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Raspberry Pi 3 based cloud supported temperature-controlled spectrophotometer design

Raspberry Pi 3 tabanlı, bulut destekli, sıcaklık kontrollü spektrofotometre tasarımı

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Abstract

Spectrophotometers are a kind of photometers that are used to find the amount of substance in the solution. Spectrophotometers detect the amount of radiation that is not absorbed by the solution in the sample chamber and gives information about the amount of substance in the sample. Spectrophotometers are used in many different fields such as chemistry, medicine, geology, environmental engineering and agriculture. Samples that will directly affect people, such as wastewater, drinking water, pharmaceuticals, are analyzed with high accuracy and possible hazards are avoided. In this study, a device that can be used in the detection of Salmonella bacteria is modeled. In addition, the fact that the heater unit of the device is on the test mechanism eliminates the need for heating in the external environment and the test data can be saved in the cloud environment over the internet connection, which is the novelty of this study. A spectrophotometer device was developed using Raspberry Pi 3 and Python software language. A 470 nm optical filter was used in the device. In addition to the features of standard spectrophotometers, the heating feature that can keep the sample temperature at the desired value has been added. This feature has been developed using the on-off logic method. Linear regression of optical measurements, R^2 value was calculated as 0.9982 in density tests between 0.1 gram and 0.2 gram. The device was developed with a Raspberry Pi 3 minicomputer, it does not need an external computer for use. Thanks to the internet connection ability of Raspberry Pi 3, the analysis results are transferred to the cloud environment, allowing the user to see the results even when they are not at the device.

Keywords: Raspberry Pi, Spectrophotometer, Python, Cloud environment, On-off control

Öz

Spektrofotometreler, çözeltideki madde miktarını bulmak için kullanılan bir tür fotometredir. Spektrofotometreler, numune haznesindeki çözelti tarafından absorbe edilmeyen radyasyon miktarını tespit eder ve numunedeki madde miktarı hakkında bilgi verir. Spektrofotometreler kimya, tıp, jeoloji, çevre mühendisliği ve tarım gibi birçok farklı alanda kullanılmaktadır. Atık su, içme suyu, ilaç gibi insanları doğrudan etkileyecek numuneler yüksek doğrulukla analiz edilmekte ve olası tehlikelerin önüne geçilmektedir. Bu çalışmada Salmonella bakterilerinin tespitinde kullanılabilecek bir cihaz modellenmiştir. Cihazın ısıtıcı ünitesinin test mekanizması üzerinde olması, dış ortamda ısıtma ihtiyacını ortadan kaldırmıştır ve test verilerinin internet bağlantısının mevcut olması durumunda bulut ortamında saklanabilmesi, bu çalışmanın sağlamış olduğu avantajdır. Raspberry Pi 3 ve Python yazılım dili kullanılarak bir spektrofotometre cihazı geliştirilmiştir. Cihazda 470 nm optik filtre kullanılmıştır. Standart spektrofotometrelerin özelliklerine ek olarak numune sıcaklığını istenilen değerde tutabilen ısıtma özelliği eklenmiştir. Bu özellik açma-kapama yöntemi kullanılarak geliştirilmiştir. Optik ölçümlerin lineer regresyonu, 0.1 gram ile 0.2 gram arasındaki yoğunluk testlerinde R^2 değeri 0.9982 olarak hesaplanmıştır. Cihaz Raspberry Pi 3 mini bilgisayarı ile geliştirilmiştir, ayrıca harici bir bilgisayara ihtiyaç duyulmamaktadır. Raspberry Pi 3'ün internete bağlanabilme özelliği sayesinde analiz sonuçları bulut ortamına aktarılarak, kullanıcının cihaz başında değilken bile sonuçları görebilmesi sağlanmıştır.

Anahtar kelimeler: Raspberry Pi, Spektrofotometre, Python, Bulut ortamı, Aç-kapa kontrolü

1 Introduction

Spectrophotometers find the amount of target material in the sample by the ratio of the amount of light sent to the sample and the amount of light reaching the detector by passing through the sample. Analysis can be made in many different areas with spectrophotometers. E.g; It is used in many different fields such as the analysis of body fluids in medicine [1], soil and nutrient analysis in agriculture and food [2], elemental analysis in chemistry [3], water analysis in environmental engineering [4], mineral analysis in geology [5]. According to Karaman et al. investigated the effect of gender and age on tooth color by measuring with a spectrophotometer in the teeth of 345 volunteers aged between 15 and 76 years [6]. Açıkgöz analyzed the water with a UV spectrophotometer and organic reagents and identified some metals in it [7]. Şenol et al. detected Lactic acid bacteria in traditional fermented foods in Turkey with

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FTIR-spectrophotometer [8]. Olawale and Oyawale performed the chemical analysis of rice husk waste produced during rice milling in Nigeria with an AA spectrophotometer [9]. Guntarti et al. performed lard analysis in sausages by FTIR-spectrophotometer [10]. With the development of technology, development boards and many components have become cheaper. In this way, it has become possible to develop spectrophotometers at very low costs and small sizes. Spectrophotometers are developing in line with the technical recommendations set by the International Commission on Illumination (CIE) [11]. Compared to old technologies, device designs developed with new development boards have become more compact and portable. In addition to its low cost, there is a tremendous reduction in usage areas. With the expansion of the internet network and the development of cloud technologies, the devices can store the measurement results in recording devices in other areas without the need for high recording volumes. Zhang et al. developed a portable spectrophotometer for water analysis. In the spectrophotometer they developed with LED, photodiode and microcontroller, they analyzed 45 different substances such as chromium and arsenide at wavelengths of 630, 605, 560, 515, 455 and 420 nm [4]. Chaianantakul et al. developed a mini spectrophotometer using an LED as the light source for plasma glucose detection [12]. Laganovska et al. have developed a spectrophotometer capable of measuring in the wavelength range of 450 to 750 nm, which can be controlled by a smart phone with a bluetooth module. They found that they got better results than low-cost spectrophotometers in comparative measurements [13]. Hosker has developed a low-cost spectrophotometer that can measure at 430 and 630 nm with the application she wrote for the light sensor of a smart phone [14]. Taha et al. developed a spectrophotometer using a phone camera as the light sensor and found that the results were similar by taking comparative measurements with a commercially used spectrophotometer [15]. Wu et al. developed an LED light source spectrophotometer and detected preservatives in foods at a wavelength of 530 nm [16]. Prasanth et al. developed a spectrophotometer to detect the amount of fat in milk and the amount of water added to milk [17]. Isaak et al. developed a low-cost spectrophotometer that can detect nitrogen, phosphorus and potassium in soil using the Raspberry Pi minicomputer [18]. Rivai et al. developed a spectrophotometer that analyzes the amount of protein in milk at a wavelength of 525 nm by using a Raspberry Pi minicomputer. By comparing the spectrophotometer, they developed and a spectrophotometer currently in use with the same samples, they determined that they obtained 2.366% incorrect measurement results [19]. Bocekci et al. designed a hand-held spectrophotometer to distinguish the color tone information of textile fabrics. The spectrophotometer is designed on the Arduino platform and a system that can detect 0-255 different color tones with the new generation color sensor has been realized [20]. Alhamdi et al. proposed a low-cost spectrophotometer device to measure blood glucose levels. The system they developed works on the FPGA platform and includes 8 LEDs of different wavelengths as a light transmitter and 8 photodiode series as a light detector. In their studies in which they measured the glucose level in the blood, the error was between 0.5% and 2.8% [21]. In [22], the biomedical device is developed to measure COPD parameters. The measured data can be sent to the computer and saved to the SD card and the data is stored in digital environment. The system offers a practical and low cost solution. In another study [23], an Internet of Things (IoT) based system that will allow remote monitoring of measured parameters is developed and data was collected by using Deneyap Card. It is transmitted to different environments and monitored successfully. Bocekci et al. designed and implemented a modular, computer-controlled spectrophotometer operating in the visible region. They concluded that the device is reliable according to repeatability and non-linearity tests. Also, when they compared the device with a commercial similar spectrophotometer, they found that the results matched [24]. Chiu et al. evaluated the uncertainty of transmittance for broadband spectrophotometer. The optimal extended uncertainties of the system were found to be 0.23247[25]. Rashid et al. proposed a spectrophotometer using LED as a light source for uric acid detection. The proposed system was compared with a system containing a halogen light source. They determined that the sensitivity of the LED light spectrophotometer was 73% higher than that of the halogen lamp. Their findings are that the LED light spectrophotometer can be used to detect uric acid in human urine [26]. Aslan et al. investigated the effect of the drying and settling processes of the ink on the color universe at certain time intervals with the spectrophotometer in the sheet offset printing technique. The values found in their study were tabulated and drying behaviors and ΔE color differences were revealed [27].

The overall aim of the study is to develop a low-cost, small-volume spectrophotometer with a heating system that transmits the measurement results to the cloud. In addition, it aims to include the high technology offered by today's opportunities. Embedded system development options such as microcontroller, Arduino and Raspberry PI were evaluated, and it was decided to use Raspberry PI 3 with the opportunities it provides. The heating system has been developed with on-off logic and Python software language. It is designed to operate at the desired wavelength thanks to the replaceable optical filter and light source. While designing this product, it was aimed to work at the desired temperature and wavelength according to the sample type to be measured.

In order to evaluate, report and back up the results of the product or products analyzed in spectrophotometer usage, an external computer is needed outside the device. Since Raspberry PI 3 is preferred in the realized design, the device can be used as a computer on its own. Thanks to this design, essential working areas in laboratory benches will be provided to the users. In addition to the space advantage, extra computer costs will be avoided. Thanks to portable memory entries and internet connections, it enables users to transfer their data without the need for additional procedures. With the sample heating feature, which is not available in standard spectrophotometers, it offers users the opportunity to measure at the desired temperature. Thanks to the developed software, the analysis results were transferred to the cloud environment, enabling users to access the analysis results from anywhere they have an internet connection.

2 System model

The product development process is divided into two main parts, software and hardware. These two main sections have been developed separately for heating systems and optical reading systems.

2.1 Heating system

The realized device has a heater system, which is not found in standard spectrometers. With this feature, temperature-related changes in the samples are prevented. The samples were brought to a desired constant temperature value during the measurement and the ambient conditions were stabilized in the measurements. The heating part of the device is divided into two main parts as software and hardware.

In the heater section, a relay that gives commands to the heating device with the signals it receives from the Raspberry PI is used. A 12V 40W ceramic heater, which can be seen in Figure 1, is used as a heating device and is made of ceramic material with a diameter of 6mm and a length of 20mm.

Figure 1. A 12V 40W ceramic heater, with a diameter of 6mm and a length of 20mm

In the design of the heating section, a single channel 5V relay of the Artou brand is used. This relay turns the heater cartridge on or off with the signals it receives from the Raspberry PI. Since Raspberry PI 3 does not have an analog input, DS18B20 is preferred as the temperature sensor shown in Figure 2. The reason for choosing this sensor is that it is low cost and small, as well as having an interrogation time of less than 750 ms and the ability to operate in a wide range such as -55°C to 125°C.

Figure 2. DS18B20 temperature sensor

After the system design was completed, the calibration of the heating system was carried out with a certified external thermometer. The 2490 model of the Almemo brand was used as a certified thermometer. Almemo thermometer is shown in Figure 3.

Figure 3. Almemo 2490 thermometer

The measurements were made for 10 minutes and took 1 data per minute. The device heating section was developed with on-off logic theory.

In this theory, the heater will turn off when it reaches a predetermined temperature and will start to heat again when it drops to a certain temperature. The software will keep the heater cartridge on until the temperature reaches 64.5 °C. When the temperature is in the range of 64.5 °C to 68.85 °C, the software will switch the heater cartridge on for 1 second and 1 second off. The software will turn off the heater cartridge when the temperature exceeds 68.85 °C. This temperature value determined in the software was determined based on user experiences after trial tests and measurements. In the first trials, the rules were; if the temperature is less than 65 °C, turn the heater on, and if the temperature is higher than 65 °C, turn the heater off. However, the heating responses of the heater cartridge caused the measured values to be constantly above 65°C. The software with the developed on-off logic algorithm does not work only at 65°C. The system will act according to any target temperature entered by the user. In the study, 65 °C was determined based on the values used by Avinash Kaur et al. while preparing the sample of Salmonella bacteria [28]. The developed software was developed by targeting this feature. Figure 4 shows heating system algorithm.

2.2 Optical system

In the software part of this study, Raspberry PI 3 minicomputer was programmed with Python software language. Thanks to the user-friendly features of the Python software language, the optical reading software was written in a text document program and then saved as .py and run. Optical reading software opens the light source with the command given by the user and records the data coming from the optical reader at certain time intervals. The recorded data is then evaluated by the user. The data obtained during optical reading can also be followed instantly by the user on the screen. The instantaneous data on the screen allows it to be detected without waiting for the end of the process, if any malfunction has occurred in the sample. The results obtained from the optical reading analyzes are saved in a folder specified in Raspberry Pi 3 in text document format. These recorded files are transferred to the user's Google drive account with the overGrive program, allowing the user to see the analysis results from any point where they can access the

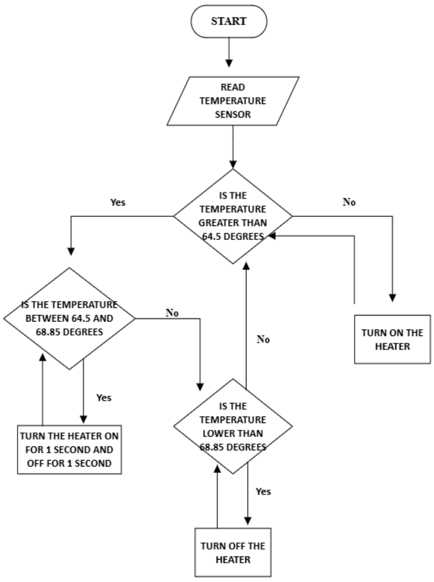
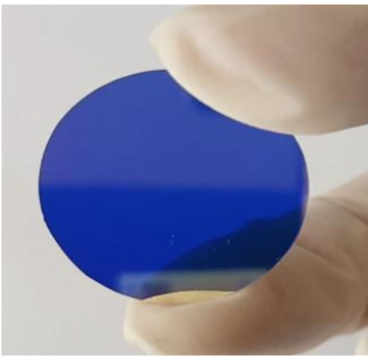


Figure 4. Heating system algorithm

The optical filter and light source seen in Figure 5 are mounted on the optical cover part of the device seen in Figure 6. 470 nm with a diameter of 1 mm Shijiazhuang tangtango optical filter which is produced by Optoelectronic Technology Co. Ltd. is used in the design of the optical measuring part. 1W Power Cob 3.6V 350mA 470nm blue chip LED is used as light source.



470 nm with a diameter of 1 mm Shijiazhuang tangtango optical filter

3.6V 350mA 470nm blue chip LED

Figure 5. Optical filter and LED

This cover design is designed for optical reading at a wavelength of 470 nm in the study. In the future uses of the device, the number of wavelengths that the device can measure can be increased by providing caps with the ability to measure at different wavelengths to be provided to the users. Optical reading software has also been developed to be wavelength independent in accordance with this design.

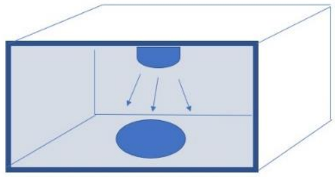


Figure 6. Optical cover

Optical reading part is designed to take measurements with more cost-effective plastic tubes instead of expensive glass cuvettes. In this way, the disposable sample tubes will provide the advantage of reducing the cuvette cleaning time from the measurement preparation times. The design of the optical reading part is accordingly sized to fit the 1.5 ml capped tube. The diameter and location of the hole that the sample tube will enter are designed to be suitable for this sample tube. LDR, which converts the beams coming from the samples into electrical data, was used to make the optical reading of the device. The position of this LDR in the measuring chamber has been determined according to the dimensions of the 1.5 ml tube used. Figure 7 shows optical measuring chamber.

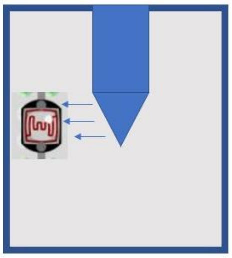


Figure 7. Optical measuring chamber

LDRs are circuit elements whose resistance varies inversely with the intensity of light falling on them. As the amount of light falling on the LDR increases, the resistance value decreases. LDR works with the lowest resistance in the light and the highest resistance in the dark. In the optical reading circuit design with LDR, the problem of giving analog signals from LDR has been encountered. Since there are no analog inputs on Raspberry PI 3, the electrical data sent by the LDR cannot be read. For this reason, an RC circuit is designed to provide optical reading. RC circuits consist of capacitors and resistors. Capacitors are used for charge storage in circuits. The current coming to the capacitor charges the capacitor, causing its voltage to rise. The resistor in this circuit, on the other hand, determines the current flowing to the capacitor, slowing down or accelerating the charging time of the capacitor. In these circuits, the time the capacitor will fill is determined by the value of the resistor. The LDR resistor will increase or decrease according to the amount of light falling on it. The rate at which the amount of light affects the LDR resistance will determine the charging time of the capacitor. When the capacitor used in the circuit reaches 1.8V, Raspberry PI 3 will detect it as logic 1 level and the time it takes for the GPIO pin to reach the logic 1 level will tell us the light level. In the optical measurement circuit, the charge time of the capacitor is determined by the amount of light falling on the LDR. This amount of light varies depending on the light absorption of the sample. Figure 8 shows optical reading software algorithm.

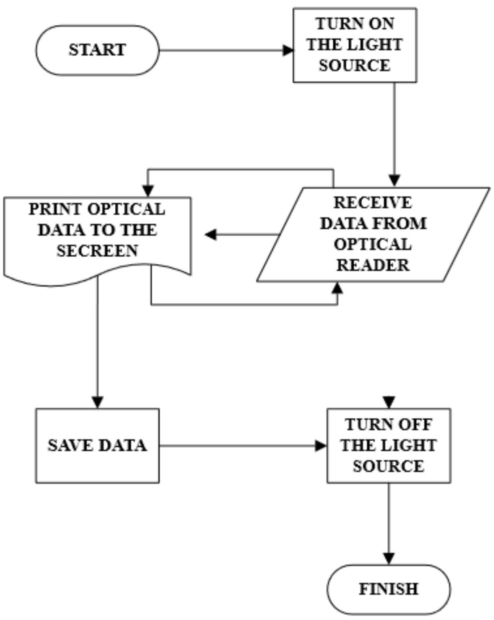


Figure 8. Optical reading software algorithm

2.3 Confidence interval analysis

Confidence interval is a kind of interval estimation for a population parameter in statistics and is an inferential statistical solution tool. Instead of estimating a population parameter value with a single number, there is a range of two (lower and upper limit) numbers that can cover this parameter value. Thus, confidence intervals show how reliable a prediction is.

In our study, a narrow range of 90% was chosen to show the precision of the confidence level measurement. Student's t distribution statistical approach was used to determine the lower and upper values of the confidence interval. The expression giving Student's t distribution is seen in Equation (1).

$$T = \frac{\bar{x} - \mu}{\sigma/\sqrt{n}} \quad (1)$$

where T is the student t distribution; $\bar{x}$ mean; μ confidence interval; σ standard deviation; n represents the number of samples.

If 90% is chosen for the confidence interval μ, as shown in Equation (2), the probability for T to be below –c is 5% and for it to be above +c is 5%.

$$\Pr(-c < T < c) = 0.9 \quad (2)$$

where T is the student t distribution; c indicates the lower and upper bounds. From here, the probability of T falling between the lower and upper limits is 90%. The 90% confidence interval expression for μ is seen in Equation (3).

$$\Pr(\bar{x} - \frac{c\sigma}{\sqrt{n}} < \mu < \bar{x} + \frac{c\sigma}{\sqrt{n}}) \quad (3)$$

where $\bar{x}$ mean; μ confidence interval; σ standard deviation; n represents the number of samples. The confidence interval for 90% can be found by Equation (4).

$$|\Delta\mu| = \frac{1,65\sigma}{\sqrt{n}} \quad (4)$$

3 Experiments and results

In this study, a low-cost spectrophotometer has been developed with features suitable for mass production in terms of both hardware and software methodology. The block diagram of the developed system and the circuit diagram are shown in Figure 9.

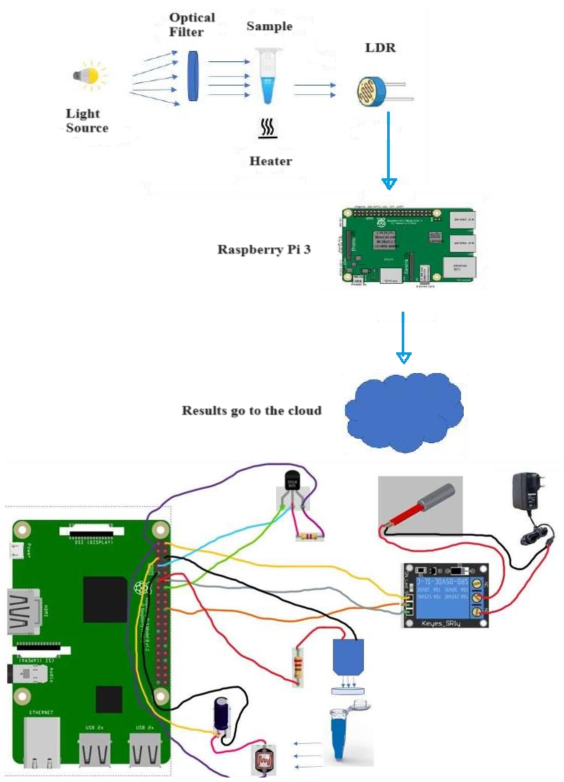


Figure 9. Developed measuring system

The developed device which is shared in Figure 10 has compact dimensions, on/off heating system and transferring the obtained data to cloud systems.

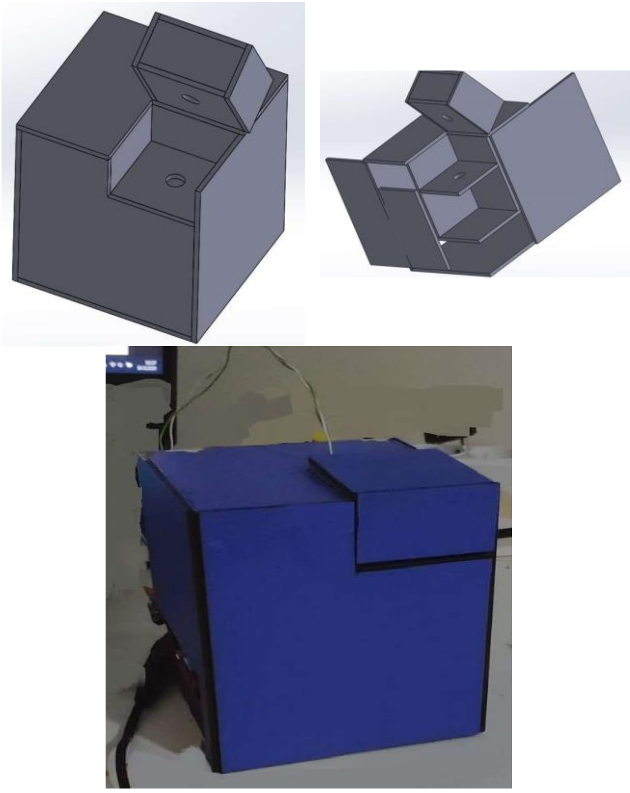


Figure 10. Developed device

During this study, a sample called blue dye, which can absorb light at a wavelength of 470 nm, was tested to model Salmonella bacteria. Protein determinations make with this dye. Measurements were made with 1.5 ml tubes. 4 different samples were measured. These samples were prepared by dissolving different weights of blue dye in 1 ml of ultrapure water. The samples were prepared as 0.1, 0.125, 0.15, 0.175, 0.2 g in 1 ml of distilled water. Measurements were completed in 3 months, with 100 repetitions. During this period, the samples were stored in the refrigerator at +4 degrees. The measurements were concluded based on the filling time value of the capacitor in the LDR-RC circuit. The filling time value range of the capacitor was determined to be between the result obtained with the light source completely turned off and the results obtained from the 1.5 ml sample tube containing only ultrapure water.

As a result of the measurements, it has been determined that the charging time of the capacitor is proportionally prolonged between ultrapure water, 0.1 g, 0.15 g and 0.2 g. E.g; In the measurement of ultrapure water sample, while the filling time of the capacitor is 202 units on average, this value is on average 223 units in 0.1 g sample, 242 units on average in 0.15 g sample and 255 units on average in 0.2 g sample. In cases where the light source is off, the capacitor gives an average value of 265 units. Figure 11 to 14 show optical measurement results.

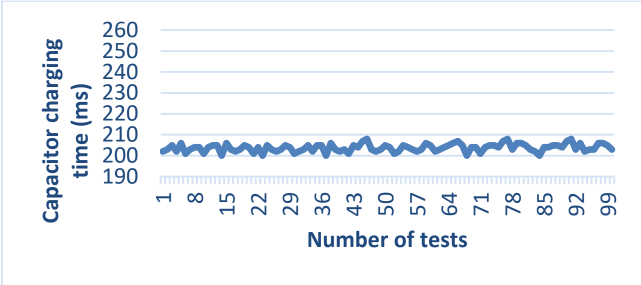


Figure 11. Optical measuring results of pure water

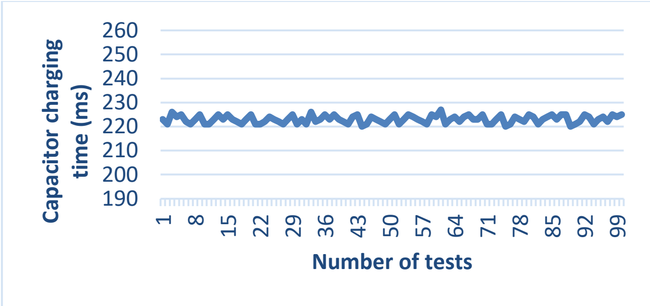


Figure 12. Optical measuring results of 0.1 g sample

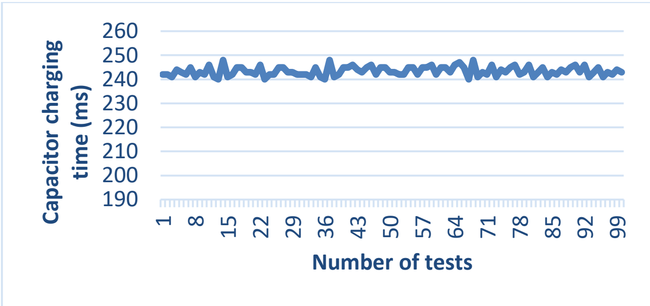


Figure 13. Optical measuring results of 0.15 g sample

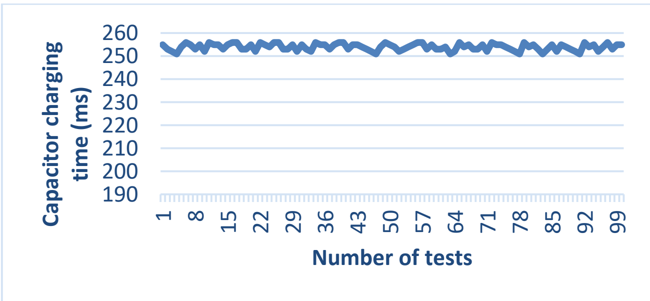


Figure 14. Optical measuring results of 0.2 g sample

Figure 15 shows the regression coefficient for the measured values at 5 different densities. As a result of the tests performed, the R^2 value was determined as 0.9982.

Figure 16 to 20 show the confidence interval analyzes found using measured values (MV) and calculated values (CV) for different densities.

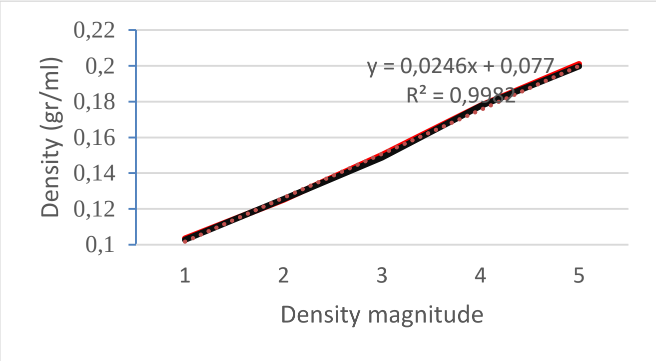


Figure 15. Optical measuring results

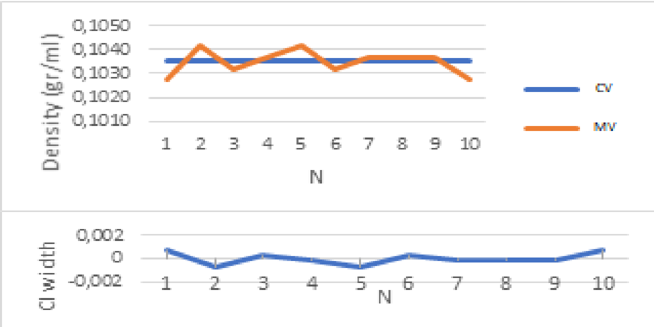


Figure 16. Optical measuring confidence interval results of 0.1 g sample

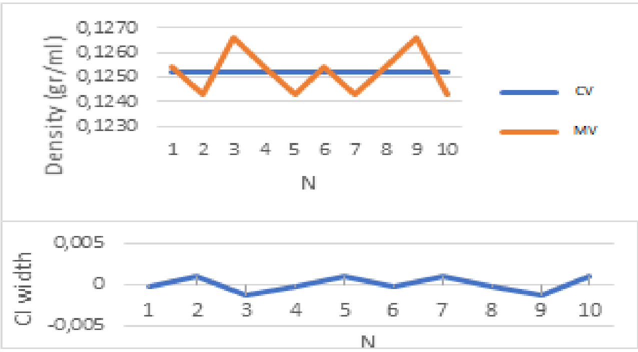


Figure 17. Optical measuring confidence interval results of 0.127 g sample

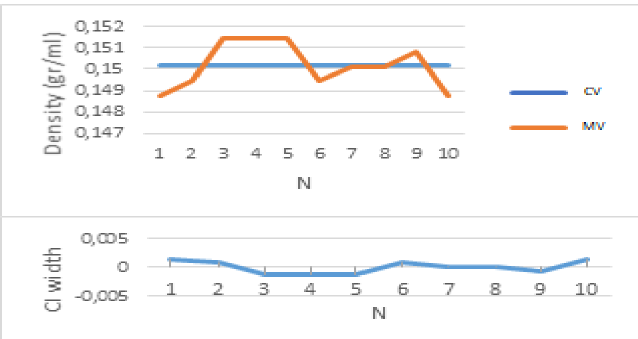


Figure 18. Optical measuring confidence interval results of 0.15 g sample

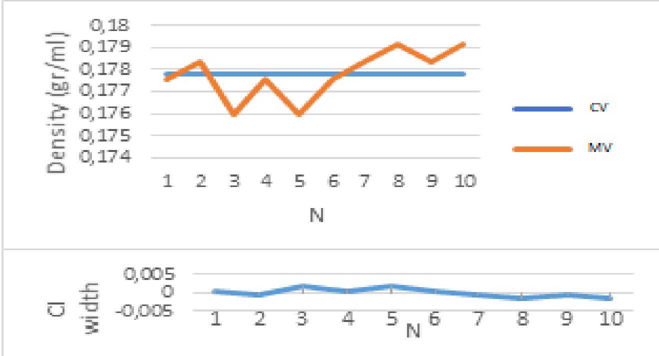


Figure 19. Optical measuring confidence interval results of 0.177 g sample

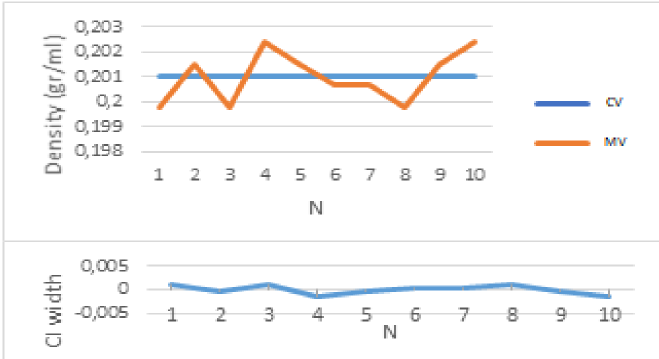


Figure 20. Optical measuring confidence interval results of 0.12 g sample

Confidence intervals of the measurements were calculated using Equation (4). Table 1 shows the results of the confidence intervals.

Table 1. Confidence intervals

Average	Std. Dev.	Conf. Int.
0.1035 g	0.000525799	0.00274454
0.1252 g	0.000911903	0.0047586
0.1502 g	0.001073907	0.00560339
0.1778 g	0.001114205	0.00581365
0.201 g	0.001032974	0.00538981

Table 2 shows the comparison of the proposed system with current studies. All the studies are presented as an alternative to a conventional spectrophotometer, and they are similar in terms of compact dimensions. The spectrophotometer we have designed differs especially in terms of the internal heater unit and the method of transferring the obtained data out of the device.

4 Conclusions

In this study, a low cost and small volume spectrophotometer design has been realized. The developed product stands out in its field with its temperature control feature besides standard spectrophotometers. In the tests performed for 5 different densities, the R^2 value was determined as 0.9982. The results obtained in the confidence interval analysis are within ∓5% deviation limits. In addition, thanks to the Raspberry PI minicomputer included in it, it prevents the use of an external computer. This allows users to find extra workspace in laboratory areas. The development of software that will process the raw data recorded in this study in the cloud environment can be suggested among the future studies. Apart from this, the spectrophotometer was produced in a specific spectrum range for salmonella bacteria. The operating spectrum can be expanded by developing transmitter and receiver modules on the same device.

Table 2. Comparison of current studies

Author	Lighting	Heather	Access	Application device
[12]	LED	-	-	Arduino Mega
[13]	LED	-	Bluetooth	Arduino Nano
[17]	LED	External	-	Raspberry Pi 3
[28]	LED	Internal	Bluetooth	Arduino Pro Mini
[18]	LED	-	-	Raspberry Pi 3
[21]	LED)/ Conventional	-	-	FPGA
Proposed System	LED	Internal	Internet	Raspberry Pi 3

Conflict of Interest

The authors declare that they have no conflict of interest.

Similarity Rate (iThenticate): 7 %

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