Multi-Channel Method of Non-isolated DC Voltmeter for EFI Instrument Measure

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Abstract. The use of instruments for vehicle repair is very important to use. However, the instrument is very expensive and many features are not used. So that in this study designed a simple measuring instrument that is able to measure the size of the sensor. The tool uses a 32bit based microcontroller integrated with bluetooth. There are 4 voltage gauge channels. The reading data is communicated to the graphic user interface (GUI) on the laptop device. The measuring instrument can record the measured sensor on a vehicle for 1 minute for analysis.

1. Introduction
The use of measuring instruments in repair activities is needed. Some tasks such as measuring battery voltage, voltage sensors, and measuring the pulse signal flowing to the actuator. When the vehicle controls the unit, the voltage value at the sensor output produces a variant from 0-5V. These measurements can be measured using a commonly used multimeter. When there is a change in voltage, the value of the change cannot be observed using an ordinary multimeter. So that we need an instrument that is able to display changes in the value of the sensors in the vehicle.

When testing the combustion engine, several sensor output voltages are not the same value. So that when 1 sensor changes the value of the fuel engine parameters such as temperature, fuel mixture, vacuum at the intake. This change in value causes a change in the value of the output voltage on the sensor. Changes in each sensor vary widely so that several sensors must be observed simultaneously [1]. Damage to 1 sensor can affect the output of the combustion engine in the form of power, torque, and emissions.

Instruments capable of displaying changes in sensor output voltage are still very expensive. The capabilities offered to exceed the need. So, it will be very difficult to own and redundant for a small vehicle repair shop. While the need for instruments is very important. Given today's vehicle technology, all devices are controlled using electronics.

This research focuses on the design of electronic systems for measuring 4-channel voltages, both for measuring the power supply voltage, sensors, and actuator signals. The sensor voltage output can be observed using a wireless line such as Bluetooth. This is done to isolate the view or logger with the measurement point [2]. Meanwhile, there is no output voltage measurement between channels. This is because vehicles that use 1 DC source come from batteries. Some basic literature is used to design voltmeter measuring instruments [3]. The microcontroller hardware uses the ARM Cortex M3 which features an analog to digital converter (ADC) as a conversion of the sensor voltage value into a readable value. The serial feature on the microcontroller is used to send measurement data.
2. Literature study

In the literature study, studies were carried out on the voltage divider, low-pass filter (LPF), ADC, microcontroller, and moving average filter. These components are the constituent of a digital voltmeter.

2.1 Divide Voltage and LPF

The use of the voltage divider circuit is intended to reduce the voltage that goes to the ADC feature on the microcontroller. The ADC input voltage is limited to the supply voltage on the microcontroller. The microcontroller used has a working voltage of 3.3V. While the voltage measurement is used to measure voltages above 25V. Of course, a good measuring instrument design is still able to measure the voltage above the working voltage of the measuring instrument. To be able to measure voltages above 3.3V, the measuring instrument is equipped with a voltage divider [4]. Figure 1 shows the LPF and buffers circuit using an operational amplifier (opamp) [5].

![Figure 1. Series of LPF and Buffer](image)

To calculate the voltage that enters the LPF circuit, it can be calculated using equation (1).

\[
V_{R1} = \frac{R_1}{(R_1 + R_2)} \times V_{in}
\]  

(1)

Where \(V_{R1}\) is the voltage at \(R_1\) (V), \(V_{in}\) is the input voltage (V). After the voltage is divided by the resistor, the voltage value is filtered using the LPF circuit. Equation (2) shows the 2nd Low-pass filter.

\[
f_C = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}}
\]  

(2)

Where \(f_C\) is the cut-off frequency (Hz). The use of LPF is to reduce noise entering the measurement process that comes from outside the measuring instrument. Because the measurement is made while the engine is running, the interference noise from the spark plug will greatly affect the sensor cable tension. Equations (3) and (4) show the buffer circuit equation in the LPF.

\[
V_{out} = V_{in}
\]  

(3)

\[
A_V = \frac{V_{out}}{V_{in}} = 1
\]  

(4)
Where $V_{out}$ is the output voltage (V), $A_V$ is the gain. In general, the buffer circuit has a gain = 1. The function of the buffer is to maintain the current flowing to the signal processing circuit such as the ADC.

### 2.2 Multichannel ADC

Equation (5) shows the ADC conversion that occurs in the ARM microcontroller.

$$ADC = \frac{V_{in}}{V_{ref}} \times (2^{bit} - 1)$$  \hspace{1cm} (5)

Where, $V_{ref}$ is the ADC reference voltage (V), $2^n$ is the width of the conversion data on the ADC. The $2^{bit}$ value on the microcontroller used is 12 bits or $2^{12}$ or 4.096 [6]. Equation (6) shows the voltage measurement results ($V_{meas}$) based on the ADC input calculation results.

$$V_{meas} = \frac{ADC}{(2^{bit} - 1)} \times V_{max}$$  \hspace{1cm} (6)

Where $V_{max}$ is the maximum voltage measured when the ADC value is 4095. Meanwhile, to get the ADC conversion sampling frequency ($f_s$) can be seen in equations (7), (8), and (9).

$$t_{ADC} = \frac{1}{ADC_{Speed}}$$  \hspace{1cm} (7)

$$t_{s_{ADC}} = t_{ADC} \times 2^{bit}$$  \hspace{1cm} (8)

$$f_s = \frac{1}{t_{s_{ADC}}}$$  \hspace{1cm} (9)

Where $t_{s_{ADC}}$ is the ADC sampling time (S), $t_{ADC}$ is the conversion rate time for 1 bit of ADC data (S), $ADC_{Speed}$ is the frequency of ADC conversion rate (Hz).

### 2.3 Multichannel ADC

Equation 10 shows the use of a moving average filter (MAF) as a smoothing voltage output. So that the noise that comes from the inner circuit is muted. Hardware damping is done by using LPF, meanwhile, in terms of data, filtering is done by using MAF.

$$MAF = \frac{(A_1 + A_2 + \cdots + A_n)}{n}$$  \hspace{1cm} (10)

Where, $A$ is the reading data in the order from 0 to n, while n is the maximum number of filtered data. Equation (11) shows the calculation of the voltage reading error (Error (%)).

$$Error \% = \frac{V_{sp} - V_{meas}}{V_{sp}} \times 100\%$$  \hspace{1cm} (11)

Where $V_{sp}$ is the voltage that should be (V), $V_{meas}$ is the voltage reading (V).

### 3. Methodology
The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

3.1 Design development
Figure 2 shows the design for developing measuring instruments that will be realized. In this study, it focuses on data processing carried out by the ARM microcontroller.

There are 4 voltage input channels with LPF and buffer. All measurement signals are entered in the multiplexer system before entering the ADC. In ARM, the readings are entered into the MAF. The MAF calculation result data is sent to the GUI via Bluetooth.

The research in this paper only focuses on the filter method for voltage measurement purposes. The filter uses the LPF as a signal filter, while the MAF is the data filter read on the ADC.

3.2 Microcontroller spesification
Table 1 shows the microcontroller specifications and ADC features used. The type and resolution of the ADC feature determine the result of the voltage reading on the sensor.

| Parameter       | Description               |
|-----------------|---------------------------|
| Architecture    | ARM 32-bit Cortex         |
| Speed           | 72 MHz                    |
| Conversion range| 3.6V                      |
| Resolution ADC  | 12-bit                    |
| ADC Type        | Successive approximation  |
| Clock ADC       | 14 MHz                    |
| $T_s$           | 13.5 cycle                |
| $t_s_{ADC}$     | 0.96 μS                   |
| $f_s$           | 1 MHz                     |

Microcontroller architecture using ARM 32-bit with a clock speed of 72 MHz. The working voltage on the microcontroller is 3.6V. The type of ADC integrated into the microcontroller is a successive approximation type with a clock speed of 14 MHz.

3.2.1 Buffer and Low-pass Filter
Figure 1 shows the LPF design with a buffer. Where there are 4 input options, each of which has a maximum measurement of 5, 10, 25, and 50V. Figure 3 shows the gain of the LPF based on the input frequency. Noise in the form of interference with the addition or reduction of the voltage value with a high enough frequency. This means that noise with high frequencies or above 150 Hz will be attenuated to 0.
4. Result and discussion
Figures 4 to 7 show the results of ADC measurements and the use of MAF with 10 data on average. Where in the measurement results there are quite large deviations, whereas when using MAF, the reading result value has a smaller deviation than not using MAF. The greater the voltage value, the greater the deviation. this can be caused by the multiplication factor in equation (6). The measurement results are obtained when measuring 1 channel. For 4 channels it is assumed the same because it uses the same design.

Tables 2 to 5 show the results of measuring errors in each condition.

| Table 2. Error measuring a maximum of 5V | Table 3. Error measuring a maximum of 10V |
|----------------------------------------|----------------------------------------|
| \( V_{\text{ref}} \) (V) | \( V_{\text{meas}} \) (V) | Error (%) | \( V_{\text{ref}} \) (V) | \( V_{\text{meas}} \) (V) | Error (%) |
| 0.40 | 0.40 | 0.93691 | 0.80 | 0.81 | 0.92221 |
| 0.80 | 0.80 | 0.46845 | 1.60 | 1.61 | 0.46110 |
Table 4. Error measuring a maximum of 25V

| $V_{ref}$ (V) | $V_{meas}$ (V) | Error (%) |
|----------------|----------------|-----------|
| 2.00           | 2.02           | 0.75686   |
| 4.00           | 4.02           | 0.37843   |
| 6.00           | 6.02           | 0.25229   |
| 8.00           | 8.02           | 0.18921   |
| 10.00          | 10.02          | 0.15137   |
| 12.00          | 12.02          | 0.12614   |
| 14.00          | 14.02          | 0.10812   |
| 16.00          | 16.02          | 0.09461   |
| 18.00          | 18.02          | 0.08410   |
| 20.00          | 20.02          | 0.07569   |
| 22.00          | 22.02          | 0.06881   |
| 24.00          | 24.02          | 0.06307   |
| 25.00          | 25.02          | 0.06055   |
| **Average**    |                | **0.18533**|

Table 5. Error measuring a maximum of 50V

| $V_{ref}$ (V) | $V_{meas}$ (V) | Error (%) |
|----------------|----------------|-----------|
| 4.00           | 3.97           | 0.76427   |
| 8.00           | 7.97           | 0.38214   |
| 12.00          | 11.97          | 0.25476   |
| 16.00          | 15.97          | 0.19107   |
| 20.00          | 19.97          | 0.15285   |
| 24.00          | 23.97          | 0.12738   |
| 28.00          | 27.97          | 0.10918   |
| 32.00          | 31.97          | 0.09553   |
| 36.00          | 35.97          | 0.08492   |
| 40.00          | 39.97          | 0.07643   |
| 44.00          | 43.97          | 0.06948   |
| 48.00          | 47.97          | 0.06369   |
| 50.00          | 49.97          | 0.06114   |
| **Average**    |                | **0.18714**|

Table 2 shows when the maximum measurement of 5V has an error of 0.22941%. Table 3 shows that when the maximum measurement of 10V has an error of 0.22581%. In Table 4, it shows when the maximum measurement of 25V has an error of 0.18533%. Table 5 shows when the maximum measurement of 50V has an error of 0.18714%. The greater the maximum measurement value, the smaller the error that occurs. This is because the scale factor is the difference in the calculation of equation (11).

5. Conclusion

Based on the test results using the LPF and MAF on the microcontroller, good results were obtained. Where there is an average error for the maximum voltage measurement of 5V of 0.22941%, 10V of 0.22581%, 25V of 0.18533%, and 50V of 0.18714%. The reading error shows that the measurement results are close to accuracy. However, if you look at the graph, the measurement results have not shown good precision.

6. Acknowledgements

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7. References
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