An asynchronous interrupt driven sampling technique for a practical monitoring system of power-line single-phase voltage and current signals

Hari Arief Dharmawan, Arinto Yudi Ponco Wardoyo, Chomsin Sulistya Widodo
Department of Physics, Faculty of Mathematics and Natural Sciences, Brawijaya University, Malang, Indonesia

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ABSTRACT

A practical monitoring system implementing an asynchronous interrupt driven sampling technique has been developed in this research. This system is intended to acquire power-line single-phase voltage and current signals as well as their related information such as RMS values and harmonic contents. The system uses a voltage transformer and a current transducer to acquire the signals of the voltage and current. A microcontroller is used in the system to perform acquisition processes, calculation, and wireless data transmission. The design activities include the development of hardware of the system and software in the microcontroller as well as monitoring software with Bluetooth technology that will run on portable devices. As part of the research, a new sampling technique was developed to provide constant and precise timings during the acquisition processes. In this technique, some peripherals related to the acquisition process were driven asynchronously using interrupt mechanisms. Some experimentation has been carried out, and the result showed that the system implementing this technique could successfully manage the timings for the synchronous acquisition sequences. Furthermore, the use of the Bluetooth interfaces in the system allowed practical monitoring process to be performed using portable devices.

Corresponding Author:

Hari Arief Dharmawan
Department of Physics, Faculty of Mathematics and Natural Sciences, Brawijaya University
Veteran Street 2, Malang, East Java, 65145, Indonesia
Email: hari_arief@ub.ac.id

1. INTRODUCTION

Monitoring systems are currently implemented in many areas. Some related research such as discussed in [1]–[13] have been carried out and presented unique techniques in the area of power electronics. Power-line voltage and current monitoring is one example of monitoring activities that are widely implemented. When a power-line voltage and current signals are monitored, a reliable analog to digital sampling system will be needed. The accurate timings of the sampling process are critical, as it would affect the value of digital data as the representation of the instantaneous signal amplitudes. Errors due to the timings will reduce the accuracy of the attained digital data as well as the measured values. Furthermore, the use of the hardware and the design of circuit should also be considered in order to provide the monitoring system that will suit a practical need.

During this time, monitoring activities are widely done remotely. Many remote monitoring systems are supported by technology advancement and innovation especially in the areas of electronics and software. Wireless technology is used globally as alternatives to wired technology for power monitoring such as presented in [14]–[16]. Among many wireless technologies, Bluetooth technology is increasingly implemented especially in portable devices. Bluetooth is also used for communicating devices on a big scale; that is for the internet of things [17]. In [18]–[22] shows the application of Bluetooth for monitoring in the areas of the power system as well as medical.

In this research, a monitoring system of power-line single-phase voltage and current signals was developed. This system is intended to be implemented as a practical monitoring system that will provide reliable data as the representation of the signals. A microcontroller is used in the system to perform acquisition processes, calculation, and wireless data transmission. The design activities included the development of hardware of the system and software in the microcontroller as well as monitoring software that would run on portable devices. An asynchronous interrupt driven sampling technique was developed to support the developed system. Some main advantages are expected from this system, i.e.:

– The system can be easily developed by implementing a simple and low power microcontroller with the built-in analog to digital converter (ADC). Common microcontrollers have an asynchronous multi-channel ADC.
– The system allows portable devices to monitor not only the important parameters related to the acquired signals, such as RMS values, maximum values, minimum values as well as harmonic contents, but also the waveform of the signals itself.
– The monitoring processes can be carried out with ease by using commonly available portable devices such as handphones, as many current portable devices contain a Bluetooth interface.
– By acquiring the signals and sending them to portable devices, the calculation processes in the microcontroller can be minimized to get the important parameters. The application in the portable devices, on the other hand, can be programmed to execute more complex calculation functions such as fast fourier transform (FFT).

2. HADWARE DESIGN AND DEVELOPMENT

The design of the proposed monitoring system is depicted in Figure 1. In Figure 1, the area within the dashed line is the hardware of the system that was designed and developed for the research purpose. The microcontroller ATMEGA128 becomes the major part of the circuit. This microcontroller was programmed to perform acquisition of analog voltage and current signals that are sent by a voltage transformer (VT) and a current transducer (CT). The ATMEGA128 is an 8-bit microcontroller which is able to perform analog to digital conversions through its internal peripheral with a resolution of up to 10-bit. There are eight channels of analog inputs available in this microcontroller, and two of them (ADC0 and ADC1 input pins) are used for the acquisition purposes in this research. The ATMEGA128 contains 4 timers, and one of them is implemented to provide constant and precise timings during the acquisition processes. The random-access memory (RAM) in this microcontroller has a size of 4 kBytes which is sufficient for storing the digital data of the voltage and current signals for one sampling sequence. The microcontroller is re-programmed through in-system programming (ISP) interface using a computer.

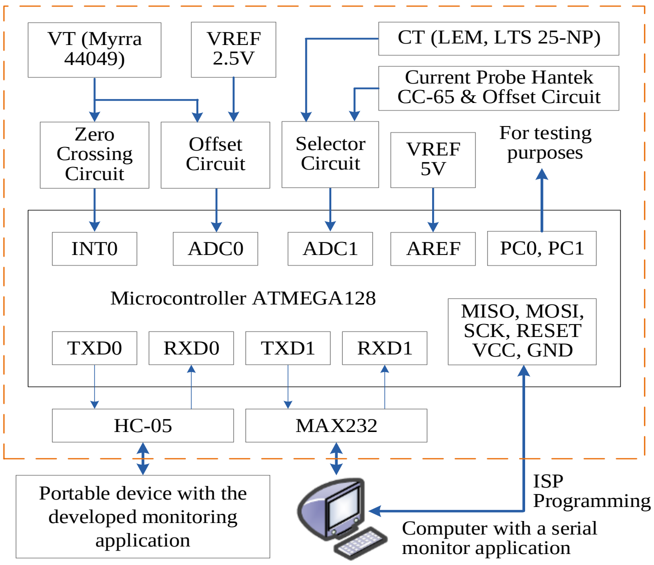


Figure 1. The design of the monitoring system

To acquire a power-line voltage signal, the voltage transformer myrra 44049 is used. This transformer provides electrical isolation between the power-line and the low voltage circuit containing the microcontroller. The transformer has an input voltage rating of 230 V and an output of 6 V. Because this transformer is a PCB mounted transformer, it will be easy to place it in the developed PCB for the circuit. Next, the current signal is acquired by the implementation of the current transducer LEM LTS-25-NP. This transducer requires a single 5 V supplies and provides a voltage output that is proportional to the input current. This output varies from 0-5 V with the center of about 2.5 V that will be outputted when the input current is zero. This transducer is also a PCB mounted transducer with six legs that can be configured to carry a maximum current of 8 A, 12 A or 25 A. The three other pins in this transducer are used for supplying the voltage of 5 V to the transducer and attaining the output voltage from the transducer. In the design and developed circuit of the system, an alternative way of measuring the current is provided. In this case, a current probe hantek CC-65 is used. This probe is in the form of a clamp which will enable measurement of current without disconnecting or ruining the electrical wires which connect the load and the power-lines. The hantek CC-65 has an input/output relation of either 1 mV/10 mA or 1 mV/100 mA. This probe can be used to measure the AC as well as DC currents of up to 65 A, with the frequency of up to 20 kHz.

The output signal from the VT is sent to the zero-crossing circuit and offset circuit. Figure 2 shows the schematic of these circuits. The zero-crossing circuit will produce a digital output that will inform the microcontroller when the zero crossing of the voltage signal occurs. This circuit contains an integrated circuit (operational amplifier LM339) which is used as a comparator. Before entering the comparator, the input signal is passed through a voltage divider (using R1ZC and R2ZC) so that a suitable lower voltage can be attained. A zener diode is added in this circuit to limit the output voltage of the voltage divider to about 2 Volts. The offset circuit, on the other hand, is implemented to achieve an output variation of the voltage between 0-5 Volts, so that it is suitable for the analog input range of the microcontroller. With this circuit, a zero voltage on its input will produce an output of 2.5 V. This voltage becomes a dc offset voltage as an alternating voltage is provided to the input of the circuit. The offset circuit also contains a voltage divider circuit (using R1VT and R2VT) to lower the voltage from the transformer. To achieve the 2.5 V dc offset, a voltage of 2.5 V is applied to the circuit (VREF 2.5 V). A voltage reference integrated circuit, i.e., LT1019 2.5 V is used to achieve the constant voltage of 2.5 V required by the offset circuit. Another voltage reference is also needed in the system (VREF 5 V), that is for the reference voltage of the ADC. In this case, an integrated circuit LT1019 5 V is implemented.

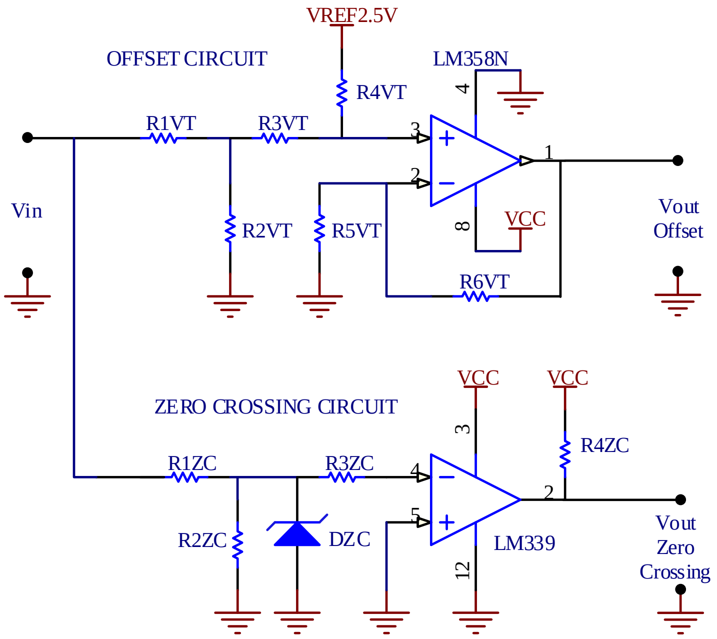


Figure 2. The zero-crossing circuit and offset circuit

The digital data representing the signals of voltage and current are temporarily stored in the RAM of the microcontroller during an acquisition sequence. After one acquisition sequence has been completed, the data are processed and formatted into strings that will be sent wirelessly through the Bluetooth module HC-05. This module is connected serially to the microcontroller through the TxD0 and RxD0 pins and a serial port protocol (SPP) is used to transfer the data. The module contains a UART interface with the baud rate that can be programmed. The HC-05 has some advantages such as it can be configured as a master or slave, easy to connect to the digital input/output of the microcontroller and there is no need for complicated settings for the operation.

In the designed system, an RS232 interface is provided through the use of an integrated circuit MAX232. This interface will enable the system to be configured by a computer. This interface is also used for debugging purposes during the development and revision of the software in the microcontroller. In addition to this interface, two pins on the microcontroller (PORTC0 and PORTC1) are used for multi-purpose digital outputs, and one of this purpose is for testing the acquisition timings during the development of the system. The prototype of the developed system can be seen from Figure 3.

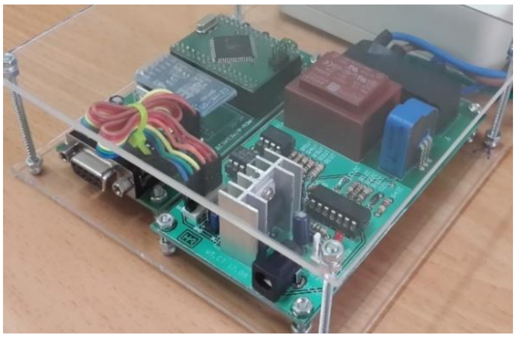


Figure 3. The prototype of the developed system

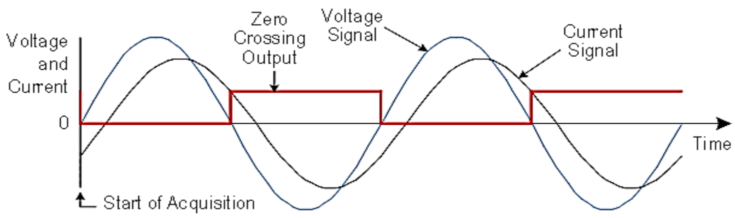
3. AN ASYNCHRONOUS INTERRUPT DRIVEN SAMPLING TECHNIQUE

In order to attain accurate sampled signals of the voltage and current, an acquisition technique was developed in this research. This technique was an enhancement of the previous technique developed by the writer [23], [24]. In this technique, some peripherals related to the acquisition process were driven asynchronously using interrupt mechanisms. One acquisition sequence, in this case, will be defined as a sampling sequence within two periods of the voltage and current signals that is periodically done by the microcontroller in order to attain the parameters of the signals. One acquisition sequence will produce 256 samples for both current and voltage signals. Each acquisition sequence is initiated with the transition of digital output from the zero-crossing circuit, i.e., by either using falling edge or rising edge. Figure 4 depicts the relation between the expected output of the zero-crossing circuit and the acquired voltage as well as current signals. It can be seen from this figure that when the falling edge is used, the sampling will begin from the positive part of the voltage signal. On the other hand, when the negative part of the voltage signal is chosen to be sampled first, then the rising edge is used.

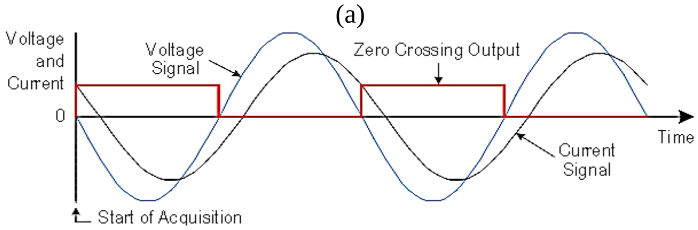
Timings for sampling the signal for every acquisition sequence are controlled by the executions of interrupt service routine (ISR) in the program of the microcontroller. In this case, the ISRs are related to the implemented peripherals inside the microcontroller, i.e., the external interrupt (INT0), timer (T1) and ADC. The ISR related to the external interrupt is programmed so that it will be executed when the transition of zero crossing output occurs. The ISRs of the timer and ADC consecutively will be executed when the timer overflows and the end of the analog to digital conversion finishes. Figure 5 shows the proposed technique for the acquisition sequence. As it is seen from this figure, the acquisition sequence is initiated when a transition (in this case from logic 1 to logic 0) is detected (at t_0). This transition will cause the execution of ISR containing the instructions to start the first analog conversion from channel 0 (ADC0) and to run the timer. A constant (K_T) is set in the register of the timer so that it will overflow at an expected time interval.

As the timer is running, the ADC is converting the analog voltage signal to a digital value. When the conversion finishes (at t_1), the ISR of the ADC will cause the execution of an instruction to read the first conversion process, and in this case, it is marked by V(1a). The ISR will also cause the ADC to be re-started to get the first sample of the analog current signal. As soon as the conversion finishes (at t_2), through the following ISR, the digital value is read and marked as I(1). The ISR will also force the ADC to perform the following sampling of the voltage signal. At t_3, the conversion completes, and the sampled value is marked as V(1b). Up to this time, the first sample of voltage and current signals are achieved. Following this time (at t_4), the timer will overflow and its ISR will run the timer by reloading the constant K_T in the register of the timer. The ISR will also cause the ADC to attain the second sample of the voltage signal. The next procedures at t_6

up to t_7 are similar to the procedure at t_1 up to t_3. However, in this case, the digitized value will be marked as the second sample. The procedure will be repeated until 128 samples of either voltage and current signals are attained.



(a)



(b)

Figure 4. The use of the zero crossing output for initiating the acquisition sequence [25] (a) falling edge and (b) rising edge

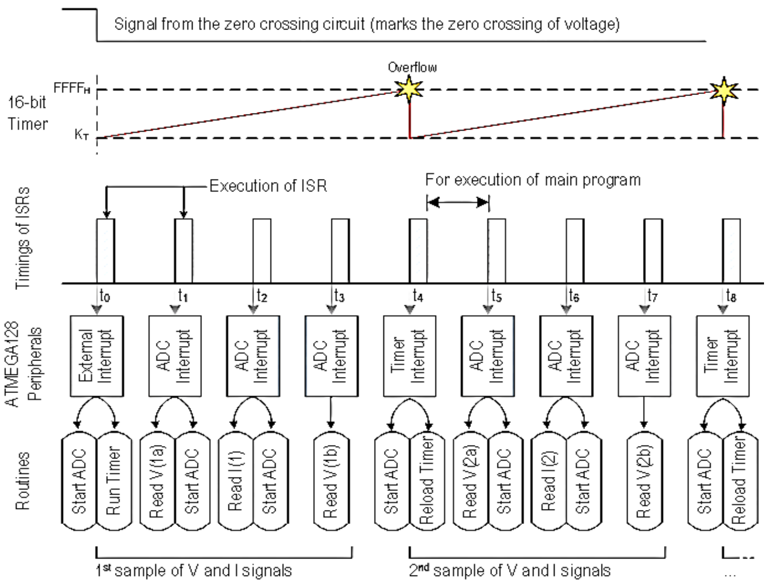


Figure 5. Acquisition of voltage and current signals

Because the sampling is done asynchronously, in this technique, the voltage signal is sampled two times that is just before and after the current signal is sampled. An approximation value of voltage is then calculated from these two samples of voltage. This approximation value is multiplied by the value of the sample of the current signal to get an instantaneous value of power. Figure 6 shows the relation between the approximated values of voltages (V_1 and V_2 up to V_{128}) and the samplings of the current signals (I_1, I_2, and up to I_{128}). In this way, the power can be calculated as follows $P_1=V_1I_1$ and $P_2=V_2I_2$

In order to get the approximated values of the voltages, the following formula is used [23]:

$$V_n = \frac{V_{na}+V_{nb}}{2\cos(1.44^{\circ})} \quad (1)$$

where n is the sampling number, i.e., 1 to 128.

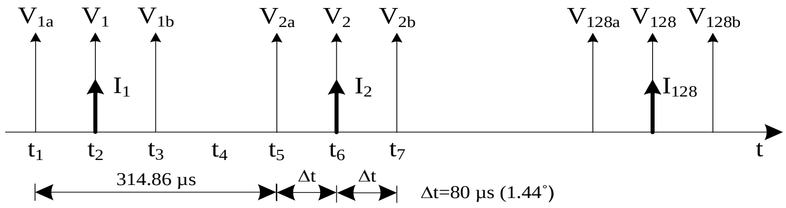


Figure 6. Approximated values of voltages and the samplings of the current signals

4. DEVELOPMENT OF APPLICATIONS

There are two applications that were developed for the system, i.e., an application for the microcontroller and a monitoring application that will be run on a portable device. The application for the microcontroller was developed using Atmel Studio 7 with C programming language. This application has the following main functions:

- To configure the implemented peripherals in the microcontroller including the interruptions.
- To perform acquisition sequence which is initiated by the transition of the zero-crossing output. The instructions include setting and running the timer, starting the ADC and reading its conversion results.
- To store the digitized values of voltage and current signals in the RAM and processing them.
- To send the instantaneous values of voltage and current signals for one acquisition sequence to a portable device through the Bluetooth module.
- To read the instruction sent by the portable devices and make a response such as sending the signals or changing the acquisition settings.

The flowchart of the application for the microcontroller can be seen from Figure 7. The Figure 7(a) contains the main program with instructions that will be executed outside the ISRs. The main function here is to start the acquisition sequence whenever an instruction containing inquiry of the signals is received. The instruction is sent by a portable device, received through an ISR of UART0 and then passed to the main program. In the main program, the procedure of starting the acquisition also contains an instruction to enable the INT0. Figures 7(b)-7(d) contain ISRs that are related to the acquisition sequence. The ISR of the INT0 will be executed first and then followed by either ISR of the ADC or ISR of the T1. The ISR of the ADC has the main functions to read the digital value from registers of the ADC, selecting the channel and stopping the acquisition sequence when 128 samples of current and voltage signals are attained.

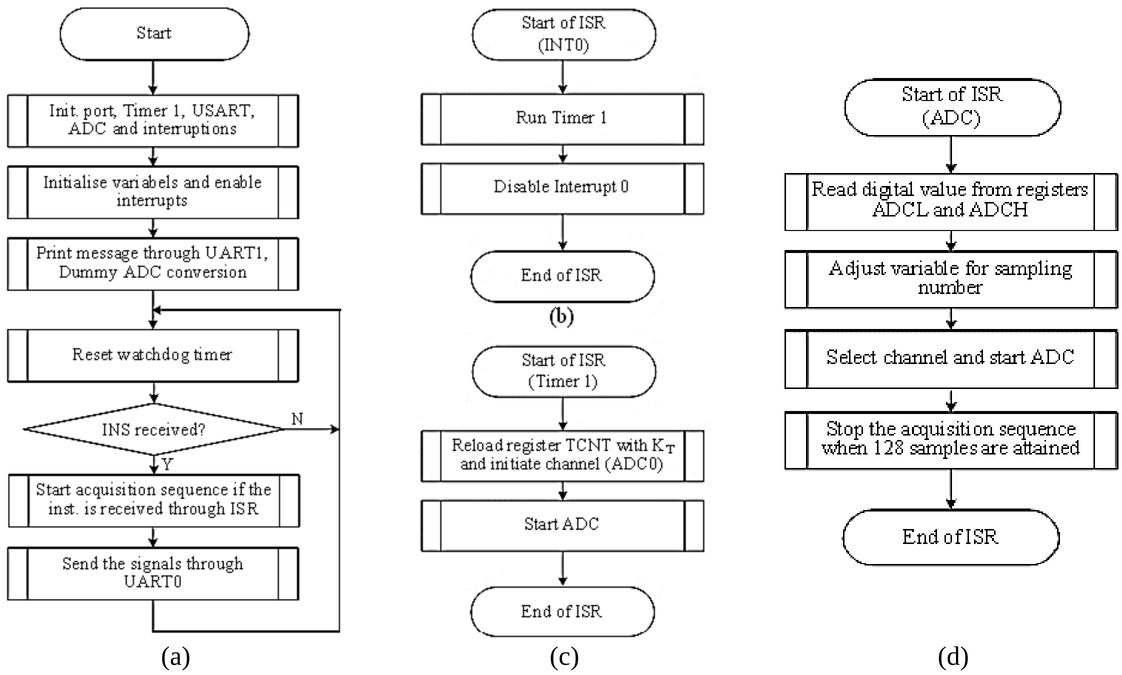
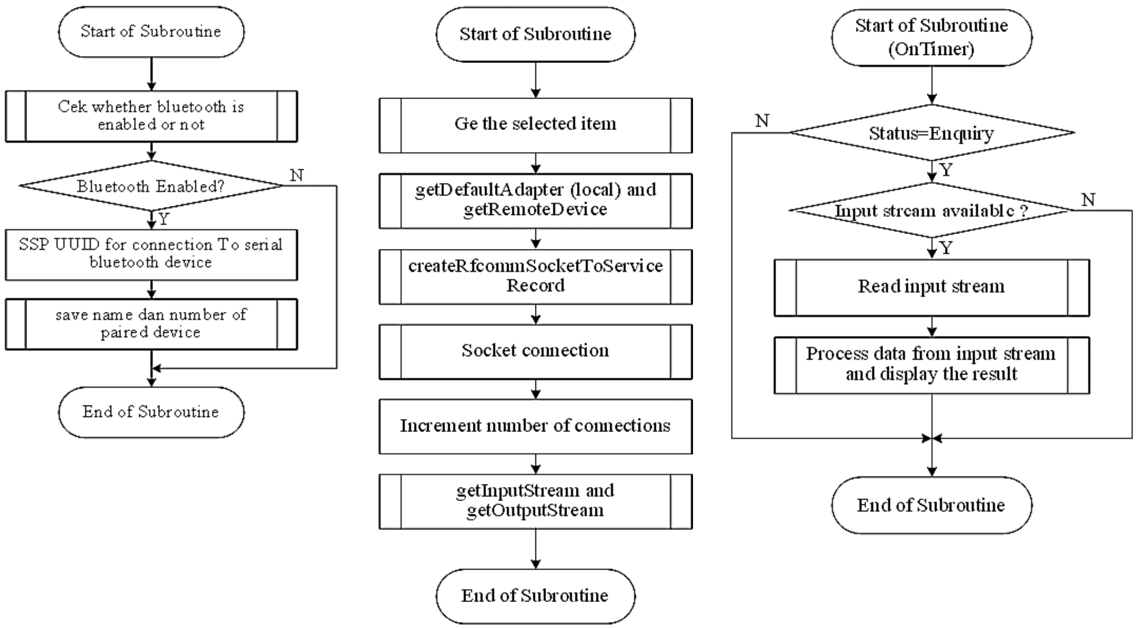


Figure 7. The flowchart of the microcontroller application for (a) main program, (b) INT0 ISR, (c) timer 1 ISR and (d) ADC ISR

The monitoring application, on the other hand, was developed using a programming tool Delphi XE8 and was intended to run on portable devices with Android operating system. The programming language used for developing the application was Pascal. The main functions of the monitoring application are as follows:
- To make a wireless connection between the Bluetooth peripherals available on the portable devices with the Bluetooth module connected to the microcontroller.
- To send inquiry of the signals periodically to the microcontroller using the Bluetooth.
- To process the received data to obtain the parameters such as RMS values, peaks, as well as harmonic contents.
- To display the signals and parameters on the screen of the portable devices.

Figure 8 depicts some subroutines for the developed monitoring application. In the Figure 8(a), the subroutine will make it sure that the Bluetooth peripheral in the portable device is enabled. If enabled, the UUID for connection will be assigned. This subroutine will be executed as the application just run. After the UUID is assigned, users will be able to make a connection to the Bluetooth module connected to the microcontroller through the subroutine shown in the Figure 8(b). Following this step, when the status is set to an inquiry by the users, a dedicated timer will be run to send an instruction to the microcontroller containing inquiry of the signals. The subroutine related to this timer will be executed any time the on-timer event is triggered. Another dedicated timer is implemented to read the status and check the availability of the received signal data, with the subroutine shown in the Figure 8(c). Whenever the data are received, they will be processed, and the signals, as well as the related parameters, are displayed on the portable device. The parameters such as RMS voltage and current as well as power were calculated using equations provided in [26].



(a) (b) (c)

Figure 8. The flowchart of some subroutines for monitoring application for (a) Bluetooth checking, (b) socket connection, and (c) input stream read

5. EXPERIMENTATION, RESULTS, AND DISCUSSIONS

The first experimentation that was carried out was intended to test the linearity of the VT; in this case Myrra 44049. The input of the VT was given a voltage that was varied from 0 V to 230 V with an increasing step of about 5 V through the use of a variac. A digital multi-meter Sanwa PC510 was connected to each input and output of the transformer to read the RMS voltage values. Figure 9 provides an example of the measurement results where V_{in} and V_{out} consecutively represent the input and output voltages of the transformer. In this figure, the measurement results are marked by the dots while the straight line is the linear trend. It can be seen here that the linearity of the transformer is acceptable as the dots are located not far from the trend line.

The second experimentation was done using the zero-crossing circuit and offset circuit. The inputs of this circuits were connected to the output of the VT while the input of VT is given a voltage from the power-line (with a voltage of about 220 V and a frequency of about 50 Hz). The outputs of the circuits are recorded by using oscilloscope Siglent SHS806. The measurement results are provided in Figure 10(a) for the zero-crossing circuit, and Figure 10(b), for the offset circuit. The Figure 10(a) shows that the logic transition of the output voltage occurs exactly at the zero crossing of the input voltage. Because the Operational Amplifier of the circuit is given single supply voltage of 5 V, the output will go low (nearly 0 V) or high (nearly 5 V) consecutively for positive or negative half cycle of the input signal. This output voltage has the levels that are suitable for the digital input of the microcontroller. The result of the experimentation also shows that the offset circuit can provide an offset voltage that makes the output voltage varies within 0-5 V as shown in Figure 10(b).

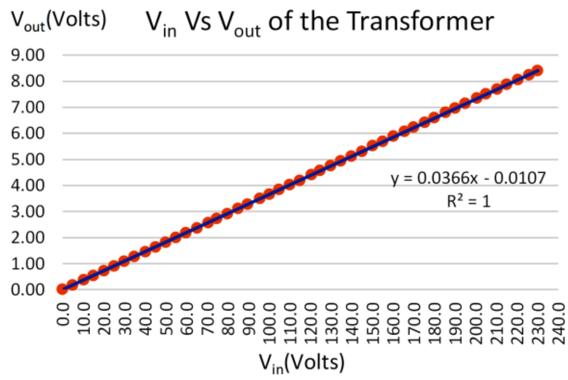
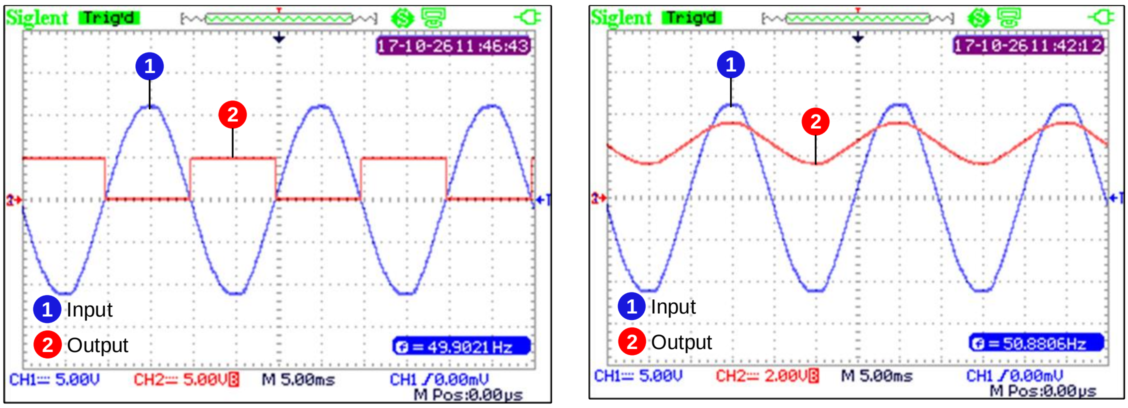


Figure 9. Graph of input voltage versus output voltage of the VT

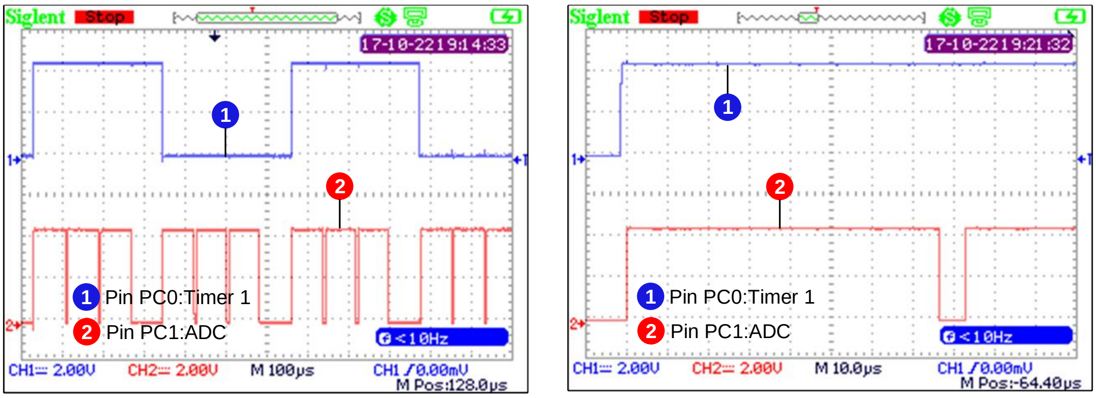


(a) (b)

Figure 10. Input and output signals of (a) the zero-crossing circuit and (b) and offset circuit

The next step of the experimentation was related to the acquisition timings implementing the microcontroller. The results were analyzed to ensure that the timings were constant and accurate. In this experimentation, the microcontroller was programmed to perform an acquisition using the developed technique. The T1 related to the timings was run without being stopped. To get the information about the timings, the logic state of pin PC0 on the microcontroller was programmed to toggle every time the ISR of the timer was executed. Furthermore, the pin PC1 was programmed to indicate the starting (with logic 1) and the end (with logic 0) of every ADC conversion. The logic states of the pins PC0 and PC1 can be seen from Figure 11. Besides using the oscilloscope to record the signals, a multi-meter Yokogawa TY710 was used to measure the frequency of the signal from the PC0. The measured frequencies using the oscilloscope and the multimeter were consecutively 1.58806 kHz and 1.588 kHz. These values were constant during the long period of the experimentation which means that T1 with its ISR had provided a constant timing for the acquisition. As the logic states toggle for every ISR execution, the frequency of the overflow occurrence of the Timer 1 is 2 times 1.588 kHz or 3.178 kHz.

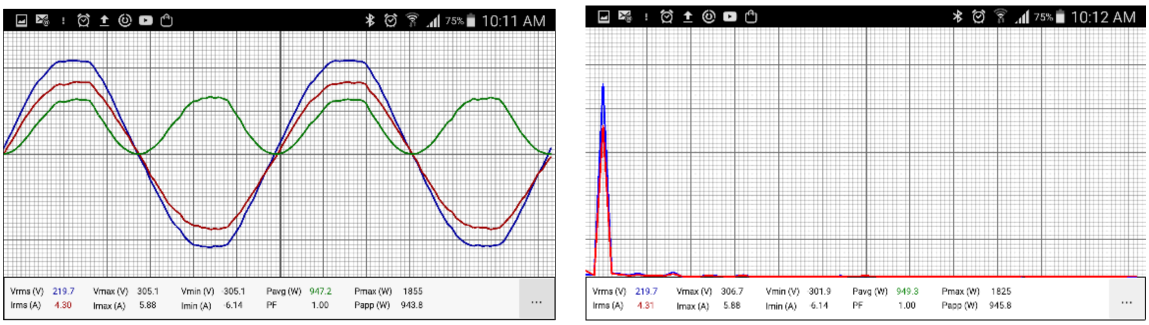
It can also be seen from the Figures 11(a) and 11(b), through the output of the PC1, that the starting and end of the conversion can be performed with the expected timing. In this case, just after the ISR of the T1 was executed, the ADC was started to perform the conversion for three times, that was to sample the voltage signal, the current signal and back to the voltage signal. The required time for these three-time conversions was less than the period of the overflow occurrence. So, there was no overlapping between the execution of the two ISRs. The Figure 11(b) shows that each conversion took less than 80 µS.



(a) (b)

Figure 11. Logic states of the pins PC0 and PC1 on the microcontroller indicating acquisition timings when (a) viewed using 100 µS/div and (b) viewed using 10 µS/div

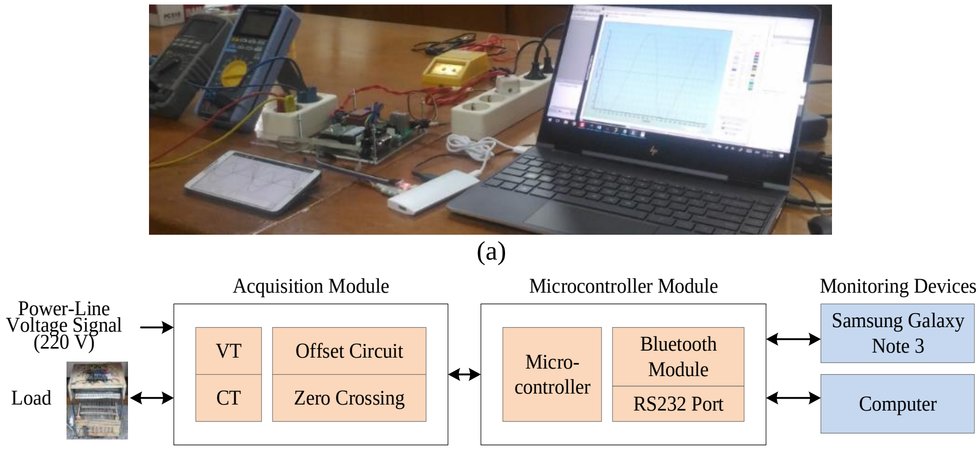
At the final step, all units in the developed system were integrated, and the monitoring application was installed on a handphone Samsung Galaxy Note 3 with Android operating system. The circuit of the monitoring system was connected to the power-lines as well as a load. The monitoring application was then run and requested the signals from the microcontroller periodically using the Bluetooth connection. In this experiment, the baud rate for the serial communication over the Bluetooth was set to 9600 baud. An example of the display on the handphone when the signals were received is provided in Figure 12(a). The harmonic contents of the signals could also be shown as provided through Figure 12(b). From all the experiment it could be shown that all units in the system including the developed monitoring application could work as expected. The monitoring application could be easily installed and used to monitor single-phase voltage and current signals as well as achieve important parameters related to the signals. As the monitoring processes could be performed through the portable device, the measurements could be performed practically.



(a) (b)

Figure 12. The monitoring display of (a) the signals and (b) harmonic contents

Figures 13(a) and 13(b) presents the photo and diagram of the experimental setup that was implemented to get the data. In this case, some measuring instruments were used such as multi-meters and oscilloscope. A variable load was used and connected to the power-line to vary the current flowing through the current transducer. The Samsung Galaxy Note 3 and computer functioned as the monitoring devices.



(a)
(b)

Figure 13. The photo (a) and block diagram (b) of experimental setup

6. CONCLUSION

A practical monitoring system implementing the asynchronously interrupt driven technique has been developed. This system is intended to acquire power-line single-phase voltage and current signals as well as their related information such as RMS values and harmonic contents. Some experimentation has been carried out, and the results showed that the monitoring could be performed wirelessly using Bluetooth technology. The monitoring application could be used to perform practical measurement as it could run with success on portable devices. Finally, the acquisition technique could successfully be applied in the system and was able to manage the timings during the acquisition sequences.

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BIOGRAPHIES OF AUTHORS

Hari Arief Dharmawan is currently a lecturer at the department of Physics, Brawijaya University, Malang, Indonesia. He received the M.Eng and PhD degrees from the School of Electrical and Information Engineering, University of South Australia, Adelaide, Australia. Majority of his publications are related to software and hardware development using embedded systems. He can be contacted at email: hari_arief@ub.ac.id.

Arinto Yudi Ponco Wardoyo received the M.Sc degree in Physics from UTAS, Hobart, Australia in 1995. His PhD degree was received from QUT, Brisbane, Australia, in 2007. He is currently a senior lecturer at the department of Physics, Brawijaya University, Malang, Indonesia. He can be contacted at email: a.wardoyo@ub.ac.id.

Chomsin Sulistya Widodo took the doctoral course at the department of Physics, School of Science and Engineering, Kumamoto University, Kumamoto, Japan and was received the PhD degree from this course. He is currently a lecturer at the department of Physics, Brawijaya University, Malang, Indonesia. He can be contacted at email: chomsin@ub.ac.id.