 nm, 605 nm, and 630 nm. The created spectrophotometer was able to differentiate between ammonia and nitrite nitrogen contamination in lab-made water. In truth, the chemical structures of the contaminants in our environment vary greatly. This indicates that they must be detected in the UV band as well, which is a feature that the majority of the portable photometers/spectrophotometers made at home lack.

This paper presents the development of a home-built spectrophotometer employing Arduino microcontroller for selected chemicals screening purpose. This brings to specific objectives which are to develop a home-built spectrophotometer equipped with Arduino platform as a microcontroller for automation. Next, to test the effectiveness and validate the UV detection of the home-built spectrophotometer device using BPA and triclosan. Lastly, to test the effectiveness and validate the visible detection of the home-built spectrophotometer device using Reactive orange 16 and Reactive Red 120. This study aims to develop a home-built spectrophotometer device based on spectroscopy principle. Different from other methods, the present device consisted of visible white LED and UV LED emitting between 190 and 600 nm spectrum. The developed device consisted of double light sources and innovative monochromator design to cater to the requirement of ultraviolet (UV) and visible ranges. A visible white LED and UV LED emitting between 190 and 600 nm spectrum were employed. Light dependent resistor (LDR) and GUVA-S12SD UV sensors were utilized as light detectors. An innovative monochromator system was incorporated with combination of stepper motor and DVD disc as a diffraction grating for wavelength selection. The effectiveness of the UV range in the device was tested using bisphenol A (BPA) and triclosan, while Reactive Orange 16 and Reactive Red 120 dyes were used for visible range. The wavelength will be detected by TSL1401CL from the sample, and it will give an output which will be displayed in a serial monitor. Afterwards, the results on all analytes from the device will be validated using commercially available benchtop UV-vis spectrophotometer.

Materials and Methods

Components and specifications

The arrangement of the hardware in the home-built spectrophotometer was based on the working principle of the benchtop instrument Shimadzu UV-1800 UV-Vis Spectrophotometer. There were two light sources used in this research namely white light LED with 8500K color temperature and UV LED with range from 190 to 380nm. Next, the "entrance slit" for the photometer was made with a piece of cardboard. The dispersion device or monochromator was made by assembling a cut up DVD with a 28byj-48 stepper motor which allows movement of the diffracted light. There was also an Edmund Optics achromatic lens that corrected chromatic distortion. Two pieces of slits with the same length were placed side by side. Furthermore, the sample holder (also known as cuvette) filled with sample solution followed by the detection using Light Dependent Resistor (LDR) sensor and GUVA-S12SD UV detector. These detectors were chosen due to their suitability of wavelength range for UV and visible analytes. Some of the detectors that were considered before were BPW34, ML8511 UV sensor, TSL1401 and TCS3200 color sensor. All of the detectors have different wavelength ranges for UV and visible but do not meet the criteria for developing the simple home-built spectrophotometer. An innovative monochromator system was incorporated with combination of step motor and disc as a diffraction grating for wavelength selection to complete the system. The schematic of a home-built spectrophotometer is shown in Figure 1 while the real device photograph is shown in Figure 2. The calibration on the distance between detector and sample cuvette was made and showed that 16cm gives the best reading of the detector. As the photoresistor detector converted the absorbed light into electrical current, the data can be transferred to the monitor via Arduino. The wavelengths were chosen by rotating the motor, and one specific visible wavelength band was chosen to pass through a handcrafted slit. The slit permits a restricted spectral bandwidth to exit the monochromator. This incident beamed on the sample held in the sample holder which was the source of this outgoing spectrum. The detectors will then read the absorbance of the samples and display the data on the serial monitor in the Arduino IDE software. Then, it will then be connected to Excel worksheet for further wavelength calculations. The wavelengths were calculated using Eq. 1:

$$n\lambda = d \sin\theta \quad (1)$$

where λ is the wavelength of a specific color; n = 1 (grating order); d = 740 (distance between slits in a DVD); and θ = diffraction angle.

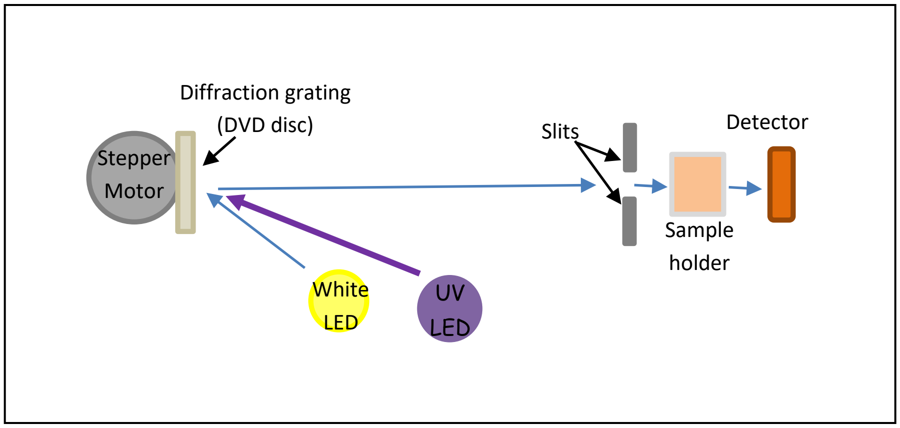

Figure 1. The schematic diagram of a portable spectrophotometer

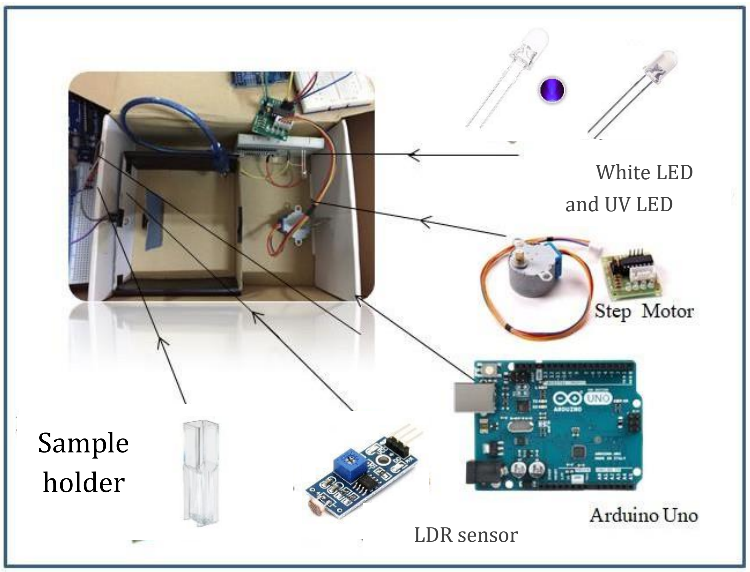

Figure 2. Portable spectrophotometer hardware arrangement

The concentration value of a chemical substance was approximately proportional to the quantity of light it absorbs when introduced to monochromatic radiation, according to Beer Lambert's law. Once the voltage readings for the light collected in the detector for the comparison and the substance being examined were gathered, the absorbance value was calculated using the following calculation in Eq.2:

$$A = \log_{10}\frac{P}{Po} = -\log_{10}(T) \qquad (2)$$

where A is absorbance; P is magnitude of transmitted light through the sample; Po is magnitude of transmitted light through the reference; and P/Po = T, which is transmittance.

Comparable to most industrial benchtop spectrophotometers, this newly built home-built Arduino spectrophotometer was small and lightweight. The home-built Arduino spectrophotometer was also very compatible with current common laboratory usage because, unlike many other home-built spectrophotometers, it can measure both UV-Vis spectrums while remaining compatible with current generic cuvettes.

Arduino programming

Arduino Uno and Arduino Nano were programmed with the system operating logic flow using the Arduino IDE 1.8.13 software as shown in Figure 3. The data of the analog transmittance signals from the UV and visible photodetectors will transform into digital signals and can be monitored through the Arduino serial monitor.

Figure 3. Arduino sketchpad in Arduino IDE software

Experimental setup

The user can select wavelengths for the UV and visible range between 190 nm and 600 nm depending on the desired analysis. For each sample's individual spectrophotometric analysis, quartz cuvettes were employed. The cuvette was filled with a minimum of 1.5 mL of the sample solution, with the optically transparent surfaces towards the light source and detector. BPA, triclosan, Reactive orange 16 and Reactive Red 120 absorb UV and visible wavelength, peaking at 226 nm, 282 nm, 493 nm and 534 nm respectively.

Preparation for BPA sample follows the steps accordingly. Firstly, the stock solution was prepared by weighing BPA powder for 100 mg and placed in 100 mL volumetric flask. Then 5mL of 30% ethanol solution was added to dissolve the powder and filled up until it reached the mark. Then 1, 2-, 3-, 4-, and 5-mL solutions were taken into another 100 mL volumetric flask, and they were filled with 30% ethanol until the mark was reached. Thus, the concentration will be for 10, 20, 30, 40 and 50 ppm. While for triclosan sample preparation, 500 mg L^{-1} of stock solution was prepared by weighing the triclosan for 0.025 g. The triclosan was dissolved in ethanol/acetone (1:1) solution for each 10 mL. Then, it was diluted into a 50 mL volumetric flask with distilled water until it reached the mark. The stock solution was kept at -20 °C. Next, 0.02 mL of solution was taken using micropipette into a 10 mL volumetric flask. The volumetric flask was filled with distilled water until it reached the mark and labelled as 1 ppm. This step was repeated for 0.04 mL, 0.06 mL, 0.08 mL and 0.1 mL of solution respectively and the volumetric flask was labelled for 2 ppm, 3 ppm, 4 ppm and 5 ppm.

For the sample preparation of the Reactive Orange 16, a stock solution was prepared by mixing 100 mg of dry analyte in 100 mL of volumetric flask to make 1000 ppm solution. Standard working solutions which have 1, 2, 3, 4 and 5 mL accordingly of Reactive Orange 16 were made by diluting of appropriate serial dilution of the stock solution to 100 mL with distilled water. Thus, making the concentration for 10, 20, 30, 40 and 50 ppm of sample. Sample preparation for Reactive Red 120, a. stock solution was prepared by mixing 100 mg of dry analyte in 100 mL of volumetric flask to make 1000 ppm solution. Standard working solutions which have 1, 2, 3, 4 and 5 mL accordingly of Reactive Orange 16 were made by diluting the appropriate serial dilution of the stock solution to 100 mL with distilled water. Thus, this made the concentration for 10, 20, 30, 40 and 50 ppm of sample. Measurements were taken accordingly, of all the samples data using the benchtop instrument which was the UV-Vis spectrophotometer with wavelength range from 190 nm to 600 nm. After that, the measurements of the samples were taken using the developed portable spectrophotometer device. The samples were poured in a cuvette and placed in the sample holder to record the absorbance. Table 1 included a list of the components as well as their local market prices. This spectrophotometer is estimated to cost around RM348.30 to build.

Table 1. List of components for home-built spectrophotometer

Components	**Quantity**	**Unit Price (RM)**	**Total (RM)**
Arduino Uno	1	31.90	31.90
Stepper motor and driver	1	9.50	9.50
Breadboard	1	6.80	6.80
Resistor	2	0.05	0.10
Jumper wire	1	2.50	2.50
Light Dependent Resistor	1	1.10	1.10
GUVA-S12SD UV detector	1	24.40	24.40
Push button	1	0.60	0.60
White LED	1	0.10	0.10
UV LED	1	0.30	0.30
DVD	1	1.00	1.00
Achromatic lens	1	270.00	270.00
Total cost (RM)			348.30

Results and Discussion

A home-built spectrophotometer was successfully built by equipping it with two light sources, UV and visible light detectors, and a monochromator which consisted of achromatic lens, DVD disc, and slit. The measuring method, calibration operations, and drift correction needed for the entire instrument functioning were written into the Arduino microcontroller, with the numeric result presented on screen. The data acquisition algorithm was successfully uploaded to the hardware setup of home-built spectrophotometer via the USB port. The detectors were chosen due to their suitability of wavelength range for UV and visible analytes. Some of the detectors that were considered before but not suitable due to the analyte's wavelength range were BPW34, ML8511 UV sensors and TSL1401 and TCS3200 color sensors. Calibration of the sensors were also conducted to allow the optimum detection of the sensors towards the light source, which resulted in 16 cm apart between light source and sensors to achieve the right spectrum and data reading. The difference in absorption between both devices and benchtop instruments were likely attributed to the use of different light sources, detectors and internal algorithms in the device employing Arduino microcontroller with UV-vis spectrophotometer. The Arduino microcontroller with UV-vis spectrophotometer uses were more sensitive and advanced detectors. In the device, the light source was calibrated as well as the sensors. The most accurate data obtained by the sensors was when the light source and sensors were 16 cm apart. This was demonstrated by the sensor calibration findings at various distances from the light source, which ranged from 2 cm to 22 cm with intervals of 2 cm (Figure 4). The highest reading of LDR was 16 cm, which gave the brightest spectrum detection in the home-built spectrophotometer.

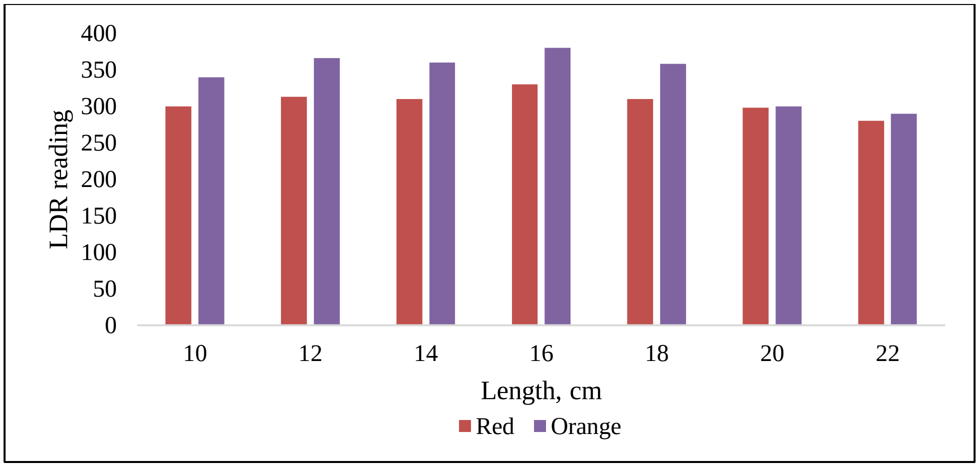

Figure 4. Calibration of different lengths between light source and sensors

To investigate whether the developed Arduino-based spectrophotometer device was functioning well, the device was applied to analyse BPA, triclosan, Reactive Orange 16 and Reactive Red 120 similar with that in benchtop UV-Visible spectrophotometer. The device could detect BPA from 10 to 50 ppm concentration (obtained through external linear graph producing R^2 = 0.9970) as shown in Figure 5a, while triclosan from 1 to 5 ppm (R^2 = 0.9971) as shown in Figure 5b. The limit of detection (LOD) and the limit of quantitation (LOQ) for BPA were 7.01 ppm and 23.38 ppm, respectively. The LOD and LOQ for triclosan were 0.60 ppm and 1.99 ppm, respectively. The results obtained from the device on all analytes were validated with a commercially available benchtop UV-vis spectrophotometer. In Figure 5c the linearity of BPA from 10 to 50 ppm obtained a correlation of R^2 = 0.9941. Triclosan showed R^2 = 0.9965 for linearity from 1 to 5 ppm as shown in Figure 5d. The LOD and LOQ were 8.58 ppm and 28.61 ppm, respectively. The LOD and LOQ for triclosan were 0.66 ppm and 2.19 ppm respectively. Different from BPA, this UV analyte triclosan, has concentration ranges 1 – 5 ppm lower than BPA due to its low concentration detection in wastewater. However, with the components used in the home-built spectrophotometer, it can only detect low concentrations starting from 1 ppm onwards.

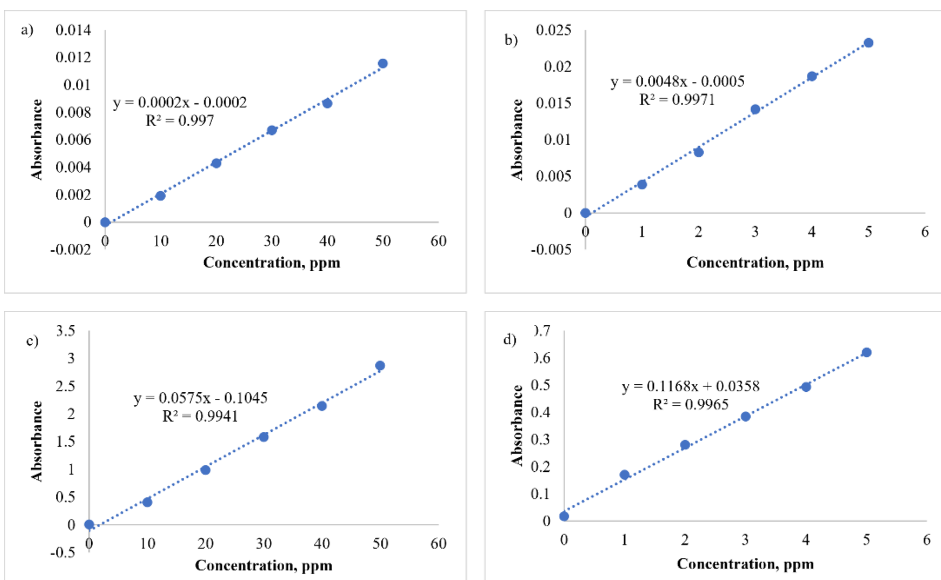

Figure 5. a) Calibration graph of BPA using the home-built spectrophotometer device b) Calibration graph of triclosan using the home-built spectrophotometer device c) Calibration graph of BPA using benchtop UV-Vis spectrophotometer d) Calibration graph of triclosan using benchtop UV-Vis spectrophotometer

As for visible range, the home-built spectrophotometer could detect Reactive Orange 16 from 10 to 50 ppm concentration (R^2 = 0.9958) as shown in Figure 6a while Reactive Red 120 (R^2 = 0.9967) in Figure 6b. The LOD and LOQ for Reactive Orange 16 were 6.76 ppm and 22.52 ppm, respectively. The LOD and LOQ for Reactive Red 120 were 6.94 ppm and 23.13 ppm, respectively. The analytes were validated with a commercially available benchtop UV-vis spectrophotometer. In Figure 6c, the linearity of Reactive Orange 16 from 10 to 50 ppm obtained a correlation of R^2 = 0.9984. Reactive Red 120 showed R^2 = 0.9974 for linearity from 10 to 50 ppm as shown in Figure 6d. The LOD and LOQ for Reactive Orange 16 were 4.43 ppm and 14.77 ppm, respectively. The LOD and LOQ for Reactive Red 120 were 3.60 ppm and 12.02 ppm respectively. As compared to the benchtop UV-Vis spectrophotometer, the home-built spectrophotometer showed lower absorbance measurement due to some factor when handling the experiment using home-built spectrophotometer. It was slightly a different spectrum color from the diffraction grating that affects the measurement.

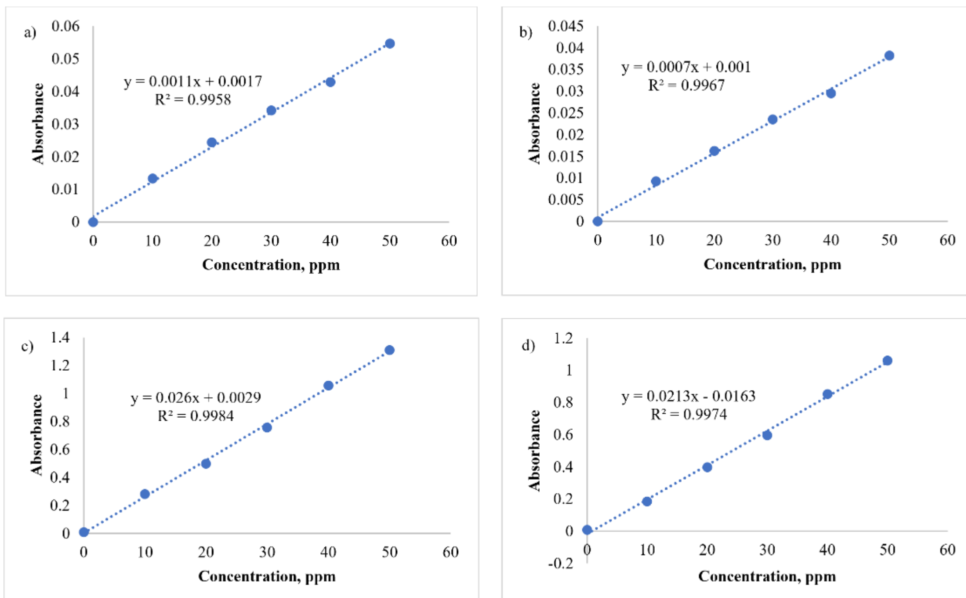

Figure 6. a) Calibration graph of Reactive Orange 16 using the home-built spectrophotometer device b) Calibration graph of Reactive Red 120 using the home-built spectrophotometer device c) Calibration graph of Reactive Orange 16 using benchtop UV-Vis spectrophotometer d) Calibration graph of Reactive Red 120 using benchtop UV-Vis spectrophotometer.

Another result that can be observed was the accuracy between the benchtop instrument and the portable Arduino device. The accuracy value was calculated using the following calculation in Eq 3:

$$y = mx + c \quad (3)$$

Nearly identical R^2, LOD and LOQ were obtained for both home-built Arduino device and the benchtop UV-visible spectrophotometer. These data indicated positive outcomes with accuracy percentage 95% and 97.2% for BPA and triclosan, 98.6% and 93.5% for Reactive Orange 16 and Reactive Red 120 dye of the home-built Arduino spectrophotometer. Comparison of the results between the benchtop instrument and home-built spectrophotometer devices showed a little difference in the accuracy percentage.

Conclusion

An automated Arduino-based semi-quantitative spectrophotometer device equipped with double light sources and innovative monochromator design for chemical analysis was developed to cater the requirement of UV and visible ranges required by a spectrophotometer for various chemical compounds. This home-built spectrophotometer device can be further made as on-site analytical tool for dye contaminants in environment, quality control device as well as other functions in future studies. As a result, this system is reasonably priced, easy to maintain due to its small size, microcontroller-based, and amenable to further expansion for data acquisition automation via microcontroller. Other than that, this home-built spectrophotometer device development also encourages more inventions of Arduino based instrumentation for various other analytes and samples.

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