Design of Raspberry Pi Web-based Energy Monitoring System for Residential Electricity Consumption

by Syafii Syafii

Submission date: 26-Feb-2022 08:18AM (UTC+0800)
Submission ID: 1771065812
File name: ICITSI_2020.pdf (382.16K)
Word count: 3675
Character count: 17999

ISBN: 978-1-7281-8196-7

Design of Raspberry Pi Web-based Energy Monitoring System for Residential Electricity Consumption

Syafii[1], Amirul Luthfi[2] And Yoli Andi Rozzi[3]
[1]Electrical Engineering Department, Universitas Andalas, Indonesia, syafii@eng.unand.ac.id
[2]Electrical Engineering Department, Universitas Andalas, Indonesia, amirulluthfi@eng.unand.ac.id
[3]Electrical Engineering Department, Universitas Andalas, Indonesia, 1920952013_yoli@student.unand.ac.id

ABSTRACT- The application of communication and information technology for monitoring household and building activities is one of the exciting topics in future smart city development research. This paper presents the design of electrical energy monitoring using the PZEM-004T energy sensor and Raspberry Pi 4 as a web server. The system designed for measuring current, voltage, power, and energy and send it to a database as the purpose for display on infographics web pages in real-time. The web pages interface has a responsive design, so the stored data in the database can access on both desktop and mobile phone for flexibility. Based on the results for various loading, it can be concluded that the design of the electrical energy monitoring device is working well with an average error of less than 2%. The user interface also shows the real-time electrical parameter on both desktop and mobile phone.

Keywords: Electrical energy monitoring, Arduino PZEM-004T sensor, and the Raspberry Pi.

1. INTRODUCTION

Home automation systems are developing rapidly, along with advances in electronic and information technology. One application of the home automation system that is growing more and more today is the smart home system to assist homeowners in monitoring and controlling the function of energy consumption automatically, remotely, and centrally. Based on the Ministry of Energy and Mineral Resources, electricity consumption in Indonesia increased year by year [1], one of the reasons for the increase in electricity consumption is the improvidence of home electricity usage. This happens because the time of use is often incorrect, ineffective, and lack of consumer awareness to save electricity, due to consumers cannot directly monitor the use of electrical energy they use.

Nowadays, the electrical energy monitoring system that has been used is by installing conventional electrical measuring devices on the electrical circuit. However, this method has shortcomings because to find out the results of the monitor, and consumers must be directed at the location where the measuring instrument is installed. This method is considered inefficient because the electrical energy monitor results are not immediately known. Then it is necessary to design a system that can be used for monitoring electricity consumption using the IoT concept in real-time and long-distance [2].

Various studies have been conducted to monitor the electric power system, including the implementation of energy management and monitoring systems based on wireless sensor networks, where this system uses the ACS712 current sensor based on the Arduino Uno microcontroller [3]. Other studies for the household scale have also been carried out using the ACS712 Flow sensor which is connected to the Arduino Uno microcontroller via Wemos DI wifi so that it can monitor web-based energy consumption [4] [5]. Next [6] is an electrical monitoring system used explicitly in street lights, this system uses GSM wireless communication via SMS using the ACS712 current sensor and a voltage sensor that uses a voltage divider circuit in the monitoring system circuit. Then another study also designed a system for monitoring energy consumption data electricity using the ESP8266 wifi platform with the PZEM-004T sensor [7][8]. Furthermore, the electrical energy consumption monitoring tool in real-time based on a microcontroller monitors electrical energy consumption by utilising a stepdown transformer to measure the source voltage from the PLN while for measuring the load current utilizing the ACS712 current sensor [9] however, in other functions this tool does not work by the planned due to a voltage drop.

Based on existing research, the microcontroller used has several limitations on the features compared to the Raspberry Pi controller. So Raspberry Pi has advantages including it can be a web server, has a larger memory, and has a real-time clock without the need to use additional components. Likewise, the analogue sensor ACS712 current and voltage sensors are less precise when compared to the PZEM-004T sensor, which has integrated the ADC system in one integrated circuit [10]. In another study [11], the accuracy of the four sensors (ACS712, WCS1800, SCT013, and PZEM-004T), the results obtained stated that the PZEM-004T sensor can provide the best performance results and also an assessment in terms of relatively lower prices compared to other sensors. Therefore, this research proposed a Raspberry Pi-based monitoring system using the PZEM-004T sensor as a voltage, current, and power reading device for electrical energy measurement. The design of this system aims to monitor the home electrical energy consumption so that consumers can find out the energy usage data.

2. RASPBERRY PI BASED ENERGY MONITORING

The energy monitoring system uses to observe the voltage, current, and power of the electrical system. This study takes the PZEM-004T to measure the energy usage, Arduino Uno as an acquisition system, and Raspberry Pi 4 that perform as a web server for data storage and user interface. The Arduino Uno was used as a repeater for transmitted data from PZEM-004T to Raspberry Pi 4 due to incompatibility communication format of PZEM-004T and Raspberry Pi. The Raspberry Pi 4, Arduino Uno, and PZEM-004T are connected through serial communication, as shown in Figure 1.

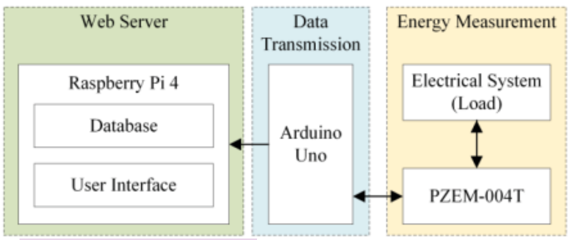


Figure 1: Block Diagram of Raspberry Pi 4 Web-based Energy Monitoring System

There are three main subsystems on Raspberry Pi web-based energy monitoring system, namely energy measurement, data transmission and the webserver. First, PZEM-004T measure voltage and current flow on the load, where this voltage and current used by PZEM-004T for energy measurement. Then, Arduino Uno sends request bytes to PZEM-004T. After that, PZEM-004T transmit the voltage, current, power, and energy data to Arduino Uno using serial communication. Subsequently, Arduino Uno forwards its data to Raspberry Pi4. On the last subsystem, Raspberry Pi store its data to the database. Furthermore, the data stored in the database show on a web-based user interface.

Schematic of Raspberry Pi 4 web-based energy monitoring system shown in Fig. 2. Firstly, the AC power source and the CT sensor connect to the PZEM-004T for voltage and current sensing, which used for calculating power and energy. After that, RX and TX pin of PZEM-004T connect to digital pins of Arduino Uno. Afterwards, these Arduino digital pins configured as serial communication pins using software serial, so it allows data transmission from PZEM-004T to Arduino Uno. Arduino Uno processes the data so that it's compatible with Raspberry Pi 4 communication protocol. Then, Arduino Uno and Raspberry Pi 4 to be connected using the USB interface so that Arduino Uno can forward the data to Raspberry Pi 4. Accordingly, by using this schematic, the voltage, current, power, and energy data can be transmitted into The Raspberry Pi 4. So, this system allows the monitoring of electrical energy by employing the Raspberry Pi 4 web server.

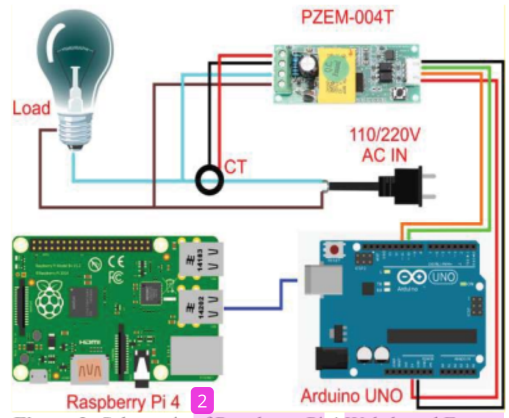


Figure 2: Schematic of Raspberry Pi 4 Web-based Energy Monitoring System

3. EXPERIMENTAL SETUP

The electricity monitoring system that observed in this study is on a household load scale. So, there are six types and two categories of load used at the research for representing load on the household scale, namely 25W, 40W, 75W incandescent lamps for representing the small load, and 200W, 300W, and 400W incandescent bulbs for representing large loads. These two loads category tested in two places. Retrieval of research data for small loads was carried out in Graha Bungo Housing in the Tunggul Hitam area of Padang city and carried out five times iteration, while for the large load is done in the Andalas University in Padang city and is done three times iteration.

The experiment starts by measuring the accuracy of electrical parameter measurement, that is the current, voltage, and Power. The Multitester VIP 8106 was used as a comparison to the designed monitoring measurement. By comparing both measuring, the deviation of measurement of the proposed monitoring system can be investigated. Its deviation value converts into a percent (%) by utilizing this formula.

$$Error = \frac{V\_Meter - D\_Meter}{V - Meter} x100\% \quad (1)$$

where:

V_Meter = Multitester VIP 8106 reading

D_Meter = Designed monitoring measurement reading

Experiments are continued to verify the proposed web-based monitoring system. This monitoring system is designed to be accessible on the local network by a variety of platforms. Two types of platforms use to access the monitoring system designed, namely The Windows 10 to find out the interface on the desktop system and The Android to find out the interface on the mobile phone system.

4. RESULTS AND DISCUSSION

A. Measurement Accuracy

The measurement accuracy was observed using 6 types of loads as described in the previous section. The first test is at a load of 25 Watts. Table 1 is the result of tests conducted using 25 Watts incandescent lamp loads. Based on research that has been done, the data obtained from measuring devices with an average value of voltage (V) = 245.16 V, the value of current (I) = 0.09A, the value of Power (P) = 22.06 watt. As for the results of the data from the tool designed for the average value of the voltage (V) = 245.19 V, rated current (I) = 0.09A, rated power (P) = 22.04 watt. Then the two data results are then compared so that the error value (deviation) will be obtained by 0.11%. Based on references sourced from[12], the mismatch value is still within reasonable limits because an average error less than 2%. Therefore, the results of testing data can be received.

Table 1 Testing PZEM-004T with Measuring Instruments Multimeters Using Philips 25W Lamp Load

Trial	PZEM-004T			Multimeter			Error (%)
	V (V)	I (A)	P (W)	V (V)	I (A)	P (W)	
Data 1	244.85	0.09	22.04	245.10	0.09	22.06	0.09
Data 2	245.76	0.09	22.04	245.50	0.09	22.10	0.25
Data 3	245.05	0.09	22.04	245.00	0.09	22.05	0.05
Data 4	245.05	0.09	22.04	245.00	0.09	22.05	0.05
Data 5	245.25	0.09	22.04	245.20	0.09	22.07	0.13

The second test was carried out on incandescent lamps with a 40 Watts load. Based on Table 2, it can be seen the results of data from measuring devices with an average voltage value (V) = 246.00 V, rated current (I) = 0.14 A, rated Power (P) = 34.44 watts. As for the results of the data from the tool designed for the average value of voltage (V) = 245.94 V, the value of current (I) = 0.14 A, rated Power (P) = 35.11 watts. So that it can be calculated the value of the error testing the tool that is equal to 1.94% in average. Existing reading mismatch values are acceptable because an average different still less than 2%.

Table 2 Testing PZEM-004T with Measuring Instruments Multimeter Uses 40-Watt Philips Lamp Load

Trial	PZEM-004T			Multimeter			Error (%)
	V (V)	I (A)	P (W)	V (V)	I (A)	P (W)	
Data 1	245.05	0.14	35.42	245.40	0.14	34.36	3.10
Data 2	245.76	0.14	35.42	245.60	0.14	34.38	3.01
Data 3	245.96	0.14	35.42	246.00	0.14	34.44	2.85
Data 4	246.66	0.14	34.64	246.60	0.14	34.52	0.34
Data 5	246.26	0.14	34.64	246.40	0.14	34.50	0.42

Furthermore, the third test was carried out on incandescent lamps with a load of 75 Watts Power. In Table 3 it can be seen a comparison of the results of data obtained from multitester VIP 8106 and designed measuring devices. For measuring devices, the average value of voltage (V) = 245.90 V, current value (I) = 0.27A, power value (P) = 66.39 watt. As for the results of the data from the tool designed for the average value of voltage (V) = 245.94 V, the value of current (I) = 0.27 A, the value of Power (P) = 67.23 watts. Furthermore, the two data results are then compared so that an error value (deviation) of 1.32% will be obtained.

Table 3 PZEM-004T Testing with Measuring Instruments Multimeter Uses a Philips 75-Watt Lamp Load

Trial	PZEM-004T			Multimeter			Error (%)
	V (V)	I (A)	P (W)	V (V)	I (A)	P (W)	
Data 1	246.36	0.27	67.70	246.50	0.27	66.56	1.72
Data 2	246.26	0.28	67.70	246.30	0.27	66.50	1.80
Data 3	246.36	0.27	67.70	246.20	0.27	66.47	1.84
Data 4	245.25	0.27	66.12	245.30	0.27	66.23	0.17
Data 5	245.45	0.27	66.91	245.20	0.27	66.20	1.07

The fourth test using a large load of incandescent lamps with load power 200-watt, using three-time repetition is done in the process of taking data. Based on Table 4, the results obtained data on multimeter VIP 8106 measuring devices with an average value for voltage (V) = 216.43 V, rated current (I) = 0.80 A, rated power (P) = 173.15 watts. As for the results of the data from the tool designed for the average value of voltage (V) = 216.31 V, the value of current (I) = 0.79 A, rated Power (P) = 171w.02 watt. So that it can be calculated the value of the error testing the tool that is equal to 1.22%.

Table 4 Testing PZEM-004T with a Multimeter Measuring Instrument Using a Philips 200-Watt Lamp Load

Trial	PZEM-004T			Multimeter			Error (%)
	V (V)	I(A)	P (W)	V (V)	I (A)	P (W)	
Data 1	216.51	0.79	171.18	216.60	0.82	177.61	3.62
Data 2	216.31	0.79	171.02	216.50	0.79	171.04	0.01
Data 3	216.11	0.79	170.86	216.20	0.79	170.80	0.04

Then the fifth test is carried out for the load incandescent lamp with 300-watt power. Based on Table 5 can be seen the acquisition of readings from multimeter VIP 8106 measuring devices with an average voltage value (V) = 216.13 V, the value of current (I) = 1.20A, the value of Power (P) = 259.36 watts. Whereas the reading of the measuring instrument is designed for the average value of the voltage (V) = 216.08 V, current value (I) = 1.19A, power value (P) = 256.68 watts. Then the second result of the existing data (deviation) error of 1.03%. Then the sixth test is the last test carried out using weights incandescent lamp 400 watts.

Table 5 PZEM-004T Testing with Measuring Instruments Multimeters Using Philips 300-Watt Lamp Load

Trial	PZEM-004T			Multimeter			Error (%)
	V (V)	I(A)	P (W)	V (V)	I (A)	P (W)	
Data 1	216.01	1.18	254.90	216.20	1.20	259.44	1.75
Data 2	216.01	1.19	257.45	216.00	1.20	259.20	0.68
Data 3	216.21	1.19	257.69	216.20	1.20	259.44	0.67

From Table 6, it can be seen for the average voltage measured on VIP 8106 measuring instrument of 215.60 V, and the average voltage measured on the design tool is 215.41V. Whereas for the average current in the multimeter VIP 8106 measuring instrument is 1.63 A and the average current in the design tool is 1.58 A. For the measured power in the multimeter VIP 8106 measuring instrument is 351.43 watt, and the average power measured in the design tool is 340.62 Watt.

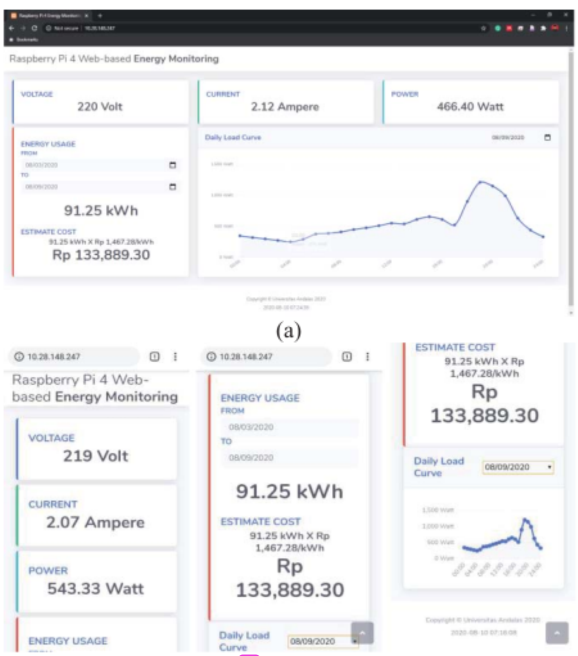
Table 6 Testing PZEM-004T with Measuring Instruments Using Philips 400 Watt Lamp Load

Trial	PZEM-004T			Multimeter			Error (%)
	V (V)	I (A)	P (W)	V (V)	I (A)	P (W)	
Data 1	215.80	1.63	351.75	215.21	1.58	340.30	3.26
Data 2	215.60	1.63	351.43	215.61	1.58	340.94	2.99
Data 3	215.40	1.63	351.10	215.41	1.58	340.62	2.99

Based on the results of the acquisition of test data that has been done on incandescent lamp loads: 25W, 40W, 75W, 200W, 300W, and 400W obtained that total average error less than 2 %. Therefore, the results of this design measurement tool can be accepted because this value within IEC-61724 standard [12].

B. User Interface of Raspberry Pi 4 Web-based Energy Monitoring System

The user interface of Raspberry Pi 4 web-based energy monitoring system is shown in Fig 3. This system designed for access to a local network. On this research, Raspberry Pi 4 set to static IP Address 10.28.148.247. By write down the Raspberry Pi 4 IP Address in the browser, the monitoring system can be accessed from a desktop or mobile phone.



(b)

Figure 3: User Interface of Raspberry Pi 4 Web-based Energy Monitoring System Accessed using (a) Windows 10 (b) Android

This user interface shows the real-time voltage, current, and power. It also displays energy usage along with the estimated cost. Moreover, it also informs the daily load curve so that the user knows for daily energy usage. It show that the designed user interface work fine form both desktop and mobile phone.

5. CONCLUSION

Based on this research, it is obtained that the combining of Raspberry Pi 4, Arduino Uno, and PZEM-004T can be used as a monitoring tool for household electrical energy usage. The monitoring system can measure and read the electrical parameters of voltage, current, and power as well as electrical energy with a good level of accuracy. The result shows the average deviation of measurement on the small load at 25W, 30W, and 75W consecutively 0.11%, 1.94%, and 1.32%. While the test results for large loads at 200W, 300W, and 400W sequentially is 1.22%, 1.03%, and 3.08%. Based on the data obtained by the measuring instrument the design has worked well, and the test results can be accepted because for all loads the error value (deviation) is at average value of less than 2%. Furthermore, the result shows that the user interface works well from both desktop and mobile phone. This indicates the Raspberry Pi 4 web-based electrical energy monitoring system can be work correctly.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the assistance rendered by DRPM KemRistek/BRIN for the financial support under Tesis Magister Research Grant 2020 (Contract No. 034/SP2H/LT/DRPM/2020).

REFERENCES

[1] National_Energy_Council, "Indonesia Energy Outlook (IEO) 2019," 2019. [Online]. Available: https://www.esdm.go.id/assets/media/content/content-indonesia-energy-outlook-2019-english-version.pdf.

[2] Z. H. Che Soh, I. H. Hamzah, S. A. Che Abdullah, M. A. Shafie, S. N. Sulaiman, and K. Daud, "Energy consumption monitoring and alert system via IoT," *Proc. - 2019 Int. Conf. Futur. Internet Things Cloud, FiCloud 2019*, pp. 265–269, 2019.

[3] M. Abo-Zahhad, S. M. Ahmed, M. Farrag, M. F. A. Ahmed, and A. Ali, "Design and implementation of building energy monitoring and management system based on wireless sensor networks," *Proc. - 2015 10th Int. Conf. Comput. Eng. Syst. ICCES 2015*, pp. 230–233, 2016.

[4] S. U. Alam, R. Ahmed, M. S. Imam, M. Farshid, M. A. Hossain, and M. A. Islam, "Design and Implementation of Website based Energy Consumption Monitoring and Controlling," *2019 Int. Conf. Comput. Commun. Informatics, ICCCI 2019*, pp. 1–7, 2019.

[5] A. M. Said, N. O. A. Aziz, W. M. El-Medany, and A. Abu Hassan, "Design and implementation of energy management systems for Bahrain smart cities," *IET Conf. Publ.*, vol. 2018, no. CP747, pp. 1–5, 2018.

[6] S. Siregar and D. Soegiarto, "Solar panel and battery street light monitoring system using GSM wireless

communication system," *2014 2nd Int. Conf. Inf. Commun. Technol. ICoICT 2014*, pp. 272–275, 2014.

[7] T. Tantidham, S. Ngamsuriyaros, N. Tungamnuayrith, T. Nildam, K. Banthao, and P. Intakot, "Energy Consumption Collection Design for Smart Building," *2018 Int. Conf. Embed. Syst. Intell. Technol. Int. Conf. Inf. Commun. Technol. Embed. Syst. ICESIT-ICICTES 2018*, no. 4, pp. 1–6, 2018.

[8] S. Wasoontarajaroen, K. Pawasan, and V. Chamnanphrai, "Development of an IoT device for monitoring electrical energy consumption," *2017 9th Int. Conf. Inf. Technol. Electr. Eng. ICITEE 2017*, vol. 2018-Janua, pp. 1–4, 2017.

[9] D. Despa, A. Kurniawan, M. Komarudin, Mardiana, and G. F. Nama, "Smart monitoring of electrical quantities based on single board computer BCM2835," *ICITACEE 2015 - 2nd Int. Conf. Inf. Technol. Comput. Electr. Eng. Green Technol. Strength. Inf. Technol. Electr. Comput. Eng. Implementation, Proc.*, pp. 315–320, 2016.

[10] K. Chooruang and K. Meekul, "Design of an IoT Energy Monitoring System," *Int. Conf. ICT Knowl. Eng.*, vol. 2018-November, pp. 48–51, 2019.

[11] R. Khwanrit, S. Kittipiyakul, J. Kudtonagngam, and H. Fujita, "Accuracy Comparison of Present Low-cost Current Sensors for Building Energy Monitoring," in *2018 International Conference on Embedded Systems and Intelligent Technology International Conference on Information and Communication Technology for Embedded Systems (ICESIT-ICICTES)*, 2018, pp. 1–6.

[12] IEC 61724-1, "Photovoltaic System Performance Monitoring—Guidelines for Measurement, Data Exchange, and Analysis (Part 1)," *Tech. Rep. 1; Int. Electrotech. Comm. (IEC)' Switzerland, Geneva,* 2017.

Design of Raspberry Pi Web-based Energy Monitoring System for Residential Electricity Consumption

ORIGINALITY REPORT

10%	6%	7%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Universiti Teknologi MARA Student Paper	2%
2	www.proceedings.com Internet Source	2%
3	Submitted to University of Central Florida Student Paper	2%
4	www.warse.org Internet Source	1%
5	Andi Irwansyah Satriananda, Lia Kamelia, Mufid Ridlo Efendi, Aep Kusnawan. "The Prototype of Smart Power Meter at Home Based on Internet of Things", 2021 7th International Conference on Wireless and Telematics (ICWT), 2021 Publication	1%
6	sustainability.uob.edu.bh Internet Source	<1%
7	Dimas Anton Asfani, Daniar Fahmi, I Made Yulistya Negara, I Gusti Ngurah Satriyadi	<1%

Hernanda et al. "Low-Voltage Arcing Detection on Non-Linear Load with Total Harmonic Distortion and Power Factor Variations", 2019 International Seminar on Intelligent Technology and Its Applications (ISITIA), 2019
Publication

8	ieeexplore.ieee.org Internet Source	<1 %
9	www.ajer.org Internet Source	<1 %
10	"The International Conference on ASEAN 2019", Walter de Gruyter GmbH, 2019 Publication	<1 %
11	Mia Galina, Muhammad Wahyu Ramadhani, Joni Welman Simatupang. "Prototype of Postpaid Electricity and Water Usage Monitoring System", 2019 International Conference on Sustainable Engineering and Creative Computing (ICSECC), 2019 Publication	<1 %
12	www.red.pe.org.pl Internet Source	<1 %
13	"ICITSI 2020 TOC", 2020 International Conference on Information Technology Systems and Innovation (ICITSI), 2020 Publication	<1 %

14	Rian Ferdian, Ratna Aisuwarya, Tati Erlina. "Edge Computing for Internet of Things Based on FPGA", 2020 International Conference on Information Technology Systems and Innovation (ICITSI), 2020 Publication	<1%

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		