Design, Build, and Analytical Simulation of Carbon Monoxide Gas Emission Measuring Instrument Based on Smartphone With Linear Regression Approach

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Abstract. To find out the level of carbon monoxide gas emission in motor vehicles, we need a tool that can measure these conditions. So in this study made a measuring tool for carbon monoxide gas emission levels in motor vehicles. This measurement tool uses the TGS 2442 sensor. While Arduino Uno as a microcontroller and signal processor, and Android smartphone as a data viewer. Based on the sensor testing obtained, the graphs obtained linear equations when measuring carbon monoxide levels in BK 6776 PAN cars $y_{reg} = 38.436 - 0.0641x$ with standard deviation values ($\delta$) = 10.816, uncertainty values of measurement results (UA_1) = 6.245 and uncertainty values regression approach UA_2 = 1.02 and on vehicles with BK 6281 AAG $y_{reg} = -3371 + 1.03x$ with a standard deviation value ($\delta$) = 157.25, the uncertainty value of the measurement results (UA_1) = 90.788 and the uncertainty value of the UA_2 regression approach = 28185.05. Retrieval of data on the measuring instrument that the standard deviation value at 10 seconds is 2375.32, at 12 seconds is 3318.42, and at 15 seconds is 2639.813. The measurement uncertainty value at 10 seconds is 1371.39, at 12 seconds is 1915.89 and at 15 seconds is 1524.1.

1. Introduction

Motor vehicles, factories, and households for long have been one of the sources of air pollution in many major cities in the world because it accounts for 70% of pollution worldwide with a composition of carbon monoxide (CO) of 99%, hydrocarbons (HC) of 89%, and oxides nitrogen (NOx) as much as 73% as well as other particulates including lead, sulfur oxides and dust particles fueled by gasoline [1].

Carbon monoxide (CO) is a toxic gas compound formed by incomplete combustion in the motor work process, CO gas is a relatively unstable gas and tends to react with other elements, CO can be easily converted into carbon dioxide (CO₂) with a little help oxygen and heat, CO is measured in units of % per volume or in ppm but in the automotive industry according to the measuring instrument used is often measured in units of % per volume [2].

The role of the instrument for measuring exhaust emissions in motor vehicles is more important for agencies such as the Health and Environment Agency and for car workshops.
2. Research Method

2.1. Tool Design and Manufacturing

2.1.1. Block Diagram. Based on the block diagram in Figure 1, this instrument includes TGS 2442 sensor to detect and estimate the content of carbon monoxide (CO) compounds by detecting gas levels in the exhaust pipe of motor vehicles. Arduino microcontroller is the main component that functions as a data processing center that will be processed before sending to the viewer (android smartphone) via bluetooth. Android smartphone functions as a viewer of data obtained from the sensor so that it can be directly seen visually.

![Block Diagram](image)

**Figure 1.** System work block diagram [3]

Based on the block diagram in Figure 1, there is a TGS 2442 sensor that functions to detect and estimate the content of carbon monoxide (CO) compounds by detecting gas levels in the exhaust pipe of motor vehicles. Arduino microcontroller is the main component that functions as a data processing center that will be processed before sending to the viewer (android smartphone) via bluetooth. Android smartphone used as a viewer of data obtained from the sensor so that it can be directly seen visually.

2.1.2. Arduino Uno Microcontroller Circuit. The vehicle exhaust emission measurement tool uses Arduino Uno which uses the ATmega 328 microcontroller as the central working controller of all design tools, including reading sensor measurement results and changing sensor measurement results to digital because the sensor output is analog. The Arduino Uno microcontroller is programmed using the Arduino IDE software which is sent through a computer USB port. The power supply used is 5V connected at pins 30 (VIN) and 29 (GND).
2.1.3 **TGS Sensor Circuit 2442.** Figaro TGS 2442 is the main transducer used in this circuit, which is a gas sensor. This sensor has a resistance value of $R_s$ that will change when exposed to gas and also has a heater that is used to clean the sensor room from outside air contamination. The structure of the sensor is shown in Figure 3.

2.1.4 **Series of Bluetooth Module HC-05.** The Bluetooth Module HC-05 electronic circuit consists of a series of standard factory recommendations. Bluetooth module can work as it should. Bluetooth Module HC-05 is a wireless communication module work at 2.4GHz by default connection as MASTER and SLAVE. Very easy to use with a microcontroller to create wireless applications. The interfaces used are serial RXD, TXD, VCC and GND. Built-in LED as an indicator of Bluetooth connection.
The input voltage is between 3.6 ~ 6V. Current when unpaired is around 30mA, and when paired (connected) is 10mA. Four 3.3V interface pins can be directly connected to various types of microcontrollers.

![Figure 4. Schematic Bluetooth Module CO-05 [5]](image)

2.2. Design and Manufacture of Software

Software design is needed because in order to run the Arduino Uno system the ATMega328P microcontroller chip will be filled with the desired command program.

2.3. Testing Tools and Data Analysis

After making tools, the next step is testing the tool in a way to calibrate the instrument take the data and analyze the data. The purpose of calibration is to achieve measurement traceability. The results of the measurements can be traced to more precise standards. In doing the calibration, it can be seen how far the difference or deviation between the true value and the value indicated by the measuring instrument. Besides, calibration is also carried out to determine the value of uncertainty. To find out the value or price uncertainty, which is the first step to find the standard deviation value, using equation 1.

\[ \delta = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \]  

(1)

Information:

\( (x - \bar{x})^2 = \) Data value x minus the average value of x

\( n = \) Number of data x

The second step is to calculate the uncertainty value in the measurement results (UA₁), using equation 2.

\[ UA_1 = \frac{\delta}{\sqrt{x}} \]  

(2)

The third step is to calculate the uncertainty value of the regression approach (UA₂). The stages to look for the value of the uncertainty of the regression approach (UA₂), namely first using the regression equation (Yₐᵢ), as in equation 3.

\[ Y_{reg} = a + bx \]  

(3)
To calculate the value of the regression equation \(Y_{\text{reg}}\), previously look for the values of \(a\) and \(b\). But to find the value of \(a\), must find the value of \(b\) first. As in equation 2.4.

\[
b = \frac{n\sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2}
\]  
(4)

So that after the value of \(b\) is known, then next calculate the value of \(a\) with equation 2.5.

\[
a = \bar{y} - b \bar{x}
\]  
(5)

After the value of the regression equation \(Y_{\text{reg}}\) is calculated, then look for the value of the sum square residual value (SSR), the equation to find the SSR as in equation 6.

\[
SSR = \sum (R)^2
\]  
(6)

After the sum square residual (SSR) value is known, it can be continued by calculating the uncertainty of the regression approach (UA), using the following equation 7 [6].

\[
UA_2 = \frac{\text{SSR}}{\sqrt{n-2}}
\]  
(7)

3. Results and Discussion

3.1. Power Supply Circuit Testing

The power supply is an important part in a circuit, namely as a voltage source. The power supply needed in this range system is a 5vcd power supply. And the chosen adapter module that is easy to find in the market is an adapter module with a 12V output with a current of 1A. The following is an adapter module testing table

| Testing | Rated voltage (x) | Deviation \((x - \bar{x})\) | Square deviation \((x - \bar{x})^2\) |
|---------|-----------------|----------------|-------------------|
|         | 1               | -0.466   | 0.217             |
|         | 2               | -0.066   | 0.004             |
|         | 3               | 0.534    | 0.285             |

\[
\bar{x} = 12.4666 \quad \sum(x - \bar{x})^2 = 0.506V^2
\]

Based on the table above, we get the above power supply test with an average value (\(\bar{x}\)) of 12.466 volts, the value of the squared deviation \((x - \bar{x})^2\) is 0.506 \(V^2\). Then the standard deviation value is calculated using the equation of \(22 \delta = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} = \sqrt{\frac{0.506}{2}} = 0.502\text{ volt} \). Furthermore, the uncertainty value of \(UA_1 = \frac{\delta}{\sqrt{n}} = \frac{0.502}{\sqrt{3}} = 0.291\text{ volts}\).

3.2. Testing the Sensor Output Against the ADC

Testing the gas sensor to find out the large output voltage generated by the sensor for several tests. This is obtained because the sensor resistance (Rs) value decreases, causing the sensor output voltage (VRL)
to rise in accordance with the magnitude of carbon monoxide (CO) levels detected by the sensor. To vary the measurement results, the gas sample is given around the sensor.

The sensor voltage is measured using a digital multimeter. In this tool using the ADC which is already available in the microcontroller which is 10 bits. Sensor test results vary with the output voltage of the output and ADC output data. The following table shows the voltage that comes out of each sensor and ADC.

| Testing | Voltage Sensor (Volt) | Rs (kΩ) | Output data on ADC | Binary         | Decimal |
|---------|-----------------------|---------|--------------------|----------------|---------|
| 1       | 0.8                   | 52.5    |                    | 0010100011     | 163     |
| 2       | 1.1                   | 35.45   |                    | 0011100001     | 225     |
| 3       | 1.3                   | 28.46   |                    | 0100001010     | 266     |
| 4       | 1.5                   | 23.33   |                    | 0100110011     | 307     |
| 5       | 1.8                   | 17.77   |                    | 0101110000     | 368     |

To find the value of the sensor resistance (Rs) the formula is used:

Where:

\[ R_s = \text{sensor resistance (Ω)} \]
\[ V_c = \text{tool voltage (V)} \]
\[ R_l = \text{prisoner divider (Ω)} \]
\[ V_{out} = \text{Output voltage (V)} \]

With \( V_c = 5 \) Volts and \( R_l = 10k \) Ω

In this tool, the reference voltage used in the ADC is \( v_{ref} = 5 \) volts and the ADC resolution of 10 bits (1024), so that the ADC output based on the input can be calculated with the following equation:

\[ \text{ADC} = \frac{V_{out}}{v_{ref}} (1024) \]  

(8)

For a 0.8 volt sensor voltage, the ADC output is:

\[ \text{ADC} = \frac{0.8}{5} \times 1024 = 163.84 \]

For a 1.1 volt sensor voltage, the ADC output is:

\[ \text{ADC} = \frac{1.1}{5} \times 1024 = 225.28 \]

For a 1.3 volt sensor voltage, the ADC output is:

\[ \text{ADC} = \frac{1.3}{5} \times 1024 = 266.24 \]

For a 1.5 volt sensor voltage, the ADC output is:

\[ \text{ADC} = \frac{1.5}{5} \times 1024 = 307.2 \]

For 1.8 volt sensor voltage, the ADC output is:

\[ \text{ADC} = \frac{1.8}{5} \times 1024 = 368.64 \]
3.3. Android Smartphone Application Design Results
The file name Test_Emission.apk with a file size of 1.5MB, the name of the Emission Test file matches the function and usability of the application. Below is a file that has been exported from the App investor and has been copied and then installed from an Android smartphone.

![Figure 5. Interface of App Inventor](image)

**Figure 5.** Interface of app inventor

On the first page of the application, there is a button "select BT module" through which the user can connect the Android with a design tool via Bluetooth.

![Figure 6. Connect Android Applications with the HC-5 Bluetooth Module](image)

**Figure 6.** Connect Android applications with the HC-5 Bluetooth module

On the display, there are Bluetooth names that are active, then select "HC-05" to connect the Android smartphone with the device. Then the CO value will appear from the vehicle exhaust emissions test equipment.

3.4. Calibrate the Tool with a Standard Measuring Instrument
So that the measurement value is in accordance with the standard measuring instrument, it is necessary to do a calibration to compare the instrument with standardized instruments, namely the E4500 e...
instruments of Auto 2000 Medan, located at JaminGinting, Sidumulyo, Kec. Medan Tuntung, Medan. The image measuring instrument "Gas Analyzer" is like in the picture below.

![Image of a measuring instrument](image)

**Figure 7.** Standard tool "e instruments E 4500"

After completing the calibration design tool is used to test motor vehicle emissions with "e instruments E 4500" with the measurement results can be seen in the table below.

| Standard Tool Data (z) | Design Tool Data (x) | \( Y = z - x \) | \( x - \bar{x} \) | \( (x - \bar{x})^2 \) |
|------------------------|----------------------|----------------|----------------|-------------------|
| 647                    | 650                  | -3            | -12            | 144               |
| 660                    | 665                  | -5            | 3              | 9                 |
| 667                    | 671                  | -4            | 9              | 81                |

\[
\sum (x - \bar{x})^2 = 234
\]

\[
\delta = \frac{\sum (x - \bar{x})^2}{n - 1} = \frac{234}{2} = 10.816
\]

\[
UA_1 = \frac{\delta}{\sqrt{n}} = \frac{10.816}{\sqrt{3}} = 6.245
\]

The testing of this measuring instrument is comparing the concentration value of a standard device with a device made with the same gas source. From the table above, we can find the uncertainty value of measurement results (UA1) by first looking for a standard deviation value of 10.816 and uncertainty value of 6,245.

**Table 4.** Testing of measuring instruments for calculations

| X  | Y  | \( x^2 \) | \( Y_{reg} \) | R    | \( R^2 \) |
|----|----|----------|--------------|------|--------|
| -1950 | 422500 | -3.229   | -0.229      | 0.052 |
| -3325 | 442225 | -4.191   | -0.809      | 0.654 |
| -2684 | 450241 | -5.575   | 0.575       | 0.331 |

\[
\sum xY = -7959 \quad \sum x^2 = 1314966 \quad \sum Y_{reg} \quad \sum R = -24 \quad \sum R^2 = 1.037
\]

\[
= -11.995
\]
To find the value of uncertainty the regression approach ($UA_2$) must know the values of a and b. Value $b = \frac{n\sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2} = \frac{3 \times (-7959) - (1986 \times -12)}{(3 \times 131496) - 3944196} = -0.0641$ while $\bar{Y} - b\bar{x} = -4 - (-0.0641 \times 662) = 38.436$ value, the regression equation is $y = -0.0641x + 38.436$. To find the value of $R$ is $Y_{\text{Reg}} = a + bx = 38.436 - 0.0641x$, after that find the value of the sum square residual (SSR) is 1,037. Then the uncertainty value of the regression approach is 1.02.

![Graph of regression line](image)

**Figure 8.** Graph of Linear regression from carbon monoxide data collection

**Table 5.** Comparison of Design Tool Data with standard e instruments E 4500 in the first measurement with the vehicle number BK 6281 AAG

| Standard Tool Data (z) (PPM) | Design Tool Data (PPM) | $Y = z - x$ | $x - \bar{x}$ | $(x - \bar{x})^2$ |
|-----------------------------|------------------------|-------------|----------------|-----------------|
| 3210                        | 3157                   | 53          | -165.33        | 27334,001       |
| 3400                        | 3340                   | 60          | 17.67          | 312,228         |
| 3510                        | 3470                   | 40          | 147.67         | 21806,429       |

$$\delta = \sqrt{\frac{\Sigma (x - \bar{x})^2}{n - 1}} = \sqrt{\frac{49452.667}{2}} = 157.25$$

$$UA_1 = \frac{\delta}{\sqrt{n}} = \frac{157.25}{\sqrt{3}} = 90.788$$

A standard deviation of 157.25 and an uncertainty value of 90.788.
Table 6. Testing of measuring instruments for calculations

| xy   |  \( x^2 \)  |  \( Y_{\text{reg}} \) |  \( R \)  |  \( R^2 \) |
|------|-------------|-----------------|---------|---------|
| 167321 | 9966649 | -119.29   | 172.29  | 29683.84|
| 200400 | 11155600 | 69.2      | -9.2    | 84.64   |
| 138800 | 12040900 | 203.1     | -163.1  | 26601.61|

\[
\sum xY = 506521 \quad \sum x^2 = 33163149 \quad \sum Y_{\text{reg}} = -11.995 \quad \sum R = -0.01 \quad \sum R^2 = 56370.09
\]

To find the value of uncertainty the regression approach \((U_{A2})\) must know the values of \(a\) and \(b\) value \(b = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2} = 1.03\), while value, \(a = \bar{Y} - b\bar{x} = 51 - (1.03 \times 3322.33) = -3371\) the regression equation is \(Y_{\text{reg}} = a + bx = -3371 + \). to find the value of \(R\) is \(Y - Y_{\text{reg}}\), after that find the value of the sum square residual (SSR) is 56370.09. Then the uncertainty value of the regression approach is 28185.05

![Graph of Linear Regression](image)

**Figure 9.** graph of Linear regression from carbon monoxide data collection

Table 7. Comparison of Design Tool Data with standard E instruments of E 4500 in the first measurement with the vehicle number BK 3181 MAM

| Standard Tool Data (z) (PPM) | Design Tool Data (PM) | \( Y = z - x \) | \( x - \bar{x} \) | \((x - \bar{x})^2\) |
|-----------------------------|------------------------|----------------|----------------|----------------|
| 760                         | 750                    | 10             | -62,667        | 3927,111       |
| 770                         | 761                    | 9              | -51,667        | 2669,444       |
| 837                         | 927                    | 90             | 114,333        | 13072,111      |
the standard deviation is 99.168 and the uncertainty value is 57.255

Table 8. Testing of measuring instruments for calculations

| x   | x^2   | Y_reg | R    | R^2  |
|-----|-------|-------|------|------|
| 7500| 562500| -23.73| 33.73| 1137.13|
| 6849| 579121| -23.719| 32.719| 1070.533|
| -83430| 859329| -23.553| -66.447| 4415.2014|

To find the value of uncertainty the regression approach (UA_2) must know the values of a and b. value b = \( \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2} = \frac{3 \times (-69081) - (2438 x (-71))}{3 \times 2000950} - 5943844 \) = 0.001 while the value of a = \( \bar{Y} - b \bar{x} = (-23.667) - (0.001x812.667) = -24.48 \), the regression equation is \( Y_{Reg} = -24.48 + 0.001x \), the value of the sum square residual (SSR) is 6623.45. Then the uncertainty value of the regression approach is 3824.05

Figure 10. graph of Linear regression from carbon monoxide data collection
From the table above it can be seen that the standard deviation value at 10th second is 2375.32, at 12th second is 3318.42, and at 15th second is 2639.813. The measurement uncertainty value at 10 seconds is 1371.39, at 12 seconds is 1915.89 and at 15 seconds is 1524.14.

### 4. Conclusions

After testing and analyzing the data obtained, conclusions can be drawn including:

1. The tool can measure carbon monoxide emissions in motor vehicles with a TGS 2442 sensor.
2. Based on the results of sensor testing and testing of measuring devices, the measurement of carbon monoxide gas emissions in motor vehicles with the TGS 2442 sensor works well.
3. Based on the test measuring instrument, obtained the specifications obtained by standard deviation in the car BK 6776 PAN 10.816, the value of the uncertainty of the measurement results 6.245 while the value of the uncertainty of the linear regression approach is 1.02, the value of the standard deviation of the BK 6281 AAG 157 car .25, the uncertainty value of the measurement results 90.78 while the uncertainty value of the linear regression approach is 1.62, the standard deviation value of human body temperature is 0.89, the uncertainty value of the measurement results 0.16 while the uncertainty value of the linear regression approach is 0.37.

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### Acknowledgments

We would like to thank the instrument and digital laboratories as well as Shaffer laboratories who have provided supporting facilities and facilities to complete this research.