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Analysis of urine pH measurement using Arduino UNO-based pH Sensor

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ABSTRACT

Naturally, humans possess excretory organs that function to eliminate metabolic waste products. Urine is one of the fluids resulting from metabolic waste in the body. Urine can serve as an indicator of actual body condition. Urine pH measurement is one of the easily accessible methods for determining the body's acid-base balance. The pH meter system for urine pH detection was constructed using a pH V1.1 sensor as hardware with Arduino Uno assistance as both hardware and software for program processing. This research focuses on designing a device to determine urine pH levels using the Research and Development (R&D) pH meter method. Device calibration using buffer solutions with pH values of 4.01, 6.86, and 9.18 yielded a device error value of 0.11% and standard deviation (S) = 0.0091. Testing was also conducted using 30 human urine samples from subjects aged 16 to 40 years. The tested urine samples were 100 ml each, with results showing pH values ranging from 4.86 to 6.97. The standard deviation (S) for urine sample testing was 0.081. The difference in standard deviation values between calibration and urine samples was attributed to probe cleanliness on the pH meter, emphasizing the importance of probe cleanliness when switching between samples.

Keywords:
Arduino Uno, pH Meter, Urine

Introduction

Naturally, humans possess excretory organs that function to eliminate metabolic waste products (Halis, 2017). Urine is one of the fluids resulting from metabolic waste in the body. Urine formation occurs in the kidney organs (Perdani, 2019). Kidney disease ranks as the 9th leading cause of death in the United States with a global prevalence of 10% to 26% (Chaudhari et al., 2017). The urine formation process is divided into three stages: filtration at the glomerulus, reabsorption and secretion at the tubules (Halis, 2017). Urine is a complex solution consisting of water, organic materials such as urea, creatinine, and uric acid, as well as inorganic materials such as sulfate, phosphate, and NaCl (Perdani, 2019). Urinary Tract Infection (UTI) is the second most common disease in the United States caused by pathogenic bacteria. Nearly 8.1 million healthcare visits annually are attributed to this disease (Seo et al., 2017). GC-MS analysis of urine samples can be used as biomarkers for early detection of bladder cancer (Zhu et al., 2019).

Urine can serve as an indicator of actual body condition. The abundance of information obtained from urine samples has led to more than 100 different types of tests being performed on urine (Halis, 2017). Urine pH in normal humans typically ranges from 4.6 to 8.0, though most commonly around 6.0 or in an acidic state (Tuah et al., 2016). Fresh urine has a pH of 6 to 7, while after urine hydrolysis, the pH changes to 9.25 (Chipako & Randall, 2020). Urine pH is also an important factor related to kidney stone disease, with urine pH $\leq$ 5.5 capable of forming anhydrate crystals (Grases et al., 2014). Accurate and precise urine pH measurement is the first step in preventing future kidney stone disease (Abbott et al., 2017). Urine pH measurement is one of the easily accessible methods for determining the body's acid-base balance (Widyastuti et al., 2013). Urine pH monitoring can also be used as an indicator for determining sugar levels in urine (Hidayat et al., 2020). In patients with kidney stone disease, to prevent crystallization, urine pH must be monitored accurately and targeted between 5.8 to 6.2 to prevent ammonium urate and carbonate apatite stones (De Coninck et al., 2018).

Current urinalysis methods consist of microscopic (sediment), macroscopic, and chemical examination of urine (Tuah et al., 2016). Urinalysis plays an important role in early detection of kidney disorders and urinary tract diseases (Hekmatynia et al., 2019). In urine examination, urinary dipstick and pH meter are two frequently used methods (Afsahi et al., 2020). pH is one of the chemical examinations of urine (Tuah et al., 2016). pH represents the concentration of hydrogen ions in solution to express the acidity or basicity level of the solution (Ngafifuddin et al., 2017). The pH concept was first introduced by Danish scientist Søren Peder Lauritz Sørensen, a chemist, in 1909 (Azmi et al., 2016). pH is also defined as the negative logarithm of hydrogen activity in aqueous solvent, which is a dimensionless quantity (Sinaga, 2012) with the following formula: pH = -log (H^+). Solutions with pH less than 7 are called acidic solutions, while basic solutions have pH greater than 7, and neutral solutions have pH = 7 (Wibowo & Ali, 2020).

There are two common methods used to measure the pH level of a solution: litmus paper and pH meter (Sinaga, 2012). The difference between these two instruments lies in display and measurement accuracy (Wibowo & Ali, 2020). Litmus paper has an output in the form of color changes for each pH measurement performed (Sinaga, 2012). This method is less accurate because the output produced is an approximation approaching the pH value (Sinaga, 2012). Meanwhile, a pH meter is a modern pH measurement instrument with digital display output (Sinaga, 2012). pH meters work on the basic principle of glass electrodes (Fajrin et al., 2020). pH meters operate using electrochemical potential that occurs between the solution inside the glass electrode and the external glass electrode of unknown composition (Barus et al., 2018). The main working principle of pH meters lies in the probe sensor in the form of a glass electrode. There is a 0.1 mm thick glass layer at the tip of the glass electrode shaped like a bulb. This bulb is fitted with a non-conductive glass cylinder filled with HCl solution. There is a silver electrode wire whose surface forms a balanced AgCl compound. The core of this pH sensor lies in the glass bulb surface that has the ability to exchange positive ions (H^+) with the measured solution (Azmi et al., 2016). However, there are several factors that make pH meter measurement less attractive: requiring routine calibration before use, needing to be kept away from liquids when not in use to extend electrode life, and requiring special training for operation (Kwong et al., 2013).

pH meter research has been extensively conducted, such as research by Ihsanto and Hidayat (2014) on creating a pH measurement device using Arduino Uno, with results showing the designed device capable of detecting pH from 1 to 9 with 0.01 resolution. Research by Azmi et al. (2016) on creating a microcontroller-based pH meter for fish ponds, with results showing the device operates based on 3 pH categories: acidic pH (0 to 6.4) with buzzer sounding 3 times, neutral pH (6.5 to 7.5) with buzzer sounding 2 times, basic pH (7.6 to 14) with buzzer sounding once. Research by Ngafifuddin et al. (2017) on creating an Arduino-based pH meter for X-ray radiography film washing machines, with results showing the pH meter using E-201C sensor can measure pH values from 1.6 to 11 with 0.01 resolution and 99% accuracy. Research by Rozaq and Setyaningsih (2018) on pH sensor calibration PKU SEN 0161 showed that the correlation between ADC values and measuring instruments was very strong (0.9895489) and the device had 99.86% accuracy. Research by Mukhlizar et al. (2019) on creating a microcontroller-based water turbidity and pH measurement device, with results showing the designed device can operate at 12 volts and maximum current of 4 amperes with relative error below 1%. Research by Rahmania et al. (2018) on Arduino Uno-based pH meter design resulted in a pH meter with 10% error value obtained during pH measurement at 40°C. Research by Lamidi et al. (2019) on diabetes mellitus and dehydration detection device based on urine conditions using artificial neural network methods, with results showing the device capable of detecting desired conditions with 80% accuracy and requiring an average of 2.03 seconds for processing. Research by Fajrin et al. (2020) on Arduino-based pH meter resulted in a device capable of operating well with error below 1.5%. Based on the above description and research, researchers finally conducted research titled "Analysis of Urine pH Measurement Using Arduino Uno-Based pH Sensor." This research is limited to pH meter device design using pH V1.1 sensor and brief simulation using urine samples. This research aims to create a urine pH detection device using pH V1.1 sensor.

Methods

The pH meter system for urine pH detection was constructed using a pH V1.1 sensor as hardware with Arduino Uno assistance as both hardware and software for program processing. This research focuses on designing a device to determine urine pH levels. This research is Research and Development (R&D)

(Rozaq & Setyaningsih, 2018) in nature, creating software on Arduino Uno to obtain pH output values and comparing them with established references to evaluate device performance.

Instruments and Materials

The instruments used in this research were pH probe, pH V1.1 sensor module, and Arduino UNO. The materials used in this research were buffer solution pH 4.01, buffer solution pH 6.86, buffer solution pH 9.18, and 30 urine samples.

Research Procedure

The initial stage of this research was assembling or creating a pH meter by connecting the pH V1.1 sensor, pH meter module, and Arduino UNO into one unit using connecting cables and soldering. The next step involved subjecting the assembled device to calibration testing using calibration solutions to determine the device's error value. The calibration solutions used were buffer solutions with pH 4.01, 6.86, and 9.18. These solutions were obtained by dissolving 250 ml of distilled water with pH powder of 4.01, 6.86, and 9.18. The maximum expected error value from the constructed pH meter was ≤ 10%. If the obtained error value exceeded the set limit, the device had to be reconstructed until meeting the predetermined requirements.

The subsequent stage, after the error value was below the maximum limit, involved data collection using 30 prepared urine samples. These urine samples were random human urine samples from subjects aged 16 to 40 years. The urine samples used were 100 ml each as shown in Figure 1, with data collection performed 5 times.

Figure 1. Urine Samples - showing the 100ml urine sample containers

Results and Discussion

Based on the conducted research, the designed pH meter device is shown in Figure 2. The device consists of a probe used to detect urine pH levels and Arduino UNO (in black box) used for data processing.

Figure 2. pH Meter - showing the assembled device with probe and Arduino unit

Table 1. Calibration Test Results

Sample (pH)	Results (pH)					Average (pH)	Difference (pH)
	I	II	III	IV	V		
4.01	3.89	3.92	3.90	3.90	3.90	3.90	0.11
6.86	6.95	6.96	6.95	6.94	6.94	6.95	0.09
9.18	9.05	9.06	9.07	9.07	9.05	9.06	0.12

Device calibration testing using buffer solutions produced data as shown in Table 1. Based on Table 1, calculations can be performed to determine the device's error percentage using the following equation:

$$\frac{\text{Difference}}{\text{Number of Samples}} \times 100\% \quad (1)$$

Device calibration results showed an error value of 0.11%, giving the device an accuracy of 99.89%. Another condition observed was device stability in data reading. Device stability can be obtained through calculations using the following equation:

$$S = \sqrt{\frac{\sum(X_i - X)^2}{N-1}} \quad (2)$$

where S is standard deviation, Xi is the device reading value, X is the average reading result, and N is the number of experiments. The obtained result was S = 0.0091.

Based on the device calibration test results, the device is suitable for use as it remains below the error threshold (10%) (Mukhlizar et al., 2019), allowing continuation with testing using prepared urine samples, with results shown in Table 2.

Based on Table 2 samples, the total number of samples was 30 human urine samples consisting of 12 male samples and 18 female samples aged 16-40 years. The urine samples used in this research were random urine samples, as random urine samples are good samples for determining urine pH, clarity, bilirubin, and color. Meanwhile, morning urine is typically used in laboratory examinations to determine protein, specific gravity, and sediment (Septyasri, 2012).

Research involving urine samples must be conducted carefully, quickly, and accurately. Septyasri (2012) stated that research using urine pH as the object needs to consider several factors that must be controlled, including urine volume, BMI, dietary intake, and kidney function. The kidney is an organ that functions as a human body stabilizer (Febryansah et al., 2020). Healthy adult kidneys have 1 million nephrons per kidney that function to produce urine and filter blood to reclaim beneficial substances back into the bloodstream (Halis, 2017). Urine samples can also provide information about internal organ function such as: urinary tract, kidneys, cortex, adrenal glands, pancreas, asymptomatic abnormalities, and body metabolism (Perdani, 2019). Body metabolic conditions can be related to acid-base balance in the body. Quoting Welch's statement, blood and urine pH are markers that can represent acid-base balance in the body (Shafira et al., 2018).

Acid-base balance relates to the regulation of free hydrogen ion concentration in the body. Decreased urine pH levels indicate that the body is experiencing metabolic acidosis, which is an acid-base balance disorder characterized by decreased blood pH as a result of low bicarbonate levels in the blood (Widyastuti et al., 2013). Urine pH varies throughout the day. This condition is influenced by the consumption of basic foods after eating, and morning urine tends to be more acidic (Septyasri, 2012). Diet also has a significant impact on urine pH. When the body lacks water consumption and has high calcium levels in consumed water, it can affect pH and cause urinary tract stones (Septyasri, 2012). In diabetes mellitus patients, insufficient insulin conditions will hinder normal glucose utilization and cause urine to tend toward acidity (Tuah et al., 2016). Acidic urine (pH ≤ 5.5) is also a factor in uric acid stone formation (Widyastuti et al., 2013). Urine with kidney stone abnormalities also tends to have pH levels ≤ 5.5 and ≥ 7.5 (Febryansah et al., 2020).

Based on Table 2, the displayed urine pH values are still within normal urine pH range; however, 10 results indicate possible diabetes mellitus, uric acid stones, and kidney stone abnormalities due to having pH ≤ 5.5. Urine sample testing was also repeated 5 times, so using Equation 3, a data collection standard deviation (S) of 0.081 was obtained, resulting in device accuracy and stability in reading pH from urine samples of 99.919%. The difference in standard deviation values obtained from calibration and urine samples was caused by differences in sample types and quantities. Urine samples contain more minerals, proteins, and other contents compared to buffer solutions used during calibration. Additionally, urine samples were more numerous, requiring greater attention to probe cleanliness on the pH meter during sample transitions.

Table 2. Urine Sample Testing Results

Name	Results (pH)					Average (pH)
	I	II	III	IV	V	
Sampel 1	5.51	5.52	5.52	5.52	5.51	5.52
Sampel 2	6.27	6.28	6.28	6.26	6.28	6.27
Sampel 3	4.98	4.99	4.99	4.98	4.98	4.98
Sampel 4	5.32	5.32	5.32	5.32	5.32	5.32
Sampel 5	5.50	5.32	5.48	5.32	5.32	5.39
Sampel 6	6.97	6.97	6.97	6.97	6.96	6.97
Sampel 7	5.90	6.01	6.03	6.01	6.01	5.99
Sampel 8	5.04	5.09	5.05	5.05	5.05	5.06
Sampel 9	5.38	5.38	5.38	5.38	5.38	5.38
Sampel 10	4.84	4.84	4.90	4.85	4.85	4.86
Sampel 11	5.80	5.82	5.75	5.73	5.77	5.77
Sampel 12	5.79	5.75	5.75	5.79	5.79	5.77
Sampel 13	6.58	6.64	6.42	6.50	6.50	6.53
Sampel 14	5.46	5.49	5.50	5.49	5.49	5.49
Sampel 15	5.91	5.91	5.90	5.91	5.91	5.91
Sampel 16	5.40	5.44	4.40	5.40	5.41	5.21
Sampel 17	5.42	5.42	5.42	5.42	5.42	5.42
Sampel 18	6.14	6.14	6.19	6.14	6.18	6.16
Sampel 19	5.81	5.81	5.81	5.81	5.80	5.81
Sampel 20	4.98	4.98	4.98	5.05	5.05	5.01
Sampel 21	6.07	6.09	6.07	6.07	6.08	6.08
Sampel 22	5.73	5.77	5.75	5.73	5.73	5.74
Sampel 23	5.84	5.82	5.75	5.73	5.77	5.78
Sampel 24	6.50	6.58	6.64	6.42	6.67	6.56
Sampel 25	6.01	5.98	5.99	5.98	5.99	5.99
Sampel 26	5.51	5.51	5.51	5.51	5.51	5.51
Sampel 27	5.39	5.37	5.45	5.38	5.37	5.39
Sampel 28	5.78	5.80	5.82	5.82	5.82	5.81
Sampel 29	6.36	6.36	6.33	6.36	6.34	6.35
Sampel 30	5.84	5.84	5.81	5.81	5.80	5.82

Conclusion

The constructed device can be used for urine pH testing. This condition is demonstrated by the device's error range of 0.11% and deviation in calibration samples (S) of 0.0091. When tested directly with urine samples, the results showed pH values ranging from 4.86 to 6.97 with reading deviation (S) of 0.081. These conditions are still within normal urine pH range; however, 10 samples were at risk of experiencing diabetes mellitus, uric acid stones, or kidney stones due to having pH ≤ 5.5. The difference in standard deviation values between calibration and urine samples was caused by probe cleanliness on the pH meter, emphasizing the importance of probe cleanliness when switching between samples.

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Conflicts of interest

The authors affirm that they have no conflicts of interest.

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