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# TECHNO-ECONOMIC FEASIBILITY STUDY OF LOW-COST AND PORTABLE HOME-MADE SPECTROPHOTOMETER FOR ANALYZING SOLUTION CONCENTRATION

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## Abstract

The purpose of this study was to evaluate the feasibility of the production of low-cost and portable arduino-based spectrophotometer with white LED as a light source for analyzing solution concentration. This spectrophotometer can be used for educational purposes in developing country. The experimental method was done in the engineering and economic evaluation perspectives. The engineering analysis was performed using a simple mass balance analysis, whereas the economic evaluation was conducted using several economic parameters, including gross profit margin, payback period, and net present value. To support the analysis, data including price, utilizing components, and specifications for apparatuses, as well as raw materials, were taken based on available online shopping webs. All calculations were done under the ideal condition for 20 years of production. The engineering result confirmed that the project was possible in the small-scale industry because all processing steps can be done using simple and commercially available equipment in the market. The economic evaluation result showed positive values for all economic parameters with several exceptions. The study is also completed with several basic theories for supporting the definition of spectrophotometer focused in this study.

Keywords: Economic analysis, Economic parameter, Engineering evaluation, Spectrophotometer.

## 1. Introduction

Recently, photometers have been widely used in various laboratories and pilot scales in universities and industries. The photometers have been generated into further developed and improved into sophisticated apparatuses. This photometer is also applied to many commercially available analytical instruments and characterization equipment [1]. Although current available photometer-related instruments and equipment are effective and available to measure many characterization analyses, the quality of the analysis directly depends on the increases in cost and complexity of the optical and electronic system, creating problems when applying the instrument for educational purposes in developing countries [2].

Common spectrophotometers are sold in the cost of ranging from 3,000 to more than 20,000 USD, informing the problems for school and university in developing countries such as Indonesia. For this reason, boosting researches on producing simple, portable, and inexpensive apparatus for chemical analyses become one of the intended issues [3]. Although many reports showed the effectiveness of current prototypes for photometers, the currently available reports are typically applicable in limited uses, specifically still for lab-scale process. Further, there is no information regarding the economic evaluation on the feasibility for commercial scale.

In our previous study [1], we developed a visible photometer that is convenient to be used for educational purposes in school. Specifically, this photometer is intended for being applied in developing countries. The designed apparatus was simple, rapid in analysis, portable, and low cost. The system was an arduino-based spectrophotometer with white LED as a light source. The system was efficient for analyzing solution concentration. Further, better results were obtained compared to the commercially available photometers. Moreover, this apparatus has been used for many applications [4-7].

Based on our previous feasibility studies on fabrication of various materials from engineering and economic evaluation perspectives [8-14], the purpose of this study was to evaluate feasibility of the production of low-cost and portable arduino-based spectrophotometer with white LED as a light source for analyzing the solution concentration. This equipment is potentially used for educational purposes in developing country. Arduino has been selected because this material is a popular electronic interactive platform recently, which was developed by microcontroller system. Arduino is also simple to use, versatile, inexpensive, and widely used in the design of electronic system and development of interactive product [15].

Furthermore, the advantages of arduino over other modules are the simplification of the use of hardware and software development needed for running the system. Arduino uses open source software and can be extended by usual programmers. Arduino has simple and clear programming environment and writing code [16], making this system useful for many applications [17-21]. Thus, the present spectrophotometer is not only for chemical analysis but also for upgrading the students and teachers in further developments of spectrophotometer and changing this device into other uses. Students can re-arrange and re-design the system produced by our spectrophotometer. In general, this spectrophotometer is not only for chemistry but also other discipline such as physics and electronics.

In this study, the ideal condition for making project was applied. The experimental method was done in the engineering and economic evaluation perspectives for fabricating the spectrophotometer that was developed in our previous study [1]. The engineering analysis was calculated using a simple mass balance analysis for the input and output materials. To support the economic evaluation, several economic evaluation parameters were calculated, such as gross margin (GPM), internal return rate (IRR), payback period (PBP), cumulative net present value (CNPV), break-even point (BEP), and profitability index (PI). To support the economic analysis, data including price, components, and specifications of apparatuses, as well as raw materials, were taken based on available online shopping webs.

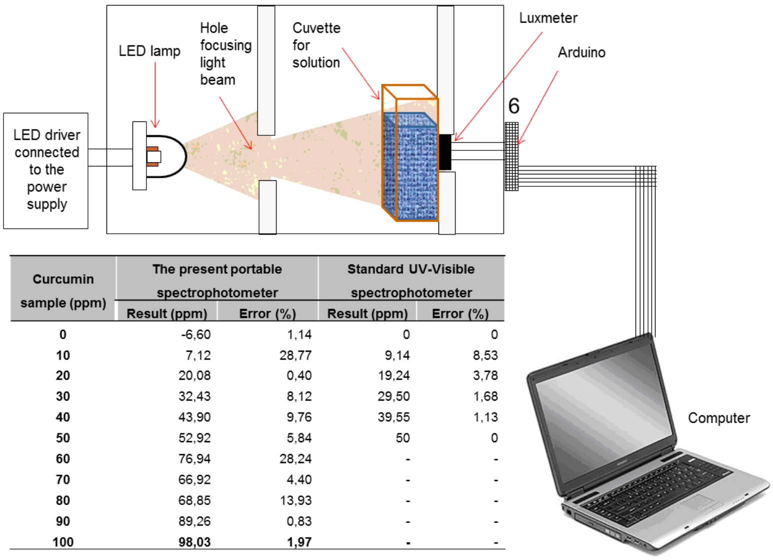
In addition, this feasibility study is important because it has three advantages. The first advantage is to understand the possibility for the production of low-cost spectrophotometer. Indeed, this helps the decision whether the scaling up process is possible or not and gives suggestion on how to optimize the project. The second advantage is when the process is feasibly done in the large-scale production. The present spectrophotometer can be used for alternative apparatus to current sophisticated photometers for developing countries. The third is to give benefit to the economic growth. In short, the successful production can create several aspects related to the socio-economic condition, including reducing the poverty.

Since the present study is the first analysis in the feasibility study, all calculations were done in the ideal condition for 20 years of production. Indeed, for scaling up process, further analyses must be done and other variables must be added. These variables (e.g., labor condition, sales and raw material, utility, as well as external condition and environmental uncertainty (i.e., competition, tax, and subsidiary)) are important to predict the realistic condition for the development of the project. However, we believe that the present analysis will drive further investigation for the large-scale production. In addition, the study was completed with the introduction of the basic information for the spectrophotometer to make reader understand and give further developments possible.

## 2. Experimental Method

The experiments were done in both engineering and economic evaluation perspectives. The process was adopted and improved from Nandiyanto et al. [1]. Systematic process used in this study is shown in Fig. 1.

The engineering analysis was calculated using a simple mass balance analysis, whereas the economic evaluation was done using several economic parameters, including GPM, IRR, PBP, CNPV, BEP, and PI sales to investment. In the economic analysis, all calculations were done and compared to the current engineering economic theories, in which these theories are well explained in Garrett [22]. To support the analysis, data for price, components, and specifications of apparatuses, as well as raw materials, were taken based on the available online shopping webs. All calculations were done in the ideal condition for 20 years of production where neither inflation nor deflation in the economic condition happens.



| Curcumin sample (ppm) | The present portable spectrophotometer | | Standard UV-Visible spectrophotometer | |
|---|---|---|---|---|
| | Result (ppm) | Error (%) | Result (ppm) | Error (%) |
| **0** | -6,60 | 1,14 | 0 | 0 |
| **10** | 7,12 | 28,77 | 9,14 | 8,53 |
| **20** | 20,08 | 0,40 | 19,24 | 3,78 |
| **30** | 32,43 | 8,12 | 29,50 | 1,68 |
| **40** | 43,90 | 9,76 | 39,55 | 1,13 |
| **50** | 52,92 | 5,84 | 50 | 0 |
| **60** | 76,94 | 28,24 | - | - |
| **70** | 66,92 | 4,40 | - | - |
| **80** | 68,85 | 13,93 | - | - |
| **90** | 89,26 | 0,83 | - | - |
| **100** | **98,03** | **1,97** | **-** | - |

**Fig. 1. Schematic diagram of portable arduino-based spectrophotometer with white LED as light source. The attached table is the comparison of the present portable spectrophotometer and standard spectrophotometer. Figure was adopted from Nandiyanto et al. [1].**

To understand the feasibility of the production of low-cost spectrophotometer, mass balance calculation was conducted with several assumptions:

- The spectrophotometer is adopted from the apparatus designed by Nandiyanto et al. [1].
- The production cycle is about 2 hours per apparatus.
- The working hours per day is from 8.00 to 16.00; Or, working hours are 8 hours per day.
- One year contains 300 days of production, while the rest is holiday and preparation time.
- The length of project operation is 20 years.
- All cost analyses were calculated based on the ideal condition, in which no economic fluctuation (either inflation or deflation) for the labor and utility costs, as well as raw material and sales price. All costs are stable during the project operation.
- The price of equipment is fixed based on the commercially available price (Table 1). The Lang Factor was used for analyzing the total plant cost (TPC) (Table 2) and total investment cost (TIC) (Table 3) [22]. The calculation showed that the TIC of this project is about five times of the total apparatus cost.
- Working wage is 2,400 USD per year, and production employs 4 workers.
- Basic electricity cost is assumed to be 0.15 USD per kWh [23]. Then, the utility is only for mostly electricity [24], which can be assumed 100 W for solder (with the usage time of 1 hour per day) and 900 W for other purposes (with utility working hours of 8 hours per day).

- The annual discounted rate is 15%. The discount rate was adopted based on the interest rate charged to the commercial banks. In this study, the discount rate was taken to be more than common interest rate in the commercial banks. This discount rate is used as the interest rate used in calculating cash flow analysis to determine the present value of future cash flows.
- Annual income tax is 10%. The income tax was used based on the common tax in Indonesia.
- The project does not run with a loan from the bank.
- The selling price of product is 500 USD per equipment.
- All products are sold completely. No product loss due to either improper quality of product or damaged/destroyed raw components is obtained. And, no consideration of waste (waste is 0%).
- All analyses are conducted in USD with a conversion rate of 10,000 IDR per USD.

**Table 1. Parts needed for designing a set of spectrophotometer.**

| No | Component | Price (USD) | |
|---|---|---|---|
| **A** | **Main part** | | |
| | 1. Arduino | 56,3 | |
| | 2. Thermal sensor | 4,5 | |
| | 3. Thermocouple | 9,5 | |
| | 4. Heater | 4,5 | |
| | 5. LCD | 10 | |
| | 6. Lux sensor | 9,56 | |
| | Sub total | | 94,36 |
| **B** | **Other supporting parts** | | 55,64 |
| | **Total** | | **150** |

**Table 2. Calculation of total plant cost.**

| Component | Factor | Cost (USD) | |
|---|---|---|---|
| **Main component** | | | |
| Purchased Equipment | 1 | 10,000.- | |
| Piping | 0.5 | 5,000.- | |
| Electrical | 0.1 | 1,000.- | |
| Instrumentation | 0.2 | 2,000.- | |
| Utilities | 0.5 | 5,000.- | |
| Foundations | 0.1 | 1,000.- | |
| Insulations | 0.06 | 600.- | |
| Painting. fireprofing. Safety | 0.05 | 500.- | |
| Yard Improvement | 0.08 | 800.- | |
| Environmental | 0.2 | 2,000.- | |
| Building | 0.08 | 800.- | |
| Land | 0.5 | 5,000.- | |
| **Subtotal 1** | | | **33,700.-** |
| **Construction** | | | |
| Construction. Engineering | 0.6 | 6,000.- | |
| Contractors fee | 0.3 | 3,000.- | |
| Contigency | 0.2 | 2,000.- | |
| **Subtotal 2** | | | **11,000.-** |
| **Total Plant Cost** | | | **44,700.-** |
| **Total Plant Cost(-Land)** | | | **39,700.-** |

**Table 3. Calculation of total investment cost.**

| Component | Factor | Cost (USD) |
|---|---|---|
| **Total Plant Cost(-Land)** | | **39.700.-** |
| **Other Capital Requirements** | | |
| **Off-site Facilities** | 0.2 | 2,000.- |
| **Plant start-up** | 0.07 | 700.- |
| **Working capital** | 0.2 | 2,000.- |
| **Subtotal** | | **4,700.-** |
| **Total Plant Investment (-land)** | | **44,400.-** |

## 3. Results

Figure 1 depicts the schematic illustration of the proposed low-cost spectrophotometer based on previous literature [1]. In short, the system contains a white-color LED light source (10 W; emitting a 450-620 nm continuous spectrum), glass cuvette cell (12.5×12.5×45 mm), and a photosensor (a light sensor (lux meter; BH1750FVI, Rohm Co. Ltd., Japan) equipped with arduino system (arduino UNO)). All components were designed and constructed into an acrylic case with dimension of 200, 130, and 150 mm for each length, width, and height, respectively. Total mass of the spectrophotometer was about 1 kg. The system was set and programmed for being able to connect to the computer (software using the Arduino IDE 1.0.6, written in C++ to control photometric analysis through a USB interface and for data acquisition to the computer).

To design a portable spectrophotometer, several components are required (Table 1). As shown in the table, the components for designing portable spectrophotometer consist of two parts: main and supporting parts. Main part is the major component that cannot be substituted, which contains arduino UNO. The supporting component is the parts that are modifiable. This component including the case and the partition equipped in the spectrophotometer. In this analysis, polyacrylic-based casing and partition were used. The cost making can be lowered to less than 30% of the total cost. However, for some cases, the supporting component can be changed into other types of materials, such as stainless steel or aluminium, depending on the users and condition for analysis. However, changing the types of materials for casing, indeed, will increase the total cost.

Based on above assumptions in the method section, the calculation can be described as follows:

- The total numbers of spectrophotometers are 4 apparatuses per day. Then, the calculation of the total spectrophotometers per year can adopt the multiplication of 300 production days with 4 apparatuses per day. Or, the total spectrophotometers that can be produced in a year are 1200 apparatuses.
- The utility cost can be calculated by multiplying the utility and working hours. The total utility used per day is about 900 W × 8 hours and 100 W × 1 hour. The total power used is 7,300 Wh per day. Adding the total 300 working days per year results in the total power of 2,190,000 Wh (= 2,190 kWh per year). Then, the utility cost can get 328,500 USD per year.

- The results showed that the TIC is relatively inexpensive since all processing steps are done using commercially available apparatuses in the market. The process can also be done as a home industry.

The first economic analysis of the present project shows excellent results. The GPM was more than 150 USD/pack. By calculating one year production, the GPM can reach 180,000 USD per year. The BEP was 55 packs in one year for profitable project.

To ensure the realistic economic analysis, Fig. 2 describes the economic evaluation of the production of low-cost spectrophotometer based on the CNPV curve. The curve was calculated using various production capacities from 5 to 100% under ideal condition. Ideal condition is assumed to have stable condition for variable and fixed costs, wage labor, utility cost, and also raw material and product prices. In this figure, the production capacity describes the sales and product condition. 100% of production capacity replies that all products are distributed and sold well, whereas 5% of production capacity is when only 5% of products are ready and sold to market.

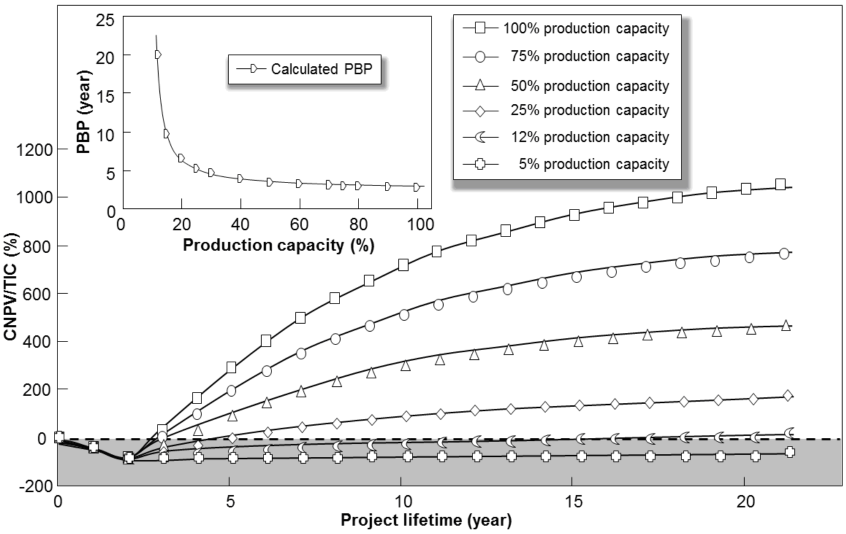


**Fig. 2. Correlation between CNPV/TIC and project lifetime under various production capacities. The paneled figure is the PBP vs project lifetime.**

As shown in Fig. 2, the relationship between TIC and the production year shows positive profitability. In the initial year, the CNPV value shows a negative value. Indeed, this is because the initial year relates to the construction and advertisement of product. CNPV value starts to increase after more than 2 years of the production for 100% of production capacity.

Regarding the production capacity, the results confirmed that the change in this parameter has a direct impact to the final CNPV. The less production capacity gives the less CNPV. In this study, we limited the production capacity to 100% because increases in the value of production of higher than 100% will create the need for adding further calculations to the labor as well as plant cost.

To ensure the impact of the production capacity on the prediction of PBP, PBP analysis is presented in the paneled curve in Fig. 2. The results correspond that the more effective production capacity implemented, the faster PBP can be obtained. When 100% of production capacity is reached, the PBP can approach less than 3 years.

Analysis of other parameters in Fig. 2 also shows that production capacity must be carried out at a level higher than 12%. If the value is less, it will create a failure in project profitability.

## 4. Discussion

The engineering analysis confirmed that the project is promising. Based on the mass balance of raw material and product, the production process can be done in the small-scale industry [14]. The main reason in strengthening this hypothesis is the condition which parts and supporting equipment for assembling spectrophotometers are commercially available in the market.

Other engineering analysis also confirmed that the production is only assembling the component and inputting the computer program. No complex utility system is required, informing that the project can be developed without limitation to the specific area (such as no need to be near to river, etc.). However, the better place for the project is near the transportation access area for easily distributing the raw material and product.

The first cost analysis for determining the profitability performance is the TIC. Based on the above assumptions, to produce 1200 products, TIC is less than 50,000 USD. This is used mostly for the system, including assembling space, storage, and computerization. This less cost can be obtained since all materials are commercially available and all production steps including assembling process can be done in small scale area.

The GPM value obtained by deviating sales and raw material prices without considering other factors shows over 150 USD per pack. Selling 1200 products per year can create GPM of 180,000 USD per year. Although GPM shows huge amount per year, the GPM analysis cannot be used directly to determine whether a project is feasible or not. Additional other project factors must be added to confirm the realistic profitability condition.

To get realistic economic analysis, additional calculation of several project factors (including utilities, total investment cost calculations, labor, etc.) is required [25]. As shown in Fig. 2, after adding these factors, cost analysis on all economic parameters shows a positive value, showing good opportunity for fabricating this product. Detailed information can be seen as follows:

i. The BEP analysis shows that the minimum processing cycle is 56 products per year (more than 5 products per month). Compared to the engineering analysis, one process cycle (to assemble the product) takes 2 hours. Then, since the one-year project contains 300 days (assuming the holiday is off-day production), the maximum production amount per year is 1200 processing cycles. Thus, BEP analysis indicates that the current project will be profitable because the minimum value of BEP has been passed.

ii. Analysis of profit to sales and TIC shows excellent results. 100% of production capacity can create profit-to-sales and profit-to-TIC of more than 38 and 310%, respectively.

iii. The detailed CNPV curve shows a positive value, although the initial years are negative. But, after passing more than 3 years of the project (for 100% of production capacity), CNPV shows positive gradient, showing the project is profitable. The ratio of final CNPV and TIC in the 100% of production capacity was more than 10 times.

iv. The results of GPM, BEP, profit to sales and TIC, and CNPV confirm positive results, showing that this project seems to attract industrial investors. However, for increasing the interest, there are several considerations.

   a. Sales. Project must be absolutely sure that the product can be absorbed by the market. Otherwise, it will be difficult to run the project.

   b. Scaling up the production. This consideration can be done only if there are a huge market to consume the product. The increasing production rate would have a great impact to the higher profit which can be earned. However, this analysis must be carefully done because scaling-up production has direct correlation to the increases in other elements, such as raw material amount, labor cost, as well as utility cost. Thus, further feasibility studies must be conducted.

   c. Corporate social responsibility (CSR) from the company or government. However, this CSR relates to the social and political condition [23].

   d. Join project with the supplier or producer company for the raw materials. This method can reduce the raw material cost, specifically for shipping and handling fees. Indeed, this can give great positive impact to the profit.

## 5. Conclusions

The production of low-cost spectrophotometer has been evaluated from engineering and economic feasibility studies. Based on above analyses, the project is prospective from engineering point of view. The cost analysis of economic parameters also presents positive value, informing the project profitable. To be more profitable, there are at least four considerations: the certainty for the need of this equipment for market, scaling-up production, applying CSR, and join production with the raw material supplier or producer. In addition, since the present study is the first analysis in the feasibility study, all economic analyses were done in the ideal condition for 20 years of production.

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## References

1. Gleick, P.H. (1996). Basic water requirements for human activities: meeting basic needs. *Water international*, 21(2), 83-92.
2. Hidayat, Z.; and Taufiq, M. (2012). Pengaruh Lingkungan Kerja Dan Disiplin Kerja Serta Motivasi Kerja Terhadap Kinerja Karyawan Perusahaan Daerah Air Minum (PDAM) Kabupaten Lumajang. *Wiga: Jurnal Penelitian Ilmu Ekonomi*, 2(1), 79-98.

3. Harris, L.M. (2008). Water rich, resource poor: intersections of gender, poverty, and vulnerability in newly irrigated areas of southeastern Turkey. *World Development*, 36(12), 2643-2662.
4. Nandiyanto, A.; and Haristiani, N. (2017). Design of simple water treatment system for cleaning dirty water in the rural area. *IOP Conference Series: Materials Science and Engineering*, 180(1), 012148.
5. Shamel, M.M.; and Chung, O. (2006). drinking water from desalination of seawater: Optimization of reverse osmosis system operating parameters. *Journal of Engineering Science and Technology* (*JESTEC*), 1(2), 203-211.
6. Kovacic, D.A.; Twait, R.M.; Wallace, M.P.; and Bowling, J.M. (2006). Use of created wetlands to improve water quality in the Midwest - Lake Bloomington Case Study. *Ecological Engineering*, 28(3), 258-270.
7. Klüpfel, A.M.; and Frimmel, F.H. (2010). Nanofiltration of river water - fouling, cleaning and micropollutant rejection. *Desalination*, 250(3), 1005-1007.
8. Phillips, D. (2009). Permeable reactive barriers: A sustainable technology for cleaning contaminated groundwater in developing countries. *Desalination*, 248(1-3), 352-359.
9. Kumar, K.S.; Kumar, P.S.; and Babu, M. (2010). Performance evaluation of waste water treatment plant. *International Journal of Engineering Science and Technology* (*JESTEC*), 2(12), 7785-7796.
10. Nandiyanto, A.B.D.; Sofiani, D.; Permatasari, N.; Sucahya, T.N.; Wiryani, A.S.; Purnamasari, A.; Rusli, A.; and Prima, E.C. (2016). Photodecomposition profile of organic material during the partial solar eclipse of 9 March 2016 and its correlation with organic material concentration and photocatalyst amount. *Indonesian Journal of Science and Technology*, 1(2), 132-155.
11. Nandiyanto, A.B.D.; Putra, Z.A.; Andika, R.; Bilad, M.R.; Kurniawan, T.; Zulhijah, R.; and Hamidah, I. (2017). Porous activated carbon particles from rice straw waste and their adsorption properties. *Journal of Engineering Science and Technology*(*JESTEC*), 12(8), 1-11.
12. Sulastri, A.; and Rahmidar, L. (2016). Fabrication of biomembrane from banana stem for lead removal. *Indonesian Journal of Science and Technology*, 1(1), 115-131.
13. Permatasari, N.; Sucahya, T.N.; and Nandiyanto, A.B.D. (2016). Agricultural wastes as a source of silica material. *Indonesian Journal of Science and Technology*, 1(1), 82-106.
14. Nandiyanto, A.B.; Ragadhita, R.; Maulana, A.; and Abdullah, A. (2018). Feasibility study on the production of biogas in dairy farming. *IOP Conference Series: Material Science and Engineering*, 288, 012024.
15. Rui-Yan, C. (2012). Principle and application of Arduino [J]. *Electronic Design Engineering*, 16, 047.
16. Srividyadevi, P.; Pusphalatha, D.; and Sharma, P. (2013). Measurement of power and energy using Arduino. *Research Journal of Engineering Science*, 2(10), 10-15.
17. Dahou, H.; El Gouri, R.; Alareqi, M.; Mateur, K.; Mezouari, A.; Zemmouri, A.; and Hlou, L. (2018). Design and implementation intelligent adaptive front-lighting system of automobile using digital technology on Arduino board. *International Journal of Electrical and Computer Engineering*, 8(1), 521-529.

18. Gunawan, T.S.; Munir, Y.M.S.; Kartiwi, M.; and Mansor, H. (2018). Design and implementation of portable outdoor air quality measurement systems using Arduino. *International Journal of Electrical and Computer Engineering*, 8(1), 280-290.
19. Jaber, A.A.; and Bicker, R. (2016). Design of a wireless sensor node for vibration monitoring of industrial machinery. *International Journal of Electrical and Computer Engineering*, 6(2), 639.
20. Sahu, J.; Choudhury, B.; and Patra, M. (2016). An effective development and analysis of a mobile robot. *International Journal of Electrical and Computer Engineering*, 6(2), 639.
21. Gunawan, T.S.; Yaldi, I.R.H.; Kartiwi, M.; and Mansor, H.(2018). Performance evaluation of smart home system using internet of things. *International Journal of Electrical and Computer Engineering*, 8(1), 400-411.
22. Garrettt, D.E. (2012). *Chemical Engineering Economics*. New York: Van Nostrand Reinhold.
23. Nandiyanto, A.B.D. (2018). Cost analysis and economic evaluation for the fabrication of activated carbon and silica particles from rice straw waste. *Journal of Engineering, Science, and Technology*, 13(6), 1523-1539.
24. Nandiyanto, A.B.D.; Andika, R.; Aziz, M.; and Riza, L.S. (2018). Working volume and milling time on the product size/morphology, product yield, and electricity consumption in the ball-milling process of organic material. *Indonesian Journal of Science and Technology*, 3(2), 82-94.
25. Machmud, A.; Ahman, E.; Dirgantari, P.D.; Waspada, I.; and Nandiyanto, A.B.D. (2019). Data envelopment analysis: The efficiency study of food industry in Indonesia. *Journal of Engineering, Science, and Technology* (*JESTEC*), 14(1), 479-488.