Systemic View to A Smart Sprinkler System for Effective Utilization of Water - A Case study of UAE

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Abstract

This paper discusses the side-effects of the poor irrigation system. and proposes a holistically deigned sprinkler to overcome the common problem faced in UAE or any deserts area. This study includes an in-depth literature review of different irrigation systems in the United Arab Emirates and analyze their pros and cons. According to the irrigation resources in the UAE, the agriculture sector uses around 83% of the total water compared to the domestic and industrial sector. To overcome the issue and optimally utilize the water resources, it is aimed to create a smart sprinkler system that seeks to minimize irrigation water spillage and loss in agriculture and plantation field. The smart sprinkler focusses on fulfilling apt admission quantity of watering of crops and also is aesthetically and ergonomically designed to delight the people passing by. Apart from that, the smart sprinkler is programmed and equipped with a soil moisture sensor to effectively utilize water by preventing its wastage. The paper explicitly details the design process of the smart sprinkler system and create different solutions by defining, analyzing the problem holistically. It will aid the municipalities, agriculturists and support the government in desert zones.

Keywords
United Arab Emirates, Irrigation, Smart Sprinkler System, Agriculture, Soil Sensor.

1. Introduction
Industrial engineering plays a vital role in swiftly delivering solutions of the utmost quality and affordability to prevailing challenges. One such challenge that has garnered attention is the issue of water shortage. This concern spans both local and global dimensions, presenting formidable obstacles to sustainable progress and environmental preservation. Recent times have witnessed a model shift towards pioneering strategies for conserving water resources, particularly within the area of irrigation systems. A notable factor contributing to water wastage is the suboptimal efficiency of irrigation methods. Conventional techniques, while historically employed, now prove to be inefficient. For instance, the standard irrigation approach of supplying 12–15 liters of water per day for every square meter of land yields a staggering 30% loss due to evaporation. This is a point of major concern in desert lands like the UAE. The United Arab Emirates (UAE) is a nation grappling with a scarcity of freshwater resources. According to EcoMENA, UAE ranks among the top ten countries in the world facing water scarcity challenges. In addition, it has one of the highest rates of water consumption globally. Enhancing water resource management in the United Arab Emirates can benefit numerous regions by rejuvenating their groundwater systems, conserving water, and improving water and irrigation quality. The capital city, Abu Dhabi, is notable for hosting the most extensive network of wastewater treatment facilities.

2. Literature review
Water scarcity is a crucial concern especially in the United Arab Emirates (UAE) since it has one of the highest per capita water usage rates in the world at 550 liters per day, a country characterized with a dry climate and limited access to freshwater resources. With the country's primary emphasis on agricultural diversification and the development of exotic plantation, good water management strategies become urgent.

Historically, traditional irrigation methods like floods, furrows, and 'Aflaj' systems were used to water agricultural lands in the UAE. Today, and with advancements in technology and growing concerns about water scarcity, modern irrigation techniques have gained popularity in the region. Notably, a (2019) study undertaken by India's Department of Civil Engineering analyzed several of watering strategies that are used around the world and in the UAE. The strategies include:

2.1 Drip irrigation:

Drip irrigation is a system that delivers water directly to the ground through small openings in pipes. It serves several purposes, such as water efficiency and disease prevention. A well-designed drip irrigation system reduces water run-off through deep percolation or evaporation to almost zero. The only drawback is that it requires regular inspection and maintenance since the pipe holes could easily get blocked by soil, which leads to high maintenance costs. The cost per year for irrigated areas between 501 and 1000 square meters is between $350 and $750. Additionally, drip irrigation systems are susceptible to damage.

2.2 Automated irrigation system

An automated irrigation system works depending on when it is programmed to work. An automated irrigation system has certain benefits, including practical simplicity of use and the ability to correct watering; measure and indicate 'how much' water to apply. However, there are downsides. It's necessary to use many sensors, which is expensive. Furthermore, it might be difficult to choose a location for the sensors that appropriately depicts the root zone.

2.3 Smart irrigation system

Smart irrigation systems offer various advantages over other irrigation systems. Smart irrigation systems can optimize water levels based on equipment's such as soil sensors that allow for water use only when and where needed. This is done with wireless moisture sensors that communicate with the smart irrigation controls and help inform the system if the landscape needs water. A smart irrigation system will help you have better control of your landscape and irrigation needs as well as peace of mind that the smart system can make decisions independently if you are away. It features real-time data and production insight where farmers can visualize production levels, soil moisture, sunlight intensity with lowered human error and overall operation costs."

Smart irrigation systems, equipped with advanced technologies and automation, can optimize water usage and promote water conservation in humid climates with eye-catching landscapes like the UAE.

Reviewing all these varied strategies across the globe with each of its benefits and limitations, we mapped and planned to integrate for the UAE application and is covered in following sections.

3. Holistic view of an innovative design of a Sprinkler

The Literature review gave insights of the varied applications of the sprinkler. This was augmented with the study of existing scenarios in the Abu Dhabi through field interactions. Both have been integrated to arrive at a model that aids in enhancing the efficacy of the system and optimize the utility of water resources. Following steps were encapsulated from defining to designing a sprinkler:

3.1 Phase 1: Define and analyze the problem.

During this phase, a comprehensive analysis was conducted to explore the underlying factors contributing to the challenges of water scarcity and wastage.

Throughout the observation, some evidence of inadequate irrigation systems was identified in various locations, such as parks, roadways, and the college.

When navigating the streets of the UAE, one can hardly overlook the presence of large water puddles that often line the sidewalks and roadways. These puddles are a result of unsuccessful attempts to irrigate crops like long irrigation periods, signifying a significant waste of water resources. Prolonged water presence on the road surface can result in infrastructure cracks over time.

The second observation pertained to improper pipe placement in certain areas. This led to some plants receiving excessive water, while others receiving inadequate amounts, leading to crop withering. Excessive watering can result in root rot and plant disease, and it destroys fine roots and impairs a plant's ability to absorb water by lowering soil oxygen levels. Wilting or yellowing of lower and inner leaves is the main sign of too much moisture. Plants may exhibit further signs of drought, such as scorch, leaf drop, and/or plant death if excessive watering persists. Additionally, the haphazard placement of pipes negatively affected the visual aesthetics of public spaces.

Finally, the hot weather in the UAE contributed to rapid water evaporation. Approximately 60% of the water used for irrigation in the UAE evaporated before reaching the plants, while only 40% of the required water was effectively utilized. As a result, selecting the optimal watering time necessitates careful consideration.

3.2 Phase 2: Developing and creating different solutions.

3.2.1 Creating the design:

The creation of design started with researching different types of irrigation systems along analyzing each of their advantages and disadvantages. The selection landed on the smart sprinkler system, while adding enhancement features to incorporate into the design. The Smart Irrigation System will help with reducing water spillage within sideroads and prevent overflooding plants with water by measuring the soil moisture using a built-in soil moisture sensor that is programmed by an Arduino IDE code.

The smart sprinkler proposed will include multiple unique features like:

- Adjustable sprinkler height to assist in sprinkling tall plants and reaching all lawn areas.
- Built-in soil-moist sensor; it helps improve water management by measuring the amount of moisture in the soil. It can be fixed or used as a portable device. This is in alignment with the concept of Binti F et al. (2015).
- Powered by Solar System Technology.
- To enhance the aesthetics, the sprinkler was designed as a flower, as it contains a stem-like tube with plastic petals surrounding the top part aligning with a look of tree.
- The smart sprinkler was designed for automation and programmed by an Arduino IDE code.

3.2.2 Proposed Design of Smart Sprinkler

The Smart Sprinkler system is designed to optimize water usage for plant irrigation by relying mostly on soil moisture sensors. Given the scarcity of freshwater resources in the region, overwatering or underwatering plants can result in water wastage and crop wilting, while excess water can seep into infrastructure, leading to surface layer damage. Therefore, incorporating a soil sensor is essential for maintaining optimal moisture levels and supporting healthy plant growth by enabling the system to assess the soil's moisture levels and determine when watering is necessary through communication with smart irrigation controls. This innovative system offers several advantages over traditional sprinkler irrigation methods.

In addition, the system is going to incorporate a solar system that uses photovoltaic (PV) materials to collect and process solar radiation into electricity. A study conducted by RMK College of Engineering and Technology in India in 2020 highlighted the benefits of solar water pumping systems. They reduce dependency on conventional electricity sources like diesel or coal-generated power for water pumping, offering cost savings in terms of upfront, operational, and maintenance expenses when compared to diesel pumps. Moreover, solar pumping systems are environmentally friendly and require less maintenance, as they eliminate fuel costs. This addition aligns with The UAE's Green Agenda - 2030, a comprehensive strategy aimed at achieving environmentally sustainable economic growth and development, including aspects related to water and clean energy.

3.2.3 Design Process of Proposed Sprinkler

The 3D model sketch of the proposed sprinkler system was done using the "Sketchup" software to help with visualizing the prototype. The sketched models included features like the shaft, which holds the sprinkler system and allows for height modification to reach different landscape heights. Moreover, the sketched model includes the sprinkler—which irrigates the plants with water. The hose transfers water from the pump to the sprinkler by passing it via the shaft, and the solar panel.

3.2.3.1 3D Sketch Design

The sketch seen in Figure 1 was carefully designed to complement the lovely appearance of a flower. To keep the design visually appealing, the sprinkler nozzle was cleverly hidden inside the petals. To enable effective water distribution through the sprinkler nozzle, it was made sure that the petals were printed marginally below it. Additionally, the design incorporated an adjustable height feature that was perfectly aligned with the central shaft. This innovation, which could be adjusted in height, basically replaced the dripping system and allowed for fine modification of the water coverage to suit different landscapes.

The soil sensor was seamlessly integrated into the system's surface. To ensure optimal functionality, the soil moisture sensor needs to be buried within the plant's root zone, as this is where the plants draw their water supply. Proper burial within the root zone guaranteed the quality of the landscape while also ensuring that the sensor had full contact with the soil, without any air gaps. The soil should be firmly but not excessively packed surrounding the sensor.

In addition, the solar panels were carefully designed to mimic flower leaves. The solar panels' ability to convert solar energy into electrical power was a prerequisite for integrating solar technology into the water pumping system. The benefit of this integration is that owners can keep some of the electricity produced. This stored energy guarantees our smart sprinkler system will always run, not only by providing a steady supply of electricity during the day but also by acting as a vital resource during night times or other energy-related emergencies.

The efficiency, adaptability, sustainability, and general appeal of the suggested design were all significantly improved by these combined qualities. The features not only emphasized visual appeal but also seamlessly blended with the surrounding plants, enhancing their aesthetic appeal.

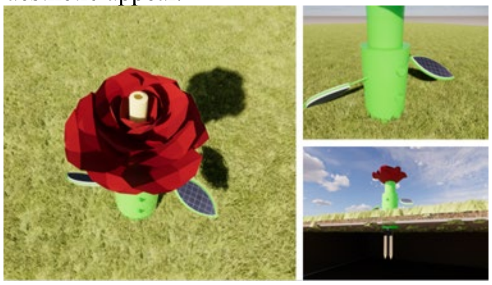

Figure 1. 3D Sketch Design

3.2.4 Design implementation through 3-D printing process

Prototype of the designed part, the shaft was 3D printed using PLA filament - a material commonly utilized in 3D printing process - then assembled with the sprinkler system (the sprinkler, hose, and water pump). Moreover, solar panels were represented using aluminum foil and a straw sticking to a leaf-like cutout, and polyester fabric was used to mimic the shape of the flower petals as seen in figure 2. Finally, the main feature, which is the soil-sensor, was placed at the surface of the sprinkler system.

Prior to printing the model, measurements of the sprinkler, hose and water pump were taken cautiously. This highlights the significance of test printing to confirm the dimensions before starting the printing of the actual 3D model.

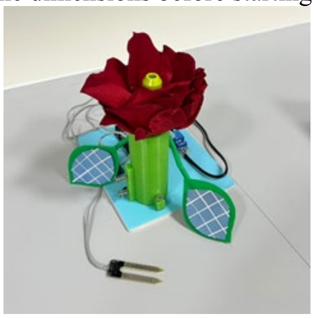

Figure 2. Printed Prototype of Sprinkler System

3.2.5 Programming the process

3.2.5.1 Tinker cad Simulation

Before composing the code for the Arduino IDE, the Tinker Cad simulation (www.tinkercad.org) was utilized. Tinker Cad is an interactive 3D-based coding simulation. This platform allows the user to design and simulate a circuit and evaluate its functionality prior to physically implementing it.

The Tinker Cad's features were leveraged to generate code blocks and construct a circuit, incorporating essential components such as the Arduino board, soil moisture sensor, and LEDs. This approach provided a visual representation of the project, facilitating the development and testing phases. This is shown in figure 3.

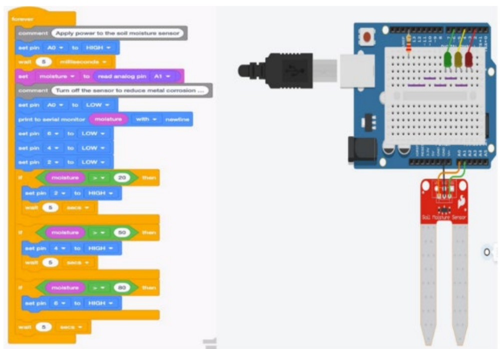

Figure 3. Tinker cad circuit simulation

3.2.5.2 Arduino Code:

Following the preliminary circuit design and simulation using Tinker CAD, Arduino IDE software was additionally used in conjunction with the simulation results. This enabled the writing of the necessary code, which was then uploaded to the Arduino UNO hardware. The program established communication between various components, including the 5V relay module, soil moisture sensor, and LED lights.

The purpose of the code is to effectively control the sprinkler system, ensuring it operates according to the intended plan and effectively waters specific areas of the landscape without causing water to overflow.

3.2.5.3 Arduino IDE Code:

Ardunio code from defining variables to, control using the ON/OFF relays, communications designed to link Arduino and PC, loop to record multiple readings, means to regulate moisture and program to stop or continue watering process is shown in Appendix-1

3.2.6 Sprinkler System Working Principles

The entire integration of the design, developing and programming fostered the following key processes:

- The sprinkler included a built-in soil moisture sensor that detects the moisture levels in the soil using three LED lights: red for drought, yellow for moderate moisture, and green for an optimal level of moisture.

- The Arduino UNO is a microcontroller board used to promote water flow and improve the performance of soil moisture sensors. However, it is significant to point out that the code responsible for these operations is not directly included in the Arduino UNO board. The code was created on a computer using Arduino IDE program and later uploaded to the Arduino UNO board. Once uploaded, the code is executed by the board's microcontroller.

- The soil moisture sensor is built-in onto the sprinkler and connected to the Arduino UNO, where it is programmed to respond to the inputs given in the code. When the soil moisture sensor detects soil moisture in the condition of dryness it will transmit signals to turn the D.C. pump on, and the red LED will be turned on, indicating the soil moisture percentage is > 20%. When the soil moisture sensor detects that the soil is being watered, the yellow LED will turn on, which indicates that the soil moisture percentage is > 50%.

When the soil moisture sensor detects a sufficient supply of water, green LED will turn on indicating a soil moisture percentage > 80%. When the soil moisture percentage level exceeds or equals 85%, the 5V relay module immediately stops the pump and water will top irrigating.

- To avoid an overflow of water, the water pump is programmed to turn on for 5 seconds and off for 5 seconds to conserve water, which is the main target of designing the sprinkler.

- The power source from the solar panels will be used to run the D.C. pump. The solar panel and the water pump are connected via a converter. The battery is also charged using the converter. In order for the pump to run at night or in an energy emergency, a battery is utilised. The PV solar irrigation system's main parts are the solar panels, battery, transformer, converter, and pump. Figure 4 below depicts the Simple layout.

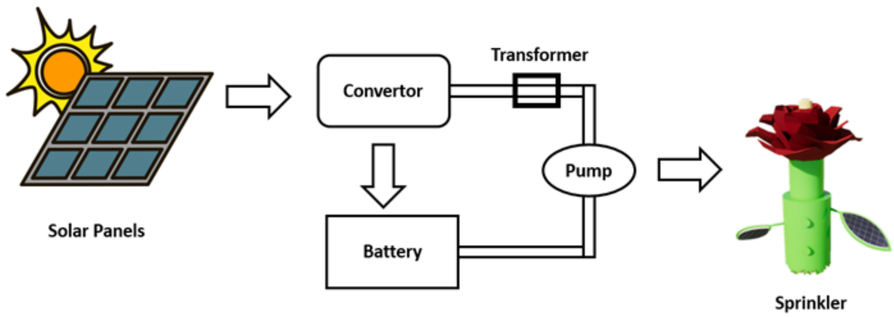

Figure 4. Simple Layout of a PV Irrigation System

3.3 Phase 3: Design evaluation and Improvement

Every project has a scope of further improvements with evolution of new processes, technological supports, and dynamic scenarios on site. Considering these dynamics into account following were perceived as current limitations and how they could be addressed:

3.3.1 Requirement and Constraints

The final stage in engineering design involves assessing the proposed solution and pursuing ongoing improvements. Restrictions are a regular occurrence during any project work and necessitate addressing them to meet the desired design's specifications and requirements.

During the development and production of the Smart Sprinkler System, a few limitations were encountered. Firstly, the utilization of the large-diameter hose used resulted in insufficient water pressure to adequately irrigate larger lawn areas.

Moreover, the soil moisture sensor employed had a limited range from 0 to 1023 ADC value, which is a common range. However, if any values exceed this range, the sensor ceases to function.

3.3.2 Discussion and Improvement

Given the limitations faced, there are several proposed enhancements to the sprinkler system. Firstly, one improvement involves enabling the sprinkler nozzle to rotate fully, covering an angle of 360 degrees. Furthermore, utilizing a narrower hose diameter to increase water pressure, allowing for irrigation over a wider area. To upgrade its appearance, incorporating a light source into the sprinkler design is suggested allowing to to become visible during nighttime. Additionally, a valuable feature for the smart sprinkler system would be its ability to detect and halt operation during severe weather conditions such as rain and wind.

4. Conclusion

In the collaborative effort, the Engineering Design Methodology was successfully implemented to tackle the issue of water scarcity, particularly faced by arid regions with exotic plantations like the UAE. Starting from defining and analyzing the problem of inadequate irrigation systems, followed by the core phase which was generating and developing various solutions. This phase contains most of the information significant to our design of the Smart Sprinkler System. Ultimately, the conclusion of the methodology involved evaluating and enhancing the design.

This proposed technology has the potential to ensure a long-term sustainability of the UAE's exotic plants by mitigating water scarcity, maximizing growth of plants and crops around the country by addressing challenges such as landscape distortion (caused by cluttered irrigation pipes), improper plant irrigation, and wastage of water due to extended watering periods. This irrigation system will operate with increased efficiency and effectiveness, aligning with the desired outcomes sought by industrial engineers when tackling challenges.

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APPENDIX-1: Arduino IDE Code for sprinkler operation

- Defining variables
  (soil sensor, green led, yellow led, red led, pumping led, relay)

```
int soilSen = A1;
int relay = A0;
float soilSenVal = 0;
int greenLed = 6;
int yellowLed = 4;
int redLed = 2;
int pumpingLed = 13;
```

➢ On/Off interval for the relay (every 5 seconds)

```
const long interval = 5000;
```

➢ Communication between Arduino and PC

- input: sensor to Arduino
- Output: Arduino to the relay and the LED lights

```
void setup(){
  Serial.begin(9600);
  pinMode (soilSen,INPUT);
  pinMode (relay, OUTPUT);
  pinMode (greenLed, OUTPUT);
  pinMode (yellowLed, OUTPUT);
  pinMode (redLed, OUTPUT);
  pinMode (pumpingLed, OUTPUT);
  pinMode (3, OUTPUT); pinMode (5, OUTPUT); pinMode (7, OUTPUT);
```

➢ Getting the 100 readings from the sensor and finding the average and converting it to percentage

```
void loop(){
   for (int i = 0; i <= 100; i++) {
    soilSenVal = soilSenVal + analogRead(soilSen); delay(1);
   }
  soilSenVal = soilSenVal/100.0;
  int SMP = map(soilSenVal, 297,1043,100,0);
```

➢ Showing Data to serial monitor

```
Serial.print ("SMVal:");
Serial.print ("\t");
Serial.println (soilSenVal);
//Serial.print ("\t");
Serial.print ("SMP:");
Serial.print ("\t");
Serial.print (SMP);
Serial.println ("%");
```

➢ (If) statement for the LEDs based on the value of soil moisture sensor

```
if (SMP >80){ digitalWrite(greenLed, HIGH);}
  else { digitalWrite (greenLed, LOW);}

if (SMP >50){ digitalWrite(yellowLed, HIGH);}
  else { digitalWrite (yellowLed, LOW);}

if (SMP >20){ digitalWrite(redLed, HIGH);}
  else { digitalWrite (redLed, LOW);}
```

➢ (If) statement for the relay to start and stop pumping

```
  if (SMP <= 30){ digitalWrite(pumpingLed, HIGH);}
  if (digitalRead(pumpingLed)==HIGH){
      unsigned long currentMillis = millis();
    if (currentMillis - previousMillis >= interval) {
        previousMillis = currentMillis;
      if (relayState == LOW){ relayState = HIGH;}
      else {relayState = LOW;}
      digitalWrite(relay, relayState);
    }
  }

  if (SMP >= 85){
    digitalWrite (relay, HIGH);
    digitalWrite (pumpingLed, LOW);
  }
  delay (100);
}
```