Conceptual design of a solar powered agriculture irrigation system for rural farming

NA Aziz¹, NAM Amin¹*, MS bin Mohamad¹, MAM Saad¹, M Izham², MTA Rahman¹, and A Mohamad¹

¹Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis (UniMAP), Kampus Alam Pauh Putra, 02600 Arau, Perlis, Malaysia.
²Institute of Engineering Mathematic, Faculty of Applied Science and Humanities, Universiti Malaysia Perlis (UniMAP), Kampus Alam Pauh Putra, 02600 Arau, Perlis, Malaysia.

nasrulamri.mohdamin@unimap.edu.my

Abstract. Based on the geographical profile of Wang Kelian, Perlis, farmers are having trouble distributing resources due to land elevation. In the present work, an automated solar powered agriculture irrigation system is proposed as a solution for the farmers to manage their farms efficiently. To provide a viable solution in designing the proposed system, a series of procedures have been employed. A survey was conducted in order to identify the customer requirement. The respondent requirements data were extracted to match with the scientific view to design the system. The data from the respondent was then linked to respond to the product characteristic by decomposing the function of the irrigation system. Herein, four conceptual designs were finalised by cross-linking the part selection through the morphological chart. Among these designs, the final agriculture irrigation system was being selected by evaluating and scoring the weight factor by using a weighted decision matrix. As a result, a fully automated conceptual design (Concept 1) was selected as the best design as the highest score of 3.96 was recorded.

1. Introduction

In recent years, the utilisation of agriculture irrigation systems has been extensively discussed [1]–[3]. The agriculture and irrigation system has been pointed out as a viable solution as an efficient and capable system in conserving resources and human effort. The irrigation system based on monitoring environmental parameters and controlling irrigation has been highlighted as the best among all reviewed systems. Eker [4] has researched a solar powered water pumping system in which the proposed system utilises a photovoltaic (PV) for a sustainable agriculture system [5]. The solar-powered pumping system is made up of two basic components; which is solar panels and pumps. The solar panel converts sunlight to direct current (DC) electricity then is stored within batteries. From the study, the solar panel provides the energy needed where it is needed. The maximum efficiency of the solar panel depends on the amount of sunlight that hits the panel and the angle that strikes the panel.

In Malaysia, the average solar radiation is reported as high as 400–600 MJ/m² per month [6], indicating Malaysia as a strategic place to fully utilise solar energy sources. Herewith, this paper proposes a solar-powered system to replace Malaysia’s conventional agriculture and irrigation system used in the rural area of Wang Kelian, Perlis. In order to develop a viable solution, many design criteria need to be considered, such as being cost-effective, convenient for the farmers and suitable to be used
in the rural area. Also, due to the rural and elevated geographical profile in which it is difficult to supply electricity, this solar-powered pumping system needs to be automated. Accordingly, this paper presents step by step procedures in establishing conceptual designs of the proposed agriculture and irrigation system.

2. Methodology

Figure 1 shows the series of procedures that were carried out in order to develop the conceptual designs of the agriculture irrigation system. Three existing precision farming systems (Aquaponic, Hydroponic and Permaculture farming systems) are observed in the benchmarking process. Furthermore, a basic criterion of the agriculture irrigation system is proposed with highlighting several issues, such as productivity, cost, ease of maintenance and ergonomics, in which these design issues are taken as a foundation in establishing the survey questions.

![Figure 1. Research process flow chart](image)

2.1. Survey Analysis

A survey is done to collect data from a group of the target users, which are specified as farmers in Perlis. With the aim to identify the user needs for the proposed system, several questions were established based from the outlined problems, project objectives, and also from the design issues obtained from the previous task. From the surveys, 71.4% agrees that the farm expenses in the long run need to be reduces, while 69% suggested for the smart system to be environmentally friendly. Besides, respondent also pointed out for the system to be more convenient. Other than that, 41 respondents agreed that agriculture and irrigation system should be affordable, while 11 respondents stood as neutral and only 1 disagreed with this statement. Also, 44 respondents agreed that the system should minimise the waste of water. From these data, it can be concluded that the proposed agriculture and irrigation system can be a useful alternative for the farmers if the system is designed with the criteria agreed by the respondent. For example, the respondent demands for affordable and convenient alternative, as well as the system should be sustainable and environmentally friendly that minimise the waste of water. From the survey data and the design identification, as well as based on the mission of the project, the engineering characteristic of the systems are then generated and analysed in house of quality (HOQ).

2.2. House of Quality

The information that consists in the HOQ shown in Figure 2 matches the respondent requirement and engineering characteristic of the agriculture irrigation system. The HOQ in Figure 2 shows the most important engineering characteristic to design the product is energy usage, material, and cost. This three-parameter is vital to develop a design that is related to irrigation. It is not surprising that the energy usage and cost are being prioritised in this field. This two-parameter is having a correlation with each other, that cost will increase with the increment of energy usage by the equipment. It’s important to have a system that provides low energy consumption and indirectly will reduce the overall cost. Meanwhile, the least important parameter for engineering characteristics is found to be the volume of the tank, time to install and weight of the system.
2.3. Product Design Specification (PDS)

The PDS is a system created at the start of the design process during the problem description. This section provides brief information on the design obligations that need to be met with the plan objective. A few of the PDS considered in this study are the key performance target. From many issues, this project specified three PDS that must be complied by the system, in which (1) the system can water the crops in the wet and dry season, (2) the system is smart and affordable, and (3) reliable and did not use electrical grid/power systems. In this project, solar energy is to be utilised as the energy source. Hence each concept designs to be generated must comply with these design specifications.

3. Concept Generation

Prior to the conceptual design, the morphological chart was developed. The morphological chart provides a structured approach to the concept generation to widen the area of search for solutions. The morphological chart helps to generate a complete design solution. The basic approach to creating the chart by listing the function requirements and different mechanisms that can be used to perform the functions listed. For each functionality option, three choices of solutions are tabulated in the morphological chart. For example, the solution proposed to operate solar pumping systems are either to use PIC, Arduino UNO Based or Raspberry Pi. While three choices of solar power are Monocrystalline solar panel, Polycrystalline solar panel and a Thin-film solar panel. Thus, the solution was selected from
the morphological chart based on their compatibility to each component. As a result, four conceptual designs proposed in this study are shown in Figure 3.

![Conceptual Designs](image)

| Concept 1 | Concept 2 |
|-----------|-----------|
| (1) Electrical pump, (2) Polyethylene pipe, (3) Waterproof ultrasonic indication water level sensor, (4) Solenoid valve, (5) Monocrystalline solar panel, (6) Arduino UNO, (7) Soil moisture and humidity sensor, (8) Lithium battery, (9) Watering device and (10) Water tank | (1) Solar panel, (2) Soil moisture and humidity sensor detector module, (3) Watering devices, (4) Arduino UNO, (5) Solenoid, (6) Automatic water tank float valve, (7) Water tank and (8) Hydraulic ramp pumps |

| Concept 3 | Concept 4 |
|-----------|-----------|
| (1) Electrical pump, (2) Soil moisture and humidity sensor detector module, (3) Polyvinyl chloride pipe, (4) Nickel iron battery, (5) Monocrystalline solar panel, (6) Stainless steel ball valve, (7) Water level sensor module and (8) Raspberry Pi | (1) Monocrystalline solar panel, (2) PIC operator, (3) Lead-acid battery, (4) Water tank, (5) Wheel water pump, (6) Galvanised pipe, (7) Stainless steel ball valve, and (8) Soil moisture and humidity sensor |

**Figure 3.** Conceptual design of an agriculture irrigation system; (a) Concept 1, (b) Concept 2 (c) Concept 3 and (d) Concept 4

As shown in Figure 3, various types of components have been selected in order to complement each other to achieve the design objectives. Each component used in the design concept have been particularly chosen by benchmarking process, and also from the data obtained in the previous section. As an example, for Concept 1 in Figure 3 (a), the Arduino acts as the main controller to control the sensor, solar and the pump. This design uses lithium type of battery, that is maintenance-free, stable, reliable and has longer life-span than other battery. Besides, lithium battery is generally smaller and lighter and has high energy storage efficiency by up to 95%. The monocrystalline solar panel has the highest
efficiency rate at the same power input as lead-acid and nickel-iron battery. Furthermore, this design is easier, less human energy and reliable cause it used automatic devices such as solenoid and electrical pump controlled by Arduino. Nevertheless, the overall cost will be highest compared to other proposed design concept because the components are fully electronic. The main controller which is Arduino only can read one code at one time, and it has slower speed rather than Raspberry Pi and PIC as used in Concept 3. There are advantages and disadvantageous of the components used and integration. Henceforth, the design selection process was done to evaluate all these established designs.

4. Design Selection

A weighted decision matrix is a decision matrix that can be implemented to evaluate and prioritise a list of options. A list of weighted criteria is established, and then the weighted factors are determined. To determine the weighting factor, a hierarchical objective tree is constructed as shown in Figure 4. This weighting factor is calculated by direct assignment based on the engineering judgement. The weights of individual categories at each level of the tree must be 1.0. In order to evaluate the weights, 11 points scale of 0 to 10 points scores are used [7]. The lowest and highest scores are 0 and 10, representing “a totally useless solution” and “ideal solution”, respectively. Accordingly, the results are tabulated in Table 1.

![Figure 4. Objective tree for the design of an agriculture and irrigation system](image)

| Design criteria                  | Weight factor | Concept 1 | Concept 2 | Concept 3 | Concept 4 |
|----------------------------------|---------------|-----------|-----------|-----------|-----------|
|                                  | Score | Rating | Score | Rating | Score | Rating | Score | Rating |
| Maintenance cost                 | 0.03  | 7      | 0.21   | 7        | 0.21   | 6      | 0.18  | 7      | 0.21   |
| Material cost                    | 0.03  | 7      | 0.21   | 7        | 0.21   | 6      | 0.18  | 6      | 0.18   |
| Manufacturing cost               | 0.03  | 6      | 0.18   | 6        | 0.18   | 6      | 0.18  | 7      | 0.21   |
| Easy to install and maintain     | 0.07  | 7      | 0.49   | 6        | 0.42   | 5      | 0.35  | 7      | 0.49   |
| High power delivery              | 0.07  | 7      | 0.49   | 7        | 0.49   | 7      | 0.49  | 6      | 0.42   |
| Easy to operate                  | 0.07  | 7      | 0.49   | 7        | 0.49   | 7      | 0.49  | 7      | 0.49   |
Table 1 shows the rating for each concept that has been obtained from the study. From the table weighted decision matrix, the data indicates that the best overall design concept would be Concept 1, with the highest rating score of 3.96. Henceforth, Concept 1 is selected as the final design for further consideration and analysis, presented elsewhere.

5. Conclusion

The study investigated the process flow in design principles of a solar powered agriculture irrigation system. In order to provide a viable alternative of agriculture irrigation system to the target users, four conceptual designs were established and evaluated. The final conceptual design was thoroughly selected through a series of procedures, such as surveys and HOQ. The final selection of the design had been performed using the concept of screening and scoring method. The weight decision matrix was used in evaluating the conceptual designs. From the evaluation, the conceptual design one (Concept 1) is selected as the final design concept, as the highest score of 3.96 was recorded. Concept 1 is fully automatic, controlled by Arduino is expected to reduce human energy and simultaneously increase the systems efficiency.

Acknowledgement

The authors acknowledge the technical support from the Faculty of Mechanical Engineering Technology at the Universiti Malaysia Perlis (UniMAP). The authors are also grateful for the financial support provided by Universiti Malaysia Perlis (UniMAP) via Research Materials Fund (RESMATE 9001-00622) grant.

References

[1] Khoa TA, Man MM, Nguyen TY, Nguyen VD, and Nam NH 2019 J. Sens. Actuator Networks. 83,45.
[2] K. A. Patil and N. R. Kale, 2017 Proceedings - International Conference on Global Trends in Signal Processing, Information Computing and Communication, ICGTSPICC 2016 543–545.
[3] L. Levidow, D. Zaccaria, R. Maia, E. Vivas, M. Todorovic, and A. Scardigno, 2014 Agric. Water Manag., 146, 84–94.
[4] I. A. Lakhia, G. Jianmin, T. N. Syed, F. A. Chandio, N. A. Buttar, and W. A. Qureshi, 2018 Journal of Sensors, 2018.
[5] B. Eker, 2005 Trakia, 2005, J. Sci, 3, 7–10.
[6] S. Mekhilef, A. Safari, W. E. S. Mustaffa, R. Saidur, R. Omar, and M. A. A. Younis, 2012, Renew. Sustain. Energy Rev 16, 1,386–396.
[7] O. Erdinc and J. R. Lewis, 2017 J. Usability Stud, 2,12, 73–91.