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Design of Urinalysis Device for Early Diagnosis of Disease Using Internet of Things-Based Sensors

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Abstract: Health is one of the most important things in life, which is why there have been many scientific discoveries in the form of medicines, medical devices, and new inventions in the field of health. Despite advances in health technology, health challenges remain a global issue, especially those related to diseases of the urinary tract and kidneys. Therefore, this study aims to detect diseases early through urine color and pH analysis using a TCS3200 sensor and an E-201C pH sensor. This device is designed to perform preliminary checks and identify risk levels based on urine color and pH characteristics associated with various urinary tract and kidney conditions, such as dehydration, kidney stones, kidney failure, and urinary tract infections. The results provided by this device are intended to support the clinical decisions of healthcare professionals and are not intended as a standalone diagnostic tool. The method used is engineering research, which includes hardware and software design, prototype development, and testing of the research device. The measurement results are displayed on an LCD and the Blynk application via NodeMCU ESP32. The test results show that the color sensor is able to classify urine color accurately, while the pH sensor has an average accuracy of 99.90% and a precision of 99.40%.

Keywords: Urinalysis, pH, color, disease, IoT.

1. Introduction

Health is one of the most important things in human life, which is the basis for the discovery of many scientific findings in the form of medicines, medical devices, or new discoveries in the field of health [1]. Physics, as a basic science that studies the laws of nature and the properties of matter, has made a significant contribution to this transformation, particularly through the development of medical instrumentation, sensor technology, and precision electronic systems [2]. The fields of electronics and physics instrumentation have become the backbone in creating more accurate, portable, and affordable medical devices, thereby expanding public access to quality health services.

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Despite ongoing advances in health technology, health challenges remain a global issue, particularly those related to urinary tract diseases, dehydration, and kidney problems. The incidence of diseases such as urinary tract infections and kidney disorders is relatively high. One way to detect these diseases early is through urine testing, particularly by observing its color and pH level. The more striking the color of the urine, the greater the possibility of a disorder in the human transport system. The kidneys affect the color of human urine, whether it is red or black [3].

According to [4], Urinary tract infections (UTIs) occur when microorganisms infect parts of the urinary system, such as the ureters, kidneys, bladder, or urethra, and their presence can be detected through urine. Urinary tract infections often occur in girls and women. One of the causes is that women have a shorter urethra, making it easier for contaminating bacteria to gain access to the bladder (5). People who are indicated to have a urinary tract infection can be identified by the characteristics of their urine. The urine of sufferers generally appears red or milky white, with an acidity level (pH) between 5.5 and 9.0 [6]. The next health problem is kidney disease, which includes various conditions such as kidney stones (nephrolithiasis) and kidney failure. Kidney stones (nephrolithiasis) are hard materials formed in the kidneys, such as stones derived from minerals and salts. Kidney stones can occur in the kidneys, ureters, bladder, and urethra. Kidney stones originate from waste in the blood that crystallizes and accumulates in the kidneys [7]. Indications of kidney stones can be seen from reddish urine with an acidity level (pH) outside the normal range, which is less than 5.5 or more than 7.5 [8]. Meanwhile, Chronic Kidney Disease (CKD) is a progressive disorder of kidney function that can be long-term or persistent, causing the accumulation of metabolic waste and preventing the kidneys from fulfilling their normal needs [9]. One of the signs of kidney failure is brown urine accompanied by low acidity (pH), which is below 5.5 [8]. Finally, the last health problem is dehydration. Dehydration is a lack of fluid in the body due to the amount excreted being greater than the amount taken in [10]. In people who are adequately hydrated, urine is usually clear or light yellow in color. However, in people who are dehydrated, urine can become more concentrated and even turn dark yellow or brownish in color with an acidity level (pH) ranging from 4.0 to 6.0 [11].

Early detection plays a very important and strategic role in efforts to reduce mortality rates from various diseases. Diagnosis at an early stage of disease development provides a greater chance of successful treatment and prevents more serious complications. One easy method of examination is urine analysis or a urine test. Urine analysis is a medical procedure that allows for the assessment of a person's health through a comprehensive analysis of various parameters contained in a urine sample [12]. The development of digital technology and the Internet of Things (IoT) is known as digital health. IoT itself is a system that connects various physical devices such as sensors and other electronic devices that can exchange data with each other via an internet connection [13]. Previous studies have developed urinalysis tools, but they still have several limitations. The limitations of the tools in previous studies include only being able to measure one disease and only using one measurement parameter, namely the color of urine.

This study aims to design and build a more accurate urine analysis tool system integrated with IoT for early disease diagnosis. This system combines two main sensors as the main parameters of the study, namely the TCS3200 color sensor to detect variations in urine color and the E-201C pH sensor to measure acidity levels, which are controlled by the NodeMCU ESP32 microcontroller. Data from the sensors will be processed using a classification algorithm developed based on medical theory references to indicate possible diseases such as urinary tract infections (UTIs), kidney disorders (kidney stones and chronic kidney failure), and dehydration. The analysis results are then sent to the Blynk application on a smartphone via a Wi-Fi connection, allowing users or medical personnel to monitor conditions. The system is also equipped with a local LCD screen to display the results on site.

2. Materials and Method

The type of research conducted is classified as engineering research. Engineering research is a design activity that leads to new contributions in every activity, both in the form of processes and products/prototypes. In this research, the design activities involved relatively new aspects [14]. The research procedure covers various steps, ranging from the development of ideas and task descriptions, concept design, functional geometry compilation, detailed design, prototype creation, to the testing stage. The design of this urinalysis device consists of two main parts, namely hardware design and software design. Hardware design includes the physical design of devices consisting of several components such as microcontrollers, sensors, displays, LCD, and sample bottles. Meanwhile, software design includes the design of programs such as display programs and sensor programs. The language used in creating these programs is C. The block diagram of this urinalysis system can be seen in Figure 1.

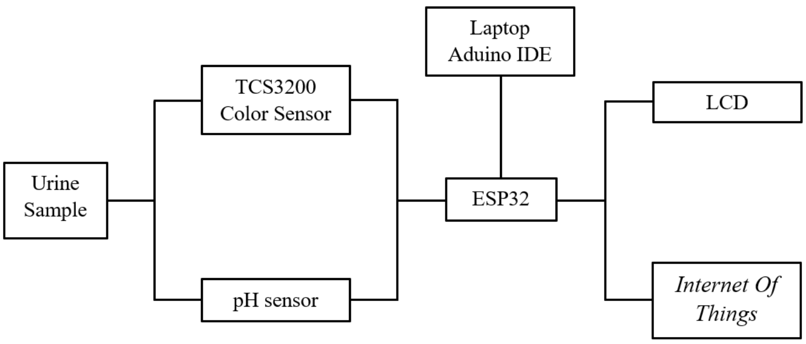


Figure 1. Block Diagram of Urinalysis System

From Figure 1, it can be seen that urine samples are measured using a TCS3200 color sensor and a pH sensor. Data from both sensors is processed by ESP32, then the results are displayed on an LCD screen. The entire program is controlled via a laptop using Arduino IDE, and this system is also connected to the Internet of Things (IoT) network to enable remote monitoring.

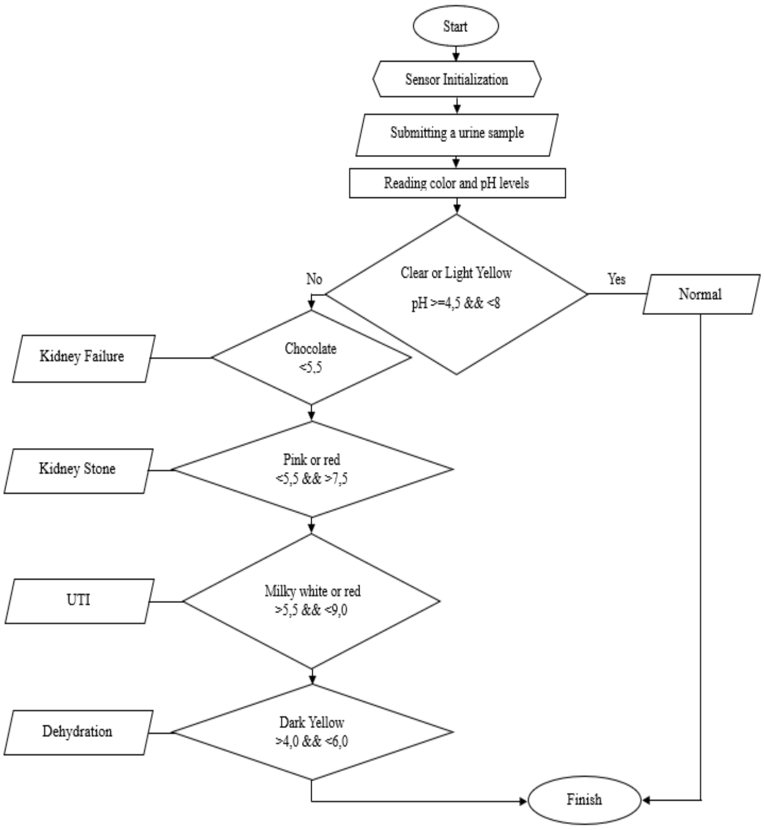


Figure 2. Flowchart of Urinalysis System

Figure 2 illustrates the workflow of the health disorder detection system based on urine color and pH analysis using sensors. The process begins with sensor initialization, followed by inserting the urine sample into the device. After that, the sensor will read the color and pH level of the urine. The next step is to check whether the urine is clear and has a pH between 4.5 and 8. If so, the result is considered normal and the process ends. However, if it does not meet the normal criteria, the examination continues to detect possible diseases. This flowchart helps in the early detection of several health conditions based on urine color and pH parameters.

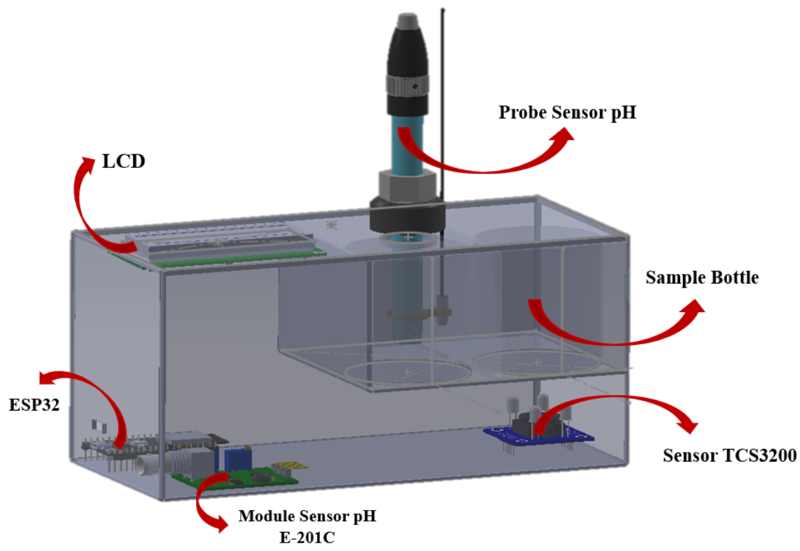


Figure 3. Design of Urinalysis

Based on Figure 3, the initial design of the urine analysis device consists of several components, such as the TCS3200 Sensor, E-210C pH Sensor, and NodeMCU ESP32. The device's output will be displayed on an LCD screen and smartphone. The TCS3200 sensor in the device functions to detect color in urine. The pH sensor is used to detect pH in urine. Then, the NodeMCU ESP32 acts as the brain to control and optimize sensor functions. The device's output results will be displayed on an LCD screen and a smartphone application.

The data collection technique involves measuring each research parameter using different urine samples. The measurement results read by the research are displayed on the device's LCD screen and on the Blynk application display on a smartphone screen. Then, the performance testing technique on the device consists of data analysis used to determine the accuracy and precision of the research device, proving that the device works well. However, before testing the device, several components such as the TCS3200 sensor and the E-201C pH sensor need to be characterized. This serves to improve the accuracy and precision of the sensors in testing the research device. After characterizing these components, the device will be tested using several samples by collecting test data generated by the research device and then analyzing the experimental data to draw conclusions about the measurement system.

3. Results and Discussion

Based on the research that has been conducted, the specifications of the urinalysis device have been obtained. The specifications of the device are in the form of performance specifications and design specifications. The performance specifications of the device can be obtained through the identification of the functions of each system component, followed by characterization testing and sensor analysis to optimize performance. The design specifications are determined based on the measurement data from the urinalysis device.

Performance specifications are determined through the mechanical design of the device, its electronic circuitry, and the characterization of its color and pH sensors. The device's mechanism can be developed to produce a urinalysis device that can detect more than one disease, and the results can be displayed not only on an LCD screen but also on a smartphone via the Blynk app and monitored remotely. The urinalysis device consists of several electronic components, with NodeMCU ESP32 as the brain to control and optimize sensor functions. This device is equipped with two sensors, namely the TCS3200 sensor to detect urine color and the E-201C pH sensor to measure the acidity or pH level in urine.

The first experiment tested the accuracy of the TCS3200 sensor before it was used to detect colors in urine. This was done to ensure that the sensor worked properly and did not cause reading errors in detecting a disease in a person. Based on the test, the accuracy data from the TCS3200 sensor can be seen in Table 1.

Table 1. Characterization of the TCS3200 Sensor

Indicator	**Output sensor**			**Theory**		
	R	**G**	**B**	**R**	**G**	**B**
White	255	251	253	255	255	255
Red	252	21	9	255	0	0
Green	8	253	39	0	255	0
Blue	22	10	255	0	0	255
Yellow	252	248	8	255	255	0

Based on Table 1, a comparison between the output values of the TCS3200 sensor and the theoretical values can be seen. The table shows that the R, G, and B values read by the sensor for white, red, green, blue, and yellow are very close to the theoretical values for each color. This indicates that the color sensor is functioning properly because the sensor provides values that are close to the theory.

Next, conduct a pH sensor reading test. This is done to see the relationship between the output value on the pH sensor and the actual pH. The results of this test are represented in a graph that can be seen in Figure 2.

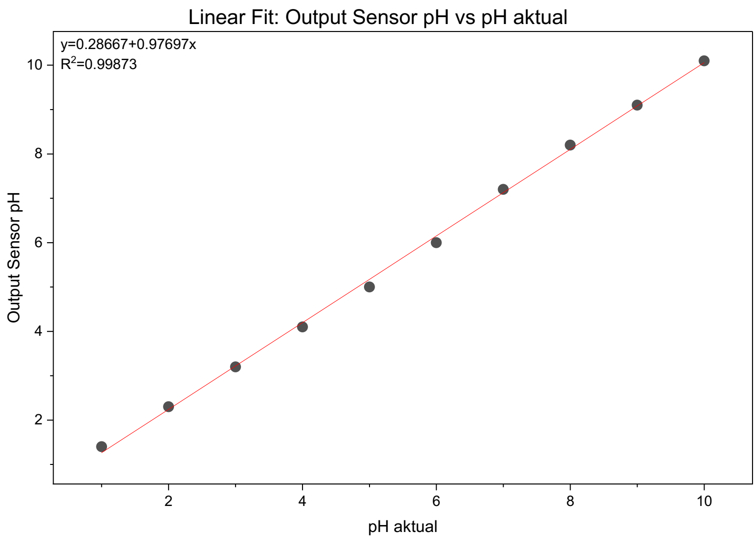
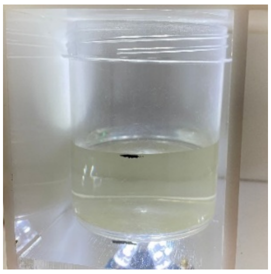
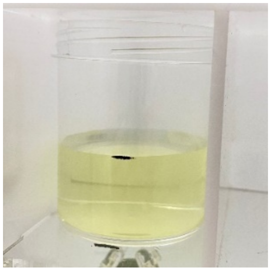
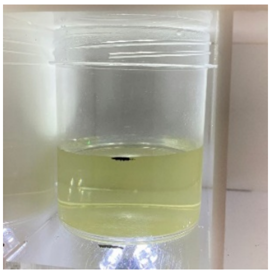


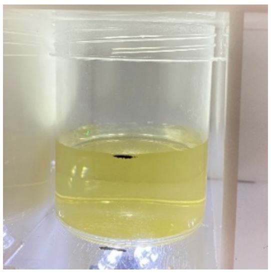
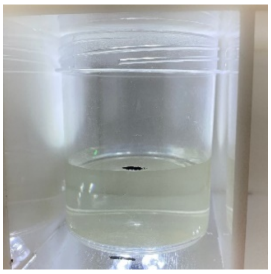
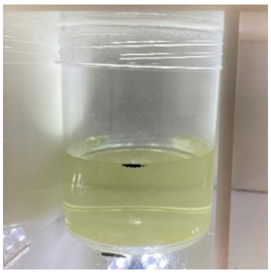
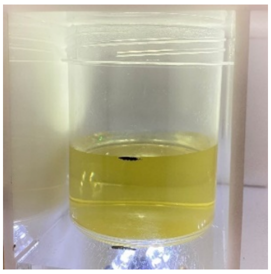
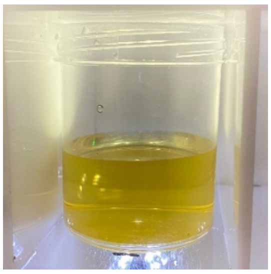
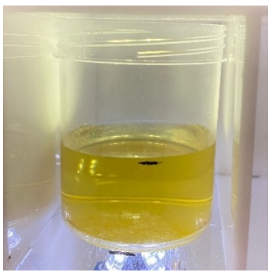
Figure 4. Characteristics of the E-201C pH sensor

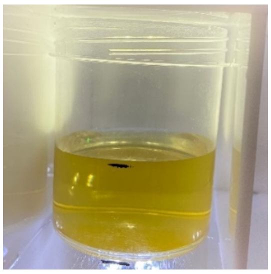
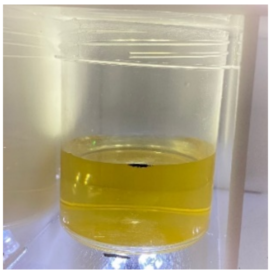
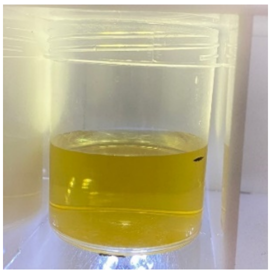
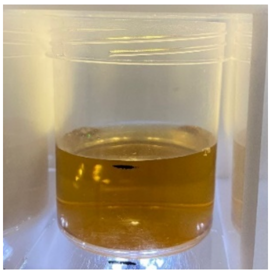
Based on Figure 18, it can be seen that the y-axis is the pH value of the standard device and the x-axis is the pH sensor output value. From the graph produced, the sensor output is directly proportional to the standard device. The R^2 value obtained from the sensor using the equation $y = a + bx$ is 0.99873, which indicates that the data produced by the sensor is quite good and accurate.

The design specifications are determined based on measurement data from research. Data is obtained from sensors and monitored through two interfaces: the Blynk application (for remote monitoring) and a serial monitor (for direct data logging). This system uses two sensors that measure two parameters, namely color and pH. The design specifications identified in this system include the accuracy and precision of the tools. Accuracy is the degree of conformity or closeness of a measurement result to the true value. The accuracy data of the TCS3200 sensor was obtained from the measurement results on the device compared with the color theory study that explains the indication of disease in each urine color. The measurement results of the TCS3200 sensor accuracy can be seen in Table 2.

Table 2. TCS3200 Sensor Accuracy Measurement Results

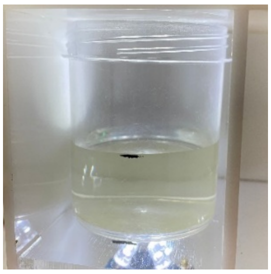
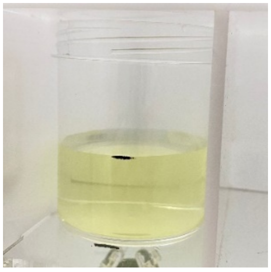
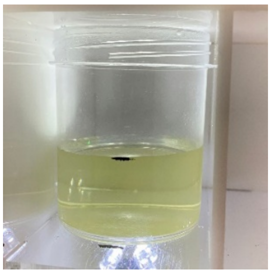
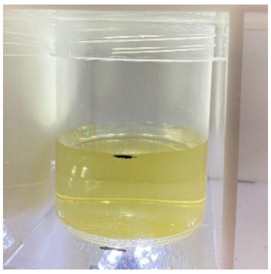
No	**Sample**	**RGB Value from Sensor**			**Reading**	**Accuracy**
		R	**G**	**B**		
1		56	60	44	Clear	Suitable
2		56	60	46	Light Yellow	Suitable
3		57	61	47	Light Yellow	Suitable

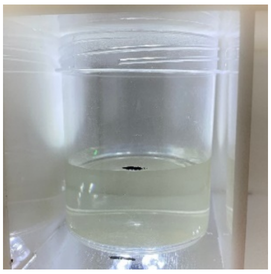
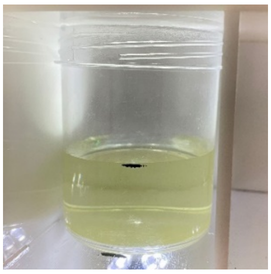
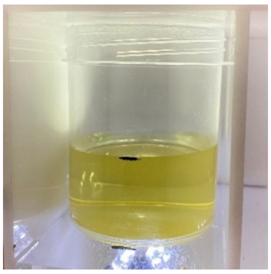
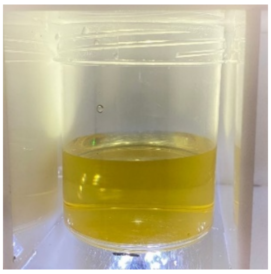
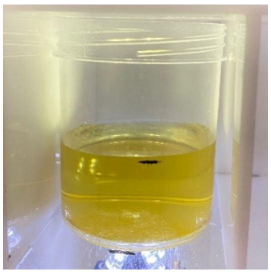
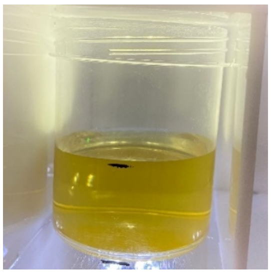
4		58	64	49	Light Yellow	Suitable
5		57	60	44	Clear	Suitable
6		56	59	45	Light Yellow	Suitable
7		59	67	51	Dark Yellow	Suitable
8		60	69	53	Dark Yellow	Suitable
9		62	71	54	Dark Yellow	Suitable

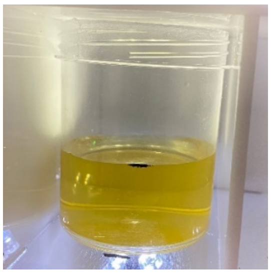
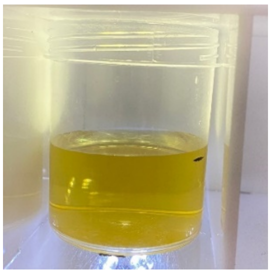
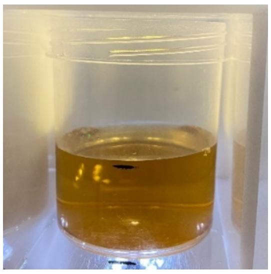
10		61	70	54	Dark Yellow	Suitable
11		60	68	53	Dark Yellow	Suitable
12		61	71	55	Dark Yellow	Suitable
13		72	85	62	Red	Suitable
14		68	80	60	Chocolate	Suitable
15		46	39	28	White Milk	Suitable

Based on Table 2, the sensor shows excellent accuracy. This is proven by conducting 15 measurement trials with no color reading errors in any urine sample. This proves that the sensor can work and function properly. Furthermore, the data from the pH sensor accuracy test results are presented in Table 3.

Table 3. Measurement Results of the Accuracy of the E-201C pH Sensor

No	Sample	pH Meter	pH Sensor	Difference	Accuracy (%)
1		5,9	5,9	0	100
2		6,42	6,41	0,01	99,84
3		6,38	6,37	0,01	99,84
4		5,63	5,62	0,01	99,82

5		6,73	6,73	0	100
6		5,28	5,27	0,01	99,81
7		4,76	4,75	0,01	99,86
8		5,5	5,5	0	100
9		5,71	5,7	0,01	99,82
10		5,58	5,57	0,01	99,82

11		5,4	5,4	0	100
12		5,31	5,3	0,01	99,81
13		4,71	4,7	0,01	99,78
14		5,44	5,44	0	100
15		6	6	0	100
		Average		0,006	99,89

Based on Table 3, the sensor shows excellent accuracy. This is proven by the measurement results of the experimental device matching the output of the standard device. From 15 measurement trials, the average accuracy value of the experimental device was obtained. The average accuracy value obtained was high, at 99.89%. This proves that the pH values measured by the experimental device are not significantly different from the pH values measured using the standard device.

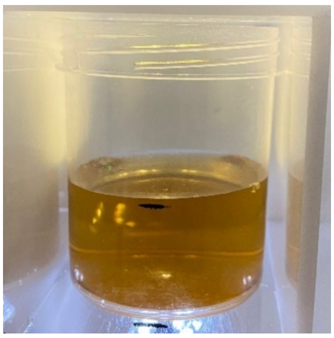
Precision is a measure of the ability to obtain similar measurement results under the same conditions. The precision data for the TCS3200 sensor was obtained from repeated measurements using the same sample. Testing the precision of the TCS3200 sensor aims to ensure that this sensor not only produces accurate readings, but is also consistent and stable in long-term use. The measurement data for the precision of the TCS3200 sensor can be seen in Table 4.

Table 4. Precision of the TCS3200 Sensor

Experiment	Sample	RGB Value from Sensor			Reading	description
		R	G	B		
1		73	85	62	Red	Suitable
2		71	85	62	Red	Suitable
3		72	85	62	Red	Suitable
4		71	86	62	Red	Suitable
5		73	85	62	Red	Suitable
6		72	86	62	Red	Suitable
7		72	85	62	Red	Suitable
8		72	85	62	Red	Suitable
9		71	85	62	Red	Suitable
10		72	86	62	Red	Suitable

Based on Table 4, 10 repeated measurement experiments were conducted. Each experiment showed high precision, as evidenced by the absence of color reading errors in each repeated reading of the urine samples. This indicates that the sensor is working and functioning properly. The results of the pH sensor precision test are presented in Table 5.

Table 5. Precision of the pH E-201C Sensor

Experiment	Sample	pH Meter	Sensor pH	Difference	Precision (%)
1		5,44	5,42	0,02	99,78
2			5,39	0,05	99,47
3			5,44	0	100
4			5,3	0,14	98,51
5			5,35	0,09	99,04
6			5,4	0,04	99,57
7			5,43	0,01	99,89
8			5,32	0,12	98,72
9			5,37	0,07	99,25
10			5,41	0,03	99,68
Average				0,057	99,39

From Table 5, it can be seen that the pH values produced by the experimental device are not significantly different from the pH values on the standard device. From 10 repeated measurement experiments, the average precision of the pH sensor was high at 99.39%. This shows that the sensor is working and functioning properly, as evidenced by the high accuracy of the experimental device.

Based on test results, this device has the advantage of being able to measure urine color and pH simultaneously, providing indications of several diseases such as dehydration or urinary tract infections. The system is connected to a smartphone via the Internet of Things (IoT) for monitoring, and its physical design is neatly packaged in a box to maintain reading stability. However, this device also has limitations. Color readings can be affected by lighting or improper sample positioning. Additionally, this device only detects diseases within a limited category, such as kidney disease, urinary tract infections, and dehydration, and cannot replace a complete laboratory examination. Therefore, this device is more suitable for use as a supporting early detection tool, not as the sole determinant of a medical diagnosis.

4. Conclusion

Based on the test results, it can be concluded that the design of the Urinalysis Device for early detection of disease has been successfully designed and works according to specifications. This device consists of a TCS3200 color sensor, E-201C pH sensor, NodeMCU ESP32, LCD, and acrylic housing designed to maintain measurement stability. In terms of performance, the device shows a very high level of accuracy and precision. The color sensor achieves 100% accuracy in classifying sample colors, while the pH sensor has an average reading difference of only 0.006 against the standard device, with an accuracy of 99.895% and a precision of 99.396%. Functionally, the device successfully measures and combines color and pH data to indicate health conditions such as normal, dehydration, kidney stones, kidney failure, and urinary tract infections, with results consistent with urinalysis theory. IoT integration through the Blynk platform also enables monitoring of results via smartphone, making this device a powerful and practical early detection tool.

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