IT & BUISNESS COLLEGE
Department: Computer Science
Project Title: Smart Sollar Panel
Group Name: Team-03

Abdrazakov Arsen ID 248715075
Abdylaev Muhhammad ID 238715042
Ermenbekov Nursultan ID 238715038
Malabaev Nurel ID 238715043
Tokoldoshov Aktan ID 238715036
Instructor: Mirlan Nurbekov

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INTRODUCTION

In recent years, the demand for renewable energy sources has significantly increased due to environmental problems and the depletion of fossil fuels. Solar energy is one of the most promising and widely used renewable energy sources because it is clean, sustainable, and widely available.

Traditional solar panels generate electricity from sunlight, but their efficiency depends on the angle of the sun and environmental conditions. To improve energy efficiency, smart solar panel systems are developed. These systems use sensors, controllers, and automated mechanisms to optimize the position and performance of the solar panel.

The purpose of this project is to design and implement a smart solar panel system that can automatically adjust its position to follow the sun and maximize energy generation. The project focuses on automation, energy efficiency, and basic control principles.

Parameter	Real Robotic Arm Systems	Our Small-Scale Prototype	Purpose of Simplification
Sensors	Vision systems, force sensors, encoders	**LDR (Light Dependent Resistor)**	Simple light detection and basic input control
Controller	Industrial controllers, PLCs	**Arduino Uno**	Easy programming and fast prototyping
Communication	Industrial buses, Ethernet, CAN	**Wired control**	Stable and simple signal transmission
Actuation	High-torque servo motors, hydraulic actuators	**SG90 servo motor**	Safe, low-power, and compact movement
Control Method	Advanced algorithms, AI-based control	**Threshold-based logic**	Easy implementation and understanding

1.1 History of Solar Energy and Solar Panels

The use of solar energy dates back to ancient times when sunlight was used for heating and lighting. The first photovoltaic solar cell was developed in the mid-20th century, which allowed sunlight to be directly converted into electrical energy.

Over time, solar panel technology has improved significantly. Modern solar panels are more efficient, affordable, and widely used in residential, industrial, and agricultural applications. Recently, smart solar systems with tracking mechanisms and sensors have become popular due to their ability to increase energy output.

1.2 Types of Solar Panel Systems Today

Today, solar panel systems can be classified into several types:

- Fixed solar panels – panels installed at a fixed angle without movement

Figure 1- Fixed solar panels

- Single-axis tracking systems – panels that follow the sun in one direction

Figure 2 - Single-axis tracking systems

- Dual-axis tracking systems – panels that follow the sun in both horizontal and vertical

directions

Figure 3 - Dual-axis tracking systems

- Smart solar panels – systems that use sensors, controllers, and automation to optimize performance

Figure 4 - Smart solar panels

2. PROBLEM STATEMENT AND OBJECTIVES

2.1 Problem Statement

The use of solar energy dates back to ancient times when sunlight was used for heating and lighting. The first photovoltaic solar cell w as developed in the mid-20th century, which allowed sunlight to be directly converted into electrical energy.
Over time, solar panel technology has improved significantly. Modern solar panels are more efficient, affordable, and widely used in residential, industrial, and agricultural applications. Recently, smart solar systems with tracking mechanisms and sensors have become popular due to their ability to increase energy output.

2.2 Project Objectives

- To design a smart solar panel system with automatic sun tracking
- To increase energy efficiency compared to a fixed solar panel
- To implement a control system using sensors and a microcontroller
- To test and analyze the performance of the system

3. SYSTEM REQUIREMENTS & CONSTRAINTS

This section describes the functional requirements and constraints of the smart solar panel system. These requirements define what the system must do and the limitations under which it operates.

3.1 Functional Requirements

The smart solar panel system must meet the following functional requirements:

- The system shall detect the direction of the sunlight using light sensors.
- The system shall automatically adjust the position of the solar panel to face the sun.
- The system shall control the movement of the panel using a motor or servo mechanism.
- The system shall operate autonomously without manual intervention.
- The system shall continuously update the panel position during daylight hours.
- The system shall provide stable operation under normal outdoor conditions.

3.2 System Constraints

The system is subject to several constraints that affect its design and operation.

3.2.1 Non-Functional Constraints

- Limited power consumption due to the use of renewable energy.
- Acceptable response time for sun tracking.
- Reliability of the system during continuous operation.

3.2.2 Mechanical Constraints

- Limited range of motion of the panel support structure.
- Physical size and weight limitations of the solar panel.
- Mechanical stability under wind and environmental conditions.

3.2.3 Safety Constraints

- Safe operation of electrical components.
- Protection against overheating and short circuits.
- Secure mounting to prevent mechanical failure.

4. SYSTEM OVERVIEW

Figure 5 - **SYSTEM OVERVIEW**

This section provides a general overview of the smart solar panel system, including its hardware and software components. The system is desi optimize energy generation.

4.1 Hardware Overview

The hardware of the smart solar panel system consists of several main components that work together to achieve automatic sun tracking.

- Solar panel – converts sunlight into electrical energy.
- Light sensors (LDRs) – detect the intensity and direction of sunlight..
- Motor / Servo motor – adjusts the position of the solar panel.
- Power supply – provides energy for system operation.
- Mechanical structure – supports the solar panel and allows controlled movement.

These components are connected to form a compact and efficient tracking system.

4.2 Software Overview

The software part of the system is responsible for data processing, decision-making, and control of the hardware components.
The main functions of the software include:

- Reading data from the light sensors.
- Comparing light intensity values to determine the sun's direction.
- Generating control signals for the motor or servo.
- Continuously updating the panel position to maintain optimal alignment with the sun.

The control algorithm operates in a loop, allowing the system to respond dynamically to changes in sunlight throughout the day.

5. PROTOTYPES

This section describes the development stages of the smart solar panel system. Several prototypes were created to test individual components and gradually build a complete working system.

5.1 Initial Prototype

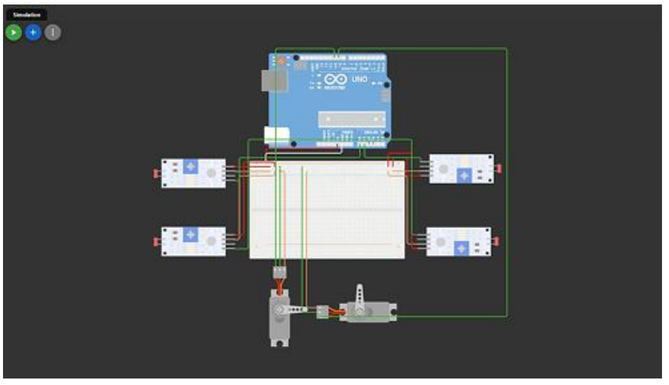

Figure 6 – 0001 Prototype

The initial prototype focused on testing the basic functionality of the light sensors and the motor. The sensors were used to measure light intensity, and simple control logic was implemented to verify the motor movement.
This stage helped to understand the behavior of the sensors and ensure correct motor response.

5.2 Intermediate Prototype

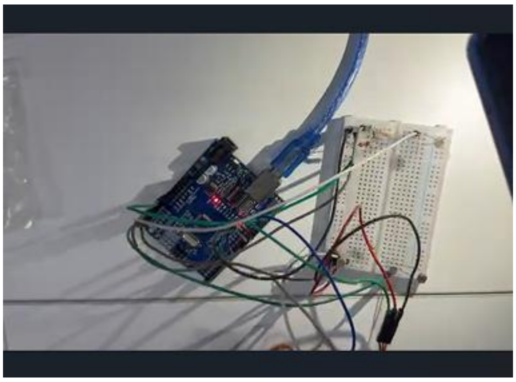

Figure 7 – 0002 Prototype

The intermediate prototype combined the sensors and the motor under microcontroller control. At this stage, basic sun-tracking logic was implemented, allowing the solar panel to move toward the strongest light source.
The system was tested under different lighting conditions to improve accuracy and stability.

5.3 Final Prototype

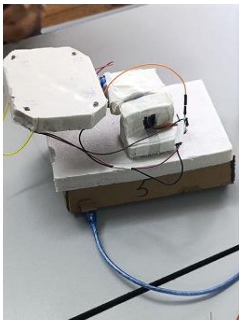

Figure 8 – 0003 Prototype

The final prototype represents a fully functional smart solar panel system. All components were integrated into a single system with a mechanical structure supporting the solar panel.
The system was able to automatically track the sun and adjust its position throughout the day, demonstrating improved energy collection compared to a fixed panel.

6. IMPLEMENTATION

This section describes the implementation of the smart solar panel system, including hardware setup, software logic, and system integration.

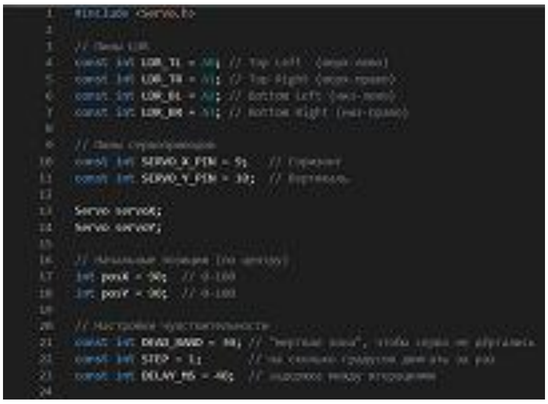

Figure 8 – Code

```
#include <Servo.h>


// Пины LDR
const int LDR_TL = A0; // Top Left  (верх-лево)
const int LDR_TR = A1; // Top Right (верх-право)
const int LDR_BL = A2; // Bottom Left (низ-лево)
const int LDR_BR = A3; // Bottom Right (низ-право)


// Пины сервоприводов
const int SERVO_X_PIN = 9;   // Горизонт
const int SERVO_Y_PIN = 10;  // Вертикаль


Servo servoX;
```

```
Servo servoY;


// Начальные позиции (по центру)
int posX = 90;  // 0–180
int posY = 90;  // 0–180


// Настройки чувствительности
const int DEAD_BAND = 30; // "мертвая зона", чтобы серво не дёргались
const int STEP = 1;       // на сколько градусов двигать за раз
const int DELAY_MS = 40;  // задержка между итерациями
```

Figure 9 – Code

```
void setup() {
 servoX.attach(SERVO_X_PIN);
 servoY.attach(SERVO_Y_PIN);


 servoX.write(posX);
 servoY.write(posY);
```

```
  // Не обязательно, но можно для отладки:
  Serial.begin(9600);
}

void loop() {
  // Считываем значения с LDR
  int tl = analogRead(LDR_TL);
  int tr = analogRead(LDR_TR);
  int bl = analogRead(LDR_BL);
  int br = analogRead(LDR_BR);

  // Усредняем по сторонам
  int top    = (tl + tr) / 2;
  int bottom = (bl + br) / 2;
  int left   = (tl + bl) / 2;
  int right  = (tr + br) / 2;

  // Разница света
  int diffLR = left  - right;  // >0 — больше слева
  int diffTB = top   - bottom; // >0 — больше сверху

  // --------------- Горизонтальный серво (X) ---------------
  if (abs(diffLR) > DEAD_BAND) {
    if (diffLR > 0) {
      // Света больше слева → поворачиваем серво влево
      posX += STEP;   // если у вас всё наоборот – смените + на -
    } else {
      // Света больше справа → поворачиваем серво вправо
```

```
    posX -= STEP;
  }
}

// --------------- Вертикальный серво (Y) ---------------
if (abs(diffTB) > DEAD_BAND) {
  if (diffTB > 0) {
    // Света больше сверху → поднимаем
    posY += STEP;   // если движение наоборот – поменяйте знак
  } else {
    // Света больше снизу → опускаем
    posY -= STEP;
  }
}

// Ограничиваем углы от 0 до 180
posX = constrain(posX, 0, 180);
posY = constrain(posY, 0, 180);

// Пишем в серво
servoX.write(posX);
servoY.write(posY);
```

6.1 Hardware Implementation

The smart solar panel system is built using an Arduino microcontroller as the main control unit. Light-dependent resistors (LDRs) are used to detect sunlight intensity. A servo motor is employed to adjust the position of the solar panel.
The system is powered through a USB connection from a laptop, which supplies sufficient power for testing and development purposes. All components are connected to the Arduino board using standard wiring.

6.2 Software Implementation

The software of the smart solar panel system is written in Arduino C++. The program is responsible for reading data from the light-dependent resistor (LDR) sensors and controlling the servo motor.
The program continuously monitors the light intensity detected by each LDR sensor. The values obtained from the sensors are compared to determine the direction of the strongest light source. Based on this comparison, the servo motor rotates the solar panel toward the LDR receiving higher light intensity.
The software operates automatically and allows the system to adjust the panel position in real time without user intervention. No complex control algorithms are used, which makes the program simple, efficient, and suitable for educational purposes.

6.3 Control Algorithm

The control algorithm of the system follows these steps:

1. Read light intensity values from the LDR sensors.

2. Compare the sensor values to determine the sun’s direction.
3. Rotate the servo motor to adjust the panel position.
4. Repeat the process continuously.

6.4 System Integration and Testing

All hardware and software components were integrated into a single system and tested under different lighting conditions. The system successfully adjusted the panel position in response to changes in light direction, demonstrating correct operation of the smart solar panel system.

7. DISCUSSION

This section discusses the system performance and the challenges encountered during the development of the smart solar panel system.

During the initial testing phase, the system did not perform as expected due to incorrect connection of the LDR sensors. The sensors were unable to accurately detect light intensity, which caused unstable and incorrect movement of the servo motor. As a result, the system responded poorly to changes in light direction.

Because of this issue, the project had to be reassembled multiple times. The hardware setup was rebuilt three to four times in order to identify the source of the problem. After further analysis, it was determined that the LDR sensors were not properly connected within a voltage divider circuit.

The problem was solved by connecting the LDR sensors using appropriate resistors. This significantly improved the accuracy of light detection and stabilized the system behavior. After implementing this solution, the smart solar panel system worked reliably and responded correctly to light changes.

This experience highlights the importance of correct sensor connection and testing during system development. Despite the difficulties, the final system achieved the intended functionality and demonstrated effective sun-tracking behavior.

8. CONCLUSION

In this project, a smart solar panel system with automatic sun tracking was designed and implemented. The system uses LDR sensors, an Arduino microcontroller, and a servo motor to adjust the panel position toward the strongest light source.

The results show that the smart solar panel system can improve energy efficiency compared to a fixed solar panel. Despite its simple control logic, the system operates reliably and demonstrates the basic principles of automation and renewable energy systems.

Overall, the project successfully meets its objectives and provides a solid foundation for further development and improvement.

9. REFERENCES

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