Smart indoor gardening: elevating growth, health, and automation

Tawfiq Alrawashdeh[1], Ibrahim Alkore Alshalabi[2], Moha'med Al-Jaafreh[3], Malek Alksasbeh[2]

[1]Department of Computer Science, Faculty of Information Technology, Al-Hussein Bin Talal University, Jordan
[2]Department of Information Technology, Faculty of Information Technology, Al-Hussein Bin Talal University, Jordan
[3]Department of Software Engineering, Faculty of Information Technology, Al-Hussein Bin Talal University, Jordan

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ABSTRACT

Recently, indoor systems for growing plants have emerged as a promising approach to address the problems related to extreme weather conditions outdoors. However, such systems must manage the plants surrounding environments to satisfy the environmental and the economical requirements. In this line, any proposed solution must address challenging factors such as plants diseases and unordinary climate situations. In this paper, propose an internet of things (IoT) indoor system that can be used to facilitate the plant growing process. The proposed system is designed to provide alternatives for outdoor climate dependency such as the vitamins provided through sunlight. Moreover, renewable energy sources (sunlight) are employed to reduce the impact on the environment. With the help of several types of sensors, the system continuously monitors the plants through their growing journey. Whereas actuator devices are employed to control the plant-feeding process based on the sensors' reported values. All the collected data will be uploaded to the cloud for analysis, utilizing a website. Additionally, the architecture of the provided system eliminates the need for human involvement, which has a degrading effect on the plant growing process.

Corresponding Author:

Tawfiq Alrawashdeh
Department of Computer Science, Faculty of Information Technology, Al Hussein Bin Talal University
P.O. Box 20 Ma'an, Jordan
Email: Tawfiq@ahu.edu.jo

1. INTRODUCTION

An indoor plant growing system offers numerous advantages, primarily the ability to create a controlled environment tailored to the specific requirements of different plant species [1]–[3]. Unlike outdoor gardens, indoor plant environments can be customized to provide optimal growing conditions throughout the year, regardless of weather conditions or location. However, managing such an environment can be challenging, requiring significant time and effort to monitor and adjust environmental factors. To address this task, the internet of things (IoT) has emerged as possible method of communication for controlled plant environment monitoring and management [4]–[6].

In line with this, our study proposes a smart management system that utilizes a variety of sensors to continuously track essential environmental variables such as temperature, humidity, and light intensity [7], [8], as depicted in Figure 1. Real-time data accessibility enables researchers to precisely assess each plant's growing environment. This approach uses actuator devices to automate the process of nutrition plants, reducing the need for human engagement and guaranteeing that each plant receives the proper amount of water and nutrients. As a result, a dependable and fruitful cultivation environment is obtained.

It is important to highlight that our system goes a decade further by using sunlight, a sustainable energy source, to power the sensors and actuators. This approach significantly reduces the overall environmental impact of the system. By harnessing renewable energy, the system operates in a sustainable and efficient manner, presenting a cost-effective and environmentally friendly approach to indoor plant management.

Figure 1. The proposed smart management system for indoor plant (prototype)

The evaluation section of our study demonstrates the effectiveness and innovativeness of our system in facilitating indoor plant growth. It promotes sustainable and healthy plant development, ensuring both efficiency and reliability. By integrating IoT technologies and renewable energy sources, our solution aims to minimize human intervention and ensure the healthy growth of indoor plants.

This paper is organized as: section 2 discusses related works, section 3 formally defines the indoor plant problem and presents our algorithmic solution, section 4 discusses the results, and section 5 concludes the paper.

2. RELATED WORK

Several studies [9]–[12] have focused on the development of smart management systems for plant growing, utilizing various technologies to automate the monitoring and management of plant environments. One such study [13] AgroCUBE is an automated microclimate chamber that enables remote control and regulation of temperature, air humidity, and soil humidity. Equipped with internal cameras, LED lighting, and an LCD interface, it facilitates data storage and management. AgroCUBE maintains stable temperature and air humidity while increasing soil humidity, offering precise control and convenient remote management.

Another study [14] PlantTalk is an IoT-based intelligent hydroponic plant factory solution, enabling smartphone-based development of its intelligence. The study showcases its flexibility in configuring plant sensors and actuators, programming plant-care intelligence, and implementing features like LED lighting and water control. PlantTalk exhibits a 53% faster reduction in CO_2 concentration compared to traditional systems and finds application in AgriTalk plant factory, furthermore, the growth and development of tomato plants are influenced by environmental factors (e.g., soil moisture, pH, temperature, and light). To optimize tomato plant growth, an IoT-based monitoring system is proposed, using internet-connected sensors to collect data on soil moisture, air temperature, light intensity, and soil nutrient/pH levels. Data is transmitted to an IoT platform for analysis, enabling informed decisions on plant care (e.g., watering and nutrient provision). Cameras monitor plant height and fruit development. Through IoT technology, communities and farmers can monitor and control tomato plant conditions in real-time via smartphone apps, enabling proactive measures for disease prevention and improved crop production and quality [15].

Another related study [16] by examines the potential of wireless sensors and IoT in agriculture, discussing challenges related to integrating this technology into traditional farming practices. It provides an in-depth analysis of IoT devices, communication techniques, and sensors used in various agricultural applications. The article explores how IoT technology supports growers throughout the crop cycle and examines the use of unmanned aerial vehicles for crop surveillance and yield optimization. It highlights state-of-the-art IoT architectures and platforms in agriculture and identifies current/future trends and research challenges.

Furthermore, a study by [17] involves monitoring nutrient concentrations (e.g., calcium, sulfate, and phosphate) in hydroponic solutions. Data is sent to an android app with a machine learning (ML) model. The ML algorithm used is linear support vector machine (linear-SVM), trained on top nutrient predictors identified through feature selection methods. It utilizes pairwise correlation matrix, extra trees classifier, and XgBoost classifier with data from three aquaponic farms in South-East Texas. Another relevant study is by [18] presents an approach to automatically control an aquaponics system using an autoML algorithm and a cloud platform for monitoring. The goal is to maintain equilibrium between plant and fish growth. Organic waste from the fish tank is utilized by plants, which then recycle the water back to the fish. A miniature model was developed with various sensors (DHT11, BH1750, soil moisture, HC-SR04, and pH) to collect data for training the autoML algorithm. Experimental results show improved event triggering and enhanced plant and fish growth compared to conventional methods.

Furthermore, Jagdale *et al.* [19] present the greenhouse system utilizes three intelligent controllers to regulate temperature, soil moisture, and light intensity. It employs various sensors to optimize environmental conditions. This IoT-based automated greenhouse promotes organic agricultural yield and growth. The system prioritizes simplicity, cost-effectiveness, wireless connectivity, and reduced manpower. Raspberry pi is utilized for programming the controllers, eliminating the requirement for external systems. Kumar *et al.* [20] proposed system provides a cost-effective solution for underdeveloped areas, utilizing a moisture sensor to control the motor via a node MCU. It efficiently irrigates plants by activating the motor when needed and sending alerts to users' mobile phones. This smart irrigation system implemented on our campus conserves energy and water resources.

Technique aims to enhance agricultural output by evaluating soil pH and collecting humidity and temperature data using sensors in [21]. These parameters are then used in a decision tree regression ML technique to identify the most suitable crop for the soil. Farmers can plant the optimal crop based on the soil type, leading to improved yields. The use of AS7265x IoT sensor was also investigated by [22], whereby the authors addressed an AS7265x IoT sensor in a transflective spectroscopic application effectively detects nitrogen fluctuations, as determined in the design phase. A novel transflective sensor apparatus was developed for a 30-day lettuce growth experiment in a MISH system, utilizing two solution tanks (80 L and 40 L). These findings highlight the successful and cost-effective monitoring of nitrogen changes in MISH systems using IoT sensors.

In summary, these studies demonstrate the potential of IoT technology and automated monitoring and management systems in enabling efficient and sustainable indoor plant growth. Our proposed smart management system for indoor plants builds upon these previous studies, utilizing renewable energy sources and automated monitoring and management to provide a reliable and efficient approach to indoor plant growing, enabling users to grow healthy and thriving plants with minimal effort and environmental impact.

3. PROBLEM DEFINITION AND ALGORITHMIC SOLUTION

The management of the indoor environment is essential to ensuring the health of plants. To produce an appropriate environment for the care of plants [23]–[25], it is necessary to carefully monitor and control these variables without causing mistakes. This requires knowing the logical relationship between humidity, temperature, photosynthesis, and carbon monoxide concentration.

The problem statement shows the necessity it is to control the environment surrounding indoor plants in order to assure their accurate health. The statement lists important variables that should be investigated, such as temperature, photosynthesis, humidity, and carbon monoxide content. It's crucial to accurately track and handle these factors without making incorrect decisions in order to preserve a healthy environment for the plants. The plants' growth and health may be significantly impacted by an unsuitable environment, which could ultimately lead to their death. To preserve the health of houseplants, it is essential to comprehend and regulate all the different environmental conditions.

The problems of growing plants indoors must be conquered including managing environmental variables such soil humidity, light, temperature, and air humidity. In order for components like pumps, fans, music, and lights to cooperate and sustain the health of the plants, it is also imperative to gather all the necessary data. our proposed method provides a monitoring system that can control the environment to address these issues. The employed algorithm by the proposed system consists of two main steps, namely data collection and processing steps.

3.1. Data collection

Obtaining the result from the soil humidity sensor and using algorithm 1 to compute the soil humidity accurately is the main objective of this phase. This value functions as a crucial parameter for the system's functionality because it establishes when watering of the plants is required. Researchers can make sure that the plants receive the right amount of moisture for growth and development by regularly checking the soil's humidity.

Algorithm 1. Calculate soil humidity

```
procedure Calculate (W)
    ►Input: W = Weather
    ►Output: humidity,ppm
        sensorValue ← 0
        for each w in W do
            ValueA1 ← Read Analog Sesnsor for Humidity
```

```
                sensorValue ← sensorValue + ValueA1
          End for
         sensorValue ← sensorValue/100
         outputValue ← ((5.0*sensorValue)/1023)
         ratio ← ((5.0-outputValue)/outputValue
         ppm ← pow((ratio/22.073), (1/-0.66659))
return ppm
  end procedure
```

The soil is growing dry, and the plants require water when the result obtained from the soil humidity sensor falls below the threshold of 40 ppm. The system is notified to act and start the watering process by this critical data. Also, can avoid plant stress, wilting, and possible harm caused by insufficient soil humidity by rapidly reacting to low soil humidity readings.

To carry out the calculations effectively, this step gathers all the information such as sensor accuracy, environmental conditions, and soil characteristics to accurately determine the soil humidity level. By employing this step and utilizing the converted soil humidity value, the system can make informed decisions regarding irrigation. Not only does it help conserve water by irrigating only, when necessary, but it also promotes the healthy growth of plants by providing them with the precise amount of moisture they require. By continuously monitoring and responding to soil moisture levels, our approach can ensure the well-being of the plants and optimize their growth in an efficient and sustainable manner.

3.2. Data processing

Algorithm 2 provides a detailed outline of the data processing step. This step begins by checking the (SD) memory card connected to the system. If the SD card is available, it proceeds to write the current date in lines 4 to 8. This serves as an important timestamp for recording data and tracking system performance over time.

Algorithm 2. Data processing

```
procedure Calculate (W)
      ►Input: ppm
      ►Output: Data Processing
      if (!check To write to SD)
          Write("initialization failed!")
      else
         Write("initialization done.")
      End if
      Configure Speaker Pin
      Play Music
     Currenttime ← millis()
     Humi← DHT.humidity
     Temp← DHT.temperature
    Write("Current humidity = ")
    Write("temperature = ")
    Write(Temp)
    if (currenttime>=3600000+oldtime)
           myFile ←  SD.open("data.txt", FILE_WRITE)
            if (myFile)
                 Write all data to SD
            End if
    End if
    if (Temp>25)
           Fan Work
    else
          Fan Stop
    End if
   Print Data to Lcd
   delay(5000)
    lcd.clear()
    value ←  Read Soil humidity
    CO_ppm←  ppm
    Soil_H ←  map(value ,1023 ,0 ,0 ,100)
    soil_Humi ←  Soil_H
    CO ← CO_ppm
    if (Soil_H<40)
            Pumb Work
            delay(Irrigation_Time)
    else
            Pump stop
End if
End procedure
```

Additionally, to further improve the growing of the planets, classical music is used since it has a positive impact on plant development (lines 9-10). The soothing melodies are known to stimulate plant growth, contributing to their overall well-being.

Continuing with data acquisition, the algorithm reads the air humidity and temperature at regular intervals of five minutes. This information is crucial for understanding the environmental conditions surrounding the plants. The acquired data is then stored in the SD card, specifically in lines 11 to 16, enabling later analysis and monitoring of temperature and humidity trends.

Based on the temperature readings, if the value exceeds 25 °C, the algorithm triggers the cooling system to activate. This action, performed in lines 23 to 27, aims to maintain a suitable temperature range for optimal plant growth. By cooling the environment, the system ensures that the plants are not subjected to excessive heat stress, which could hinder their development.

Moving on to soil moisture management, the algorithm progresses to read the soil humidity levels from the sensor in lines 31 to 41. If the recorded value falls 40, indicating insufficient moisture in the soil, the algorithm triggers the watering system. This prompts the system to initiate a three-minute watering cycle to supply the plants with the necessary hydration. After completion, the algorithm rechecks the soil humidity value to assess whether further watering is required or if the plants have reached an optimal moisture level.

By adhering to this algorithm, the system ensures efficient data processing, utilizes music stimulation for plant growth, monitors air humidity and temperature, and responds promptly to the soil's moisture requirements. This comprehensive approach facilitates the overall health and flourishing of the plants, creating an environment conducive to their thriving growth.

4. EVALUATION

The data collection component of the system plays a crucial role in gathering essential information about the plant's environment. Soil humidity sensors provide insights into the moisture levels in the soil, ensuring that plants receive adequate hydration. Carbon monoxide sensors help monitor air quality and detect any potential risks or harmful gases that may affect plant health. Temperature sensors are instrumental in maintaining the ideal temperature range for plant growth. By continuously monitoring these parameters, the system can make informed decisions about the necessary actions to optimize the growing conditions dependent on normal distribution of measurements shown in Table 1.

Table 1. Normal distribution of measurements

Light	Temperature	Soil humidity	CO	Humidity
6 Hours	20-25	40%	4 PPm	90%

Once the data is collected, it is transmitted to the data processing component, which consists of multiple Arduino and raspberry pi units shown in Figure 2. These units possess the computational power to analyze the collected data and extract meaningful insights. By employing algorithms and models, the data processing component can identify patterns, trends, and deviations from optimal conditions. The actuator component's suitable actions will be decided upon using the results of this analysis.

The data gathering devices are easily controlled and communicated with according to the Arduinos, which are programmed using the Arduino IDE. They ensure the sensors function properly and send reliable data for analysis. The overall monitoring and control procedure is made easier by the raspberry pi's role as a local server in the interim. It offers a consolidated platform for data processing, data storage, and information distribution to the end user.

A website is linked to the system to make the studied data available to end users. Users of the website can browse and examine the data acquired to learn more about the environmental factors that affect the growth of plants. The website is a useful resource for analyzing variations in data, making defensible choices, and monitoring the development of the plants that are shown in Figure 3.

Additionally, in the case of any concern situations, the system includes the option to deliver summary reports to end users via short messaging service (SMS). With the help of this function, users are guaranteed fast notification of significant alterations to the plant's environment, enabling them to respond immediately as needed.

Water pumps, lightbulbs, and speakers indicate run the actuator component, which can be programmed to carry out a variety of tasks in response to the data analysis carried out by the data processing component. The device can imitate natural climate situations by altering the lights, giving the plants the ideal amounts of light exposure. To ensure that the plants acquire the right nutrients for optimal growth, the fertilization amount is adjusted based on the temperature and humidity that were observed. Additionally, the system can play music from time to time, as studies have demonstrated that it has positive impacts on plant growth and development.

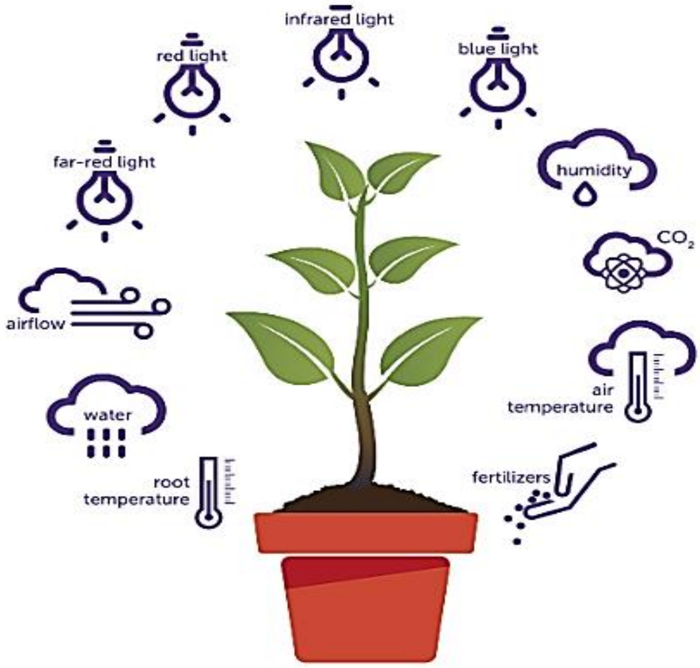

Figure 2. Arduino protype

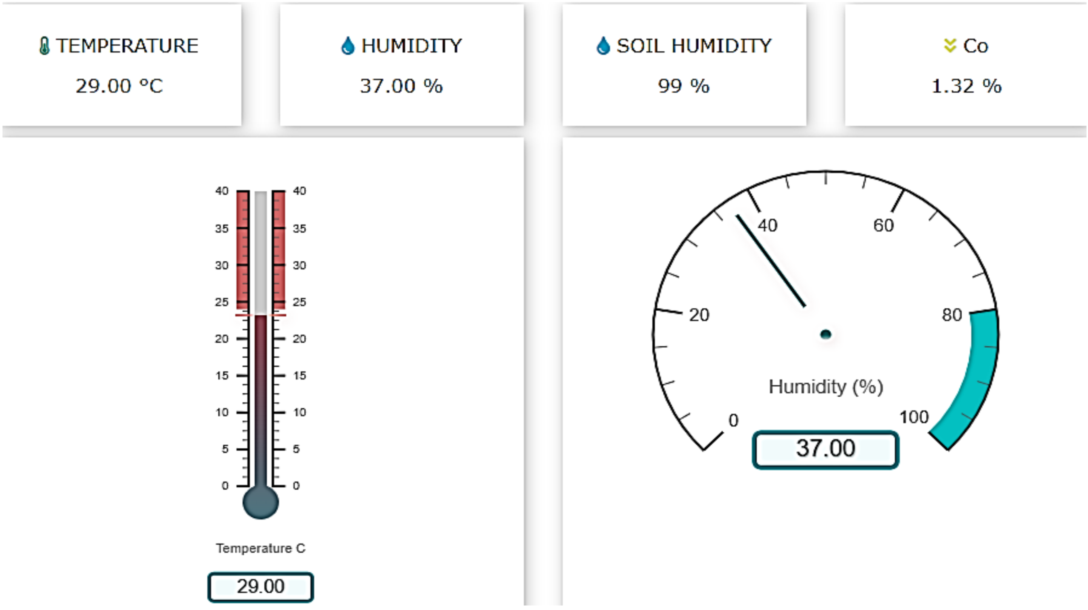

Figure 3. Web site for smart management system

To evaluate the reliability of the system, an initial test was conducted over a 16-day period to monitor the plant's environment shown in Table 2. The results, depicted in Figure 4, provide a visual representation of the collected data, showcasing the system's ability to maintain the monitored factors (humidity, temperature, and CO level) within the expected range. This successful demonstration highlights the system's effectiveness in regulating and optimizing the plant growing process, ensuring healthy and thriving plants.

Table 2. Result for 16 days

Hours	Humidity	Air humidity	Temperature	CO
1	72	71	20	0.46
2	73	69	20	0.44
3	73	71	22	0.44
4	73	73	22	0.46
5	73	83	23	0.49
6	73	74	21	0.57
7	73	71	22	0.54
8	73	69	23	0.49
9	73	67	24	0.46
10	73	68	25	0.46
11	73	69	25	0.41
12	73	70	26	0.39
13	73	77	24	0.82
14	73	91	23	0.92
15	72	91	22	0.85
16	72	81	21	0.85

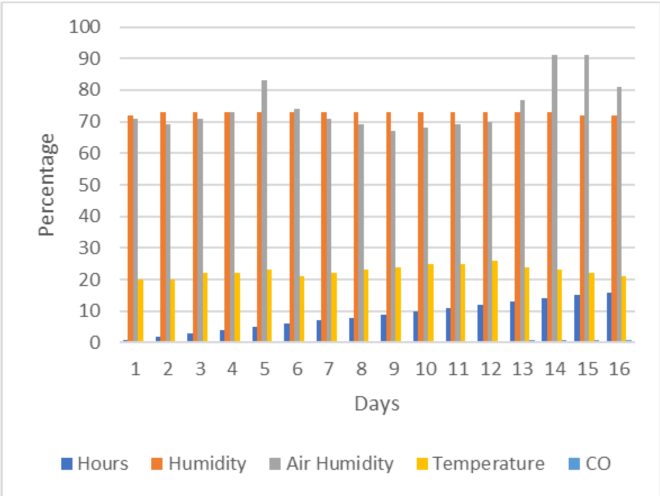

Figure 4. Sensors recorded values over 16-days testing period

5. CONCLUSION

This study presented an indoor system for growing plants to address the challenges caused by outdoor extreme weather conditions. The proposed solution manages the plants' surrounding environments efficiently to meet environmental and economical requirements, tackling issues such as plant diseases and abnormal climate situations. As discussed, the proposed system reduces outdoor climate dependency by employing a renewable energy source (sunlight) and using various sensors to monitor plants during their growth stages. Actuator devices control the plant-feeding process based on the sensors' reported values, eliminating the need for human involvement. The system's automation and renewable energy sources make it a promising solution to improve plant growth efficiency and sustainability while reducing the impact on the environment.

To improve the capabilities of our smart systems, future research should be focusing on maximizing the benefits of indoor smart systems by developing ML models. These models can utilize historical data from various measurements to provide predictive insights and assist in automated decision-making processes. By analyzing patterns, identifying correlations, and suggesting adjustments, ML algorithms can optimize growing conditions and create an ideal indoor environment. Integrating ML capabilities would enhance the precision, efficiency, and convenience of the indoor smart system for applications such as plant cultivation and indoor farming.

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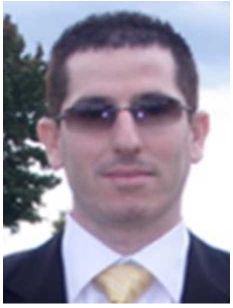
BIOGRAPHIES OF AUTHORS

Tawfiq Alrawashdeh serves as an assistant professor at the Department of CS, Al-Hussein Bin Talal University, Jordan. He got a bachelor's in Computer Science from Al Hussein Bin Talal University (AHU) Jordan in 2005. He then gets a master's in Computer Science from Al-Balqa' Applied Jordan 2011. He received his Ph.D. in 2020 from University Sultan Zainal Abidin, Malaysia. His research interests focus on cloud computing and task scheduling. He worked as a Head of Programming Division at Al Hussein Bin Talal University from 2005 to 2014. Then worked for Al Hussein Bin Talal University from 2014 to present as lecturer where he teaches a different course in computer science collage. In additional, he starts working as Director of Computer and Information Technology Center from 2018 to present. He can be contacted at email: tawfiq@ahu.edu.jo.



Ibrahim Alkore Alshalabi received his B.Sc. in Computer Science from Al-Isra Private University, Amman, Jordan in 1997, his Master of Computer Applications (MCA) from Bangalore University, India in 2007, and his Ph.D. in Computer Science and Engineering from the University of Bridgeport, USA in 2016. From 1997-2004 he was Assistant Lecturer at Ma'an Community College, Al-Balqa Applied University, Jordan. From 2007 to 2009 he was an assistant lecturer at Al-Hussein Bin Talal University, Jordan. He is currently an Assistant Professor at Al-Hussein Bin Talal University, College of Information Technology, Jordan. His research interests are e-learning, m-learning, wireless communications, and networks. He was an active committee member of the International Conference on Engineering Education, instructional technology, assessment, and e-learning (EIAE 2010, EIAE 2011). He can be contacted at email: ibrahim.m.alshalabi@ahu.edu.jo.

Moha'med Al-Jaafreh received his B.Sc. in Electrical/Communication Engineering from Mutah University, Karak, Jordan in 1999, his Master of Engineering Studies (Software and System Engineering) from University of Technology/Sydney in Australia (UTS) in 2004, and his Ph.D. in Software Engineering from University of Technology/Sydney in Australia (UTS) in 2009. From 2009-2014 he was Assistant Professor at Software Engineering Department in Al-Hussein Bin Talal University, Jordan. From 2014-2018 he was Assistant Professor (A) at Department of Software Engineering in Al-Hussein Bin Talal University, Jordan. He is currently an Associate Professor at Department of Software Engineering in Al-Hussein Bin Talal University, College of Information Technology, Jordan. His research interests are software engineering, embedded systems, fuzzy logic and smart systems. He can be contacted at email: mjaafreh@ahu.edu.jo.

Malek Alksasbeh received his B.S degree in Computer Science from Mu'tah University, Jordan, in 2005, and the M.S. and Ph.D. degrees in Information Technology from the University Utara Malaysia (UUM), Malaysia, in 2008 and 2012, respectively. Alksasbeh is a Full Professor in the College of Information Technology at Al-Hussein Bin Talal University (AHU). His research interests are in the areas of smart systems, information retrieval, and instructional technology. He can be contacted at email: malksasbeh@ahu.edu.jo.