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Developing next-generation educational mobile games in light of technological trends: a study on the "Obstacle Run" game

Şeyhmus Aslan, Buğrahan Bilir, Qusai Gazawy

Department of Computer Engineering, Faculty of Engineering, Çankırı Karatekin University, Çankırı, Turkiye

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Corresponding Author: Şeyhmus Aslan, seyhmus.aaslan@gmail.com

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ABSTRACT

The focus of this study is directed towards the examination of the design, development, and analysis of user feedback for the hyper-casual game known as "Obstacle Run," with the aim of enhancing mathematical skills. A comprehensive analysis of the game's design, mechanics, and user experience is conducted. The primary objective of the game is to foster the improvement of mathematical skills in an enjoyable manner and to provide support for the learning process through straightforward game mechanics. An in-game mechanism, requiring players to engage in solving mathematical calculations and problems, is presented by the game titled "Obstacle Run." Increasing the character count within the game is envisioned as a means to bolster mathematical proficiency. This study meticulously focuses on the detailed examination of this unique game, where game design, mechanics, and mathematical calculations come together. Additionally, an exploration of the potential of gamification within game development and education is carried out. The results have been derived from the testing of the game prototype and the subsequent analysis of player feedback. This research is also regarded as a step towards comprehending the connection between hyper-casual games and mathematics education, with the aim of presenting a novel perspective in this domain. It is to be noted that this study is intended to serve as a valuable guide for game developers and educators alike. Its findings are poised to serve as a significant resource for future game projects and strategies in mathematics education. In conclusion, this study provides a summary of a significant endeavor aimed at elucidating the potential of hyper-casual games, such as "Obstacle Run," in facilitating the development of mathematical skills and exploring the possibilities of gamification in the realm of education.

Keywords: Mobile games, C++, unity, mathematics

INTRODUCTION

This research study focuses on the design and development of hyper-casual games. Its primary objective is to examine the game "Obstacle Run," which aims to help players improve their mathematical skills while incorporating simple mechanics. In the game, the goal is to increase the character's count and enhance mathematical abilities. This game presents mathematical calculations and problem-solving skills to players in an enjoyable manner. The article aims to provide a detailed analysis of game design, game mechanics, and mathematical calculations. Additionally, this study explores the potential of gamification in game development and education. The results are based on testing the game prototype and analyzing player feedback. This article is considered an important step in better understanding the connection between hyper-casual games and mathematics education, offering a fresh perspective in this field. It aims to serve as a useful guide for game developers and educators. The findings of this study will be a valuable resource for future game projects and mathematics education strategies.

The aim of this study is to examine the impact of using mathematical operations in the design of my hyper-casual game, "Obstacle Run," and to make a significant contribution in this field. In line with this goal, this game, which aims to provide both an enjoyable and educational experience, enhances players' mathematical skills and equips them with the ability to solve mathematical problems. While highlighting the development and importance of hyper-casual games, we will now take a step further to delve into the evolution of this dynamic game genre in the literature in more detail.

In today's gaming industry, diversity has emerged with the advent of different game genres, and it has drawn attention to a new category of games known as hybrid-casual games.

Hybrid-casual games, based on the studies by Knezovic (2022) and Facebook Gaming (2020, 2022), are simple and intuitive games with hyper-relaxing mechanics. These games focus on mechanics such as rotation, stacking, matching, and timing while also incorporating broader meta-game elements. Meta-game elements aim to enhance participant engagement by combining various elements such as social features, in-game progression mechanics, game narratives, and competitive aspects. Hybrid-casual games offer a more intriguing gaming experience by integrating meta-game elements into the core gameplay of hyper-casual games. This allows players to enjoy both a straightforward and relaxing gaming experience while also taking advantage of the game's deeper features (Pizzo, 2023).

The origins of hyper-casual and hybrid-casual games can be traced back to video game arcades. In the late 1970s and early 1980s, video game arcades became increasingly popular. These arcades, though lacking sophisticated design and gameplay, attracted the interest of teenagers and young adults. During this time, games that competed for high scores became significant. Major video game competitions like Atari's Space Invaders Championship were organized. The emergence of home video game consoles created competition for video game arcades. In particular, the Nintendo Entertainment System (NES) played a pivotal role in popularizing home gaming experiences. With the success of the NES, the video game industry became commercialized and competitive (Scullion, 2019; Wirtz, 2022).

Hybrid-casual games offer a gaming experience by utilizing meta-game elements for long-term engagement. These meta-game elements provide players with both short and long-term goals and objectives, often associated with rankings or high scores (Brandstater, 2021). They incorporate the fundamental elements of competition into these entertainment-focused games. Additional meta-game elements may include character progression, core development, and other in-game progression features, as well as social aspects like group chats, leaderboards, and friendly competitions. Hyper-casual games have quickly become repetitive with low retention rates. While the seven-day average retention rate for mobile games is approximately 20%, it drops to 10% for hyper-casual games (Pangle, 2022). Consequently, game developers are now primarily focusing on hybrid-casual games. Hybrid-casual games bring the retention level on par with other mobile games by encouraging continuous engagement and motivation through meta features and progression elements (Brandstater, 2021; Facebook Gaming, 2022; Pangle 2022).

The "Obstacle Run" game operates within the same framework as a few popular games like "2048," "Threes!," and "Math Riddles." However, there are distinct differences among these games. "2048" and "Threes!" are puzzle games where players aim to combine numbers on the board using their mathematical skills. These games can help enhance mathematical thinking and strategic planning abilities. However, unlike "Obstacle Run," these games do not directly involve solving mathematical problems and do not offer a unique mechanism for increasing numbers. On the other hand, "Math Riddles" is a puzzle game where players progress by solving various mathematical problems. However, this game often provides a static experience and, unlike "Obstacle Run" lacks dynamic gameplay or mechanics involving obstacles (Dorokhine & Bratt, 2022; Pocket Gamer, 2017; Taş & Taş 2021).

While most hyper-casual games are primarily focused on entertainment, "Obstacle Run" also serves as a learning tool. Additionally, the game incorporates mechanics that involve increasing the character's count and encountering obstacles based on mathematical operations. These features enable the game not only to be fun but also to enhance strategic thinking and quick decision-making skills. Detailed information about the game is provided in Chapter 2.

METHODS

If we briefly talk about the game, it revolves around an adventure where a character progresses on a flat surface, encountering doors and obstacles. As the character passes through doors, their number increases, while it decreases when they collide with obstacles. The objective of the game is to pass through as many doors as possible to increase the count and surpass the designated enemy count. If the character's count exceeds the enemy count, the player wins the game; otherwise, they lose.

The Unity game engine introduces essential concepts for developers to use when creating their games. The "Scene Management Hierarchy" allows you to organize and control transitions between game scenes, representing the sections and levels of your game. The "Prefab System" facilitates the easy creation of reusable objects, enhancing project organization and saving time. "Input Management" provides developers with the freedom to determine how in-game controls will function, compatible with both old and new systems. The camera defines how players perceive the game world, significantly influencing the player experience. "MonoBehaviors" components are used to add functionality to objects, enabling objects to listen to, process, and respond to events. Finally, "Basic Methods" are functions used in MonoBehaviors components, allowing objects to become interactive within the game world. Unity streamlines the game development process with these fundamental concepts, as illustrated in Figure 1.

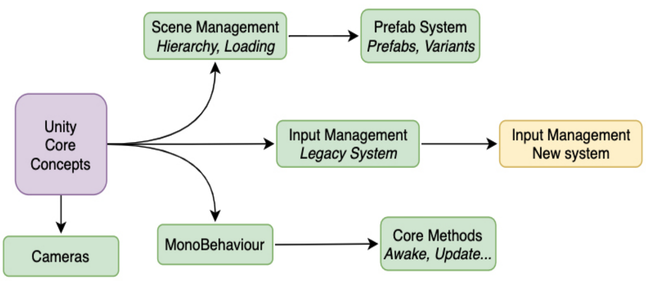

Figure 1. The core concepts of unity

3D Objects

In the game development process, various objects are used that support the game's mechanics and create the game's atmosphere. These objects include elements with which players will interact and which will shape the gaming experience. Figure 2 provides examples of a few objects. These objects serve as the fundamental building blocks of the game and enable players to immerse themselves in the game world.

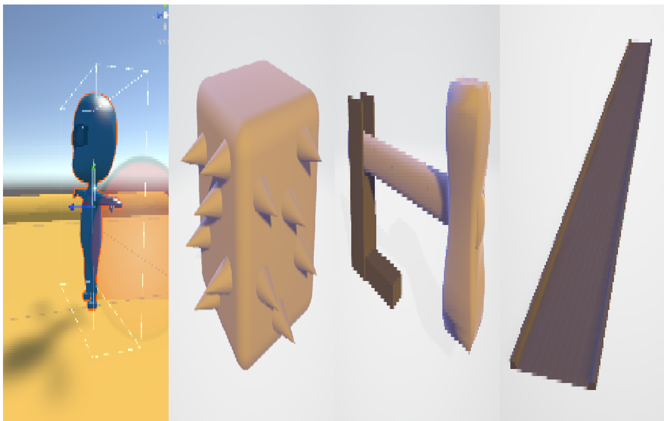

Figure 2. Three-dimensional object.

Game Menu Designs

Menu design is important from the perspectives of user interface and user experience. A game menu enables the user to perform functions such as starting the game, transitioning between levels, adjusting settings, and customization options. In this study, factors to be considered in game menu design and principles of good design have been emphasized. It is important for menu design to be user-friendly, aesthetically appealing, guide the user, and provide easy access to other sections within the game. This study focuses on essential options that should be present in the menu, user interface elements, and visual design elements. Additionally, different types of menus and menu designs suitable for various game genres have been discussed.

Using and Editing Scripts in Unity

Unity provides a user-friendly Editor for arranging and adjusting the properties of objects. Editing objects involves operations like setting their positions, modifying rotations, changing scales, adding and removing components, and more. We can see an edited version of level 1 of the game in Figure 3. Using scripts in Unity, you can control various components and objects in your game. Scripts add flexibility and power to the development process by allowing you to program the functionality and gameplay of your game. In Unity, scripts are created using the C# programming language and are written using integrated development environments like MonoDevelop, Visual Studio, or JetBrains Rider.

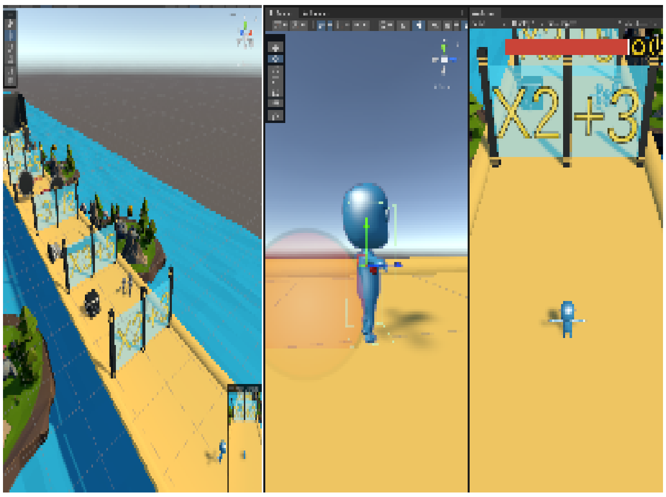

Figure 3. The layout of level 1

Script Files

The script files used in this game project are created using the C# programming language within the development environment provided by the Unity game engine. These script files are designed to control the game's functionality and regulate the behaviors of various objects. For managing a character with alternative costumes or abilities, the Alt_Character script file is utilized, while triggering and managing movements such as walking or jumping animations are handled by the Animatorich script file. Script files like these play a significant role in managing different components and interactions within the game. Each one is designed to control or customize a different aspect of the game. Effective use of these script files can significantly enhance the game's fluidity, realism, and user experience.

RESULTS AND DISCUSSION

Surveys and Reviews

We have a series of questions directed at users of the Obstacle Run game. These questions are designed to gather insights into what users think about the game, how they interact with it, and which features of the game they like or dislike. This information will assist in evaluating the current version of the game and planning for future updates and improvements. Below, you can find details about these feedback questions. Survey questions:

- In your opinion, which age group do you think this game is suitable for? (5 - 8 / 8 - 13 / 13 - 18 / 18+)
- How many hours do you play the Obstacle Run game per day? (0-1 Hour / 1-2 Hours / 2-3 Hours / 3+)
- Please rate the level of enjoyment of the game. (0-Very Bad, 1-Bad, 2-Fair, 3-Good, 4-Very Good)
- Do you think that as you play the Obstacle Run game, you have improved your hand-eye coordination and mathematical problem-solving speed, making it easier to pass levels? (Yes / No)
- Do you believe that your speed in performing mathematical calculations has increased after spending time playing the Obstacle Run game? (Yes / No)
- Do you think that the character, enemy, obstacle, and environmental designs used in the game make it more appealing? (Yes / No)
- In your opinion, was the character optimization in the game at an ideal level? (Yes / No)
- Do you think the instructions provided at the beginning of the game were sufficient for you to be able to play the game? (Yes / No)

The responses given by users to these questions can be seen in Figure 4 and Figure 5. As shown in Figure 4, many users are in the age range of 8-18 and spend their time playing this game for 0 to 2 hours a day. Furthermore, a significant majority of users find the game very enjoyable. When considering these responses, and upon examining the answers in Figure 5, it can be concluded that an educational game can provide support to a user in their education phase, helping them enhance both their mathematical skills and physical abilities. Particularly, as the level of enjoyment in the game, in-game optimization, and the design-theme-graphics coherence increase, users tend to spend more time with the game. This, in turn, can contribute more to the user's education and development. As seen from the answers to the survey questions in Obstacle Run, approximately 80% of users believe that playing this game enhances their ability to perform mathematical calculations and improves their hand-eye coordination, among other physical motor/ reflex movements. They have even mentioned that as they spend more time playing the game, they can tackle more challenging levels proportionally, even when the character speed increases, and obstacles become more difficult in the advanced levels. Especially, since the vast majority of users agree that more challenging levels become easier to overcome, it can be presented as evidence that the game positively contributes to the user in terms of mathematical calculation abilities and personal skills.

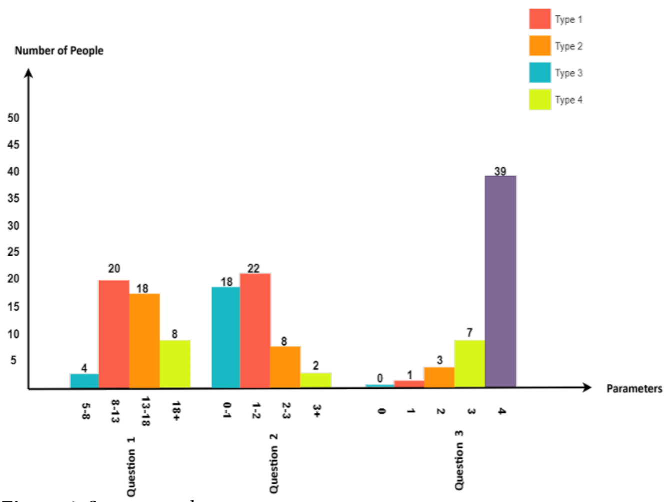

Figure 4. Survey results

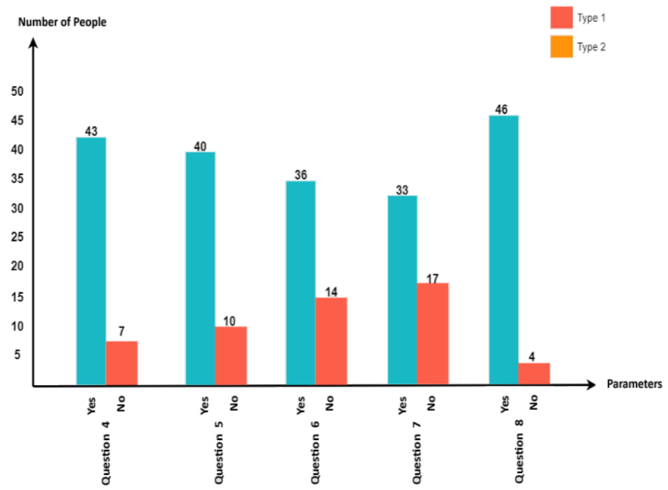

Figure 5. Survey results

In conclusion, approximately 80% of respondents who answered the questions expressed that they enjoy playing Obstacle Run, and they believe the game has contributed to their personal development depending on the variables in the game. This demonstrates that in today's world, games can provide support in education and important aspects such as decision-making skills. Furthermore, by establishing a direct or inverse relationship based on the criteria found in the survey questions, a more optimized game can be designed in each aspect, considering the educational aspect, the time spent by the user playing the game, and the game's likability by the user. This way, especially individuals in the education phase can receive significant support for their education.

CONCLUSION AND FURTHER GUIDELINES

General Conclusion

As a result of this project, it has been observed that a math-focused hyper-casual game can offer a unique experience. The game provides an opportunity for players to improve their mathematical skills while also highlighting their strategic thinking abilities. However, some disadvantages, such as a limited target audience and gameplay diversity, should also be taken into account. The findings from this project demonstrate that mathematical skills can be enhanced through games. It has been proven that the world of gaming is an effective platform for teaching various subjects and developing skills. In this context, it is important to develop and diversify more math-focused games in the future.

Future Work

Within the scope of this study, the focus was on the design, development, and analysis of user feedback for the "Obstacle Run" game. The findings have helped us evaluate the overall success of the game and the user experience. However, since the gaming industry is a rapidly evolving and changing field, there are various opportunities to build upon our current work and make our game more engaging and interactive.

The rapid advancement of technology and the emergence of new and exciting opportunities like VR provide the potential to further expand our game and enhance the user experience. VR offers the potential to provide users with a more immersive and realistic gaming experience, allowing them to interact with the game world in a deeper way. In a platform game like "Obstacle Run," VR technology could offer users a realistic running and obstacle-crossing experience. This could encourage users to engage more with the game and enrich the overall gaming experience.

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Hybrid charging station integration of solar power and IGBT technology for sustainable electric vehicle fast charging

Ferhat Kuzu[1], Atilla Ergüzen[2]

[1] Department of Defense Technologies, Institute of Science, Kırıkkale University, Turkiye
[2] Department of Computer Engineering, Faculty of Engineering, Kırıkkale University, Kırıkkale, Turkiye

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Corresponding Author: Ferhat Kuzu, ferhatkuzu08@gmail.com

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ABSTRACT

Aims: The aim of the study is to design a hybrid charging station that utilizes renewable energy sources, employs energy storage capabilities, incorporates insulated gate bipolar transistor (IGBT) technology, and provides a fast-charging solution. This design is intended to address the energy challenges arising from the widespread adoption of electric vehicles, offering a sustainable solution by harnessing renewable energy and storing it efficiently.

Methods: This study introduces a hybrid-charging station designed to address the charging needs of electric vehicles (EVs) and powered by renewable sources such as solar energy. The station utilizes IGBT technology in its rectifier section. Achieving an impressive 95% energy efficiency in 400 V direct current (DC) fast charging is experimentally validated. The charging process is initiated with energy derived from solar panels and nonstop transitions to battery or pulse width modulation (PWM) rectifier power as needed. The rectifier section employs the Sinusoidal PWM method for sampling a sinusoidal waveform, while pulse width modulation is used for the converter section by calculating the duty cycle.

Results: The hybrid charging station has demonstrated nonstop operation on both the grid and solar energy throughout the tests. The utilization of IGBT technology in the rectifier and converter sections contributes to achieving 400 V DC fast charging with a high energy efficiency rate of 95%. Parameters of the PWM rectifier and DC-DC converter have been simulated using MATLAB that is confirming the station's performance. Practical implementation has shown that values are close to the simulation.

Conclusion: The widespread use of fossil fuel-powered vehicles poses environmental and health risks due to carbon emissions. The increasing popularity of EVs addresses this concern, but challenges arise in charging infrastructure and grid suitability. This study proposes a hybrid charging station using PV modules and a storage unit with a DC-DC converter. Fast-charging capabilities and grid integration are included for non-solar periods. The system offers energy savings, has broad applications, and can operate independently, making it suitable for various scenarios. Future research can explore higher battery capacities, increased charging capabilities, and advanced technologies for optimal energy use.

Keywords: Hybrid charge station, DC and fast charge, renewable energy, photovoltaic (PV) system, PWM rectifier

INTRODUCTION

The innovation in transportation, initiated by the invention of internal combustion and electric motors due to the 19th-century industrial revolutions, is progressively intensifying energy demand. Vehicles commonly used in contemporary transportation with internal combustion engines rely on fossil fuel sources. One of the most significant disadvantages of internal combustion engine technology (Fossil fuels) is CO2 emission. According to a study conducted in the USA, 27% of all emissions originate from transportation (URL-1, 2021). The environmental damages caused by fossil fuels, their adverse effects on human health, and their limited reserves have heightened the societal demand for renewable energy sources as an alternative. Climate change and greenhouse gas emissions are experienced all over the world. The main reason behind them is the energy obtained from fossil fuels instead of renewable energy sources. Therefore, it is necessary to use renewable energy sources more actively (Çetintaş et al., 2017). Energy demand and consumption are increasing day by day, in parallel with population growth. Currently, a significant portion of the energy requirement is met from fossil sources. Fossil resources not only have limited capacity on Earth but also possess a specific reserve lifespan. Moreover, the utilization of fossil fuels is leading to a gradual acceleration of environmental and climatic issues. Individuals have become more conscious of the adverse impacts of fossil fuels on the environment and human health. Consequently, countries have begun to address a portion of their energy needs through renewable energy sources. Some renewable energy sources employed in these efforts include wind, solar, geothermal, hydro, and biomass energy (Gürbüz et al., 2021).

Compared to vehicles using fossil fuels, renewable energy sources are labeled clean energy that does not harm the environment. The increasing awareness of the environmental damage caused by carbon emissions from vehicles using fossil fuels, predominantly those with internal combustion engines, coupled with advancements in battery technologies, is steadily driving interest toward electric vehicles (EVs).

Consequently, EVs, exclusively equipped with electric motors, are becoming more prevalent each day. In line with the increasing use of EVs, energy requirements and charging infrastructure issues are gaining prominence. Research indicates that the energy demand for charging EVs imposes a significant burden on the grid, leading to adverse situations such as the increased use of power plants using fossil fuels to meet the growing demand for electrical energy. As a solution to this issue, gradual improvements should be made to address grid inadequacies and the utilization of renewable energy sources should be progressively increased.

The increase in EVs has triggered a growing demand for efficient and environmentally friendly charging solutions. In response to the need to limit greenhouse gas emissions and advance sustainable energy practices, there is an increasing interest in charging stations powered by renewable energy sources. This study presents an innovative hybrid charging station design that utilizes renewable energy for civilian and military EVs and features a fast-charging capability. The design is monitored in real-time with the assistance of a microcontroller, ensuring the system's shutdown in case of any issues. Additionally, batteries are employed as a storage unit to provide uninterrupted charging solutions. The detailed examination of the technical specifications of this charging station design, along with the utilization of simulation results, aims to realize the implementation of the design. When renewable energy-based hybrid charging stations are academically examined, charging methods, economical solutions, and decision-making mechanisms are categorized into various groups. Some of the studies that were conducted are listed below.

As per the U.S. Department of Energy (USDE), only 15% of the fuel used in internal combustion engine (ICE) cars is utilized for propelling the vehicle. Energy is lost in fossil fuel vehicles because it is dissipated as friction and heat in the moving system. While fossil fuel vehicles often require maintenance, EVs efficiently allocate over 75% of their energy towards propulsion. EVs typically offer an average range of 4 to 8 miles per kilowatt-hour (kWh) (Tie et al., 2013).

As depicted in Figure 1, electric cars are entirely powered by electricity. In contrast, as illustrated in Figure 2, hybrid cars feature two engines: one electric and one internal combustion. Hybrid vehicles utilize electricity for initial acceleration and switch to a fossil fuel source for other driving conditions. However, hybrid vehicles are not environmentally friendly due to their use of fossil fuels.

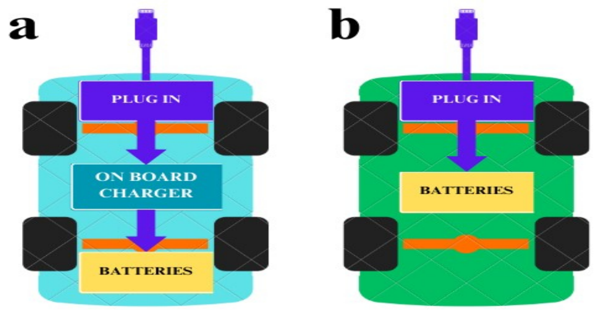

Figure 1. (a) AC charging; (b) DC fast charging

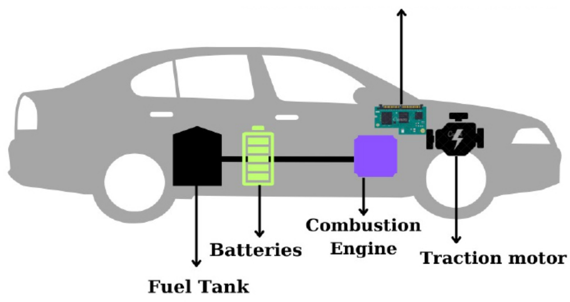

Figure 2. Hybrid car internal structure

Thanks to advances in battery technology, electric cars have now achieved the necessary range for practical use. As technology continues to evolve, these range distances are steadily increasing. In this way, EVs have started to replace hybrid vehicles in the market.

Electric cars do not have an internal combustion engine. For this reason, they do not create CO_2 gas emissions, which are harmful to the environment. It also does not cause noise pollution. It is more economical as it uses electrical energy as fuel. There are both household chargers and stationary charging stations for charging. The performance of EVs is higher than fossil fuel vehicles (Çetintaş et al., 2017).

The most significant disadvantage of electric vehicle (EV) charging due to solar panel (PV) charging is the variability in the desired PV production with intelligent charging. Intelligent charging can provide flexibility in EV chargers (Mouli et al., 2016). There are several methods to increase the driving range of an EV. The first is the battery capacity. The second goal is to reduce charging time to enhance usability. However, the structure limits the infrastructure dedicated to conductivity (where the AC-DC converter is included in the charging station) (Saber et al., 2017). EVs offer three critical capabilities for existing power plants: the ability to adjust charging power, rapid fluctuations in charging power and discharging capability. EV charging typically involves maintaining a constant power flow until the battery reaches total capacity (Mouli et al., 2017).

Standardizing existing charging stations, connection structures, and communication protocols enhances the quality and speed of charging for customers. This development makes the EV system more efficient, contributing to widespread adoption worldwide. Various countries have established international standards to promote charging station development and broader use (Sutopo et al., 2018). Table 1 illustrates the EV standards of some countries.

Table 1. EV standards by country (Ng et al., 2011)

EV	Country
Society of Automotive Engineers (SAE)	USA
International Electrotechnical Commission (IEC)	Europe
Japanese Electrotechnical Committee (JEC)	Japan
China Electricity Council (CEC)	China

IEC 62196 is used as the standard in EV charging stations. Charging voltages are divided into alternative current (AC) and DC. It has been observed that the electric car charge voltages are examined at three different levels. It is the charging process with a standard socket without any safety precautions. There are three levels: level 1, 120 VAC charging method; level 2, 208-240 VAC charging method; and level 3, 208-850 VDC, respectively, fast charging method is applied. (Angelov et al., 2018). Charging is carried out with a single-phase/three-phase mains and grounding line. AC power supply line should be at most 32A, 250V AC (single phase), or 480VAC (Dericioglu et al., 2018). In the fast charge method, a charge rate of up to 70% in the vehicle battery can be reached with a 30-minute charge. In this method, the EV is connected to the AC mains supply by using a unique battery control system to control the devices in the battery system (IEC et al., 2010).

The design incorporates insulated gate bipolar transistor (IGBT) technology, providing advantages and disadvantages. The utilization of IGBT is evident in both the rectifier section and the DC-DC converter section, which features maximum power point tracking (MPPT) functionality. IGBT rectifier is a pulse width modulation (PWM) rectifier constructed using IGBTs (Gelman et al., 2014). A PWM rectifier offers the following advantages: adjustable DC voltage, energy recovery, power factor correction, and low harmonics (Hans et al., 1980). Rectifier switching activities initially employed silicon-controlled rectifiers (SCRs), followed by the adoption of gate turn-off thyristors (GTOs), and subsequently integrated with IGBTs. Significantly, advancements in IGBT technology have been made today, establishing it as a preferred device in converters covering the DC connection voltage range crucial for traction rectifiers (700 to 1500 VDC) (H. G. Eckel et al., 2005).

What distinguishes this study from other works is its capability to provide charging solutions for both military and civilian vehicles. The design's adaptability to challenging terrain conditions, flexibility, portability, and remote controllability signify compliance with military standards. The remote controllability feature allows intervention in emergencies. Additionally, the design aims to minimize waiting times in military settings through its fast-charging capability. EVs also create an advantage in military applications, but high reliability is required. Another advantage of this design is its ability to operate silently, providing a strategic benefit (Khalil et al., 2009).

In the study by Liu and Makaran, they designed a battery charger powered by solar energy, a renewable energy source. DC/DC converter was used in the design. This study was designed mainly for small vehicles. This study encompasses a hybrid charging station powered by renewable energy sources, particularly solar energy. The hybrid charging station also functions as a fast-charging station, constituting the amalgamation of two systems. The first system involves an IGBT rectifier, while the second incorporates an MPPT-enabled DC-DC converterC-DC topologies are utilized in this system. The AC obtained from the grid is converted to direct current (DC) through the IGBT rectifier. Simultaneously, the DC from the MPPT system is combined with the rectifier output, resulting in the collaborative operation of the two systems. This feature allows for installation in any desired location without the necessity of grid power. The presence of grid energy at the installation site is optional.

METHODS

Renewable Energy

The energy demand, initiated with the Industrial Revolution, has brought about specific challenges due to the use of fossil fuels and the impact of a growing population. The production of most goods and associated logistical activities heavily relies on fossil fuel resources, leading to environmental problems and hazardous carbon emissions affecting the atmosphere. As alternatives to these issues, environmentally friendly and clean energy sources, known as renewable energy sources, have gained increasing significance (Öymen et al., 2020). Geothermal, hydroelectric, solar, biomass, and wave energy are examples of renewable energy sources. These sources are becoming more crucial as countries invest more in their utilization due to their inexhaustible nature (Bekar et al., 2020).

Solar energy, one of the renewable energy sources, is utilized not only for heating, cooling, and obtaining hot water but also for electricity generation. The most common method of electricity production from solar energy involves photovoltaic applications using solar cells. To harness energy from solar radiation effectively, it is ideal to be located between latitudes of 45° north and south (Karamanav et al., 2007). Turkiye, geographically situated between 36-42° north latitudes, enjoys an advantageous position for solar energy compared to many other countries. According to the Turkiye Solar Energy Potential Atlas (GEPA), created to maximize the utilization of solar energy and assess its potential in electricity generation, Turkiye has an annual average of 2741 hours of sunlight and a total energy amount of 1527 kWh/m² per year (Arca et al., 2022). Figure 3 provides Turkiye's monthly solar radiation values.

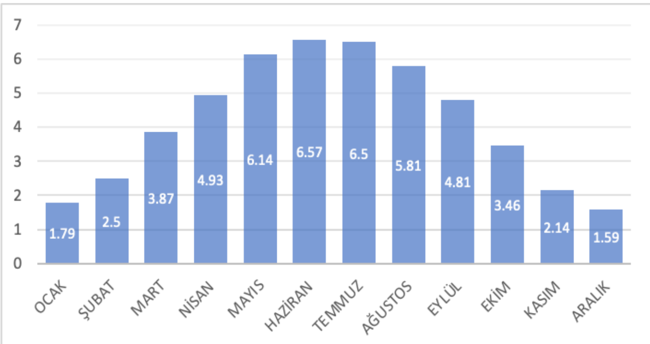

Figure 3. The solar radiation values for Turkiye by month (kWh/m²) (URL-2, 2022)

Electrical Equivalent Circuit Model of Solar Cells

The similarity of solar cells to diode structures can be referred to as photodiodes due to their resemblance to diode currents, according to Equation 1. For the electrical equivalent circuit of a solar cell, a single-diode electrical circuit model is preferred for its simplicity and reliability (Karabaş et al., 2019). This choice is due to the complexity of the dual-diode structure and the lack of a significant difference in the modeling stage (King et al., 2004). Figure 4 illustrates the single-diode equivalent circuit for a solar cell.

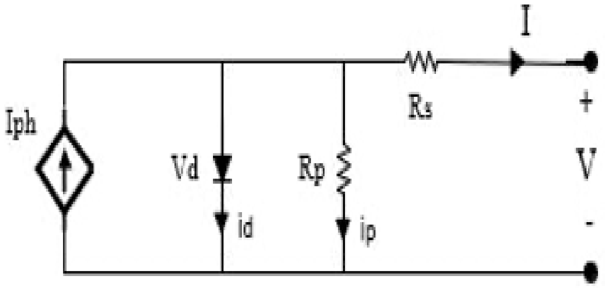

Figure 4. Monocrystalline solar cell electrical equivalent circuit

In the figure's equivalent circuit of the solar cell, Iph represents the solar energy photon current, Vd the diode, Rp the parallel resistance, and Rs the series resistance. Since Rp and Rs introduce conduction losses, they negatively impact the cell efficiency. Rp is the resistance that reflects defects due to the crystal structure of the cell, while Rs represents the internal resistance of the solar cell. The series-connected Rs resistance affects the short-circuit current, while the parallel-connected Rp resistance influences the open-circuit voltage (Ozcalik et al., 2013). I and V indicate the current and voltage of the solar cell. The adapted Iph current equation, according to Figure 4, is provided below when a load is connected to the solar cell contacts. The I current is the generated current of the solar cell. The formulas containing calculations for the solar cell are specified in Equations (1), (2), (3), (4), and (5).

$$I = Iph - id - ip \tag{1}$$

$$id = I_0\left(e^{\frac{qV_D}{mkT}} - 1\right) = I_0\left(e^{\frac{q(V_{pv}+I.Rs)}{mkT}} - 1\right) \tag{2}$$

$$ip = \frac{V_D}{R_p} = \frac{(V_{pv}+I.R_s)}{R_p} \tag{3}$$

$$I = Iph - I_0\left(e^{\frac{q(V_{pv}+I.Rs)}{mkT}} - 1\right) - \frac{(V_{pv}+I.R_s)}{R_p} \tag{4}$$

$$I = Iph.(1 + C_0(T - 300)) - I_0\left(e^{\frac{q(V_{pv}+I.Rs)}{mkT}} - 1\right) - \frac{(V_{pv}+I.R_s)}{R_p} \tag{5}$$

In the given equations, I represents the output current, I0 is the diode saturation current, q denotes the elementary charge of an electron (1.602×10^(-19) C), K is the Boltzmann constant ($1.381\times10^{(-23)}$ J/K), and T represents the temperature in Kelvin (Bayrak et al., 2012).

Three-Phase PWM Rectifier

A three-phase DGM rectifier is an electronic circuit utilized for converting alternating current to DC through PWM. Its operational principle involves managing current control and voltage transformation by controlling the conduction and cutoff states of three groups of semiconductor switches, similar in structure to the three groups of diodes in a bridge rectifier. The DGM controller adjusts the conduction time of each switch based on the magnitude and phase angle of the input voltage. The longer the conduction time of the switch, the higher the output voltage, and vice versa. Upon adjustment of the conduction time, the average voltage across the switch reaches the desired value throughout the entire cycle. Adding a capacitor to the output minimizes voltage fluctuations (Zhou, 2023).

IGBT rectifiers are devices that drive the applied alternating current to convert it into the desired DC through PWM technique. In previous applications, rectifiers developed using thyristors had lower efficiency, lower power factors, insufficient switching frequencies, and higher harmonic distortions, making using IGBT rectifiers more advantageous. IGBT rectifiers have been employed in the design of the charging station, aiming for high efficiency and a higher power factor. An IGBT rectifier consists of four elements: a transformer, a semiconductor switch IGBT, a capacitor, and an inductor.

In the circuit depicted in Figure 5, Vin represents the input voltage, Q1, Q2, Q3, Q4, Q5, and Q6 denote the IGBT semiconductor switching elements, L represents the inductance, C represents the capacitor, R represents the load resistance, Io represents the output current, and Vo represents the output voltage. The IGBTs are switched to adjust the desired DC at the system's output.

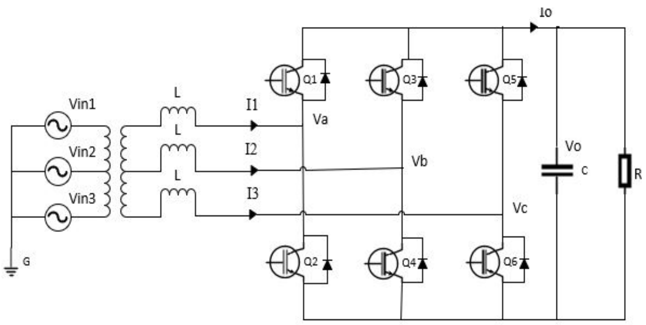

Figure 5. Three-phase PWM rectifier topology

The control method for the three-phase PWM rectifier is provided in Figure 6. The Proportional-Integral (PI) control method adjusts the gain by comparing the externally provided reference DC information with the output DC information, allowing the desired DC to be set at the output. The Control Unit transmits the error value obtained by comparing the rectifier output voltage with the reference input voltage generated using a sine wave table, along with the DC voltage value and the "Modulation Index" value, which will be obtained using the "Duty Cycle" value. Multiple methods are used for switching semiconductors IGBTs in PWM rectifiers. Some of these methods are as follows.

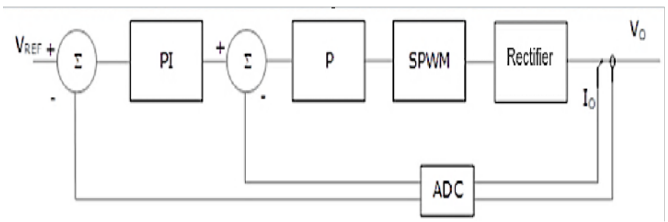

Figure 6. The control method of the PWM rectifier

Hysteresis current control (HCCPWM): The hysteresis current-controlled PWM method is one of the preferred control methods due to its direct control of current, simplicity, and short dynamic response time. This control method calculated the error ratio between the actual current and the reference current generated by the control algorithm. Semiconductor devices remain in conduction within the specified maximum and minimum limits for the calculated error value, allowing the current to flow. When the current error value reaches certain limits, signals that decrease or increase the current value are sent to the switching element. Figure 7 illustrates the current error and PWM signal.

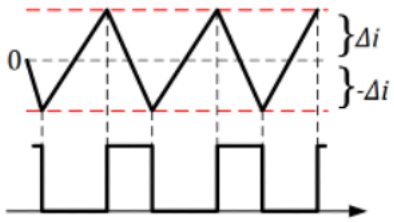

Figure 7. Current error in hysteresis current control

A PI controller is employed as the system control algorithm. The voltage error information from the DC output is controlled through the PI controller, determining the magnitude of the current coming from the grid. The voltage measured from the grid allows the determination of the grid angle through the phase-locked loop (PLL). Additionally, it ensures the creation of a synchronous current reference with the grid. The grid current is subtracted from the reference current for the current error. This error value determines the switching states (Evren et al., 2021).

Space vector pulse width modulation (SVPWM): Another technique used in the semiconductor switching of power electronic devices in industrial applications is the SVPWM technique. This technique offers advantages such as a constant output voltage and a high power factor with fewer harmonics in the output voltage. Unlike other techniques, SVPWM utilizes a reference vector. In operating a three-phase system, the SVPWM for SVPWM, similar to the structure in Figure 5, has eight conduction states for three of the six switching elements for the upper switches. The lower switches operate inversely to the upper switches.

In Figure 8, the vector representation for the eight possible switching states of the rectifier is provided. The reference vector is determined in the region where the calculation result falls and is closest to three neighboring vectors (Yüksek et al., 2019).

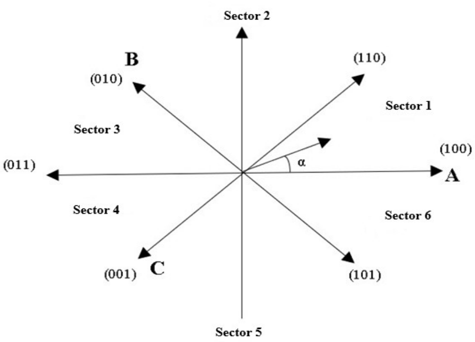

Figure 8. Voltage vector parts of a space vector according to the network

Sinusoidal pulse width modulation (SPWM): The SPWM technique is the industry's most widely used switching technique compared to the other two techniques. This technique is based on a carrier-based modulation technique. In this technique, the angle of the obtained reference current is phase-shifted by the angle between the desired voltages. This waveform is compared with a high-frequency carrier triangular wave to generate the necessary PWM pulses for switching. Instead of keeping the width of all pulses constant in this modulation technique, it is varied proportionally to the amplitude of a sinusoidal wave considered as the center of each pulse. At the same time, distortion factor and low-order harmonics are significantly reduced with this method. According to literature studies, the SPWM signal exhibits better performance than other PWM signals, as it has fully open and closed states of the switching element despite having an equal switching frequency to the carrier wave. The efficiency of the rectifier is improved through the control method based on the comparison made with the SPWM method. Other advantages of this method include decreasing the Total Harmonic Distortion (THD) of the output current and voltage. Figure 9 illustrates the generation of the required PWM signal with a triangular carrier wave.

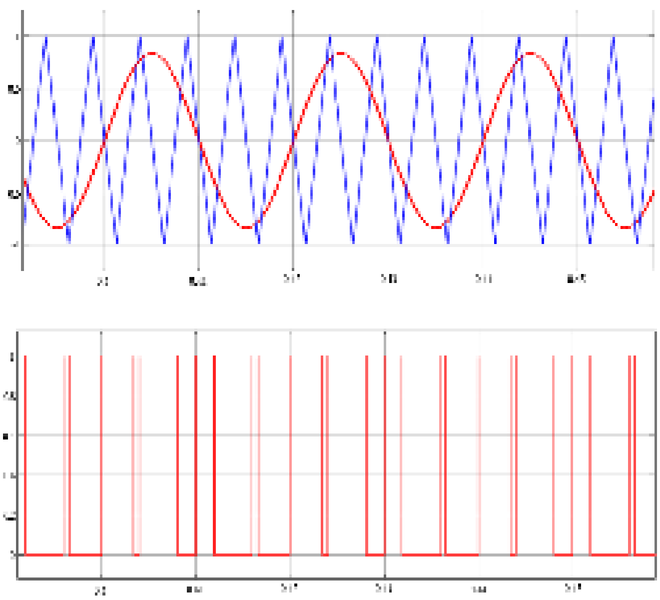

Figure 9. PWM signal compare of one phase for three phase rectifier

In this study, the SPWM method has been employed as the switching control method for the rectifier. Information regarding the simulation and implementation conducted using this method is provided in the Results section. The required PWM signal is generated by comparing the low-frequency sine wave with the high-frequency (10-20 kHz) carrier triangular signal. When the carrier triangular signal is smaller than the sine wave, the output voltage, Vout, equals Vdc. Otherwise, the output voltage is equal to -Vdc. This calculation is shown in Equation 6.

$$I = \begin{cases} +V_{DC}, V_{reference} > V_{carrier} \\ -V_{DC}, V_{reference} < V_{carrier} \end{cases} \quad (6)$$

The pulse widths of the SPWM waveform are calculated as indicated in Figure 10.

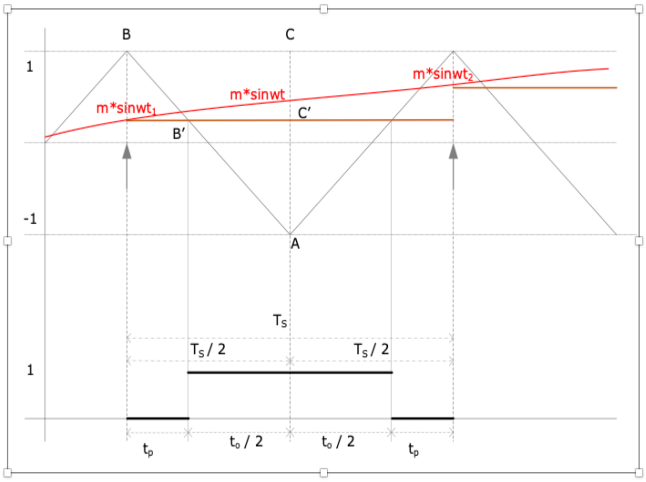

Figure 10. SPWM pulse width calculation method

$$B'C' = (AC' * BC) / AC \quad (7)$$

$$m = VRef / VC \quad (8)$$

$$t0 = Ts/2 * (1 + m * \sin(wt1)) \quad (9)$$

$$w = 2\pi f_{AC} \quad (10)$$

$$tp = Ts/4 * (1 - m * \sin(wt1)) \quad (11)$$

$$Ts = 1/Fs \quad (12)$$

Here, m represents the modulation index, f is the measurement frequency, and Ts denotes the measurement time. Also, sampling has been done for a specific time interval. The calculated values define the time that needs to be applied due to the switching.

Buck-Boost Type DC-DC Converter

Switching DC-DC converters provides a regulated DC output by adjusting the DC input to the desired value using the PWM method. Although this system is quite diverse, it is commonly used in thermal power plants, the iron and steel industry, solar power plants, and many other places. There are three types: step-down, step-up, and both step-down and step-up. Additionally, there is a type with MPPT capability. In the conducted study, two DC-DC converters were used. The first one is a step-down and step-up type DC-DC converter with MPPT capability. The other one is a buck-boost type DC-DC converter without MPPT capability. Generally, these converters consist of a semiconductor device (IGBT, MOSFET, BJT), inductor, diode, and capacitor elements. Figure 11 illustrates the schematic of a step-down and step-up DC-DC converter. In the circuit shown, Vs represents the input voltage, S the semiconductor switching element, D the diode, L the inductor, C the capacitor, R the load resistance, and Vo the output voltage. In a buck-boost circuit, the input voltage can be lower than, higher than, or equal to the output voltage. It is necessary to examine the conduction (S on) and cutoff (S off) states of the S switch in the circuit analysis. In Figure 12, the conduction and cutoff durations are shown, Equation (13) provides the duty cycle calculation, and Equation (14) presents the theoretical output voltage formula for the converter.

$$p = \frac{t_{on}}{t_{on}+t_{off}} = \frac{t_{on}}{Ts} \quad (13)$$

$$V_o = \frac{p}{1-p} * V_s \quad (14)$$

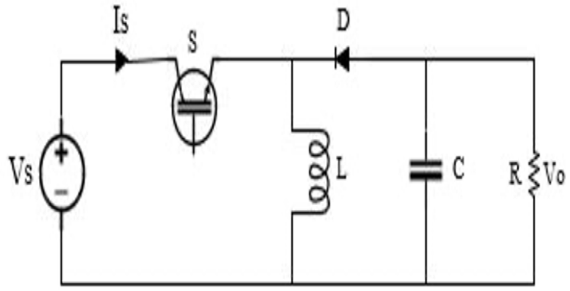

Figure 11. Buck-boost DC-DC converter circuit

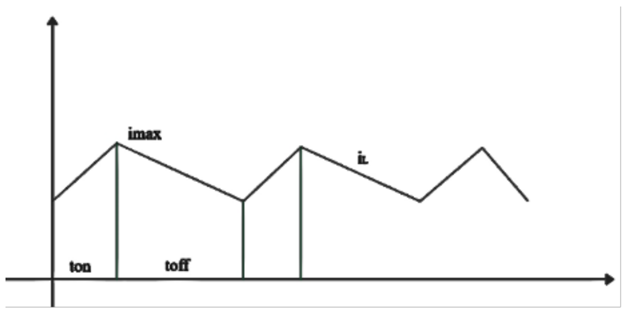

Figure 12. Buck-boost converter duty cycle

Here, p represents the duty cycle, Vo is the output voltage, Vs is the input voltage, t (ton and toff) is the on and off times of the S switch, and Ts is the switching period. The duty cycle, denoted by P, can take values between 0 and 1. Different voltage levels are obtained for different P values. When P < 0.5, it is a step-down type; when P > 0.5, it is a step-up type (Çalışkan et al., 2017). Capacitors and inductors are used to reduce the fluctuations in the converter's output. The inductance value used to minimize the reduction in output current should be adjusted.

The expression describing the inductor current and the voltage across the circuit when the switch is ON is given in Equation (15).

$$\begin{cases} \frac{di_L}{d_t} = \frac{1}{L}(V_s) \\ \frac{dv_0}{d_t} = \frac{1}{C}(-\frac{V_o}{R}) \end{cases} ,0 < t < dT,\ S{:}\,ON \quad (15)$$

The expression describing the inductor current and the voltage across the circuit when the switch is OFF is given in Equation (16).

$$\begin{cases} \frac{di_L}{d_t} = \frac{1}{L}(V_o) \\ \frac{dv_0}{d_t} = \frac{1}{C}(-i_L - \frac{V_o}{R}) \end{cases} ,dT < t < T,\ S{:}\,OFF \quad (16)$$

To achieve the desired output values for a buck-boost type DC-DC converter, the output voltage, capacitor capacitance, and inductor inductance must be adjusted. The circuit's output voltage is given in Equation (17), the value of the inductor to be used is given in Equation (18), and the value of the capacitor to be used is given in Equation (19) (Dogra et al., 2014).

$$V_o = DV_S/(1-D) \quad (17)$$

$$L_o = (1-D)V_o/(\Delta I_{L0})f_s \quad (18)$$

$$C_o = D/\{(Rf_s)(\Delta V_{C0}/V_o)\} \quad (19)$$

System Setup and Operating Structure

Electric vehicle hybrid charging station control system: The structure for the hybrid charging station is provided in Figure 13. The hybrid charging station comprises one rectifier, two buck-boost converters, batteries, and photovoltaic panels. Energy for the EV in the hybrid charging station is supplied in two ways: first, through solar energy, and second, from the grid. The energy obtained from the sun and charging the EV also charges the batteries in the storage unit simultaneously. This way, when there is no charging process, the energy obtained from the sun is preserved. In cases where solar energy is not sufficient for the charging process, the charging process is provided through the batteries, and when both are not sufficient, the charging process is ensured with the DC rectified from the grid through the rectifier.

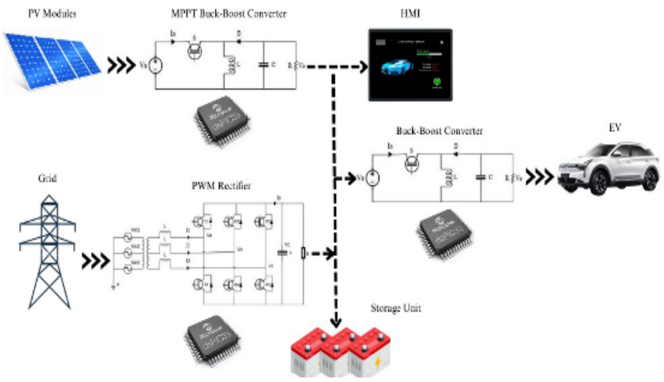

Figure 13. Hybrid charge station topology

These adjustments in the system ensure the maximum use of energy from the sun and are monitored and controlled in real-time through the human machine interface (HMI). A 10.1” TFT All-in-One computer is used as the HMI unit. The PWM rectifier performs the AC-DC conversion, converting 380V AC to 408V DC. The energy obtained from the sun, with the MPPT feature of the buck-boost converter, tracks the maximum power point to produce 408V DC at its output. The second buck-boost converter used in the system provides the DC required for the EV. The system’s output can be adjusted from 0 to 400V DC. Control in the PWM rectifier and DC-DC converters is provided by the dsPic33ep256mc206 microcontroller.

PV modules: The system utilizes 60 monocrystalline solar panels with a power rating of 450W each. Selecting monocrystalline solar panels is attributed to their higher efficiency, longer lifespan, lower thermal losses, and aesthetic appeal. Additionally, the panels are connected in series and parallel configurations, with 10 panels in series and 6 in parallel, producing approximately 460V DC at the output. Considering an output of 10A per panel, it is observed that the system can deliver a total current of 600A. Furthermore, each panel has a power output of 450W, as indicated in Table 2. Cumulatively, the system boasts a total power of 27,000 watts, showcasing its substantial energy capacity. The specific characteristics of the panels are provided in Table 2.

Table 2. The electrical characteristics of the used solar panel in the system

Description	Values
PV panel maximum power (W)	450
Maximum power point current (A)	10.6
Open circuit voltage (V)	46.6
Maximum power point voltage (V)	42.3
Module efficiency (%)	20.3

Storage unit: The storage unit is used to ensure the continuity of the system and to meet the energy needs in cases where solar energy is insufficient. The system uses 30 VRLA (Valve Regulated Lead Acid) batteries. The charging process of the batteries is provided by the energy generated by the PV modules. The Buck-Boost converter uses the energy stored in the batteries to charge the EV in case of need. The technical specifications of the VRLA batteries are given in Table 3.

Table 3. The technical specifications of the VRLA battery used in the system

Description	Values
Nominal voltage	12V
Capacity	100A
Charge current	20A
Nominal charge voltage	13.6V
Boost charge voltage	14.2V

HMI: A typical display unit, the HMI, monitors system measurements and adjusts them within the desired range. The HMI consists of a TFT panel, a processor, and a remote communication module. Through the HMI, the control process is carried out, and the system has the task of turning off the rectifier section based on the solar energy potential and operating the DC-DC converters. The control unit in the system is the HMI. The image belonging to the HMI is presented in Figure 14.

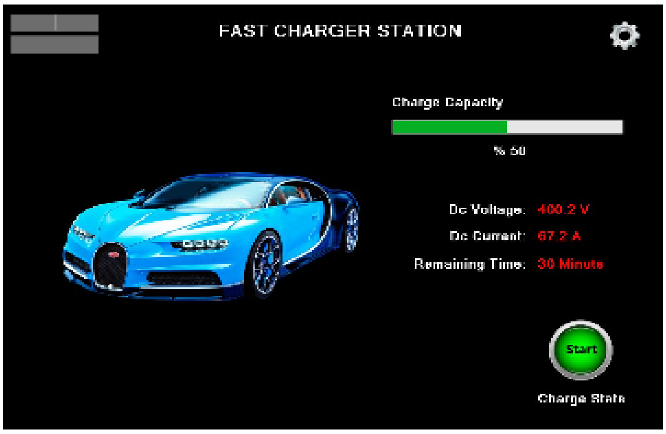

Figure 14. HMI screen of hybrid charge station

Buck-boost type DC-DC converter design: The step-up/step-down type DC-DC converter in the circuit in Figure 15 is used for two purposes. The first converter transforms the 250V to 460V DC from the PV panels into 408V DC required for charging the batteries at the output. This DC-DC converter, unlike the others, has the MPPT feature. This feature is implemented only in software without the need for any hardware changes. With MPPT, the maximum power point of the energy obtained from the sun is determined. The second converter has an input voltage range of 300V to 408V DC, which will not discharge the batteries deeply. It uses the voltage from the batteries and generates 400V DC at the output to charge the EV batteries. The system uses IGBT, coil, diode, and capacitor as switching elements.

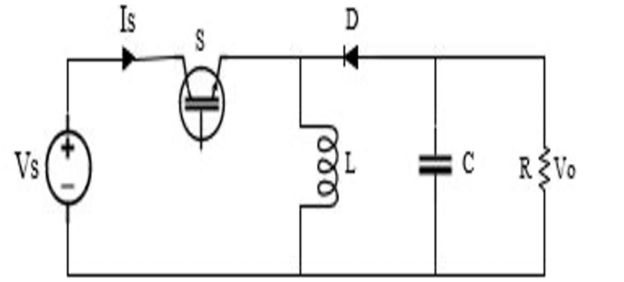

Figure 15. Buck-boost DC-DC converter circuit

If we consider that the PV output voltage is 400V DC, the required duty cycle can be calculated using Equation (14) as follows:

$$V_o = \frac{d}{1-d} * V_{in} \Rightarrow \frac{V_i}{V_o} = \frac{400V}{408V} = 0.98 \Rightarrow d = 0.505 \text{ duty cycle}$$

The duty cycle of the IGBT switch is calculated as 50.5%. The minimum current of the circuit is determined to be 10A. The switching frequency is chosen as 20 kHz. The required inductance value can be calculated using Equation (18) as follows:

$$L_o = (1-D)V_o/(\Delta I_{LO})f_s \Rightarrow (1-0.505) * 408/10 * 20 * 10^3 = 1.01\, mH$$

Here, the calculated value is approximately 1 mH. Assuming a load value of 100 ohms for the system's start and considering a ripple of 100mV in the output voltage, the required capacitor value can be calculated using Equation (19) as follows:

$$C_o = D/\{(Rf_s)(\Delta V_{CO}/V_o)\} = 0.505/\{(100 * 20 * 10^3)(100 * 10^{-3}/408)\} = 1030 \text{ uF}$$

PWM rectifier design: In the circuit shown in Figure 16, the PWM rectifier converts 380V three-phase alternating current from the grid into 408V DC. IGBT is used as the switching element in the circuit. In addition to this, a transformer, inductors, capacitors, and diodes are used as isolation and voltage reduction components. In this case, the storage unit's batteries represent the load resistance.

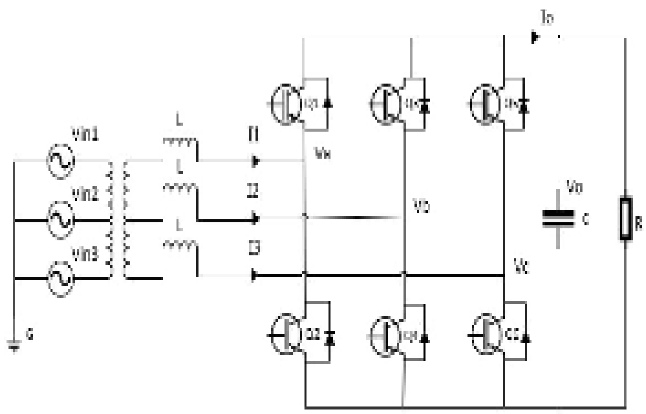

Figure 16. Three-phase PWM rectifier circuit

The role of the rectifier during the system's operation is to become active when the energy obtained from the sun and stored in the batteries is insufficient, thus performing the charging process.

The PWM rectifier has a power factor (PF) exceeding 95%. The current harmonic is below 5%. The switching frequency of the PWM rectifier is 16 kHz. The calculated period for this frequency value is determined using Equation (12) as follows:

Fs = 16 kHz

$$Ts = 1/Fs = 1/(16 * 10^3) = 62.5 \text{ us}$$

RESULTS

PWM Rectifier Simulation Study

Simulations were conducted based on the theoretical values of the PWM rectifier used in the system. In this study, inductors, capacitors, transformers, and switching elements were assumed to be ideal. As depicted in Figure 17, the circuit simulation was implemented using Matlab/Simulink.

The simulation results are presented in Figure 16. The AC signal from the input has been converted to 408V DC through the PWM rectifier. The IGBT switching frequency is selected as 16 kHz. The corresponding triangular wave signal generates the main PWM pulses. The modulation index is 30.5%. The simulation graphs for input voltage and current are shown in Figure 17, indicating that the fluctuation in the output voltage of the PWM rectifier is close to 100 mV. Additionally, the rectifier is loaded with a 5-ohm resistor. The graphs for output voltage and current are provided in Figure 18. The IGBT switching signals generated by the SPWM are shown in Figure 19.

As shown in Figure 18, the output voltage is specified as 400V DC. The load at the output draws approximately 82A current. Both current and voltage have fluctuations of up to 100mV and 100mA. The system starts with a soft start, reaching nominal values in 0.3 seconds. Additionally, Figure 20 provides the switching PWM pulses. Feedback information is obtained from the input voltages and compared with a triangular wave at a frequency of 16 kHz to enable the IGBTs to switch according to the SPWM method. This result is multiplied by the modulation index, allowing controlled adjustment of the SPWM for the desired output voltage.

Buck-Boost Type DC-DC Converter Simulation Study

A simulation study has been conducted based on the theoretical values of the DC-DC converter used in the system. This study considered the inductor, capacitor, and switching elements ideal. The circuit simulation, as shown in Figure 21, was implemented using the Matlab/Simulink.

For the initial condition, the resistance value is calculated below to allow a minimum current, also known as the damper load, to pass through the resistor. The resistance value is calculated for a 408V charging voltage and a 4A load resistance.

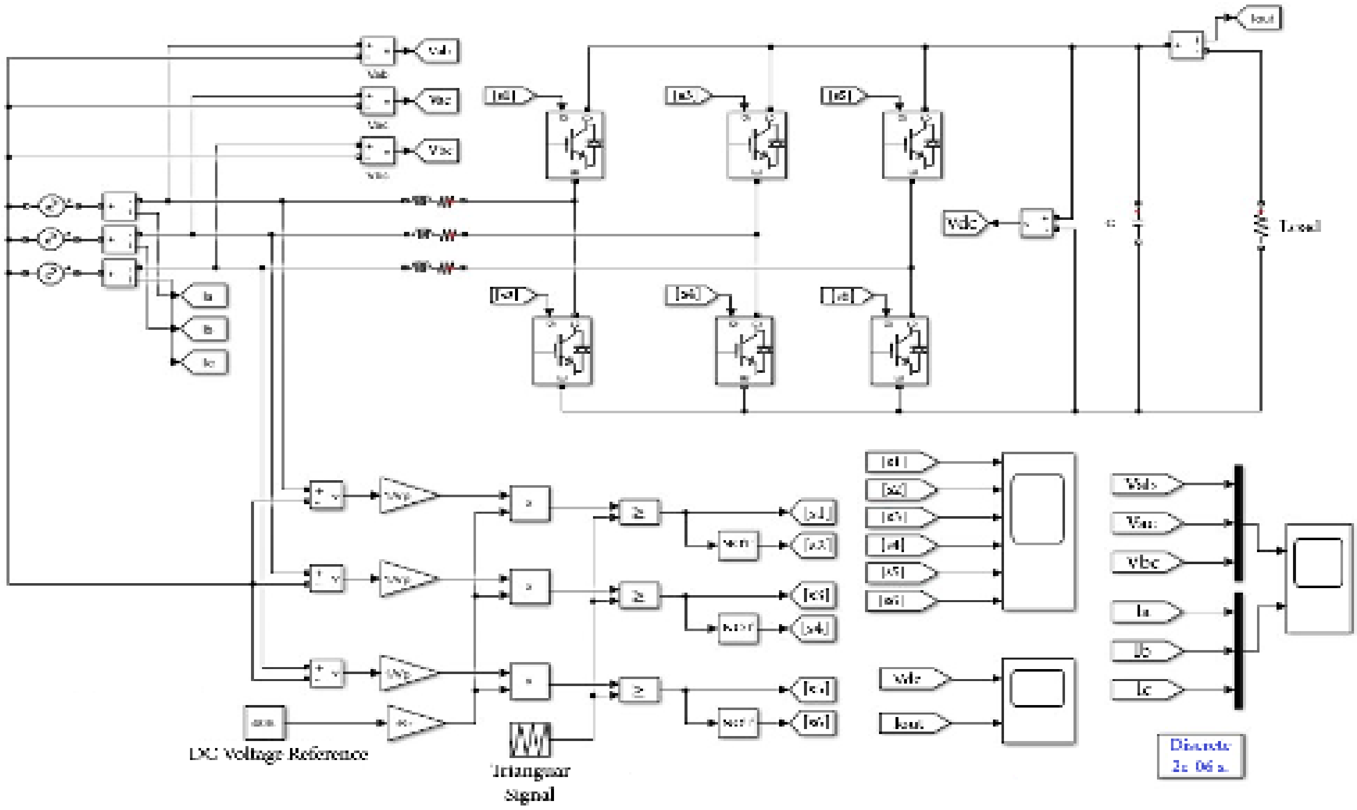

Figure 17. Three-phase PWM rectifier circuit (Detailed)

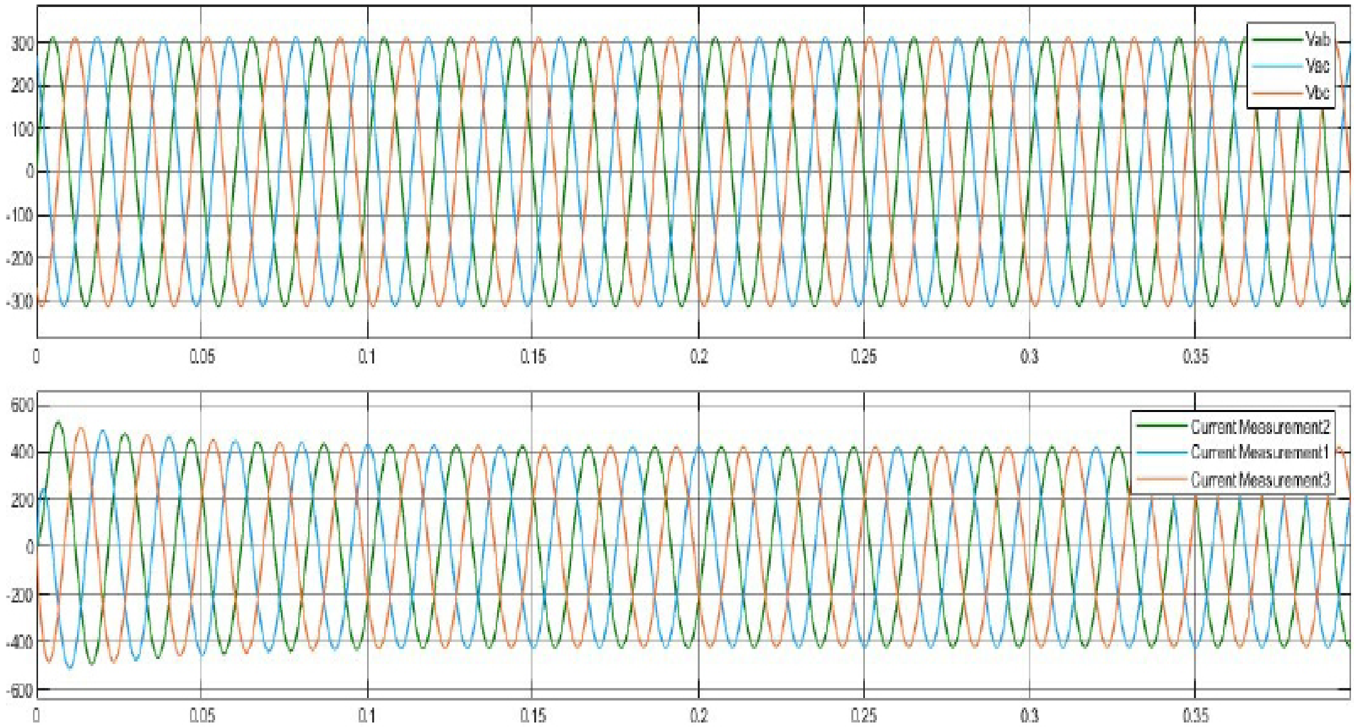

Figure 18. PWM rectifier input voltage and currents

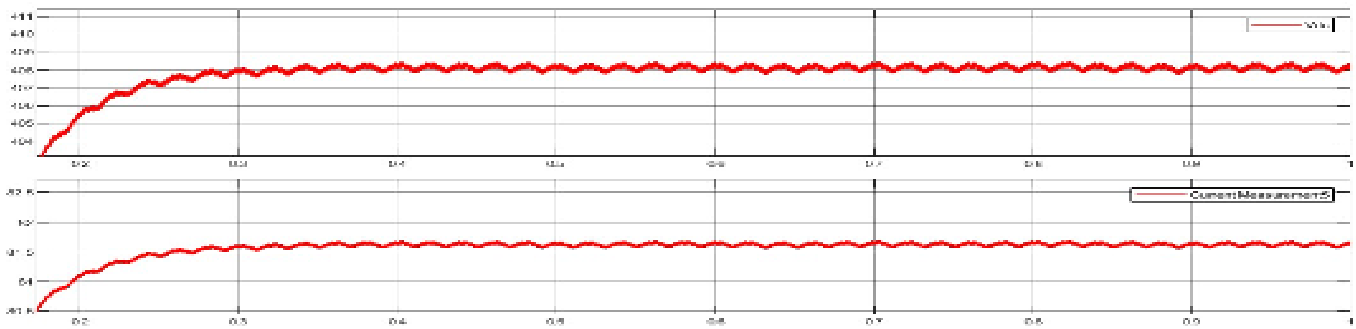

Figure 19. PWM rectifier output voltage and currents

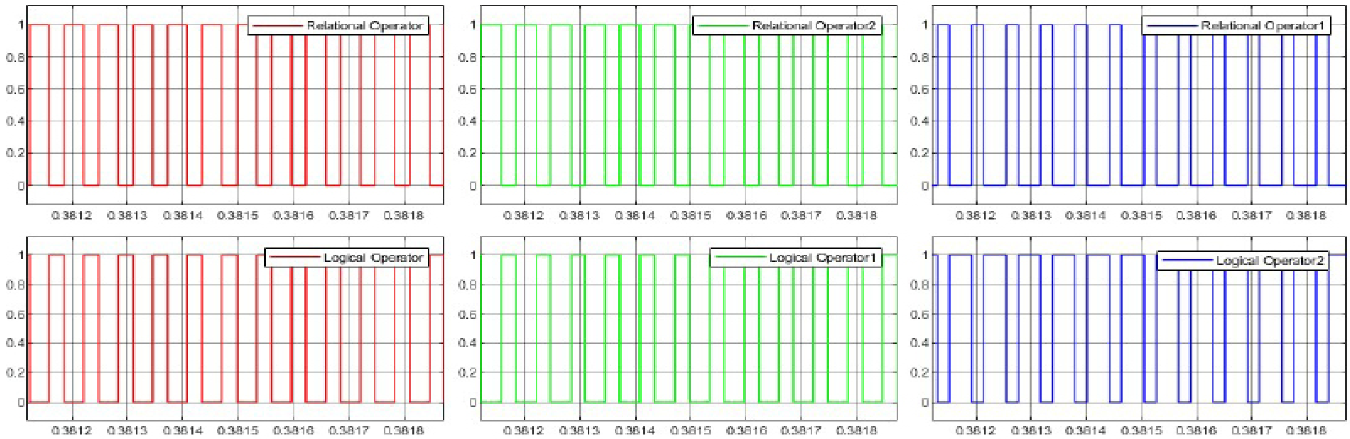

Figure 20. PWM rectifier for 6 IGBT SPWM pulses that produced with modulation index

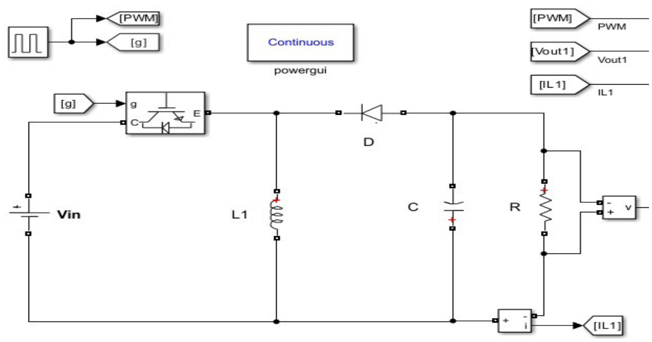

Figure 21. Buck-boost type DC-DC converter simulation model

$$\text{Ryük} = \text{Vnominal} / \text{Imin} = 408 / 4 = 102\ \Omega$$

In the simulation conducted for the buck-boost converter, a 408 Ω resistor was used as the load, and the calculated capacitor and inductor values were utilized. The input voltage was set to the nominal voltage of 400V DC from the panels. The IGBT switching frequency was chosen as 20 kHz, and the duty cycle period was set to the calculated value of 50.5%. The simulation results are presented in Figure 22.

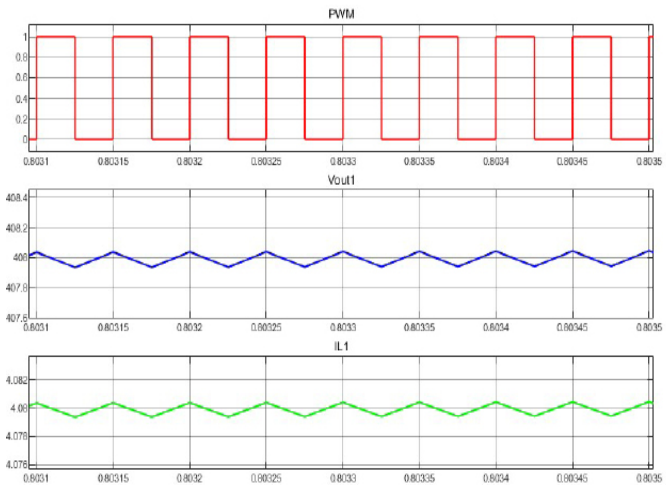

Figure 22. DC-DC converter simulation graphics

As a result of the simulation, the PWM signal, output voltage, and output current related to the duty cycle of the IGBT switch were obtained, as shown in Figure 18. The IGBT was driven with a 50.5% duty cycle. The load voltage has a ripple voltage of 100 mV, while the load current is at a value of 4A with a 100 mA fluctuation.

Hybrid Charging Station Experiment and Implementation

The experimental and implementation phase of the hybrid charging station was conducted using Matlab/Simulink simulation. The study involved images of the 380V AC power source, PWM rectifier, DC-DC converter, Transformer, Power Supply, Mainboard, IGBTs, and HMI unit, as depicted in Figure 19.

As seen in Figure 23, the circuit consists of several electrical components. Additionally, a 100A MCCB (Moulded Case Circuit Breaker) has been utilized to protect any short circuits in the system's inputs and outputs. For the storage unit, 30 units of 12V VRLA batteries have been employed to charge the EV. Fluke brand measurement tools were used to measure input and output voltages. The switching frequencies were monitored with an oscilloscope.

Before connecting the application circuit to regular EVs, tests were conducted under load in a test environment. These tests were conducted based on the voltage and current values simulated. Isolated driver circuits were used to drive the IGBTs. All power supplies were provided from the supply card shown in Figure 19. The power supplies in the system are divided into 12V and 5V. In Figure 24, a 408.0V DC is observed at the outputs of both the PWM rectifier and the DC-DC converter.

In Figure 25, the switching frequency of the DC-DC converter is provided. The duty cycle period starts as a soft start at 50.5%.

The simulation and application results show that a 408V DC output is provided for the PWM rectifier with a fluctuation level below 1%. It is also shown in Figure 20. Additionally, the switching pulses for the PWM rectifier are shown in Figure 26. The IGBTs are driven with a soft start, ensuring work safety by shutting down the system in case of any danger. When the system's efficiency is theoretically calculated, it exceeds 95%, aligning well with the practical application. The Buck-Boost type DC-DC converter converts the voltage obtained from solar energy to 408V DC to charge the batteries in the storage unit and serves as an energy source for the second converter.

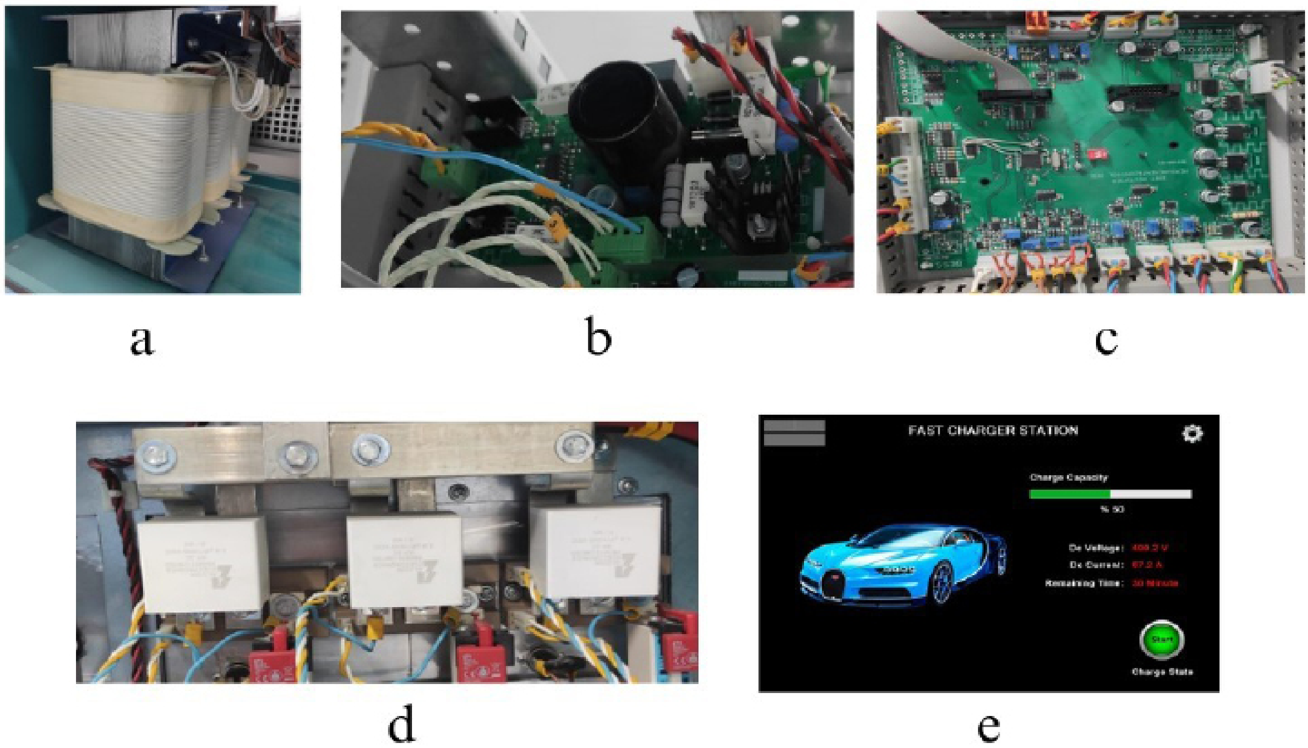

Figure 23. (a) Transformer, (b) power supply card, (c) main board, (d) IGBTs, (e) HMI unit

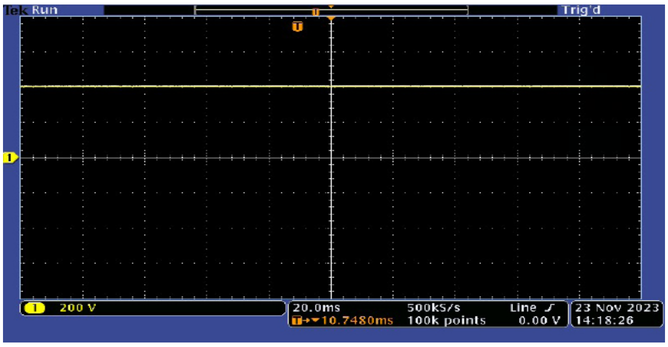

Figure 24. PWM rectifier output voltage with oscilloscope

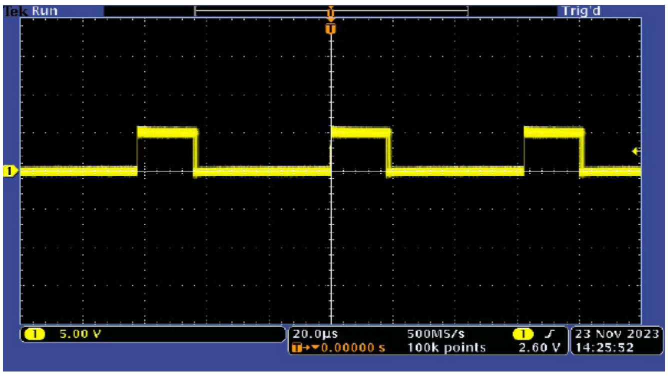

Figure 25. DC-DC converter PWM pulses

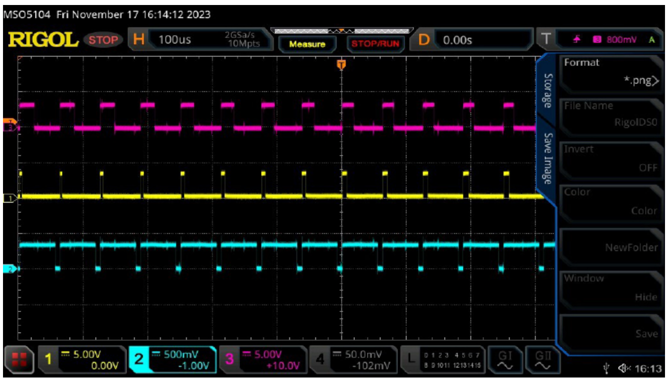

Figure 26. PWM rectifier IGBT SPWM pulses for three-phase

DISCUSSION

The dependence on vehicles using fossil fuels for transportation, which is significant in our lives, harms the environment and human health. Vehicles utilizing fossil fuels also contribute significantly to carbon emissions, posing a substantial threat to the atmosphere and impacting global climates. For these reasons, the number of environmentally friendly EVs is increasing daily. However, this rise raises questions about the charging infrastructure and the suitability of the electrical grid.

This study transfers the DC generated through PV modules to the storage unit using a buck-boost type DC-DC converter. The batteries in the storage unit charge, and fully charged batteries are sufficient to charge multiple vehicles. The hybrid charging station employs a fast-charging method, offering up to 70% charge in half an hour if the vehicle's specifications allow. In cases where solar energy is insufficient, and the storage unit is not enough for vehicle charging, the grid-powered rectifier is activated. The system contributes to energy savings by utilizing solar power.

Hybrid charging stations have no space limitations and can be used by individuals or companies. They are suitable for military vehicles in remote areas, providing independence from the grid. The system operates based on renewable energy without dependence on the grid. Future research can focus on increasing battery capacities and providing charging capabilities for EVs supporting up to 1000 VDC. Advancements in fast-charging technologies can increase current flow and allow for higher power levels. Increasing the number of PV modules can power multiple vehicles with solar panels alone. Bidirectional rectifiers can transfer excess energy back to the grid, incorporating different control structures and artificial intelligence for optimization.

CONCLUSION

The development and implementation of hybrid charging stations represent a promising solution to address the environmental and health concerns associated with traditional fossil fuel-powered transportation. By harnessing solar energy through photovoltaic modules and employing an innovative buck-boost DC-DC converter, this study demonstrates a sustainable approach to charging EVs while minimizing reliance on the conventional grid. The hybrid charging stations not only contribute significantly to reducing carbon emissions but also offer flexibility for use in diverse settings, including remote areas and military applications. The incorporation of fast-charging technology, coupled with the ability to draw power from both solar and grid sources, ensures a reliable and efficient charging infrastructure. As we look toward the future, further research and advancements in battery capacities, fast-charging technologies, and bidirectional rectifiers, combined with artificial intelligence optimization, hold the key to enhancing the viability and scalability of this eco-friendly solution.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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Advancing defense capabilities through integration of electro-optical systems and computer vision technologies

Ziya Elri[1], Atilla Ergüzen[2]

[1] *Department of Defense Technologies, Institute of Science, Kırıkkale University, Turkiye*
[2] *Department of Computer Engineering, Faculty of Engineering, Kırıkkale University, Kırıkkale, Turkiye*

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Corresponding Author: Ziya Elri, ziyaelri@gmail.com

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ABSTRACT

The paper comprehensively addresses the integration of advanced technologies to enhance defense capabilities, with a particular focus on critical tasks such as object detection, tracking, and distance measurement. To this end, the integration of IMX219-77 cameras and Nvidia Jetson Nano is proposed, emphasizing the utilization of their respective features. Commonly used tools like open source computer vision (OpenCV) and GStreamer are preferred for ensuring cohesive integration between hardware and software components. On the software front, tools such as OpenCV and GStreamer are preferred for tasks related to computer vision and multimedia processing. The MOSSE algorithm is selected for object tracking due to its speed, efficiency, and resilience to changes in lighting conditions. Additionally, distance measurement is achieved through the use of Stereo Vision techniques. The results of the study demonstrate the effectiveness and accuracy of the proposed integration. It is found that accurate distance measurements with a margin of error ranging from 0 to 2 mm, falling within acceptable limits mentioned in relevant literature, can be achieved. This underscores the efficacy of the proposed technologies for tasks such as object detection, tracking, and distance measurement. The aim of the study is to conduct an in-depth examination of the integration of advanced tools such as IMX219-77 cameras and Nvidia Jetson Nano for use in defense operations. It seeks to showcase how this integration can strengthen defense strategies and provide protection against potential threats. Additionally, the study aims to lay the groundwork for ongoing innovation and development in defense technologies. In conclusion, the integration of electro-optical systems and computer vision technologies has the potential to significantly enhance defense capabilities and contribute to national security efforts. The advantages provided by this integration can serve as a valuable resource for researchers seeking to develop new solutions in defense and security domains.

Keywords: Object detection and tracking, distance measurement, stereo vision, OpenCV, GStreamer

INTRODUCTION

In today's world, the defense industry plays a crucial role in ensuring national security, particularly in strategic tasks such as reconnaissance, threat detection, and target identification. In this context, the use of electro-optical systems holds significant importance. Electro-optical systems, as a perfect combination of light and electronics, provide ideal tools for capturing, processing, and analyzing visual information.

The increasing utilization of electro-optical systems in the defense industry and security applications demonstrates their capability to successfully fulfill strategic tasks such as enemy threat detection, target tracking, reconnaissance missions, and safeguarding security boundaries. The precise and effective use of electro-optical systems is of critical importance for defense strategies. These systems enhance national security by providing high performance in defense operations and offering the potential for effective defense against various threats.

Particularly, the object detection and distance measurement capabilities of electro-optical systems have become one of the primary objectives in the defense industry. Through technologies like stereo camera systems, enemy positions can be identified, threats classified, and strategic tasks such as target identification for fire control systems can be carried out more effectively. Furthermore, open-source computer vision libraries like open source computer vision (OpenCV) are widely used to enhance the efficiency and utilize the potential of electro-optical systems more effectively.

The rapid advancements in computer vision and video surveillance fields are leading to significant breakthroughs in object detection, tracking, and measurement areas. These latest technologies are revolutionizing various sectors such as defense, security, healthcare, and industrial applications. The use of deep learning and computer vision algorithms plays a crucial role in achieving these remarkable outcomes.

Stereo vision technology, involving the use of a pair of cameras to perceive objects in three dimensions, is an impressive and progressive research area that mimics the human visual system. Extensive studies conducted in this field have extensively addressed various aspects of stereo vision systems and algorithms.

Raghunandan and colleagues examined the application areas of various object detection algorithms, simulating and implementing algorithms such as face detection, skin detection, and target detection using MATLAB 2017b. The study also discussed the challenges and applications of object detection methods in fields like defense, security, and healthcare (Raghunandan et al., 2018).

Abdelmoghit Zaarane et al. propose a system for measuring inter-vehicle distances in autonomous driving using stereo camera setup and image processing. The system achieves high accuracy in real-time inter-vehicle distance measurement through vehicle detection, template matching, and geometric calculations (Zaarane et al., 2020).

Abhishek Badki and colleagues investigate rapid object detection within milliseconds and depth approximation through coarse quantization, achieving results comparable to state-of-the-art stereo methods for continuous depth perception. The research contributes to advancing object detection and depth approximation techniques, demonstrating the efficacy of coarse quantization methods in certain scenarios (Badki et al., 2020).

Adam Wacey discusses a stereo camera system comprising an imaging sensor chip and optical device, capable of capturing images side by side and generating volumetric image data based on binocular disparity. The system's image processor constructs three-dimensional volumetric data from imaging frames, identifies moving objects, determines their depth position, and clips volumetric data around them (Wacey, 2020).

Andres Erazo, Eduardo Tayupanta, and Seok-Bum Ko aim to develop a method for object detection in 3D environment navigation using the 2D cameras of mini drones. For this purpose, a TensorFlow network was fine-tuned for specific object classification, and the distances between drones and detected items were measured using epipolar geometry. An average measurement accuracy of 0.6094 was determined, with a processing time of approximately 0.02 seconds for object prediction. The results demonstrate that object detection using 2D cameras can be effectively performed (Erazo et al., 2020).

Ashok Kumar Bandı et al. engineered a specialized system for locations with sporadic human presence, such as bank vaults and residential properties, focusing on identifying intruders to enhance surveillance and security measures, ensuring prompt detection and response to unauthorized access attempts (2023).

Ахметов and colleagues present a system for measuring object distance based on stereo images, providing a brief overview of its purpose, operational algorithm, and performance results (Ахметов et al., 2022).

Elmehdi Adil, Mohammed Mikou, and Ahmed Mouhsen devise a Python-based algorithm for stereo vision systems to measure obstacle distances, demonstrating high accuracy and real-time performance in distance calculation (Adil et al., 2022).

Fan, Rui and collaborators discuss recent advancements in parallel computing architectures to enhance autonomous vehicle perception capabilities, focusing on computer stereo vision. The article provides a comprehensive overview of both hardware and software aspects, contributing to the understanding and advancement of autonomous vehicle perception technology (Fan, 2020).

G. Chandan, A. Jain, H. Jain, and Mohana (2018) focused on real-time object detection and tracking using deep learning and OpenCV (Chandan et al., 2018).

Hamid Laga and collaborators contribute significantly to depth estimation from RGB images, reviewing traditional techniques and advancements in deep learning-based methods. The review highlights the broad applications of depth estimation methodologies across various fields, including robotics, autonomous driving, and medical diagnosis (Laga et al., 2022).

Haydar Yanık and Bülent Turan lay the theoretical groundwork for an industrial image-based measurement device, proposing a novel method for distance detection. The study evaluates the proposed method's accuracy and outlines future work focusing on error detection and hardware-software development (Yanık et al., 2021).

Huei-Yung Lin and colleagues introduced a novel sensor system design for depth recovery based on rotational stereopsis, integrating the rotation of an image sensor to generate visual parallax from multiple viewpoints using a single imaging device, enhancing depth measurement accuracy and flexibility in depth measurement systems, contributing to advancing depth recovery technology (Lin et al., 2021).

In this study, Xiaoxiao Long and colleagues propose a novel method for multi-view depth estimation from a single video frame. Depth estimation plays a crucial role in various applications such as perception, reconstruction, and robot navigation. This study introduces a new Epipolar Spatio-Temporal (EST) transformer to explicitly associate multiple estimated depth maps with geometric and temporal coherence, thus achieving temporally consistent depth estimation (Long et al., 2021).

J. C. Njuguna and collaborators present a novel hardware architecture for the MOSSE tracker algorithm, achieving impressive performance metrics on an FPGA platform. The research contributes to advancing real-time object tracking through efficient hardware implementations of tracking algorithms (Njuguna et al., 2022).

Jia-Yao Su, Che-Ming Wu, and Shuqun Yang develop an innovative deep learning-based algorithm for object tracking, integratinfg motion direction and time series information. The proposed algorithm utilizes a loss function to learn motion direction and employs an attention mechanism for tracking result reliability scoring, enhancing object tracking performance across various datasets (Su et al., 2023).

Ling Bai and colleagues explored the application of OpenCV for face recognition, emphasizing the utilization of cascade classifiers based on Haar-like features and principal component analysis (PCA) of AdaBoost for achieving notable high detection and recognition rates under varying lighting conditions (Bai et al., 2022).

M. A. Dewedar and their team introduced a UAV tracking system implemented using OpenCV, evaluating its performance through a comparative analysis with a real dataset and providing insights into the effectiveness of the UAV tracking system, contributing to advancing UAV tracking technology and highlighting the utility of OpenCV in such applications (Dewedar et al., 2022).

Matteo Poggi and their team address the challenge of stereo matching in computer vision, tracing its evolution and discussing recent trends in learning-based depth estimation. The comprehensive review contributes to the understanding of state-of-the-art techniques in stereo matching and depth estimation (Poggi et al., 2022).

N. Dardagan and colleagues conducted a comprehensive evaluation of seven object trackers implemented in OpenCV, utilizing the MOT20 dataset, aiming to address crucial questions within the field and provide insights into the strengths and limitations of different tracking algorithms, contributing to advancing the understanding and application of object tracking in computer vision (Dardagan et al., 2021).

N. Dardagan and colleagues conducted an evaluation of seven distinct object trackers integrated within the OpenCV library, employing the MOT20 dataset for assessment. The study aimed to ascertain the performance characteristics of various object trackers and discern the specific conditions and object types for which these trackers demonstrate optimal efficacy. This comprehensive evaluation substantially enhances our comprehension of the efficacy of different algorithms within OpenCV for object tracking purposes (Dardagan et al., 2021).

O. Haggui and colleagues presented a recent study focusing on the challenging problem of human tracking in real-world computer vision applications, evaluating OpenCV tracking algorithms' reliability and comparing them with a particle filter algorithm based on color and texture features for pedestrian tracking accuracy in dynamic scenarios, aiming to enhance the performance of human tracking algorithms (Haggui et al., 2021).

Rui Fan and collaborators discuss recent advancements in parallel computing architectures to enhance autonomous vehicle perception capabilities, focusing on computer stereo vision. The article provides a comprehensive overview of both hardware and software aspects, contributing to the understanding and advancement of autonomous vehicle perception technology (Fan, 2020).

S. Ristanto and collaborators developed a stereo camera system using the OpenCV library on the Python platform, capable of providing stereoscopic images and videos in PNG or AVI formats. The system's experimental results demonstrate potential applications in physical measurements, with disparity decreasing as the object moves away from the camera (Ristanto et al., 2021).

Sudhir Khare et al. introduced a study focusing on the development of an image processing technique for measuring the field of view of electro-optical imaging systems, aiming to enhance precision and efficiency through a user-friendly graphics user interface approach (Khare et al., 2021).

Udit Malik highlighted the increasing demand for machine learning techniques in image processing, particularly focusing on leveraging the open-source Python library OpenCV for implementing machine learning algorithms, shedding light on the evolving landscape of computer vision and its practical applications (Malik, 2022).

Xiyan Sun and colleagues propose a method for binocular stereo vision using MATLAB calibration and OpenCV matching, aiming for efficient and precise non-contact detection and quality control. By calibrating and rectifying stereo cameras, the method computes object distances based on acquired disparity values, demonstrating effectiveness in meeting distance measurement requirements (Sun et al., 2019).

Xucheng Wang and colleagues propose a convolutional neural network wintegrating epipolar geometry and image segmentation for light-field depth estimation. The method achieves high rankings in quality assessment metrics and accurately predicts depth from real-world light-field images (Wang et al., 2020).

Yandong Liu developed a novel object identification method tailored for industrial robots, leveraging image processing techniques, which efficiently detects objects amidst varied backgrounds, determines their distance from the camera, and tracks their motion direction using Python-based OpenCV algorithms (Liu, 2023).

Zaarane et al. propose a system for measuring inter-vehicle distances in autonomous driving using stereo camera setup and image processing. The system achieves high accuracy in real-time inter-vehicle distance measurement through vehicle detection, template matching, and geometric calculations (Zaarane et al., 2020).

Recent advancements in areas such as image processing, stereo vision technology, deep learning, and object tracking have led to significant innovations in the defense industry and other sectors. These advancements contribute to strengthening national security and public safety by enhancing the performance of electro-optical systems.

In conclusion, the significance of electro-optical systems and image processing technologies in the defense industry and security applications is undeniable, marking a field that continues to evolve and improve. The adept use of these technologies plays a pivotal role in upholding national security and ensuring public safety.

METHODS

Outlined in this section are the software and hardware tools chosen to fulfill the objectives of object detection, tracking, and distance measurement within electro-optical systems.

The decision to merge two IMX219-77 cameras with Nvidia Jetson Nano for this study stemmed from various factors.

Primarily, the IMX219-77 camera's high resolution and expansive field of view render it perfect for tasks such as object detection and recognition. Its detailed image capture capability and heightened sensitivity in detecting objects are paramount. Furthermore, the broad field of view empowers the cameras to effectively scan diverse environmental conditions and detect objects across a wide area.

Secondly, the adoption of a low-power yet high-performance platform like Jetson Nano presents an apt solution for real-time image processing needs. Leveraging Jetson Nano's GPU-accelerated computing prowess allows for swift execution of intricate image processing algorithms, thereby augmenting application performance. Additionally, its low power consumption ensures prolonged battery life, ideal for portable devices.

Lastly, the amalgamation of IMX219-77 cameras and Jetson Nano yields a compact and portable solution. This integrated system proves optimal for mobile and embedded applications where device size, weight, and portability are paramount. As a unified system, it facilitates seamless assembly and usage, offering heightened efficiency when deployed together.

For these reasons, the combination of IMX219-77 cameras and Nvidia Jetson Nano is an ideal choice for electro-optical system applications such as object detection, tracking, and distance measurement.

In the realm of software, the decision was made to employ OpenCV and GStreamer. This choice stems from several key reasons:

Firstly, OpenCV library stands as a widely adopted open-source framework for developing computer vision and image processing applications. Offering an extensive array of tools and algorithms, it supports fundamental and advanced operations such as image and video processing, object detection, and feature recognition. Its comprehensive toolset and wide user base provide developers with flexibility, efficiency, and robustness in various applications.

Secondly, GStreamer serves as an open-source multimedia framework specifically designed for multimedia processing tasks. It excels in tasks such as manipulation, conversion, and processing of video and audio streams. Additionally, its capability to utilize GPU acceleration enhances its performance, particularly in real-time video processing applications. The integration of GStreamer complements the functionality provided by OpenCV and addresses potential issues related to frame rates, thereby ensuring smooth and efficient processing (Manolescu et al., 2024).

For target detection and distance measurement, the MOSSE and Depth Estimation (Stereo Vision) algorithms have been selected.

By leveraging these algorithms and software tools, the study aims to achieve robust and efficient object detection, tracking, and distance measurement capabilities within electro-optical systems.

MOSSE is a tracking algorithm used for object tracking purposes. The MOSSE algorithm learns the characteristics of an object from a specified region and then tracks the object using these learned features. Named after the expression MOSSE, the algorithm focuses on minimizing the sum of squared errors obtained during the object tracking process. The main advantages of the MOSSE algorithm are:

- Fast Tracking: MOSSE is optimized for real-time object tracking applications. By employing fast and efficient computation methods, it can track objects at high speeds.
- Requires Less Training Data: MOSSE can utilize a small amount of training data to learn the object's features. This advantage allows for more efficient utilization of memory and computational resources.
- Resilient to Lighting Changes: The algorithm is resistant to changes in lighting conditions, enabling it to cope with lighting variations that may occur during object tracking.

The MOSSE algorithm is commonly used in security systems, automatic tracking systems, and video analytics applications.

Depth Estimation (Stereo Vision) is the process of obtaining depth information about objects in a scene. Stereo vision attempts to acquire distance information of objects by analyzing images captured from a pair of cameras. The lateral separation between the two cameras enables the generation of a three-dimensional representation.

The stereo vision process includes the following steps:

- Computing Epipolar Geometry: Determining the epipolar geometry between the two cameras is essential for associating the positions of points in the images and consequently calculating depth information.
- Generating Disparity Maps: A disparity map is created to identify differences between the two images. Disparity represents the horizontal distance between a point's position in one image and its position in the other image.
- Creating Depth Maps: Using the disparity map, the depth of each point in the scene is computed. Depth information is typically obtained using stereo camera calibration and epipolar geometry.

Stereo vision finds applications in various fields such as autonomous vehicles, robotics, augmented reality, and virtual reality. This technique provides an important tool for understanding object distances and improves positioning and detection in various applications.

Proposed Algorithm

The image captured from the IMX219-77 cameras is transmitted to the Jetson Nano via a video stream created using Gstreamer. Subsequently, the received image data is captured with OpenCV and converted into the appropriate format, then compared with a database within a function capable of detecting and recognizing objects. During this comparison process, the MOSSE algorithm actively plays a crucial role. Once the target is detected, one of the images remains normal while the other is converted into a depth map using Stereo Vision. In this process, the images obtained from the two cameras are horizontally mapped, and the depth information obtained from the calculations provides us with the distance between the object and the camera. Finally, the processed image is displayed on the screen, completing the process, as shown Figure 1.

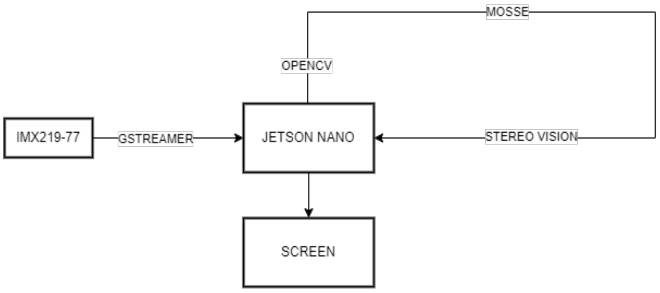

Figure 1. The block diagram of the system

A depth map is created using the stereo vision technique. In this process, two cameras are aligned horizontally, parallel to each other, and at a fixed distance. The depth of objects is calculated using the parallax difference between the images obtained from the cameras. Epipolar geometry is utilized to generate the depth map. Epipolar geometry is a concept that geometrically defines the relationship between two cameras. This relationship is expressed through geometric structures such as epipolar lines, epipolar planes, and the fundamental matrix. The principles of epipolar geometry are used to estimate the possible location of an object from an image captured by one camera in the image captured by the other camera.

Disparity refers to the difference in pixel positions between different cameras in stereo vision systems. This difference is utilized to determine the depth of objects and is a crucial measurement in stereo vision systems. In Figure 2, it is observed as: (OpenCV, 2024)

$$disparity = x - x' = \frac{BF}{D} \tag{1}$$

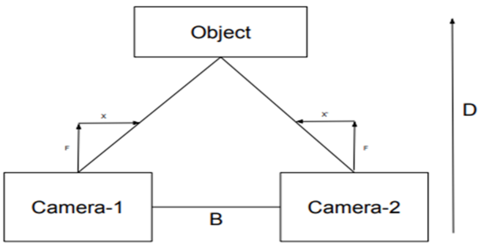

Figure 2. At the focal point of two cameras: depth and distance measurement

Here, 'B' denotes the inter-camera distance, 'F' represents the focal length of the lenses, and "x-x'" indicates the difference in pixel positions of the object in the image. In practice, the focal length 'F' and inter-camera distance 'B' are often unknown and manual measurement may lead to errors. Therefore, the Least-Squares method is employed.

The Least-Squares method minimizes errors in a dataset to find a model that best represents the relationship between data points. By minimizing the sum of squared errors between data points, this method determines a line or curve. Using the Least-Squares method, a parameter 'M' is derived, which is set equal to the product of 'B' and 'F'.

To incorporate this equation into the software algorithm, it is transformed into a Linear Regression expression.

$$x - x' = \frac{M}{D} \tag{2}$$

The smaller focal length results in larger disparity and better perception of object depth. Increasing the distance between cameras (baseline) leads to an increase in disparity, enhancing the perception of distant objects. Since the focal length of the IMX219 cameras is 2.85 mm and remains constant, the relationship between disparity and depth has been examined based on the distance between the cameras.

Linear Regression is used to model the relationship between a dependent variable and one or more independent variables. Its aim is to predict the dependent variable given the values of the independent variables. This method expresses relationships in the dataset with a linear model, best fitting the data points. As seen in Equation-3, our dependent variable 'D' and independent variable '(x-x')' are used to model situations where a linear relationship exists in the operation, finding the 'M' parameter that best fits the data points to this linear model.

$$D = \frac{M}{x - x'} \tag{3}$$

To be used within the software algorithm:

$$a = \frac{1}{x - x'} \tag{4}$$

Equation is equated and the equation:

$$D = M\ x\ a \tag{5}$$

is obtained (OpenCV,2024).

Normally, for a single image frame, this equation can provide reliable results with a very low error rate. However, in real-time camera systems during the calculation/measurement of depth (D) and disparity (a) values, errors may occur manually or through algorithms. Hence, to find the most suitable values, OpenCV's "solve()" function is employed. Upon running the function, once the 'M' value is found, the depth value is determined using Equation-6.

$$D = \frac{M}{disparity} \tag{6}$$

When looking at Figure 3, disparition measurements of two different stereo camera systems with focal length of 2.96 mm and pixel size of 1.12 µm and two different Baseline values (30 mm and 80 mm) were compared by examining five different depths ranging from 230 cm to 70 cm. The results are as follows:

Distance Perception: Increasing the Baseline length increases the parallax difference between objects. This leads to an increase in the disparition perceived by the stereo imaging

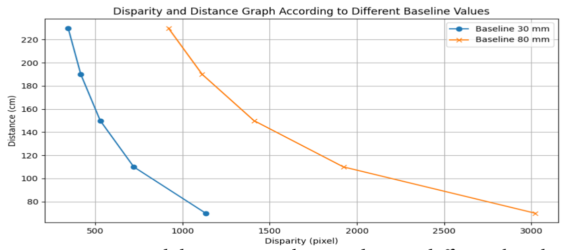

Figure 3. Disparity and distance graph according to different baseline values

system and allows for a more precise measurement of the distance between objects. Conversely, decreasing the Baseline length reduces the parallax difference and makes the distance perception less precise.

Depth Perception: Stereoscopic imaging systems calculate the depth of objects based on disparition. Increasing the Baseline length enhances the depth perception, making the difference in depth between objects more pronounced. However, an excessively large Baseline value can overly sensitize the depth perception and result in unnecessary details. On the other hand, decreasing the Baseline value reduces the depth perception and makes the difference in object distances less pronounced.

Field of View and Perspective: Increasing the Baseline length narrows the field of view and alters the perspective. This may cause the stereo imaging system to focus on a narrower area and have a more distinct perspective. Conversely, decreasing the Baseline length widens the field of view and leads to a less distinct perspective.

The Figure 4 displays the inverse disparity values for objects at different distances. Inverse disparity is a measure used in stereo vision systems to calculate depth information from images taken from different viewpoints and is the mathematical inverse of disparity. Disparity is the horizontal position difference of the same point in images taken by two cameras, and inverse disparity is the inverse of this value. That is, the larger the disparity, the smaller the inverse disparity, and vice versa.

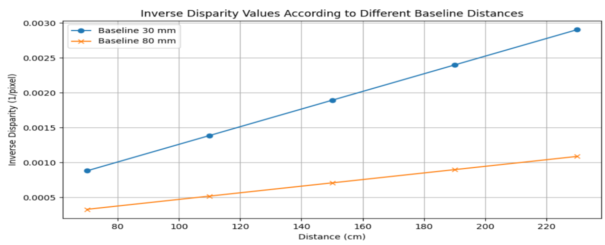

Figure 4. Inverse disparity and distance graph according to different baseline values

In the graph, the x-axis represents distance in centimeters, and the y-axis represents inverse disparity in units per pixel. The values of inverse disparity for two different baseline distances are shown: 30 mm and 80 mm. As the distance increases, both lines show an increase in inverse disparity values, but at different rates.

This graph is particularly useful for applications such as 3D reconstruction, where choosing the correct baseline distance is crucial for accurate depth estimation. It shows that as the baseline distance increases, the rate of increase in inverse disparity also goes up. This indicates that longer baseline distances can provide more precise depth measurements for closer objects. However, this also means that disparity becomes harder to detect for more distant objects, as smaller disparity values lead to larger inverse disparity values, making the depth estimation less precise.

According to the academic literature, a margin of error of 3% is generally considered acceptable. Similar results were obtained in the study conducted by Uğur Can Boz and İdris Sancaktar (2023), where they detected vehicle chassis deformities using stereo imaging (Boz & Sancaktar, 2023). Another study by Zelin Meng and colleagues presents a lightweight depth estimation method based on binary vision technology using ORB features and brute-force matching. This method predicts camera movement and estimates depth using triangulation theory based on the pixel coordinates of matching point pairs, providing high accuracy and real-time performance (Meng et al., 2021). R. Arokia Priya Charles and Anupama V. Patil proposed a methodology for object detection using a dual-camera system. The developed method processes images using thresholding and blob detection techniques to find the centers of objects and accurately determine their distances using stereographic depth values (Charles et al., 2021).

The results obtained in the study fall below the threshold mentioned in the academic literature and are consistent with the examples. A margin of error ranging from 0 to 2 mm was observed at distances between 70 and 230 cm in the x-y plane.

RESULTS

In this study, it has been observed that the integration of electro-optical systems, deep learning algorithms, and computer vision technologies significantly enhances the capabilities of defense and security applications. Through the utilization of stereo vision technology and advanced object detection methods, defense strategies can effectively identify threats, track targets, and conduct reconnaissance missions with precision and efficiency. This establishes a fundamental understanding of the importance of electro-optical systems in defense strategies, emphasizing their critical role in safeguarding national security by enabling essential tasks such as reconnaissance, threat detection, and target identification. Similarly, the combination of IMX219-77 cameras and Nvidia Jetson Nano, coupled with OpenCV and GStreamer, in this study has demonstrated remarkable performance in object detection, tracking, and distance measurement tasks. The MOSSE algorithm, utilized for object tracking, has proved to be robust and efficient, while stereo vision techniques have enabled accurate depth estimation crucial for defense operations. The findings of this research, falling within acceptable error margins, underscore the reliability and effectiveness of the implemented techniques. With a margin of error of 0-2 mm observed in the x-y plane, the study provides valuable insights into the practical application of electro-optical systems for defense purposes.

DISCUSSION

This study demonstrates that the integration of electro-optical systems, deep learning algorithms, and computer vision technologies significantly enhances the capabilities of defense and security applications. Through the utilization of stereo vision technology and advanced object detection methods, defense strategies can effectively identify threats, track targets, and conduct reconnaissance missions with precision and efficiency. This establishes a fundamental understanding of the importance of electro-optical systems in defense strategies, emphasizing their critical role in safeguarding national security by enabling essential tasks such as reconnaissance, threat detection, and target identification.

Similarly, the combination of IMX219-77 cameras and Nvidia Jetson Nano, coupled with OpenCV and GStreamer, in this study has demonstrated remarkable performance in object detection, tracking, and distance measurement tasks. The MOSSE algorithm, utilized for object tracking, has proved to be robust and efficient, while stereo vision techniques have enabled accurate depth estimation crucial for defense operations. The findings of this research, falling within acceptable error margins, underscore the reliability and effectiveness of the implemented techniques. With a margin of error of 0-2 mm observed in the x-y plane, the study provides valuable insights into the practical application of electro-optical systems for defense purposes.

The results of this study, when compared with previous research conducted in the literature, indicate similar outcomes. For example, many previous studies have emphasized the importance of stereo vision techniques and object detection algorithms in defense and security applications (Zaarane et al., 2020; Raghunandan et al., 2018). These studies have demonstrated the critical role of electro-optical systems in defense operations, such as threat detection, target tracking, and reconnaissance missions.

Additionally, the results of this study highlight the reliability and effectiveness of stereo vision techniques and object detection algorithms. Specifically, it has been observed that the MOSSE algorithm provides fast and efficient object tracking, while stereo vision techniques enable accurate depth estimation. These findings suggest that electro-optical systems are a critical component in defense and security applications, and the proper integration of these technologies enhances operational capabilities.

While the selection of hardware and software components has been carefully made, it is essential to acknowledge the limitations of the technologies employed. For instance, although the choice of IMX219-77 cameras and Nvidia Jetson Nano offers specific advantages in terms of resolution and computational power, the exclusion of other alternatives may limit the scope of the research.

For instance, further research may be needed to determine the effectiveness of the algorithms and techniques under specific conditions. Additionally, since this study only evaluated a specific hardware and software configuration, different results may be obtained on different platforms and applications. By utilizing more powerful software and hardware components, advancements in this field of study can be further pursued. And also, future research can contribute to a better understanding of the potential in this area by further developing these technologies and testing them in different applications.

CONCLUSION

The study's findings highlight the significant advancements achieved through the integration of electro-optical systems, deep learning algorithms, and computer vision technologies within defense and security applications. Utilizing stereo vision technology and sophisticated object detection methods, defense strategies can now efficiently identify threats, track targets, and conduct reconnaissance missions with precision. This research establishes the critical role of electro-optical systems in safeguarding national security by enabling essential tasks such as reconnaissance, threat detection, and target identification. Specifically, the combination of IMX219-77 cameras and Nvidia Jetson Nano, alongside OpenCV and GStreamer, has demonstrated remarkable performance in object detection, tracking, and distance measurement tasks. The robustness and efficiency of the MOSSE algorithm for object tracking, coupled with accurate depth estimation enabled by stereo vision techniques, underscore the reliability and effectiveness of the implemented methodologies. With observed error margins falling within acceptable ranges, the study provides valuable insights into the practical application of electro-optical systems for defense purposes, including a margin of error of 0-2 mm in the x-y plane. Moreover, by leveraging the potential of electro-optical systems and computer vision algorithms, defense strategies can be fortified to mitigate risks and safeguard against potential threats effectively. Furthermore, the study's forward-looking perspective emphasizes its contribution to future research and development in defense technologies, offering insights and methodologies for further advancements in object detection, tracking, and measurement techniques. This research also underscores the rapid advancements in computer vision and video surveillance technologies, showcasing their transformative impact not only within defense and security sectors but also across various industries including healthcare and industrial applications, thus reflecting their broader implications and potential.

ETHICAL DECLARATIONS

Referee Evaluation Process
Externally peer-reviewed.

Conflict of Interest Statement
The authors have no conflicts of interest to declare.

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Author Contributions
All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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Personalized special training follow-up application Cardiofit2

Bilge Esin Akbaba[1], Elif Akpınarlı[1], Fatih Sarısoy[2], Büşra Yılmaz[2], Ömer Şenel[3], Mehmet Günay[4]

[1]*Department of Computer Engineering, Gazi University, Ankara, Turkiye*
[2]*Faculty of Sport Sciences,Gazi University, Ankara, Turkiye*
[3]*Department of Coaching Education, Faculty of Sport Sciences, Gazi University, Ankara, Turkiye*
[4]*Department of Physical Education and Sports Education, Faculty of Sport Sciences, Gazi University, Ankara, Turkiye*

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Corresponding Author: Büşra Yılmaz, busra.yılmaz7@gazi.edu.tr

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ABSTRACT

Mobile applications are preferred by many people due to the convenience they provide to users and their low cost. Mobile applications, which are widely used in many fields, also appear in many different forms in the field of fitness and health. Mobile application experts, who closely follow technological developments, update these applications periodically. Thus, with new training and nutrition recommendations provided to users, users are provided with easy access to technological developments as well as developments in sports. Mobile applications also aim to create a fitness and health routine for their users in daily life with the feedback they provide based on user preferences and motivating warnings to users. The fitness and health application we have developed called "Cardiofit2" also allows users to save their personal information and access personalized exercise programs created using this information. The application is designed to enable users to easily achieve their fitness goals with weekly exercise programs in the short and long term. It also aims to provide more comprehensive support to users with features such as exercise history, daily water consumption warnings, pedometer and smart watch integration. Cardiofit2 is an improvable platform that helps users gain healthy lifestyle habits with its aesthetic design and strong technical infrastructure. The application aims to guide users in achieving their fitness goals with its user-friendly interface, personalized exercise programs and health tracking features. It supports users' transition from a sedentary lifestyle to a healthier lifestyle with regular feedback and motivational alerts.

Keywords: Fitness, kotlin, firebase, mobile application

INTRODUCTION

Nowadays, increasing interest in a healthy lifestyle has increased the use of mobile applications. Mobile fitness applications offer strong support to individuals in setting, tracking and achieving personal health goals with the advantages offered by portable technology. For this reason, many people use fitness applications to improve their physical and mental health [Yu et al., 2021; Liu et al., 2016].

A number of innovative technologies in mobile fitness applications are also used to monitor general activity and physical conditions. In particular, there are many applications for weight loss and exercise tracking. As a result of the research, it was concluded that there are more than 30,000 health and fitness applications worldwide [Ahn et al., 2023]. These applications, which appeal to a wide user base, bring the world of fitness to mobile platforms, allowing individuals to increase their physical activity levels and take steps towards a healthy lifestyle [Yu et al., 2021; Liu et al., 2016].

Applications that focus especially on home-based exercises offer a suitable alternative for adults, providing positive behavioral development in the individual with the approach of using social cognitive theory and persuasive technology principles, and also support psychological mechanisms for users to maintain their exercise habits with home-based mobile applications [Voth et al., 2016; Khaghani-far et al., 2016; Nissen et al., 2022].

A study examining long-term use effects provides important insights into how users use fitness apps and why they stop using them [Herrmann et al., 2017]. In this context, ease of use, satisfaction, fitness success and social connection stand out among the factors that determine users' intention to continue using applications [Curralo et al., 2022; Jee, 2017].

SmartStep provides an important example of integrating the step counting feature in the project [Hegde et al., 2016; Voth et al., 2016]. SmartStep stands out with its ability to classify daily activities such as sitting, standing, walking and cycling with high accuracy. This feature inspired the integration of a similar step counting feature in the project in the context of tracking and analyzing the activities performed by users [Hegde et al., 2016].

On the other hand, a smart watch step counting application developed for adults also provides an important example that can be evaluated in the project [Folkvord et al, 2021; Yang et al., 2020; Chalmers et al., 2021; Bhargava et al., 2020]. This application includes a special step counting algorithm and has achieved successful results in young adults in laboratory studies and short-term field studies [Boateng et al., 2022].

Mobile fitness applications have a key role in helping individuals achieve their healthy life goals with their various features and design elements that appeal to a wide range of users [Zhang et al., 2020]. However, greater emphasis on user experience needs to be placed in the design of these applications, data collection methods need to be standardized, and strategies to encourage long-term use by users need to be developed [Philip et al., 2022; Germini et al., 2022]. In this regard, the closer interaction of fitness applications with their users and the provision of personalized services further contributes to increasing the use of these technologies [Higgins, 2015; Rockmann et al., 2019].

This study aims to contribute to individuals reaching their personal health goals more consciously and effectively by emphasizing the importance of mobile technology in the field of health and fitness. The exercise program of the application has been prepared by sports scientists who are experts in the field. In addition, Cardiofit2 was inspired by the studies carried out in the field during the development phase of the application, ensuring that it is a user-friendly application.

METHODS

Kotlin programming language was used in addition to Firebase and Android Studio during the development process of the mobile fitness application.

Firebase's real-time database feature, users can instantly track their exercise levels and dynamically adjust their programs. Firebase's workout data and level management capabilities create a strong foundation for supporting users in reaching their fitness goals and creating personalized workout programs. This platform effectively stores users' preferred exercise types, set goals, and daily exercise times, providing a completely personalized exercise experience within the application.

Users can also integrate their smart watches into the application. Heart rate data, Firebase It works synchronously with the application through real-time database solutions such as Realtime Database or Cloud Firestore. In this way, users can see their heart rate changes while exercising or tracking their daily activities. Thanks to Firebase's powerful infrastructure, this data is stored and retrieved quickly, so users can access accurate and up-to-date information at any time. This heart rate data of the users is constantly updated and recorded within the application.

During the development process of the project, Kotlin language was preferred and Android Studio was used. Giraffe | Version 2022.3.1 was used. Kotlin is a programming language recommended and supported by Google, especially for Android application development. While this language incorporates the powerful features offered by Java, it also provides a more effective experience for developers by offering a more modern, expressive and error-proof structure.

The application, developed for mobile devices using the Kotlin language on Android Studio, had an efficient development process thanks to Kotlin's flexible structure and short code blocks. Since Kotlin is compatible with Java, it allows the use of existing Java libraries without any problems.

The Kotlin language in the development of the application that works compatible with smart watches has been an important factor, especially in terms of effectively processing the sensor data provided by smart watches. The extensive standard libraries in the Kotlin language and the nature of the language have enabled the performance of the smartwatch application to be increased and developed quickly.

Core KTX (1.7.0) is the library used to optimize the core functionality of the application and the interaction with the Android platform. It is compatible with projects written in Kotlin and has facilitated the development processes of the project.

AppCompat (1.6.0): Standardized the unit visibility and behavior of the application interface, providing a consistent experience across a wide range of devices.

Material Components (1.6.0): It is a library that provides UI components and style support in accordance with Google's Material Design guidelines. It has helped the application to have a modern and user-friendly interface.

Jetpack Compose (1.8.2): It is a framework that supports modern Android UI design Notified data changes automatically updated the UI, simplifying the development process and improving code readability.

Firebase Authentication: It is a library used for user authentication and management It was used to ensure secure authorization processes of users.

Firebase Firestore: Firebase, a real-time database It is a library that stores and syncs application data with Firestore. It was used to quickly synchronize application data between users.

Firebase Cloud Messaging (FCM): Used to make users interactive and send notifications on a daily basis.

Firebase UI (8.0.2) firebase It is a library for quickly creating UI components using Firestore . It was used to make it easier for users to interact with the database.

These libraries supported different aspects of the project and contributed to the application providing a strong user experience. The use of each library is chosen to meet the specific requirements of the project and optimize your development process. Various features offered by Firebase are seamlessly integrated in the Android Studio environment with the application written using the Kotlin language.

Kotlin, Firebase It works in harmony with features such as Authentication and Realtime Database, ensuring the security of user data and effective management of real-time updates. Modern features of the Kotlin language have made Firebase integration more readable and manageable.

Studio's advanced emulator support has been a great advantage in the process of testing applications developed using the Kotlin language in accordance with different screen sizes and device features. The expressive power provided by the Kotlin language has allowed tests on the emulator to be carried out more comprehensively and effectively. Using the Kotlin language reduced code duplication in the overall development process of the project, facilitated debugging processes, and made applications more readable and maintainable. These advantages of the Kotlin language, together with Android Studio, allowed the project to be implemented more efficiently. In this way, the development process progressed faster and eventually a mobile application emerged that offers users a more powerful and robust mobile experience.

Exercise Models Offered by the Mobile Application to Users

The exercise program page of the developed application at different loads represents a modular design that allows users to access and manage exercise programs within a certain period of time. These designs are programs that offer customized exercises that guide users to reach the optimal fitness level in a specified time.

The 12-Week Exercise Program provides users with a two-week adaptation at a lower load and includes a special RecyclerView to ensure optimal adaptation to exercise during this period and to get maximum efficiency from the planned exercise program.

In Figure 1: A first level tightening program is offered to users over the ideal weight, tailored to their resting heart rate and personal characteristics.

1.-2 . Weeks	3.-4. Weeks	5.-6.-7.-8. Weeks	9.-10.-11.12. Weeks
10 Dk Warm up Run 5 Dk Stretch Vo2 Max =%50-55 2 Days in a Week 400 Kcal /2 Target Time = 40dk Colling Down 5 Dk	10 Dk Warm up Run 5 Dk Stretch Vo2 Max = %50-55 3 Days in a Week 600 Kcal /3 Target Time = 30 Dk Colling Down 5 Dk	10 Dk Warm up Run 5 Dk Stretch Vo2 Max = %60-65 3 Days in a Week 900 Kcal /3 Target Time = 45 Dk Colling Down 5 Dk	10 Dk Warm up Run 5 Dk Stretch Vo2 Max = %70-75 4 Days in a Week 1600 Kcal /4 Target Time = 60 Dk Colling Down 5 Dk

Figure 1. Level one exercise program

When planning the exercise program, appropriate heart rate ranges are automatically calculated by the program, taking into account the user's resting heart rate and age. When the smart watch exceeds or falls below these heart rate ranges, the smart watch gives an audible and vibrating warning and ensures that the user stays within the heart rate ranges calculated according to his personal characteristics. During the first two weeks of adaptation, users are helped to adapt to exercise with 200-kcal or 40 minutes of light-paced workouts two days a week. In weeks 3 and 4, users are expected to complete a 200-kcal exercise in 30 minutes. 5.6.7.8. During the following weeks, users are expected to complete a 300-kcal exercise in 45 minutes. 9.10.11.12. During the following weeks, users are expected to complete a 450-kcal exercise in 60 minutes. Each The exercise starts with a 10-minute warm-up run followed by 5 minutes of stretching movements. Exercises are completed with a 5-minute low-tempo cool-down run. 12 weeks old After the exercise period, the second level exercise program is unlocked for users, and users can continue the 8-week level 2 exercise program with the new calculated heart rate intervals.

8-Week Exercise Program: Users are expected to be at their ideal weight or have completed the first level exercise program. It aims to provide users with maximum efficiency in a shorter time with 8-week individually planned exercises.

In Figure 2: Users who are at their ideal weight or who have successfully completed the first level exercise program are offered an 8-week second level exercise program tailored to their resting heart rate and personal characteristics.

1.-2 . Weeks	3.-4. Weeks	5.-6. Weeks	7.-8. Weeks
10 Dk Warm up Run 5 Dk Stretch Vo2 Max =%50-55 3 Days in a Week 600 Kcal /3 Target Time = 30dk Colling Down 5 Dk	10 Dk Warm up Run 5 Dk Stretch Vo2 Max = %50-55 4 Days in a Week 1000 Kcal /4 Target Time = 40 Dk Colling Down 5 Dk	10 Dk Warm up Run 5 Dk Stretch Vo2 Max = %60-65 4 Days in a Week 1200 Kcal /4 Target Time = 45 Dk Colling Down 5 Dk	10 Dk Warm up Run 5 Dk Stretch Vo2 Max = %70-75 4 Days in a Week 1600 Kcal /4 Target Time = 60 Dk Colling Down 5 Dk

Figure 2. Second level exercise program

In the second level exercise program, the first 1.2 in the heart rate intervals calculated individually from the users. During the following weeks, users are expected to complete a 200-kcal exercise in 30 minutes, 3 days a week. In weeks 3 and 4, users are expected to complete a 250-kcal exercise in 40 minutes, 4 days a week. 5.6. During the following weeks, users are expected to complete a 300-kcal exercise in 45 minutes, 4 days a week. 7.8. During the following weeks, users are expected to complete a 400-kcal exercise in 60 minutes, 4 days a week. Each exercise begins with a 10-minute warm-up run followed by 5 minutes of stretching movements. Exercises are completed with a 5-minute low-tempo cool-down run.

In Figure 3: The flow diagram of the developed mobile application and the steps of the application such as registration, gender selection, physical characteristics, training target smart watch connection are presented in detail.

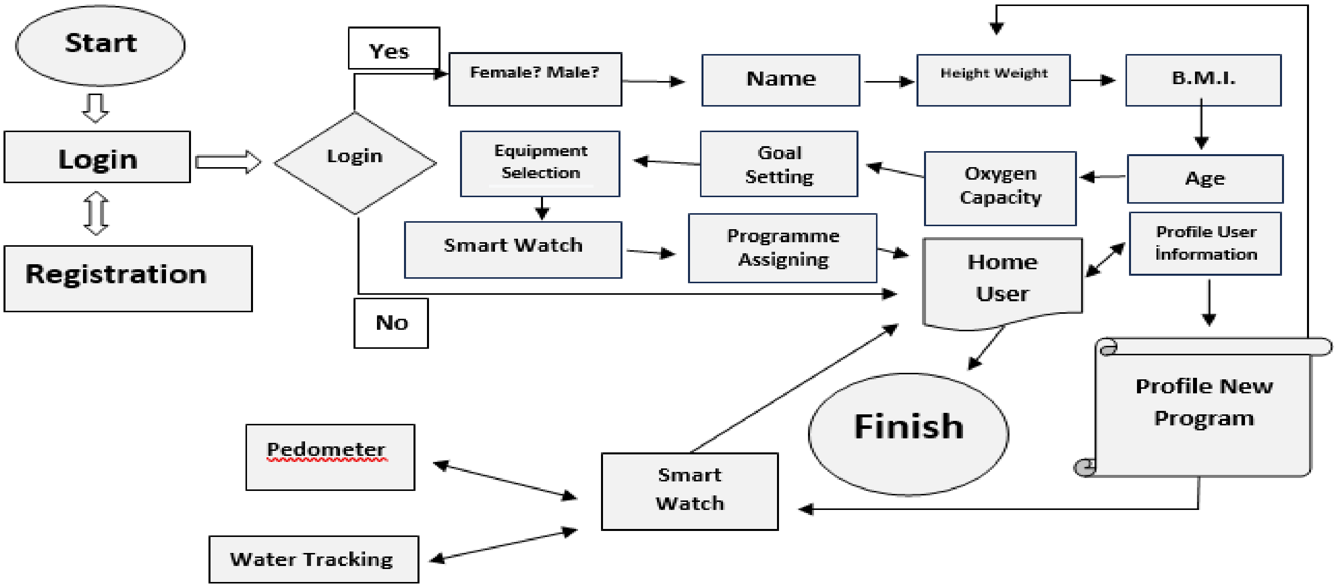

Figure 3. Cardiofit2 flow diagram

In Figure 4: After users download the mobile application from playstore, the user is greeted by the registration page. After the user registers to the mobile application with a personal e-mail, the mobile application asks the user to enter physical characteristics such as age, gender, height and weight. Based on the training goal chosen by the user, the sports equipment he owns and the information he has entered into the mobile application, a personalized exercise model and pulse ranges are determined for the user to achieve optimal efficiency. The user can then access the personalized exercise program when he/she logs in to the application with the e-mail he/she registered with. The mobile application also offers users the ability to view their exercise history, step counting and daily water tracking. The mobile application instantly retrieves users' heart rate data from Firebase via the integrated smart watch and reports it weekly as a graphic.

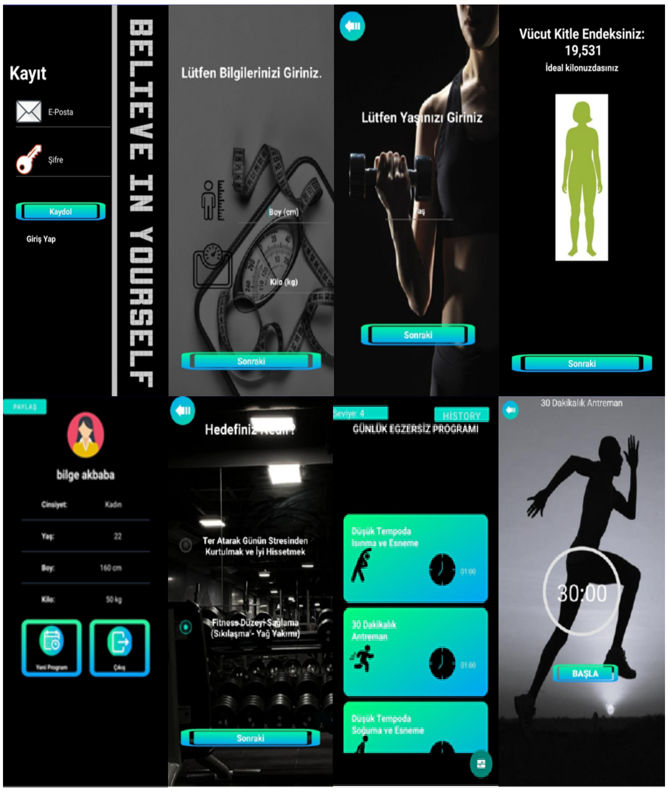

Figure 4. Registration page of the mobile application, personal information.

The mobile application aims to ensure that the user gets maximum efficiency from the exercise by giving vibrating and audible warnings when the pulse exceeds or falls below the range, so that the users stay within the individually determined pulse ranges during exercise with the integrated smart watch.

In Figure 5: The water tracking feature allows controlling daily water consumption by calculating the amount of water that should be consumed daily with the "kilo*0.33 formula" according to the personal characteristics of the users. The mobile application aims to reach the ideal daily water consumption by sending water drinking reminders to users at regular intervals. Users enter the amount of water they consume in ml on the water tracking page. They can also track the amount of water consumption retrospectively. Daily water consumption tracking has been added to increase the functionality of the mobile application and make it more useful.

Figure 5. Water tracking

In Figure 6: The pedometer feature is designed for users to track the total distance traveled during exercise by recording their daily step counts. This feature allows users to access past records as well as track their daily activities. Monitoring historical records and reporting the increase in performance aims to motivate users and encourage them to maintain healthy lifestyle habits.

Figure 6. Pedometer

In Figure 7: The Mobile Application uses the smart watch's health services access feature to access users' instantaneous heart rate data and transfer this data to Firebase. It saves to Firestore In addition, it constantly monitors the pulse ranges in the individually planned exercise, thus contributing to getting maximum efficiency from the planned exercise program by giving audible and vibrating warnings to the users to stay at the maxwmum and minimum pulse values determined in the program. The mobile application works integrated with the smart watch, providing a comprehensive solution focused on healthcare services and thus providing users with an interactive, user-friendly experience. In this respect, the mobile application successfully handles both technical details and complex scenarios related to healthcare. The collaboration of the mobile application with the smartwatch application provides the user with an optimally personalized health and fitness experience.

Figure 7. Instant pulse

CONCLUSION

The mobile application we have designed is designed to provide a personalized and motivating fitness experience to support users in reaching their fitness and health goals.

The mobile application encourages users to adopt healthy living habits with its aesthetic design and strong technical infrastructure. Its user-friendly interface, customized exercise programs and health tracking features make the application a valuable and effective assistant for users. This application provides guidance on achieving fitness goals and supports users in maintaining a healthy lifestyle.

This comprehensive fitness application has the potential to become a platform that can be further developed in the future. AI integration in future versions of the app may further enrich the user experience. In this way, artificial intelligence integration can make the process of using the application smarter and more interactive for users, enabling them to achieve their wellness goals faster and more effectively.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally refereed.

Conflict of Interest Statement

The authors do not have a conflict-of-interest statement.

Financial Disclosure

The authors declare that this study has received no financial support.

Author Contributions

All authors declare that they agree with the design, implementation, and analysis of the article and approve the final version

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Diabetes prediction utilizing soft voting classifier

Erkan Akkur

Turkish Medicines and Medical Devices Agency, Ankara, Turkiye

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Corresponding Author: Erkan Akkur, eakkur@gmail.com

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ABSTRACT

Diabetes is one of the dangerous diseases that bring about abnormalities in blood sugar levels. Early treatment can mitigate the negative consequences of this disease. Machine learning algorithms can be leveraged to predict this disease at an early stage. In this study, a soft voting ensemble classifier approach combining random forest, AdaBoost and gradient boost algorithms is adopted to predict diabetes with the highest possible accuracy. The proposed method was tested on a publicly available dataset. The proposed approach predicted diabetes with 100% accuracy. As a result of the experiments conducted within the scope of the study, polyuria and polydipsia variables were found to be the most significant risk factors for this disease. The suggested approach outperformed similar studies in the literature.

Keywords: Diabetes prediction, machine learning, ensemble learning, soft voting classifier

INTRODUCTION

Diabetes is a chronic disease characterized with abnormal levels of sugar in the blood. It may occur when insulin is not produced enough and cells are not sensitive enough to its action. The global statistics available indicate that this disease affected 529 people in 2021. Should the incidence of diabetes maintain its current rate, it is projected that 1.3 billion people will be affected by diabetes in 2050. This situation underscores the prevalence and prominence of this disease as a global health problem (Ong et al., 2023). Diabetes is characterized by several contributing factors and human errors that render the diagnosis of this disease complex. A blood test may not provide sufficient information for an adequate diagnosis of the disease. Generally, the initial symptoms of diabetes are so subtle that not even an experienced physician can identify them accurately (Alam et al., 2021). Diagnosing the disease at an early stage and identifying risk factors is crucial to address the increasing challenges in preventing diabetes and the barriers in managing the disease and its complications, as it has become a mandatory component of healthcare delivery worldwide.

Machine learning (ML) is a process of analyzing and mining data at a large scale (big data) to help discover knowledge. There has been substantial attention on ML and data mining approaches for the diagnosis, management and other associated clinical management of diabetes in recent years. By attaining high prediction rates, such algorithms can help physicians with accurate prognostic predictions based on patient clinical data and can be leveraged for diagnostics in new patient enrolments (Chaki et al., 2022). Furthermore, it is feasible to boost the performance of ML algorithms by implementing different methods. Ensemble learning (EL) techniques, which attempt to build models based on multiple classifiers instead of a single classifier, are one of the methods used to enhance model performance by compensating for the disadvantages of single classifiers. When multiple classifiers are applied together to train the input data, the actual predictions may outperform the result obtained by a single classifier (Mienye et al., 2022).

This study aims to predict diabetes disease and identify risk factors using a soft-voting ensemble learning model by leveraging a dataset generated following the risk factors of diabetes disease.

LITERATURE SURVEY

There are many studies in the literature on self-management, automatic detection, diagnosis and self-management of diabetes through ML algorithms. Laila et al. (2022) tested different ensemble ML algorithms to predict risk factors in the early stage of diabetes disease. Experiments were performed on a dataset collected from the UCI repository of several datasets comprising 17 risk factors. The random forest (RF) algorithm attained the highest prediction rate with 97% accuracy. Dutta et al. (2022) sought to predict diabetes at an early stage by proposing a model that addresses ensemble learning. The study leveraged methods such as missing value imputation, feature selection and k-fold cross-validation to ready the dataset for classification. The prediction model attained an accuracy of 73.5% and an AUC of 0.832. Rahman et al. (2023) suggested a ML-based approach for the prediction of this disease using socio-demographic attributes. RF algorithm yielded a higher prediction rate with 99.36% accuracy in comparison to other methods. The SHAP analysis was used to identify variables that are associated with diabetes risk. Al-Haija et al. (2022) conducted a study including a comparative analysis of various classifiers to analyse the risk factors of the disease. The study used a dataset with different symptoms, known as Diabetes Risk Prediction. The Shallow neural network (SNN) method attained an accuracy rate of 99.23%. Sen et al. (2023) attempted to predict this disease using decision tree-based ensemble learning models. The Extra Tree method yielded the highest prediction rate with 99.2% accuracy. Gundogdu (2023) introduced a model that blends the XGBoost algorithm and RF feature selection. As a result of the study, the suggested method attained an accuracy of 99.2% and an AUC of 0.993. Bhat et al. (2023) tried to predict diabetes disease using different ML algorithms. The Pima Indian diabetes dataset of 768 patients from the UCI was employed. As a consequence of the experiments, the decision tree technique performed the best with an accuracy rate of 91%.

PROPOSED METHODOLOGY

In this study, a soft voting ensemble classifier is used to classify diabetes as positive and negative. Figure 1 presents the proposed ensemble architecture.

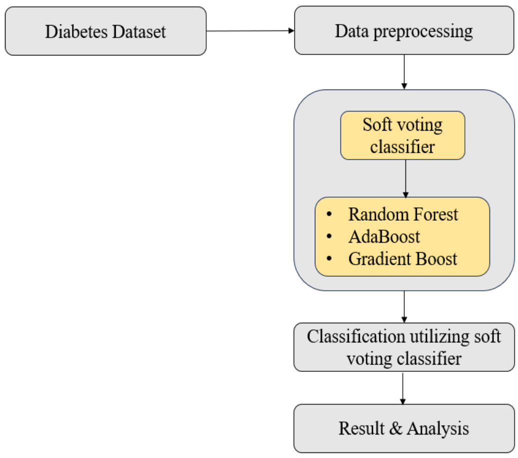

Figure 1. Suggested model architecture

Dataset

The dataset employed in this study was produced by Islam et al. (2020) and can be retrieved from the UCI machine learning repository. It is made up of data collected from 520 patients at Sylhet Diabetes Hospital in Sylhet, Bangladesh through a questionnaire survey. Of the 520 patients, 320 were positive and 200 were negative. The dataset is organized into 16 attributes including symptoms related to diabetes. All features except age have categorical values such as Yes/No. These features are tabulated in Table 1.

Table 1. Features information of the dataset

No	Features	Range
1	age	[20-65]
2	gender	Male, Female
3	polyuria	yes, no
4	polydipsia	yes, no
5	sudden weight loss	yes, no
6	weakness	yes, no
7	polyphagia	yes, no
8	genital trush	yes, no
9	visual blurring	yes, no
10	itching	yes, no
11	irritability	yes, no
12	delayed healing	yes, no
13	partial paresis	yes, no
14	muscle stiffness	yes, no
15	alopecia	yes, no
16	obesity	yes, no

Data pre-processing

Data pre-processing is a crucial step in converting data into a handy and productive format that can be ingested into a ML algorithm (Garcia et al., 2016). Firstly, it was checked whether there was any missing data in the data set, and it was seen that there was no missing data in the data set. Then, the yes/no categorical values in the data set were converted into 0 and 1 numerical values by one-hot encoding method.

Model Architecture

The suggested method involves a soft voting ensemble classifier including random forest (RF), gradient boost (GB) and AdaBoost algorithms.

- **Random Forest (RF):** This model seeks to enhance the classification value in the classification process by creating more than one decision tree. In the model, the highest-scoring decision tree is selected among the independently considered decision trees (Breiman, 2001).
- **AdaBoost:** This model is a boosting algorithm that aims to obtain stronger learners through progressive fusion using multiple weak learners. The algorithm works by iteratively training weak learners and assigning higher importance to erroneous cases resulting from previous classifiers (Sevinc, 2022).
- **Gradient boost (GB):** This model adopts the gradient boosting technique to transform weak learners into strong learners. Each new decision tree created in the algorithm is based on the principle of minimizing the errors calculated in the previous tree. In the algorithm, a prediction is initially derived with the generated decision tree. The difference between the prediction and the target is calculated. In each new iteration, a new tree is formed with the calculated difference. As a result, the aim is to zero the difference between the prediction and the target (Aziz et al., 2020).
- **Soft voting ensemble classifier (SVE):** The EL algorithms are methods that aim to bring together different classifiers called individual learners and can provide successful results in predictive studies. The SVE method is a flexible, easy and powerful EL approach that can yield high performance in classification problems. It classifies the input data according to the probability of all predictions generated by the different individual classifiers. This method seeks to sum the prediction probabilities produced by the individual models for the class labels and to predict the class label with the highest probability (Ruta et al., 2005).

RESULTS AND DISCUSSION

The SVE model combining AdaBoost, RF and GB algorithms was utilized to predict diabetes risk. For the training and testing process, the dataset was randomly subdivided into 80% training data and 20% test data. To determine the optimum hyperparameters of the ML algorithms, hyperparameter tuning was conducted with the GridSearchCV procedure in the Sklearn library (Pedregosa et al., 2011). Table 1 illustrates the best parameter combination resulting from the grid search.

Accuracy, precision, recall and F1-score performance metrics were adopted to evaluate the robustness and efficiency of the algorithms, respectively. Table 2 presents the performance of the individual classifiers for the prediction of diabetes. When the results were analyzed, the RF algorithm attained a better prediction rate than the other models with 97.6% accuracy, 98.45% precision, 96.88% recall and 97.66% F1-Score.

Table 2. The best hyperparameters of ML algorithms

RF	AdaBoost	GB
n_estimators=200	n_estimators=100	n_estimators=200
max_depth=50	learning_rate=0.01	learning_rate=0.1
random_state=42	random_state=42	random_state=42

The SVE approach was utilized to improve the performance of the individual classifiers and provide an efficient prediction rate. Figure 2 shows the confusion matrix of the proposed model for correctly or incorrectly predicted diabetes. The SVE approach correctly classified all positive and negative examples in the dataset.

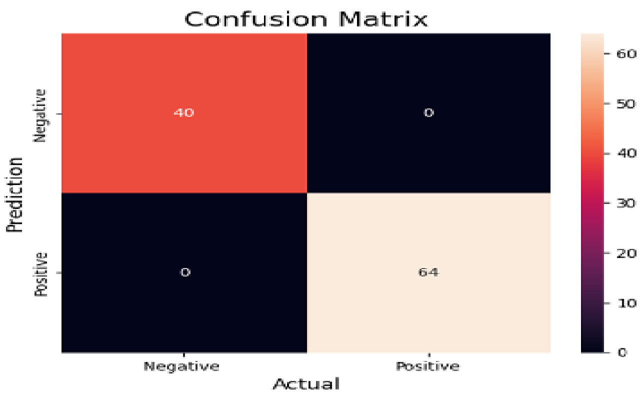

Figure 2. The confusion matrix of suggested soft voting classifier

The comparative analysis graph of the individual classifiers and the proposed SVE approach to diabetes disease prediction is presented in Figure 3. The SVE technique enhanced the performance of the individual classifiers and attained 100% accuracy.

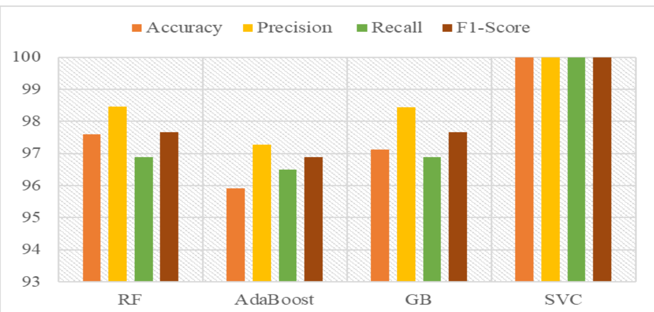

Figure 3. The comparison of individual classifiers with the suggested soft voting classifier approach

Table 3. Prediction results of the models according to performance measures

Models	Accuracy	Precision	Recall	F1-score
RF	97.6	98.45	96.88	97.66
AdaBoost	95.92	97.28	96.49	96.88
GB	97.12	98.44	96.88	97.66

In addition to classification, ML algorithms can measure the relative importance of each feature in a dataset. Figure 4 depicts the feature relative scores of RF, AdaBoost and GB algorithms for the diabetes dataset. Accordingly, all three algorithms considered polyuria and polydipsia considered as the most significant risk factors for diabetes mellitus. Polyuria is defined as excessive urine secretion and polydipsia as excessive thirst. The studies in the literature on the risk factors of diabetes mellitus indicate that polyuria and polydipsia are the most prominent risk factors as reported in this study (Pawar et al., 2017; Sekowski, 2022). The presence of polydipsia and polyuria may indicate elevated blood sugar levels in the body. It is vital to control blood sugar to prevent any health complications that may arise from this condition (Balaji, 2019).

Figure 4. The feature relative scores of diabetes

Table 4 shows the classification performance of the proposed prediction model for the prediction of diabetes compared to the studies conducted in the literature using the same dataset. After the comparisons, the proposed model achieved a high prediction rate compared to similar studies in the literature.

Table 4. Comparison of the suggested model with similar studies in the literature

Study	Model	Accuracy (%)
Laila et al. (2022)	RF	97.00
Sen et al. (2023)	Extra Tree	99.20
Gundogdu (2023)	XGBoost	99.20
Rahman et al. (2023)	RF	99.36
Suggested Model	SVE	100

CONCLUSION

Diabetes can affect many people dangerously today. Early diagnosis can mitigate the consequences of this disease. The method proposed in this study has achieved remarkable results in predicting diabetes. In addition, the variables of polyuria and polydipsia, which are selected to be the most significant risk factors of diabetes, are consistent with the studies in the literature. Investigating the effectiveness of deep learning algorithms for diabetes prediction is planned in future studies.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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