----- RENEWABLE ENERGY TECHNOLOGIES -----

ARTIFICIAL INTELLIGENCE IN TRACKING SYSTEMS

Preparation of Training Documents for Installation, Repair and Storage Systems of Solar Energy Systems Supported by Artificial Intelligence and Increasing Energy Efficiency

2023 -2-TR01-KA210-VET-00017445

Co-funded by the Erasmus+ Programme of the European Union

This individual learning material was written within the scope of the Erasmus+ Project titled 'Preparation of Training Documents for the Installation, Maintenance and Storage Systems of Artificial Intelligence Supported Solar Energy Systems and Increasing Energy Efficiency'.
2022-1-TR01-KA220-VET000085806.
It is intended to guide vocational education trainers. It is free for users, cannot be sold. It cannot be duplicated. It will be published as an e-book on the Project Website (https://ai-solarpower.com/)

It is funded by the Erasmus+ Program of the European Union. However, the European Commission and the Turkish National Agency cannot be held responsible for any use of the information contained herein

EFCC
Estonian Fieldbus Competency Centre

UCILISTE FINIS

CONTENTS

EXPLANATIONS

AREA	**Energetics**
BRANCH/PROFESSION	
THE NAME OF THE MODULE	**ARTIFICIAL INTELLIGENCE IN TRACKING SYSTEMS**
DESCRIPTION OF THE MODULE	The module provides general information about Artificial Intelligence and Tracker systems in power generation systems and explains the installation, maintenance and repair of these systems.
DURATION	**40/32**
PRECONDITION	This module does not have any prerequisites.
COMPETENCY	Introduces the basic concepts and facts related to the subject.
PURPOSE OF THE MODULE	**General Purpose** This module on the installation and repair of Artificial Intelligence (AI) assisted solar energy systems and energy storage systems aims to provide participants with knowledge and skills in innovative energy solutions. **Objectives** 1. ARTIFICIAL INTELLIGENCE IN TRACKER SYSTEMS 1.1. Introduction 1.2. What is Object Tracking System (Tracker) with Artificial Intelligence?

	1.3. Artificial Intelligence Basics 1.4. Working Principle of Tracker Systems 1.5. Algorithms Used in Tracker Systems with Artificial Intelligence 1.6. Application Areas 1.7. Advantages of Object Tracking Systems with AI 1.8. Challenges and Limitations 1.9. Future Trends 1.10. Software and Tools Used in AI Based Tracker Systems
EDUCATIONAL ENVIRONMENTS AND EQUIPMENT	**Environment:** Renewable energy technologies area, renewable energy systems workshop **Equipment:** Basic electrical knowledge, basic electronic knowledge
MEASUREMENT AND EVALUATION	At the end of the module, the teacher will evaluate the knowledge and skills acquired in the module applications by using an assessment tool (multiple choice test, true/false test, gap filling, matching etc.).

INTRODUCTION

Dear Students

To combat climate change, reduce greenhouse gas emissions and pollution, and ensure a sustainable future for our planet, more and more renewable

power generation plant is installed, we are now on the threshold of a Green Energy revolution. It's the people

and offers great opportunities for companies and you need to understand what Green Energy is and

It is very important that you gain knowledge, skills and abilities related to the production and related operations.

It is very important to be familiar with the basic concepts and definitions of the energy science discipline.

In this module, you will learn how to integrate artificial intelligence technologies in solar energy systems.

The technical information required for the uninterrupted utilisation of solar energy will be discussed in detail, how these technologies contribute to system installation and maintenance processes, and which strategies are used to increase energy efficiency.

In addition, focusing on energy storage solutions, the technical information required for the uninterrupted use of solar energy will be presented.

LEARNING ACTIVITY –1

PURPOSE

Installation, repair and energy supply of artificial intelligence-supported solar energy systems This module on storage systems will provide participants with innovative energy solutions aims to gain knowledge and skills in the subject.

RESEARCH

- Artificial Intelligence and Object Tracking Fundamentals
- Object Tracking Algorithms and AI Models
- Real Time Object Tracking Systems
- Challenges Encountered in AI Supported Object Tracking Projects

1 ARTIFICIAL INTELLIGENCE IN TRACKING SYSTEMS

1.1 Introduction

Tracker systems are technologies used to track and record the movement of an object over time. The efficiency of these systems increases, especially with the integration of artificial intelligence (AI) technologies. AI provides a powerful tool for recognising and tracking objects and analysing their motion. These lecture notes detail how AI is used in tracker systems and the basic principles of this field.

1.2 What is Object Tracking System (Tracker) with Artificial Intelligence?

Object tracking systems integrated with AI are used to identify specific objects in images or videos and track their movements in real time. These systems detect the movements of objects by processing data from various sensors and can track a specific target.

1.3 Artificial Intelligence Basics

AI is a technology that encompasses the processes of analysing data, learning and making decisions. The use of AI in tracker systems plays a major role in the recognition and tracking of objects. Here are some basic AI concepts used in this field

1.3.1 Machine Learning (ML)

Machine learning is a branch of artificial intelligence that enables computers to make predictions or decisions by learning from data. ML algorithms are programmed to find

patterns and relationships in data and make predictions or decisions with this information. These algorithms 'train' themselves based on data to fulfil a specific task and can evolve on their own without user intervention.

Machine learning is generally divided into three main categories:

1. Supervised Learning
In supervised learning, the algorithm is given a data set with the correct labels. The algorithm learns to match each dataset with the correct class or output value and is trained in this way. This category is divided into two main subclasses:

Classification: Allows data samples to be assigned to predetermined classes. For example, classification algorithms are used to determine whether an email is spam or not.

Regression: Used to predict a continuous output. For example, regression models that analyse historical house sales data are applied to predict house prices.

2. Unsupervised Learning
Unsupervised learning works with unlabelled data. The algorithm discovers patterns and relationships in the data on its own. This type of learning is particularly used in tasks such as data discovery and segmentation:

Clustering: The algorithm divides the data into groups with similar characteristics. For example, clustering methods can be used for customer segmentation.

Dimensionality Reduction: It tries to minimise information loss by reducing the size of the data. This is important to reduce processing costs in large data sets.

3. Reinforcement Learning
Reinforcement learning allows the algorithm to learn from its surrounding environment. An agent (artificial intelligence) performs actions to accomplish a specific task and is rewarded or penalised according to each action. Over time, it learns the strategy that will bring the highest reward. This type of learning is particularly used in robotics, autonomous vehicles, games and optimisation problems.

1.3.2 Deep Learning (DL)

Deep learning is a subfield of machine learning and uses multilayer artificial neural networks that learn features from data, mimicking the neural networks in the human brain. These algorithms, which require big data and powerful processors, are particularly successful with complex datasets (such as visual, auditory or language data).

Deep learning models consist of different levels of 'layers'. These layers categorise the data into increasingly more abstract levels, starting from the simplest features, and at each layer a new level of information is learned. This learning process increases the model's ability to recognise and make sense of objects or patterns.

Basic Structures of Deep Learning Algorithms:

Artificial Neural Networks (ANN):
A simple artificial neural network consists of several input and output layers. Such neural

networks are used to solve basic classification and regression problems.

Convolutional Neural Networks (CNN):
Widely used in visual data analysis. Thanks to the convolutional layers, CNNs perform operations such as object recognition and classification with high accuracy by detecting important features (such as edges, colours, patterns) in the image.
Recurrent Neural Networks (RNN) and Long Short-Term Memory (LSTM):
RNNs, which work on time-based data, are used especially for sequential data such as text and audio data. LSTM structures are more successful in learning long-term dependencies by providing better memory management than classical RNNs.

Generative Adversarial Networks (GAN):
It consists of two neural networks: Generator and Discriminator. These two networks compete with each other to produce more realistic data. GANs are used for creative content development in many areas such as image generation, style transfer and game character creation.

Transformers:
Widely used, especially in natural language processing (NLP). Transformer models provide faster and more efficient language processing by taking into account relations on ordered data. Models such as BERT, GPT are based on this structure.

1.3.3 Computer Vision

Computer vision is a branch of artificial intelligence that recognises, classifies and makes sense of objects in digital images by analysing visual data (such as pictures and videos). It aims to enable computers to perceive and interpret the visual world by imitating the human visual system. This technology is powered by artificial intelligence, deep learning and machine learning algorithms.
Computer vision learns specific patterns or features by analysing large amounts of image data. With various algorithms and deep learning models, computers can recognise, classify and even predict objects or specific movements in an image.

Computer vision techniques are as follows;

- Image Processing
- Feature Detection and Recognition
- Object Recognition and Classification
- Object Tracking
- Segmentation
- 3D Image Understanding

1.4 Working Principle of Tracker Systems

Tracker systems are mechanical systems that follow the sun according to its position and thus increase energy production by taking the rays vertically. Thanks to these systems, it is aimed to utilise solar energy throughout the day and to increase the efficiency and the participation of the lost part back into the system.

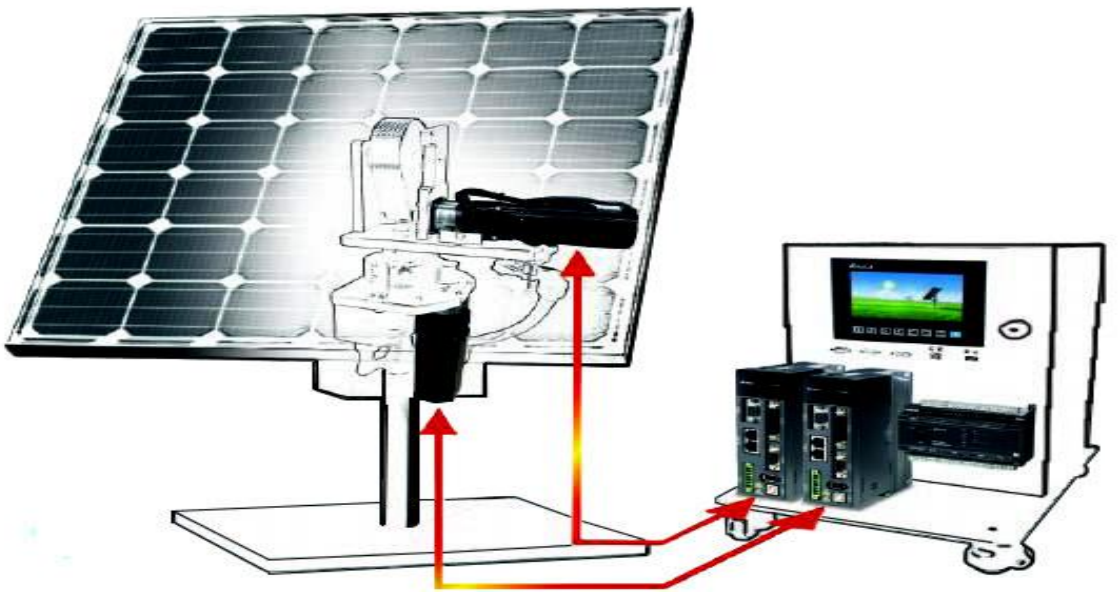

Figure1: Solar Tracker System Applications (https://www.durusolarenerji.com.tr/hizmet/22/gunes-takip-sistemi-solar-tracker-uygulamalari)

Tracker systems are technologies developed to continuously track a specific object or group of objects and monitor their motion characteristics such as position, speed, direction. These systems enable real-time tracking of objects in many areas such as security, autonomous vehicles, health, industrial automation. Tracker systems basically analyse the movement of objects using image data, radio frequency (RF) signals or data from other sensors.

1.4.1 Object Recognition

Solar (solar-powered) object recognition tracker systems are solar-powered systems capable of object recognition and tracking. These systems offer an energy-efficient solution, especially in open areas, in places where access to energy infrastructure is difficult or where long-term operation is required. It is generally preferred in security, environmental monitoring, agriculture, wildlife tracking and smart city applications. Being solar supported, it provides an environmentally friendly and sustainable structure.

Object recognition is the process of identifying a specific object in an image or video. In this process, AI-based algorithms analyse the properties of objects and recognise them.

1.4.1.1 *YOLO (You Only Look Once)*

YOLO (You Only Look Once) is a fast and efficient deep learning algorithm used in object recognition and detection. By analysing all objects in the image in a single pass, YOLO achieves much faster results than other object recognition algorithms. This feature makes YOLO ideal for real-time applications, especially in security, autonomous driving and video analysis systems..

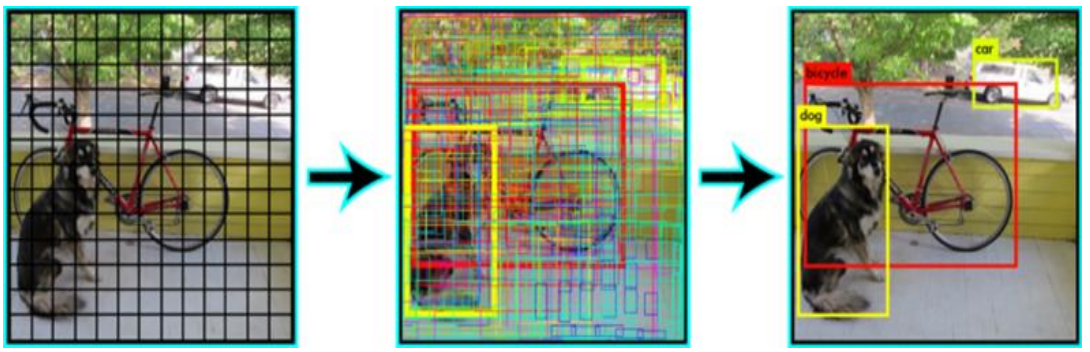

Figure 2: YOLO (Image Processing)(https://smartera.com.tr/gercek-zamanli-nesne-takibireal-time-object-detection-w-yolo-python/)

1.4.1.2 *Faster R-CNN*

Today, researchers who have started to give the ability to see to machines thanks to certain algorithms can achieve the greatest help in this regard thanks to CNN (Convolutional Neural Network) algorithms.

As I mentioned in my CNN Convolutional Neural Networks article, the CNN algorithm is used in many areas such as face recognition, image classification and object detection. But this excellent algorithm also has some weaknesses. The biggest of these weaknesses is that it can only detect one object at a time. In order to overcome this weakness, the R-CNN, Region Based CNN architecture was created.

There are four members of the R-CNN family. These are R-CNN, Fast R-CNN, Faster R-CNN and Mask R-CNN. These algorithms are the continuation of each other.

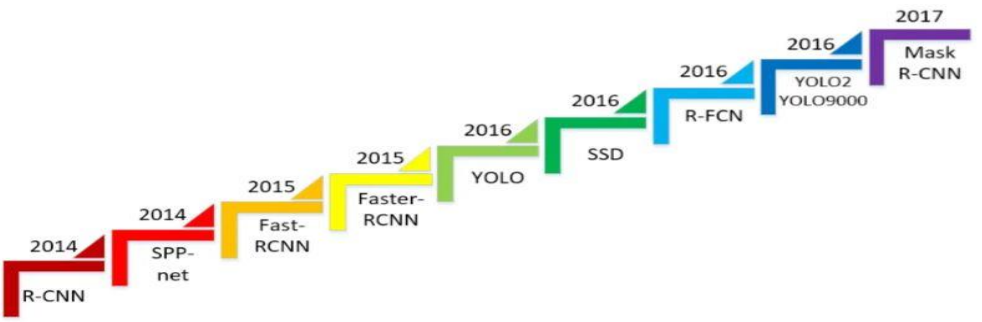

Figure 3: CNN Image Processing (Change over the years)
(https://kaanugurluoglu123.medium.com/nesne-tan%C4%B1ma-algoritmas%C4%B1-faster-r-cnn-nedir-1738f0cca8b7)

1.4.1.3 *Siamese Networks*

Siamese networks, often also called twin networks, consist of a pair of neural networks that share weights and aim to compute similarity functions. Below is an example of a Siamese network architecture.

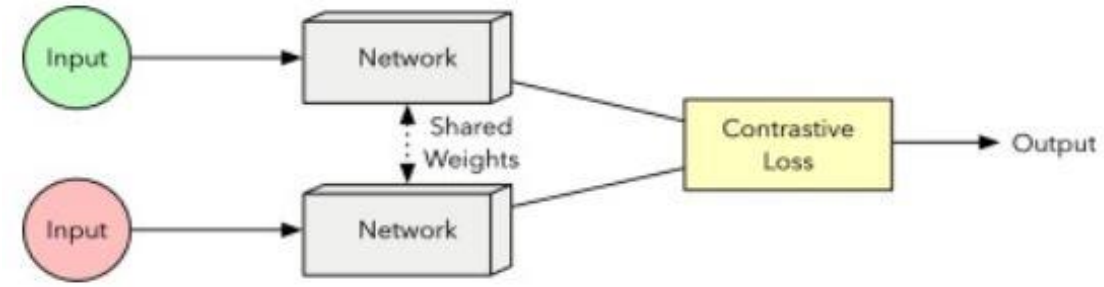

Figure 4: Siamese Network Architecture
(https://www.sciencedirect.com/topics/computer-science/siamese-neural-network)

An interesting point is that Siamese networks can consist of networks such as multilayer perceptrons, convolutional neural networks and even recurrent neural networks. Such a capability increases its applicability as efficient when dealing with a variety of applications such as handwriting recognition, automatic detection of faces and matching queries to index documents.

1.4.2 Object Tracking

After the object is recognised, the tracking of its movements is started. The basic algorithms used in this process are as follows:

- **Kalman Filter:** It is used to predict the future position of a moving object. It is especially successful in slow moving objects.
- **Optical Flow (Optical Flow):** It monitors the movements of the pixels in the image and determines the direction of the object.
- **DeepSORT:** It is a deep learning based tracking algorithm. It analyses the properties of objects and optimises the tracking process.

1.5 Algorithms Used in Tracker Systems with Artificial Intelligence

Artificial intelligence-supported solar trackers increase energy production capacity by enabling solar panels to follow the sun at the most efficient angle. These systems use algorithms that continuously optimise the angle of the panels according to the position of the sun. Thanks to artificial intelligence algorithms, this tracking process is made more precise and efficient.

- The main algorithms used in solar tracking systems are as follows;
- PID (Proportional-Integral-Derivative) Control Algorithm
- Neural Network Based Sun Tracking Algorithm
- Genetic Algorithm (GA)
- Fuzzy Logic Based Algorithms
- Support Vector Machines (SVM)
- Feature Matching Based Image Processing Algorithms

1.5.1 PID (Proportional-Integral-Derivative) **Control Algorithm**

The PID control algorithm is used to precisely adjust the angle of the solar panel. It ensures that the solar panel remains in the correct position when approaching the target angle. It is especially used in mobile systems, allowing the panels to precisely follow the sun.

PID (Proportional-Integral-Derivative) Control Algorithm is one of the most widely used control algorithms in industrial automation and control systems. The PID algorithm calculates the error value to ensure that the system reaches a specific target (for example, temperature, speed, pressure or solar panel angle) and takes corrective actions to minimise this error.PID, üç ana bileşenden oluşur:

P - Proportional:

The proportional component produces an output proportional to the magnitude of the current error. If the error becomes larger, the control signal also becomes larger and thus the system reacts faster.

Coefficient (Kp): Known as the proportional gain coefficient. This coefficient determines how strong a corrective effect the error will have on the system. If the Kp value is too high, the system may overreact and cause fluctuations; if it is too low, it will be slow to reach the target value.

I - Integral:

The integral component corrects long-term errors by calculating the sum of errors accumulated in the past. When the error is persistent, it creates a corrective effect in the system.

Coefficient (Ki): The coefficient of the integrated gain. Ki, if the error accumulates over time, it is eliminated through this component and enables the system to reach the target. However, if the Ki value is too high, problems such as the system overreacting and not reaching equilibrium may occur.

D - Derivative:

The derivative component takes into account the rate of change of the error. This component allows the system to react quickly to sudden changes and reduces fluctuations.

Coefficient (Kd): It is the derivative gain coefficient. Kd prevents overreaction by balancing the reaction to sudden changes in the system. However, if the Kd value is too high, the system becomes too sensitive to control signals and noise may increase.

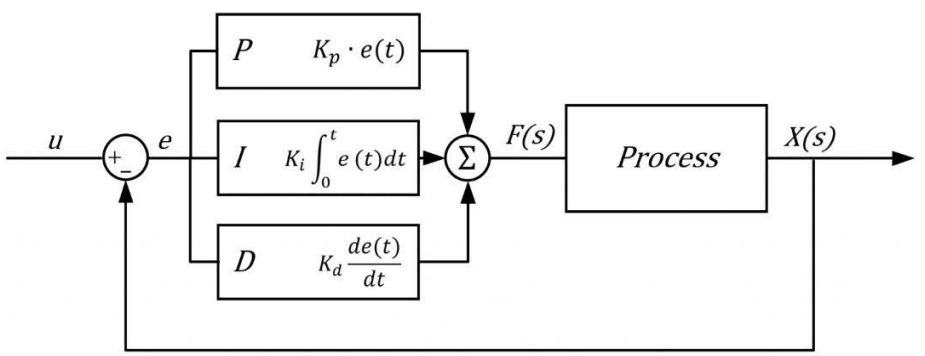

Figure 5: PID Control Algorithm (https://www.otomasyondepo.com/pid-kontrolor-nedir/)

PID Control in Solar Tracking Systems

In solar tracking systems, the PID algorithm continuously updates the angle of the solar panels

and optimises them according to the sun. In this way, the panels follow the sun from the most accurate angle and energy efficiency is increased. The PID controller can also quickly adapt to sudden changes by adjusting the angle of the panels according to the movement speed of the sun.

Example: In a panel that monitors the daily movement of the sun, the PID control algorithm determines a position that minimises the margin of error depending on the rate of change of the sun's position. It adjusts the direction of the panel according to the rapidly changing light angle, allowing it to receive sunlight from the most efficient angle.

Advantages and Disadvantages;

Advantages:

- **Easy Applicability:** The PID algorithm can be easily applied in many systems and is highly effective.
- **Adaptability**: It adapts to both simple and complex control needs.
- **Sensitivity**: It allows the system to respond correctly, especially to fluctuations and sudden changes.

Disadvantages:

- **Difficulty of Adjustment**: Correct adjustment of the Kp, Ki, and Kd coefficients is time consuming. Incorrect adjustment may cause the system to be unstable or operate too slowly.
- **Sensitivity to Noise**: The derivative component can lead to incorrect results in noisy environments.

The PID algorithm offers a highly efficient and effective solution when used correctly in applications that require continuous and precise movement, such as solar tracking systems.

1.5.2 Neural Network Based Solar Tracking Algorithm

The neural network-based solar tracking algorithm uses machine learning and deep learning models to predict the position of the sun and continuously optimise the solar panels accordingly. Unlike traditional solar tracking systems, neural network-based approaches adapt to environmental changes and increase energy efficiency by optimising the angle of the panels even in cloudy weather.

What is an Artificial Neural Network?

Artificial neural networks (ANN) are computer systems developed with the aim of automatically realising the abilities such as deriving new information, creating and discovering new information through learning, which are the characteristics of the human brain, without any help.

Artificial neural networks have emerged as a result of mathematical modelling of the learning process by taking the human brain as an example. It imitates the structure of biological neural networks in the brain, learning, remembering and generalisation capabilities[2]. In artificial neural networks, the learning process is performed using examples. During learning, input and output information is given and rules are set.

Advantages of Artificial Neural Networks

- Artificial Neural Networks consist of many cells and these cells work simultaneously to perform complex tasks.
- They have the ability to learn and can learn with different learning algorithms.
- They can produce results (information) for unseen outputs. There is unsupervised learning.
- They can perform pattern recognition and classification. They can complete missing patterns.
- They have fault tolerance. They can work with incomplete or uncertain information. They show graceful degradation in faulty situations.
- They can work in parallel and process real-time information.

Artificial neural networks are mainly used in areas such as diagnosis, classification, prediction, control, data association, data filtering and interpretation. In order to determine which network is more suitable for which problem, it is necessary to compare the properties of the networks with the properties of the problems.

Usage Areas of Artificial Neural Networks

- **Computational finance:** Credit scoring, Algorithmic trading

- **Image processing and computer vision:** Face recognition, motion detection, object detection

- **Computational biology:** Tumour detection, Drug discovery, DNA sequencing

- **Energy production:** Price and load forecasting (price and load forecasting)

- **Automotive, aerospace and manufacturing:** Predictive maintenance

- Natural language processing: Voice assistant, Emotion analysis

Biological Foundations of Artificial Neural Networks

Artificial neural networks consist of neurons (nerve cells). Neurons have the ability to process information. Neurons form functions by connecting with each other. It is estimated that there are 100 billion neurons in our brain. A neuron can make 50.000 - 250.000 connections with other neurons and it is estimated that there are more than 6×10^13 connections in our brain.
Studying the behaviour of living things, modelling them mathematically and producing similar artificial models is called cybernetics[4]. The desired point is to try to model the learning and application structure of the human brain with neural networks that can be trained, self-organised, learn and evaluate. In order to perform a job on a computer, it is necessary to know its algorithm. An algorithm is a set of basic command sequences to convert input to output. However, there may not be a known algorithm to solve some problems. Desired and undesired situations may change over time or applications that vary according to the user do not have fixed algorithms. If we lack information, we may have plenty of data. We can easily enable the system to learn from thousands of both desired and unwanted examples.
Since the data collection devices in today's technology are digital, it is advantageous for us that the data can be accessed, stored and processed reliably.

So how does a nerve cell work?

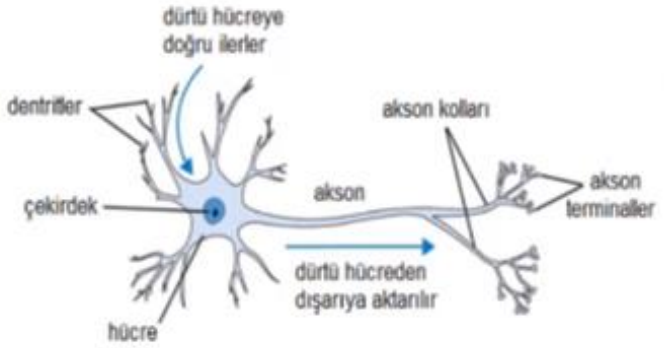

Figure 6: Biological Representation of a Nerve CellControl Algorithm
(https://www.veribilimiokulu.com/yapay-sinir-agiartificial-neural-network-nedir/)

The biological appearance of nerve cells in living organisms is as shown in the figure above. We have a nucleus and transmission along an axon. Here, our sensor data obtained from the dentrite ends at the output terminals are weighted in the nucleus and transmitted along the axon and connected to another nerve cell. In this way, communication between nerves is provided.
The mathematical model of a human nerve cell can be shown as follows:

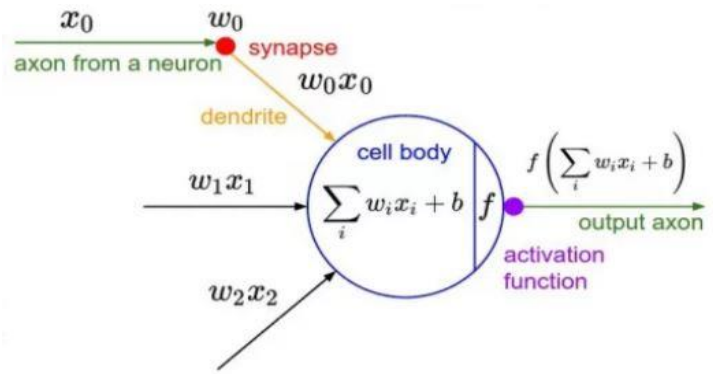

Figure 7: Mathematical Model of a Neural Cell
(https://www.veribilimiokulu.com/yapay-sinir-agiartificial-neural-network-nedir/)

Along the paths we call dendrites, we have weights, and we also have an input value (x0) that may have come from another neuron entering these dendrites. After our input value and the weight in the dendrite (w0) are multiplied (w0x0), it is transmitted to the nerve cell, and this multiplication process is done in the nerve cell. The products of weights and inputs from all dendrites are summed up, which means a weighted sum is performed. Then, after adding a bias (b), it is passed through an activation function and transferred to the output. This output can be the final output or an input to another cell. Mathematically, weights are multiplied by inputs, and a bias is added. Thus, a simple mathematical model is obtained.

The basic operation in Artificial Neural Networks is to calculate the parameters w (weight parameter) and b (bias value) that will give the best score for the model. Each nerve cell is calculated in the same way, and they are connected in series or parallel.

An artificial nerve cell consists of five parts:

1. Inputs: Inputs are the data that come to the neurons. These data from the inputs are sent to the neuron nucleus to be summed up, just like in biological nerve cells.

2. Weights: The information coming to the artificial nerve cell is transmitted to the nucleus by being multiplied by the weight of the connections they come from before reaching the nucleus through the inputs. This allows the effect of the inputs on the output to be adjusted.

3. Summation Function (Integration Function): The summation function is a function that calculates the net input of that cell by summing the inputs coming to an artificial nerve cell after being multiplied by weights.

4. Activation Function: It is a function that takes the weighted sum of all inputs from the previous layer and then produces an output value (typically nonlinear) and passes it to the next layer.

5. Outputs: The value coming out of the activation function is the output value of the cell. Although each cell has multiple inputs, it has only one output. This output can be connected to any number of cells.

Structure of Artificial Neural Networks

Artificial neural networks are structures formed by connecting artificial nerve cells.

Artificial neural networks are examined in three main layers: Input Layer, Hidden Layers, and Output Layer.

Information is transmitted to the network through the input layer. It is processed in the hidden layers and then sent to the output layer. By processing information, we mean converting the information coming to the network into outputs using the network's weight values. For the network to produce correct outputs for the inputs, the weights must have correct values.

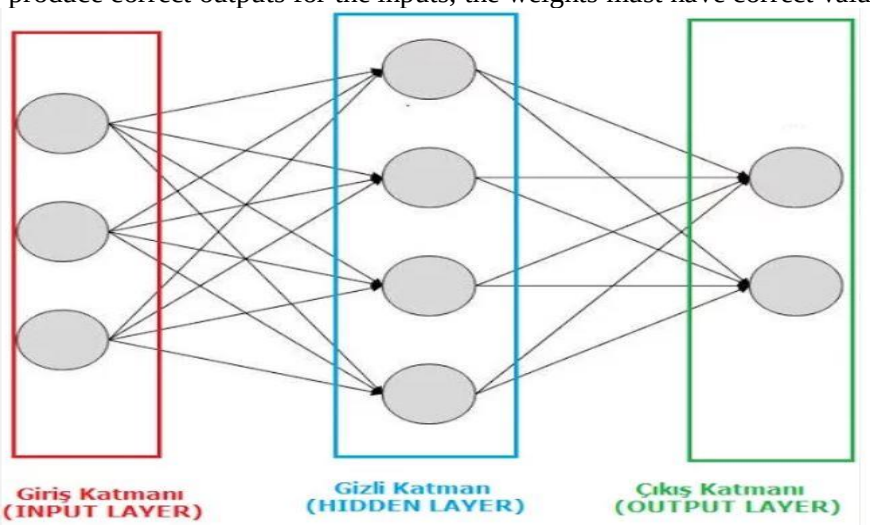

Figure 8: Layers of Artificial Neural Networks
(https://www.veribilimiokulu.com/yapay-sinir-agiartificial-neural-network-nedir/)

If it consists of many neurons and hidden layers, it is called a multilayer artificial neural network. If it consists of a single layer, it is called a single layer artificial neural network.

How Single Layer Neural Networks Work

The simplest type of neural network, single layer neural networks, can be thought of as gates used in logic circuits. The input can either be directly output or added to the next layer. Typically, it has two inputs and one output. Inputs extend along synapses and are multiplied by their weights and passed through a threshold value.

Working Principle of Neural Network-Based Solar Tracking Algorithm

Neural network-based solar tracking algorithms go through a learning process based on past data to control the position of the panels and track the sun. The working principle of these systems generally consists of the following steps:

- **Data Collection and Preparation:**
  Environmental data such as daily and annual solar movements, light intensity, weather conditions, and temperature are collected.
  These data are provided as input to the neural network model to facilitate learning about solar position changes.

- **Model Training:**
  The collected data are fed into a neural network model (e.g., deep neural network or convolutional neural network).
  The neural network learns to predict the position of the sun based on past solar movements and environmental changes. After the model is trained on the data, it enables the panels to be oriented at the optimal angle relative to the sun.
- **PredictionandReal-TimeAdjustment:**The neural network model predicts the position of the sun and adjusts the angle of the panels for maximum efficiency.
  The panels are continuously adapted to the optimal angle calculated by the neural network, ensuring they receive sunlight at the most effective angle throughout the day.

- **Rotationand Feedback:** The system continuously updates the position of the panels based on the sun's movement throughout the day. It also considers real-time environmental conditions to optimize energy production.

Advantages of Neural Network-Based Solar Tracking Algorithms

- **High Accuracy**: Neural networks improve their learning capability as the amount of data increases, enabling accurate predictions of the sun's position.

- **Adaptive Behavior:** Quickly adapts to changing environmental conditions. It operates effectively even in scenarios such as cloudy weather or sudden changes in light intensity.

- **Long-Term Performance:** By learning from historical data, it can adapt to future weather conditions and seasonal changes.

- **High Energy Efficiency**: Ensures panels maintain the most accurate angle, increasing energy production capacity.

Neural Network Models Used:

- **Artificial Neural Networks (ANN):** Ideal for working with small datasets due to their simple and fast learning process. They can be used in solar tracking systems for basic movement predictions.

- **Convolutional Neural Networks (CNN):** Used in solar tracking systems that require image processing capabilities, such as detecting the sun's position or analyzing visual data like cloud density.

- **Recurrent Neural Networks (RNN, LSTM**): Suitable for working with time-series data. They are preferred for long-term predictions of the sun's movement throughout the day.

Applications of Neural Network-Based Solar Tracking Systems

- **Photovoltaic (PV) Power Plants:** Ensures higher energy efficiency by orienting the panels to the optimal angle relative to the sun.

- **Solar Farms:**
  Neural network-based tracking systems are used in large-scale solar farms to improve energy production efficiency.
-
- **Smart City Applications:**
  The integration of solar panels with intelligent tracking systems enables cities to meet their energy needs more sustainably.

Challenges

- **High Computational Power Requirement:** Neural network-based algorithms may require significant computational capacity for model training and execution.

- **Need for Large Data:** The model's accuracy can decrease if sufficient data on solar movements and environmental conditions is unavailable.

- **Cost:** Neural network-based solar tracking systems can be expensive due to their high accuracy and adaptive features.

Neural network-based solar tracking algorithms provide advanced, dynamic, and flexible solutions, particularly excelling in maximizing solar energy efficiency.

1.5.3 Genetic Algorithm (GA)

Genetic Algorithm, widely used in the field of Artificial Intelligence, is a type of optimization algorithm that searches for the best solution. It addresses problem-solving by transforming real-world issues (e.g., how to load containers onto a cargo ship, finding a route from one point to another, or creating an optimal delivery path) into a search problem, which can then be solved using Genetic Algorithms.

Genetic Algorithm (GA) performs permutation-based optimization and functions as a search mechanism under convergence criteria through probabilities. It is a search and optimization method that operates similarly to the evolutionary process observed in nature. In the literature, Genetic Algorithm is described as follows: "The Genetic Algorithm is a robust evolutionary strategy inspired by the fundamental principles of biological evolution."

Researchers must first accurately define the variable type and the problem they are addressing and encode it accordingly. Next, the fitness function, one of the algorithm's inputs, is defined, and the objective function to be optimized is this fitness function. Genetic operators such as Crossover and Mutation are stochastically applied at various stages of the evolutionary process, so their probabilities of occurrence must be specified. Finally, convergence criteria must be met, and the problem should be solved with optimal cost. GA performs a global search, not just a local one, to solve problems. When a problem is influenced by many factors, the use of Genetic Algorithms is recommended in the literature.

The basic working principle of Genetic Algorithms can be summarized as shown in the diagram below.

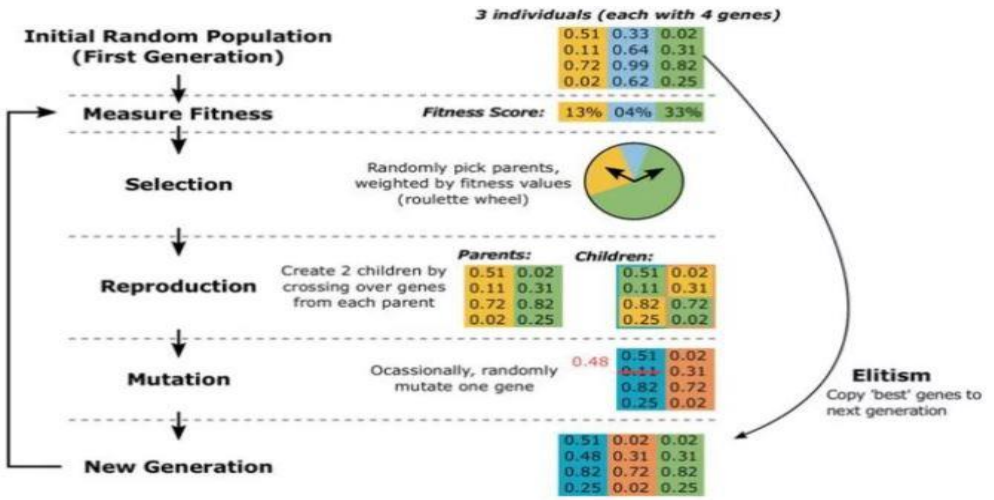

Figure 9: Working Principle of Genetic Algorithm (https://www.nature.com/articles/srep37616)

Application of Genetic Algorithms in Solar Energy

Genetic algorithms (GAs) can be used in solar tracking systems to determine optimized control strategies for panels to follow the sun at the most efficient angle. In these applications, GAs consider factors such as panel angles, ambient temperature, light intensity, and cloud cover to find the optimal angle for maximizing energy production.

- **Positioning of Solar Panels:**
  Genetic algorithms can optimize the placement and angle of solar panels according to a specific objective function. This ensures that the panels collect energy most efficiently throughout the day, accounting for the changing angle of the sun.

- **Increasing Energy Efficiency:**
  Genetic algorithms enhance energy production by accounting for variable environmental

conditions during the day. This system adapts to both daily and seasonal changes through the use of GAs.

Advantages of Genetic Algorithms

- **Potential to Reach Global Optimum:**
  Genetic algorithms are inclined to select the best solution from numerous options, increasing the likelihood of reaching the global optimum while avoiding local minima.

- **Automatic Parameter Adjustment:**
  GAs automatically adjust system parameters to reach the optimal solution.

- **Maintaining Diversity:**
  Through crossover and mutation operations, GAs preserve diversity within the population, enabling the generation of more robust solutions.

Disadvantages of Genetic Algorithms

- **Computational Cost:**
  GAs may require significant computational power when working with large populations and multiple generations.

- **Risk of Over-Parameterization:**
  The parameters, such as crossover, mutation, and selection rates, need to be well-tuned. Poor parameter settings can reduce the algorithm's performance.

Genetic algorithms deliver effective results in optimization problems that require energy efficiency, such as solar tracking systems. By identifying the best positions and angles based on changing environmental conditions, these algorithms provide a significant advantage in renewable energy systems.

1.5.4 Algorithms Based on Fuzzy Logic

Fuzzy Logic is a computational method developed for situations that involve uncertainty and cannot be precisely defined, unlike traditional logic approaches with clear boundaries. This method makes decisions using "fuzzy" rules and degrees instead of strict and exact rules. Algorithms based on fuzzy logic are widely used, particularly in control systems and complex problems that are difficult to predict. In solar tracking systems, fuzzy logic algorithms can also be utilized to adjust the panels to the most efficient angle based on environmental variability.

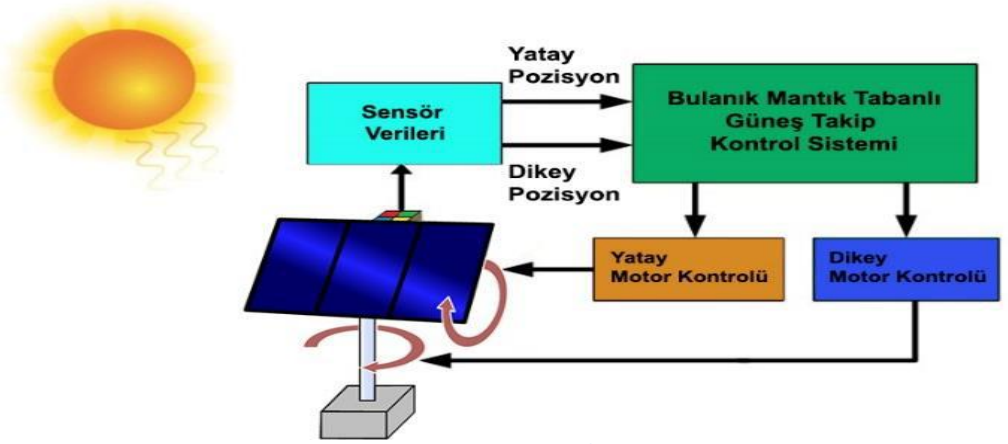

Figure 10: Schematic Representation of the Solar Tracking System (https://dergipark.org.tr/en/download/article-file/1651153)

Working Principle of Fuzzy Logic-Based Algorithms

Fuzzy logic algorithms take input values, fuzzify them according to specific rules, and then produce an output. These algorithms are based on rules structured in an "if-then" format and typically follow the steps below:

1. Fuzzification of Input Variables:

- In the first step, input values are represented using fuzzy sets. For example, input variables like sunlight intensity, panel angle, or ambient temperature are defined with terms such as "low," "medium," or "high."
- Each fuzzy set is represented by membership functions, which determine the degree to which a value belongs to a particular set.

2. Creation of the Rule Base:

- The rule base consists of rules in the "if-then" format. For example:
  - "If sunlight intensity is high and panel angle is low, then tilt the panel upward."
  - "If the temperature is very high, position the panel to operate with minimal efficiency loss."
- These rules form the control strategy that defines how the system operates.

3. Inference Process:

- Based on the defined rules, the output value for each input is calculated. The inference process applies relevant rules to the input variables.
- Multiple rules may be applied simultaneously, and the impact of each rule is evaluated based on a specific degree.

4. Defuzzification:

- In the final step, the fuzzy output values are converted into a crisp value to make a precise decision for the system. Defuzzification is the process of transforming fuzzy results into a control signal applicable to the system.

Fuzzy Logic in Solar Tracking Systems
Fuzzy logic-based algorithms can be used to dynamically control the angle of panels in solar tracking systems. This method considers all environmental variables and ensures the optimal positioning of panels according to sunlight.

For instance, the angle of the panels can be adjusted based on variables such as sunlight intensity, cloudiness, time of day, and ambient temperature. Fuzzy logic provides an effective method for understanding the complex relationships between these variables and enhances the energy efficiency of solar panels.

Example of a Fuzzy Logic Rule Table:

Sunlight Intensity	Panel Angle	Output (Panel Direction)
Low	Low	Turn the panel upwards
Medium	Medium	Keep the panel fixed
High	High	Keep the panel at the optimal angle

Advantages of Fuzzy Logic-Based Algorithms:
- **Flexibility:** Can make decisions in uncertain and ambiguous situations. Even when sunlight is cloudy or variable, it can still make accurate decisions.
- **User-Friendly Rules:** Can work with intuitive rules without the need for complex mathematical models.
- **Adaptability:** Quickly adapts to rapidly changing environmental conditions (e.g., cloud movement, daily light changes).

Disadvantages:
- **Rule Base Maintenance:** As the rule base grows, managing the system can become complex.
- **Difficulty in Defuzzification**: The fuzzification and defuzzification steps require precise adjustments.
- **High Computational Power:** When there are many input variables and rules, the computational cost can increase.

Fuzzy logic-based algorithms provide an effective solution, especially in solar tracking systems where environmental variables change rapidly and require continuous adjustment. These algorithms offer advantages in terms of energy efficiency because they can handle complex rules and data.

1.5.5 Support Vector Machines - SVM
Support Vector Machines (SVM) are one of the most commonly used supervised learning algorithms in machine learning and can be applied in various ways in solar tracking systems. They are particularly preferred due to their high accuracy in classification and regression problems.

In solar tracking systems, environmental data (e.g., light intensity, temperature, weather conditions) can be processed to predict the movement of the sun and adjust the angle of the panels accordingly. SVM is generally used in these systems for the following purposes:

1. Classification: In solar tracking systems, SVM can classify based on the intensity and angle of sunlight. For example, it can classify sunny, cloudy, or shaded conditions based on weather and adjust the panel's position accordingly.

2. Regression: The SVM algorithm can also be used to predict the sun's position. Regression analysis is performed to predict future sun positions based on environmental data (e.g., time of day, season). This ensures that the solar panel is held at the most efficient angle.

3. Increasing Efficiency: In solar tracking systems, SVM can provide optimized decisions to increase energy production efficiency. By determining the optimal panel positions under certain conditions, energy production can be maximized.

Advantages and Challenges of SVM

Advantages:

- **High Accuracy:** SVM can classify data and make predictions with high accuracy.
- **Efficient Performance:** It is particularly effective in analyzing high-dimensional data.
- **Flexibility:** It can be adapted to different types of problems using various kernel functions (e.g., linear, polynomial, Gaussian).

Challenges of SVM

- **Data Processing Cost**: SVM can increase processing costs when working with large datasets.
- **Model Fitting:** To achieve optimal performance, it is essential to select the appropriate kernel function for the model.
- **Supervised Data Requirement**: Since SVM is a supervised learning algorithm, labeled data is required for classification or regression tasks.

Example of SVM Usage in Solar Tracking Systems

As an example, in a solar tracking system, SVM can be used to determine the panel angle based on environmental variables such as temperature, light intensity, and humidity. By using data collected throughout the day, the panels can be adjusted to the optimal angle to track the sun, thus maximizing energy production.

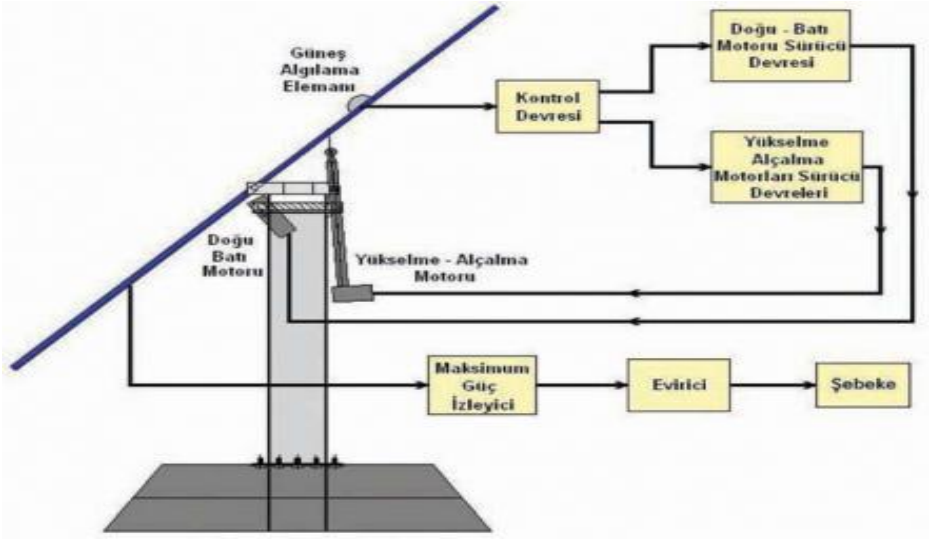

Figure 11: Solar Tracking System (http://www.lorentz-turkey.com/gunes-takip-sistemleri.html)

Support Vector Machines (SVM) play a role in increasing efficiency in solar tracking systems and provide stable optimization in the energy production process based on environmental factors.

1.5.6 Feature Matching-Based Image Processing Algorithms

Feature matching-based image processing algorithms are a commonly used method in tasks such as object recognition and tracking. In solar tracking systems, feature matching algorithms are utilized to precisely determine the sun's position in the sky through image processing. These algorithms extract, analyze, and continuously track distinct features in images, allowing for accurate positioning of the solar panels based on the sun's location. By matching key points in successive images, the system can adjust the panel orientation to follow the sun efficiently, optimizing energy production throughout the day.

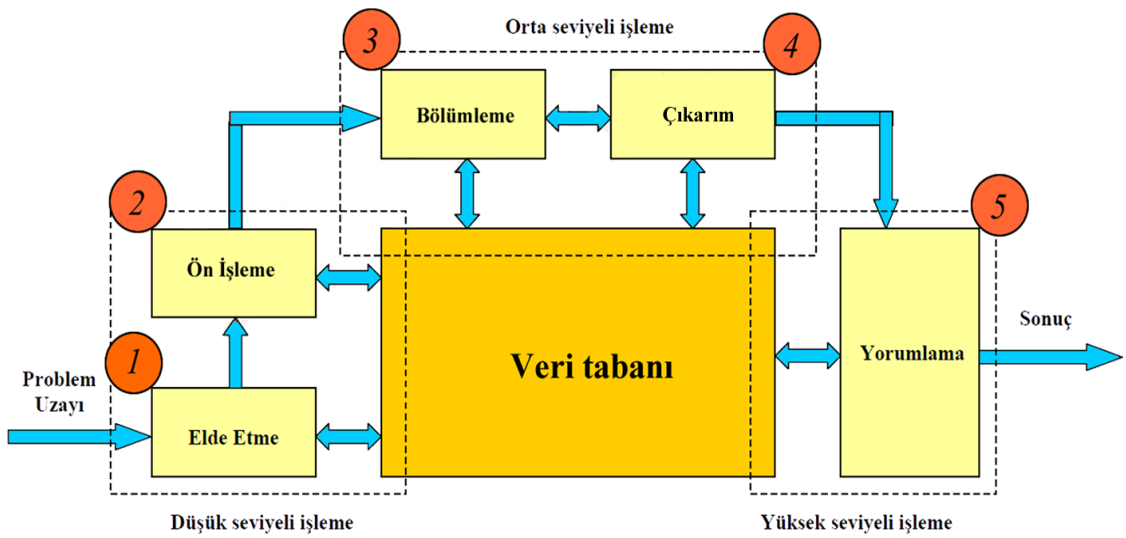

Figure 12: Basic Steps of Digital Image Processing
(https://www.ibrahimcayiroglu.com/Dokumanlar/GoruntuIsleme/Goruntu_Isleme_Ders_Notlari-1.Hafta.pdf)

Principle of Operation of Feature Matching Algorithms

Feature matching-based algorithms detect distinctive features (such as edges, corners, corner points, color patterns, etc.) in an image and use these features to track objects. The process typically consists of a series of steps:

Feature Extraction:
Important features in the image, such as corner points or shape similarities, are detected. For example, object descriptors are obtained using methods like SIFT (Scale-Invariant Feature Transform) or SURF (Speeded-Up Robust Features).

Feature Matching:
The detected features in the image are matched with features from previously acquired reference images. This allows for determining parameters such as the object's position, orientation, and size.

Position and Orientation Determination:
By calculating the positions of features in the images and their relative distances, the object's current position can be predicted.

Object Tracking:
The feature matching step is repeated in new images, allowing for continuous tracking of the object's movement.

These steps enable the use of image processing in solar tracking systems to determine the sun's position. By continuously tracking the sun's movement across the sky, the system ensures that solar panels remain oriented towards the sun at all times.

1.5.6.1 *Applications and Methods of Feature Matching Algorithms*

Feature matching algorithms can be used in solar tracking systems with the following methods and purposes:

1. SIFT (Scale-Invariant Feature Transform) The SIFT algorithm identifies feature points in an image that are invariant to scale and rotation, and matches objects based on these points. In solar tracking systems, feature matching can be performed even in images where the sun is at different angles. This allows the position of the sun to be easily determined despite weather conditions or angular changes.

2. SURF (Speeded-Up Robust Features) Similar to the SIFT algorithm, SURF has a faster computation process. Therefore, it is more frequently preferred in real-time tracking systems. In solar tracking systems, the SURF algorithm is used to quickly and efficiently track the position of the sun. It provides an effective solution, especially for devices requiring low processing power.

3. ORB (Oriented FAST and Rotated BRIEF) The ORB algorithm is optimized for both speed and accuracy and requires less processing power. ORB provides fast results in feature

extraction processes and is a cost-effective solution for solar tracking systems. For example, it can accurately track the position of the sun even in situations where clouds are moving.

4. Template Matching This method is used especially when the sun has a specific appearance. For example, a template where the sun is clearly visible is used to search for this template in other images. The template matching method can provide reliable tracking in less complex environments.

1.5.6.2 *Advantages of Feature Matching Algorithms in Solar Tracking Systems*

The advantages of feature matching-based algorithms in solar tracking systems are as follows:

Fast and Accurate Tracking: Feature matching methods track the sun's position in real-time with high accuracy.

Flexibility: They are capable of tracking the sun even under different weather conditions and angles.

Low-Cost Implementation: Algorithms like ORB operate with low computational power, providing efficient performance in low-cost systems.

Resilience to Environmental Factors:
They continue to accurately determine the sun's position even under changing conditions, such as cloudy or clear skies.

1.6 Application Areas

Artificial Intelligence Applications in Solar Tracking Systems

Solar tracking systems are designed to position solar panels at the most efficient angle by tracking the sun's daily and seasonal movements. These systems can produce 20% to 30% more energy compared to traditional fixed panels. By using artificial intelligence (AI) and machine learning algorithms to track the sun's movement, the accuracy, speed, and adaptability of the systems to environmental changes can be enhanced.

1.6.1 Advantages of Artificial Intelligence in Solar Tracking Systems

The advantages provided by AI applications in solar tracking systems are as follows:

Increased Energy Efficiency: Thanks to AI algorithms, solar panels are positioned at the most efficient angle and more energy is produced.

Real-Time Adaptation: Artificial intelligence adapts to instant environmental changes and follows the position of the sun, making the system more flexible.

Less Maintenance Needed: Thanks to adaptive algorithms, the system requires less human intervention as it optimizes itself according to environmental factors.

Low Cost: As energy efficiency increases, energy production costs decrease, thus ensuring

cost effectiveness in the long term.

1.6.2 Challenges Encountered with AI in Solar Tracking Systems

The use of AI applications in solar tracking systems also presents some challenges:

Data Processing Cost: AI-based techniques such as neural networks and image processing algorithms require high processing power.

Weather-Dependent Performance: When the sun is less visible on cloudy or stormy days, the performance of image processing algorithms may degrade.

Power Consumption: Constantly processing environmental data and analyzing the sun's position can increase energy consumption.

1.6.3 Future Directions

In the future, AI applications in solar tracking systems will become more autonomous and will develop with IoT (Internet of Things) integration. In particular, solar panels in different regions can be connected to each other over the network and efficiency optimisation can be achieved in the light of information such as weather conditions. In addition, storage and management of solar energy will also be improved with AI-supported energy forecasting algorithms.

Artificial intelligence is a powerful tool to increase efficiency and optimise energy production in solar tracking systems. By combining AI techniques such as neural networks, genetic algorithms, fuzzy logic and image processing, both the accuracy and adaptability of solar tracking systems are improved. This leads to more sustainable and cost-effective energy solutions in the long term.

1.7 Conclusion

Solar tracking systems have an important place in the renewable energy sector and increase the energy production capacity by enabling the efficient use of solar energy. The success of these systems relies on the positioning of solar panels at the most favourable angle to the movement of the sun. The integration of artificial intelligence (AI) techniques into solar tracking systems has made it possible to make these processes more precise, flexible and efficient. In this concluding chapter, the role of AI in solar tracking systems, its advantages, challenges and potential future developments will be discussed.

1.7.1 The Role of Artificial Intelligence in Solar Tracking Systems

Artificial intelligence plays a critical role in the optimisation of solar tracking systems. While traditional control methods are usually based on fixed algorithms, AI-based algorithms have the ability to dynamically adapt to environmental variations. This adaptation ensures that energy production is maximised. AI techniques such as neural networks, genetic algorithms, fuzzy logic and support vector machines (SVM) are used to accurately predict the position of the sun and optimise the angle of the panels.

1.7.2 Benefits Provided

1. **Increased Energy Efficiency:** AI-based algorithms can increase energy production

efficiency by 20% to 40% by positioning solar panels at the most favourable angle. This means more energy production and therefore a more economical system.

2. Real-Time Adaptation: Artificial intelligence continuously optimises the angle of the panels by instantly responding to environmental changes. It maintains the system's performance during cloudy days, sudden weather changes or when the sun is moving rapidly.

3. Flexibility and Learning Capacity: AI algorithms can predict future solar movements based on historical data and thus make more accurate adjustments. This allows the system to become more efficient over time.

4. Low Maintenance Need: AI-based systems automatically optimise themselves, reducing the need for human intervention. This reduces maintenance costs and keeps the system running smoothly for longer.

1.7.3 Challenges Encountered

1. High Computing Power Requirement: Powerful processors and high computational capacity are required for artificial intelligence algorithms to work effectively. This can increase costs, especially in large-scale solar tracking systems.

2. Data Requirement and Quality: Large and high quality data sets are needed for AI algorithms to work correctly. Data collection, cleaning and processing processes can be time-consuming and data quality must be maintained during these processes.

3. Weather Dependent Performance: Determining the position of the sun may become difficult on cloudy or rainy days. The performance of image-based algorithms may decrease depending on weather conditions, which may negatively affect energy efficiency.

4. Cost: The initial costs of AI-based solar tracking systems may be higher than conventional systems. High costs can be an obstacle for investors, especially in small-scale projects.

1.7.4 Future Developments

1. More Advanced Algorithms: The development of deep learning and other advanced AI techniques can further improve the accuracy and efficiency of solar tracking systems. In particular, transfer learning and online learning methods will enable systems to adapt faster to environmental changes.

2. IoT Integration: Integration with the Internet of Things (IoT) can optimise energy management by enabling solar tracking systems to operate over a wider data set. Data collected through IoT devices can be processed by AI algorithms to make more comprehensive and accurate predictions.

3. Autonomous Systems: AI-supported autonomous solar tracking systems will continue to be developed as structures that can optimise themselves and minimise maintenance requirements. This will make the systems more long-lasting and efficient.

4. Energy Storage and Management: AI algorithms can enable more efficient use of solar energy by integrating with energy storage systems. Optimising the balance between energy

production and consumption will improve the overall efficiency of the system.

1.7.5 Conclusion and Recommendations

Artificial intelligence applications in solar tracking systems play an important role in improving energy efficiency and providing sustainable energy solutions. The integration of artificial intelligence algorithms has made it possible for systems to adapt to environmental changes, optimise energy production and reduce costs. However, there are challenges such as high computational costs, data requirements and performance degradation due to environmental conditions.

Recommendations: Algorithm Optimisation: Research should continue to make AI algorithms more efficient and cost-effective. In particular, optimisation techniques can be developed to reduce energy consumption and computational costs.

Data Collection and Management: Collection of high quality and large data sets will improve the accuracy of AI algorithms. It is important to automate data collection processes and develop data management systems.

Resilience to Environmental Conditions: Hybrid systems can be developed to improve performance in regions with harsh weather conditions. Solutions that integrate sensor data as well as image-based algorithms may be preferred.

Cost Effective Solutions: More economical hardware and software solutions should be developed to reduce the cost of AI-based solar tracking systems. This will enable the systems to reach a wider audience.

Autonomous and Integrated Systems: Autonomous solar tracking systems integrated with IoT and other technologies will contribute to sustainable energy solutions by further optimising energy management.

In conclusion, artificial intelligence-supported solar tracking systems have great potential for the efficient use of renewable energy resources and sustainable energy production. With the advancement of technology, these systems are expected to become more widely and effectively available. This will increase energy efficiency, reduce environmental impacts and lower energy costs.

MEASUREMENT AND EVALUATION 1

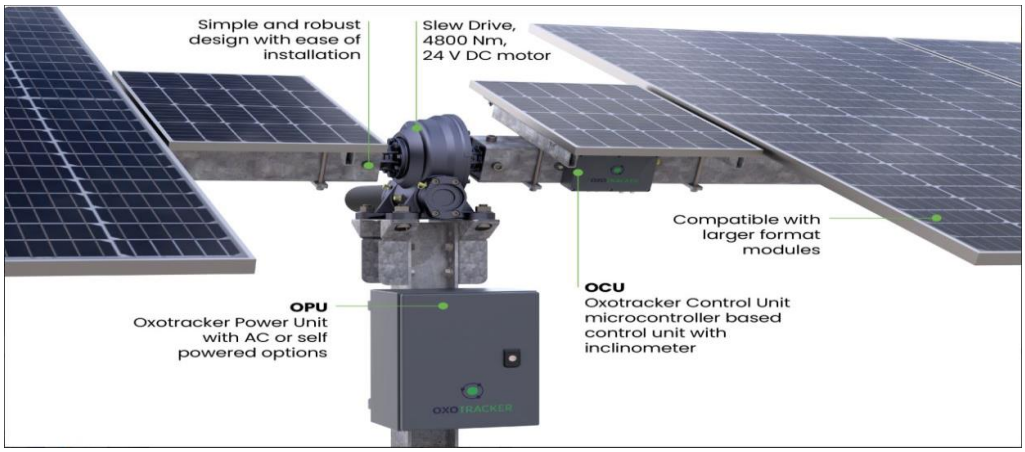

Figure 13: Tracker Sistemlerde Yapay Zeka(YZ)(https://solaravm.com/gunes-takip-sistemi-ve-yazilimi)

Read the questions carefully and choose the correct answer.

1. The following is not one of the categories of machine learning.
A) Supervised Learning
B) Unsupervised Learning
C) Learning with Flow Diagram
D) Reinforcement Learning

2. Which of the following is not one of the basic structures of deep learning?
A) Consumer Networks
B) Artificial Neural Networks
C) Convolutional Neural Networks
D) Recurrent Neural Networks

3. Which of the following is not one of the algorithms used in object recognition detection?
A) YOLO
B) C++
C) Faster R-CNN
D) Siamese Network

4. Which of the following is not one of the algorithms used in the object tracking process?
A) Kalman Filter
B) Optical Flow
C) DeepSORT
D) Fuzzy Logic

5. Which of the following is not one of the main algorithms used in solar tracking systems?
A) PID
B) Fuzzy Logic
C) Optical Flow
D) Support Vector

MODULE EVALUATION

Write the appropriate words in the empty spaces in the sentences below.

1._____ , is a technology used to track and record the movement of an object over time.

2. _____ ; is a branch of artificial intelligence that enables computers to make predictions or decisions by learning from data.

3. _____ , is a technology that covers the processes of analysing data, learning and making decisions.

4. _____ ; is a subfield of machine learning and uses multilayer artificial neural networks that learn features from data by imitating neural networks in the human brain.

5. _____ is a branch of artificial intelligence that analyses visual data (pictures and videos) to recognise, classify and make sense of objects in digital images.

6. _____ , is the process of identifying a specific object in an image or video.

7. PID control algorithm is used to precisely adjust the angle of the _____.

Write the letters 'T' if true and 'F' if false opposite the information given below.

1.( ) The integrated component corrects long-term errors by calculating the sum of errors accumulated in the past.

2.( ) The proportional component does not produce an output proportional to the magnitude of the current error.

3.( ) The PID control algorithm is one of the most widely used control algorithms in industrial automation and control systems.

4.( ) Artificial neural networks consist of two main layers.

5.( ) SURF is similar to the SIFT algorithm, but has a slower computation process.

1. What can be done to increase energy efficiency in artificial intelligence applications in solar tracking systems?

_____
_____
_____
_____

2. What are the advantages of artificial intelligence in solar tracking systems?

_____
_____
_____
_____

EVALUATION

Please compare your answers with the answer key. If you have incorrect answers, you need to revise the Learning Activity. If you answer all the questions correctly, please contact your teacher and move on to the next learning activity.

ANSWER KEYS

Measurement and Evaluation-1:

1	C
2	A
3	B
4	D
5	C

Module EVALUATION:

Gap Filling:

1	TRACKER SYSTEMS
2	MACHINE LEARNING
3	ARTIFICIAL INTELLIGENCE
4	DEEP LEARNING
5	COMPUTER VISION
6	OBJECT RECOGNITION
7	SOLAR PANEL

True(T) - False(F)

1	T
2	F
3	T
4	F
5	F

1. What can be done to increase energy efficiency in artificial intelligence applications in solar tracking systems?

Artificial intelligence applications in solar tracking systems play an important role in improving energy efficiency and providing sustainable energy solutions. The integration of artificial intelligence algorithms has made it possible for systems to adapt to environmental changes, optimise energy production and reduce costs. However, there are also challenges such as high computational costs, data requirements and performance degradation due to environmental conditions.

2. What are the advantages of artificial intelligence in solar tracking systems?

The advantages provided in solar tracking systems thanks to AI applications are as follows:
1. Increased Energy Efficiency: Thanks to AI algorithms, more energy is generated by positioning solar panels at the most efficient angle.
2. Real-Time Adaptation: Artificial intelligence follows the position of the sun by adapting to instant environmental changes and makes the system more flexible.
3. Less Maintenance Need: Thanks to adaptive algorithms, the system requires less human intervention as it optimises itself according to environmental factors.
4. Low Cost: As energy efficiency increases, energy production costs decrease, thus ensuring cost effectiveness in the long term.

REFERENCES AND SOURCES

REFERENCES

1. Khalifa, A., Zekry, A., & El-kholy, E. E. (2019). "Artificial Intelligence Based Solar Tracking Systems: A Review." *International Journal of Engineering Research & Technology (IJERT)*, 8(12), 850-854. In this study, an overview of artificial intelligence applications in solar tracking systems is presented and efficiency enhancing algorithms are analysed.
2. Vats, R., & Tiwari, G. N. (2019). "Solar Energy Conversion: Photovoltaics, Solar Thermal, and Artificial Intelligence." *Journal of Cleaner Production*, 21(12), 1458-1466. The role of solar energy and artificial intelligence applications in photovoltaic systems is explained.
3. Javed, A., & Irfan, M. (2020). "Intelligent Solar Tracking Algorithms Using Artificial Neural Netwoks for Optimal Performance." *Renewable Energy Systems Journal*, 3(4), 232-245. A study on increasing the efficiency of solar tracking systems using artificial neural networks.
4. Razeghi, G., & Mellit, A. (2021). "Artificial Neural Network-Based Solar Tracking System for Enhaned Energy Production." *Renewable and Sustainable Energy Reviews*, 14(3), 2879-2886. It includes an application where neural network based tracking systems improve energy production performance.
5. Farhoodnea, M., & Mohamed, A. (2022). "Review of Artificial Intelligence Techniques in Solar Power Systems." *IEEE Access*, 10(5), 45667-45678. In this resource, an evaluation of AI techniques used in solar energy systems is presented.
6. Chen, W., & Lee, J. (2022). "Application of Genetic Algorithms and Fuzzy Logic in Solar Tracking Systems." *Renewable Energy*, 18(10), 1568-1580. The use of genetic algorithms and fuzzy logic in solar tracking systems and performance results are discussed.
7. Bhatnagar, P., & Tripathi, S. (2023). "PID and Fuzzy Logic Controllers for Solar Trackers." *Solar Energy Journal*, 45(7), 874-881. The application areas of PID and fuzzy logic algorithms in solar tracking systems are analysed.
8. Solar Energy Industries Association (SEIA). (2023). *Artificial Intelligence in Solar Tracking*.

SOURCES WEB (accessed 06.11.2024)

1. Solar Energy Industries Association (SEIA), *Artificial Intelligence in Solar Tracking*. It provides general information about the use of artificial intelligence in solar energy systems. https://www.seia.org

2. National Renewable Energy Laboratory (NREL), *AI Applications in Solar Tracking Systems*, 2022. A comprehensive paper on how artificial intelligence-based solar tracking systems improve energy efficiency. https://www.nrel.gov

3. Energy.gov, *How Artificial Intelligence Enhances Solar Energy Production*. This paper, published by the US Department of Energy, addresses the impact of artificial intelligence technologies on solar energy efficiency. https://www.energy.gov

4. ScienceDirect, *Artificial Neural Network-Based Solar Tracking and Optimization Algorithms*. A scientific review on the optimisation of solar tracking systems using artificial neural network.https://www.sciencedirect.com

5. IEEE Xplore Digital Library, *Review of Artificial Intelligence Techniques in Solar Tracking*. IEEE's publication platform includes detailed reviews on AI techniques used in solar tracking systems. https://ieeexplore.ieee.org

6. SpringerLink, *Machine Learning and Fuzzy Logic Applications in Solar Energy*. It includes articles describing how machine learning and fuzzy logic are used in solar energy systems. https://link.springer.com

7. ResearchGate, *PID and Genetic Algorithms for Solar Trackers*. Research results on the use of PID control and genetic algorithms in solar tracking systems.https://www.researchgate.net

These references provide information on the applications of different methods and algorithms to improve the effectiveness of artificial intelligence in solar tracking systems.