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[Home](#) > [Archives](#) > **Vol 9, No 3**

Vol 9, No 3

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 DOI: <https://doi.org/10.11591/eei.v9i3>

Table of Contents

[Design aspects of high voltage transmission line](#)

Jabbar Qasim Fahad, Riyadh Kamil Chillab

 PDF
853-861

[Experimental simulation analysis for single phase transformer tests](#)

Ali N. Hamoodi, Bashar A. Hammad, Fawaz S. Abdullah

 PDF
862-869

[Automated irrigation system based on soil moisture using arduino board](#)

Safwan A. Hamoodi, Ali N. Hamoodi, Ghanim M. Haydar

 PDF
870-876

[An efficient feature selection algorithm for health care data analysis](#)

Mythily R., Aisha Banu. W, Dinesh Mavaluru

 PDF
877-885

[Design and simulation hybrid filter for 17 level multilevel inverter](#)

Marshal Andrea Hutabarat, Syafruddin Hasan, Ali Hanafiah Rambe, Suherman Suherman

 PDF
886-897

[Application of phase-metric compensation method for geoelectric control of near-surface geodynamic processes](#)

Kuzichkin O. R., Vasilyev G. S., Grecheneva A. V., Mikhaleva E. V., Baknin M. D., Surzhik D. I.

 PDF
898-905

[Using bacterial interaction and stereoscopic images for the location of obstacles on autonomous robots](#)

Fredy Martinez, Edwar Jacinto, Fernando Martínez

 PDF
906-913

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JOURNAL CONTENT

 Search

Search Scope

 All

Browse

- By Issue
- By Author
- By Title

INFORMATION

- For Readers
- For Authors
- For Librarians

Linear quadratic regulator and pole placement for stabilizing a cart inverted pendulum system	PDF
Mila Fauziyah, Zakiyah Amalia, Indrazno Siradjuddin, Denda Dewatama, Rendi Pambudi Wicaksono, Erni Yudaningtyas	914-923
Non-invasive moisture content measurement system based on the ESP8266 microcontroller	PDF
Agustami Sitorus, Novrinaldi Novrinaldi, Ramayanty Bulan	924-932
Determination of transient thermal characteristics for thermal electric behavioral models of integrated circuits	PDF
Drakin A. Yu, Potapov L. A., Shkolin A. N.	933-942
Simulations of the CNFETs using different high-k gate dielectrics	PDF
Ankita Dixit, Navneet Gupta	943-949
Dye pH variation on blueberry anthocyanin based dye sensitized solar cell	PDF
Zainul Abidin, Eka Maulana, Panca Mudjirahardjo, M. Ivan Fadillah	950-955
Performance evaluation of low-cost IoT based chlorophyll meter	PDF
Heri Andrianto, Suhardi Suhardi, Ahmad Faizal	956-963
Generalized sub band analysis and signal synthesis	PDF
Evgeny G. Zhilyakov, Sergei P. Belov, Ivan I. Oleinik, Sergei L. Babarinov, Diana I. Trubitsyna	964-972
On the evaluation of noise immunity of different classes of wideband signals	PDF
Evgeny G. Zhilyakov, Sergei P. Belov, Andrei S. Belov, Alexander S. Belov, Sergey A. Rachinsky	973-979
Triple layer image security using bit-shift, chaos, and stream encryption	PDF
Ajib Susanto, De Rosal Ignatius Moses Setiadi, Eko Hari Rachmawanto, Ibnu Utomo Wahyu Mulyono, Christy Atika Sari, Md Kamruzzaman Sarker, Musfiqur Rahman Sazal	980-987
Diagnosis of arrhythmia based on ECG analysis using CNN	PDF
Muayed S. AL-Huseiny, Noor Khudhair Abbas, Ahmed S. Sajit	988-995
Hand gesture recognition using discrete wavelet transform and convolutional neural network	PDF
Muhammad Biyan Priatama, Ledya Novamizanti, Suci Aulia, Erizka Banuwati Candrasari	996-1004
A comparison between the performance of DWT and LWT in image watermarking	PDF
Dujan B. Taha, Taha Basheer Taha, Najla Badie Al Dabagh	1005-1014
Video steganography based on DCT psychovisual and object motion	PDF

Muhammad Fuad, Ferda Ernawan	1015-1023
MRI brain tumor segmentation: A forthright image processing approach Noor Elaiza Abd Khalid, Muhammad Firdaus Ismail, Muhammad Azri AB Manaf, Ahmad Firdaus Ahmad Fadzil, Shafaf Ibrahim	PDF 1024-1031
Automated segmentation and detection of T1-weighted magnetic resonance imaging brain images of glioma brain tumor Nur Hanina Izani Muhammad Zaihani, Rosniza Roslan, Zaidah Ibrahim, Khyrina Airin Fariza Abu Samah	PDF 1032-1037
Negative refraction metamaterial with low loss property at millimeter wave spectrum B. A. F. Esmail, H. A. Majid, F. A. Saparudin, M. Jusoh, A. Y. Ashyap, Najib Al-Fadhali, M. K. A. Rahim	PDF 1038-1045
Security performance analysis for power domain NOMA employing in cognitive radio networks Thi-Anh Hoang, Chi-Bao Le, Dinh-Thuan Do	PDF 1046-1054
Hybrid optical communications for supporting the Palapa Ring network Ucuk Darusalam, Fitri Yuli Zulkifli, Purnomo Sidi Priambodo, Eko Tjipto Rahardjo	PDF 1055-1066
Reconfigurable modified wilkinson power divider using PIN diode switch N. Edward, N. A. Shairi, A. Othman, Z. Zakaria, I. D. Saiful Bahri	PDF 1067-1073
Implementation of e-education in Africa via space digital video broadcasting system Dimov Stojce Ilcev	PDF 1074-1084
D2D communication for spectral efficiency improvement and interference reduction: A survey Abdullah H. Alquhali, Mardeni Roslee, Mohamad Y. Alias, Khalid S. Mohamed	PDF 1085-1094
IoT-oriented software platform applied to sensors-based farming facility with smartphone farmer app P. Visconti, N. I. Giannoccaro, R. de Fazio, S. Strazzella, D. Cafagna	PDF 1095-1105
Using queuing theory to describe adaptive mathematical models of computing systems with resource virtualization and its verification using a virtual server with a configuration similar to the configuration of a given model Alexey I. Martyshev, Dmitry V. Pashchenko, Dmitry A. Trokoz, Mihail P. Sinev, Boris L. Svistunov	PDF 1106-1120
Adoption of technology on E-learning effectiveness Zarina Denan, Zarina Abdul Munir, Rahayu A. Razak, Kardina Kamaruddin, Veera Pandiyan Kaliani Sundram	PDF 1121-1126
Application of fuzzy logic in order to plan and create software for converting sound to text Hiwa Hasanzadeh, Jafar Majidpour	PDF 1127-1136

Application of deep learning to enhance the accuracy of intrusion detection in modern computer networks Jafar Majidpour, Hiwa Hasanzadeh	PDF 1137-1148
Satellite imagery and machine learning for aridity disaster classification using vegetation indices Sri Yulianto Joko Prasetyo, Kristoko Dwi Hartomo, Mila Chrismawati Paseleng, Dian Widiyanto Chandra, Edi Winarko	PDF 1149-1158
An intelligent agent model for learning group development in the digital learning environment: A systematic literature review Budi Laksono Putro, Yusep Rosmansyah, Suhardi Suhardi	PDF 1159-1166
IPv6 campus transition: A Central Luzon State University case study Marlon A. Naagas, Nemesio A. Macabale Jr, Thelma D. Palaoag	PDF 1167-1175
Teacher and student readiness using E-learning and M-learning Ramadiani Ramadiani, Azainil Azainil, Achmad Nizar Hidayanto, Dyna Marissa Khairina, Muhammad Labib Jundillah	PDF 1176-1182
Quality and size assessment of quantized images using K-Means++ clustering Davin Ongkadinata, Farica Perdana Putri	PDF 1183-1188
Image processing based eye detection methods a theoretical review B. Vijayalaxmi, Chavali Anuradha, Kaushik Sekaran, Maytham N. Meqdad, Seifedine Kadry	PDF 1189-1197
Basic principles of blind write protocol Khairul Anshar, Nanna Suryana, Noraswaliza Noraswaliza	PDF 1198-1207
Deep learning based facial expressions recognition system for assisting visually impaired persons Hendra Kusuma, Muhammad Attamimi, Hasby Fahrudin	PDF 1208-1219
The study of attention estimation for child-robot interaction scenarios Muhammad Attamimi, Takashi Omori	PDF 1220-1228
Decision support system for determining chili land using weighted product method Ramadiani Ramadiani, Bayu Ramadhani, Zainal Arifin, Muhammad Labib Jundillah, Azainil Azainil	PDF 1229-1237
Search for a substring of characters using the theory of non-deterministic finite automata and vector-character architecture Dmitry V. Pashchenko, Dmitry A. Trokoz, Alexey I. Martyshkin, Mihail P. Sinev, Boris L. Svistunov	PDF 1238-1250
Information processing in info-communication media of geodynamic monitoring on the basis of adaptive queuing system Kuzichkin O. R., Eremenko V. T., Loginov I. V., Grecheneva A. V., Eremenko A. V., Dorofeev N. V.	PDF 1251-1259

[Classification of batik patterns using K-Nearest neighbor and support vector machine](#)
Agus Eko Minarno, Fauzi Dwi Setiawan Sumadi, Hardianto Wibowo, Yuda Munarko

[PDF](#)
1260-1267

[Hybrid neural networks in cyber physical system interface control systems](#)
Sergei Sokolov, Anton Zhilenkov, Sergei Chernyi, Anatoliy Nyrkov, Nikolay Glebov

[PDF](#)
1268-1275

[PNSCares: The android based mobile application to manage student complaints](#)
N. Illias, N. H. Abdul Hamid, Z. A. Shaffiei

[PDF](#)
1276-1283

[City i-Tick: The android based mobile application for students' attendance at a university](#)
S. R. Alimin, N. H. Abdul Hamid, Z. A. Nasruddin

[PDF](#)
1284-1290

[Comparison analysis of chattering in smooth sliding mode controlled DC-DC buck converter using constant plus proportional reaching law and proposed reaching laws](#)
K. B. Siddesh, B. Banakara, R. Shivarudraswamy

[PDF](#)
1291-1298

[A risk management framework for distributed scrum using PRINCE2 methodology](#)
Mohammad Esteki, Taghi Javdani Gandomani, Hadi Khosravi Farsani

[PDF](#)
1299-1310

00983030 Bulletin of EEI Stats

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Control and Optimization

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8

H Index

Publisher	Institute of Advanced Engineering and Science (IAES)
Publication type	Journals
ISSN	20893191, 23029285
Coverage	2017-2019
Scope	<p>Bulletin of Electrical Engineering and Informatics publishes original papers in the field of electrical, computer and informatics engineering which covers, but not limited to, the following scope: Computer Science, Computer Engineering and Informatics: Computer Architecture, Parallel and Distributed Computer, Pervasive Computing, Computer Network, Embedded System, Human–Computer Interaction, Virtual/Augmented Reality, Computer Security, Software Engineering (Software: Lifecycle, Management, Engineering Process, Engineering Tools and Methods), ... Electronics: Electronic Materials, Microelectronic System, Design and Implementation of Application Specific Integrated Circuits (ASIC), VLSI Design, System-on-a-Chip (SoC) and Electronic Instrumentation Using CAD Tools, digital signal & data Processing, , Biomedical Transducers and instrumentation, Medical Imaging Equipment and Techniques, Biomedical Imaging and Image Processing, Biomechanics and Rehabilitation Engineering, Biomaterials and Drug Delivery Systems; Electrical and Power Engineering: Electrical Engineering Materials, Electric Power Generation, Transmission and Distribution, Power Electronics, Power Quality, Power Economic, FACTS, Renewable Energy, ... Telecommunication and Information Technology: Modulation and Signal Processing for Telecommunication, Information Theory and Coding, Antenna and Wave Propagation, Wireless and Mobile Communications, ... Instrumentation and Control Engineering: Optimal, Robust and Adaptive Controls, Non Linear and Stochastic Controls, Modeling and Identification, Robotics, Image Based Control, Hybrid and Switching Control, Process Optimization and Scheduling, Control and Intelligent Systems, ...</p>
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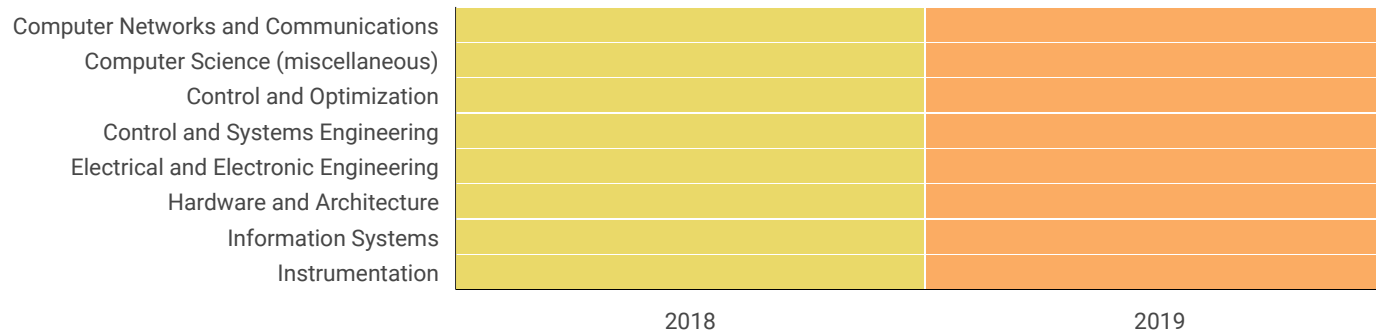
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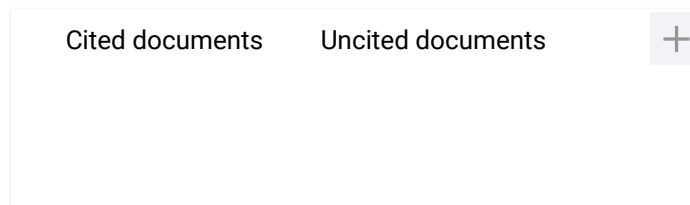
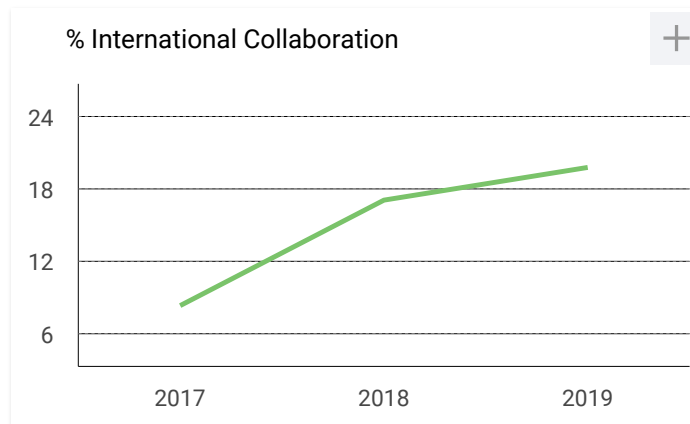
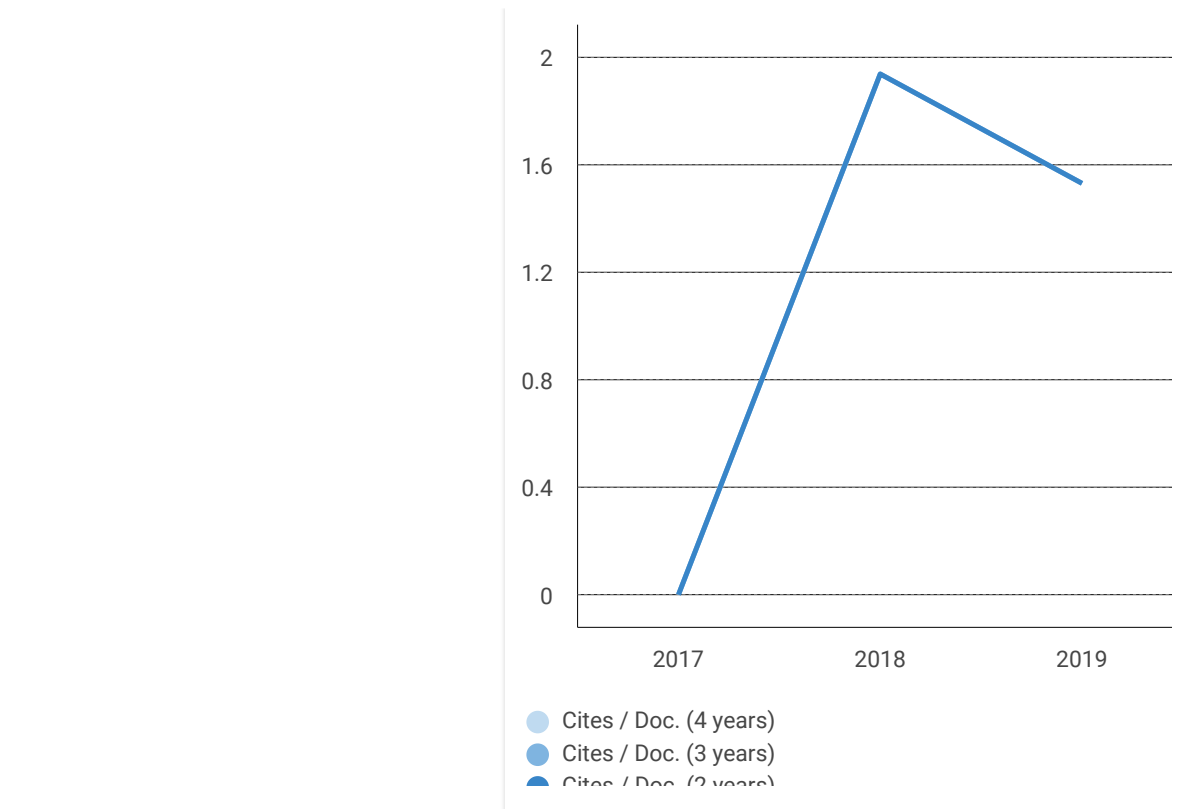
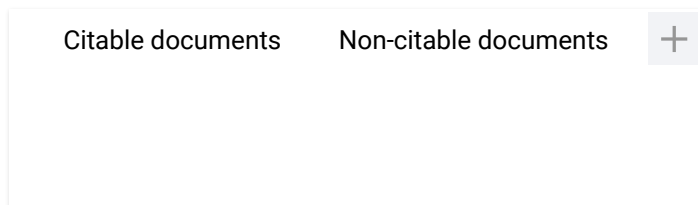
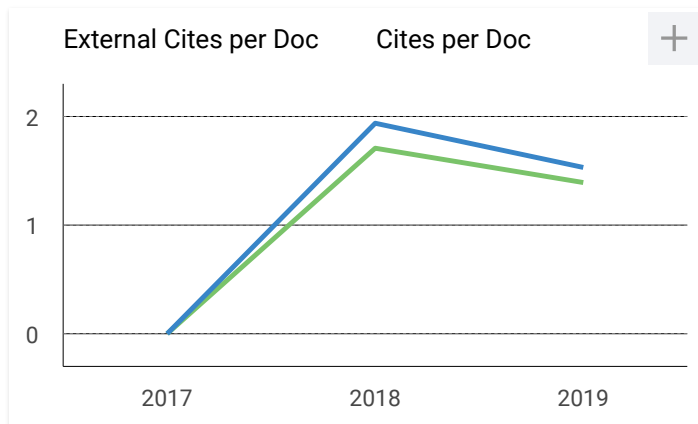
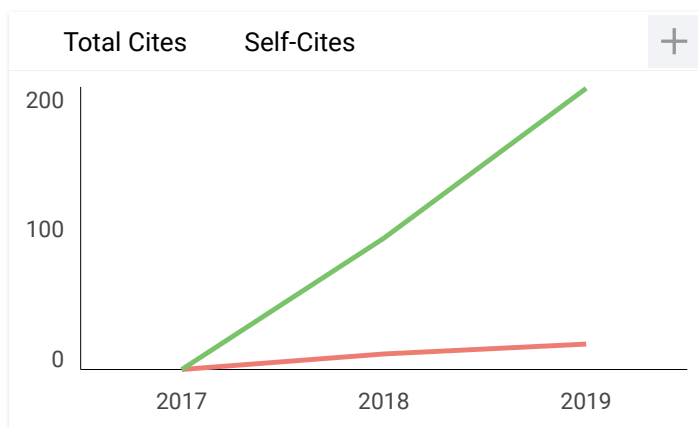
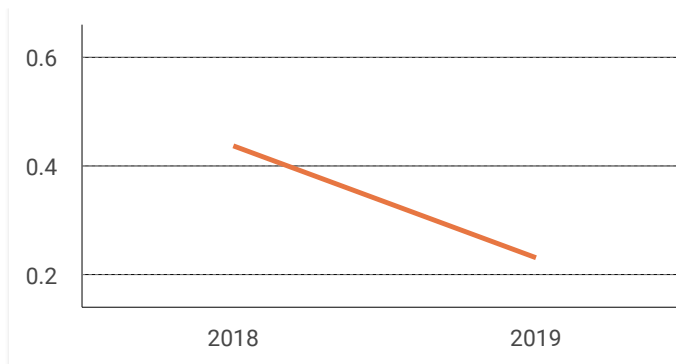


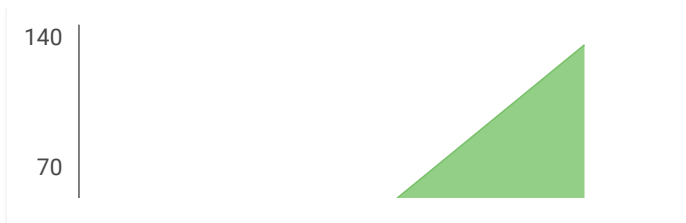
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Melanie Ortiz 7 months ago

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Dear Team

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D **Duke** 2 months ago

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Handrils 12 months ago

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H

Heru Santoso Wahito Nugroho 1 year ago

I think you should submit article through online submission (not via email)
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Melanie Ortiz 1 year ago

SCImago Team

Dear Heru, thanks for your participation! Best Regards, SCImago Team

M

Muhamad 1 year ago

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Performance evaluation of low-cost IoT based chlorophyll meter

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ABSTRACT

Nutrient deficiencies in plants can be identified using a chlorophyll meter. However, current chlorophyll meters are still expensive and have many disadvantages. In this paper, a low-cost IoT-based chlorophyll meter has been developed. The performance of a low-cost IoT-based chlorophyll meter has been compared with the performance of a spectrophotometer (SP-3000nano) and a commercial chlorophyll meter (SPAD-502). A low-cost IoT-based chlorophyll meter has been functioning properly which is able to measure the chlorophyll content of plants in the field, get positions based on GPS satellites, store data in a memory module, and send data to the service system platform. The test results showed the coefficient of determination (R^2) between SPAD-502 values and low-cost IoT-based chlorophyll meter values is 0.9705, this shows a significant correlation. An IoT-based chlorophyll meter can be used as a cheap alternative to the SPAD-502 chlorophyll meter.

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1. INTRODUCTION

Communication and information technology will facilitate farmers to explore innovative ways to minimize risks and to increase production [1]. Recently, Internet of Things (IoT) as one part of communication and information technology is developing rapidly and has been widely applied in various fields, such as in agriculture. The IoT is a combination of all the "things" by using the internet as the backbone of a communication system to build intelligent interactions between people and objects around them [2, 3]. Most IoT technology solutions in the field of agro-industry and the environment focus on monitoring (62%), controls (25%), logistics (7%), and predictions (6%) [4].

In field of agriculture, the nitrogen content in the soil can be determined through the chlorophyll content of plant leaves, because nitrogen content is strongly related to chlorophyll content [5, 6]. Sensor technology can be used to detect the chlorophyll content of plant leaves based on the ability of the leaves to absorb, transmit and reflect light [7]. This technology has been applied to spectrophotometer [8, 9] and chlorophyll meter [10-14]. Spectrophotometer can be used to analyze chlorophyll pigments in extracted plant leaves, but this method has disadvantages such as destructive, tiring and time consuming [13]. This device is not only expensive but also has a large size therefore it is only used in laboratories. Meanwhile, between fields and the laboratories are generally separated by long distances [15]. Therefore, carrying the leaves of plants from field to the laboratory becomes ineffective and inefficient.

A chlorophyll meter allows non-destructive measurement of chlorophyll content in the field, however chlorophyll meters available on the market are still expensive. Van Den Berg and Perkins [16] have reported that a portable chlorophyll meter (CCM-200) is an effective, rapid, and non-destructive devices for estimating the chlorophyll content in sugar maple leaves during the growing season. Another chlorophyll meter is SPAD-502, it is the most widely used chlorophyll meter [7]. Several studies have been conducted to measure the chlorophyll content of various plants using SPAD-502 [10, 17-21]. The chlorophyll content in leaves is expressed in Chlorophyll Content Index (CCI) unit or Soil Plant Analysis Development (SPAD) unit. Chlorophyll content of plant leaves in the CCI unit is calculated using [22]:

$$CCI = \frac{\% \text{ transmission IR}}{\% \text{ transmission RED}} \quad (1)$$

Conversion from CCI to SPAD is calculated using [22]:

$$SPAD = k \log(CCI) + c \quad (2)$$

Where:

k: Confidential slope coefficient

c: Confidential offset value

As an example, computational processes for calculating the amount of Nitrogen (N) fertilizer that must be given to plants (corn and wheat) consists of calculating the average value of chlorophyll content from the field and calculating chlorophyll content from the reference area where N levels are high. N recommendation for plants (corn and wheat) is calculated using [23-25]:

$$N = 6 + (7 \times D) \quad (3)$$

Where:

N = N (lb/A) needed at Feekes 5 for optimal growth

D = The difference between the average chlorophyll measurements from the agricultural land and the reference areas that have high N levels (in a SPAD unit)

2. RELATED WORKS

Several studies on the design and realization of a low-cost chlorophyll meter have been carried out. Takeuchi et al [26] reported the development of a simple PAM chlorophyll fluorometer for monitoring vegetation conditions using a Programmable Logic Controller (PLC) and a computer. Maleki et al [27] reported the development of a device to measure nitrogen content in lettuce plants using the TCS230 sensor. Lamb et al [28] reported the development of a fluorometers based on LED for quantification of chlorophyll in the field and in the laboratory. Sookchalearn and Abdullakasim [29] reported the development of a tool to measure the chlorophyll content of cassava plants using TCS230 sensor and added a Global Position System (GPS) module to get a location when measuring chlorophyll content of plant leaves in the field. Limitations of previous studies, namely requires expensive costs [26], destructive [28], no data sending facility to the server for agricultural data management [26-29], no data storage facility in non volatile memory therefore data will be lost if the power is turned off [26-29], no data location based on GPS satellites [26-28], and no interface to external devices [26-28].

New innovations are needed on chlorophyll meter devices to meet user needs and provide solutions to the current limitations of chlorophyll meters, namely by applying IoT technology, storage facility, location based on GPS satellites and data sending facility to the service system platform for agricultural data management. This study is primarily interested in design and realization of a low-cost IoT-based chlorophyll meter for collecting chlorophyll content and location data from the field and send it to the service system platform. The performance of a low-cost IoT-based chlorophyll meter is also compared to more expensive chlorophyll meter (SPAD-502) and spectrophotometer (SP-3000nano).

3. RESEARCH METHOD

The research method consists of four stages, namely designing IoT-based service system architecture for monitoring plant nutrition deficiencies (Figure 1), developing low cost IoT-based chlorophyll meter, testing the low cost IoT-based chlorophyll meter and evaluating the performance of a low cost

IoT-based chlorophyll meter. The first stage is designing IoT-based service system architecture for monitoring plant nutrition deficiencies. The IoT-based service system architecture for monitoring plant nutrition deficiencies consists of IoT-based chlorophyll meters, wireless access points, service system platforms and remote monitoring devices. In this system, farmers can measure the chlorophyll content of plant leaves, mark a location based on GPS satellites at the time of measurement in the field and send data to the service system platform using an IoT-based chlorophyll meter. The low-cost IoT-based chlorophyll meter uses the API Key as an ID to enter and communicate with the service system platform. This system can be used for effective and efficient agriculture because it only requires one IoT-based chlorophyll meter device to collect data rather than installing multiple sensors in the field, such as in the Wireless Sensor Network system (WSN) [30-31].

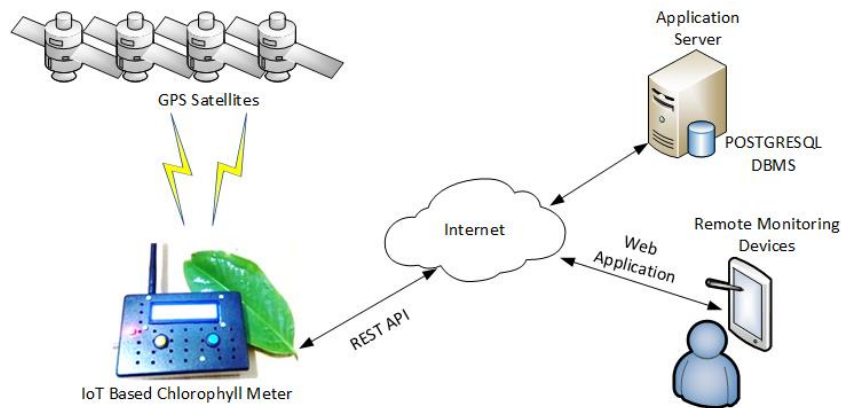


Figure 1. An IoT-based service system architecture for monitoring plant nutrition deficiencies

3.1. Developing a low-cost IoT-based chlorophyll meter

The second stage is developing a low cost IoT-based chlorophyll meter. Low cost IoT based chlorophyll meter devices consist of NodeMCU, red and infrared LEDs, spectral sensor (TSL2561), GPS module (GPS6MV2), LCD module, pushbutton, and memory module. Table 1 shows connection of NodeMCU pins with other components. Figure 2 shows an IoT based chlorophyll meter device that has been developed.

Table 1. Connection of NodeMCU pins with other components

NodeMCU Pins	LCD Module	TSL2561 Sensor	Memory Module	GPS6MV2	PushButton
D0					D0
D1	SCL	SCL			
D2	SDA	SDA			
D5			SCK		
D6			MISO		
D7			MOSI		
D8			CS		
D9				TX	
D10				RX	



Figure 2. IoT based chlorophyll meter realization

3.2. IoT-based chlorophyll meter flowchart

Main program flowchart (Figure 3), starting with the process of initializing the components, then selecting the online or offline mode. If offline mode is selected, then the data will be stored in the memory module when the button is pressed. If online mode is selected, then the data will be sent to the database server when the button is pressed. Sub program flowchart (Figure 4) to obtain chlorophyll content and location based on GPS satellites starting with the process of obtaining positions based on GPS satellites (Long and Lat), reading the intensity of red and infrared light transmitted by the leaf on the spectral sensor, and calculating the CCI values. Finally, CCI, Long and Lat are displayed on the LCD.

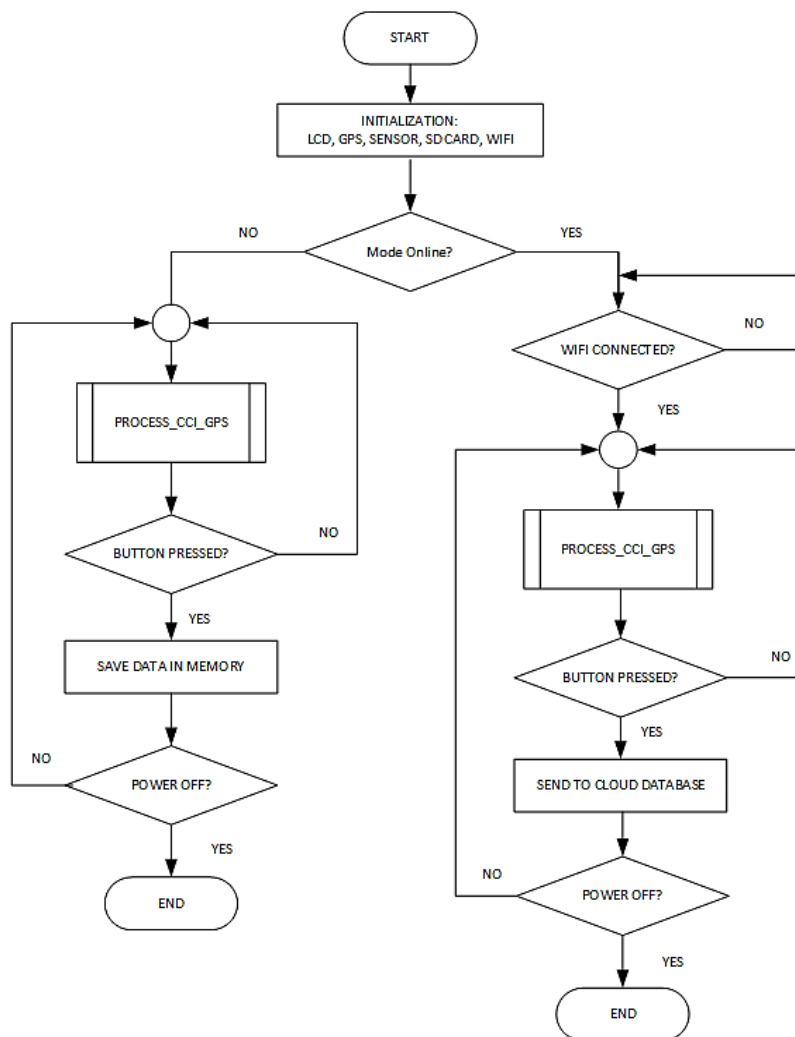


Figure 3. Flowchart of main program

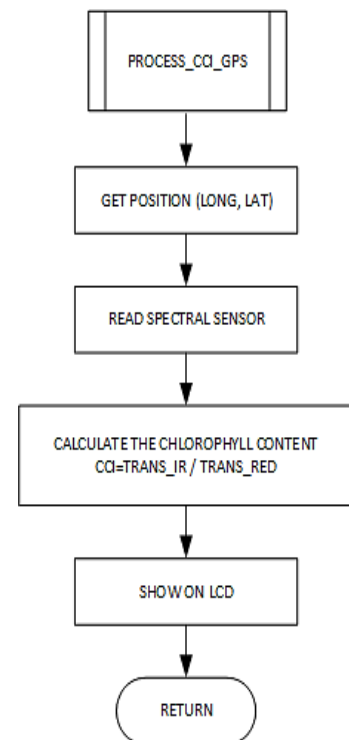


Figure 4. Flowchart of process CCI and GPS

4. RESULTS AND DISCUSSION

A low-cost IoT-based chlorophyll meter testing has been conducted by comparing the performance of a low-cost IoT-based chlorophyll meter with a chlorophyll meter (SPAD-502) and a spectrophotometer (SP-3000nano). Measurements of chlorophyll content were conducted on the leaves of maniltoa grandiflora (young leaves, adult leaves and old leaves). The leaf chlorophyll content was measured using a low-cost IoT-based chlorophyll meter and a SPAD-502 at four different positions (Figure 5) and repeated five times which were then taken the average value. We have also measured the leaf chlorophyll content using a spectrophotometer (Figure 6). As shown in Figure 7 to Figure 9, the measuring chlorophyll content results using a spectrophotometer, a SPAD-502 and a low-cost IoT-based chlorophyll meter are strongly correlated. It can be concluded that young leaves have less chlorophyll content than mature leaves and old leaves. The leaves that contain the most chlorophyll are old leaves. As chlorophyll is linearly correlated with

nitrogen, young leaves have less nitrogen content than mature leaves and old leaves. Young leaves need more nitrogen than mature leaves and old leaves.



Figure 5. Measurement of chlorophyll content in four positions



Figure 6. Measurement of chlorophyll content through Leaf extract

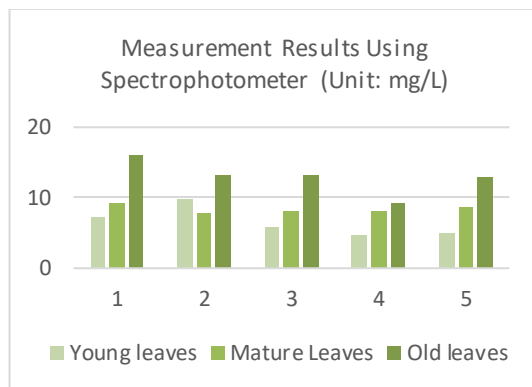


Figure 7. Measurement of chlorophyll content using Spectrophotometer

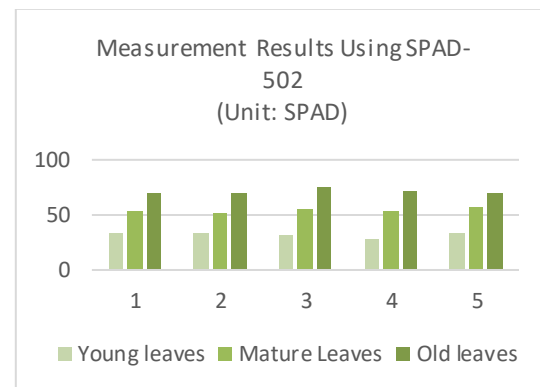


Figure 8. Measurement of chlorophyll content using SPAD-502

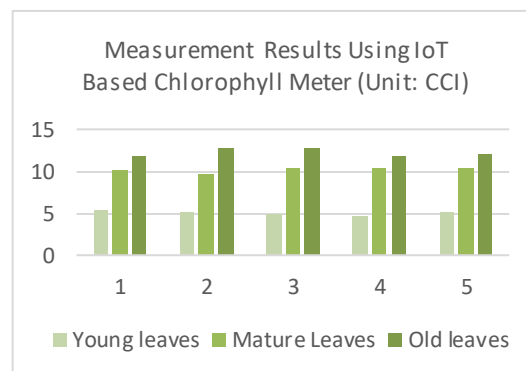


Figure 9. Measurement of chlorophyll content using low-cost IoT-based chlorophyll meter

The strength of the correlation between chlorophyll content measurement using a low-cost IoT-based chlorophyll meter and a SPAD-502 is assessed using the coefficient of determination (R^2). From the test results, we obtained an R^2 of 0.9705 (Figure 10), this shows a very strong correlation between low-cost IoT-based chlorophyll meter values and SPAD-502 values. A low-cost IoT-based chlorophyll meter has been used successfully to measure chlorophyll content, these results in accordance with other reports [13, 27, 29, 32].

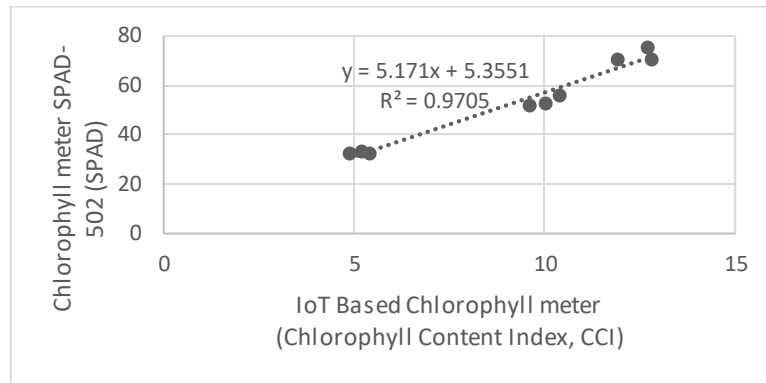


Figure 10. Correlations between SPAD values and IoT-based Chlorophyll meter in the leaves of *manihot grandiflora*

Testing of a sensor module, a memory module, and an LCD module is conducted by inserting leaf in a low-cost IoT-based chlorophyll meter and pressing a button to save data into memory and send data to the server. Test results show the device has worked well, chlorophyll content of plant leaves and location based on GPS satellites can be displayed on the LCD, stored in memory and sent to the server. Figure 11 shows the data displayed on the LCD and data in the form of text files stored in memory.

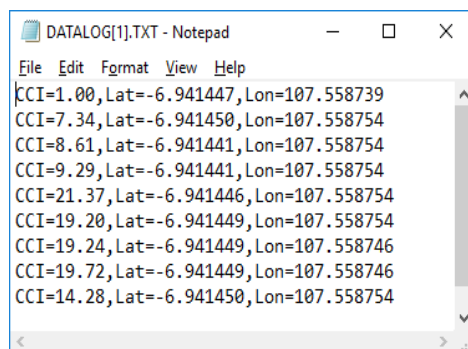


Figure 11. Memory module and LCD test results

Testing of communication between IoT-based chlorophyll meter device and service system platforms has been conducted by sending chlorophyll content and location based on GPS satellites data from a low-cost IoT-based chlorophyll meter to the service system platform. Figure 12 shows data received by the service system platform is displayed on monitor page (<http://e-agriculture.net/>).

Smart Farming Collect Monitor Back	<div> × Logout </div>																	
	Home / Monitor																	
	Device klorofilmeter1																	
	Show 10 entries Search:																	
	<table> <tr> <th>Device Name</th><th>Date</th><th>CCI</th><th>Longitude</th><th>Latitude</th></tr> <tr> <td>klorofilmeter1</td><td>2019-02-14T08:45:07.632Z</td><td>9.11</td><td>107.610573</td><td>-6.890449</td></tr> <tr> <td>klorofilmeter1</td><td>2019-02-14T23:48:25.141Z</td><td>1</td><td>107.558769</td><td>-6.941475</td></tr> </table>				Device Name	Date	CCI	Longitude	Latitude	klorofilmeter1	2019-02-14T08:45:07.632Z	9.11	107.610573	-6.890449	klorofilmeter1	2019-02-14T23:48:25.141Z	1	107.558769
Device Name	Date	CCI	Longitude	Latitude														
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klorofilmeter1	2019-02-14T23:48:25.141Z	1	107.558769	-6.941475														

Figure 12. Data from a low-cost IoT-based chlorophyll meter is displayed on the monitor page

5. CONCLUSION

The results have shown that low-cost IoT-based chlorophyll meter are functioning properly, which is able to measure chlorophyll content, get location, display data on the LCD, store data in memory, and send data to the service system platform. A strong correlation was obtained between measurements of chlorophyll content using IoT-based chlorophyll meters, SPAD-502 and spectrophotometer. The test results showed a significant relationship between SPAD-502 values and low-cost IoT-based chlorophyll meter values. Therefore, IoT-based chlorophyll meter can be used as a cheap alternative to SPAD-502 chlorophyll meter. In our future work, the data collected in the database server will be processed for the purpose of providing fertilizer recommendations to plants. In addition, the performance of a service system platform to monitor the chlorophyll content of plants (<http://e-agriculture.net/>) will be evaluated.

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