Design and analysis of a solar integrated agriculture irrigation system for rural farming area

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Abstract. Precision farming involves a management strategy to increase productivity and economic returns with reduced environmental impacts. Precision farming is available for small farm agriculture and big farm agriculture, and it plays a significant role in rural development programs in the agriculture industry. Accordingly, an automated solar integrated agriculture irrigation system is proposed to effectively help farmers in rural areas supply the water to their farms. The proposed automated system is expected to increase productivity and provide better quality control, as well as minimising the work labour time. The system was designed by considering various design factors, such as the reliability, safety, and ergonomic factors, to ensure the product is user friendly. Besides, the material selection process and parametric studies conducted to determine the right sizing and position of the components are discussed. Computational Fluid Dynamic (CFD) analysis was used to simulate the water tank to visualise the water flow. From the design analysis, a higher water tank placement and bigger pipe diameter are found to make the system more efficient.

1. Introduction

Agriculture, forestry, and fishing once have been the backbone of the Malaysian economy that produces products for domestic consumption, as well as the earner of foreign exchange [1]. Nevertheless, the global race of industrialisation has resulted in the rise of the manufacturing industry in the country, causing these sectors to lag and put on the backburner [2]. In 2019, the government of Malaysia had called for a proposition to rebuild the country’s agriculture industry through modernised technologies, comprehensive policies and remunerative strategies [3]. In line with these issues, the efforts to improve the overall agriculture system has been actively researched [1].

One major factor in improving productivity and maximising crop yield is by effective watering system [4,5]. The traditional fertigation system requires electrical pumping system to transfer water into the storage tank. Every two or three hours’ timer will operate the actuator valve to supply water and fertiliser to the farm [6]. For that purpose, both components which are valves and pump need electricity sources to be operated. Nevertheless, the use of generators is non-environmental friendly and expensive due to high purchase of fuel, poor generator maintenance and repair capabilities [7]. Also, the generator cannot be operated at continuous extended duration due to small engine and fuel consumption, and even
worse that there are some farms still have no electric sources to power this generator [8]. Moreover, the situation may be more difficult for the farms located at the higher ground, as it is usually does not have a reliable water source.

Therefore, it is vital to provide a viable alternative in supplying water that is far from water sources, especially for the farms located in rural areas. Accordingly, Aziz et al. [9] has proposed four conceptual designs of a solar integrated agriculture irrigation system and has selected the best design, namely Concept 1. This present work extends the work done in [9]. As the conceptual design has been thoroughly selected, this paper presents the system overview and elaborate the product development process for the agriculture irrigation system to work properly.

2. System overview

Figure 1 shows the conceptual design and its computer aid drawing for the proposed agriculture and irrigation system. The main component of this concept design is an electrical pump, monocrystalline solar panel and Arduino UNO. This conceptual design is fully automatic, controlled by Arduino that can reduce human energy and increase efficiency. The fully controlled device can increase productivity, better quality control and minimise work labour time. Arduino can detect the humidity and indicate the level of water by using a sensor.

![Figure 1. (a) Conceptual design of an agriculture irrigation system [9] and (b) Computer Aid Drawing of Irrigation and Agriculture System](image)

The proposed system consists of three main components, namely the (1) Mechanical sub-system, (2) Control sub-system and (3) Power supply. The mechanical sub-system is used to deliver the water and control the irrigation. Two main components in the mechanical sub-system are the DC pump and solenoid valve. The DC pump is used to deliver water to the system, while the solenoid valve controls the irrigation process., the control sub-system is used to control the whole system and ensure the system is fully automatic, with the main components are Arduino UNO board, humidity sensor, and the ultrasonic sensor. Likewise, the power supply is used for supplying the power to the system. The schematic diagram for the agriculture and irrigation system is shown in Figure 2.

In Figure 2, there are a total of 4 modules used in the system, includes the (1) Solar energy module, (2) Sensing module, (3) The raw water collection module and (4) Water control module. All four modules are vital to effectively works for the whole system to be efficient. Each module requires different interfaces to perform its respective functions. The solar energy charges the module by a solar panel that will absorb the solar energy and convert it to electrical energy. The electrical energy provides from the sunlight was stored in the battery. Likewise, the raw water module collects water from groundwater by the electrical pump, and the water was stored in the water tank. Next, the sensing module has a temperature sensor and a humidity sensor with its functions and send signals to the microcontroller to proceed with follow-up actions. The water control module will be activated when it receives a low
humidity signal from the humidity sensor, and it will operate the pump to allow water flow to the roots of the plants.

**Figure 2.** Schematic diagram of the agriculture and irrigation system.

3. **Product design**

This project starts with the conceptual design of the product [9]. After the conceptual design and core system was finalised, the design was converted into physical parts. This phase is known as the embodiment design phase, where further design analysis was done, focusing on the technical criteria of the targeted system.

3.1. **Material selection**

Material selection is crucial for decision making throughout product development. It is to identify the suitable and appropriate material properties to avoid failure during the manufacturing or assembly process. For the piping system, the mechanical properties of density, young's modulus, and ultimate tensile strength are the key parameters considered for the selection to avoid failure during the operation. Also, the cost is considered to be in the range of affordable range in order to comply with the respondent demands [9]. Five types of materials are analysed, and Stainless Steel (316) was selected. While, for the water tank, the advantage, disadvantages and prices for each type of water tank are analysed. Numerous water tank types can be found in the market, such as galvanised steel, polyethene, concrete, and fibre glass storage tank. As a result, the Polyethylene tank is chosen as it is more cost-effective than other types of tank, as well as it is lightweight, portable, and corrosion-resistant.

3.2. **Parametric design**

Equally important to the material selection, the proper sizing and the position of the components are analysed. For the water tank, the cube type tank was chosen to ease the water tank placement in the system. The water tank size was not calculated because it was selected among the available water tank in the market. But, the position of the water tank is thoroughly analysed. It is crucial to determine the right position of the water tank because it will directly affect the performance of the watering system. The water tank is drafted and modelled by utilising commercially available software. Afterwards, the 3D model was converted into the) model and analysed. The inlet of the water tank temperature was set as 330K, and the inlet mass flow rate was set at 0.024 kgs⁻¹, mimic the actual flow rate from the water
pump. Likewise, the output static pressure at the bottom part was set as 1564.89 Pa due to hydrostatic pressure in the water tank. The simulation results are shown in Figure 3.

Figures 3 (a) and (b) show the velocity streamline of the water tank at 0.1 and 0.16 meters, respectively. In Figure 3 (a), the blue colour represents the water’s velocity that goes through the water tank, which is at 0.1668 ms\(^{-1}\), while at the output flow, the contour colour is represented in turquoise, which is 0.2206 ms\(^{-1}\). In contrast, the water’s velocity for the tank at 0.16 m was found to be increased to 0.7396 ms\(^{-1}\) and the output was 0.2209 ms\(^{-1}\), which is higher than the output velocity in Figure 3 (a). Theoretically, the simulation proves the equation of hydrostatic pressure, where the increment of high value increases the pressure inside the water tank. Before the product development, several changes were made, tally to the results obtained in the simulation.

After the water collects and fills up tank storage, the water from the tank should flow through the pipe and valve for watering the plant slot. The volume of the liquid is calculated using Eqn. 1, with \( V \) is the volume, \( A \) is the area of the outlet and \( C_d \) is the discharge coefficient. While the velocity at the outlet is calculated by Eqn. 2, with \( C_v \) is the velocity coefficient and \( H \) is the height of the outlet. From these equations, it can be concluded that a bigger pipe size and high placement of the water tank is better for the system.

![Figure 3. Velocity streamline of the water tank at (a) 0.10 m and (b) 0.16 m.](image)

\[
V = C_d \ A \ (2 \ g \ H)^{\frac{1}{2}} \quad (1)
\]

\[
\nu_{\text{outlet}} = C_v \ (2 \ g \ H)^{\frac{1}{2}} \quad (2)
\]

3.3. Design for reliability

Design for reliability is necessary to ensure the products and systems works at a specified function for an unexpected lifecycle. The major phases of a design of reliability involve identifying, analysing, verifying and validating failures over time. Design for reliability in quality over time is to satisfy users for an extended period. This work used an automatic irrigation system by utilising the solar energy system as a power source to supply energy. By utilising renewable energy sources, this work predicted that it would not easily run out. This project provides the solar charge controller functions to regulate the current from solar panels and prevent the battery from overcharging. Overcharging can cause loss
of electrolytes, resulting in damage to the battery and sense when the battery is fully charged and stop
the amount of current flowing to the battery. The solar charge controller was designed to be discharged
over a long period and recharged many times.

3.4. Design for safety

Design for safety involves hazard and risk identification to eliminate or minimise injury risks
throughout the life of a product. The utilisation of solar energy as an energy source was made after
considering that it has the least negative impact on the environment [7]. Solar does not produce a
greenhouse effect and pollutes the water [7]. It also does not create any noise pollution [8]. Solar was
designed as a low-risk device that protects people from electric shock, in which most solar charge
controllers includes a low voltage disconnect feature that switches off the supply to the load if the battery
voltage falls below the cut-off voltage. Hence, it prevents the battery from permanent damage and
increases life expectancy.

3.5. Design for ergonomics and aesthetic

The proposed system was designed by considering the ergonomic factor, aims to be comfortable,
safe and productive workspaces by bringing human limitations and abilities into the design of a
workspace. Ergonomics include the individual’s body size, strength and abilities. The automatic
irrigation system is an ergonomic design that required less human works to operate the system.
Automatic irrigation has a moisture sensor. Therefore, if the moisture sensor finds out the soil is dry,
the sprinkler system delivers the needed water for plants. This system helps to meet all garden watering
needs and help people prevent plants from dying. The human anatomy and posture are not affected when
using an automatic irrigation system because it runs automatically and is easy to install. Design aesthetic
includes factors such as balance, pattern, colour, and shape. The design aesthetic for the automatic
irrigation system is the management of cable wiring. Cable wiring management is important to create
pleasing a visually and clean work environment. Well organised wiring cables improve the airflow and
prevent overheating. The design aesthetic for cable wiring is to avoid tangled and complicated cable
disasters. Lastly, the piping system is arranged neatly to create good views of the product.

4. Product prototype

After the design analysis was done, with the components, material, sizing and position are all
determined, the prototype was produced for proof of concept. The goal for the prototype testing was to
evaluate and validate the design guidelines. From the prototype testing, it was found that pumping water
source into storage tank by using pump and ultrasonic is only detectable if the water level indicates that
the tank is already in limit or full. Herein activated the solenoid valve when the soil moisture sensor
detected whether the soil is wet or dry. The flow of water from the storage tank is dependent on gravity
to apply the pressure to the solenoid valve. By using the concept of \( P = \rho gh \), it is proved that the higher
the storage tank, the higher the pressure will apply to the flow of the pipe. Therefore, it can be concluded
that the higher water tank bigger pipe diameter was found to yield a better performance of the proposed
agriculture and irrigation system. Henceforth, the storage tank tower is then added to the product for the
storage tank to be placed at the top of it so that the water pressure can be applied when these two
conditions have been applied.

In complementary to the developed product, field testing for solar measurement was conducted. The
collection of the solar data was done using multimeter Pro’s Kit MT-1210, at an open space in the same
farm area. The data was collected and averaged from 5 data set, within five respective days at 9 am 12
pm, 3 pm and 6 pm at a constant position and place. From the data collection, the average in a day
monocrystalline solar panel can collect the voltage around 19.78V. Herein, it can be concluded that the
solar panel can be used as a direct voltage to operate the Arduino Uno without using external battery
sources.

The final prototype is then assembled as in Figure 4 and tested. The fully functioned prototype is
then used to present to the user and audience on how the product functions.
5. Conclusion

The present work discussed the design analysis of a solar integrated agriculture irrigation system designed to suit the rural farming area. From the study, the system introduced in this work has proven its function ability and is ready to be integrated with solar sources. This product is expected to bring many impacts on the environment and society. This product uses renewable energy, which is secure and does not create any destructive impacts on the environment and society. Utilising renewable energy can decrease carbon impression as electrical energy utilised is not delivered from burning fossil fuel, which is very hurtful to the environment.

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