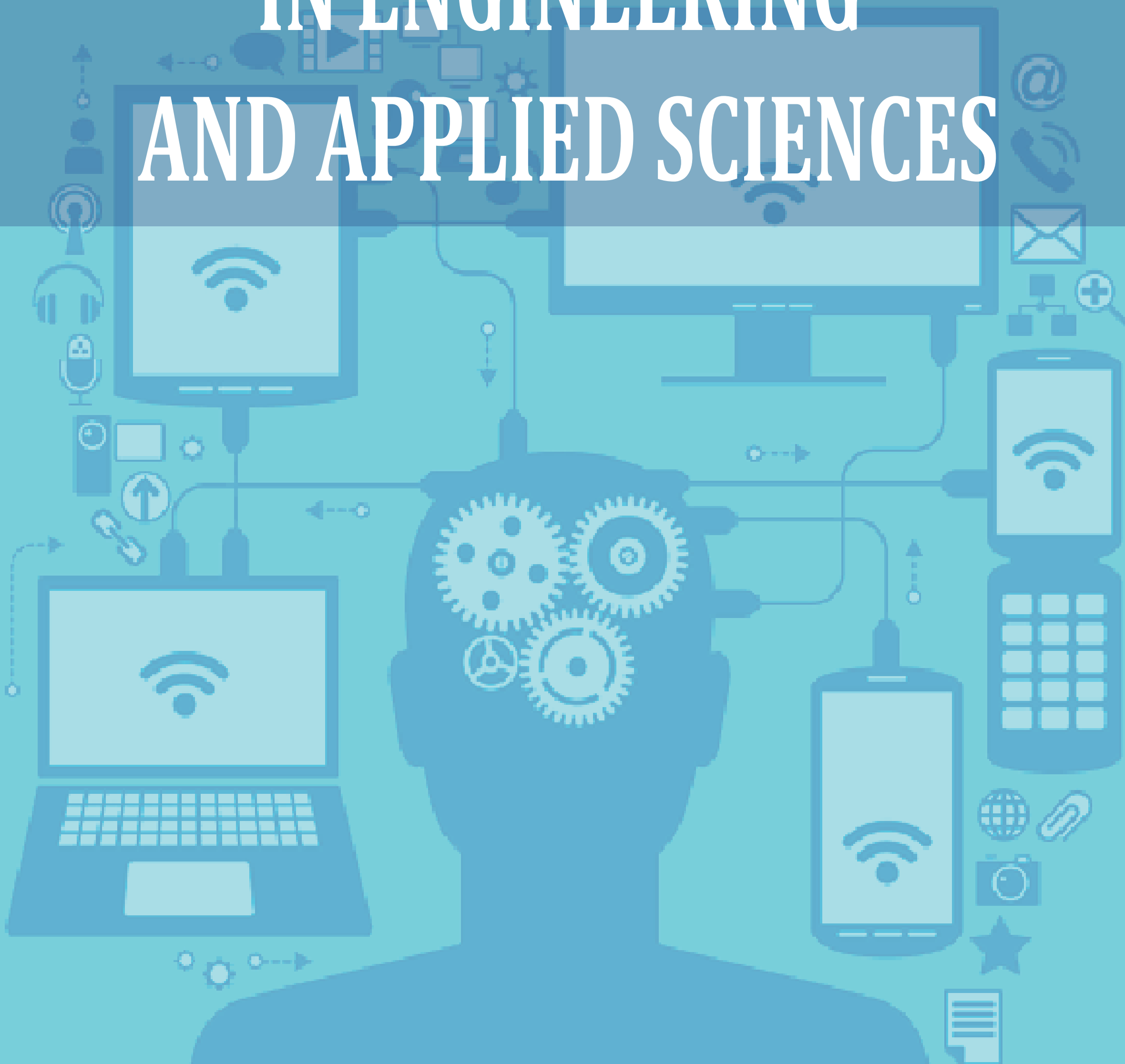
CONTEMPORARY RESEARCH IN ENGINEERING AND APPLIED SCIENCES



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Researches Publications®
(The Licence Number of Publicator: 2014/31220)
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USA: +1 631 685 0 853
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Iksad Publications – 2024©

ISBN: 978-625-378-026-5
Cover Design: İbrahim KAYA
October / 2024
Ankara / Türkiye
Size = 16x24 cm

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PREFACE

Dear Readers,

It is with great pleasure that I present to you this compilation of insightful chapters that delve into the pressing issues of our time, encompassing advancements in technology, environmental sustainability, and innovative methodologies in various fields. This book is a testament to the collaborative efforts of esteemed authors and researchers who have dedicated their expertise to contribute to the ongoing discourse in their respective domains.

In the first chapter, **"Utilization of Digital Agricultural Technologies in Greenhouse Cultivation: A Necessity in Modern Times,"** the authors explore the transformative impact of digital technologies on agricultural practices, particularly in greenhouse cultivation. Their findings underscore the importance of integrating smart technologies to enhance productivity and sustainability in agriculture, addressing the challenges posed by a growing global population.

The second chapter, **"Investigation of High Pass Filter Circuit Using Only MOS Transistor,"** presents a novel approach to circuit design, showcasing the potential of MOS transistors in creating efficient high-pass filter circuits. This work not only contributes to the field of electronics but also opens avenues for further research and development in integrated circuit design.

In the third chapter, **"Multi-Objective Optimization: Non-Dominated Sorting Genetic Algorithm II (NSGA II),"** the author provides a comprehensive overview of multi-objective optimization techniques, particularly the NSGA-II algorithm. This chapter is essential for researchers and practitioners seeking to navigate the complexities of optimizing multiple conflicting objectives in various applications.

Lastly, the chapter titled **"Determination of Suleyman Demirel University Students' Level of Social Acceptance of Renewable Energy Resources Use and Investment"** sheds light on the critical role of social acceptance in the transition to renewable energy. The insights gained from this research are invaluable for policymakers and educators aiming to foster a more sustainable future.

It is important to note that the ideas and materials presented in each chapter are the sole responsibility of the respective authors. Furthermore, the publisher does not assume any responsibility for the content or accuracy of the information provided. The contributions reflect the individual research and perspectives of the authors, and readers are encouraged to critically evaluate the information presented.

I would like to extend my heartfelt gratitude to all the contributors for their hard work and dedication in bringing this book to fruition. Your commitment to advancing knowledge and understanding in your fields is truly commendable. I also wish to thank ISPEC PUBLICATION for their support in publishing this work. Additionally, I would like to thank our readers for your interest and engagement with this important work. It is my hope that the insights shared within these pages will inspire further research, discussion, and action towards a more sustainable and technologically advanced future.

Thank you for joining us on this journey of exploration and discovery.

Respectfully,

Serkan Güldal

Lead Editor

03.12.2024

CHAPTER 1

UTILIZATION OF DIGITAL AGRICULTURAL TECHNOLOGIES IN GREENHOUSE CULTIVATION

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DOI: https://dx.doi.org/10.5281/zenodo.14425516

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INTRODUCTION

Technological advances have significantly facilitated various agricultural processes by providing alternative solutions to existing problems and ensuring precise and timely execution of production and applications. It has also contributed considerably to efficient, productive, high-quality agricultural production. The rising global population and decreasing agricultural land have made technology essential to meet the increasing food demand. With technological development, producers have started obtaining higher yields and better-quality products from the same unit area (Kılavuz and Erdem, 2019; Özgüven, 2023).

Smart greenhouses are an agricultural innovation that merges technology with farming (Soheli et al., 2022). Smart agricultural technologies aim to apply the right amount of input to the right place at the right time using appropriate methods, thereby increasing plant production. The smart farming revolution can address the challenges faced in traditional agriculture (Abdel-Fattah et al., 2021). Different crops have unique requirements for their growing environment, including temperature, humidity, light, and other factors. With smart agricultural greenhouse control systems, we can optimize the growing environment according to the needs of various crops, thereby enhancing growth efficiency. Consequently, the advent of smart agriculture has increasingly become a necessity in modern times (Sundmaeker et al., 2016; Wang, 2024).

Digital agriculture applications involve the real-time collection of information and data from agricultural fields using various sensors, cameras, or systems. These data are transmitted to develop software to analyze, store, and manage data-driven processes (Özgüven, 2023). The concept of digital agriculture is often confused with precision agriculture technology. Precision agriculture applications generally suggest field farming because the sensors, devices, equipment, and systems developed for precision agriculture are more suitable for field farming, where precision agriculture is most intensively used (Özgüven, 2023).

Technological advancements have also manifested in greenhouse farming, leading to the increased use of greenhouse automation systems. Producers must adjust environmental factors inside the greenhouse according to the needs of their crops. Providing the greenhouse climate more accurately and efficiently with artificial setups is possible (Öz et al., 2008). Greenhouse automation refers to the system architecture that uses sensors and electronic units placed at various points within the greenhouse to monitor and control factors like temperature, light, soil moisture percentage, internal humidity, and fertilizer levels via a computer program (Ciğer, 2010; Latha, 2016; Arıcı, 1999). Additionally, smart systems, machines, and objects that communicate with each other and have internet access can increase efficiency and enable more effective use of energy, water, fertilizer, and resources (Dayıoğlu et al., 2016). Ciğer (2010) defined automation as a method where the production process, controlled by electronic equipment from the processing of input material to the output product, is integrated among industrial equipment.

1. SMART GREENHOUSE AUTOMATION AND MONITORING OF GROWING CONDITIONS

The primary goal of greenhouse cultivation is to create the most favorable environmental conditions for the plants produced in the greenhouse, ensuring their growth is highly controlled and free from adverse conditions. Since it is impossible to control natural ecological conditions, it is easier to control the climate conditions inside the greenhouse. When managing the climate inside a greenhouse, the greenhouse volume should be large enough to give the impression that the plants are in a natural environment. This leads to increased growth and productivity. Ventilation, heating, cooling, and lighting are the most critical greenhouse design factors. (Öneş, 1990; Arıcı, 1999).

Smart greenhouses are an advanced farming method that plays a crucial role in the future of modern agriculture. These greenhouses use a range of automation, control systems, and sensors to optimize plant cultivation, save energy and water, monitor and enhance plant health, and simplify operational processes (Kesercioğlu et al., 2023). Öz et al. (2008) reported that smart greenhouses (heating, cooling, irrigation, fertilization, lighting, and ventilation) automatically control systems. In this way, it can achieve the optimum conditions desired by the plants.

1.1. Heating and Cooling Systems

Temperature plays a significant role in the growth and development of plants inside the greenhouse. Both very low and high temperatures harm plants; low temperatures limit plant growth, while high temperatures cause wilting. Therefore, temperature is a leading parameter in greenhouse control (Siddiqui et al., 2017). Plants commonly grown in greenhouses are typically adapted to average temperatures between 17-27°C. Hence, the optimal internal greenhouse temperatures should be between 15-20°C at night and 22-28°C during the day (Büyüktaş, 2023). Generally, greenhouses need heating when the average outside temperature is below 15°C. When the average outside temperature is below 27°C, natural ventilation will prevent extreme internal temperatures; artificial cooling methods (fog, fan-pad, shading) become essential when temperatures exceed this value to maintain product quality. The internal temperature should not reach 30-35°C for extended periods. The control of ventilation windows should not be abrupt, as sudden climate changes inside the greenhouse can stress plants. Greenhouse heating is achieved using various systems based on the cultivation method, crop pattern, and climate conditions. When the internal temperature drops to 17°C, the heating system automatically starts operating and stops when the desired temperature is reached, thus providing a continuous cycle between the set temperatures (Öz et al., 2008). It is economically advisable to keep nighttime temperatures at a minimum of 15°C and daytime temperatures between 22-26°C (Kürklü and Çağlayan, 2005).

Modern greenhouses control temperature variations using well-planned heating systems. The energy required for greenhouse heating is determined by the heat which greenhouse needs per unit of time. Factors like greenhouse volume, the requirements of the plants to be grown, cultivation times, ventilation rates, surface area, covering material, local weather conditions, and potential heat leaks are considered in heating. The success of heating automation depends on the system's response when the greenhouse needs rapid heating (Titiz, 2004).

1.2. Irrigation Systems

Smart agricultural applications provide significant convenience and advantages in efficient water use and management in agricultural irrigation. Studies have utilized soil moisture sensors, IoT-based dynamic irrigation planning systems, machine learning models, and artificial intelligence techniques to determine irrigation needs and improve irrigation processes. These applications have not only saved water but also increased crop productivity. These advancements in water management are crucial for addressing the challenges related to water resources in the agriculture sector. Greenhouse plants are sensitive to irrigation water's pH and EC balance, affecting plant response. Therefore, it is critical to check the pH and EC balance of the water before irrigation and fertilization to ensure plant health and productivity. Accurate and precise measurements are essential. Knowing the pH, EC, weight, and total drainage values before each irrigation ensures correct and appropriate feeding each time. All sectors need automatic measuring devices for this purpose.

In automatic irrigation systems, irrigation programs can determine the amount and duration of irrigation and irrigation timing. Different programs are created according to the plant type or water requirement and stored in the computer memory for later use. Thus, controlled and economical water use is provided (Oz et al., 2008). (Öz et al., 2008). Information obtained through Wi-Fi-connected moisture sensors placed in cultivation areas enables better water management, resulting in water conservation. Users can also monitor the processes remotely from their homes or other locations (Ray, 2017).

Furthermore, water quality can be measured using sensor nodes with wireless network communication (Paventhan et al., 2012). IoT allows real-time water quality monitoring, including conductivity, water temperature, pH, turbidity, and dissolved oxygen (Ray, 2017). Recent technological advancements in agricultural activities have introduced new irrigation methods for reduced water usage and real-time weather forecasts (Ray, 2017).

1.3. Ventilation Systems

In the greenhouse, after absorbing the non-reflected solar radiation, some of this absorbed energy is used as latent heat for evaporation. At the same time, the rest increases the temperature of the environment. The hot air inside needs to be replaced with cooler outside air at specific rates and periods before reaching dangerous levels for plants. The internal temperature should not exceed 30°C even on the hottest days. Good ventilation can lower the internal temperature. Proper ventilation also helps maintain the desired humidity levels and ensures adequate CO_2 levels by preventing depletion (Kürklü et al., 2005). Long-term relative humidity above 80%, especially at night, accelerates the spread of fungal diseases. Adjusting the vapor pressure balance inside the greenhouse regulates transpiration and reduces disease problems. If greenhouses are not heated at night, the inside and outside temperatures become almost equal, and if the outside humidity is high, it becomes difficult to reduce the inside moisture. (Yılmaz, 2013). When the temperature exceeds the desired level, windows automatically open for natural ventilation. A mechanical ventilation system activates to expel hot and humid air if natural ventilation is insufficient. This cycle continues constantly within the desired temperature range (Öz et al., 2008).

1.4. Fertilization Management

Fertilization in greenhouses is a fundamental aspect of successful plant cultivation. The quantity and form of fertilizer used, as well as the method of application, are crucial. When selecting the fertilization method, soil fertility, plant production system, and irrigation must be considered. Smart fertilization is a root zone management tool that directly provides suitable water and nutrient composition to the roots according to the crop development cycles. These systems, integrated with soil moisture sensors and weather data, deliver the required amount of water precisely when needed, ensuring water conservation. Designed by soilless and traditional farming methods, these systems prevent plant nutrient deficiencies by maintaining optimum nutrient solution levels (Anonymous, 2024).

Greenhouse areas are mostly far from residential areas due to their geographical location. Because of this distance, irrigation and fertilization can become quite challenging. Thus, automation systems are essential in cultivation areas. In agricultural fields equipped with automation systems, various sensors can measure and monitor all values related to plants. Additionally, data from the agricultural area can be recorded for retrospective analysis and reporting. One of the system's key features is the fertilization unit, which allows fertilization with desired values similar to the irrigation method on the applied field. This ensures that plants receive their necessary minerals and water regularly. The amount of fertilizer needed for each plant is determined using weight sensors integrated into the system, allowing plant-specific fertilization amounts. The agricultural automation system also aims to inform the user. Notifications are generated within the system and emailed to inform users about system activation, real-time changes, and unexpected errors.

Furthermore, instant information can be accessed using the designed mobile application. The system can operate manually and automatically, and remote control options are provided. The manual mode system can operate at any time and day for application, irrigation, and fertilization. In automatic mode, irrigation decisions are made based on data from the sensors, eliminating the need to visit the greenhouse for irrigation and fertilization, thereby reducing the human workload in agriculture. Time-focused irrigation ensures regular watering, increasing efficiency and preventing water waste. The fertilization system prevents over-fertilization, posing significant problems for plants and soil (Kurt et al., 2022).

1.5. Disease, Pest, and Weed Control

Greenhouse-grown plants grow faster and healthier. During this period, the primary factor affecting plant productivity is the inability to diagnose diseases quickly. When diagnosis is delayed, the disease spreads over a wide area. If these factors are detected quickly and necessary precautions are taken, plant productivity and quality will increase. Currently, the leaves of diseased plants are collected and identified in laboratory conditions, which prolongs the process and delays treatment. Instead of evaluating a single sample, continuous observation of the entire plant development process and prompt intervention is a more accurate option. This requires using real-time deep learning-based methods with the highest accuracy (Karakan, 2022).

A pheromone trap system attracts pests and insects in the greenhouse and processes photos taken at specific times with artificial intelligence to detect, count, and report pests automatically. The types and numbers of pests can be tracked metrically via the web panel, and necessary warnings can be made automatically. Balanced use of pesticides and fertilizers helps improve quality and minimize input costs. Controlled use can predict potential plant damage by collecting data via IoT-based sensor nodes (Ray, 2017). IoT and smart systems can evaluate plant diseases, pests, and weeds at early stages and inform farmers using smart tools to eliminate pests and pathogens with precision targeting. Autonomous weeding, precise weed management, weed detection, weed control, robotic arms, smart spraying, and inter-row weed cleaning can be done using computer vision and artificial intelligence (Natu and Kulkarni, 2016; Sujaritha et al., 2017; Partel et al., 2019).

2. SENSORS AND MONITORING SYSTEMS

Greenhouses have sensors that constantly monitor data such as air temperature, humidity, soil moisture, and sunlight. This data facilitates monitoring plant health and growth conditions (Öz et al., 2008). Precise monitoring of the interior environment of a greenhouse is only possible by intelligently selecting and strategically deploying sensors. Only in this way can comprehensive and accurate detection of environmental parameters in various regions of the greenhouse be achieved (Wang, 2024). Sensors in smart remote sensing systems are responsible for measuring and monitoring all desired factors (Karaman, 2022). Different sensors can monitor soil moisture levels, pH values, irrigation system control, plant growth, disease and pest detection, and weather conditions. The collected data is analyzed to provide meaningful information about plant health, environmental conditions, and other factors, enabling rapid intervention and continuous optimization (Kumar et al., 2021; Öz et al., 2008).

To obtain comprehensive environmental data, temperature, light, and humidity sensors are evenly distributed throughout the greenhouse. Light sensors are strategically positioned to detect changes in light and allow real-time monitoring of light conditions. Temperature-humidity sensors are used to measure air temperature and humidity at two-hour intervals during the day and four-hour intervals at night. When levels exceed/fall below desired levels, the microcontroller sends corresponding signals to the interface device. The microcontroller is programmed to activate the heating system when the temperature drops below the desired level. The cooling system will activate if the temperature is detected above the desired level. In other words, if the temperature falls below the desired level, the heater will activate to increase the temperature and automatically stop working when the temperature reaches the desired range. It also uses various sensors to collect environmental information, such as temperature, humidity, pressure, wind speed, precipitation, and location. (Li-Ying, 2016; Hua, 2014; Harshit et al., 2019; Özgüven, 2023).

Optical, mechanical, electrochemical, airflow, and position sensors are becoming more widespread. Image recognition is one of the most critical areas. Sensors can provide images that allow farmers to make appropriate and more informed decisions at the right time and to be warned early about diseases and pests. At the same time, smart monitoring offers the possibility of optimizing harvest, monitoring plant quality characteristics, and increasing income (Goedde et al., 2020).

Automatic monitoring systems are essential in smart digital farming, allowing farmers to make and implement quick and accurate decisions at the right time. In precision and digital agriculture, the real-time monitoring and measurement of parameters such as air and greenhouse gas monitoring, plant monitoring, soil monitoring, water quality, and irrigation parameters, as well as soil parameters like temperature, humidity, conductivity, pH value, and nutrient content, are crucial for sustainable agricultural management. To measure these parameters in real-time, IoT sensors, data analysis, decision support systems, and artificial intelligence must be used in a coordinated manner (Çakmakçı and Çakmakçı, 2023).

The soil moisture sensor periodically measures the volumetric water potential in the soil and reports it to the control system. It monitors soil moisture content, controls irrigation in greenhouses, and measures moisture loss over time due to evaporation for various plant species. The soil moisture sensor reminds the user to irrigate greenhouse plants and monitor soil moisture content. The microcontroller sends a signal to the relevant devices to turn the pump on/off to meet the requirements based on the soil condition signal. When soil wetness reaches a threshold level, the microcontroller sends a signal to turn off the pump via reliable interface devices. There is a fixed moisture sensor to measure the moisture in the soil. If there is not enough water in the soil (<70%), the pump automatically starts supplying water until it reaches the threshold value. On the other hand, when the moisture level reaches the desired level, the pump will automatically stop working (Soheli et al., 2022).

The sensor camera and data analytics provided continuous feedback on plant health and growth status, aiding harvest timing and crop quality. This allows farmers to make better decisions and use resources more effectively. (Kesercioğlu et al., 2023). Sensors can also automatically collect data for pest control, such as detecting the presence of pests or determining when a trap is activated by catching a pest (Friha et al., 2021). According to Yue et al. (2018), advanced high-resolution sensors significantly improve smart pest detection.

Smart sensors, robotics, region-based convolutional neural networks (R-ESA), UAVs, IoT devices, artificial intelligence, and machine learning-based computer vision techniques can help achieve sustainable production with lower-cost production, less labor, reduced harvest costs, yield optimization, and increased productivity (Horng et al., 2020; Zhang et al., 2020; Sharma et al., 2022).

3. SMART GREENHOUSE BASED ON IOT TECHNOLOGY

One of the ways to make a greenhouse (smart) is to integrate IoT (Internet of Things) technology (Dagar et al., 2018). Smart farming uses IoT technology to maximize agricultural productivity and ensure the most efficient use of resources by reducing operational costs. Special equipment, wireless connectivity, software, and computer technologies are part of the IoT (Samaila et al., 2018). IoT technology offers unconventional and practical solutions in many areas, including smart agriculture, and has promising potential. In agriculture, IoT technology has made significant advances in agricultural management. This technology ensures that all agricultural devices and equipment work together in an integrated manner in irrigation and fertilization processes (Kumar and Periasamy, 2022). Wireless sensor networks (WSNs) collect data from different sensing devices. In addition, it is emphasized that cloud services should be integrated with IoT to analyze and process the data collected by the remote sensing system (Farooq et al., 2020; Alaboz et al., 2022). To dominate the cultivated area with IoT technology, ICT (Information Communication Technology), ground sensors, and remote sensing systems should be integrated with robots, autonomous vehicles, and other automatic devices (Belal et al., 2020).

According to Akkas and Sokullu (2017), interconnected computing devices, sensors, objects, microcontrollers, and cloud servers that can transfer and control data over a network can be remotely controlled without human intervention to other devices. Sensors capture data inside and outside the greenhouse and automatically transmit it to a central cloud server for storage. End-user devices can access this data, and the information generated about their crops, appropriate harvest time, energy consumption, etc., can be used (Gomes et al., 2015). In addition, cloud endpoints can be used to store data for faster processing. IoT sensors and infrastructures can monitor and control the conditions of the environment. The integrated IoT cloud server allows it to process data remotely and control IoT infrastructures such as irrigation valves and window openers. The IoT cloud server will enable farmers to monitor and control via mobile devices instead of manual monitoring. As a result, IoT-enabled greenhouse farming allows farmers to plant multiple crops in favorable seasons with minimal human effort, increasing productivity and reducing labor costs (Jumaah et al., 2021; Hosny et al., 2024).

An IoT-based automated smart greenhouse is a system designed to automate the management of greenhouse cultivation. The system integrates IoT-based remote sensing technologies, AI-based decision support systems, and advanced data analytics tools to manage climate control, irrigation, fertilization, and pest control processes. By leveraging real-time data from a network of sensors, the smart greenhouse system adjusts environmental parameters such as temperature, humidity, light, and soil moisture to create optimal plant growth conditions. The system can also predict potential issues, provide early warnings, and suggest preventive measures based on historical data and predictive modeling. This approach ensures efficient resource utilization, minimizes human intervention, and enhances crop yield and quality. Implementing IoT-based automated smart greenhouses represents a significant advancement in precision agriculture, contributing to sustainable farming practices and food security (Meng et al., 2021).

When discussing the use of IoT in greenhouse automation, it is necessary to first touch on how the need arose. Danita et al. (2018) defined greenhouses as climate-controlled structures with walls and roofs specially designed for the off-season cultivation of plants.

Researchers have stated that most greenhouse systems use manual systems to monitor temperature and humidity, which can be uncomfortable for workers. Greenhouse workers visit the greenhouse daily and manually monitor the environment (such as temperature and humidity) to ensure the productivity of the plants. At this point, it has been reported that using IoT and, therefore, the automation of greenhouse systems can solve some problems without any human intervention (Subahi and Bouazza, 2020).

Although IoT has been a technological phenomenon studied recently, it is not a standard application. The difficulties encountered in obtaining IoT structure are also included in the literature. Lucero (2016) describes these difficulties in his study: managing complexity, creating and maintaining reliable connections, ensuring data security and privacy, making the best use of data, and enabling an open IoT ecosystem.

4. CONCLUSION

Greenhouse farming in Turkey has not yet gained its thoroughly modern identity. In Turkey, greenhouses equipped with modern systems and found in developed countries are few. In particular, failure to regularly control the temperature and humidity of the greenhouse indoor air causes negative results. The most crucial criterion for increasing plant productivity is to achieve optimum growing conditions. Using digital agricultural applications in greenhouse plant cultivation has improved agricultural processes and maximized operational efficiency. There is a greater need for scientific and technological developments to cope with the challenges encountered in greenhouse cultivation, which will increase in the future, and to increase efficiency. New technologies developed in recent years make processes more efficient. These technologies improve yield and quality, reduce costs, and increase irrigation and plant nutrient use efficiency. It can also reduce pollution caused by efficient, rational fertilization and pesticide use. Remote control of critical climate variables in the greenhouse optimizes crop growth and contributes significantly to sustainable agricultural practices. Integrating remote sensing technologies into agriculture by solving cost issues can facilitate the sustainability of the greenhouse sector. Agricultural technology should be based on sustainability, reduce input requirements, facilitate applications, make high use of agricultural biology, and be respectful and reliable to nature, humans, and resources such as soil, the environment, and water. Future work should optimize greenhouse management, continuously monitor technological developments, and, as a result, bring more advanced data analysis and machine learning algorithms to the sector.

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CHAPTER 2

INVESTIGATION OF HIGH PASS FILTER CIRCUIT USING ONLY MOS TRANSISTOR

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DOI: https://dx.doi.org/10.5281/zenodo.14425580

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INTRODUCTION

Introduced in 1917 by G. Campbell and K. Wagner, the filter can be categorized as low-pass filter (LPF), high-pass filter (HPF), bandpass filter (BPF) and band-stop filter (BSF) (Campbell, 1922). Analog filters are used in many fields, such as communication engineering, communication circuits, control engineering, and digital image processing (Erdogan, Topaloglu, Kuntman, & Cicekoglu*, 2004; Metin, Kaluç, Öncü, & Cicekoglu, 2022; Neemuchwala, Gupta, & Kadam, 2021). Traditionally, passive filters are designed using resistors (R), capacitors (C), and inductors (L) (Khan, Alam, Masud, & Amin, 2016; Sahin & Guler, 2017; Yuce & Minaei, 2012). However, filter circuit designs are made using ready-made circuit blocks or different circuit elements to avoid inductors in IC designs. Filter circuits using active circuit elements in the literature, Second Generation Current Conveyors (CCIIs)(Horng, 2001, 2004), Current Differencing Transconductance Amplifier(CDTA) (Shah, Quadri, & Iqbal, 2007), Dual-X Current Conveyor Transconductance Amplifier (DXCCTA) (K. B. Singh, Joshi, & Ranjan, 2020), Operational Transconductance Amplifier (OTA) (Metin, Pal, Minaei, & Cicekoglu, 2009), and more are available. There are also filter circuits designed in the literature using memristors instead of resistors and memcapacitors instead of capacitors (Y. Li, Yang, Yu, & Díez, 2017; Sozen & Cam, 2014; Sözen & Çam, 2013). High-pass passive filters are electronic circuits that pass signals above a certain frequency and attenuate lower frequencies. The primary purpose of high-pass filters is to reduce the impact of unwanted signals by blocking low-frequency components. They are often used in audio and RF (radio frequency) applications to eliminate noise or filter out unwanted interference (Sedra & Smith, 1987). The MOSFET conducts when the gate voltage exceeds the threshold voltage. When there is a voltage drop between the drain and source with the voltage applied to the gate, it resembles Ohm's law with this similarity and in some applications, MOS transistors are used as resistors (Herencsar, Koton, Jerabek, Vrba, & Cicekoglu, 2011; Metin, Pal, & Cicekoglu, 2011). The MOS capacitor has a capacitance value due to the oxide layer between the gate and the channel, and in some studies, MOS transistors have been used instead of capacitors (de Oliveira, Carneiro, Soares, Oliveira, & Gomes, 2024; T. B. Singh, Ranjan, & Bhatt, 2023). In addition, due to the capacitance value formed in the oxide layer between the gate channel of the MOS transistor, the memcapacitor circuit element was introduced to the literature by using the MOS transistor as a capacitor (Gur et al., 2023).

This study used MOS transistors instead of capacitors and resistors, which are the traditional circuit elements used in high-pass passive filters. In place of the capacitor, the MOS transistor's oxide layer capacitance value between the gate and the channel was utilized. In addition, using the MOS transistor as a resistor, the gate voltage was controlled, a voltage drop between the drain and the sink was achieved, and a structure per Ohm's law was obtained.

1. MATERIALS AND METHODS

1.1 High Pass Passive Filter

High-pass passive filters block frequencies up to a certain value depending on the voltage frequency applied to the input and transmit frequencies after a certain value. As shown in Fig. 1, high-pass filters consist of a series capacitor and a series resistor. The output voltage is taken across the resistor. At low frequencies, the capacitor connected in series with the circuit behaves like an open circuit and does not pass voltage values. At high frequencies, the capacitor behaves like a short circuit and passes the voltage values (Sedra & Smith, 1987).

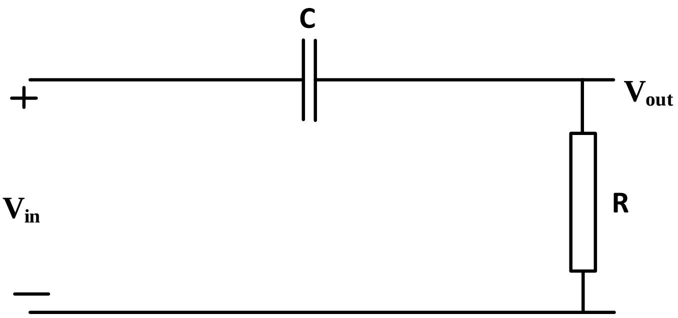


Figure 1: High-pass passive filter circuit

When the capacitor and resistor are connected in series and the output is taken through the resistor, it is called a high-pass filter. In this study, NMOS is used instead of capacitor and PMOS is used instead of resistor. The output of the circuit is taken over PMOS.Since there is a voltage difference between the drain and source terminals in the linear region of the MOS transistor, the current flowing through the MOSFET becomes proportional to the voltage, similar to Ohm's law. This makes the MOS transistor an adjustable resistor. It can be used in electronic circuits where the resistance value needs to be adjusted dynamically (Manolescu & Popa, 2010; Wee & Sarpeshkar, 2008; Xiang & Sturm, 2012). The MOS transistor used as a tunable resistor is shown in Fig. 2.

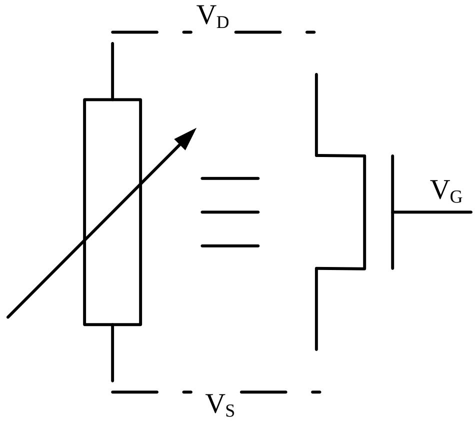


Figure 2: MOS transistor is used as a variable resistor

Using MOSFET as a capacitor, the gate-oxide layer of the MOS transistor acts like a capacitor due to an oxide layer between the gate and the channel. Since the MOS capacitor is insulated between the gate and the channel, the capacitance value may change depending on the voltage applied to the gate. The MOS transistor can therefore be used as a voltage-controlled capacitor (Innocent et al., 2002; S. Li & Zhang, 2012; Tiebout, 2003). The MOS transistor used as a tuned capacitor is shown in Fig. 3.

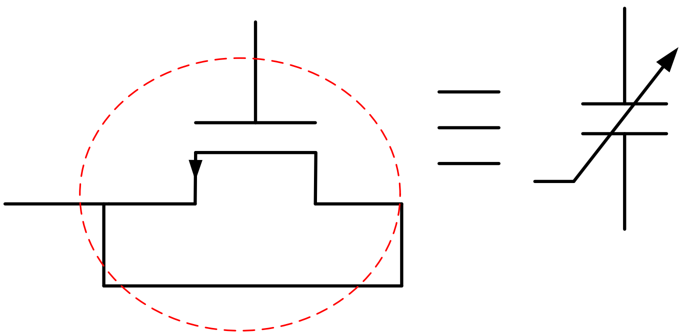


Figure 3: MOS transistor used as a variable capacitor (Tiebout, 2003)

The transfer function of the high-pass passive filter is as shown in Equation 1;

$$H(jw) = \frac{V_{out}}{V_{in}} = \frac{R}{R + \frac{1}{jwC}} \tag{1}$$

If jw=s is written in Equation 1;

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{R}{R + \frac{1}{sC}} = \frac{sRC}{1 + sRC} \tag{2}$$

The cut-off frequency of a high-pass passive filter;

$$f_c = \frac{1}{2\pi RC} \tag{3}$$

The proposed HPF configuration is shown in Fig. 4 and consists of only a MOS transistor as a MOS resistor(Kumar, Vista, & Ranjan, 2019) and a MOS capacitor (Shen, Khatri, & Zourntos, 2006):

$$R_{MOS} = \frac{1}{\mu_n c_{ox}\left(\frac{W}{L}\right)\left(V_G - V_T\right)} \tag{4}$$

$$C_{MOS} = C_{OX} A \tag{5}$$

μ_n, C_{ox}, W, L, and V_T are standard MOSFET parameters. However, the control voltage V_G allows the MOS transistor to be used as an adjustable resistor. Equations 6 and 7 provide the transfer function and cut-off frequency of the suggested filter circuit shown in Fig. 4.

$$H(s) = \frac{sR_{MOS2}C_{MOS1}}{1 + sR_{MOS2}C_{MOS1}} \tag{6}$$

$$f_c = \frac{1}{2\pi R_{MOS2}C_{MOS1}} \tag{7}$$

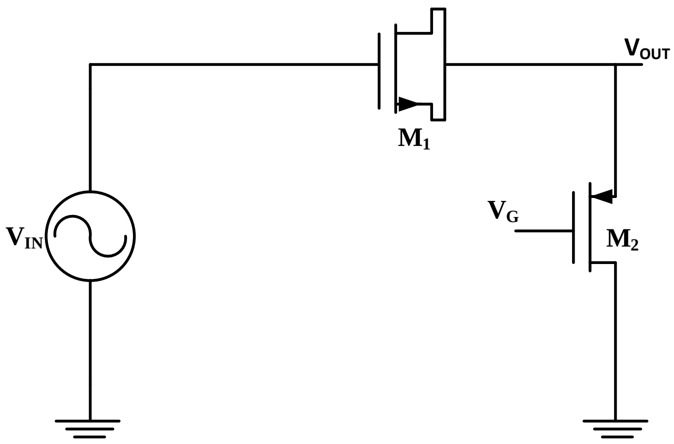


Figure 4: Proposed high-pass filter circuit

The channel length and channel length parameters of the MOSFET of the MOS-based high-pass filter circuit designed in Fig. 4 are given in Table 1.

Table 1: Channel length and width parameters of the MOSFET.

MOS Transistor	W(µm)	L(µm)
M_1	5	1
M_2	0.36	0.36

2. RESULTS AND DISCUSSION

To verify the proposed high-pass passive filter circuit, V_G=-0.5V was taken and simulated using 0.18µTMSC CMOS technology. The cut-off frequency is shown in Fig. 5 as 80MHz at -3dB, where the gain is halved.

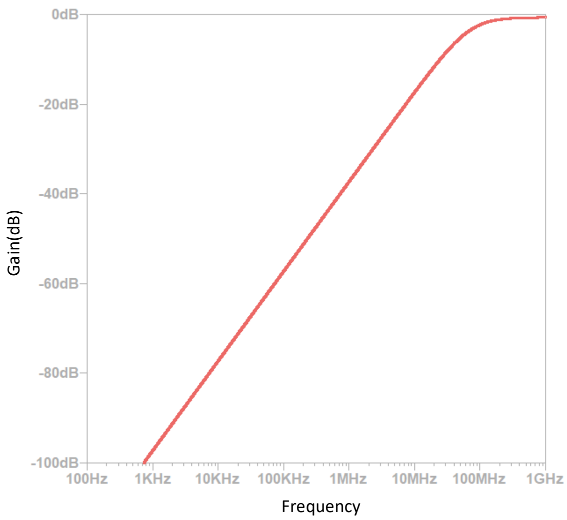


Figure 5: Frequency response of the proposed HPF circuit

The frequency response shown in Fig. 6 was taken at different control voltage values. It can be controlled electronically without any hardware adjustments. The control voltage V_G was taken as -0.25V, -0.5V and -0.75V respectively. Accordingly, the cut-off frequencies were measured as 1MHz, 80MHz, and 480 MHz, respectively.

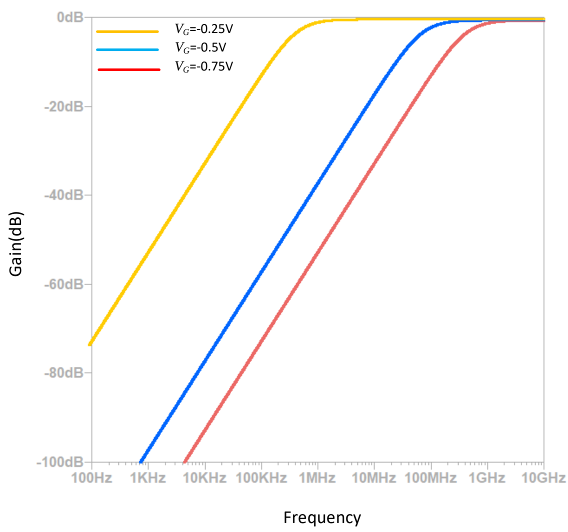


Figure 6: Frequency response of the proposed HPF circuit at different V_G values

The channel width and length of the MOS transistor used as a resistor in the high-pass passive filter circuit changes the resistance value of the MOS transistor. The cutoff frequency variation at different channel widths (*W*) is tested in Fig. 7. Channel widths of 0.36µm, 0.7µm, and 1µm were taken, respectively, and the corresponding cut-off frequencies were measured as 80MHz, 142MHz, and 191MHz.

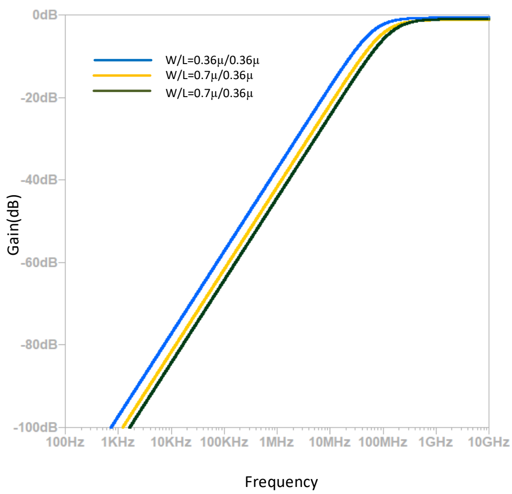


Figure 7: Frequency response of the HPF circuit at different MOS channel widths

Finally, the proposed high-pass filter circuit is analyzed at different temperature values. Operating electronic circuits at different temperatures adds a great advantage to electronic circuits. Fig. 8 shows the cut-off frequency measured at different temperature values, -25^{o}C, 25^{o}C, and 50^{o}C, and it is seen that the cutoff frequency does not. The designed filter circuit operates without any degradation at different temperatures.

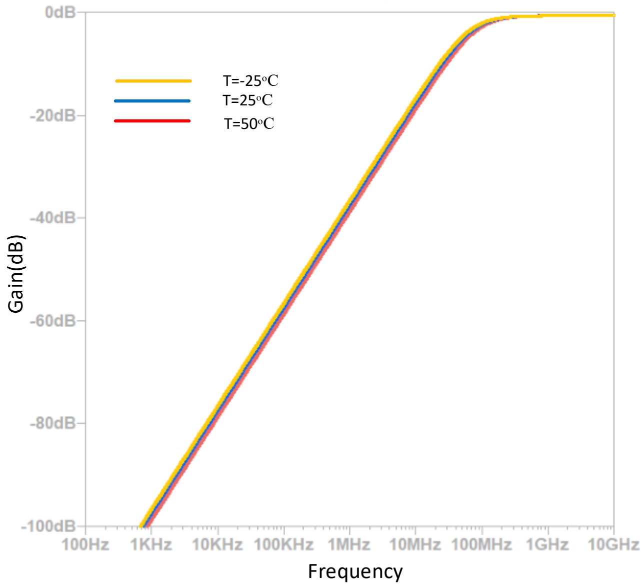


Figure 8: Frequency response of the HPF circuit at different temperature values

The phase angle is the difference between the input and output voltage and varies with frequency. It is 90° at low frequencies and 0 ° at high frequencies. Fig. 9 displays the single-layer high-pass filter circuit's phase-frequency plot.

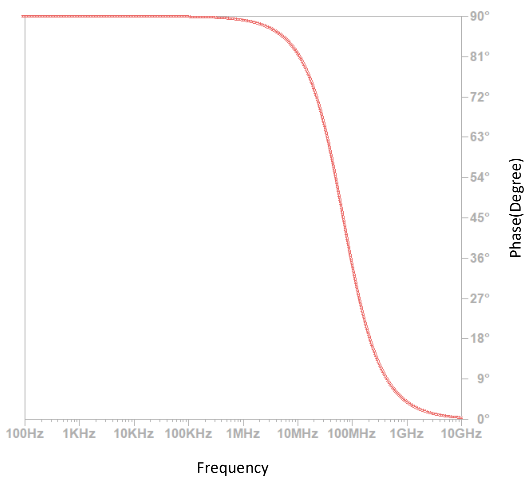
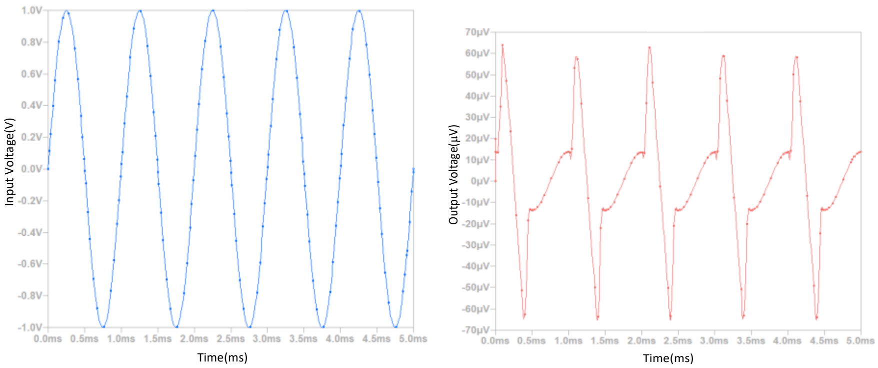


Figure 9: The phase-frequency plot of the HPF circuit

In filter circuits, the relationship between input and output voltage is considered. The input and output voltages are nearly equal at low frequencies. However, as you go to higher frequencies, the output voltage weakens and reaches zero. Fig. 10:a and b show the input and output voltages at 80MHz, respectively. The output voltage decreases as the frequencies rise, as predicted.



a) **b)**

Figure 10: a) input voltage **b)** output voltage of the HPF circuit at 80MHz

3. CONCLUSION

This study uses an active circuit element, a MOS transistor, instead of a capacitor and resistor in the high-pass passive filter design. The simulation results were verified using 0.18µm TMSC CMOS technology parameters. Only active circuit elements were used in the designed circuit, and it was shown that the circuit is suitable for IC technology. Without altering any of the high-pass filter circuit's hardware, the cut-off frequency can be adjusted by varying the gate voltage of the PMOS transistor that serves as a resistor. Therefore, the circuit is electronically controllable. The simulation results were also analyzed at different temperature values, and the operability of the circuit at different temperature values was demonstrated. The simulation results show that the cut-off frequency changes to varying values of the channel length and width (*W/L*) of the PMOS transistor used as a resistor. This study will be a reference for designing other active and passive filter circuits using MOS transistors in future studies.

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CHAPTER 3

MULTI-OBJECTIVE OPTIMIZATION: NON-DOMINATED SORTING GENETIC ALGORITHM II (NSGA II)

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DOI: https://dx.doi.org/10.5281/zenodo.14425675

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INTRODUCTION

Multi-objective optimization (MOO) is a fundamental area of research focused on solving problems that involve several conflicting objectives (Cheng, Shi & Qin, 2012; Wang & Rangaiah, 2017). Unlike single-objective optimization, where the goal is to identify a single optimal solution, MOO produces a set of solutions that represent trade-offs among the different objectives. (Gupta, Singh, Das & Lease, 2021; Holdsworth & Simpson, 2016). These solutions form the Pareto front, where each solution is considered optimal in the sense that no other solution can improve one objective without worsening another. Applications of MOO span a wide range of domains, including engineering design, financial portfolio management, environmental planning, and artificial intelligence, making it an essential tool for decision-making in complex systems (Gunantara, 2018).

Evolutionary algorithms (EAs) have proven particularly effective for tackling MOO problems because they can explore large and complex solution spaces without requiring gradient information. Among these, the Non-Dominated Sorting Genetic Algorithm II (NSGA-II) has emerged as one of the most popular and widely used algorithms, celebrated for its efficiency, simplicity, and effectiveness in solving multi-objective problems (Deb, 2002; Tian, Wang, Zang & Jin, 2017).

The algorithm integrates three essential components that make it exceptionally robust:

1. Fast Non-Dominated Sorting: A mechanism for classifying solutions based on Pareto dominance that reduces computational overhead.
2. Crowding Distance Assignment: A method for preserving solution diversity by evaluating the density of solutions around a candidate.

3. Elitism: Guaranteeing the preservation of optimal solutions across generations facilitates improved convergence toward the actual Pareto front

The simplicity and efficiency of NSGA-II have made it the benchmark for multi-objective evolutionary algorithms, inspiring numerous variants and extensions (Deb, 2002). Its applicability extends across many optimization problems, from standard test functions to real-world challenges with complex constraints and objectives (Zatarain Salazar, Hadka, Reed, Seada & Deb 2024).

This chapter aims to provide a comprehensive exploration of NSGA-II. It begins with a foundational overview of MOO and evolutionary algorithms and then delves into the technical details of NSGA-II, including its algorithmic steps, strengths, and limitations.

1. MULTI-OBJECTIVE OPTIMIZATION

Optimization is obtaining the best result under given conditions. Mathematically, it is the process of making any function minimum or maximum according to given constraints. The methods developed to study, model, and solve optimization problems are called optimization techniques, and there are three essential components of an optimization problem.

1. Objective Function: This refers to the function that must be optimized by maximizing or minimizing it. For example, production processes have common objectives such as maximizing profit or minimizing costs.
2. Variables (Unknowns): These are the factors that affect the value of the objective function. In a production context, variables may include resource allocation or time utilized for various operations
3. Constraints: Rule relations that ensure that unknowns or variables take certain values and do not take specific values.

In an optimization problem, the maximum and minimum functions can be examined as single-objective or multi-objective without constraints (Gunantara, 2018). When the problem is limited to a single objective function, it is referred to as single-objective optimization. Historically, particularly since the Second World War, most research in the optimization field has been devoted to understanding, developing, and applying methodologies tailored to single-objective problems. Over time, this research has culminated in a wide range of algorithms, broadly categorized into gradient-based techniques, which rely on mathematical derivatives, and heuristic-based methods, which employ search strategies inspired by natural or computational processes. In contrast, when an optimization problem encompasses multiple, often conflicting, objective functions, it is classified as multi-objective optimization. This type of optimization presents distinct challenges, as it requires identifying trade-offs between objectives, leading to a set of solutions referred to as the Pareto front. In management and decision-making contexts, multi-objective optimization is frequently called multi-criteria decision-making (MCDM), reflecting its focus on balancing diverse priorities to guide informed decision-making processes (Deb, 2001: 1).

In mathematics, engineering, economics, agriculture, automotive, and many real-life problems, we encounter problems with multiple objectives rather than single objectives. When we consider an optimization problem related to the purchase of automobiles with two objectives, and each objective has a different solution, we consider automobiles with price ranges between 15000$ and 150000$. The price-comfort graph for cars is shown in Figure 1. The most expensive car with the highest comfort is solution number 2, and the cheapest car with the lowest comfort is solution number 1. If a single-objective decision is to be made based only on price, the low-priced solution is chosen, and car number 1 is selected. Manufacturers will produce only one type of car with low comfort based only on price. People who are willing to pay more money and value comfort will choose car number 2, and there are other choices with different prices and comfort. While cars 1 and 2 are the best choices for a single objective, there are better choices when considering two or more objectives. In multi-objective optimization problems, the presence of multiple objectives inherently precludes the existence of a single optimal solution. Without additional preference information, no solution within this set can be unequivocally deemed superior to the others. This is in contrast to single-objective optimization, where the aim is usually to identify a single optimal solution. The fundamental distinction, therefore, lies in the nature of optimality: Single-objective optimization seeks a singular best solution, whereas multi-objective optimization identifies a spectrum of optimal solutions representing trade-offs among competing objectives (Deb, 2001: 2).

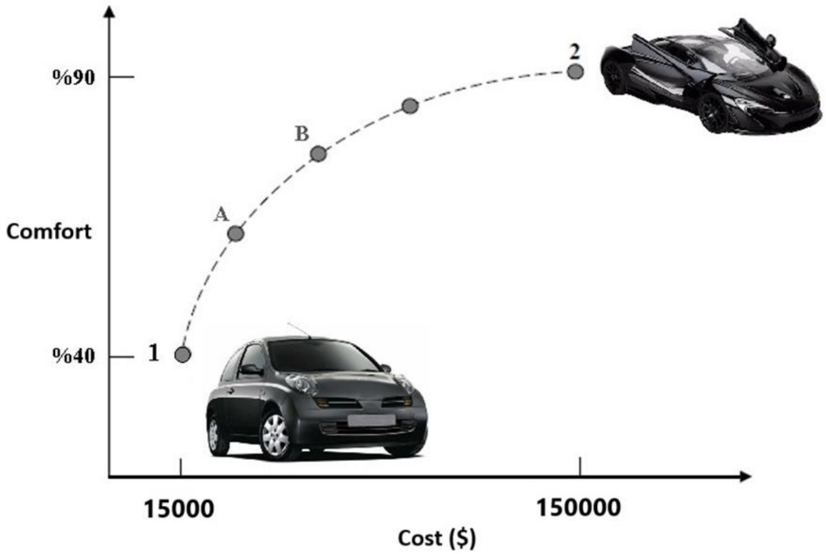

Figure 1: Hypothetical solutions to the car purchase decision-making problem (Deb, 2001)

Optimization problems with multiple objectives are constantly encountered in today's real-life problems in mathematics, engineering, social sciences, economics, agriculture, aviation, automotive, and many other fields. MOO aims to find optimal solution values for multiple objectives (Gunantara, 2018).

Multi-objective optimization problems are generally more complex to solve than single-objective optimization problems. While trying to maximize one of the objective functions, the other objective or objectives may be minimized. A maximized objective function can be minimized by multiplying by "-1". Many optimization algorithms have been developed to solve only one type of optimization problem (Deb, 2001: 14).

Multi-objective optimization problems where all objective and constraint functions are linear are classified as multi-objective linear programming (MOLP) problems. Like its single-objective counterpart, MOLP is characterized by a well-defined theoretical framework that aids in analyzing and resolving these problems. In contrast, when one or more objective or constraint functions are nonlinear, the problem is classified as a nonlinear multi-objective optimization problem. Unlike linear cases, such problems do not benefit from general convergence guarantees, which complicates their theoretical and practical treatment. This distinction is particularly important because most real-world multi-objective optimization scenarios inherently involve nonlinearity, often lacking any specific structure that can be systematically leveraged for simplification (Deb, 2001, p. 15).

In the scarification method, the objectives in a multi-objective optimization problem are assigned weights and combined into a single objective function by summing them (Nedjah & Mourelle, 2015). Weighted single objective optimization problem,

$$min \sum_{i=1}^{N} w_i f_i \,(x)$$

$$g_j(x) \leq 0, j = 1,2, \ldots, J$$

$$h_k(x) = 0, k = 1,2, \ldots, K$$

w_i are weight coefficients and have the following constraints.

$0 \leq w_i \leq 1$ and $\sum_{i=1}^{N} w_i = 1$

The literature also mentions objective substitution in multi-objective optimization. In this method, the objectives are ranked according to their importance. Given that this impacts the solution process, it is crucial to establish the appropriate priority among the objectives. The problem is approached as a single-objective optimization by transforming the objective function at each step, while the remaining objectives are treated as constraints.

The most popular multi-objective evolutionary algorithms can be categorized into three categories according to the way individuals are selected and evaluated (Nedjah & Mourelle, 2015). Figure 2 shows the main categories along with the main algorithms and methods.

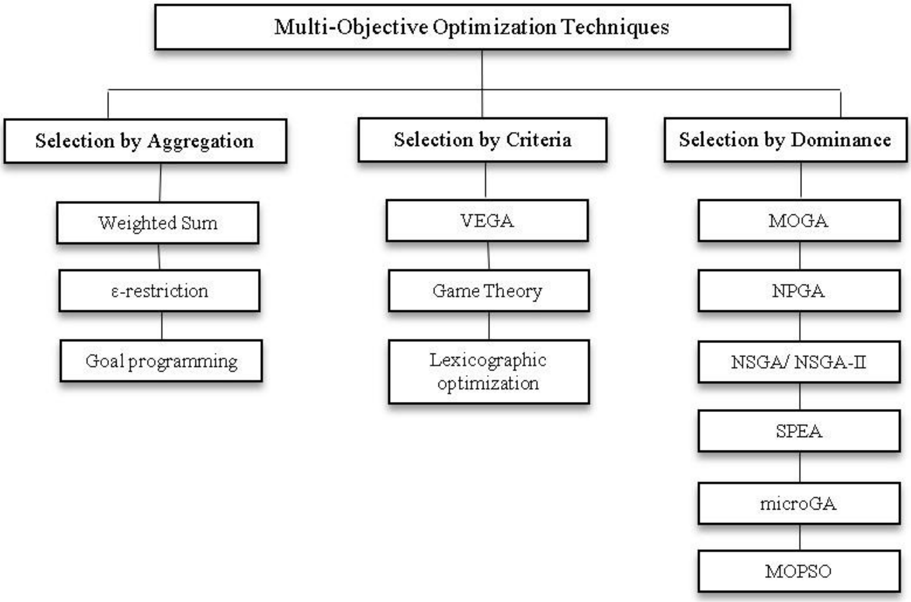

Figure 2: Classification of Multi-objective Methods and Algorithms

The difficulties of classical techniques used in solving multi-objective problems are as follows (Coello, Lamont, Van Veldhuizen, 2007: 7);

In multi-objective optimization, combining multiple objectives into a single objective function leads to a single optimal solution. However, this method is limited to identifying solutions that optimize all objectives simultaneously, which is often essential for solving practical, real-world problems.

- When converting a multi-objective problem into a single-objective one, it is crucial for the decision-maker to have a clear understanding of the priorities of the objectives.
- The weight vector can be much more difficult to define

if the objective functions are not deterministic.

- Classical techniques are susceptible and depend on weight or demand levels.

1.1. Pareto-Optimal Solution

Pareto optimality, a concept developed by Italian economist and sociologist Vilfredo Pareto in the early 20th century, is commonly used in evolutionary algorithms for multi-objective optimization. This framework assesses and classifies solutions as superior, inferior, or equivalent based on their performance across various objectives.

Pareto-optimal represents a collection of trade-offs in MOO problems. This set can be depicted as a curve or surface within the objective space. Non-dominated solutions are characterized by their lack of inferiority across all objectives while demonstrating a distinct advantage in at least one. The primary objective of MOO is to identify the Pareto frame, which provides decision-makers with a diverse range of optimal trade-offs to guide informed decision-making (Deb, 2001, p. 20).

In contrast to single-objective optimization, where solutions can be ranked from best to worst to identify a single optimal solution, multi-objective optimization produces a set of equally optimal solutions. This group of solutions reflects the multiple trade-offs inherent in the problem, as no single solution is universally superior across all objectives (Ergül, 2010).

In MOO problems, the solution is represented as a vector. Accordingly, the MOO problem can be formulated as a vector minimization problem, expressed as follows (Kaya, 2016):

$Min\colon \{f_1(x), f_2(x), \ldots, f_N(x)\}$ //Solution Area (1.1)

Constraints

$f_i(x),\ i = 1,2, \ldots, N$ //Objective Function Vector (1.2)

$g_j(x) \leq 0,\ j = 1,2, \ldots, J$ // Inequality (1.3)

$h_k(x) = 0,\ k = 1,2, \ldots, K$ //Equality (1.4)

In multi-objective optimization problems, there is an objective function vector rather than a single objective function. In Pareto-based selection methods, the selection of individuals from the population is advantageous because it relies on the dominant relationship among them (Nedjah & Mourelle, 2015). All of the solutions on the Pareto front are equal to the others. In this context, it is necessary to determine the set of solutions by the objective functions. In this case, the concepts of dominant and subdominant in Pareto optimal need to be explained to determine an optimal point.

Consider a problem with M objective functions. A decision vector (x_1) to another decision vector (x_2) is dominant if and only if the following conditions are met ($x_1 \prec x_2$ is shown as):

x_1 in all objective functions x_2 is better than or $f_i(x_1) < f_i(x_2)$, $\forall i = 1, \dots, M$

x_1, x_2 is very good at at least one objective function, or $f_i(x_1) \leq f_i(x_2)$, $\exists i = 1, \dots, M$

Similarly, an objective vector (f_1) to another objective vector (f_2) is dominant if it is better than it on all objectives, or at least much better than it on at least one objective function ($f_1 \prec f_2$). Figure 3 shows the dominance relationship. Here, individuals X, Y, and Z dominate over individual T. Solution point T is called the dominant solution. Solutions that are not dominated by any other solutions from the Pareto front.

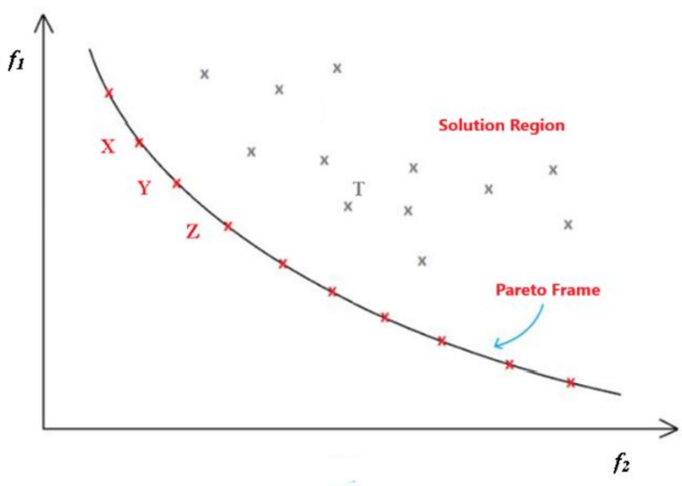

Figure 3: Pareto optimal frame

Heuristic techniques, including artificial neural networks, genetic algorithms, and simulated annealing, are commonly employed to address multi-objective optimization problems.

However, these methods must be repeated many times to find each solution. As a result, the computational complexity of classical heuristics for multi-objective optimization is quite high. To avoid this, multi-objective heuristics have been developed. The NSGA-II is one of the most effective methods for MOO problems in literature.

1.2. Non-Dominated Sorting Genetic Algorithm-II (NSGA-II)

NSGA-II developed by Deb in 2002, is a prominent heuristic approach frequently applied to MOO problems, designed to efficiently identify Pareto-optimal solutions. This method is rooted in Pareto-based approaches, originally inspired by Goldberg's work in 1989. The foundational concept of the algorithm was first implemented by Srinivas and Deb in 1994 (Srinivas & Deb, 1995). The initial version of NSGA emphasized solution diversity, which was maintained through the use of a sharing parameter (σ_{share}) that required comparing each solution with every other solution in the population. NSGA-II was developed to refine the original NSGA to address its limitations, including high computational complexity, lack of elitism, and reliance on the predefined (σ_{share}) parameter. The updated version introduced several enhancements, such as fast nondominated sorting and crowding distance operators. These changes not only improved the algorithm's efficiency and eliminated the need for a predefined sharing parameter but also incorporated elitism to ensure better preservation of high-quality solutions while maintaining population diversity.

In NSGA-II, for all objectives, individuals are compared with the individuals in the first surface solution in the Pareto solution instead of comparing with whole populations. NSGA-II has low computational complexity and, since it considers efficiency, it offers the opportunity to be applied in many areas. In NSGA-II, designed based on a genetic algorithm, dominance ranking, and crowd distance calculation algorithms are applied in addition to genetic algorithm operations. In NSGA-II, the initial population is first created, and the solutions obtained by searching for the possible solution sets of each objective are ranked according to their superiority in the Pareto solution. In this ranking, the fast dominant ranking method is used (Kocatürk & Altunkaynak, 2019).

1.2.1. Non-Domination Ranking

To identify the individuals in a population to the first-order dominant surface, the dominance of the individuals is checked by comparing each solution with the other solutions in the population. This process is repeated for all solutions in the first dominant surface. For other dominant surface solutions, the same process is repeated by removing the first-ranked solutions from the Pareto solution set. Thus, individuals are classified into different dominance clusters according to their degree of dominance (Türkşen, 2011; Kocatürk & Altunkaynak, 2019).

For each element p in the population P, the number of dominant solutions (n_p) and the set of solutions (S_p) in which solution p is dominant are determined, and the dominance counter of the solutions is assumed to be zero. Each solution p is compared with the other elements, and the element with a dominance count of zero is assigned to a separate Q and forms the second dominant surface Q. The process repeats the comparisons for each element in the set, forming the third dominant surface. The process continues until all solutions form surfaces. The fast dominant ranking is as follows (Deb, 2002).

Step 1: for each $p \in P$

$S_p = \emptyset$, p the solution set dominated by the solution is defined

$n_p = 0$, p the number of dominant solutions to the solution is defined

For each $q \in P$

If p dominates q, add q to the set of solutions dominated by p, $S_p = S_p \cup \{q\}$.

- Else if q dominates p, p belongs to the first front, $n_p = n_p + 1$
- If $n_p = 0$, there is no dominant solution to solution p. Solution p belongs to the first surface. The rank of solution p is 1 ($p_{rank} = 1$). The solution p is added to surface 1, and the first surface is updated. $F_1 = F_1 \cup \{p\}$.

Step 2: for each $p \in P$ Step 1 repeated.

Step 3: Surface counter is taken as 1, $i = 1$.

Step 4: i. while as long as the surface is different from the empty set, $F_i \neq \emptyset$

(i+1). For the surface, the set where the elements are collected is taken as the empty set, $Q = \emptyset$.

For each $p \in F_i$

For each $q \in S_p$ $n_q = n_q - 1$

If $n_q = 0$

$Q = Q \in \{q\}$. If Q is an empty set, the sorting process is over.

If Q is not an empty set, the surface counter is incremented by one, $i = i + 1$.

The new surface is assigned to set Q, $F_i = Q$.

The reason why it is called the fast dominant ranking algorithm is that the ranking of solutions is faster than NSGA since the dominance counter for each solution and the solution set in which the relevant solution is dominant are used in the ranking of Pareto solutions (Türkşen, 2011; Kocatürk & Altunkaynak, 2019).

The purpose of ranking in NSGA II is to compare the values of the elements in the population with each other to form F_1 or the first front with the solutions that dominate the other solutions. By removing the elements forming the first front, the distorting effect of the answers forming the first front is removed from the elements in the next second front while finding the next front. Of the remaining individuals of the population, the dominant ones form F_2. Continuing in this way, the individuals in the first and second facades are removed from the population, and the remaining solutions that cannot be defeated are added to the third facade. Continuing in this way, the other surfaces are formed.

1.2.2. Crowding distance

In some cases, the order may not be decisive in deciding between solutions. Figure 4 shows that solutions 1, 2, and 3 are in the first front and cannot be selected because they have the same rank. After the non-dominated ranking is completed, the crowd distance is assigned. Crowding distance measures how close an individual is to its neighbors. For the crowd distance calculation, the solutions are on the same optimal surface (Kocatürk & Altunkaynak, 2019).

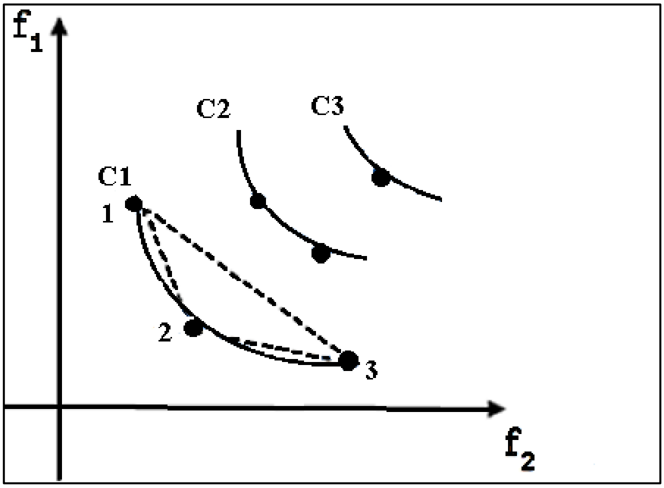

Figure 4: Selection between the same row

Points 1 and 2, 2 and 3 are less distant than points 1 and 3. Point 2 is eliminated as it has a low impact on the overlap, while solutions 1 and 3 remain on the front.

Using the crowd distance operator is important to ensure spread and diversity in the Pareto solution. The main objective is to measure the Euclidean distance between the function values of the solutions on a given dominant surface. Individuals with larger Euclidean distances, i.e., individuals less similar to each other, result in more diverse individuals (Figure 5). The crowding distance algorithm is given in Table 1.

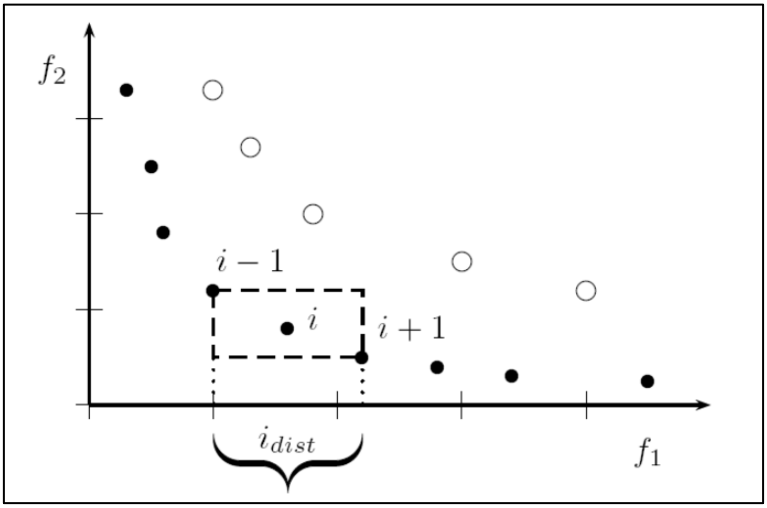

Figure 5: Illustration of crowd distance assessment (Nedjah & Mourelle, 2015)

Table 1: Crowding distance algorithm

$l = \|I\|$	Number of solutions in *I*
For each *i*	
$I[i]_{distance} = 0$	The initial distance is taken as zero
For each m	
$I = sort(I, \mathrm{m})$	$i.$ elements on the surface are sorted
$I[i]_{distance} = I[\mathrm{l}]_{distance} = \infty$	i boundary value elements on surface i are assigned infinite distance
i=2 *i*=($l-1$)	For all other points, the distance is calculated
$\frac{I[i+1].m - I[i-1].m}{f_m^{max} - f_m^{min}}$	

1.2.4. Crowded-Comparison Operator

In crowded tournament selection, as many solutions are selected as the size of the match pool. Parents, order of dominance (r_i) and crowd distance (d_i) from the population using binary tournament selection (Türkşen, 2011).

If $r_i < r_j$ or $r_i = r_j$ & $d_i > d_j$, solution i is preferred over solution j.

The tournament process continues until the initial population size is complete.

After the dominant ranking operations are performed, crossover and mutation operators, which are among the steps of the genetic algorithm, are used to increase the success of the algorithm in the evolutionary process, to preserve the diversity in the solution space and to avoid local minima.

1.2.5. Crossover operator

Crossover is a genetic operator that exchanges genes between parents to produce two new chromosomes, taking the best traits from each of them. This process takes place during evolution according to a user-definable cross probability.

In most of the crossover operators in the literature, the codes of two randomly selected elements are cut and split, and two new individuals are created by swapping the codes (Yang, 2010: 175).

The new individuals produced by crossover from the parents are expected to be better, but if they are worse than the parents, they will be eliminated in other steps of the genetic algorithm. If the codes of the parents are very similar, the individuals produced after the crossover process will be very similar to each other, in such a case the diversity in the population will decrease. Crossing parents whose binary codes are different from each other will increase diversity and better results are expected (Ergül, 2010).

1.2.6. Mutation operator

Since there are multiple local minima in many optimization problems, it is likely that individuals with the genetic algorithm will quickly converge to a point of the objective function and take one of the local minima as a solution. But in such a case, it is a problem that it cannot reach the general solution. The way to eliminate the rapid convergence to local minima is to obtain new solutions through mutation in the solution space, that is, chromosome changes.

Mutation is defined as a hereditary change that occurs when one or more gene values in a chromosome are altered from their initial state. Through this process, a better solution may be found by incorporating the new gene value into the gene pool. Mutation plays a crucial role in genetic algorithms, as it helps prevent the population from becoming trapped in local optima.

The sequences to be mutated in the chromosomes are randomly selected and the change is made according to the mutation method. Mutation involves flipping the value of the bit to be mutated in binary chromosomes. Mutation is performed by replacing someone's values in individuals with zero or zero values with one (Yang, 2010: 176). In real-valued chromosomes, mutation is performed by subtracting or adding a small number of randomly selected values.

In the dominant sequential genetic algorithm, after crossover and mutation, the objective functions are recalculated, and then the parent and child individuals are combined. Fast non-dominated sorting is applied to the combined population. The crowding distance and termination criterion are evaluated by generating a new population. If the condition is met, the algorithm terminates; otherwise, the selection process is resumed.

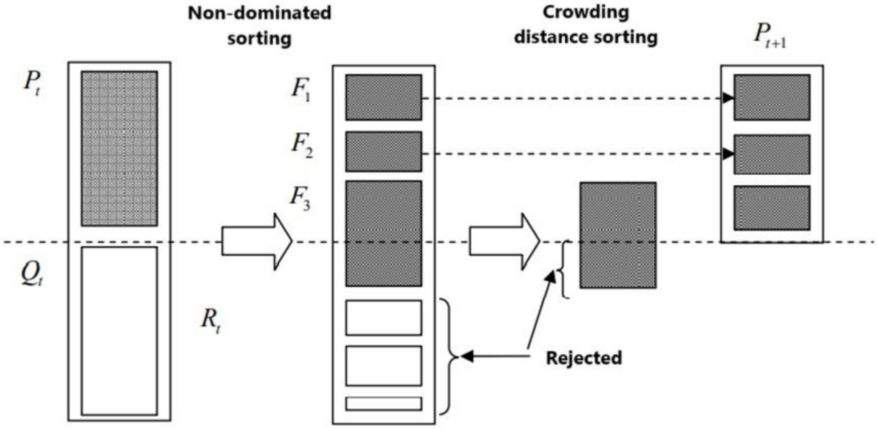

Figure 6: NSGA II flow diagram (Deb, 2001: 234, Türkşen, 2011)

NSGA-II starts with an initial population P_1 of N solutions. Elitism proceeds differently from other iterations, as it compares the dominant solutions of the previous population. By applying genetic operators (crossover and mutation) to the initial population Q_1 population is created. Then P_1 and Q_1 populations are merged to obtain a 2N-dimensional population R_1. In the R_1 population, solutions are sorted according to their dominance, and all solutions are grouped by obtaining F_i surfaces. The first surface (F_1) solutions are the best dominant solution set and have more importance than the other solutions. For the t^th^ iteration in the algorithm, $R_t = P_t \cup Q_t$ After the combined population is created, the set R_t is sorted according to the dominance criterion and the fronts are created. Since there should be N solutions in the P_{t+1} population, we start with the solutions in the first front (F_1), and if the number of elements in F_1 is less than N, we move to the second front (F_2). Until N solutions are found, they are selected from the other dominant facades according to their priorities in the ranking. If the last solution is more than N solutions with the number of elements of the received front, the required solutions are taken with the crowd distance operator. First, solutions with large distance values are selected. Crossover and mutation operators are applied to the resulting population P_{t+1} and Q_{t+1} population is created. The algorithm continues to run until the stopping criterion is met (Deb, 2002).

CONCLUSION

The exploration of Multi-Objective Optimization (MOO) highlights its critical role in addressing complex real-world problems characterized by conflicting objectives. NSGA-II, a widely recognized evolutionary algorithm, emerges as a robust tool for efficiently identifying Pareto-optimal solutions. Its key components, including fast non-dominated sorting, crowding distance assignment, and elitism, enable it to maintain diversity, enhance solution quality, and overcome the limitations of earlier methods. The algorithm's adaptability across diverse domains—from engineering to economics—demonstrates its versatility and effectiveness in solving both theoretical and practical optimization challenges. By balancing trade-offs among multiple objectives, NSGA-II provides decision-makers with a spectrum of optimal solutions, ensuring informed and strategic outcomes.

Future advancements in NSGA-II and related MOO techniques are anticipated to further refine computational efficiency and solution precision, paving the way for broader applications in increasingly complex systems.

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CHAPTER 4

DETERMINATION OF SULEYMAN DEMIREL UNIVERSITY STUDENTS' LEVEL OF SOCIAL ACCEPTANCE OF RENEWABLE ENERGY RESOURCES USE AND IINVESTMENT

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DOI: https://dx.doi.org/10.5281/zenodo.14425753

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INTRODUCTION

Energy has been a fundamental aspect of human existence, fulfilling a crucial role in all aspects of life and representing one of the most basic needs of humanity. In the contemporary era, energy assumed a pivotal role in both individual consumption and national development, as well as economic growth. Energy consumption is a significant indicator of a country's level of development. It is on the rise with the advent of industrialization and technological advancement. This increasing need has given rise to the imperative of identifying more modern and sustainable energy resources. Historically, energy demand has been met primarily from easily accessible fossil fuels, namely natural gas, coal, and oil (Çukurçayır and Sağır, 2008). However, these resources present a significant risk to a sustainable future, given their adverse impact on the environment.

The utilization of renewable energy sources has gained prominence as an environmentally benign and sustainable alternative to fossil fuels. Among these energy sources, geothermal, solar, and hydroelectric energy stand out for their capacity to replenish themselves and their lack of detrimental impact on the natural environment (Camagni et al., 1998, Çolak et al., 2008). Furthermore, alternative sources that have yet to achieve widespread adoption, such as wave, tidal, and current energy, and hydrogen energy, also hold significant promise for the future (Koçaslan 2014, Öymen, 2020).

The utilization of fossil fuels results in the accumulation of carbon emissions within the atmosphere, which in turn accelerates global warming. Consequently, adverse effects such as glacial melting, damage to ecosystems, and a reduction in biodiversity have been observed. The utilization of renewable energy sources is of paramount importance in the mitigation of these environmental damages. These resources, which result in fewer carbon emissions and are not finite, provide a solution for sustainable development (Şenpınar and Gençoğlu, 2006).

The transition to renewable energy sources entails not only environmental benefits but also social and economic dynamics. The adoption and support of such projects by the local community represent a critical factor in the success of renewable energy investments. It is therefore of great importance to understand the social acceptance process and the factors affecting this process (Wüstenhagen et al., 2007). In regions where renewable energy plants are established, the participation and information of the public in the projects increases the success of these projects (Kılıç, Yılmaz and Sarı, 2017).

Turkey has the potential to utilize more domestic and renewable energy resources to meet its energy needs. However, in order to realize a sustainable energy policy, it is necessary to manage these resources effectively and raise social awareness. The concept of sustainability aims to ensure the transfer of existing resources to future generations and forms the basis of energy policies (Kaya, 2018, Çorakbaş and Çeken, 2021). However, the number of studies on renewable energy resources in Turkey has increased considerably in recent years. The study conducted by Karatepe et al. (2012) aiming to determine the level of awareness of university students in Turkey regarding renewable energy sources was carried out with the participation of 112 volunteer students studying at the Faculty of Technical Education, Department of Electricity in Marmara, Afyon Kocatepe and Düzce Universities. In the content of the study, a 5-point Likert scale was developed with questions about the demographic characteristics of the students and questions about renewable energy education, renewable energy potential in Turkey, and how this potential is used. As a result of the study, it was determined that the awareness level of the students was high, but the students did not have sufficient knowledge about the law on renewable energy resources and renewable energy technologies.

In the study conducted by İpekoğlu, Üçgül, and Yakut (2014), a measurement tool comprising 25 items was employed to ascertain the perception of renewable energy resources among university students. The items were found to comprise three subscales: the renewable energy knowledge scale, the future predictions scale on energy, and the renewable energy future orientations scale. The study was conducted on 85 students enrolled at Suleyman Demirel, Akdeniz, Afyon Kocatepe and Pamukkale Universities. The reliability and validity of the measurement tool developed in line with these studies were evaluated in accordance with quantitative data collection techniques. It was determined that the tool was reliable and valid for evaluating the perception of renewable energy.

It is therefore imperative that the transition to renewable energy is accelerated, both to address environmental concerns and to guarantee the security of the energy supply. This study seeks to make a contribution to the existing literature on this topic by examining the awareness levels of students at Suleyman Demirel University with regard to renewable energy and the level of social acceptance of these resources.

1. MATERIAL AND METHOD

This research project aims to examine the measures and attitudes of students at Suleyman Demirel University towards the use of renewable energy sources and investments against global warming, with a particular focus on reducing them to a more specific level. Concurrently, the efficacy of the strategies and action plans devised by local governments for the purpose of adapting to evolving climate conditions was evaluated. The objective of the study was to ascertain the level of awareness by examining student perspectives on renewable energy sources. The objective of the study was to ascertain the level of awareness by examining the perspectives of students on renewable energy sources. The research was conducted through the collection of data from 381 students currently enrolled at Suleyman Demirel University during the 2023-2024 academic year. The sample size was determined through a power analysis, with a 95% confidence level and a 5% margin of error (p=0.05). The questionnaire comprises two principal sections. The first section addresses demographic information, including questions on the characteristics of the participants, such as gender, age, class and faculty. The second section is a scale measuring attitudes towards the use and investment of renewable energy resources, comprising a total of 30 questions. In addition, factor analysis was carried out at this stage of the study and it was concluded that the questions were grouped under four main factors. Scale of community acceptance levels regarding the use and investment of renewable energy resources for these questions:

1. **Concept Knowledge:** It measures the participants' knowledge levels about basic environmental concepts such as global warming, sustainability and greenhouse gas emissions.
2. **Knowledge of Climate Change:** Evaluates participants' awareness and knowledge levels about climate change and global warming.
3. **Knowledge of Renewable Energy:** Measures participants' level of knowledge about renewable energy resources and their attitudes towards these resources.
4. **Other Opinions of the Participant:** Evaluates the general thoughts of the participants about renewable energy and climate change and the policies they support.

The survey data were evaluated using factor analysis, t-test and one-way analysis of variance (ANOVA) methods. In addition, the main hypotheses of the study are stated.

H_1: There is a statistically significant difference between the male and female groups with regard to their awareness of renewable energy sources.
H_2: There is a statistically significant difference between age groups in the awareness of renewable energy sources in at least one group.
H_3: There is a statistically significant difference between class levels in terms of awareness of renewable energy sources in at least one group.
H_4: There is a statistically significant difference between Faculty in terms of awareness of renewable energy sources in at least one group.

The factor analysis yielded the grouping of 30 questions under four main factors. These factors were identified as 'concept knowledge', 'climate change knowledge', 'renewable energy knowledge' and 'other thoughts of the participant'.

2. RESULTS AND DISCUSSION

2.1. Analysis of the Scale of Public Acceptance Levels Related to the Use and Investment of Renewable Energy Resources at the Level of Gender Groups

Table 1 provides a detailed account of the results of the analyses carried out to examine the impact of the gender variable on the elements of the awareness of renewable energy sources. A t-test was employed to ascertain whether there is a notable discrepancy between the relationship between the concept knowledge, climate change renewable energy, and opinions of the participant other aspects of renewable energy and other as perceived by male and female groups, in accordance with the factors of awareness.

Table 1. T-test Results for Gender Variable

Variable	Factors	Group	n	$\bar{x}$	Std.	p-value
Gender	Concept Knowledge	Male	199	10,352	2,3841	0,873
		Female	182	10,313	2,314	
	Knowledge of Climate Change	Male	199	23,407	2,515	0,359
		Female	182	23,153	2,867	
	Knowledge of Renewable Energy	Male	199	68,442	6,599	0,306
		Female	182	69,154	6,942	
	Other Opinions of The Participant	Male	199	16,553	2,157	0,942
		Female	182	16,176	2,162	

*p<0.05

Table 1 indicates that there is no statistically significant difference between the sexes in terms of renewable energy knowledge, as determined by a t-test. The mean score for women was calculated to be 68.44, while the mean score for men was 69.15. In the analysis, the t-statistic value was 0.306, and the p-value was also 0.306. The results demonstrate that there is no statistically significant difference between the sexes with regard to renewable energy knowledge at the 95% confidence level. Furthermore, no significant difference was identified between the sexes with regard to the remaining opinions expressed by the participants. The mean score for women was 16.55, while the mean score for men was 16.18. The t-statistic value was 0.942, and the p-value was 0.942, indicating that there was no significant difference between the two groups at the 95% confidence level. The results of the analysis for both variables (renewable energy knowledge and other considerations) demonstrated that there was no significant difference between men and women. In conclusion, the results of this study indicate that there is no significant effect of gender on concept knowledge, climate change awareness, renewable energy knowledge, and general attitudes. The findings demonstrate that there are no notable differences in knowledge or attitudes between men and women in these four areas. This suggests that gender does not play a significant role in determining knowledge levels or opinions on such environmental and social issues.

2.2. Analysis of the Scale of Public Acceptance Levels Related to the Use and Investment of Renewable Energy Resources at the Level of Age Variable

Table 2 depicts the effect of age categories on the awareness of renewable energy sources. The aim was to determine whether there is a significant difference in the relationship between the factors of awareness variable and renewable energy, as perceived by individuals within the 17-19, 20-22, 23-25, and 26+ age groups. To this end, ANOVA was employed.

Upon analysis of Table 2, the results of the concept knowledge variable are as follows: The mean score for the 17-19 age group was 10.21, with a standard deviation of 2.51. In the 20-22 age group, the mean was found to be 10.27, with a standard deviation of 2.08. In the 23-25 age group, the mean was found to be 10.18, with a standard deviation of 2.58. In the age group comprising individuals aged 26 and above, the mean was 10.84, with a standard deviation of 2.32. The results of the ANOVA test indicated that the p-value was 0.293, suggesting that there was no statistically significant difference between the age groups in terms of concept knowledge. Furthermore, the ANOVA test yielded a p-value of 0.244, indicating that there was no statistically significant difference between the age groups in terms of climate change knowledge. The p-value for the ANOVA test in the analysis of renewable energy knowledge was 0.012, indicating a statistically significant difference between age groups in this domain. Post-hoc Tukey HSD tests revealed that there were significant differences between the 17-19 age group and the 26+ age group, as well as between the 20-22 age group and the 26+ age group. Additionally, the p-value for the remaining opinions of the participants was 0.136, indicating that there was no statistically significant difference between the different age groups in terms of the remaining opinions of the participants.

Table 2. ANOVA Results for Age Variable

Variable	Factors	Group	n	$\overline{x}$	Std.	p-value
Age	Concept Knowledge	17-19	84	10,214	2,508	0,293
		20-22	139	10,273	2,077	
		23-25	94	10,181	2,578	
		26+	64	10,844	2,318	
	Knowledge of Climate Change	17-19	84	23,714	2,758	0,244
		20-22	139	23,000	2,732	
		23-25	94	23,191	2,554	
		26+	64	23,484	2,667	
	Knowledge of Renewable Energy	17-19	84	68,202	7,447	0,012
		20-22	139	67,892	6,163	
		23-25	94	69.021	6,322	
		26+	64	71,125	7,277	
	Other Opinions of The Participant	17-19	84	16,500	2,103	0,136
		20-22	139	16,554	1,982	
		23-25	94	16,074	2,411	
		26+	64	16,250	2,240	

*p<0.05

The results exhibit notable discrepancies between age groups, particularly with regard to renewable energy knowledge. The elevated level of knowledge observed in the group aged 26 and above may be attributed to the fact that this age group possesses greater experience and knowledge. The absence of significant differences in other variables suggests that age groups exhibit comparable levels of knowledge regarding issues such as concept knowledge and climate change knowledge. This may also indicate that educational and informational activities exert similar effects on all age groups.

2.3. Analysis of the Scale of Community Acceptance Levels Related to the Use and Investment of Renewable Energy Resources at Class Level

Table 3 depicts the impact of grade level on the awareness of renewable energy issue. The ANOVA employed to ascertain whether there were notable discrepancies in the relationship between awareness of renewable energy and the factors associated with the preparatory class and 1-4+ groups, stratified by level of grade.

The results of the ANOVA test for the concept knowledge variable, as presented in Table 3, indicate that the p-value is 0.082, suggesting that there is no statistically significant difference between the different grade levels in terms of concept knowledge. With regard to climate change knowledge, the p-value is 0.231, which allows us to conclude that there is no statistically significant difference between the different grade levels in terms of climate change knowledge. The analysis of renewable energy knowledge yielded the following results: The p-value derived from the ANOVA test was 0.155, indicating that there was no statistically significant difference between the grade levels in terms of renewable energy knowledge. Similarly, the p-value derived from the ANOVA test conducted on the other opinions of the participants was 0.292, indicating that there was no statistically significant difference between the grade levels in terms of the other opinions of the participants.

The results exhibit no statistically significant discrepancies between grade levels with respect to concept knowledge, climate change knowledge, renewable energy knowledge, and the participants' other opinions. These findings indicate that there are no notable discrepancies in the knowledge levels of students across different grade levels, suggesting that the educational process exerts a comparable influence on all grade levels. The absence of a significant difference between grade levels, particularly in the context of renewable energy knowledge, may imply that this subject is taught and comprehended in a uniform manner across all grade levels.

Table 3. ANOVA Results for Grade Variable

Variable	Factors	Group		n	$\bar{x}$	Std.	p-value
Level of Grade	Concept Knowledge	Preparatory class		25	10,920	2,100	0,082
		Grade 1		93	10,043	2,386	
		Grade 2		80	10,262	2,344	
		Grade 3		77	9,987	2,185	
		Grade 4		88	10,625	2,579	
		Grade 4+		18	11,389	1,720	
	Knowledge of Climate Change	Preparatory class		25	23,400	3,149	0,231
		Grade 1		93	23,204	2,764	
		Grade 2		80	23,800	2,892	
		Grade 3		77	22,727	2,410	
		Grade 4		88	23,273	2,567	
		Grade 4+		18	23,722	2,164	
	Knowledge of Renewable Energy	Preparatory class		25	68,600	5,759	0,155
		Grade 1		93	68,086	6,810	
		Grade 2		80	68,200	6,928	
		Grade 3		77	68,143	6,435	
		Grade 4		88	70,239	7,181	
		Grade 4+		18	70,833	5,628	
	Other Opinions of The Participant	Preparatory class		25	16,400	2,217	0,292
		Grade 1		93	16,516	2,119	
		Grade 2		80	16,812	1,909	
		Grade 3		77	16,143	2,082	
		Grade 4		88	15,807	2,387	
		Grade 4+		18	17,389	2,004	

*p<0.05

2.4. Faculty Level Analysis of the Community Acceptance Levels Scale Regarding the Use and Investment of Renewable Energy Resources

Table 4. illustrates the impact of faculties on awareness of renewable energy issue, as evidenced by the ANOVA results. The objective was to ascertain whether there is a notable discrepancy in the correlation between awareness of renewable energy and a total of 11 groups with a Faculty of Medicine to the Faculty of Engineering and Natural Sciences.

Table 4. ANOVA results for Faculty variable

Variable	Factor	Group	n	$\bar{x}$	Std.	(p)
Faculty	Concept Knowledge	Faculty of Medicine	32	11,437	1,848	0,000
		Faculty of Dentistry	33	10,636	1,981	
		Faculty of Health Sciences	30	9,600	2,471	
		Faculty of Economics and Administrative Sciences	31	9,323	2,399	
		Faculty of Communication	30	10,200	2,188	
		Law School	32	10,656	2,266	
		Faculty of Architecture	30	11,300	2,480	
		Faculty of Fine Arts	36	9,639	1,838	
		Faculty of Education	33	10,636	2,510	
		Faculty of Humanities and Social Sciences	31	90,161	2,647	
		Faculty of Engineering and Natural Sciences	63	10,714	2,246	
	Knowledge of Climate Change	Faculty of Medicine	32	24,219	2,498	0,211*
		Faculty of Dentistry	33	23,667	2,996	

		Faculty of Health Sciences	30	21,933	3,005	
		Faculty of Economics and Administrative Sciences	31	23,387	2,996	
		Faculty of Communication	30	23,100	2,426	
		Law School	32	22,875	2,379	
		Faculty of Architecture	30	23,400	3,035	
		Faculty of Fine Arts	36	23,306	2,493	
		Faculty of Education	33	23,606	2,668	
		Faculty of Humanities and Social Sciences	31	23,484	2,580	
		Faculty of Engineering and Natural Sciences	33	23,175	2,459	
	Knowledge of Renewable Energy	Faculty of Medicine	32	72,125	5,001	0,039
		Faculty of Dentistry	33	68,030	5,997	
		Faculty of Health Sciences	30	66,300	11,0490	
		Faculty of Economics and Administrative Sciences	31	66,806	7,021	
		Faculty of Communication	30	68,700	5,984	
		Law School	32	69,937	5,946	
		Faculty of Architecture	30	70,100	6,999	
		Faculty of Fine Arts	36	69,889	6,181	
		Faculty of Education	33	68,909	5,293	
		Faculty of Humanities and Social Sciences	31	68,226	5,981	
		Faculty of Engineering and Natural Sciences	33	68,032	6,623	

	Other Opinions of The Participant	Faculty of Economics and Administrative Sciences	32	16,437	1,899	0,458
		Faculty of Communication	33	16,909	1,791	
		Law School	30	16,667	2,040	
		Faculty of Architecture	31	16,484	2,322	
		Faculty of Fine Arts	30	16,100	2,280	
		Faculty of Education	32	16,219	2,338	
		Faculty of Humanities and Social Sciences	30	16,000	2,304	
		Faculty of Engineering and Natural Sciences	36	16,083	2,32225	

*p<0.05

Table 4 reveals that, when the faculties were analyzed according to the concept knowledge variable, the p-value was 0.000 as a result of the ANOVA test. This indicates that there is a statistically significant difference between the faculties in terms of concept knowledge. With regard to the variable of climate change knowledge, the p-value is 0.211, indicating that there is no statistically significant difference between the various faculties with respect to climate change knowledge. The ANOVA results for renewable energy knowledge yielded a p-value of 0.039, indicating a statistically significant difference between the various faculties in terms of their knowledge of renewable energy. An analysis of the participants' other opinions revealed a p-value of 0.458, suggesting that there is no statistically significant difference between the faculties in this regard.

The results yielded statistically significant differences between the various faculties with regard to both concept knowledge and renewable energy knowledge. The results demonstrate that students in the Faculty of Medicine exhibit superior levels of both concept knowledge and renewable energy knowledge compared to students in other faculties. This can be attributed to the fact that students in the Faculty of Medicine undergo a more rigorous and comprehensive educational programmed, resulting in greater exposure to these topics. No significant differences were observed between faculties in terms of climate change knowledge and other opinions expressed by participants. This suggests that these issues are taught and understood in a similar manner across all faculties.

3. CONCLUSION

This study aims to determine the social acceptance levels of Suleyman Demirel University students regarding the use and investments of renewable energy resources. The research results revealed differences in renewable energy awareness and attitudes according to gender, age, class and faculy variables. While there was no significant difference in terms of gender, significant differences were detected between age groups in terms of renewable energy knowledge. The fact that the group aged 30 and above has a higher level of knowledge may be due to the fact that this age group has more experience and knowledge. The lack of significant differences in other variables indicates that there are similar knowledge levels between age groups on topics such as concept knowledge and climate change knowledge.

Analyses between faculties show that there are significant differences in terms of conceptual knowledge and renewable energy knowledge. It has been observed that the conceptual knowledge and renewable energy knowledge levels of Faculty of Medicine students are higher than those of other faculties. This situation can be explained by the fact that Faculty of Medicine students go through a more intense and comprehensive education process and are more exposed to these subjects. There are no significant differences between faculties in terms of climate change knowledge and other opinions of the participants. This shows that these subjects are treated and understood similarly in all faculties. However, apart from this, when an evaluation was made on the basis of all faculties in general, it was concluded that the education and awareness of university students about renewable energy was not sufficient. Accordingly, The findings of the research emphasize that the transition to renewable energy should be accelerated and society should be made aware of this issue. The use of renewable energy resources plays a critical role in solving environmental problems and ensuring energy supply security. In this context, universities need to give more importance to education and awareness activities on renewable energy. For this purpose, universities can develop educational programs to increase such activities, increase the possibility of social participation and cooperation by including student clubs and communities in these activities, and enable raising awareness. Apart from this, universities can cooperate with various external stakeholders and direct students to use these resources through sustainable campus practices. In conclusion, as an important part of this process, universities should raise awareness of their students about renewable energy and raise competent individuals in this field.

ACKNOWLEDGEMENT

In this study, 'chatGPT-4o' programs were used in the literature review section, and 'Google Translate' and 'DeepL Translate' programs were used for translation and grammar editing.

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Publishing House

ISBN: 978-625-378-026-5