

A Development of a Portable Sugar Measuring Device for Americano Coffee Using The Electrical Conductivity Principle

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ABSTRACT

This research presents the development of a portable device for non-destructive sugar measurement in Americano coffee using electrical conductivity (EC) and temperature compensation principles. The study identifies key factors influencing the total dissolved solids (TDS) in Americano coffee, including water volume, coffee concentration, and sugar content. Experimental results show an inverse correlation between sugar content and TDS, enabling the estimation of sugar levels through EC analysis. A prototype was designed incorporating an analog EC sensor, a temperature sensor, and an Arduino Nano microcontroller. Calibration of the EC sensor achieved an accuracy within 0.60% error, and temperature compensation equations were derived for both hot and iced Americano variants to enhance precision. The device classifies sugar content into low, normal, and high levels based on WHO guidelines and demonstrated 100% accuracy across validation tests for both beverage types. This portable solution provides a rapid and user-friendly method for assessing sugar levels in coffee, with potential applications in health monitoring and dietary management.

Keywords: Americano coffee, Sugar measurement, Electrical conductivity, Total dissolved solids, Temperature compensation, Portable device

1. INTRODUCTION

Granulated sugar or sucrose is a term used to refer to a water-soluble carbohydrate composed of carbon, hydrogen, and oxygen ($C_{12}H_{22}O_{11}$). It is classified as a disaccharide [1]. Sugar is widely used in food and beverages. Excessive and prolonged sugar consumption has long-term health consequences, a global concern due to its increasing trend. This issue is partially attributed to a lack of physical activity and excessive sugar intake, which can lead to overweight, insulin resistance, and

metabolic disorders. Additionally, excessive sugar consumption contributes to other health complications [2-6].

Studies have shown that global sugar consumption often exceeds the World Health Organization (WHO) recommendation of no more than 6 teaspoons (24 grams) per day. In many countries, individuals consume between 20 and 25 teaspoons (100 – 125g) of sugar daily, significantly surpassing recommended limits [7]. As a result, diabetes has become a major public health concern worldwide, with over 500 million adults diagnosed globally, and a substantial proportion unaware of their condition. Additionally, obesity rates have risen dramatically, affecting more than 1 billion people across all age groups. Economic projections indicate that within the next few decades, the financial burden of obesity-related healthcare costs could reach nearly 5% of global GDP [8-9].

Moreover, excessive sugar consumption has been strongly linked to cardiovascular diseases, high cholesterol, tooth decay, and other chronic conditions, including cirrhosis, gout, and depression. As these trends continue to escalate, addressing dietary sugar intake remains a critical challenge in public health efforts worldwide [10-11].

A study published in *Nutrients* highlights that free sugar intakes as a percentage of total energy are highest among children and adolescents (12-14% of total energy) and lowest among older adults (8% of total energy) [12]. Moreover, Research published in the *Public Health Nutrition* journal discusses how sugar consumption is directly associated with GDP and urbanization rates, indicating that higher sugar intake correlates with increased economic development and urbanization [13].

Coffee is one of the most widely consumed beverages globally, with consumption patterns varying across different regions and cultures. During the 2021/2022 coffee year, global coffee consumption reached approximately 176 million 60-kilogram bags, up from nearly 167 million bags in the previous year [14]. It is estimated that over 2.25 billion cups of coffee are consumed globally every day, highlighting coffee's pervasive presence in daily routines worldwide. The largest coffee-consuming regions include the European Union, the United States, and China, with significant increases observed in these areas [15].

Americano coffee is a popular beverage in many countries, particularly in the United States, South Korea, and Thailand. Americans consume approximately 400

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million cups of coffee per day, averaging about 3 cups per person. This places the United States among the top 10 coffee-consuming countries in the world. Among coffee drinkers, around 35% prefer black coffee, including Americano. South Koreans consume an average of 2–3 cups of coffee per day, particularly among individuals aged 40–50, who form the country's primary workforce. An iced Americano is one of the most popular coffee choices. These findings indicate that Americano coffee is widely preferred across different countries, especially among working professionals seeking both energy and a healthier coffee option [16-17].

The electrical conductivity is the main principle to measure sugar in Americano coffee. There are some researches related to this article shown as follows:

Giulia Angeloni and her research team studied the total dissolved solids, density, pH, conductivity, and viscosity in different coffee brewing methods. They found that espresso had the highest concentrations of caffeine and chlorogenic acids (CGA), whereas mocha and filtered coffee contained three to six times lower concentrations. The classic espresso method was the most efficient in extracting caffeine and CGA, yielding nearly twice as much as other brewing methods [18].

Niny Z. Rao focused on the effects of coffee roasting on chemical extraction in cold brew coffee. They compared hot and cold brew coffee made from Colombian Arabica beans roasted at light, medium, and dark levels. Their findings indicated that roasting level significantly affected the extraction of brown-colored compounds and total dissolved solids (TDS). Other factors, such as coffee bean surface wetting, pore dynamics, and solubility of chemical compounds, played a crucial role in chemical extraction, with water temperature influencing these factors [19].

Shailesh Kumar Dewangana investigated the impact of temperature on electrical conductivity (EC) and total dissolved solids (TDS) in water. They found that temperature significantly affects both EC and TDS; as water temperature increases, electrical conductivity rises due to faster molecular movement, which enhances ion transport. Additionally, higher temperatures may alter the solubility of certain substances, potentially affecting TDS measurements. For example, some salts become less soluble at higher temperatures, which could lead to a decrease in TDS [20].

Poojitha and Athmaselvi studied the effects of ohmic heating on bananas, particularly the impact of sucrose concentration on electrical conductivity. Their research found that ohmic heating is a rapid heating technique applicable to food products. An increase in sucrose concentration resulted in lower electrical conductivity, leading to a longer heating time [21].

This research aims to develop a portable sugar measuring device for Americano coffee that can measure sugar in hot/iced Americano coffee non-destructively. The electrical conductivity and temperature compensation are used to develop the proposed prototype. The

analog total dissolved solids (TDS) sensor (AB202) and temperature sensor (DS18B20) are used as main sensors that connect to the microcontroller (Arduino nano Type C) to process each variable and interpret to sugar level. This approach allows for accurate measurement and analysis of the factors of sugar measurement in coffee, paving the way for further research on its application to other types of coffee or other beverages.

2. THEORETICAL BACKGROUNDS

The theoretical backgrounds related to this research that should be reviewed beforehand for more understanding are the solution conductivity, temperature compensation for electrical conductivity measurement and total dissolved solids (TDS).

2.1 Solution Conductivity

The solution conductivity is the ability of a solution to conduct an electric current, varying with the concentration of ions in the solution. It can be measured using an alternating current with a two-electrode system. The meter applies a voltage between the two electrodes, creating an electric field. When the electrodes come into contact with the solution, positive ions or cations within the solution move from the positive electrode to the negative electrode following the electric field, allowing the current to be measured. Since the solution has an inherent electrical resistance, the voltage decreases as a result [22 – 23].

The standard measurement for specific conductivity (C) is expressed in S/cm to compensate for differences in electrode size. This is determined by the product of the measured conductivity (G) and the electrode cell constant (L/A), where L represents the length of the liquid column between the electrodes and A denotes the electrode surface area. The equation is given by:

$$C = G \times \frac{L}{A} \quad (1)$$

where C is specific conductivity (S/cm or $\mu\text{S/cm}$), G is the measured conductivity (S), L is the length between the electrodes (cm), and A is the electrode surface area (cm^2).

Factors affecting the solution conductivity are ion concentration in solution, type of ions, and temperature. The solution consists of dissolved ions, such as sodium ions, which can move through water. Therefore, solutions with a higher concentration of ions can conduct more electrical current. Moreover, ions such as Na^+ , K^+ , Mg^{2+} , Ca^{2+} , HCO_3^- , Cl^- , and SO_4^{2-} tend to have good electrical conductivity. Finally, electrical conductivity increases by approximately 1.9% for every 1°C rise in temperature in most solutions shown in Fig. 1 [24]. This makes temperature compensation necessary to ensure accurate comparisons of conductivity measurements.

According to Fig. 1, it is evident that temperature significantly affects conductivity measurements. As the temperature increases, the conductivity also rises. This

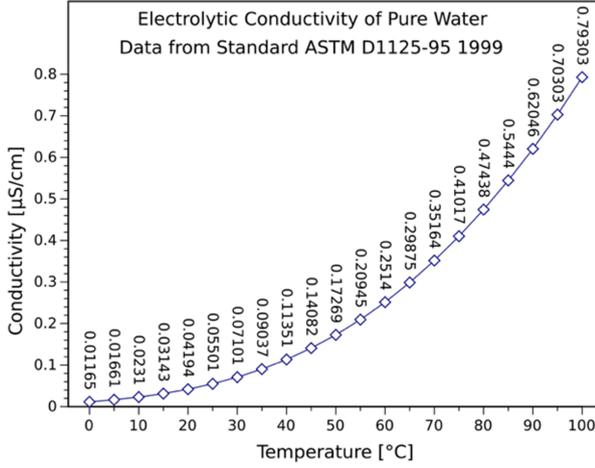


Fig. 1: Relation between electrical conductivity and temperature (0 to 100° C) of pure water.

can be explained by the fact that temperature influences the dissociation of water molecules. When the water temperature increases, the molecules move faster and possess higher kinetic energy. The freely moving ions contribute to enhanced electrical conductivity in the solution or liquid.

2.2 Temperature Compensation for Electrical Conductivity Measurement

Temperature compensation for electrical conductivity measurement refers to adjusting the measured conductivity value to be equivalent to the value at a standard reference temperature (typically 25°C). This adjustment is necessary because temperature affects ion mobility in a solution, which in turn influences conductivity, diffusion coefficients, and water viscosity.

According to the Nernst-Einstein equation, it establishes a proportional relationship between electrical conductivity (EC) and the diffusion coefficient (D) of dissolved ions, as shown in (2) [25].

$$EC = \frac{F^2}{RT} Dz^2c \quad (2)$$

or

$$EC = \text{constant} \times \frac{D}{T} \quad (3)$$

where F is Faraday's constant (C/mol), R is the gas constant (J/mol·K), T is the absolute temperature (K), z is the electrical charge (-), and c is the molar concentration of dissolved ions (mol/L).

The Stokes-Einstein equation establishes a relationship between the diffusion coefficient of small particles (D) moving through a viscous fluid (η) and the physical properties of the fluid, such as viscosity and temperature, shown in (4).

$$D = \frac{k_B T}{6\pi\eta r} \quad (4)$$

where D is the diffusion coefficient (m²/s), k_B is the Boltzmann constant (J/K), T is temperature (K), η is fluid

viscosity (kg·m⁻¹·s⁻¹), and r is the hydraulic radius of a diffusing particle (m).

The ratio of the diffusion coefficients (D) at two different temperatures (T_1 and T_2) is shown in (5).

$$\frac{D_1/T_1}{D_2/T_2} = \frac{\eta_2}{\eta_1} \quad (5)$$

Since electrical conductivity (EC) is directly proportional to D/T shown in (3), the same ratio applies:

$$\frac{D_1/T_1}{D_2/T_2} = \frac{EC_1}{EC_2} = \frac{\eta_2}{\eta_1} \quad (6)$$

where T_1 is set as the measured fluid temperature, and T_2 is set as the referent temperature (25°C).

The temperature compensation formula can be derived as (7) [25].

$$\frac{EC}{EC_{25}} = \frac{\eta_{25}}{\eta} \quad (7)$$

where EC is measured conductivity at a given temperature ($\mu\text{S}/\text{cm}$), EC_{25} is fluid conductivity at 25°C ($\mu\text{S}/\text{cm}$), η is fluid viscosity at the measured temperature (kg·m⁻¹·s⁻¹), and η_{25} is fluid viscosity of at 25°C (kg·m⁻¹·s⁻¹).

Since electrical conductivity depends on fluid viscosity caused by temperature, the linearization method needs to be applied for electrical conductivity measurement. A linear relationship between temperature and conductivity is widely used by expanding a nonlinear temperature compensation equation into a Taylor series expansion, resulting in the following equation [26]

$$EC = EC_{25}(1 + a\Delta T) \quad (8)$$

where EC is the temperature-compensated conductivity ($\mu\text{S}/\text{cm}$), EC_{25} is fluid conductivity at 25°C ($\mu\text{S}/\text{cm}$), and a is the temperature coefficient of solution (°C⁻¹), and ΔT is a difference between standard temperature (25 °C) and measured temperature (°C).

This temperature compensation equation ensures that conductivity measurements taken at different temperatures can be compared consistently. The example of the conductivity measurement of water using nonlinear and linear methods is shown in Fig. 2.

According to Fig. 2, the temperature compensation factor (a) for electrical conductivity (EC) typically falls within the range of 0.01 °C⁻¹ to 0.03 °C⁻¹. Hayashi's study [26] on natural waters found a compensation factor of 0.019 °C⁻¹, which aligns closely with the theoretical value (0.020 °C⁻¹). This suggests that the empirical values observed in natural water systems are consistent with the theoretical predictions.

2.3 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) refers to the measurement of the total amount of dissolved solids, including both inorganic and organic substances, present in water. The TDS value of any given water sample is expressed in milligrams per liter (mg/L) or parts per million (ppm)

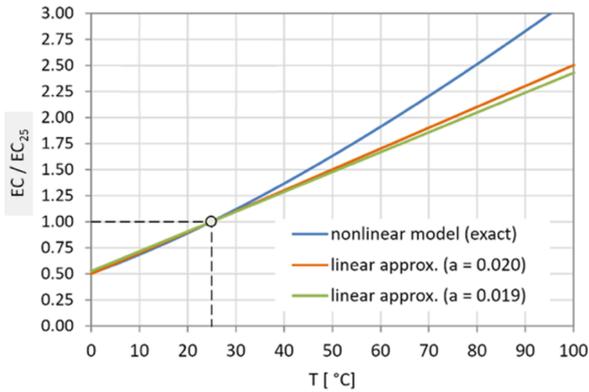


Fig. 2: EC/EC_{25} (x -axis) in the temperature range between 0 to 100° C (y -axis) [26].

[27]. It is commonly used to assess water quality. A high TDS value indicates that the water contains a large number of dissolved minerals, such as calcium, magnesium, and sodium. However, the TDS measurement represents the total concentration of dissolved solids in the solution and does not specify the exact types of minerals present in the water.

TDS and EC are closely related parameters. To convert EC to TDS, the following formula is commonly used (9) [28].

$$TDS = k \times EC \quad (9)$$

where TDS is the total amount of dissolved solids in water (mg/L), k is a conversion factor that varies based on the composition of dissolved solids in the water (-), and EC is temperature-compensated conductivity ($\mu S/cm$).

According to (9), the factor (k) typically ranges between 0.5 and 0.9. For many natural waters, a commonly used approximation is 0.64 [28].

3. MATERIALS AND METHODS

The materials used in this research are described. Then, the methods such as prototype design, experimental process, and prototype calibration are also explained in this section.

3.1 Materials

The main components of the prototype are an analog EC sensor module, temperature sensor, microcontroller, step-up voltage module, charger module, battery, and LED display.

The analog EC Sensor module is used to measure the combined content of all inorganic and organic substances dissolved in water. Additionally, this sensor is food-grade material, and it also has a waterproof property [29].

The temperature is one of the most important variables because the EC depends on the temperature. Therefore, the temperature needs to be measured to compensate for the EC measurement. This research uses DS18B20 temperature sensor which has high accuracy ($\pm 0.5^\circ C$) and a wide measurement range (-55 to $125^\circ C$).

The sensor is covered by a 304-grade stainless steel casing that can be clean easily with normal water [30].

In order to analyse the data, the Arduino Nano Type-C is used. This microcontroller has a small size ($45\text{ mm} \times 18\text{ mm} \times 7\text{ mm}$) [31].

The MT3608 module is an integrated circuit (IC) specifically designed for voltage step-up (boost conversion). It is commonly used to convert low voltage from small batteries, such as lithium-ion batteries, into a higher voltage suitable for electronic devices that require greater power [32].

To control the battery charging, the TP4056 module is an integrated circuit (IC) specifically designed for charging lithium-ion (Li-ion) batteries. It features a USB Type-C input port and supports an input voltage of 5V. The module has a cutoff charging voltage of $4.2V \pm 1\%$ and includes over-discharge protection at 2.5V [33].

In this research, the 3.7V 400mAh lithium-polymer (Li-Po) battery is used. It is widely used in portable electronic devices due to its compact size, lightweight design, and high energy capacity [34].

3.2 Method

This research consists of two methods: (1) a study of the factors affecting the TDS value in Americano coffee, and (2) prototype development. In order to develop the portable sugar measuring device for Americano coffee, every factor, such as water volume, coffee concentration, temperature, and sugar content that relates to the TDS value needs to be known. The standard TDS meter measures the TDS value in each specific condition to find the related factors affecting sugar content in Americano coffee. The result of this method is explained in the results section.

After receiving the related factors affecting the sugar content in Americano coffee, the prototype development method is performed. The portable sugar measuring device is designed and developed. Each component used for prototype development is measured and designed using 3D software shown in Fig. 3.

Each component is connected. Then, the microcontroller is coded to control sensors cooperating with each component. In order to calibrate the EC sensor, the standard EC calibration liquid, which has a constant value of $1,413\ \mu S/cm$ at $25^\circ C$, is used. When the room environment is set to $25^\circ C$, the EC sensor is dipped into the standard EC calibration liquid for calibration shown in Fig. 4.

4. RESULTS

Since this research employs two methods, the results can be divided into two parts: the factors affecting TDS values and the prototype development. The results from the first part of the experiment will lead to the development of the prototype in the second part.

When the EC sensor is ready, the prototype is used to measure with sugar content in Americano coffee. The result will be described in the next section.

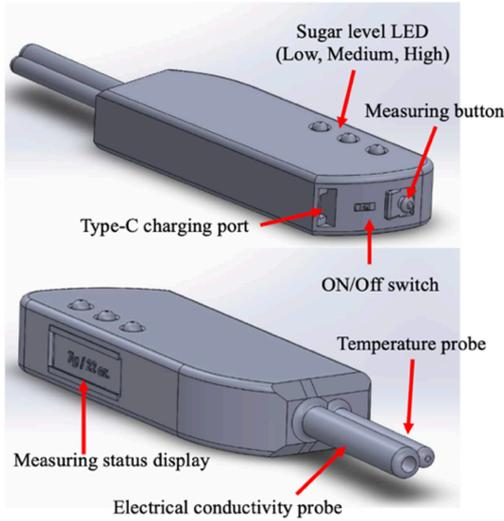


Fig. 3: The prototyping design.

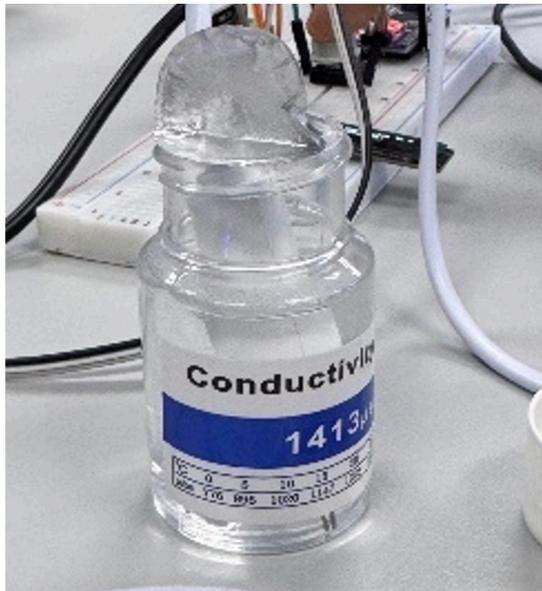


Fig. 4: EC sensor calibrated by standard EC calibration liquid.

4.1 The result of factors affecting TDS values

The study of variables affecting the TDS value that relates to EC will help in understanding the behaviour and trends of TDS when influenced by other factors. The data obtained by a standard TDS meter in the laboratory has been analysed and utilized for the development of the device in the subsequent section.

The first variable that needs to be verified is water content. This experiment measures the TDS value varying the water volume from 100 – 180mL. Each water sample is at 25°C. The selected volume is a commonly used volume for brewing coffee. The experiment was conducted five times to confirm the accuracy of the results. The result is shown as follows:

Table 1: Effect of water content on TDS.

Water volume (mL)	TDS (PPM)					Mean	S.D.
	1	2	3	4	5		
100	327	327	334	334	336	331.60	4.28
120	332	336	336	334	336	334.80	1.79
140	336	336	336	334	336	335.60	0.89
160	336	336	335	334	336	335.40	0.89
180	336	336	336	336	335	335.80	0.45

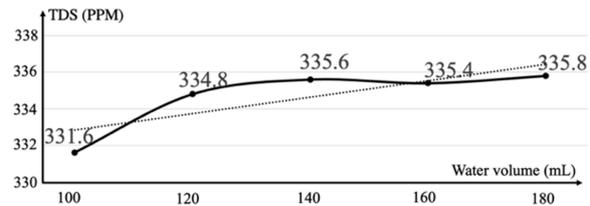


Fig. 5: TDS value of each water volume.

Table 2: Effect of coffee content on TDS at 90°C.

Coffee volume	TDS (PPM)					Mean	S.D.
	1	2	3	4	5		
Single shot	1112	1112	1112	1112	1112	1112.00	0
Double shots	1112	1112	1112	1112	1112	1112.00	0

Table 3: Effect of coffee content on TDS at 50°C.

Coffee volume	TDS (PPM)					Mean	S.D.
	1	2	3	4	5		
Single shot	1112	1112	1116	1116	1112	1113.60	2.19
Double shots	1116	1112	1116	1116	1116	1115.20	1.79

The mean of the TDS value of each water volume can be plotted as the Fig. 5 that each mean value of TDS is close to the trend line. The standard deviation indicates the clustering of data.

The next experiment is to measure the TDS of a single shot (30mL or 1 ounce) and a double shot Espresso at 90°C, which is the ordinary hot coffee temperature from an espresso machine. This experiment will demonstrate whether the volume of coffee affects the TDS value. The result is shown in Table 2.

Then, each coffee sample was left until it reached 50°C, and the TDS value was measured again shown in Table 3.

Tables 2 and 3 show that the volume of Espresso shot does not affect the TDS value. However, when the temperature changes, the TDS value changes only slightly.

The next factor is coffee concentration. This experiment measures the TDS of single and double shots, varying the water content at 90 °C. The result is shown in Table 4.

The mean of the TDS value from Table 4 can be plotted in Fig. 6

According to Fig. 6, TDS in coffee represents the

Table 4: Effect of coffee concentration on TDS at 90°C.

Water volume (mL)	Coffee content (shot)	TDS (PPM)					Mean	S.D.
		1	2	3	4	5		
100	Single	1078	1078	1073	1073	1112	1082.80	16.51
	Double	1112	1108	1099	1108	1108	1107.00	1.58
120	Single	1008	1008	1004	1004	1004	1005.60	2.19
	Double	1103	1108	1108	1108	1103	1106.00	2.74
140	Single	957	954	954	954	954	954.60	1.34
	Double	1078	1065	1061	1065	1065	1066.80	6.49
160	Single	920	913	913	909	909	912.80	4.49
	Double	1012	1020	1,016	1008	1012	1013.60	4.56
180	Single	870	884	888	881	881	880.80	6.68
	Double	957	950	939	913	888	929.40	28.55

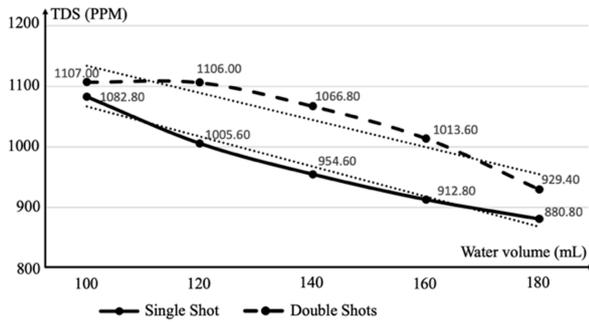


Fig. 6: TDS value of each coffee concentration.

Table 5: The TDS of 12g sugar dissolved in 100-180mL water.

Sugar content (g)	Water volume (mL)	TDS (PPM)					Mean	S.D.
		1	2	3	4	5		
100	200	212	216	216	216	216	212.00	6.93
	120	236	236	236	238	238	236.80	1.09
12	140	249	249	249	251	253	250.20	1.79
	160	261	261	260	261	260	260.60	0.55
	180	268	268	266	266	268	267.20	1.09

concentration of dissolved substances. When the coffee concentration decreases, the number of dissolved solids in the final brew also decreases. This leads to a lower TDS value because there are fewer dissolved compounds per unit volume of liquid.

The last important factor needed to know to develop the prototype is the sugar concentration. The 12g of sugar, which is half of the maximum daily sugar intake for an adult recommended by WHO [7], varying the water content, is measured. The result is shown in Table 5.

The mean of the TDS value from Table 5 can be plotted in Fig. 7. It was found that the TDS of the sugar solution is inversely proportional to the amount of sugar concentration close to the trend line.

Now, single shots of 120mL standard hot Americano coffee, with varying sugar contents from 5–30g, are measured for TDS. Each sample is at 90°C. The result is shown in Table 6.

The mean values of Table 6 can be plotted in order to

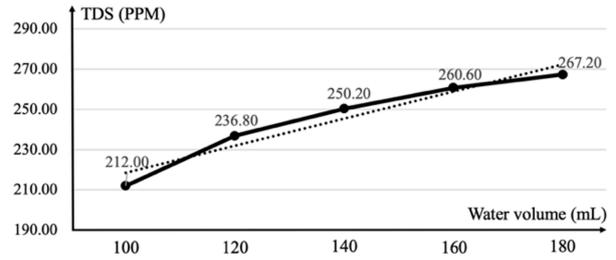


Fig. 7: TDS value of sugar solution varying from 100 to 180mL of water.

Table 6: TDS of hot Americano coffee varying sugar contents from 5–30g.

Water volume (mL)	Sugar content (g)	TDS (PPM)					Mean	S.D.
		1	2	3	4	5		
120	5	1036	1036	1040	1040	1040	1038.40	2.19
	10	1016	1016	1012	1008	1012	1012.00	4.00
	15	920	957	950	954	954	947.00	15.29
	20	888	891	891	891	884	889.00	3.01
	25	857	857	857	857	857	857.00	0.00
	30	784	787	791	791	791	788.80	3.19

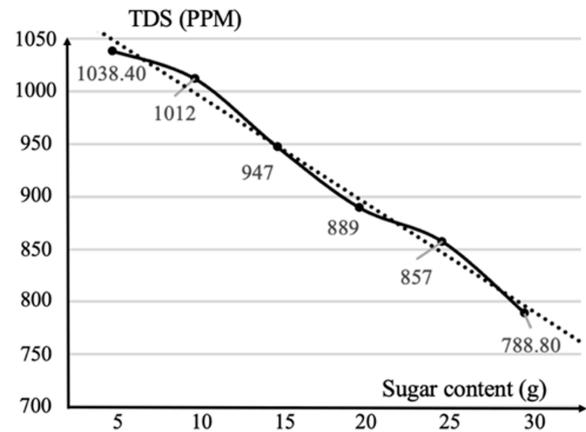


Fig. 8: TDS value of Americano coffee varying 5–30g sugar.

show the TDS trend of Americano coffee with varying sugar content in Fig. 8. It was found that the TDS of hot Americano coffee is inversely proportional to sugar content.

From the previous experiments, they conclude that the factors affecting to the TDS are water content, as shown in Fig. 5. This result relates to the principle of dilution. Sugar content also affects the TDS. This is because sugar does not dissociate into ions in water, causing other ions in the coffee to become diluted shown in Fig. 7.

The factors that slightly affect changes in TDS are temperature (Table 2 – 3) and coffee concentration Fig. 6. The trend of sugar content affecting the TDS of Americano coffee is shown in Fig. 8. These data are used to develop a portable sugar measuring device that will be described in the next section.

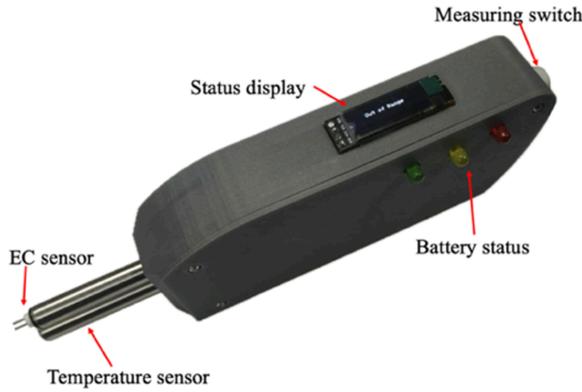


Fig. 9: A prototype of a portable sugar measuring device.

Table 7: Prototype calibration result.

EC reference (μS/cm)	Measured EC (μS/cm)					Mean	Error (%)
	1	2	3	4	5		
1413	1423.42	1421.14	1420.05	1420.74	1422.41	1421.55	0.60

Table 8: The EC of Americano coffee at 25°C.

Temperature (°C)	EC (μS/cm)
24.33	1769.00
24.31	1768.35
25.00	1831.55
24.87	1841.63
26.50	1919.81
Average	1826.07

4.2 The Prototype Calibration

A prototype of a portable sugar measuring device is completely assembled shown in Fig. 9.

The prototype integrates EC and temperature sensors to measure and transmit data to a microcontroller for processing and display. The EC sensor was calibrated by the standard EC calibration liquid at 25°C. The result of EC sensor calibration is shown in Table 7 that the mean EC value deviates by only 0.60% from the standard calibration solution at 25°C, confirming the prototype’s readiness for use.

Given that water volume affects EC, this study standardizes the test volume to 120 mL—the typical amount for a cup of single-shot Americano. Temperature also slightly influences EC; thus, the compensation equation (8) was applied to enhance measurement accuracy.

To apply this equation, the temperature coefficient of Americano coffee (*a*) must be determined experimentally. This requires measuring the EC of unsweetened Americano at 25°C, as shown in Table 8.

In the experiment, it was hard to control the temperature to be exactly 25°C. Therefore, the average value of temperature between 24 - 26°C is used in the calculation.

Because of the large temperature difference between hot and iced coffee, the temperature coefficient of

Table 9: The EC of iced Americano coffee.

Time (Minutes)	Temperature (°C)	EC (μS/cm)
0	3.78	582.59
5	4.78	568.63
10	6.01	576.13
15	6.75	593.82
20	8.84	587.49
Average		581.73

Table 10: The EC of hot Americano coffee.

Time (Minutes)	Temperature (°C)	EC (μS/cm)
0	61.35	3174.78
5	61.28	3173.73
10	60.80	3164.81
15	60.70	3130.08
20	60.82	3153.13
Average		3159.31

Americano coffee (*a*) should be calculated separately using the linear regression method.

For iced Americano, the temperatures between 0 – 20 minutes are measured shown in Table 9.

According to equation (8), the equation is adjusted to a linear equation ($y = ax + b$) to use the linear regression method shown as follows

$$\frac{EC}{EC_{25}} = a\Delta T + 1 \tag{10}$$

From equation (10), the coefficient (*a*) can be calculated using a linear regression equation.

$$a = \frac{N \sum xy - \sum x \sum y}{N \sum x^2 - (\sum x)^2} \tag{11}$$

where *x* is ΔT , *y* is $\frac{EC}{EC_{25}}$, and *N* is 5 (number of data).

From equation (11), the coefficient (*a*) is 0.00146. Therefore, the equation of EC of iced Americano (EC_{iced}) with temperature compensation is shown as follows:

$$EC_{iced} = EC_{25}(1 + 0.00146\Delta T) \tag{12}$$

where EC_{iced} is a temperature-compensated conductivity of iced Americano (μS/cm), EC_{25} is conductivity of the Americano at 25°C (1826.07 μS/cm), and ΔT is the difference between the standard temperature (25°C) and the measured temperature (°C).

According to (12), it can be concluded that the EC of iced Americano changes 0.144% when its temperature changes 1°C.

For hot Americano, the process of iced Americano is also applied. Therefore, the temperatures of hot Americano between 0 – 20 minutes are measured and shown in Table 10.

When the linear regression method is applied to hot Americano, the equation of EC of hot Americano (EC_{hot}) with temperature compensation is shown as follows:

$$EC_{hot} = EC_{25}(1 + 0.02029\Delta T) \tag{13}$$

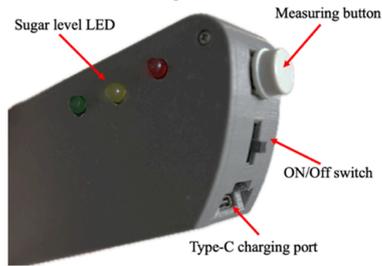


Fig. 10: ON/OFF switch, measuring button and Type-C charging port.

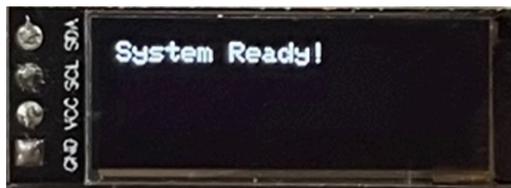


Fig. 11: The Status display shows “System Ready” when the prototype is ready to measure.

where EC_{hot} is a temperature-compensated conductivity of hot Americano ($\mu\text{S}/\text{cm}$), EC_{25} is conductivity of the Americano at 25°C ($1826.07 \mu\text{S}/\text{cm}$), and ΔT is the difference between the standard temperature (25°C) and the measured temperature ($^\circ\text{C}$).

In equation (13), it can be concluded that the EC of hot Americano changes 2.029% when its temperature changes 1°C .

According to equations (12) and (13), the temperature coefficients of hot and iced Americano are different. Therefore, the prototype needs to be designed to identify the type of Americano coffee with more accuracy.

4.3 The Prototype Working System

The discovered equations (12) and (13) are coded to a microcontroller (Arduino Nano Type-C) inside the prototype to separate the processing method into 2 types (hot and iced) of Americano.

When the switch located at the end of the prototype shown in Fig. 10 is ON, the sugar status LED will blink from green to red to check the device status. Then, the status display shows the message “System Ready” to enter standby mode shown in Fig. 11.

To measure sugar content, the user immerses the EC and temperature sensors in the target Americano coffee and presses the measurement button. The system first detects the coffee’s temperature to classify it as hot or iced. Based on this classification, it applies temperature compensation using Equation (12) or (13), then measures electrical conductivity. The result is displayed either on the screen or via an LED indicator within approximately 6–10 seconds.

Sugar levels are categorized according to WHO guidelines [7]: “Low” (1–10 g), “Normal” (11–15 g), and “High”



Fig. 12: The example of sugar level shown by the prototype.

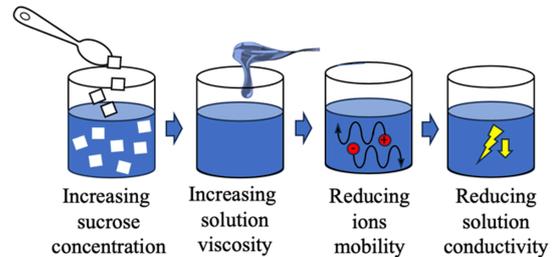


Fig. 13: Effect of sucrose concentration on electrical conductivity.

(≥ 16 g). The example is shown in Fig. 12.

4.4 The Prototype Accuracy Result

The performance of the sugar content measuring device for Americano coffee was evaluated based on its display range, using criteria adapted from the WHO to ensure comprehensive applicability.

The system first classifies the type of Americano coffee based on the reading temperature: $0\text{--}10^\circ\text{C}$ as iced (using equation 12), $50\text{--}100^\circ\text{C}$ as hot (using equation 13), and $11\text{--}49^\circ\text{C}$ as “Out of Range.”

To validate the prototype’s accuracy, both hot and iced Americano samples were prepared using a single shot of espresso (30 mL) mixed with 120mL of water, totalling 150mL. Sugar was added in known quantities ranging from 1 to 24 g. The device then measured sugar content in both coffee types, with each measurement repeated twice (T_1 and T_2). Results are presented in Tables 11 – 12, which indicate that the device is capable of accurately displaying sugar content within the specified range and can effectively differentiate between hot and iced Americano coffee based on temperature.

5. DISCUSSION

This discussion is organized into three sections according to the experimental findings, which are factors influencing TDS values, prototype calibration, and prototype accuracy.

According to factors influencing TDS values, to investigate the influence of water volume on TDS, measurements were performed using a TDS meter under laboratory conditions. As illustrated in Fig. 5, increasing the volume of pure water to 80 mL raised the TDS value from 331.6 to 335.8, reflecting a percentage increase of approximately 1.27% relative to the initial value. This

Table 11: The prototype results in an iced Americano.

Sugar content (g)	Temperature (°C)		Sugar status	Result
	T ₁	T ₂		
1	4.60	3.10	Low sugar	Correct
2	4.30	3.40	Low sugar	Correct
3	2.60	3.50	Low sugar	Correct
4	1.30	3.90	Low sugar	Correct
5	5.20	4.30	Low sugar	Correct
6	4.00	4.00	Low sugar	Correct
7	2.20	3.20	Low sugar	Correct
8	3.10	4.10	Low sugar	Correct
9	7.00	3.30	Low sugar	Correct
10	1.30	3.30	Low sugar	Correct
11	2.60	3.60	Normal sugar	Correct
12	2.50	4.50	Normal sugar	Correct
13	3.90	3.90	Normal sugar	Correct
14	2.90	2.60	Normal sugar	Correct
15	3.40	2.90	Normal sugar	Correct
16	3.60	4.40	High sugar	Correct
17	4.80	1.60	High sugar	Correct
18	3.30	1.50	High sugar	Correct
19	5.50	1.90	High sugar	Correct
20	4.10	2.50	High sugar	Correct
21	3.30	3.50	High sugar	Correct
22	2.80	1.70	High sugar	Correct
23	5.30	2.10	High sugar	Correct
24	4.40	3.40	High sugar	Correct

Table 12: The prototype results in a hot Americano.

Sugar content (g)	Temperature (°C)		Sugar status	Result
	T ₁	T ₂		
1	60.60	71.00	Low sugar	Correct
2	62.70	71.50	Low sugar	Correct
3	74.60	67.10	Low sugar	Correct
4	75.00	64.80	Low sugar	Correct
5	61.60	52.00	Low sugar	Correct
6	70.40	50.60	Low sugar	Correct
7	63.60	65.50	Low sugar	Correct
8	60.10	62.40	Low sugar	Correct
9	63.70	71.10	Low sugar	Correct
10	64.20	64.60	Low sugar	Correct
11	61.20	71.00	Normal sugar	Correct
12	61.50	71.20	Normal sugar	Correct
13	69.60	60.50	Normal sugar	Correct
14	70.50	62.30	Normal sugar	Correct
15	70.80	61.10	Normal sugar	Correct
16	69.40	70.20	High sugar	Correct
17	67.00	76.90	High sugar	Correct
18	58.90	68.00	High sugar	Correct
19	68.60	69.90	High sugar	Correct
20	50.60	71.20	High sugar	Correct
21	71.70	62.60	High sugar	Correct
22	62.00	73.10	High sugar	Correct
23	60.50	61.30	High sugar	Correct
24	60.90	71.80	High sugar	Correct

suggests that while the effect of water volume variation on TDS is minor, it remains quantifiable.

Further analysis of Tables 2 and 3 indicates that the concentration of pure coffee (Espresso) has a negligible impact on TDS, and that the temperature of the Espresso shot only marginally alters the TDS reading. When Espresso was diluted with varying amounts of water to form Americano coffee, a clear inverse relationship was observed between coffee concentration and TDS (Fig. 6). This can be attributed to the dilution effect: as

concentration decreases, the number of dissolved solids per unit volume also decreases, thereby lowering TDS.

A final critical variable is the dissolved sugar (sucrose) concentration. As shown in Fig. 7, sugar concentration exhibits an inverse relationship with TDS. Because sucrose does not dissociate into ions in aqueous solution, it does not directly contribute to conductivity-based TDS measurements. However, increased sugar concentration elevates the viscosity of the solution, impeding ion mobility and reducing conductivity. This process is shown in Fig. 13.

Consequently, the TDS value decreases with higher sugar content. This trend is further demonstrated in Fig. 8, where incremental additions of sugar to Americano coffee result in lower TDS values.

In prototype calibration, it addresses the derivation of a temperature compensation equation for the prototype device. Temperature is a major factor influencing electrical conductivity and must be accounted for, particularly given the significant thermal disparity between hot and iced Americano. Without compensation, measurements may be prone to error. The experimental outcomes led to the development of two separate temperature compensation equations, each tailored for either hot or iced Americano coffee, to ensure consistent measurement accuracy across temperature ranges.

The accuracy of the prototype was assessed following calibration and integration of the temperature compensation model. The device was used to measure sugar content in both hot and iced Americano coffee, with two trials conducted for each. Results indicated that the prototype reliably produced accurate readings. However, the device currently requires 6–10 seconds to complete data processing due to the computational load. Future iterations should incorporate a higher-performance microcontroller to improve processing efficiency. Additionally, enhancing the system to report sugar content in grams would improve resolution. Finally, more ingredients affecting to viscosity and conductivity should be developed in the next model.

6. CONCLUSION

A portable device was developed to measure sugar content in Americano coffee using electrical conductivity with temperature compensation. Key variables affecting TDS, such as water volume and sugar concentration, were experimentally evaluated. The calibrated prototype accurately identified coffee type (hot or iced) and classified sugar levels in line with WHO guidelines. Validation showed reliable performance across a wide sugar range. Though processing takes 6–10 seconds, future improvements may enhance speed and precision. This device offers a practical solution for monitoring sugar intake in coffee.

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