Realtime IoT based Harmonics Monitoring System Review with Potential Low-Cost Devices with Experimental Case Study

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ABSTRACT

This paper presents a harmonic analyzer that used IoT and smart apps for low-cost and portable solutions. We contribute a short review of harmonics measurement methods and experimental approaches for monitoring harmonics using an IoT-based system. The proposed device was built from a current sensor, a voltage sensor, and a microcontroller with an IoT transmitter which is integrated with Matlab© cloud and smart apps (android). In specific, we experimented with testing and validated our proposal using the standard instrument under a fair treatment. The measurement scenario was taken on the point of comment coupling in the building campus for 5 to 10 minutes of each comparable instrument. Based on experimental results, the proposed device could monitor the harmonics profile drawn by the loads in the building campus. The trade-off between cost and performance is founded as the truth that it takes about 1 minute to update the harmonics data. Furthermore, the average error of THDV is 5.7%, and THDI is 4.7% which is higher than the expensive instrument. These values are acceptable based on IEEE standards. Besides, it could monitor harmonics in real-time through an android application which is easy to use and portable. In addition, the cost of making the proposed device is cheap compared to the price of the standard instruments in the market.

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1. INTRODUCTION

The use of nonlinear load that concluding semiconductor and coil components such as laptop, computer, Adjustable Speed Drives (ASD), Variable Frequency Drives (VFD), Switch Mode Power Supply (SMPS), electric motor significantly increasing. It is because of global trend develops smart grid systems, smart tools, and Electrical Vehicles (EV) [1]. The use of nonlinear load produces harmonic in electric power systems. The harmonic caused some troubles, as in research [2-4]. Research that decreasing harmonic also has been done in research [5-7]. However, the impacts of harmonic tend to be ignored by users because there is no monitoring system for the electrical signal quality provided by the electrical providers [8]. Even though electrical energy monitoring system becomes an important subject to give information to users [9]. The measurement of harmonic usually uses harmonic analyzer like in Goh's research, etc. [10]. The harmonic analyzer has some lacks which are expensive, hard into integrated into the SCADA system, and cannot be used to monitor long distances in real-time [11]. Research in [11-14] shows the power and harmonic measurement yet need expensive hardware, hard to find, and cannot be used in monitoring long distances in real-time. Table 1 shows the comparisons of those related instruments.

Table 1. Short Review

Reference	Processor	Method	IoT	Display From
[11]	LabView	Stockwell	No	PC (LabView)
[15]	ADE 7880	Not explained	Yes	PC
[16]	Intel Galileo and MATLAB	DFT	No	PC (Matlab)
[17]	Arduino UNO, Harmonic Analyzer, LabView	FFT (calculate from harmonic analyzer)	No	PC (LabView)
[18]	Intel Galileo	DFT	No	LCD
-	Power Quality Analyzer Fluke 1735	DFT	No	LCD

The research discusses harmonic measurement that has been done by a lot of researchers. AuthorS [11] made a prototype of THD_I monitoring using a CT-235 current sensor. ADAM-3968 converter A/D PCI-170HGU took sampling data of CT-235 current sensors and sent it into a personal computer (PC945GCM-S2L). A personal computer that integrated with LabView software received it, transforms sensor data to the frequency of domain using Stockwell transformation, and showed a value of the harmonic. Authors in [15] made a prototype of harmonic monitoring using PT, CT, IC ADE 7880 known as polyphase multifunction energy metering IC with harmonic monitoring). Zigbee collected the harmonic data and sent it into the Zigbee receiver, then is forwarded to users through Global System for Mobile Communication (GSM) technology.

Authors in [16] made a monitoring prototype of THDI in a car inverter using an ACS sensor. Intel Galileo took sampling data of ACS current sensor then sent it to Matlab© using data cable. Matlab© receives that sampling data and transforms it to the frequency of domain using the Discrete Fourier Transformation (DFT) method to analyze the harmonic. DFT is defined as a discrete signal sequence in the X(m) frequency domain, represented in exponential form. The discrete signal sequence is a sequence of values obtained from the continuous (analog) signal sampling process. The DFT equation can be written as

$$X(m) = \sum_{n=0}^{N-1} x(n).e^{-\frac{j2\pi nm}{N}} \tag{1}$$

Where $e^{-j2\pi nm/N}$ can be changed to (2) Euler for easy calculation. Equation (2) is substituted into (1), giving (3).

$$e^{-j\theta} = cos(\theta) - j\,sin(\theta) \tag{2}$$

$$X(m) = \sum_{n=0}^{N-1} x(n).[cos(2\pi nm/N) - j\,sin(2\pi nm/N)] \tag{3}$$

The DFT method requires N^2 processes to complete N computation (sample data). If there are 8 sample data, it requires 64 times the process. This causes the process of the DFT method to take a long time. Calculate of THDI based on IEEE standard, and THD_I result showed in Matlab©. In [17], they made a smart energy meter for power quality monitoring using a voltage sensor (step down transformer with voltage distribution coil), current sensor (ACS712-30A), measuring harmonic data using a harmonic analyzer that showed through a personal computer. Author in [18] presents the design and experimental Low-Cost Harmonic Analyzer (LCHA) on a car inverter. Researcher in [19][20] Interfacing of MATLAB with Arduino. However, the IoT system in that study has not been implemented.

In this paper, we present a portable harmonic monitoring device by applying IoT and Matlab© Cloud technology. These are some of the things that are our contribution to this paper. We introduce a brief overview of the harmonic measurement method with an experimental approach based on device design. We present design results and experimental results validated with standard harmonic equipment.

The rest of this paper is organized as follows. Section 2 describes the research methods, followed by the results and analysis in section 3. Finally, the conclusion is in section 4.

2. RESEARCH METHOD

2.1. System Description

Fig. 1 shows a block diagram of the proposed harmonics instrument. The proposed system consists of hardware and software sections. The hardware consists of voltage and current sensors for measuring voltage and current, respectively, and the microcontroller with an IoT transmitter. The software is built for microcontrollers and smart apps on the android system, including for Matlab© cloud and google spreadsheet. The proposed system working principles is as follows. The measured voltage and current are sent to the microcontroller through an ADC pin. The microcontroller took sampling data of sensor in every 1 period 20 ms (frequency 50 Hz) as much as 512 data and sent to the Matlab© cloud database for further computation. The Matlab© received transformed sampling data of the time domain into the frequency domain using the FFT method and calculates the THD value focused on the frequency 50-650 Hz (1st–13th). The equation (4) and (5) is THD analysis based on IEEE 519. Fig. 1 shows the flowchart in Matlab©.

$$THDV = \frac{\sqrt{\sum_{n=2}^{N} V_n{}^2}}{V_1} 100\% \tag{4}$$

$$THDI = \frac{\sqrt{\sum_{n=2}^{N} I_n{}^2}}{I_1} 100\% \tag{5}$$

where N is the frequency of focus, V_1 represents RMS fundamental voltage (V), V_n is the RMS voltage in the frequency of focused (V), I_1 is the RMS fundamental current (A), V_n is RMS current infrequency of focused (A). Finally, the results are sent to the google spreadsheet before being loaded into android smart apps.

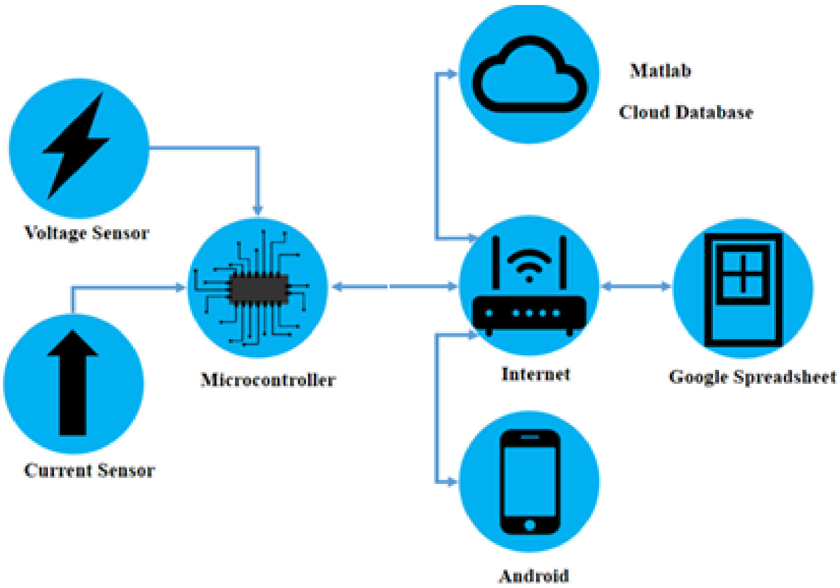


Fig. 1. Proposed IoT-Based Harmonic Instrument

2.2. Hardware Prototyping

Based on Fig. 1, the hardware used for harmonic measurement consists of sensors, a microcontroller with an IoT transmitter, and a router and smartphone. Those are connected and configured according to Fig. 1. The prototype of the proposed system is depicted in Fig. 2. Table 2 describes the device wiring diagram. Voltage sensor is ZMPT101B module with input rated (RMS) 250 VAC, turns ratio 1000:1000, linearity <0.2% (20% dot~120% dot). Output sensor of voltage in analog signal 0-5 V with offset voltage 2.5 VDC (if it uses VCC 5 V). For example, in research [21][22] that using the module of voltage sensor ZMPT101B. The current sensor is SCT-013-000 with input rated (RMS) 100 A, turns ratio 1:2000, linearity <0.2%. For example, current sensor SCT-013-000 in research [22][23]. The current sensor has output in the current signal. However, it has to be converted into a voltage signal so that it can be read by the microcontroller.

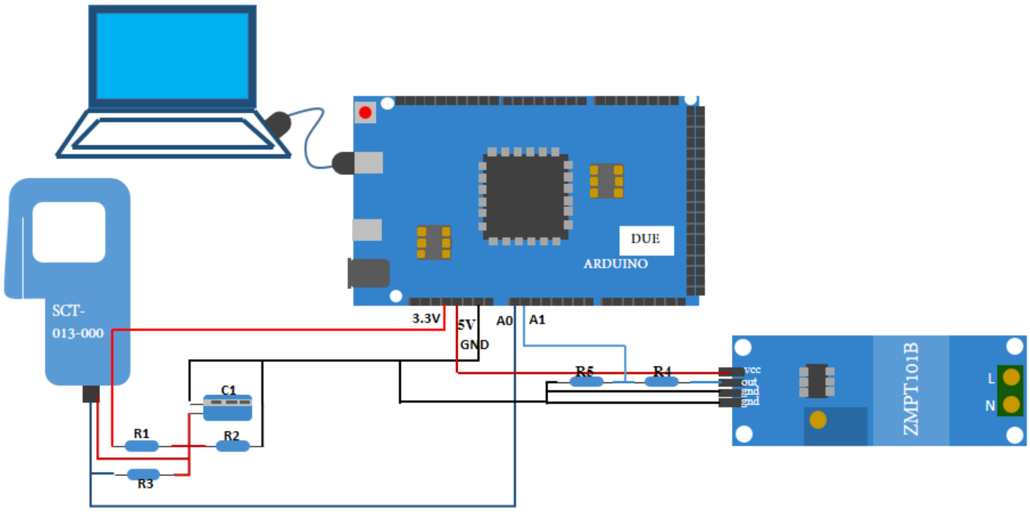


Fig. 2. Hardware Set-up and prototyping

Table 2. Hardware specification

System	Component Name	Component Parts	Description
Current Sensor	SCT-013-000	R1	10 kΩ
		R2	10 kΩ
		R3	38 Ω
		C1	10µF /16 V
		Voltage Source	3.3 VDC
Voltage Sensor	ZMPT101B	R4	1 kΩ
		R5	1 kΩ
		Voltage Source	5 VDC
Microcontroller	Arduino	Voltage Source	from laptop USB connection
Data Processing	Matlab©		
Microcontroller and Matlab© Connection for (programming and setting only)	Data Cable		
Matlab ©, Database, Android Connection	Internet		

Fig. 3 shows an additional current sensor circuit (burden resistor) which is used to change the output signal. In specific, R3 in Fig. 3 is determined by:

- Determine the maximum current. In the system, the maximum current is limited to 60 A.
- The maximum IRMS value is changed to the peak value.
  = 60 A * √2
  = 84.85 A
- The result of the peak current of the primary coil is divided by the sensor winding, which is 2000 turns.
  = 84.85 / 2000
  = 0.0424 A (secondary coil peak IRMS).
- The reference voltage is 3.3 VDC, so the calculation of the ideal load resistance:

= (AREF/2) / secondary current peak
= (3.3 V / 2) / 0.0424
= 1.65 V / 0.0424
= 38.91 Ω

The microcontroller is Arduino with the mainboard based on Atmel SAM3X8E ARM Cortex-M3 CPU, operating voltage 3.3 VDC, clock speed 84 MHz, ADC resolution 12 bit, completed by IoT transmitter.

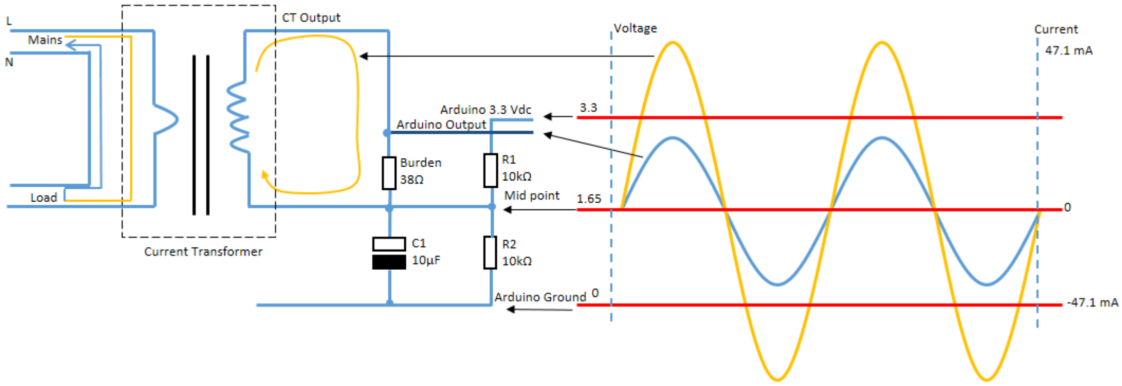


Fig. 3. Additional Circuit of SCT-013-00 (Burden Resistor)

2.3. Software Development

Software is developed and embedded in the microcontroller for the sampling process and sending data to the cloud. The execution process is assisted by an Android smartphone application which is developed as a user-friendly intermediary with its users. This android application is useful for accessing the cloud to carry out data processing and inputting data to a google spreadsheet then, the resulting harmonic profile is displayed to the smartphone in the form of a bar graph. Matlab© cloud performs FFT computation according to the flowchart in Fig. 4. The final target is to obtain current and voltage distortion values according to equations 3 and 4. Moreover, Matlab© sends THD (%) value to google sheet through URL. The FFT method produces a rectangular number (a + jb). The rectangular number will be converted to a magnitude value. Matlab© has an abs function to find the magnitude value. The THD is calculated based on the RMS value, so the magnitude must be converted into an amplitude value then divided by 1.414.

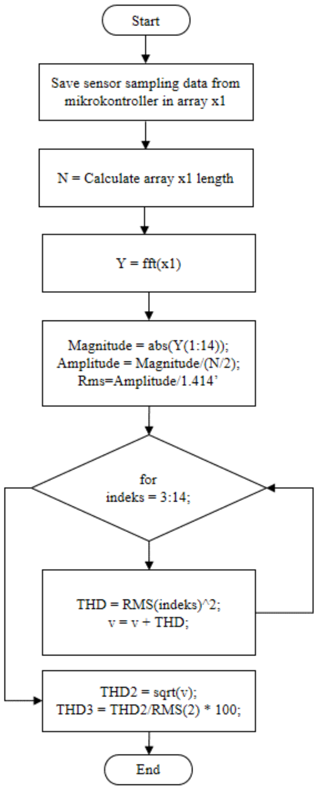


Fig. 4. FFT Computation

Google sheet received, saved the data in a sheet, then sent it into a cloud database using JSON (Javascript Object Notation) data transmission format. The saved data in the cloud database will always be updated as long as the system is working. Users can monitor the harmonics using the android application as long as it is connected to the internet network. The android application was developed by using Android Studio released by Google, Inc.

2.4. Experiment Scenario

We experimented with the following scenarios, as illustrated in Fig. 5. Direct measurements at the point of common coupling (phase R) of lecture and practice buildings (B12) at the State University of Malang. The data is taken from the central panel of the building right at the incoming electricity to the building. Monitoring experiments were carried out in real-time for 5 minutes to 10 minutes and were carried out several times. This data collection is scheduled when the building is full of lectures and practicum activities so that various existing loads produce harmonics that can be detected by the proposed system. In addition, equation (6) is used to determine the accuracy of the measurement error of the device by comparing actual data using the Three-Phase Power Quality Analyzer Fluke 1735.

$$E_{rr} = D_{Three-Phase\ Power\ Quality\ Analyzer} - D_{system} \quad (6)$$

After the experiment, we performed the mean analysis and compared it with the standard harmonic equipment to see the difference in measurements of the developed device. The selection of this standard device is also part of the comparison with competitor methods based on DFT with represented by Power Quality Analyzer Fluke 1735.

Fig. 5. Experiment. Measurement data was taken on 07/12/2020 10:47:30 until 10:56:30

3. RESULTS AND DISCUSSION

A brief review of the introduction has shown the most method used for harmonic monitoring is DFT. However, DFT requires large memory and processor for sampling and computation. To provide a low-cost solution, the FFT method was developed and integrated with the IoT-could solution to reduce the memory on computation tasks.

Based on our development, the cost for hardware and software is around IDR 555000, which is eighty-one times compared to the price of one of the Harmonic Analyzers, LUTRON DW-6095. It is because the software used is free of charge, and the bill is only for hardware. In specific the Matlab © is used only for the development phase, while the running system used the cloud https://www.mathworks.com/solutions/cloud.html that could be free for research and academic purposes.

Table 3 shows that the lowest THDi was 5% at 10:52:05 and the highest was at 10:56:30 which reached 11%. A high THDi indicates the presence of a harmonic load at work. According to the IEEE Std 512 standard, the allowable THDi is around 2.5%. Based on these measurements, we can conclude that the harmonics in the lecture building have exceeded the allowable threshold. It is necessary to install a harmonic filter on the PCC to reduce the current distortion.

Table 3. THDV and THDI measured by the proposed instrument

Time	THDV	THDI
10:47:30	5%	24%
10:49:20	10%	24%
10:50:12	9%	23%
10:51:21	6%	29%
10:52:04	6%	27%
10:53:05	5%	23%
10:54:06	10%	24%
10:55:00	6%	31%
10:55:49	7%	29%
10:56:30	11%	31%

Table 4 and Table 5 respectively are the results of the comparison of measurements of THDi and THDv using the FFT (proposed system) method with the DFT method (comparison), where in general, there is a difference in measurements that exceeds 3% and 2%, respectively. When examining Table 3 further, the comparison technique produces harmonic readings of THDi below 2% and THDv above 20%.

Table 4. THDV comparison

Time	THDV		Err (%)
	FFT (%)	DFT (%)	
10:47:30	5	1.9	3.1
10:49:20	10	1.9	8.1
10:50:12	9	1.8	7.2
10:51:21	6	1.9	4.1
10:52:04	6	1.9	4.1
10:53:05	5	1.9	3.1
10:54:06	10	1.9	8.1
10:55:00	6	1.8	4.2
10:55:49	7	1.8	5.2
10:56:30	11	1.8	9.2
Average Error			5.64

Table 5. THDI comparison

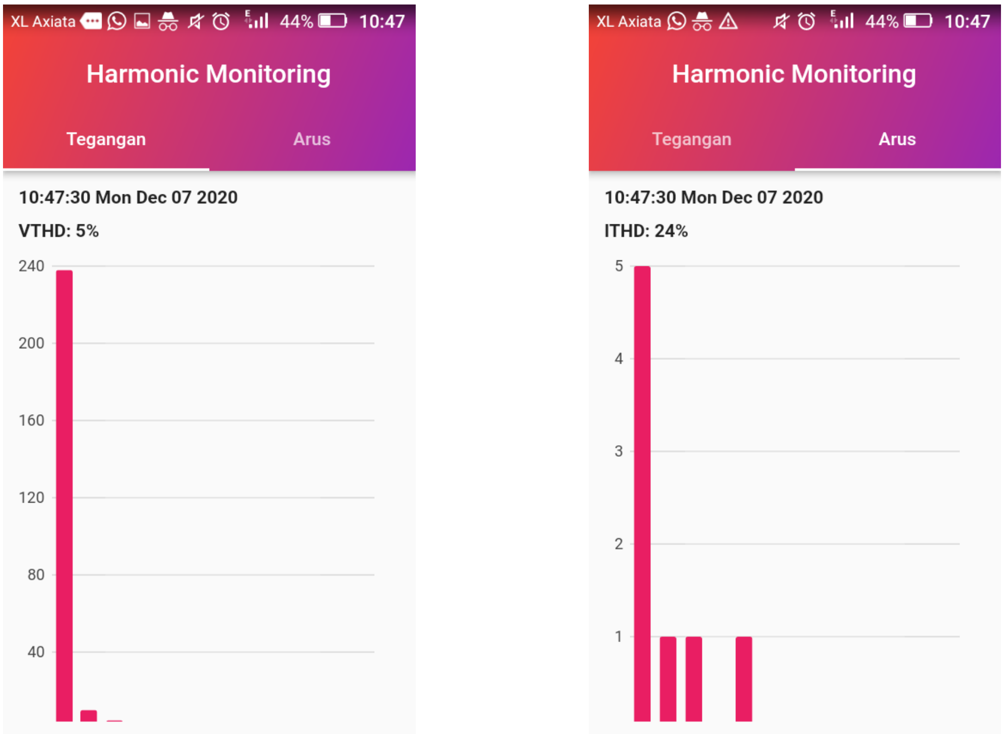
Time	THDI		Err (%)
	FFT (%)	DFT (%)	
10:47:30	24	22	2
10:49:20	24	22.8	1.2
10:50:12	23	21.8	1.2
10:51:21	29	20.7	8.3
10:52:04	27	21	6
10:53:05	23	21.4	1.6
10:54:06	24	22.7	1.3
10:55:00	31	22	9
10:55:49	29	21.8	7.2
10:56:30	31	22.8	8.3
Average Error			4.5

Vol. 7, No. 2, August 2021 pp. 259-268

In general, it can be seen that the results of the THDi and THDv measurements using the FFT method are less precise than the DFT method. This happens because the number of sampling is different between the two instruments being compared. The proposed instrument aims to pursue a low-cost market. Of course, this results in a trade-off in its performance that cannot beat the DFT technique on a very expensive comparison instrument.

More specifically, the experiment showed that the THDV mean error was around 5.64% (Table 3) and the THDI average error was 4.5%. For a cheap device, this is certainly very good considering that the developed instrument only requires 1/81 times smaller than the DFT instruments on the market. On the other hand, increasing the precision and accuracy of measurements means that it requires more expensive investments in processors, memory, and supporting devices.

Fig. 6 shows the display of the THDI (a) and THDV (b) harmonic profiles on android. Each bar in this diagram shows the magnitude of the harmonics in %, which the more to the right, the greater the frequency. This frequency is a multiple of n times the 50Hz source frequency. The display on the graph is sufficient to represent the information needed to represent harmonics.



(a) THDv (b) THDi

Fig. 6. Harmonics profile on Android smartphone. Time (day, date, month, year), THDV, THDI, and RMS value in frequency on focused (50-650 Hz). The X-axis shows the frequency of observations (1st-13th), and the Y-axis shows the RMS value.

4. CONCLUSION

In conclusion, the research shows the design of a harmonic monitoring system with low-cost devices that are implemented at the B12 building of Electrical Engineering, Universitas Negeri Malang, using an IoT system. This system shows the result of harmonic monitoring in real-time. It can be accessed anytime through android as long as it is connected to the Internet network. Based on the test, the average THDV error is 5.7%, and THDI is 4.5%, and it takes about 1 minute to update the harmonics of data in real-time.

In the future, the selection of current, voltage, and microcontroller components can use other components with good accuracy to reduce reading errors and speed up the computing process and the data transmission. The harmonics analysis process can use a microcontroller with high specifications such as Raspberry Pi. Harmonics monitoring application can also be developed into a data logger so that previous data can be stored.

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