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Sensing and Bio-Sensing Research

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03 September 2021	Artikel disubmit melalui editor manager jurnal SBSR dengan judul: Multi sensor application-based urine measurement for early detection of diabetes. (lampiran 1. Bukti email konfirmasi dari editor, foto editorial manager jurnal, dan approval pdf file)		3
03 September 2021		Email konfirmasi dari editor bahwa artikel telah diterima dengan kode SBSR-D-21-00077. (Lampiran 2. Bukti email editor dan lampiran artikel yang dikirim)	4
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Lampiran 1

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Multi sensor application-based urine measurement for early detection of diabetes

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Multi sensor application-based for measuring the quality of human urine on first-void urine.
--Manuscript Draft--

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Article Type:	Research Paper
Keywords:	ammonia; human urine; pH urine; sensor; turbidity; and urine detection
Corresponding Author:	Anton Yudhana, PhD Universitas Ahmad Dahlan Yogyakarta, Yogyakarta INDONESIA
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Abstract:	Urine can be used to diagnose diabetes in a non-invasively manner. This study aims to create a quality urine detection based on urine pH, turbidity, and ammonia concentration by using multi-sensor: pH4502C to measure pH level, turbidity sensor to measure urine turbidity, and MQ-137 to measure ammonia concentration. Urine samples of 15 subjects were collected early in the morning before doing any activities. For the experiment. all sensors can be read analog signals which are received by an Arduino Nano as a micro-controller and converted into digital values in the form of pH scale, Nephelometric Turbidity Units (NTU), and Parts Per Million (ppm). These values are displayed on the LCD display. Our experiments showed that the measured sensor using the system was compared with the calculated sensor from a manual calculation using an equation. These comparisons were used to know the error percentage. The experiment results found that the average of error percentage from pH sensor, turbidity sensor, and ammonia sensor was 0.0061% (very small), 5.098% (very small), and 1.679% (very small), respectively. The urine measurement from 15 subjects was obtained pH urine of 5.6293, Turbidity urine of 0.59 NTU, and ammonia urine of 0.66 ppm. The accuracy of pH sensor, ammonia sensor, and turbidity sensor are 97.693%, 98.321%, and 97.095%. All sensors were proved capable to measure the quality of human urine. However, The measurement results are sensitive to the voltage of the sensor.

Lampiran 2

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Multi sensor application-based for measuring the quality of human urine on first-void urine

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Abstract: Urine can be used to diagnose diabetes in a non-invasively manner. This study aims to create a quality urine detection based on urine pH, turbidity, and ammonia concentration by using multi-sensor: pH4502C to measure pH level, turbidity sensor to measure urine turbidity, and MQ-137 to measure ammonia concentration. Urine samples of 15 subjects were collected early in the morning before doing any activities. For the experiment, all sensors can be read analog signals which are received by an Arduino Nano as a micro-controller and converted into digital values in the form of pH scale, Nephelometric Turbidity Units (NTU), and parts per million (ppm). These values are displayed on the LCD display. Our experiments showed that the measured sensor using the system was compared with the calculated sensor from a manual calculation using an equation. These comparisons were used to know the error percentage. The experiment results found that the average of error percentage from pH sensor, turbidity sensor, and ammonia sensor was 0.0061% (very small), 5.098% (very small), and 1.679% (very small), respectively. The urine measurement from 15 subjects was obtained pH urine of 5.6293, Turbidity urine of 0.59 NTU, and ammonia urine of 0.66 ppm. The accuracy of pH sensor, ammonia sensor, and turbidity sensor are 97.693%, 98.321%, and 97.095%. All sensors were proved capable to measure the quality of human urine. However, the measurement results are sensitive to the voltage of the sensor.

Keywords: ammonia, human urine, pH urine, sensor, turbidity, and urine detection

Introduction

The human body has three metabolic waste removal system, such as excretion, secretion, and defection [1]. The excretory system process and disposes of metabolic wastes that are not used by the body. This system has the ability to remove toxins from the body. Excretory system consists of the kidneys, liver, lungs, and skin. Urine is a metabolic product, which is excreted by the kidneys through the process of urination. For the human body, the excretion system is important to eliminate of the residual molecules filtered by the kidneys and to maintain the hemostasis of body fluids. Before being excreted through the urethra, urine first filtered by the kidneys and stored in the urinary bladder. Human produces 1.5 to 2 liters of urine per day [2]. Urine contains various types of substances, such as urea, ammonia, protein breakdown residues, excess substances in the blood, and urine acids [3], [4]. Therefore, urine needs to be eliminated from the body so that it does as not harm our health.

Urine quality can be characterized by color, clarity, and odor. Urine color is affected by fluids and drinks consumed by the body [5], [6] . Bright and clear urine color indicates that the body has consumed adequate amount of fluids, on the contrary, cloudy urine indicates that the body is dehydrated and lacks fluids [7]. The urine odor is affected by the ammonia content [8]. The high ammonia level is caused by lack of fluids in the body [9]. The increase in ammonia concentration in urine increase is caused by the hydrolysis of urea into ammonia (NH_3), ammonium, and ion carbonate (CO_3^{2-}) [10], [11]. A low ammonia concentration in the urine is a sign of a positive acid balance compared to the bicarbonate concentration [12]. In addition, the quality of urine will change due to the effects of bacterial growth. Urine becomes cloudy if left for a long time because it is contaminated with bacteria. Urinary bladder infections can cause odor and cloudiness of urine [13], [14].

In medicine, urine is used to diagnose diseases, such as colorectal cancer [15], diabetes mellitus [16], pregnancy complications [17], and to determine various kidney diseases such as: (Glomerulonephritis, nephrotic syndrome, and pyelonephritis) [18]. Typically, diabetes mellitus is diagnosed using an invasive method that involves pricking the skin to draw blood [19], However, the invasive test requires high costs and a long testing time. Other diabetes test include the fasting blood sugar test [20], glucose tolerance test [21], Hemoglobin A1C test (HbA1c) [22], radioactive iodine uptake test [23], serum glucose test [24], thyroid test echo-diagram, thyroid function test [25], and GC/MS based metabolic approach [26]. However, these tests are also expensive and it takes a long time to get the results.

Previous studies have shown that urine can be used as an alternative solution to solve testing problem in diabetic patients [27]–[30] . According to [31], diabetes is a metabolic disorder caused by the function of the pancreas not being able to produce enough insulin for the body or not being able to utilize the insulin produced effectively. There are two types of diabetes, type 1 and type 2 diabetes, which cause high blood glucose levels and can cause abnormal body conditions [32]. Glucose cannot enter the cells of diabetic patients. As a result, the pancreas cannot produce insulin and the liver will break down rapidly to meet glucose [33]–[35].

There are three methods to examine urine in the body, namely macroscopic, microscopic [36], [37] and urine chemistry checkup [38]. Analysis of erythrocytes, epithelial cells, Red Blood Cells (RBC), White Blood Cells (WBC) bacteria, crystals, parasites, and leukocytes using microscopic methods [39],

[40]. The microscopic method examines the color, clarity, odor, and pH of urine. Urine chemistry checkup tests for glucose, ketones, blood, bilirubin, protein, urobilinogen, nitrite, and leukocyte esterase. The urine of diabetics contains excess glucose, which is excreted in the urine.

Non-invasive urine testing can be achieved by using smart sensors [41], [42]. The motivation to detect diabetes in a non-invasive method is easy operation, high sensitive, not expensive, and real-time testing [43], [44]. Urine can be used as new biomarkers in early detection of non-invasive diseases [45]. Several studies have reported research in the field of urine as a new biomarker for non-invasive detection of diabetes mellitus. [46] reported non-invasive detection framework for diabetic complication through image processing and pattern analysis of facial color. The detection of macroalbuminuria using urine has been reported in [47], [48]. Research result from [49] detected the diabetes mellitus by facial block color with a sparse representation classifier. [50] conducted the experiment to detect urea in urine using an electrochemical sensor. [30] reviewed non-invasive detection for diabetes mellitus advance in biosensors will be available in the future to detect diseases [51], [52]. Biosensors also can be used for bacteria detection in urine [53], [54]. Non-invasive detection of urine by using smart toilet systems were introduced by [55]–[57]. A non-invasive detection of heart rate by using sensor was introduced by [58]. The non-invasive detection also was used for liver detection using smart sensors [59], monitoring of sweet glucose in urine [60], creatinine levels [61], [62], point-of-care monitoring of kidneys [63], and real-life application diagnostics [64]. In other fields, smart sensors can be used for monitoring in agriculture field to improve the production [65], modification of manual raindrop [66], human emotion as physiological field [67], monitoring devices to care for the elderly [68].

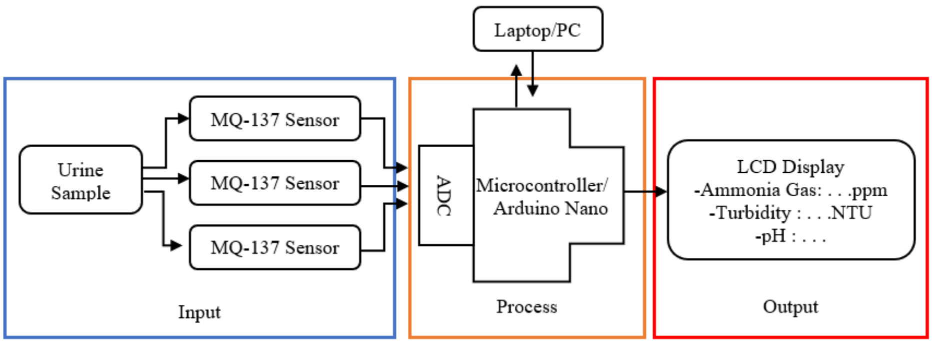
The purpose of this study is to create a urine quality detector consisting of pH, turbidity, and ammonia concentration using multi sensor. This study was carried out non-inventively by collecting urine samples from 15 healthy subjects. The sensors consisted of: pH4502C to measure pH level, turbidity sensor to measure urine turbid, and MQ-137 to measure ammonia concentration. The analog signals in urine are measured by sensors and sent to the Arduino Nano microcontroller converted into digital values in the form of pH scale, Nephelometric Turbidity Units (NTU), and Parts Per Million (ppm). All results can be displayed on the LCD display.

Materials and Methods

1. Hardware Design

Fig 1 shows the hardware design in this research. Three sensors were connected to a sample urine including pH sensor, turbidity sensor, and ammonia sensor. These sensors are controlled by the Arduino Nano and the measurements are sent to LCD display (Nokia 5010). Output data from three sensors are in the form of digital value with the numeric of pH measurement value, Nephelometric Turbidity Unit (NTU), and Part Per Million (ppm). This design makes patients easier to measure urine quality at a low cost and without to go to a hospital. Each sensor has a unique ID which allows to supply single-sided access to sample under test (SUT)

Figure 1. Functional block diagram of system hardware



The electronic circuit follows the block diagram as shown in **Fig 2** basically the electronic circuit has been designed to take several urine samples to measure pH urine, turbidity urine, and ammonia urine. all sensors are produced the different an analog voltage which the electronic circuit represents that the analog voltages are delivered to the ADC (analog-to-digital) input through the micro-controller. As a hypothesis in this study, each urine sample has a different resistor. This resistor is used as a comparison of urine content including pH, turbidity, and ammonia concentration.

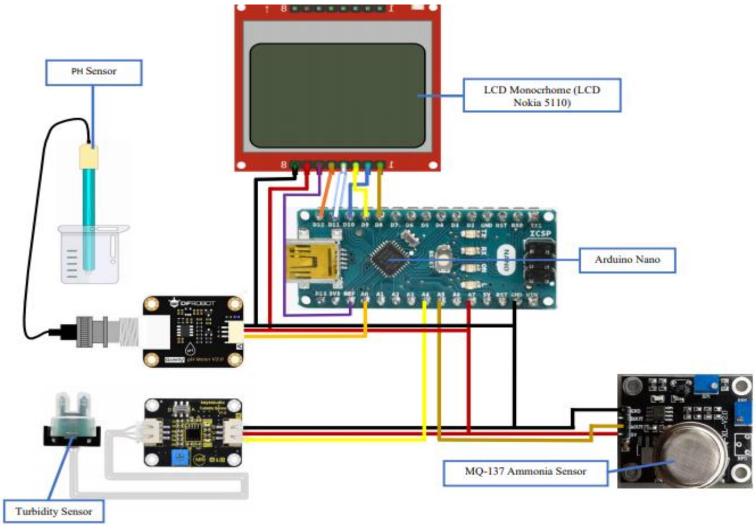
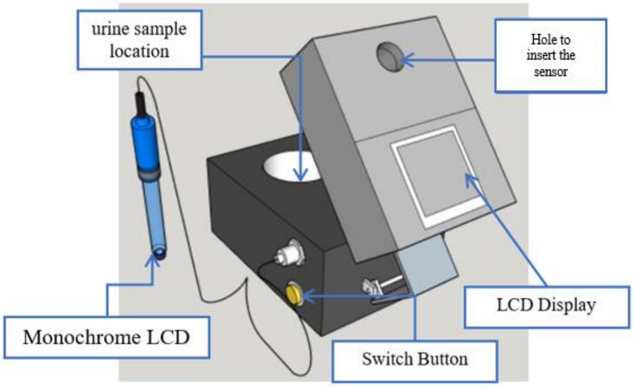


Figure 2 Electronic circuit of our proposed system

All electronic circuit are implemented and assembled in the form of prototype as shown in **Fig 3.** This prototype was designed using 3D CAD software to minimize the overall size of the system.



a) 3D digital design

b) Implementation of the actual system

Figure 3. Prototype of the proposed system

2. Software Design

Fig 4 shows the flowchart of our system. Once the Arduino Nano was connected to the power supply, the system automatically started initializing and reading all sensors. The Arduino Nano is constantly checking the analog values of each sensor. These values are converted into digital values

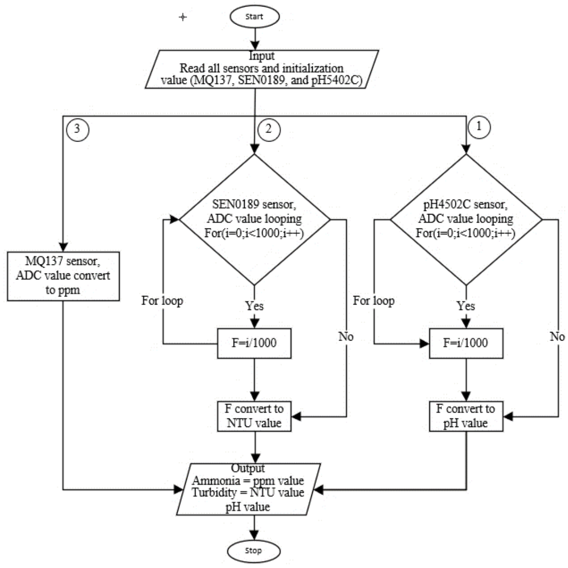


Figure 4. The flowchart of our system

Analog values from sensors are read 1000 times and the average value is calculated. This calculation applies to pH, NTU, and ppm. The looping systems are installed in this prototype which the system starts to work and read the sensor from $i = 0$. If the condition of i is less than 1 approximately equals to 1000, then $f = \frac{i}{1000}$ and was repeated until 1000, the read value is analog value then it was converted to pH measurement values, Nephelometric Turbidity Units (NTU), and parts per million (ppm). All results are displayed and delivered to the LCD display sensor calibration. Library “U8glib.h” was installed in the Arduino Nano as the initialization program of LCD and the initialization of the pin number for the output. The initialization program can be seen in Fig 5.

```
//Inisialisasi LCD
#include “U8glib.h” // Include U8glib.library
U8GLIB_PCD8544 u8g(13, 11, 10, 9, 8)
int Variabel;
```

Figure 5. An initialization pin in LCD

The purpose of the initialization is to determine the variables that will be used in this sensor. For this initialization, we assigned a unique pin number to each sensor for pH, turbidity, and ammonia. **Fig 6** shows the pin for the pH sensor, turbidity sensor, ammonia sensor, the float, and integer variable.

```
//Inisialisasi Program PH
cost int PH = A0;
float Po;
float data;
float TeganganPH;
float SensorPH;
```

a) Initialization pH sensor

```
//Inisialisali Program Turbidity
const int TBY = A4;
int val;
static float kekeruhan;
static float teganganTBY;
float sensorTBY;
float dataTBY;
```

```
//Inisialisasi Program MQ-137
int MQ = A5; //Sensor pin
float m = -0.263; //Slope
float b = 0.42; //Y-Intercept
float R0 = 2.78;//Sensor Resistance in fresh air from
previous code
float teganganMQ;
float RS_gas;
float rasio;
float sensorMQ;
```

c) Initialization ammonia

Figure 6. Initialization three sensor, float and integer listing: a) pH, b) Turbidity, and c) ammonia.

According **Fig 6**. The input data from each sensor are marked on the input pin: pH sensor marked on pin (A0), turbidity sensor marked on pin (A4), and ammonia sensor marked on pin A5). The purpose of the initialization is to determine the variable that used in the sensors. The initialization in library also requires the initialization pin from pH sensor, ammonia sensor, and turbidity sensor which this is to recognize the sensor through the pin by sensor. Float variable is used to output analog data into digital numbers in the form of fractions while integer(int) is used to output the analog to an integer. Output on LCD display can use initialization "serial.begin(9600)" as shown in **Fig.7.**

Figure 7. An Initialization output analog data in LCD

```
void setup()
{
 serial .begin(9600);
 u8g.seFont(u8g_font_6x10);
}
```

"serial.begin(9600)" is to determine the speed of sending and receiving data through the serial port which in the above program uses a speed of 9600bps. U8g.sseFont(u8g_font_5x10) is to set the font that comes out on the LCD. After the initialization program is prepared according to the needs of each component and variable, the next step is to arrange the initialization program according to the system flowchart (seen **Fig 4**). the reason for choosing "serial.begin(9600)" includes: the speed of sending and receiving in the system is suitable and minimal error, the baud rete "serial.begin(9600)" is the baud rate

```
void loop()
{
for(int a = 0; a < 1000; a++)
{
TBY sensor = TBY sensor + analogRead(TBY);
}
MQ sensor = analogRead(MQ);
TBY sensor = TBY sensor/1000.0;
val= sensorTBY+808;

pH sensor = pH sensor/1000.0;
double voltage Ph = pH sensor*(5.0/1023.0);
Po = 6.86 + ((2.67 - Voltage Ph) / 0.17);

Voltage TBY =  val*(5.0/1023.0);
Voltage MQ = MQ sensor*(5.0/1023.0);

turbidity = 100.00-(voltage TBY/5)*100.00;
RS_gas = ((5.0*10.0)/voltage MQ)-10.0;
rasio = RS_gas/R0;
double ppm_log = (log10(rasio)-b)/m;
double ppm = pow(10, ppm_log);
```

that corresponds to the data transferred between microcontroller and PC, and the standard pc in this system is 9600. These flowcharts are displayed the looping program the sequence of commands is continuously repeated until a condition is reached as shown in **Fig 8**. These initializations main from three sensors are looped 1000 times. The purpose of this program is to get the steady data from sensor.

Figure 8. An initialization main program of pH, turbidity, and ammonia

3. Sensor Calibration

Sensor calibration is performed by matching its value to a known standard value. pH calibration was conducted by comparison utilizing pH digital measurement tool and pH liquid which is pH was calibrated by immersing pH sensor on pH liquid 4.00 and pH 6.86 to compare until the value represents similar measurement result to liquid pH metered. If measurement result hasn't been accurate yet, then the calibration voltage was changed rapidly to be adapted and wait until the measured value is equal to liquid value. Turbidity sensor calibration utilizes distillation water until indicate turbidity point on 0 NTU. Whereas ammonia sensor (MQ-137) was calibrated using ammonia liquid with calibration result show on 0 ppm.

4. Data Collection

Data collections are taken from 15 urine samples with 30 ml each sample. Void urine in the morning was used in this research to know urine quality based on the first voided urine by respondent after early wake up before doing any activities. every device and sensor are turned on and successfully carried out the testing. Then sensors were dipped to urine sample for a few minutes until the appearing value on LCD unchanged. These procedures are applied for pH test, turbidity test, and ammonia test. To keep the accuracy, measured sample was kept for data collection. The urine sample testing procedures are displayed in **Fig 8**.

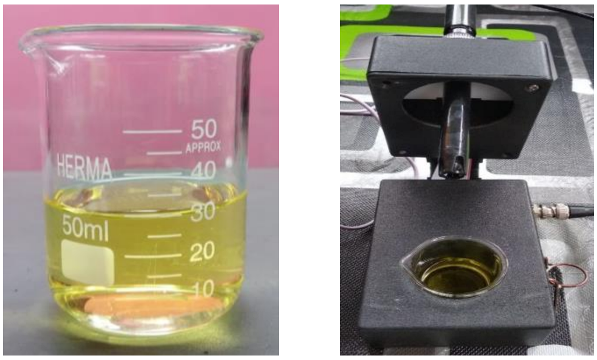


Figure 8. Urine sampling

Results and Discussions

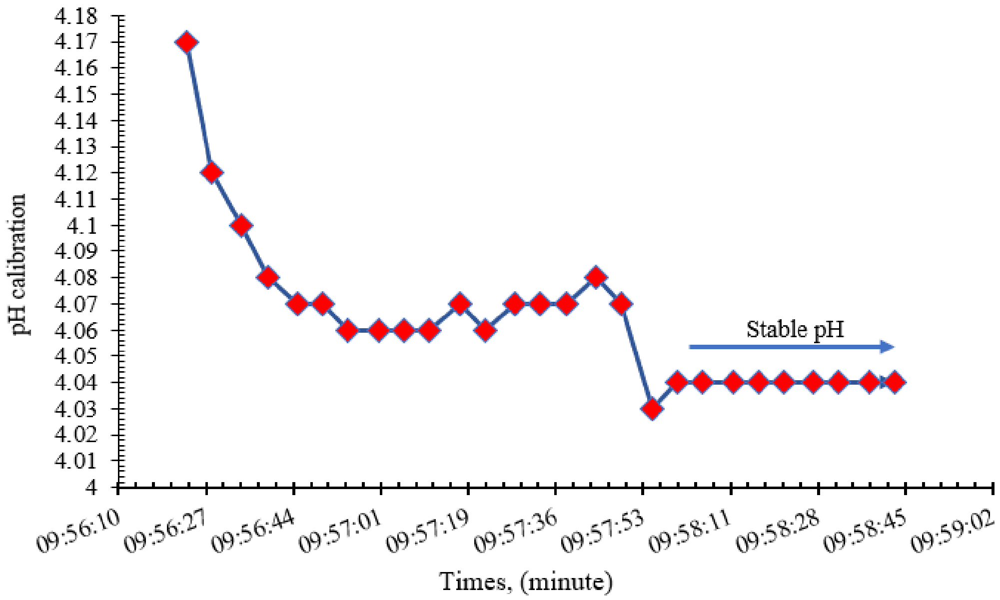
In this study, first-morning-void urine was examined to know urine quality based on the first voided urine by the respondent after an early wake up before doing any activity. first-morning-void urine was examined to know urine quality based on the first voided urine by the respondent after an early wake up before doing any activity. First-morning-void urine is valuable to measure albuminuria and is more reliable than 24-H urine void introduced by [69]. According to [70], [71] the first-morning-void urine consists of the value of urea, calcium, urine acid, and phosphorus. our systems are implemented to examine pH urine, turbidity urine, and ammonia urine from 15 respondents in which the result from systems have been compared with manual calculation using equation. Three sensors are included: pH-4502C as pH sensor, turbidity sensor, and MQ123 as ammonia sensor. the experiment results from pH detection, turbidity detection, and ammonia detection are described below:

pH detection on first-morning-void urine

pH urine levels were used to identify the presence of disease in the body. pH sensors have been reported by [72] to detect urea in urine through the implementation of iridium oxide films (IROF). According to [73] pH normal on human urine ranging from 4.5 to 8.0. In this study, a PH-4502C sensor was applied to read pH in urine that combined with Arduino Nano to convert pH value to digital analog. Then the pH value has shown at LCD Display. This system was relevant with the work from [74] in which they have applied the temperature sensor in the body by using the DS600 sensor. the sensor was designed to send the analog to digital (ADC) input of the micro-controller. A detection system representing analog value to LCD was also used by [58] to monitor heart rate using MAX30100.

In this study, urine was obtained from 15 respondents and saved at cup/glass like as show in **Fig 8** This prototype was designed flexibly to facilitate patient on urine testing. Before test, this system previously was calibrated using buffer liquid to obtain accurate result like on **section 3**. Calibration process and tools testing may affect the rated voltage and calibration voltage which can be seen in **Fig 9**.

Figure 9. show the test result of measured pH, pH calculated, calibration voltage and rated voltage of urine in the morning.



According to **Fig 9** pH values were firstly shown around 4.17. Then pH value was reduced and stable at 4.04. it was indicated that the urine sample was stable. Sensor calibration methods are followed for other experiments. Stable pH at calibration stage requires time around 1 minute. Sensor calibrations aims to obtain appropriate result with the real condition. Every sensor previously are calibrated before testing [75]. Rated Voltage (RV) is voltage obtained by prototype. However, Calibration Voltage (CV) is voltage obtained along calibration process. Rate voltage value and calibration voltage can be utilized to count error percentage. To obtain accurate result, this tool has been compared between measured pH and pH Calculated manually which is measured pH is testing result using prototype. However, calculated pH is result of pH calculation using equation (1) as follows:

$$Po = \text{pH buffer} + \frac{\text{Cv}-\text{Rv}}{0{,}17} \quad (1)$$

Where, value of 2.68 is calibration voltage. 2.97 is measured voltage, and 0.17 is voltage (V).

The voltage in the sensor was displayed as the human body a large resistor [76]. The output system from microcontroller is influenced on the voltage. Furthermore, error value on this prototype was determined by using different value between measured pH and calculated pH. Error percentage values were determined using **Eq.2**. The calculation of measured pH and calculated pH can be seen in **Eq 1**. The result of pH calculation was indicated that this tool has difference measured pH value and calculated pH value relatively small. Error percentage was described below:

$$ErrorPercentage = \left|\frac{pH\ measured - pH\ calculated}{pH\ calculated}\right| x100\% \quad (2)$$

The calculation voltage result, measured pH, and calculated pH on urine detection testing are described in **Fig 11**.

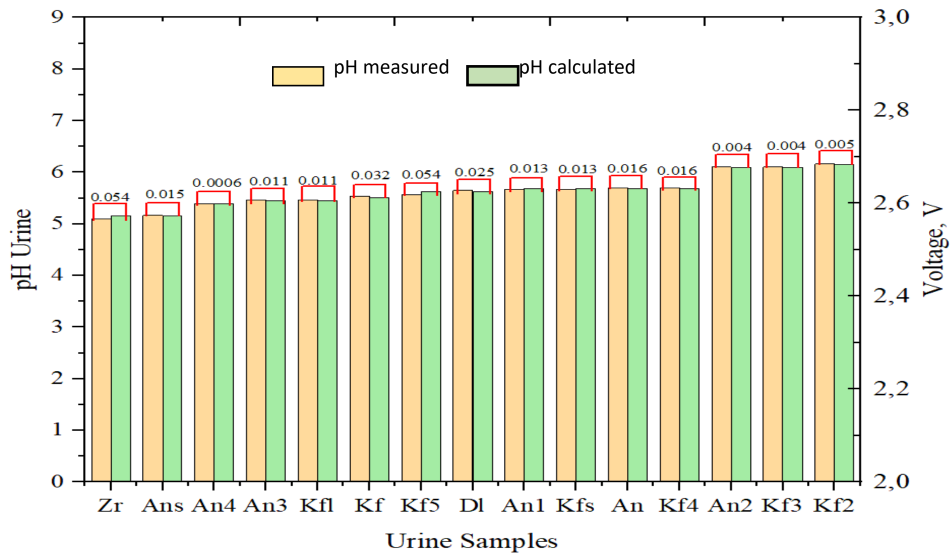


Figure 11. The testing result of pH urine by using prototype (pH measured), the calculation of pH urine manually (pH calculated) dan voltage.

pH urine detection in **Fig.11** represents the result of measured pH, calculated pH, and voltage (V). measured pH was obtained from pH testing result of urine by using prototype like as **Fig 3**, however, calculated pH was obtained from manual calculation. Measured pH and calculated pH aims to know the error percentage of every sample which was obtained from the difference of measured pH and pH Calculated. Form this testing, the prototype found the difference value between measured pH and pH Calculated relatively normal with a mean value of measured pH was 5.6293 and calculated pH was 5.6286. the difference between the testing result of measured pH and calculated pH was around 0.0188. According to the result of this study, pH urine detection from respondents indicates the normal level. Voltage can be used to identify the pH urine. The voltage from systems is indicated an increase when the pH increase. Voltage as a resistor for the object like body, urine, and blood. The output result from the sensor is influenced by voltage introduced by [66]. As a resistor, the voltage also uses in the field of agriculture to measure nitrogen in the paddy soil over the TCS3200 sensor to identify the color [77]. The voltage sensor can be determined the AC or DC voltage level. The type of voltage is resistive type sensor and capacitor type. From theses study, the pH urine and voltage have a straight proportional. In addition, voltage in the systems are affected by pH urine. When the pH urine is high level, such as the respondent's urine (kf2), the voltage value also increases. It means that human urine has different resistance. Moreover, urine resistance may be used as a particular parameter for pH measurement. According to [76], [78] sensor detection in human urine depends on the voltage output divider equation which every human urine has a different resistor. Several previous study from [59] and [60] have reported that the diagnosis smart sensing to detect creatinine level using a sensor is depended on voltage output on creatinine. Voltage output from sensor also can be used to measure heart rate, skin temperature dan galvanic skin using the sensor. The respondent in this study has a different resistance. As a basic line, the result of pH urine detection was dependent on the result of output voltage. The detail can be seen in **Fig 11.** The higher the voltage generated, the pH in the urine is more alkaline and increases. This result was relevant to the previous research from [80] that pH measurement depends on the output voltage. This prototype has been calculated the error percentage to validate the tool. This tool was proved to be able to measure pH urine with an error percentage of 0.0061% (very small). The highest pH level from 15 respondents are urine from kf2 and the lowest pH urine from respondents are code (zr). 15 respondents in this study were indicated that there were no symptoms of diabetes and the pH measurement results from respondents were declared normal. According to [79] normal values for urine is from pH 5.0 to 6.0.

Turbidity detection on first-morning-void urine

Before urine was tested, this tool previously was calibrated using distillation water until the turbidity point is 0 NTU. Then 15 urine samples were tested using a turbidity sensor to know the turbidity of urine. Urine solubility signal can be used to detect the deposition of protein albumin and globulin on urine. Previous research from [78] discussed he measurement of turbidity urine are measured through continuity flow principle using an infrared sensor. However, this study was installed sensor turbidity directly in the sample urine. According to [69] turbid urine indicate that human urine has the deposition of protein albumin and globulin, while clear urine indicates healthy urine. The turbidity sensor is a device for reading the level of turbidity in a liquid with NTU (Nephelometric Turbidity Units). The workings of this sensors are the light emitted into the liquid will be blocked by particles and deposits suspended then the level of scattering and transmitted light will be received by the photodiode and measured. SEN0198 as turbidity sensor was applied to measure the turbidity urine which this prototype was developed by using EPA Method 180.1 [80]. From the validation section, it is observed that the EPA Method 180.1 is suitable for measuring the turbidity level from 0 to 40 NTU (nephelometric turbidity units). These systems are relatively complex. However, the EPA Method 180.1 is not able to measure at turbidity levels above 40 NTU. as the equation based on instruments in compliance with the EPA Method 180.1 are suitable for measuring turbidity, the formula for NTU can be seen in Eq 3.

$$NTU = \left(\frac{A*(B+C)}{C}\right) \tag{3}$$

Where, A is NTU found in diluted sample, B is volume of dilution water, mL, and C is sample volume taken for dilution, mL. In a single laboratory (EMSL-Cincinnati), using surface water samples at levels of 26, 41, 75, and 180 NTU, the standard deviations were ±0.60, ±0.94, ±1.2, and ±4.7 units, respectively.

The experiment result shown that the measured NTU from system or prototype was compared with calculated NTU from manual calculation using by using **Eq 4**. The purpose of this comparison is to know the error percentage of this tool. Urine from 15 respondents has been taken in the morning to be tested those turbidity rates.

$$errorpercentage = \left|\frac{turbidity\ measured - turbidity\ calculated}{turbidity\ calculated}\right| \tag{4}$$

In detail, turbidity testing result using prototype, manual calculation, and voltage can be seen in this **Fig 12** below:

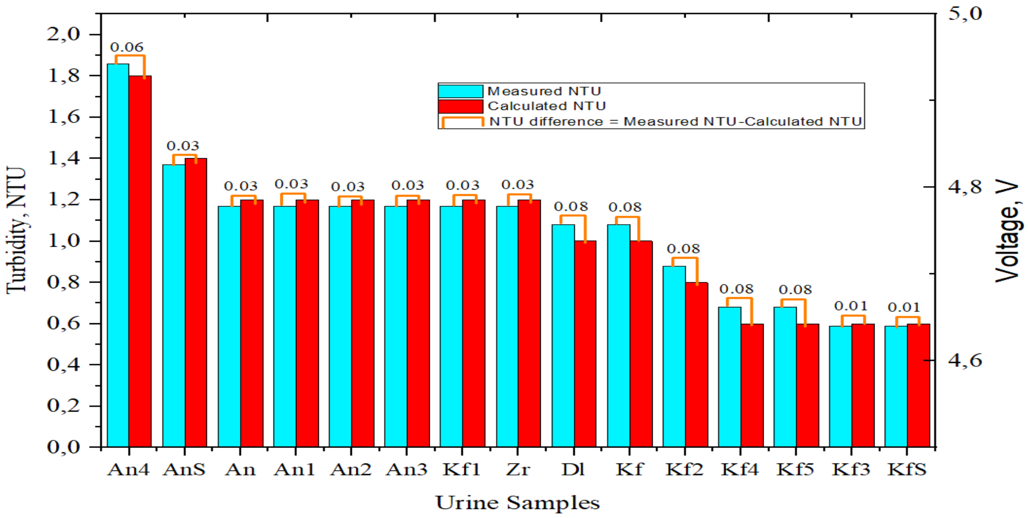


Figure 12. Turbidity testing result in the morning using tool, manual calculation and voltage

As **Fig 12.** it shows that the voltage also was affected by turbidity value from urine sample. The correlation between turbidity measured and turbidity calculated were simulation by using the coefficient of determination (R^2) with significant correlation that can be seen in Fig. 14. Sample urine with code

(An4) indicates high turbidity level and high voltage. While sample urine with code (KfS) indicates low turbidity level and low voltage. When the voltage test tool increases then the turbidity rate also increases. Output turbidity value of urine was dependent on output voltage urine in which human urine has a different resistor. This result was in line with the review of [82] that the voltage comparison with TSS concentration is directly proportional, in which the higher TSS concentrate, the higher voltage result. Furthermore, the experiment result shows that the measured NTU is value from the system or prototype with average result of 0.59 NTU while the calculated NTU is manual calculation using **Eq. 3** with the average result of 0.60 NTU. The average of error percentage from these calculations are 5.098% (very small). These results are indicated that the tool was proved to be able to measure turbidity in human urine.

Ammonia concentration detection on first-morning-void urine

The sensor was applied to detect ammonia concentration in urine using MQ137 that was calibrated by using ammonia liquid. MQ137 sensor is an electrochemical sensor and varies resistance to ammonia gas (NH_3). The workings of this sensors are to use a heater contained in the sensor section when exposed to ammonia gas (NH_3), the value of the resistance of the sensor will change. The urine testing was applied in the morning to know urine quality like as explained in **section 1**. Ammonia concentration in urine was used for the first detection of diseases like kidney, urinary tract disorders, and gastrointestinal bleeding [76]. The use of ammonia sensors may decrease cost, more flexible and disposable sensing platform that can be validated easier [78]. These systems were installed the current output of 0-4 vdc signal with a 220 Ω resistor which ADC system was transferred to Arduino as digital converter. As formula, these systems can be calculated by using Eq. 4:

$$V = \frac{A}{1023} x5 \tag{4}$$

Where, V is voltage, Vdc, A is digital count, 5 is full scale ADC voltage range, and 1023 is 2^{10}-1 as number of discrete counts for 10-bit ADC. According Eq 4 can be used to calculate the resistance error of the sensor. The result of ammonia concentration of urine in this prototype was compared with manual calculation to know the error percentage of these tools. The manual calculation of urine ammonia concentrate was used **in Eq 5** below. The equation of resistance error (*RS*) on any gas

$$Rs = \frac{5xR_L}{V} xR_L \tag{5}$$

Where V is voltage and R_L *is* resistance load of the MQ137 sensor. After resistance error was obtained, then be calculated ratio between RS_{gas} and *RO* using **Eq 6**:

$$ratio = \frac{Rs_{gas}}{RO} \tag{6}$$

To look for difference value of PPM between measured ammonia and calculated ammonia are described in **Eq 8.**

$$error\ percentage = \left(\frac{ppm\ ammonia\ measured - ppm\ ammonia\ calcualted}{ppm\ ammonia\ calculated}\right) x\ 100\% \tag{8}$$

The experiment result from ammonia concentration using this system are included manual calculation of ammonia concentration, and voltage that shown in **Fig 13.**

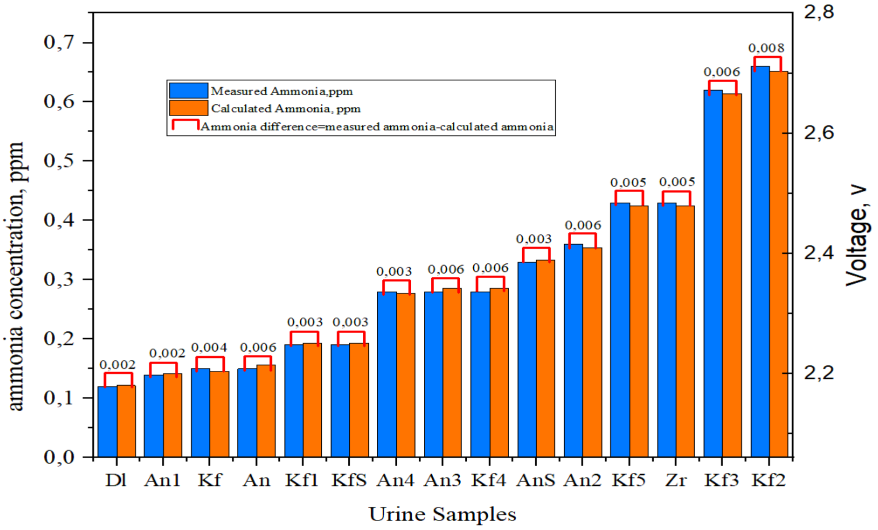


Figure 13. the result of ammonia concentration testing of urine in the morning using tool, manual calculation, and voltage.

as **Fig 13**. It shows that the correlation between measured ammonia (using a prototype) and calculated ammonia (using an equation) was affected by voltage. The ammonia concentration is straight proportional where ammonia concentration is low then the voltage is also low. Sample urine with code (Kf2) indicates high ammonia level and high voltage value while sample urine with code (Dl) indicates low ammonia level and low voltage value. These systems are applied in 15 urine samples to identify the ammonia in urine. Voltage in this system can be used to identify ammonia concentration in urine because every urine has a different resistor. This work was relevant to the previous research from [81] which reported the ammonia sensor for health monitoring with the result of the increasing of current based on the ammonia concentration. When the current was increased, the ammonia concentration was increased also. Other research has investigated the effect currently on urine detection [82] and blood cells in urine [83]. the voltage output changes in proportion to the time of testing carried out. The sensor of this prototype can read ammonia concentrate in urine. Based on the experiment results, the error percentage from this system is very small with an average of 1.679%. The average of the measured ammonia from the system or prototype is 0.66 ppm while the average of the calculated ammonia from manual calculation using equation is 0.65 ppm. From the experiment result, the measurement of the ammonia concentration from 15 respondents are indicated that the respondents are declared under normal conditions. These results have been compared with the results of a study from [84] which reported that chronic kidney disease (CKD) patients had ammonia levels ranging from 1.26 to 6.33 ppm. This system was proved to be able to measure the ammonia concentration in human urine.

Sensor Accuracy

The correlation between sensor measured value from the prototype and sensor calculated value from the equation applies to identify the sensor accuracy. The coefficient of determination (R^2) quantifies the amount of variability on the dependence variable described by the model as Eq. 9.

$$R^2 = \frac{SST}{SSE} - 1 \quad (9)$$

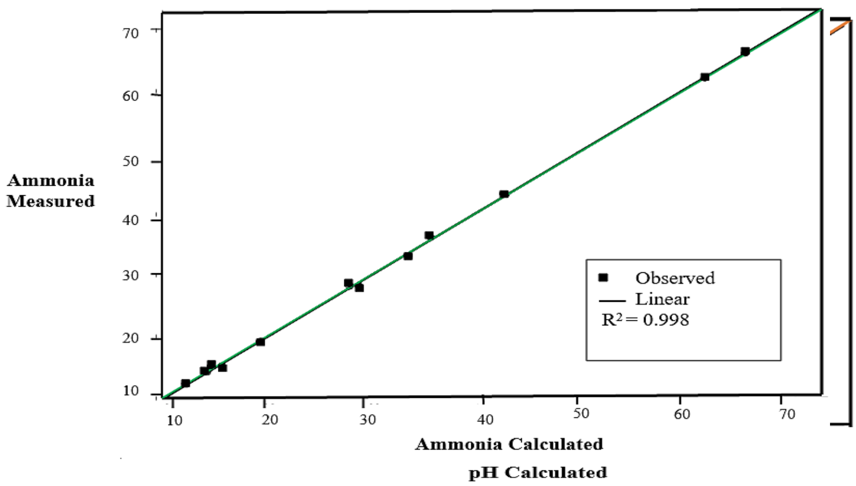
Where SSE represents the sum of squared errors (squared residuals). SST represents the sum of squared variation on a dependent variable. The regression models have refined the analysis through the coefficient of determination R-squared (R^2) values which is the range of R-squared between 0% and 100%. The higher R-squared (R^2) represents a higher explanation of the response data. In addition, the statistical analysis to know the significant difference between sensor measured value and sensor calculated value can be performed by using p-value (Chi-square test). P-value is one analysis of nonparametric comparative test that conducted on two variables (independency test) where the data scale of both variables is nominal. P-value can be described by using Eq 10.

$$x^2 = \Sigma \frac{(0i - Ei)^2}{Ei} \quad (10)$$

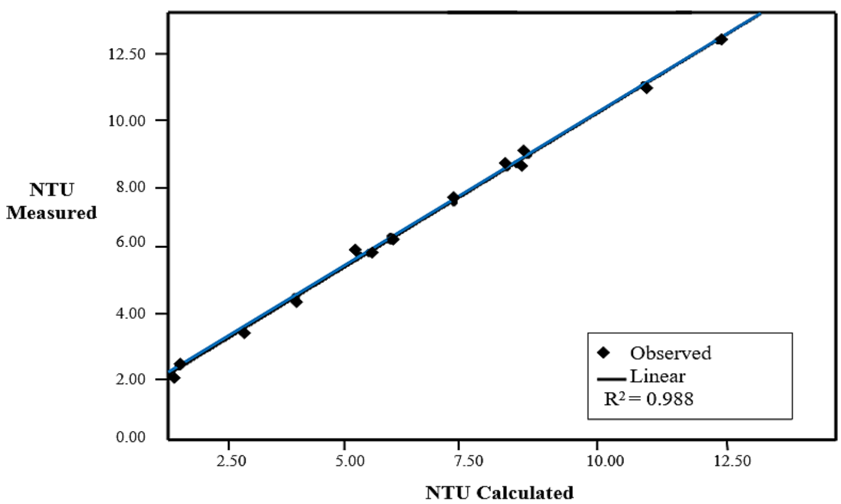
Where, X^2 represents Chi square value, $0i$ represents observed value, and Ei represents expected value

The experiment result found that R^2 value from pH sensor, ammonia sensor, and turbidity sensor are 0.968, 0.998, and 0.988 respectively. These data are indicated that the correlation between sensor measured and calculated are significant correlation. the accuracy from each sensor (pH, ammonia, and turbidity) are 97.693%, 98.321%, and 97.095%. In addition, p-value analysis from this prototype is 0.166 of pH sensor, 0.009 of ammonia sensor, and 0.250 of turbidity sensor. From each sensor, p-values are greater than 0.001 (level of significance) which it describes that the difference between sensor measured and sensor calculated is no significant difference. P-value can be described in **Figure 14** which the correlation from the analysis is linear. In other word, the output of the prototype is acceptable value. These results are relevant with the previous research from [83] that are applied to find the correlation between the actual and measured volume of urinary with the accuracy is 95.51% and the correlation between actual from prototype and measured volume is linear characteristic.

a) The correlation between pH measured and pH calculated



b) The correlation between ammonia measured and ammonia calculated



c) The correlation between turbidity measured and turbidity calculated

Figure 14. The correlation test between sensor measured (pH, ammonia, and turbidity) and sensor calculated

Conclusions

Three sensors are applied in this study to create a urine quality detector consisting of pH urine, turbidity urine, and ammonia urine using multi sensor. The sensors consisted of: pH4502C as pH sensor, turbidity sensor, and MQ-137 as ammonia sensor. The study was carried out non-inventively by collecting urine samples from 15 healthy subjects or respondents. The experiment results were indicated that the average of the error percentage from pH sensor, turbidity sensor, and ammonia sensor were of 0.0061% (very small), 5.098% (very small), and 1.679% (very small). In addition, the pH level, turbidity, and ammonia concentration were affected by voltage which the increasing of pH, turbidity, and ammonia concentration in human urine was proportional with the increasing of voltage in the system or prototype. From the experiment result, the measurement of pH, turbidity, and ammonia concentration from 15 respondents were indicated that the respondents were declared under normal condition and not found any disease like diabetes. The accuracy of pH sensor, ammonia sensor, and turbidity sensor are 97.693%, 98.321%, and 97.095%.

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Conflict of Interest:
The authors have stated no conflict of interest

Credit Statements (Authors Contribution):
Anton Yudhana: Supervision, Project Administration, and Methodology. **Subhas Mukhopadhyay:** Validation and Methodology. **Oky Dicky Ardiansyah Prima:** Conceptualization, and Resources. **Son Ali Akbar:** Visualization/Data Presentation, and Software. **Fatma Nuraisyah:** Data Curation, Formal Analysis, Laboratory Sample, and Instrumentation. **Ilham Mufandi**: Writing-Original Draft, Writing-Review, Editing, Preparation Data, and Creation of The Published Work. **Khoirul Hafizh Fauzi**: Investigation, dan Collect Data. **Nurul Ainun Nasyah**: Investigation and Analysis Tools, and Collect Data

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Lampiran 3

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Multi sensor application-based urine measurement for early detection of diabetes

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When revising your manuscript, please consider all issues mentioned in the reviewers' comments carefully: please outline every change made in response to their comments and provide suitable rebuttals for any comments not addressed. Please note that your revised submission may need to be re-reviewed.

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Kind regards,
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Editor-in-Chief

b. List comment dari reviewer:

Sensing and Bio-Sensing Research

Editor and Reviewer comments:

Reviewer #1: The author has prepared the article well. Articles are neatly and systematically arranged. Previous research also has been performed well and adequately. However, the problem to be solved is not explained in detail. Thus, it is not clear what the purpose of this research is. In addition, there is no development of the proposed theory or new method other than practical efforts to make a better instrument. It is proposed, for example, that there is an effort to classify sensor readings using a specific classification method.

Reviewer #2: Q1: This paper is very detailed explaining the combination of three sensor in the human urine for non-invasive diagnosis and also the devices in this paper are well established. However, the reviewer not find the session that mention the medical knowledge how to estimate the potential for diabetes from urine. For example, the existing test strips estimate the potential for diabetes by detecting the presence of ketones and microalbumin in urine. The reviewer provides a suggestion to change the title to the multi-sensor for measuring urine quality. it would be better and more suitable for this paper.

Q2: as figure 1 line 14. What is the meaning of the different colour in the functional block diagram. If possible. it changes only use black color or uniform colour. Not use many color, It makes misunderstand.

Q3: Figure 3a is not clear to me because there is a word in image is missing. It may be suggested to change the figure.

Q4: Figure 6 line 9-12. these figures are mention the initialization pH sensor, turbidity, and ammonia. It could be explained what is the function and the purpose that you used that listing program.

Q5: This paper uses the serial.begin(9600) (shown in figure 7 line 19) why you use this serial.begin(9600) and it is more better that giving the comparison with other device .

Q6: In data collection session. You did not mention how many (ml) urine samples that you use in this research for each item.

Q7: as figure 4 line 11-13. In the flowchart you are mention the f=1/1000 for each sensor. I suggest that you explain the meaning in the part of paragraph. It makes more the reader easy to understand

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Author's Response To Reviewer Comments

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We thank the editor and reviewers through reading of our manuscript, valuable comments, and suggestions that helped us to improve the manuscript. As indicated below, we have tried to do our best to respond to all the points raised. Please contact me if you need any further information.

Replies to reviewer#1 for Q1:
We really respect with the reviewer opinion. As recommended by the reviewer, we have added the statistical analysis by using R2 value and p-value (chi-square test). This analysis is to compare between the prototype result and actual result. Please see Figure 14. Hope this response can explain what the purpose of this study.

Replies to reviewer#2 for Q1:
We deeply appreciate for your suggestion. Along with the suggestion from reviewer, we have revised the title: "Multi sensor application-based for measuring the quality of human urine on first-void urine".

Replies to reviewer#2 for Q2:
In line with the reviewer's suggestion (figure 1, line 14), we have modified the figure by using one color only.

Replies to reviewer#2 for Q3:
As recommended by the reviewer, we have deleted and changed the figure 3 that makes the figure easy to understand and nothing missing word in figure 3.

Replies to reviewer#2 for Q4:
We have explained the function and the purpose of initialization.

Replies to reviewer#2 for Q5:
We have added the described regarding the serial.begin(9600).

Replies to reviewer#2 for Q6:
We have added the urine sample volume.

Replies to reviewer$7 for Q7:
I deeply thanks for your suggestion. We have added some description in the manuscript.

once again, we deeply thank the reviewer for the suggestion in this manuscript. We have attached all comment in the manuscript.

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Multi sensor application-based for measuring the quality of human urine on first-void urine

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A B S T R A C T

Urine can be used to diagnose diabetes in a non-invasively manner. Examination of blood sugar levels as an indicator of diabetics is currently carried out using invasive methods. However, most people are not comfortable with the invasive methods used. Early diagnosis of diabetics using non-invasive methods is very important to continue to be developed, including by checking the quality of the urine. This study aims to create a quality urine detection based on urine pH, turbidity, and ammonia concentration by using multi-sensor: pH4502C to measure pH level, SEN0189 to measure urine turbidity, and MQ137 to measure ammonia concentration. Urine samples of 15 subjects were collected early in the morning before doing any activities. For the experiment, all sensors can be read analog signals which are received by an Arduino Nano as a micro-controller and converted into digital values in the form of pH scale, Nephelometric Turbidity Units (NTU), and parts per million (ppm). These values are displayed on the LCD display. Theexperiments showed that the measured sensor using the system was compared with the calculated sensor from a manual calculation using an equation. These comparisons were used to know the error percentage. The average value of urine measurement from 15 subjects obtained pH urine of 5.62, turbidity urine of 0.59 NTU, and ammonia urine of 0.66 ppm. The accuracy percentages of pH sensor, ammonia sensor, and turbidity sensor are 97.69%, 98.32%, and 97.09%. All sensors were proved capable to measure the quality of human urine. The results of this study became the basis for the initial diagnosis of diabetes from the quality of the urine using non invasive method.